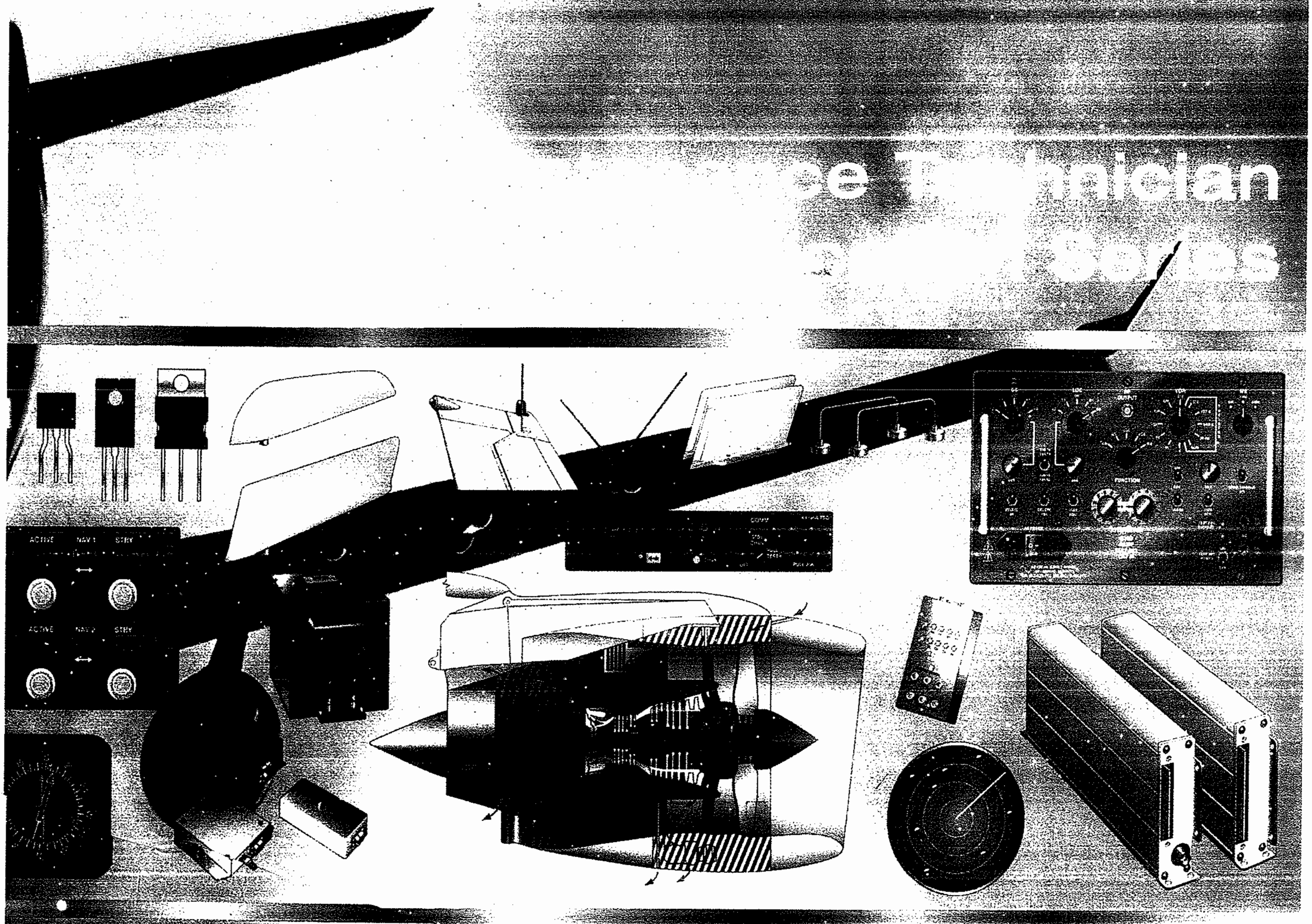
Module 14

LEVEL B2 CERTIFICATION

PROPULSION



Turbine Engines
Engine Indicating Systems
Starting and Ignition Systems

COMPLIANT WITH
EASA
European Aviation Safety Agency
EASA PART 66/147

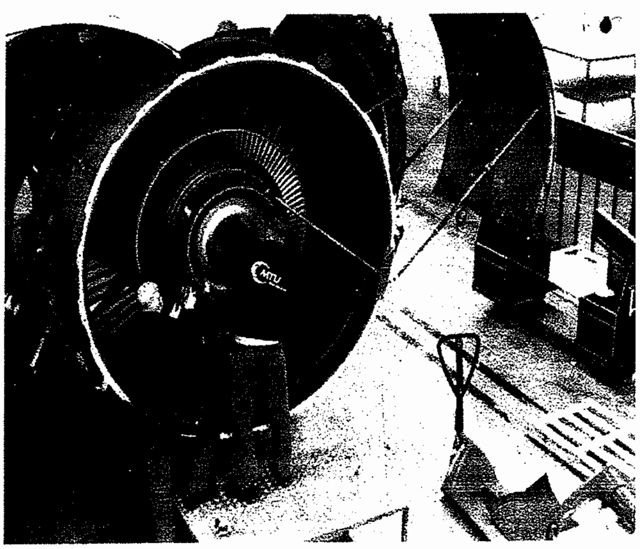
MODULE 14

FOR B1 LEVEL CERTIFICATION

PROPULSION

Aviation Maintenance Technician Certification Series

COMPLIANT WITH
EASA PART 66/147



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WELCOME

The publishers of this Aviation Maintenance Technician Certification Series welcome you to the world of aviation maintenance. As you move towards EASA certification, you are required to gain suitable knowledge and experience in your chosen area. Qualification on basic subjects for each aircraft maintenance license category or subcategory is accomplished in accordance with the following matrix. Where applicable, subjects are indicated by an "X" in the column below the license heading.

For other educational tools created to prepare candidates for licensure, contact Aircraft Technical Book Company.

We wish you good luck and success in your studies and in your aviation career!

EASA LICENSE CATEGORY CHART

	Module number and title	A1 Airplane Turbine	B1.1 Airplane Turbine	B1.2 Airplane Piston	B1.3 Helicopter Turbine	B2 Avionics
1	Mathematics	X	X	X	X	X
2	Physics	X	X	X	X	X
3	Electrical Fundamentals	X	X	X	X	X
4	Electronic Fundamentals		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
8	Basic Aerodynamics	X	X	X	X	X
9A	Human Factors	X	X	X	X	X
10	Aviation Legislation	X	X	X	X	X
11A	Turbine Aeroplane Aerodynamics, Structures and Systems	X	X			
11B	Piston Aeroplane Aerodynamics, Structures and Systems			X		
12	Helicopter Aerodynamics, Structures and Systems				X	
13	Aircraft Aerodynamics, Structures and Systems					X
14	Propulsion					X
15	Gas Turbine Engine	X	X		X	
16	Piston Engine			X		
17A	Propeller	X	X	X		

FORWARD

PART-66 and the Acceptable Means of Compliance (AMC) and Guidance Material (GM) of the European Aviation Safety Agency (EASA) Regulation (EC) No. 1321/2014, Appendix 1 to the Implementing Rules establishes the Basic Knowledge Requirements for those seeking an aircraft maintenance license. The information in this Module of the Aviation Maintenance Technical Certification Series published by the Aircraft Technical Book Company meets or exceeds the breadth and depth of knowledge subject matter referenced in Appendix 1 of the Implementing Rules. However, the order of the material presented is at the discretion of the editor in an effort to convey the required knowledge in the most sequential and comprehensible manner. Knowledge levels required for Category A1, B1, B2, and B3 aircraft maintenance licenses remain unchanged from those listed in Appendix 1 Basic Knowledge Requirements. Tables from Appendix 1 Basic Knowledge Requirements are reproduced at the beginning of each module in the series and again at the beginning of each Sub-Module.

How numbers are written in this book:

This book uses the International Civil Aviation Organization (ICAO) standard of writing numbers. This methods displays large numbers by adding a space between each group of 3 digits. This is opposed to the American method which uses commas and the European method which uses periods. For example, the number one million is expressed as so:

ICAO Standard	1 000 000
European Standard	1.000.000
American Standard	1,000,000

SI Units:

The International System of Units (SI) developed and maintained by the General Conference of Weights and Measures (CGPM) shall be used as the standard system of units of measurement for all aspects of international civil aviation air and ground operations.

Prefixes:

The prefixes and symbols listed in the table below shall be used to form names and symbols of the decimal multiples and submultiples of International System of Units (SI) units.

[illegible]		PREFIX	SYMBOL
1 000 000 000 000 000 000	$= 10^{18}$	exa	E
1 000 000 000 000 000	$= 10^{15}$	peta	P
1 000 000 000 000	$= 10^{12}$	tera	T
1 000 000 000	$= 10^{9}$	giga	G
1 000 000	$= 10^{6}$	mega	M
1 000	$= 10^{3}$	kilo	k
100	$= 10^{2}$	hecto	h
10	$= 10^{1}$	deca	da
0.1	$=10^{-1}$	deci	d
0.01	$= 10^{-2}$	centi	c
0.001	$= 10^{-3}$	milli	m
0.000 001	$= 10^{-6}$	micro	µ
0.000 000 001	$= 10^{-9}$	nano	n
0.000 000 000 001	$= 10^{-12}$	pico	p
0.000 000 000 000 001	$= 10^{-15}$	femto	f
0.000 000 000 000 000 001	$= 10^{-18}$	atto	a

International System of Units (SI) Prefixes

This module 14, written for the B2 avionics technician, covers the basics of turbine engines along with increased detail on the electronic controls, computerization, and monitoring systems that contribute to the exceptional efficiency and reliability which both industry and the traveling public demands. A basic understanding of each engine system and its relevant components provides the background needed to understand not just the electronic functions, but how and why each device benefits the system to provide value to overall operations and reliability. Following completion of this module the technician should be familiar with engine starting techniques, basic operations, and the meaning and causes of both normal and abnormal indications.

Module 14 Syllabus as outlined in PART-66, Appendix 1.

	LEVELS
CERTIFICATION CATEGORY →	**B2**
Sub-Module 01 - Turbine Engines	
(a) Constructional arrangement and operation of turbojet, turbofan, turboshaft and turbopropeller engines;	1
(b) Electronic engine control and fuel metering systems (FADEC).	2
Sub-Module 02 - 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
Sub-Module 03 - Starting and Ignition Systems Operation of engine start systems and components; Ignition systems and components; Maintenance safety requirements.	2

REVISION LOG

VERSION	ISSUE DATE	DESCRIPTION OF CHANGE	MODIFICATION DATE
001	2016 02	Module Revision	[illegible]

ACKNOWLEDGMENTS

Special thanks to and acknowledgment of:

Mike Stitt, Electronics Engineer, ADA, MI.

SUB-MODULE 01

TURBINE ENGINES

SUB-MODULE 02

ENGINE INDICATING SYSTEMS

CONTENTS

SUB-MODULE 03

SUB-MODULE 01

PART-66 SYLLABUS LEVELS

CERTIFICATION CATEGORY → B2

Sub-Module 01
TURBINE ENGINES
Knowledge Requirements

14.1 Turbine Engines

(a)	Constructional arrangement and operation of turbojet, turbofan, turboshaft and turbopropeller engines;	1
(b)	Electronic engine control and fuel metering systems (FADEC).	2

Level 1
A familiarization with the principal elements of the subject.

Objectives:
(a) The applicant should be familiar with the basic elements of the subject.
(b) The applicant should be able to give a simple description of the whole subject, using common words and examples.
(c) The applicant should be able to use typical terms.

Level 2
A general knowledge of the theoretical and practical aspects of the subject and an ability to apply that knowledge.

Objectives:
(a) The applicant should be able to understand the theoretical fundamentals of the subject.
(b) The applicant should be able to give a general description of the subject using, as appropriate, typical examples.
(c) The applicant should be able to use mathematical formula in conjunction with physical laws describing the subject.
(d) The applicant should be able to read and understand sketches, drawings and schematics describing the subject.
(e) The applicant should be able to apply his knowledge in a practical manner using detailed procedures.

A discussion of turbine engines begins with some of the basic physics behind turbine engine operation.

ENERGY

Energy is typically defined as something that gives us the capacity to perform work. As individuals, saying that we feel full of energy is probably indicating that we can perform a lot of work. Energy can be classified as one of two types: either potential or kinetic.

POTENTIAL ENERGY

Potential energy is defined as being energy at rest, or energy that is stored. Potential energy may be classified into three groups: (1) that due to position, (2) that due to distortion of an elastic body, and (3) that which produces work through chemical action.

Water in an elevated reservoir, and an airplane raised off the ground sitting on jacks are examples of the first group; a stretched bungee cord on a Piper Tri-Pacer or compressed spring are examples of the second group; and energy in aviation gasoline, food, and storage batteries are examples of the third group.

To calculate the potential energy of an object due to its position, as in height, the following formula is used:

A calculation based on this formula will produce an answer that has units of foot pounds (ft-lbs) or inch pounds (in-lbs), which are the same units that apply to work. Work, which is covered later in this chapter, is described as a force being applied over a measured distance, with the force being pounds and the distance being feet or inches. It can be seen that potential energy and work have a lot in common.

Example: A Boeing 747 weighing 450 000 pounds needs to be raised 4 feet in the air so maintenance can be done on the landing gear. How much potential energy does the airplane possess because of this raised position?

$$\begin{aligned} \text{Potential Energy} &= \text{Weight} \times \text{Height} \\ PE &= 450\,000\ lb \times 4\ ft \\ PE &= 1\,800\,000\ ft\text{-}lbs \end{aligned}$$

As mentioned previously, aviation gasoline possesses potential energy because of its chemical nature. Gasoline has the potential to release heat energy, based on its British thermal unit (BTU) content. One pound of aviation gas contains 18 900 BTU of heat energy, and each BTU is capable of 778 ft-lbs of work. So if we multiply 778 by 18 900, we find that one pound of aviation gas is capable of 14 704 200 ft-lbs of work.

Imagine the potential energy in the completely serviced fuel tanks of an airplane.

KINETIC ENERGY

Kinetic energy is defined as being energy in motion. An airplane rolling down the runway or a rotating flywheel on an engine are both examples of kinetic energy. Kinetic energy has the same units as potential energy, namely foot pounds or inch pounds. To calculate the kinetic energy for something in motion, the following formula is used:

$$\text{Kinetic Energy} = \tfrac{1}{2}\,\text{Mass} \times \text{Velocity}^2$$

To use the formula, we will show the mass as weight ÷ gravity and the velocity of the object will be in feet per second. This is necessary to end up with units in foot pounds.

Example: A Boeing 777 weighing 600 000 lbs is moving down the runway on its takeoff roll with a velocity of 200 fps. How many foot pounds of kinetic energy does the airplane possess? *(Figure 1-1)*

$$\begin{aligned} \text{Kinetic Energy} &= \tfrac{1}{2}\,\text{Mass} \times \text{Velocity}^2 \\ \text{Kinetic Energy} &= \tfrac{1}{2} \times (600\,000 \div 32.2) \times 200^2 \\ KE &= 372\,670\,807\ ft\text{-}lb \end{aligned}$$

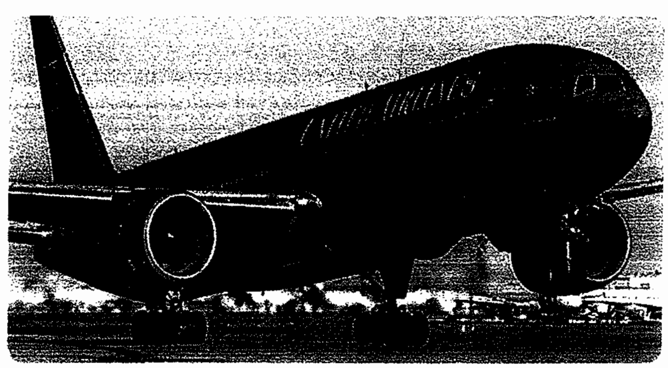


Figure 1-1. Kinetic energy (Boeing 777 taking off).

NEWTON'S LAWS OF MOTION

The physic laws originated by Sir Isaac Newton are particularly applicable to the operation of turbine engines.

FIRST LAW

Objects at rest tend to remain at rest and objects in motion tend to remain in motion at the same speed and in the same direction, unless acted on by an external force.

When a magician snatches a tablecloth from a table and leaves a full setting of dishes undisturbed, he is not displaying a mystic art; he is demonstrating the principle of inertia. Inertia is responsible for the discomfort felt when an airplane is brought to a sudden halt in the parking area and the passengers are thrown forward in their seats. Inertia is a property of matter. This property of matter is described by Newton's first law of motion.

SECOND LAW

When a force acts upon a body, the momentum of that body is changed. The rate of change of momentum is proportional to the applied force.

Bodies in motion have the property called momentum. A body that has great momentum has a strong tendency to remain in motion and is therefore hard to stop. For example, a train moving at even low velocity is difficult to stop because of its large mass. Newton's second law applies to this property.

Based on Newton's second law, the formula for calculating thrust is derived, which states that force equals mass times acceleration:

$$(F = MA)$$

Mass equals weight divided by gravity, and acceleration equals velocity final minus velocity initial divided by time. Putting all these concepts together, the formula for thrust is:

$$Force = \frac{Weight\ (Velocity\ Final - Velocity\ Initial)}{Gravity\ (Time)}$$

$$F = \frac{W\,(Vf - Vi)}{Gt}$$

Example: A turbojet engine is moving 150 lbs of air per second through the engine. The air enters going 100 fps and leaves going 1 200 fps. How much thrust, in pounds, is the engine creating?

$$F = \frac{W\,(Vf - Vi)}{Gt}$$

$$F = \frac{150\,(1\,200 - 100)}{32.2\,(1)}$$

$$F = 5\,124 \text{ lb of thrust}$$

THIRD LAW

For every action there is an equal and opposite reaction.

Newton's third law of motion is often called the law of action and reaction. This means that if a force is applied to an object, the object will supply a resistive force exactly equal to and in the opposite direction of the force applied. It is easy to see how this might apply to objects at rest. For example, as a man stands on the floor, the floor exerts a force against his feet exactly equal to his weight. But this law is also applicable when a force is applied to an object in motion.

Forces always occur in pairs. The "acting force" means the force one body exerts on a second body, and reacting force means the force the second body exerts on the first.

When an aircraft propeller pushes a stream of air backward with a force of 500 lbs, the air pushes the blades forward with a force of 500 lbs. This forward force causes the aircraft to move forward. A turbofan engine exerts a force on the air entering the inlet duct, causing it to accelerate out the fan duct and the tailpipe. The air accelerating to the rear is the action, and the force inside the engine that makes it happen is the reaction, also called thrust.

BERNOULLI'S PRINCIPLE

Bernoulli's principle explains the action of a liquid flowing through the varying cross-sectional areas of tubes. In ***Figure 1-2*** a tube is shown in which the cross-sectional area gradually decreases to a minimum diameter in its center section. A tube constructed in this manner is called a "venturi". Where the cross-sectional area is decreasing, the passageway is referred to as a *converging duct.* As the passageway starts to spread out, it is referred to as a *diverging duct.*

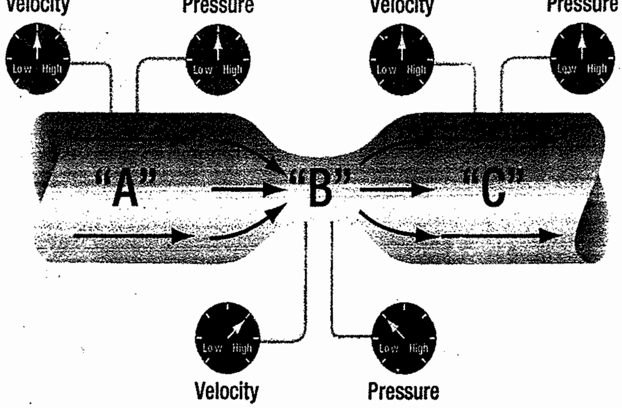


Figure 1-2. Bernoulli's principle and a venturi.

As a fluid flows through the venturi tube, at A, B, and C are positioned to register the velocity and the static pressure of the liquid. The venturi in ***Figure 1-2*** is used to illustrate Bernoulli's principle, which states: *The static pressure of a fluid (liquid or gas) decreases at points where the velocity of the fluid increases, provided no energy is added to nor taken away from the fluid.*

The velocity of the air is kinetic energy and the static pressure of the air is potential energy. In the wide section of the venturi (points A and C of ***Figure 1-2***), the liquid moves at low velocity, producing a high static pressure, as indicated by the pressure gauge. As the tube narrows in the center, it must contain the same volume of fluid as the two end areas. In this narrow section, the liquid moves at a higher velocity, producing a lower pressure than that at points A and C, as indicated by the velocity gauge reading high and the pressure gauge reading low.

Bernoulli's principle is important in understanding how some of the systems used in aviation work, including how the wing of an airplane generates lift or why the inlet duct of a turbine engine on a subsonic airplane is diverging in shape. Key to Bernoulli's principle is that the total pressure of the airflow remains the same while static pressure varies due to negotiation of the curvature of a venturi or wing. As the static pressure of the fluid decreases to move over the curved surface, dynamic pressure increases, expressed as an equation:

Total Pressure = Static Pressure + Dynamic Pressure

BOYLE'S & CHARLES' LAW

Boyle's Law states that when the temperature of a gas is kept constant and the pressure inscreased, its volume is decreased proportionately. In reverse; when a gas is at a constant temperature and presure decreases, volume increases. ***(Figure 1-3)***

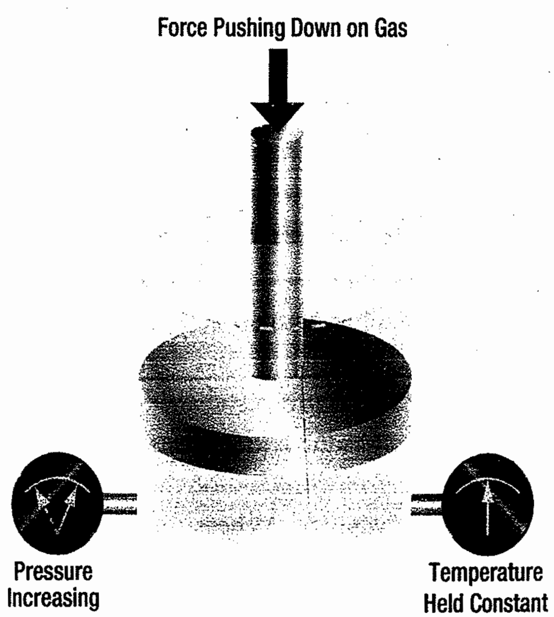


Figure 1-3. Boyle's Law example.

By itself Boyle's Law is of little use because in practice air is not compressed at a constant temperature. Although if we use Boyle's Law in combination with Charles' Law, it becomes more useful. Charles' Law states that if air is heated at a constant pressure, the change in volume will vary with the change in temperature. Therefore, the volume of a mass of gas at constant pressure is proportional to the temperature of the gas (air). So, the product of the pressure and volume of the air through each stage within a turbine engine is proportional to the temperature of the air at the stage.

During compression, as work is done to increase pressure and decrease volume, there is a corresponding rise in temperature. During combustion, the addition of fuel to burn with the air increases the pressure and there is a corresponding increase in volume. During exhaust, there is a decrease in the pressure and temperature of the gas with an additional increase in volume. ***(Figure 1-4)***

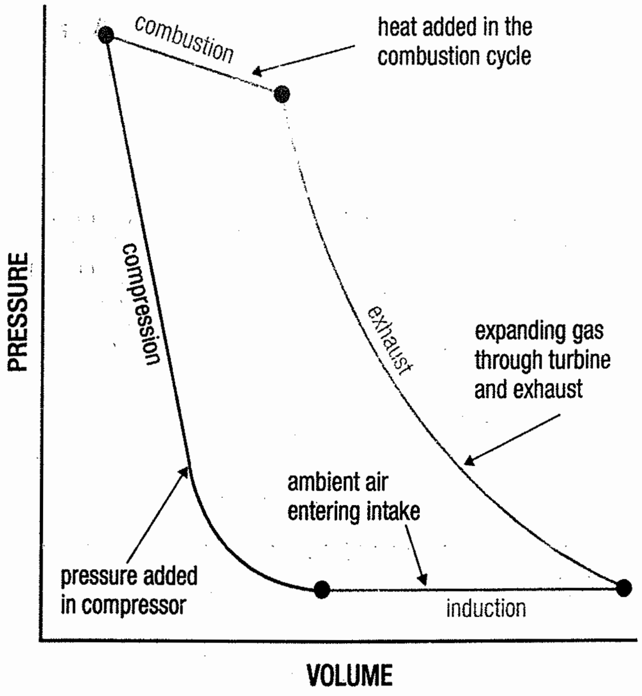


Figure 1-4. Pressure/volume relationship.

FORCE, WORK, POWER AND TORQUE

FORCE

Before the concept of work, power, or torque can be discussed, we must understand what force means. According to the dictionary, force is the intensity of an impetus, or the intensity of an input. For example, if we apply a force to an object, the tendency will be for the object to move. Another way to look at it is that for work, power, or torque to exist, there has to be a force that initiates the process.

The unit for force in the English system of measurement is pounds, and in the metric system it is newtons. One pound of force is equal to 4.448 newtons. When we calculate the thrust of a turbine engine, we use the formula "Force = Mass × Acceleration," and the thrust of the engine is expressed in pounds. The GE90-115 turbofan engine (powerplant for the Boeing 777-300), for example, has 115 000 pounds of thrust.

WORK

The study of machines, both simple and complex, is in one sense a study of the energy of mechanical work. This is true because all machines transfer input energy, or the work done on the machine, to output energy, or the work done by the machine.

Work, in the mechanical sense of the term, is done when a resistance is overcome by a force acting through a measurable distance. Two factors are involved: (1) force and (2) movement through a distance. As an example, suppose a small aircraft is stuck in the snow. Two men push against it for a period of time, but the aircraft does not move. According to the technical definition, no work was done in pushing against the aircraft. By definition, work is accomplished only when an object is displaced some distance against a resistive force. To calculate work, the following formula is used:

$$Work = Force\ (F) \times distance\ (d)$$

In the English system, the force will be identified in pounds and the distance either in feet or inches, so the units will be foot-pounds or inch-pounds. Notice these are the same units that were used for potential and kinetic energy. In the metric system, the force is identified in newtons (N) and the distance in meters, with the resultant units being joules. One pound of force is equal to 4.448 N and one meter is equal to 3.28 feet. One joule is equal to 1.36 ft-lb.

Example: How much work is accomplished by jacking a 150 000-lb Airbus A-320 airplane a vertical height of 3 ft? (*Figure 1-5*)

$$\begin{aligned} Work &= Force \times distance \\ &= 5\,000\ lbs \times 4\ ft \\ &= 600\,000\ ft\text{-}lbs \end{aligned}$$

Figure 1-5. Airbus A-320 being jacked.

Example: How much work is accomplished when a tow tractor is hooked up to a tow bar and a Boeing 737-800 airplane weighing 130 000 lbs is pushed 80 ft into the hangar? The force on the tow bar is 5 000 lbs.

$$\begin{aligned} Work &= Force \times distance \\ &= 5\,000 \times 80\,ft \\ &= 400\,000\,ft\text{-}lbs \end{aligned}$$

In this last example, notice the force does not equal the weight of the airplane. This is because the airplane is being moved horizontally and not lifted vertically. In virtually all cases, it takes less work to move something horizontally than it does to lift it vertically. Most people can push their car a short distance if it runs out of gas, but they cannot get under it and lift it off the ground.

POWER

The concept of power involves the previously discussed topic of work, which was a force being applied over a measured distance, but adds one more consideration - time. In other words, how long does it take to accomplish the work. If someone asked the average person if he or she could lift one million pounds five feet off the ground, the answer most assuredly would be no. This person would probably assume that he or she is to lift it all at once. What if he or she is given 365 days to lift it, and could lift small amounts of weight at a time?

The work involved would be the same, regardless of how long it took to lift the weight, but the power required is different. If the weight is to be lifted in a shorter period of time, it will take more power. The formula for power is as follows:

$$Power = Force \times distance \div time$$

The units for power will be foot pounds per minute, foot pounds per second, inch pounds per minute or second, and possibly mile pounds per hour. The units depend on how distance and time are measured.

Many years ago there was a desire to compare the power of the newly evolving steam engine to that of horses. People wanted to know how many horses the steam engine was equivalent to. Because of this, the value we currently know as one horsepower (hp) was developed, and it is equal to 550 foot pounds per second (ft-lb/s).

It was found that the average horse could lift a weight of 550 lb, one foot off the ground, in one second. The values we use today, in order to convert power to horsepower, are as follows:

$$\begin{aligned} 1\,hp &= 550\,ft\text{-}lb/s \\ 1\,hp &= 33\,000\,ft\text{-}lb/min. \\ 1\,hp &= 375 \text{ mile pounds per hour (mi-lb/hr)} \\ 1\,hp &= 746 \text{ watts (electricity conversion)} \end{aligned}$$

To convert power to horsepower, divide the power by the appropriate conversion based on the units being used.

Example: What power would be needed, and also horsepower, to raise the GE-90 turbofan engine into position to install it on a Boeing 777-300 airplane? The engine weighs 19 000 lb, and it must be lifted four ft in two minutes.

$$\begin{aligned} Power &= Force \times distance \div time \\ &= 19\,000\,lbs \times 4\,ft \div 2\,minutes \\ &= 38\,000\,ft\text{-}lbs / min \\ Horsepower\,(Hp) &= 38\,000\,ft\text{-}lbs / min \div \\ &\quad 33\,000\,ft\text{-}lbs / min\,Hp = 1.15 \end{aligned}$$

The hoist that will be used to raise this engine into position will need to be powered by an electric motor because the average person will not be able to generate 1.15 hp in their arms for the necessary two minutes.

TORQUE

Torque is a very interesting concept and occurrence, and it is definitely something that needs to be discussed in conjunction with work and power. Whereas work is described as a force acting through a distance, torque is described as a force acting along a distance. Torque is something that creates twisting and tries to make something rotate.

If we push on an object with a force of ten lbs and it moves ten inches in a straight line, we have done 100 in lbs of work. By comparison, if we have a wrench ten inches long that is on a bolt, and we push down on it with a force of ten lbs, a torque of 100 lb in is applied to the bolt. If the bolt was already tight and did not move as we pushed down on the wrench, the torque of 100 lb in would still exist. The formula for torque is:

$$Torque = Force \times distance$$

Even though the formula looks the same as the one for calculating work, recognize that the distance value in this formula is not the linear distance an object moves, but rather the distance along which the force is applied.

Notice that with torque nothing had to move, because the force is being applied along a distance and not through a distance. Notice also that although the units of work and torque appear to be the same, they are not. The units of work were inch pounds and the units of torque were pound inches, and that is what differentiates the two.

Torque is very important when thinking about how engines work. Gas turbine engines create torque in advance of being able to create work or power. The turbine blades at the back of the engine extract energy from the high velocity exhaust gases. The energy extracted becomes a force in pounds pushing on the turbine blades, which happen to be a certain number of inches from the center of the shaft they are trying to make rotate. The number of inches from the turbine blades to the center of the shaft would be like the length of the wrench discussed earlier.

MOTION

The study of the relationship between the motion of bodies or objects and the forces acting on them is often called the study of "force and motion." In a more specific sense, the relationship between velocity, acceleration, and distance is known as kinematics.

Motion may be defined as a continuing change of position or place, or as the process in which a body undergoes displacement. When an object is at different points in space at different times, that object is said to be in motion, and if the distance the object moves remains the same for a given period of time, the motion may be described as uniform. Thus, an object in uniform motion always has a constant speed.

SPEED AND VELOCITY

In everyday conversation, speed and velocity are often used as if they mean the same thing. In physics they have definite and distinct meanings. Speed refers to how fast an object is moving, or how far the object will travel in a specific time. The speed of an object tells nothing about the direction an object is moving. For example, if the information is supplied that an airplane leaves New York City and travels eight hours at a speed of 150 mph, this information tells nothing about the direction in which the airplane is moving. At the end of eight hours, it might be in Kansas City, or if it traveled in a circular route, it could be back in New York City.

Velocity is that quantity in physics which denotes both the speed of an object and the direction in which the object moves. Velocity can be defined as the rate of motion in a particular direction. Velocity is also described as being a vector quantity, a vector being a line of specific length, having an arrow on one end or the other. The length of the line indicates the number value and the arrow indicates the direction in which that number is acting.

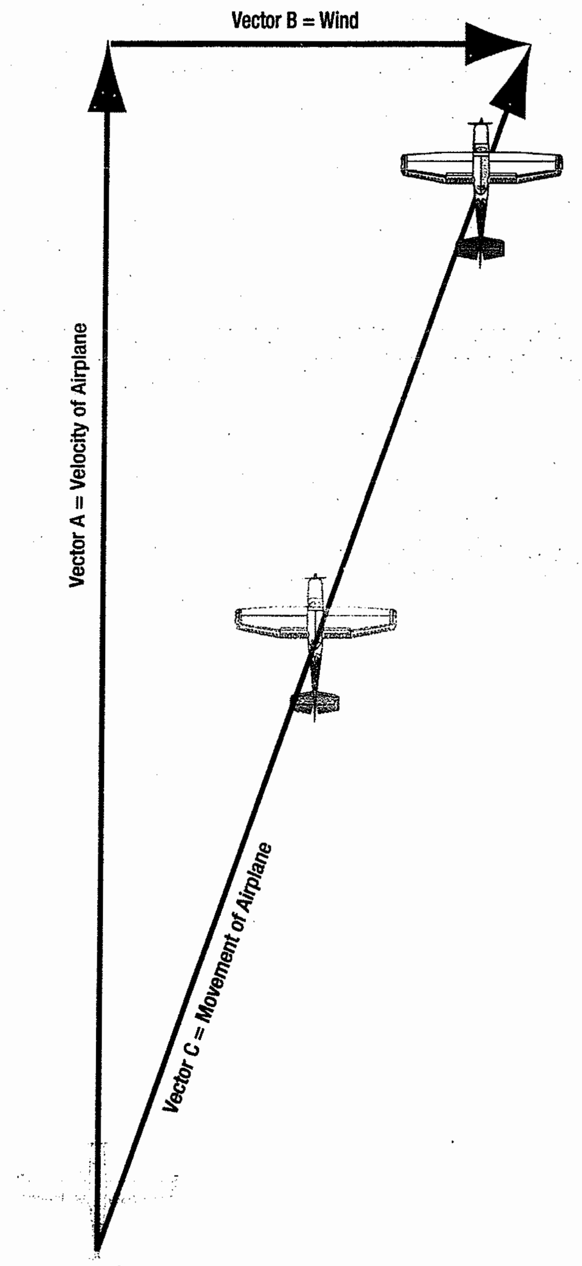


Figure 1-6. Vector analysis for airplane velocity and wind velocity.

Two velocity vectors, such as one representing the velocity of an airplane and one representing the velocity of the wind, can be added together in what is called vector analysis. *Figure 1-6* demonstrates this, with vectors "A" and "B" representing the velocity of the airplane and the wind, and vector "C" being the resultant. With no wind, the speed and direction of the airplane would be that shown by vector "A." When accounting for the wind direction and speed, the airplane ends up flying at the speed and direction shown by vector "C."

Imagine that an airplane is flying in a circular pattern at a constant speed. Because of the circular pattern, the airplane is constantly changing direction, which means the airplane is constantly changing velocity. The reason for this is the fact that velocity includes direction.

To calculate the speed of an object, the distance it travels is divided by the elapsed time. If the distance is measured in miles and the time in hours, the units of speed will be miles per hour (mph). If the distance is measured in feet and the time in seconds, the units of speed will be feet per second (fps). To convert mph to fps, multiply by 1.467. Velocity is calculated the same way, the only difference being it must be recalculated every time the direction changes.

ACCELERATION

Acceleration is defined as the rate of change of velocity. If the velocity of an object is increased from 20 mph to 30 mph, the object has been accelerated. If the increase in velocity is 10 mph in five seconds, the rate of change in velocity is 10 mph in five seconds, or two mph per second. If this were multiplied by 1.467, it could also be expressed as an acceleration of 2.93 feet per second per second (fps/s). By comparison, the acceleration due to gravity is 32.2 fps/s. To calculate acceleration, the following formula is used:

$$\textit{Acceleration } (A) = \frac{\textit{Velocity Final } (Vf) - \textit{Velocity Initial } (Vi)}{\textit{Time } (t)}$$

Example: An Air Force F-15 fighter is cruising at 400 mph. The pilot advances the throttles to full afterburner and accelerates to 1 200 mph in 20 seconds. What is the average acceleration in mph/s and fps/s?

$$A = \frac{Vf - Vi}{t}$$

$$A = \frac{1200 - 400}{20}$$

$$A = 40\ ^{mph}/_{s} \text{ or by multiplying by } 1.467,\ 58.7\ ^{fps}/_{s}$$

In the example above, acceleration was found to be 58.7 fps/s. Since 32.2 fps/s is equal to the acceleration due to gravity, divide the F-15's acceleration by 32.2 to find out how many G forces the pilot is experiencing. In this case, it would be 1.82 Gs.

GENERAL REQUIREMENTS

Aircraft require thrust to produce enough speed for the wings to provide lift or enough thrust to overcome the weight of the aircraft for vertical take off. For an aircraft to remain in level flight, thrust must be provided that is equal to and in the opposite direction of the aircraft drag. This thrust, or propulsive force, is provided by a suitable type of aircraft heat engine. All heat engines have in common the ability to convert heat energy into mechanical energy by the flow of some fluid mass (generally air) through the engine. In all cases, the heat energy is released at a point in the cycle where the working pressure is high relative to atmospheric pressure.

The propulsive force is obtained by the displacement of a working fluid (again, atmospheric air). This air is not necessarily the same air used within the engine. By displacing air in a direction opposite to that in which the aircraft is propelled, thrust can be developed. This is an application of Newton's third law of motion. It states that for every action there is an equal and opposite reaction. So, as air is being displaced to the rear of the aircraft the aircraft is moved forward by this principle. One misinterpretation of this principle is air is pushing against the air behind the aircraft making it move forward. This is not true.

Rockets in space have no air to push against, yet, they can produce thrust by using Newton's third law.

Atmospheric air is the principal fluid used for propulsion in every type of aircraft powerplant except the rocket, in which the total combustion gases are accelerated and displaced. The rocket must provide all the fuel and oxygen for combustion and does not depend on atmospheric air. A rocket carries its own oxidizer rather than using ambient air for combustion. It discharges the gaseous byproducts of combustion through the exhaust nozzle at an extremely high velocity (action) and it is propelled in the other direction (reaction).

The propellers of aircraft powered by reciprocating or turboprop engines accelerate a large mass of air at a relatively lower velocity by turning a propeller. The same amount of thrust can be generated by accelerating a small mass of air to a very high velocity. The working fluid (air) used for the propulsive force is a different quantity of air than that used within the engine to produce the mechanical energy to turn the propeller.

Turbojets, ramjets, and pulse jets are examples of engines that accelerate a smaller quantity of air through a large velocity change. They use the same working fluid for propulsive force that is used within the engine. One problem with these types of engines is the noise made by the high velocity air exiting the engine. The term turbojet was used to describe any gas turbine engines, but with the differences in gas turbines used in aircraft, this term is used to describe a type of gas turbine that passes all the gases through the core of the engine directly.

Turbojets, ramjets, and pulse jets have very little to no use in modern aircraft due to noise and fuel consumption. Small general aviation aircraft use mostly horizontally opposed reciprocating piston engines. While some aircraft still use radial reciprocating piston engines, their use is very limited. Many aircraft use a form of the gas turbine engine to produce power for thrust. These engines are normally the turboprop, turboshaft, turbofan, and a few turbojet engines. "Turbojet" is the former term for any turbine engine. Now that there are so many different types of turbine engines, the term used to describe most turbine engines is "gas turbine engine." All four of the previously mentioned engines belong to the gas turbine family.

All aircraft engines must meet certain general requirements of efficiency, economy, and reliability. Besides being economical in fuel consumption, an aircraft engine must be economical in the cost of original procurement and the cost of maintenance; and it must meet exacting requirements of efficiency and low weight to horsepower ratio. It must be capable of sustained high power output with no sacrifice in reliability; it must also have the durability to operate for long periods of time between overhauls. It needs to be as compact as possible, yet have easy accessibility for maintenance. It is required to be as vibration free as possible and be able to cover a wide range of power output at various speeds and altitudes.

These requirements dictate engine fuel delivery systems provide metered fuel at the correct proportion of fuel/air ingested by the engine regardless of the attitude, altitude, or type of weather in which the engine is operated. The engine needs a type of oil system that delivers oil under the proper pressure to lubricate and cool all of the operating parts of the engine when it is running. Also, it must have a system of damping units to damp out the vibrations of the engine when it is operating.

POWER AND WEIGHT

The useful output of all aircraft powerplants is thrust, the force which propels the aircraft. A reciprocating engine is rated in brake horsepower (bhp), the gas turbine engine is rated in thrust horsepower (thp):

$$Thp = \frac{\text{thrust} \times \text{aircraft speed (mph)}}{\text{375 mile-pounds per hour}}$$

The value of 375 mile-pounds per hour is derived from the basic horsepower formula as follows:

$$1\ hp = 33\,000\ \text{ft-lbs per minute}$$

$$33\,000 \times 60 = 1\,980\,000\ \text{ft-lbs per hour}$$

$$\frac{1\,980\,000}{5\,280\ \text{ft in a mile}} = 375\ \text{mile-pounds per hour}$$

One horsepower equals 33 000 ft lb per minute or 375 mile pounds per hour. Under static conditions, thrust is figured as equivalent to approximately 2.6 pounds per hour. If a gas turbine is producing 4 000 pounds of thrust and the aircraft in which the engine is installed is traveling at 500 mph, the thp is:

$$\frac{4\,000 \times 500}{375} = 5\,333.33\ thp$$

It is necessary to calculate the horsepower for each speed of an aircraft, since the horsepower varies with speed. Therefore, it is not practical to try to rate or compare the output of a turbine engine on a horsepower basis. The aircraft engine operates at a relatively high percentage of its maximum power output throughout its service life. The aircraft engine is at full power output whenever a take off is made. It may hold this power for a period of time up to the limits set by the manufacturer. The engine is seldom held at a maximum power for more than two minutes, and usually not that long. Within a few seconds after liftoff, the power is reduced to a power that is used for climbing and that can be maintained for longer periods of time. After the aircraft has climbed to cruising altitude, the power of the engine(s) is further reduced to a cruise power which can be maintained for the duration of the flight.

FUEL ECONOMY

The basic parameter for describing the fuel economy of aircraft engines is usually specific fuel consumption. Specific fuel consumption for gas turbines is the fuel flow measured in (lbs/hr) divided by thrust (lbs). This is called thrust-specific fuel consumption. Equivalent specific fuel consumption is used for the turboprop engine and is the fuel flow in pounds per hour divided by a turboprop's equivalent shaft horsepower. Comparisons can be made between the various engines on a specific fuel consumption basis.

At low speed, reciprocating and turboprop engines have better economy than the pure turbojet or turbofan engines. However, at high speed, because of losses in propeller efficiency, a reciprocating or turboprop engine's efficiency becomes limited above 400 mph less than that of the turbofan. Equivalent specific fuel consumption is used for the turboprop engine and is the fuel flow in pounds per hour divided by a turboprop's equivalent shaft horsepower. Comparisons can be made between the various engines on a specific fuel consumption basis.

DURABILITY AND RELIABILITY

Durability and reliability are usually considered identical factors since it is difficult to mention one without including the other. An aircraft engine is reliable when it can perform at the specified ratings in widely varying flight attitudes and in extreme weather conditions. Standards of powerplant reliability are agreed upon by the engine manufacturer, and the airframe manufacturer. The engine manufacturer ensures the reliability of the product by design, research, and testing. Close control of manufacturing and assembly procedures are maintained, and each engine is tested before it leaves the factory.

Durability is the amount of engine life obtained while maintaining the desired reliability. The fact that an engine has successfully completed its type or proof test indicates that it can be operated in a normal manner over a long period before requiring overhaul. However, no definite time interval between overhauls is specified or implied in the engine rating. The time between overhauls (TBO) varies with the operating conditions, such as engine temperatures, amount of time the engine is operated at high-power settings, and the maintenance received. Recommended TBOs are specified by the engine manufacturer.

Reliability and durability are built into the engine by the manufacturer, but the continued reliability of the engine is determined by the maintenance, overhaul, and operating personnel. Careful maintenance and overhaul methods, thorough periodical and preflight inspections, and strict observance of the operating limits established by the engine manufacturer make engine failure a rare occurrence.

OPERATING FLEXIBILITY

Operating flexibility is the ability of an engine to run smoothly and give desired performance at all speeds from idling to full power output. The aircraft engine must also function efficiently through all the variations in atmospheric conditions encountered in widespread operations.

COMPACTNESS

To affect proper streamlining and balancing of an aircraft, the shape and size of the engine must be as compact as possible. In single engine aircraft, the shape and size of the engine also affect the view of the pilot, making a smaller engine better from this standpoint, in addition to reducing the drag created by a large frontal area.

Weight limitations, naturally, are closely related to the compactness requirement. The more elongated and spread out an engine is, the more difficult it becomes to keep the specific weight within the allowable limits.

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

A typical gas turbine engine consists of:

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

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

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

TURBINE ENGINE TYPES

One of the greatest single factors influencing the construction features of any gas turbine engine is the type of compressor or compressors for which the engine is designed. Four types of gas turbine engines are used to propel and power aircraft. They are the turbofan, turboprop, turboshaft, and turbojet. ***(Figure 1-7)*** The term "turbojet" was used to describe any gas turbine engine used in aircraft. As gas turbine technology evolved, these other engine types were developed to take the place of the pure turbojet engine. The turbojet engine has problems with noise and fuel consumption in the speed range that airliners fly (.8 Mach). Due to these problems, use of pure turbojet engines is very limited. So, almost all airliner type aircraft use a turbofan engine.

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

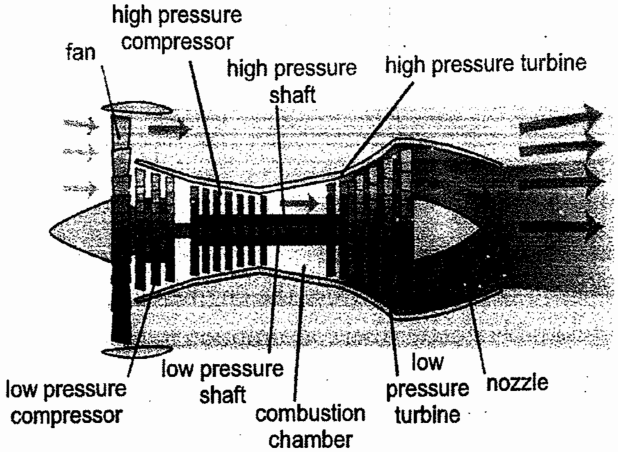
BYPASS RATIO

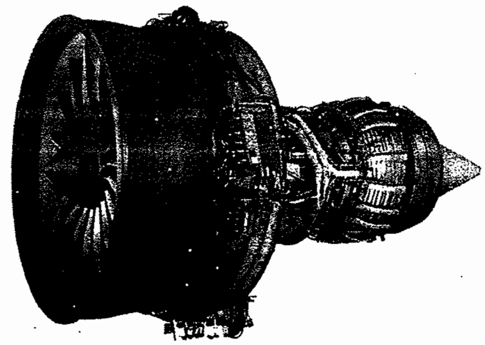
Turbofan engines can be low bypass or high bypass. The amount of air that is bypassed around the core of the engine determines the bypass ratio. As can be seen in ***Figure 1-8***, the air generally driven by the fan does not pass through the internal working core of the engine. The amount of air flow in lbs/sec from the fan bypass compared to the amount of air that flows through the core of the engine is the bypass ratio.

$$\textit{Bypass ratio} = \frac{\textit{100 lb/sec flow fan}}{\textit{20 lb/sec flow core}} = \textit{5:1 bypass ratio}$$

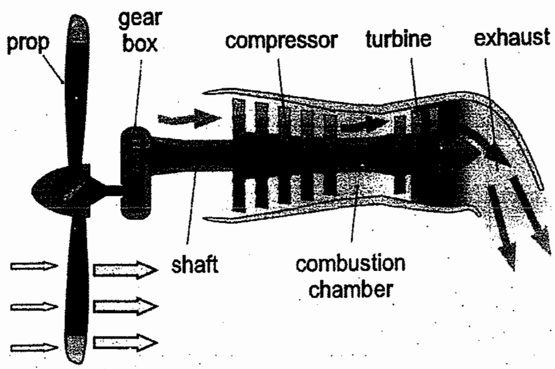
Turbofan engines are generally categorized as high bypass or low bypass in accordance with their bypass ratios. Most transport category aircraft use high bypass engines. Some low bypass turbofan engines are used in speed ranges above .8 Mach (military aircraft). These engines use augmenters or afterburners to increase thrust. By adding more fuel nozzles and a flame holder in the exhaust system extra fuel can be sprayed and burned which can give large increases in thrust for short amounts of time.

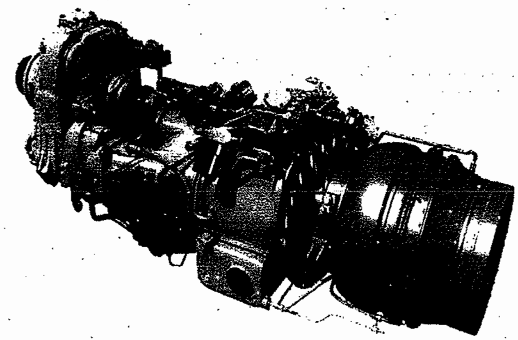
turbo fan



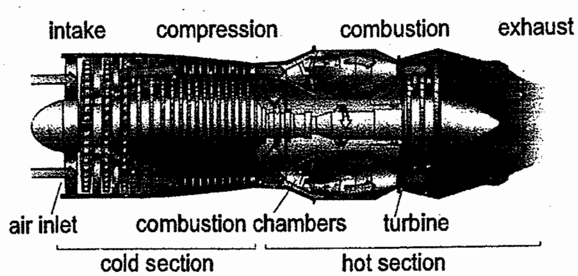


turbo prop

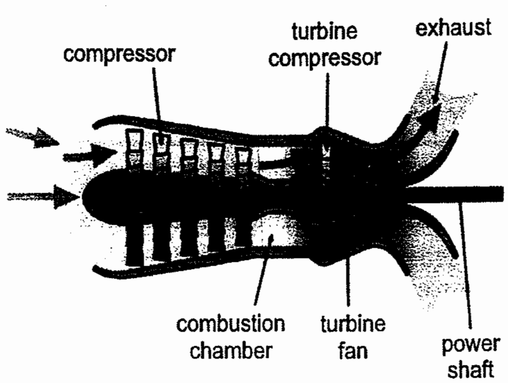




turbo jet



turbo shaft



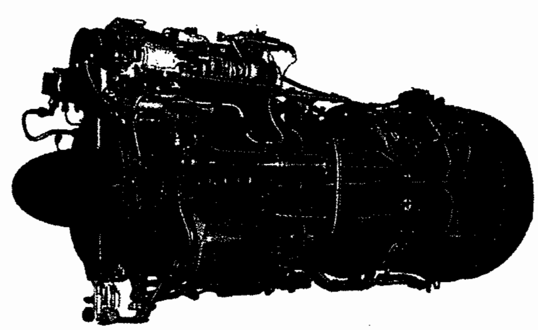


Figure 1-7. The four primary types of gas turbine engines.

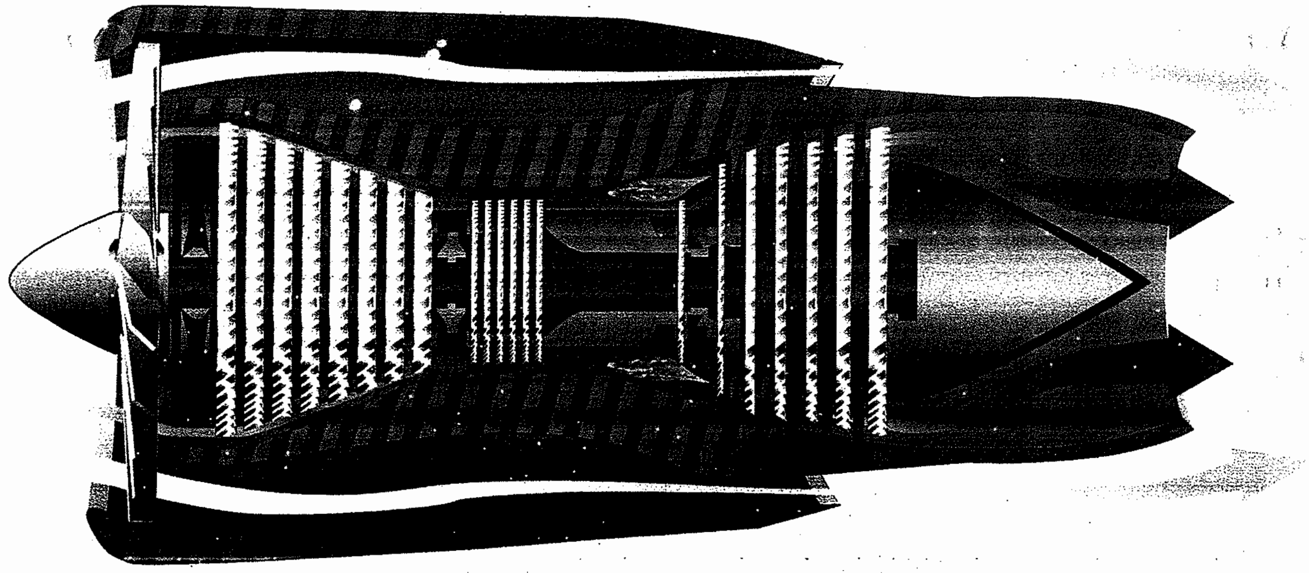


Figure 1-8. Fan airflow and core airflow of a turbofan engine.

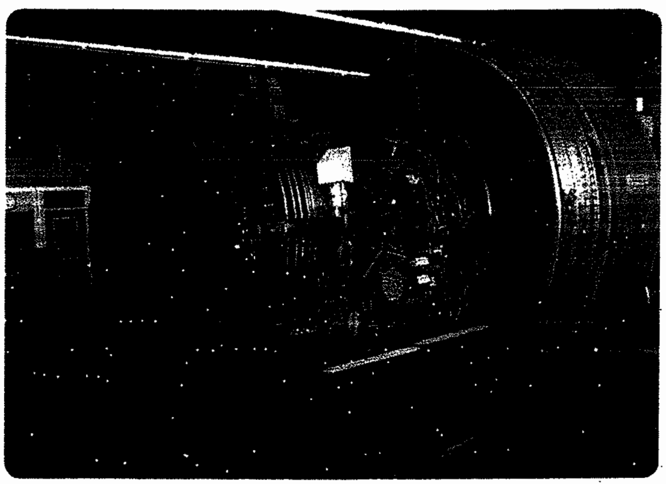


Figure 1-9. A turbofan engine.

The turbofan gas turbine engine is, in principle, the same as a turboprop, except that the propeller is replaced by a duct enclosed axial flow fan. (*Figure 1-9*) The fan can be a part of the first stage compressor blades or can be mounted as a separate set of fan blades. The blades can be mounted forward of the compressor.

The general principle of the fan engine is to convert more of the fuel energy into pressure. With more of the energy converted to pressure, a greater product of pressure times area can be achieved. One of the major advantages is turbofan production of this additional thrust without increasing fuel flow. The end result is fuel economy with the consequent increase in range. Because more of the fuel energy is turned into pressure in the turbofan engine, additional stages must be added in the turbine section to provide the power to drive the fan. This means there is less energy left over and less thrust from the core exhaust gases.

Also, in a mixed-exhaust nozzle (where fan air and core air mix in a common nozzle before entering ambient conditions) the exhaust nozzle must be larger in area. The result is that the fan develops most of the thrust. The thrust produced by the fan more than makes up for the decrease in thrust of the core (gas generator) of the engine. Depending on the fan design and bypass ratio, it produces 80 percent of the turbofan engine's total thrust.

Two different exhaust nozzle designs are used with turbofan engines. The air leaving the fan can be ducted overboard by a separate fan nozzle (*Figure 1-7*), or it can be ducted along the outer case of the basic engine to be discharged through the mixed nozzle (core and fan exhaust together). The fan air is either mixed with the exhaust gases before it is discharged (mixed or common nozzle), or it passes directly to the atmosphere without prior mixing (separate nozzle). Turbofans are the most widely used gas turbine engine for air transport aircraft. The turbofan is a compromise between the good operating efficiency and high thrust capability of a turboprop and the high speed, high altitude capability of a turbojet.

The turboprop engine is a gas turbine engine that turns a propeller through a speed reduction gear box. This type of engine is most efficient in the 300 to 400 mph speed range and can use shorter runways that other aircraft. Approximately 80 to 85 percent of the energy developed by the gas turbine engine is used to drive the propeller. The rest of the available energy exits the exhaust as thrust.

The turboshaft engine used in aviation is a gas turbine engine made to transfer horsepower to a shaft to operate something other than a propeller. They are used primarily to power helicopters and auxiliary power units (APU's). APU's are used on large aircraft to provide electrical power and bleed air on the ground and emergency backup power in flight.

TURBINE ENGINE FUEL SYSTEMS

GENERAL REQUIREMENTS

The fuel system is one of the more complex aspects of the gas turbine engine. It must be possible to increase or decrease the power at will to obtain the thrust required for any operating condition. In turbine-powered aircraft, this control is provided by varying the flow of fuel to the combustion chambers.

However, some turboprop aircraft also use variable pitch propellers; thus, the selection of thrust is shared by two controllable variables, fuel flow and propeller blade angle.

The quantity of fuel supplied must be adjusted automatically to correct for changes in ambient temperature or pressure. If the quantity of fuel becomes excessive in relation to mass airflow through the engine, the limiting temperature of the turbine blades can be exceeded, or it will produce compressor stall and a condition referred to as rich blowout. Rich blowout occurs when the amount of oxygen in the air supply is insufficient to support combustion and when the mixture is cooled below the combustion temperature by the excess fuel. The other extreme, lean flame out, occurs if the fuel quantity is reduced proportionally below the air quantity. The engine must operate through acceleration and deceleration without any fuel-control-related problems.

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

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

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

TURBINE FUEL CONTROLS

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

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

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

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

HYDROMECHANICAL FUEL CONTROLS

Hydromechanical fuel controls were used and are still used on many engines, but their use is becoming limited giving way to electronic based controls. Fuel controls have two sections, computing and metering, to provide the correct fuel flow for the engine. A pure hydromechanical fuel control has no electronic interface assisting in computing or metering the fuel flow. It also is generally driven by the gas generator gear train of the engine to sense engine speed. Other mechanical engine parameters that are sensed are compressor discharge pressure, burner pressure, exhaust temperature, and inlet air temperature and pressure. Once the computing section determines the correct amount of fuel flow, the metering section through cams and servo valves delivers the fuel to the engine fuel system. Actual operating procedures for a hydromechanical fuel control is very complicated and still the fuel metering is not as accurate as with an electronic type of interface or control. Electronic controls can receive more inputs with greater accuracy than hydromechanical controls. Early electronic controls used a hydromechanical control with an electronic system added on the system to fine tune the metering of the fuel. This arrangement also used the hydromechanical system as a backup if the electronic system failed. ***(Figure 1-10)***

HYDROMECHANICAL/ELECTRONIC FUEL CONTROL

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

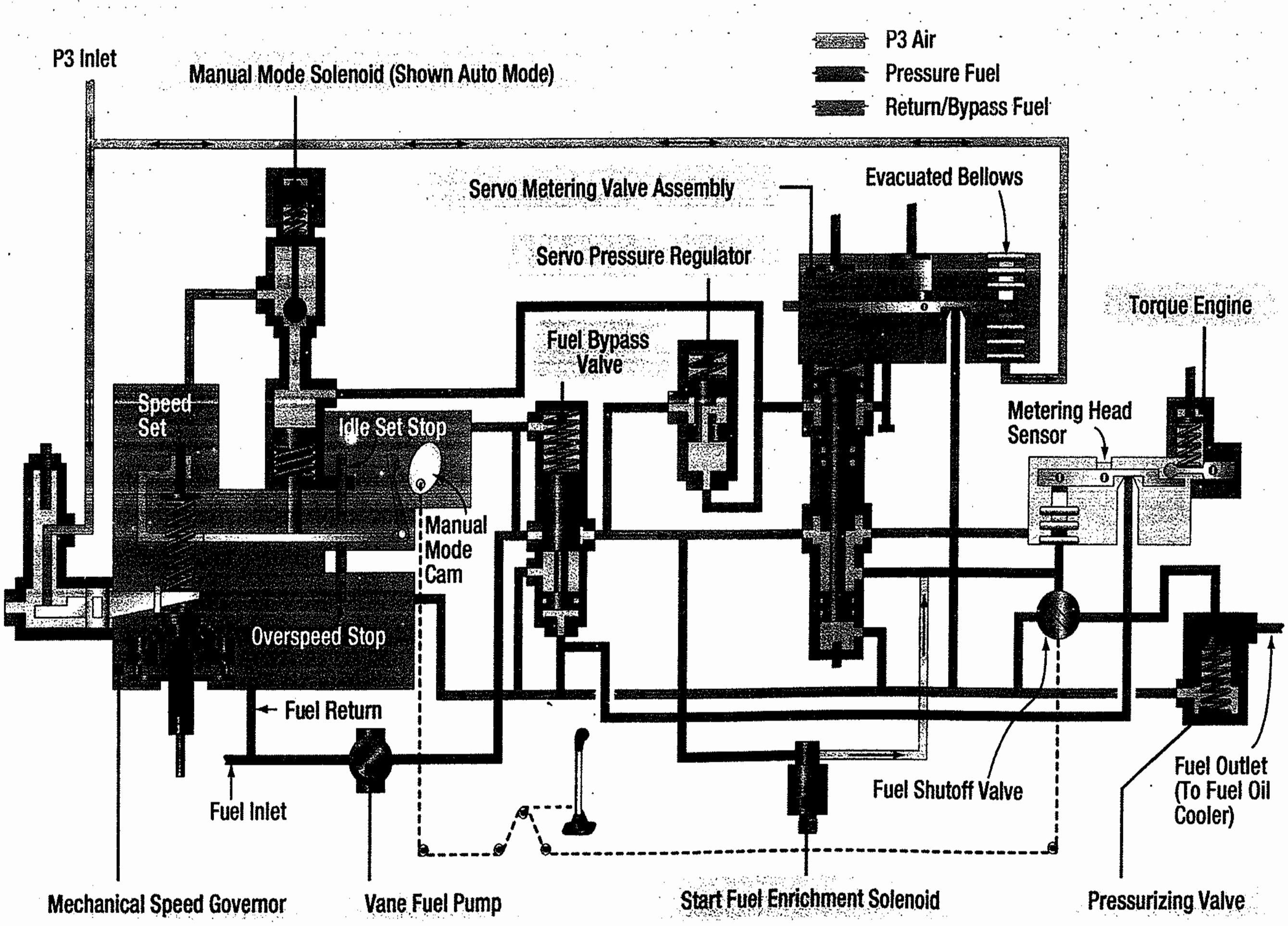


Figure 1-10. Fuel control assembly schematic hydromechanical/electronic.

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

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

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

The total engine fuel and control system consists of the following components and provides the functions as indicated:

1. The vane fuel pump assembly is a fixed displacement fuel pump that provides high pressure fuel to the engine fuel control system. ***(Figure 1-11)***

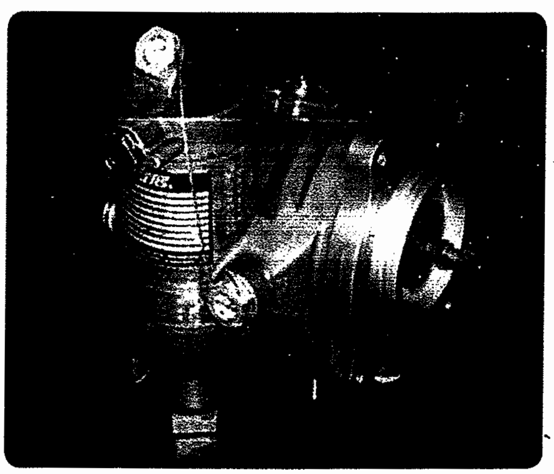


Figure 1-11. Fuel pump and filter.

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

Fuel is supplied to the fuel control through a 200-micron inlet filter screen and is metered to the engine by the servo operated metering valve. It is a fuel flow/compressor discharge pressure (Wf/P3) ratio device that positions the metering valve in response to engine compressor discharge pressure (P3). Fuel pressure differential across the servo valve is maintained by the servo-operated bypass valve in response to commands from the EFCU. ***(Figure 1-10)***

The manual mode solenoid valve is energized in the automatic mode. The automatic mode restricts operation of the mechanical speed governor. It is restricted to a single overspeed governor setting above the speed range controlled electronically. De-energizing the manual mode valve enables the mechanical speed governor to function as an all speed governor in response to power lever angle (PLA). The fuel control system includes a low power sensitive torque motor which may be activated to increase or decrease fuel flow in the automatic mode (EFCU mode). The torque motor provides an interface to an electronic control unit that senses various engine and ambient parameters and activates the torque motor to meter fuel flow accordingly. This torque motor provides electromechanical conversion of an electrical signal from the EFCU. The torque motor current is zero in the manual mode, which establishes a fixed Wf/P3 ratio.

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

Located downstream of the metering valve are the manual shutoff and pressurizing valves. The shutoff valve is a rotary unit connected to the power lever. It allows the pilot to direct fuel to the engine manually.

The pressurizing valve acts as a discharge restrictor to the hydromechanical control. It functions to maintain minimum operating pressures throughout the control. The pressurizing valve also provides a positive leak tight fuel shutoff to the engine fuel nozzles when the manual valve is closed. The flow divider and drain valve assembly proportions fuel to the engine primary and secondary fuel nozzles. It drains the nozzles and manifolds at engine shutdown. It also incorporates an integral solenoid for modifying the fuel flow for cold starting conditions.

During an engine start, the flow divider directs all flow through the primary nozzles. After start, as the engine fuel demand increases, the flow divider valve opens to allow the secondary nozzles to function. During all steady state engine operation, both primary and secondary nozzles are flowing fuel. A 74-micron, self bypassing screen is located under the fuel inlet fitting and provides last chance filtration of the fuel prior to the fuel nozzles. The fuel manifold assembly is a matched set consisting of both primary and secondary manifolds and the fuel nozzle assemblies. Twelve fuel nozzles direct primary and secondary fuel through the nozzles causing the fuel to swirl and form a finely atomized spray. The manifold assembly provides fuel routing and atomizing to ensure proper combustion.

The EEC system consists of the hydromechanical fuel control, EFCU, and aircraft mounted power lever angle potentiometer. Aircraft generated control signals include inlet pressure, airstream differential pressure, and inlet temperature plus pilot selection of either manual or auto mode for the EFCU operation. Engine generated control signals include fan spool speed, gas generator spool speed, inner turbine temperature, fan discharge temperature, and compressor discharge pressure. Aircraft and engine generated control signals are directed to the EFCU where these signals are interpreted. The PLA potentiometer is aircraft mounted in the throttle quadrant. The PLA potentiometer transmits an electrical signal to the EFCU, which represents engine thrust demand in relation to throttle position. If the EFCU determines a power change is required, it commands the torque motor to modulate differential pressure at the head sensor. This change in differential pressure causes the metering valve to move, varying fuel flow to the engine as required.

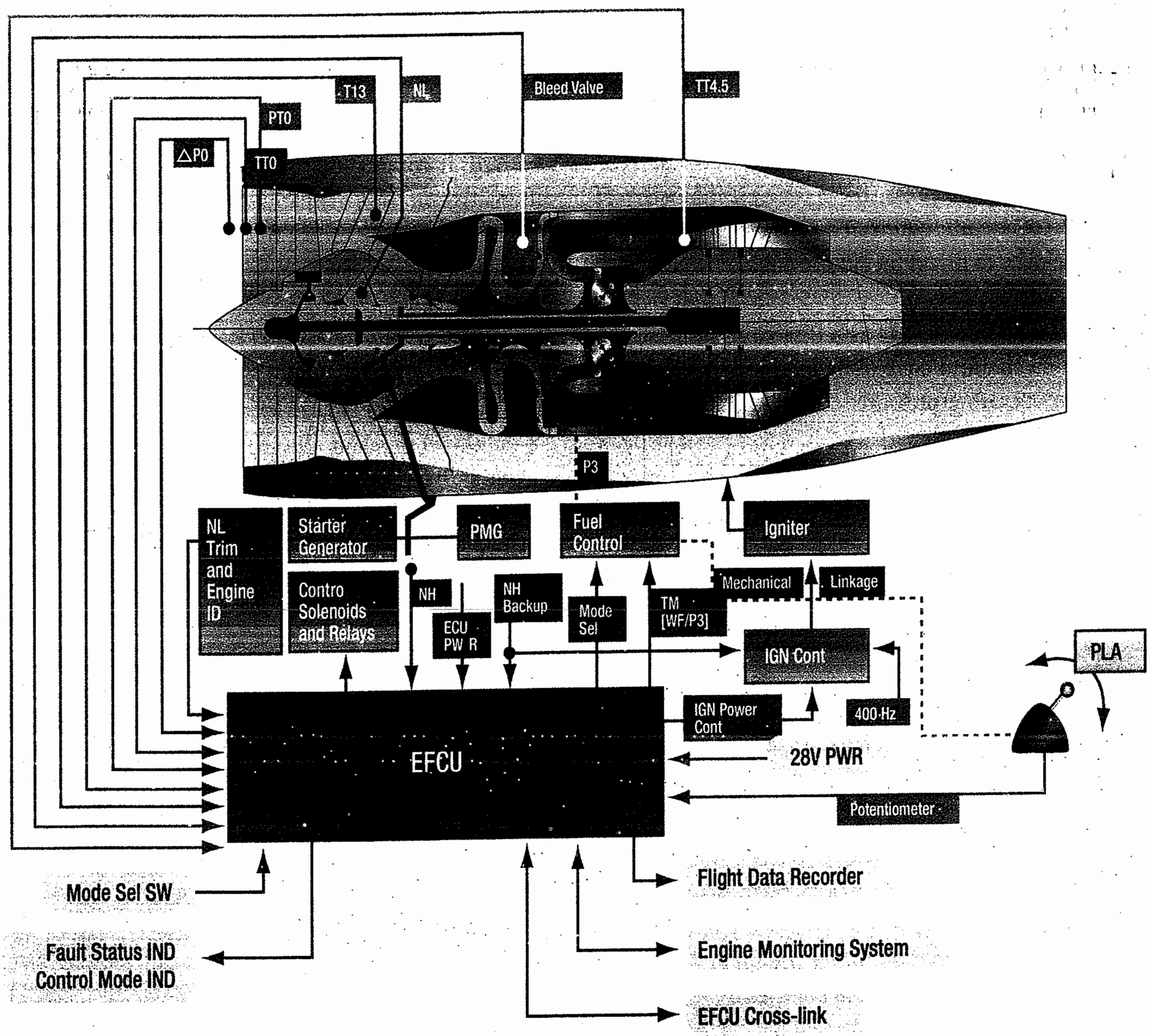
The EFCU receives electrical signals which represent engine operating variables. It also receives a pilot initiated signal (by power lever position) representing engine thrust demand. The EFCU computes electrical output signals for use by the engine fuel control for scheduling engine operation within predetermined limits. The EFCU is programmed to recognize predetermined engine operating limits and to compute output signals such that these operating limits are not exceeded. The EFCU is remotely located and airframe mounted. An interface between the EFCU and aircraft/engine is provided through the branched wiring harness assembly. ***(Figure 1-12)***

FADEC FUEL CONTROL SYSTEMS

A full authority digital electronic control (FADEC) has been developed to control fuel flow on most new turbine engine models. A true FADEC system has no hydromechanical fuel control backup system. The system uses electronic sensors that feed engine parameter information into the EEC. The EEC gathers the needed information to determine the amount of fuel flow and transmits it to a fuel metering valve. The fuel metering valve simply reacts to the commands from the EEC. The EEC is a computer that is the computing section of the fuel delivery system and the metering valve meters the fuel flow. FADEC systems are used on many turbine engines from APUs to the largest propulsion engines.

FADEC FOR AN AUXILIARY POWER UNIT

The first example system is an APU engine that uses the aircraft fuel system to supply fuel to the fuel control. An electric boost pump may be used to supply fuel under pressure to the control. The fuel usually passes through an aircraft shutoff valve that is tied to the fire detecting/extinguishing system. An aircraft furnished in-line fuel filter may also be used. Fuel entering the fuel



SYMBOLS	
NH	Core spool speed
NL	Fan spool speed
PTO	Free stream total pressure
PLA	Power lever angle
TTO	Total temperature
T4.5	Interturbine temperature
T13	Fan exit air temperature
△P	Indicated airspeed

Engine Control System

Figure 1-12. Engine control system.

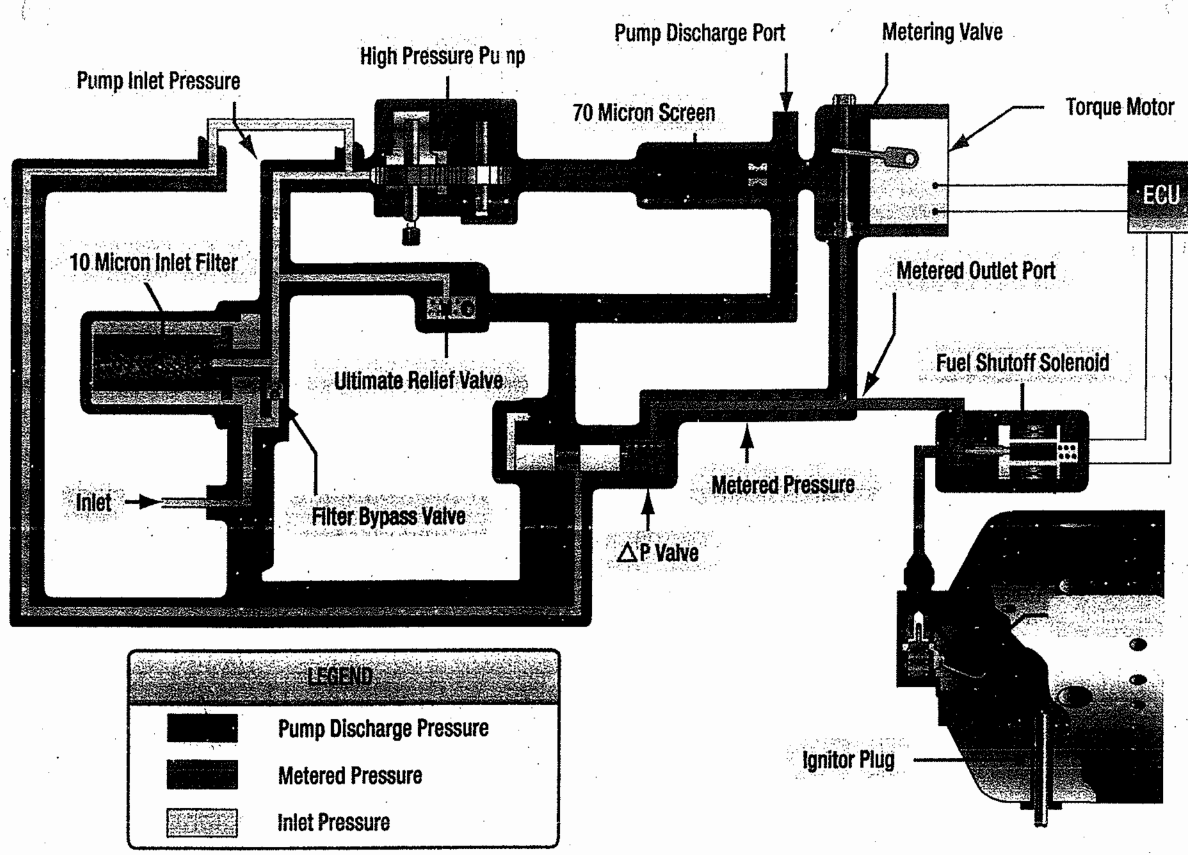


Figure 1-13. APU fuel system schematic.

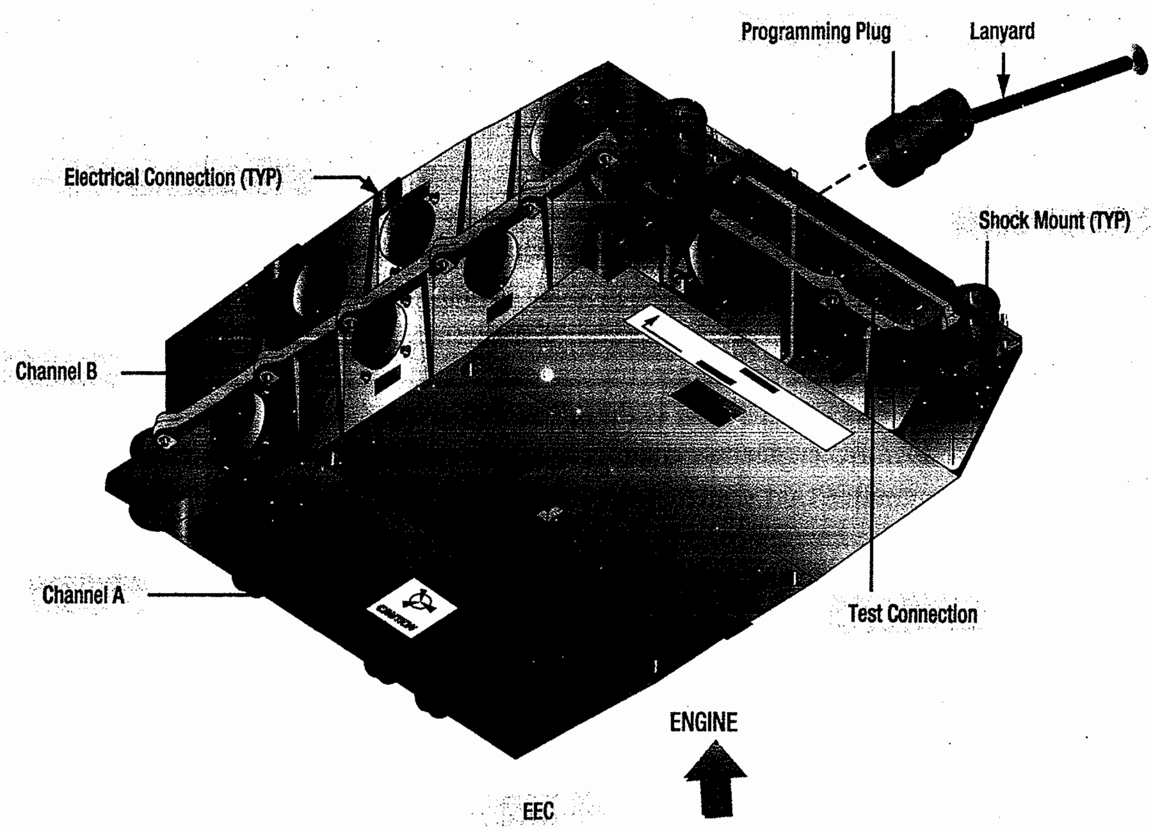


Figure 1-14. EEC and programming plug.

control unit first passes through a 10 micron filter. If the filter becomes contaminated, the resulting pressure drop opens the filter bypass valve and unfiltered fuel then is supplied to the APU. Shown in ***Figure 1-13*** is a pump with an inlet pressure access plug so that a fuel pressure gauge might be installed for troubleshooting purposes. Fuel then enters a positive displacement, gear type pump. Upon discharge from the pump, the fuel passes through a 70 micron screen. The screen is installed at this point to filter any wear debris that might be discharged from the pump element. From the screen, fuel branches to the metering valve, differential pressure valve, and the ultimate relief valve. Also shown at this point is a pump discharge pressure access plug, another point where a pressure gauge might be installed.

The differential pressure valve maintains a constant pressure drop across the metering valve by bypassing fuel to the pump inlet so that metered flow is proportional to metering valve area. The metering valve area is modulated by the torque motor, which receives variable current from the ECU. The ultimate relief valve opens to bypass excess fuel back to the pump inlet whenever system pressure exceeds a predetermined pressure. This occurs during each shutdown since all flow is stopped by the shutoff valve and the differential pressure valve, is unable to bypass full pump capacity. Fuel flows from the metering valve out of the FCU, through the solenoid shutoff valve and on to the atomizer. Initial flow is through the primary nozzle tip only. The flow divider opens at higher pressure and adds flow through the secondary path.

FADEC FUEL CONTROL PROPULSION ENGINE

Many large high-bypass turbofan engines use the FADEC type of fuel control system. The EEC is the primary component of the FADEC engine fuel control system. The EEC is a computer that controls the operation of the engine. The EEC housing contains two electronic channels (two separate computers) that are physically separated internally and is naturally cooled by convection. The EEC is generally placed in an area of the engine nacelle that is cool during engine operation. It attaches to the lower-left fan case with shock mounts. ***(Figure 1-14)***

The EEC computer uses data it receives from many engine sensors and airplane systems to control the engine operation. It receives electronic signals from the flight deck to set engine power or thrust. The throttle lever angle resolver supplies the EEC with a signal in proportion to the thrust lever position. The EEC controls most engine components and receives feedback from them. Many components supply the EEC with data for engine operation.

Power for the EEC comes from the aircraft electrical system or the permanent magnet alternator (PMA). When the engine is running, the PMA supplies power to the EEC directly. The EEC is a two channel computer that controls every aspect of engine operation. Each channel, which is an independent computer, can completely control the operation of the engine. The processor does all of the control calculations and supplies all the data for the control signals for the torque motors and solenoids. The cross-talk logic compares data from channels A and B and uses the cross-talk logic to find which EEC channel is the best to control the output driver for a torque motor or solenoid bank. The primary channel controls all of the output drivers. If the cross-talk logic finds that the other channel is better for control of a specific bank, the EEC changes control of that one bank to the other channel. The EEC has output driver banks that supply the control signals to engine components. Each channel of the EEC supplies the driver banks with control signals. The EEC has both volatile and nonvolatile memory to store performance and maintenance data.

The EEC can control the engine thrust in two modes, which can be selected by use of a mode selection switch. In the normal mode, engine thrust is set with EPR; in the alternate mode, thrust is set by N1. When the fuel control switch is moved from run to cutoff, the EEC resets. During this reset, all fault data is recorded in the nonvolatile memory. The EEC controls the metering valve in the fuel metering unit to supply fuel flow for combustion. ***(Figure 1-15)*** The fuel metering unit is mounted on the front face of the gearbox and is attached to the front of the fuel pump. ***(Figure 1-16)***

The EEC also sends a signal to the minimum pressure and shutoff valve in the fuel metering unit to start or stop fuel flow. The EEC receives position feedback for several engine components by using rotary differential transformer, linear variable differential transformer, and thermocouples. These sensors feed engine parameter

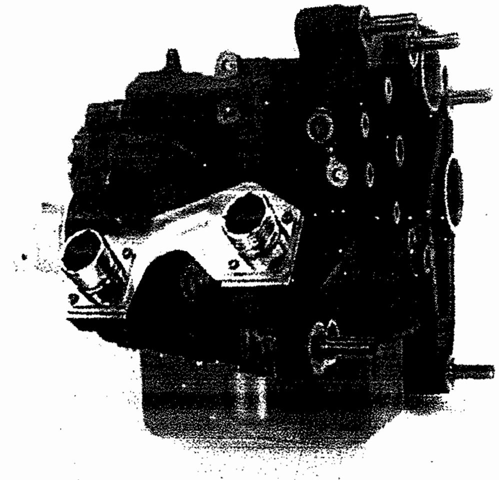


Figure 1-15. Fuel metering unit.

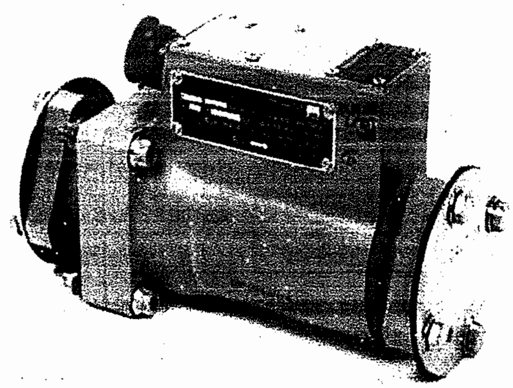


Figure 1-18. Fuel flow transmitter.

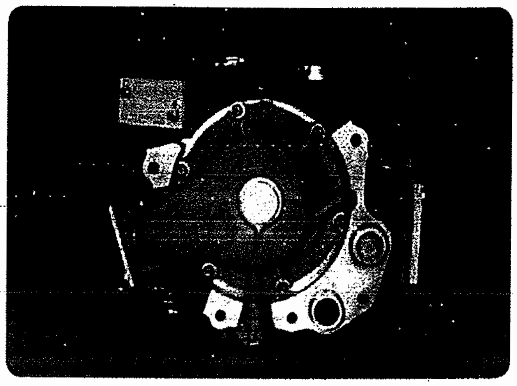


Figure 1-16. Fuel pump.

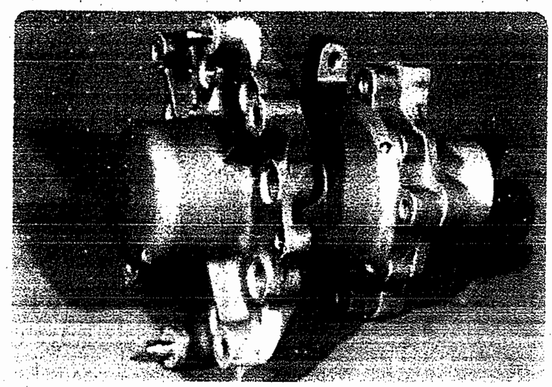


Figure 1-19. Fuel distribution valve.

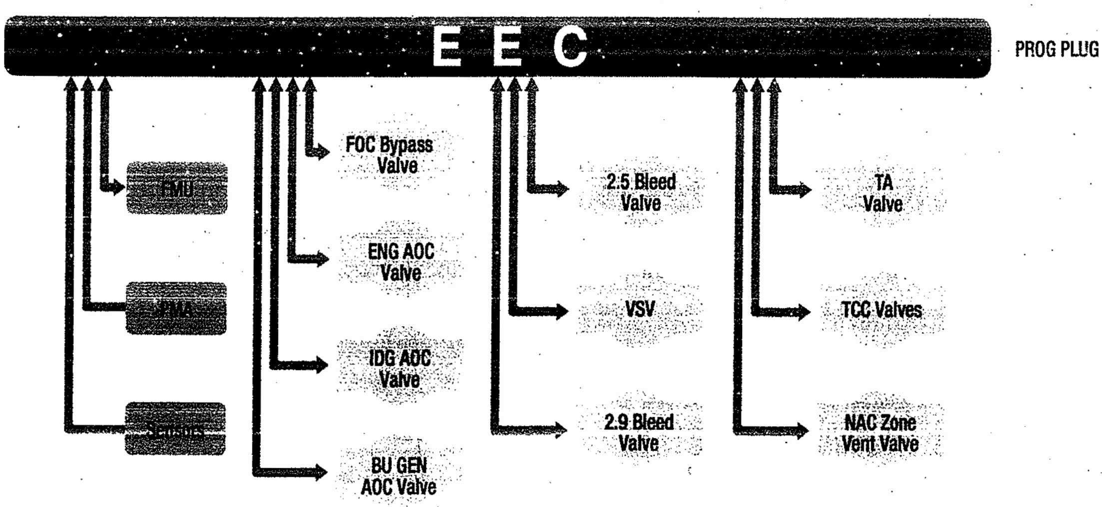


Figure 1-17. Systems controlled by EEC.

information from several systems back to the EEC. The fuel control run cutoff switch controls the high pressure fuel shut off valve that allows or cuts off fuel flow. The fuel temperature sensor thermocouple attaches to the fuel outlet line on the rear of the fuel/oil cooler and sends this information to the EEC. The EEC uses a torque motor driver to control the position of the metering valve in the fuel metering unit. The EEC uses solenoid drivers to control the other functions of the FMU. The EEC also controls several other subsystems of the engine, as shown in ***Figure 1-17***, through torque motors and solenoids, such as fuel and air oil coolers, bleed valves, variable stator vanes, turbine cooling air valves, and the turbine case cooling system.

Each channel of the EEC has seven electrical connections, three on each side and one on the bottom. Both channels share the inputs of the two connections on the top of the EEC. These are the programming plug and test connector. The programming plug selects the proper software in the EEC for the thrust rating of the engine. The plug attaches to the engine fan case with a lanyard. When removing the EEC, the plug remains with the engine. Each channel of the EEC has three pneumatic connections on the bottom of the EEC. Transducers inside the EEC supply the related and opposite EEC channel with a signal in proportion to the pressure. The pressures that are read by the EEC are ambient pressure, burner pressure, LPC exit pressure, and fan inlet pressure. Each channel has its own wire color that connects the EEC to its sensors. Channel A wiring is blue and channel B sensor signals are green. The non-EEC circuit wire is gray while the thermocouple signals are yellow. This color coding helps simplify which sensors are used with each channel.

FUEL SYSTEM OPERATION

The fuel pump receives fuel from the airplane fuel system. The low pressure boost stage of the pump pressurizes the fuel and sends it to the fuel/oil cooler (FOC). The fuel flows from the FOC, through the fuel pump filter element, and then to the high pressure main stage of the pump. The high pressure main stage increases the fuel pressure and sends it to the fuel metering unit (FMU). It also supplies servo fuel to the servo fuel heater and engine components. Fuel for combustion (metered fuel) goes through the fuel flow transmitter to the distribution valve. ***(Figure 1-18)*** The fuel distribution valve supplies metered fuel to the fuel supply manifolds. ***(Figure 1-19)*** The fuel injectors get the metered fuel from the fuel supply manifolds and spray the fuel into the engine for combustion. ***(Figure 1-20)***

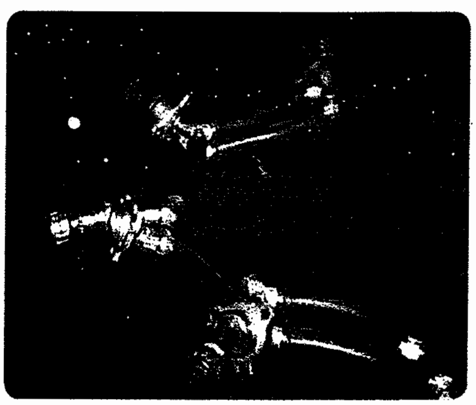


Figure 1-20. Fuel manifolds.

The fuel pump housing contains a disposable fuel filter element. The fuel filter differential pressure switch supplies a signal to the EEC that indicates an almost clogged filter condition. Unfiltered fuel can then bypass the filter element if the element becomes clogged.

ENGINE FUEL SYSTEM COMPONENTS

MAIN FUEL PUMPS (ENGINE DRIVEN)

Main fuel pumps deliver a continuous supply of fuel at the proper pressure and at all times during operation of the aircraft engine. The engine driven fuel pump must be capable of delivering the maximum needed flow at appropriate pressure to obtain satisfactory nozzle spray and accurate fuel regulation.

These engine driven fuel pumps may be divided into two distinct system categories:

1. Constant displacement
2. Non-constant displacement

Their use depends on where in the engine fuel system they are used. Generally, a non-positive displacement (centrifugal pump) is used at the inlet of the engine driven pump to provide positive flow to the second stage of the pump. The output of a centrifugal pump can be varied as needed and is sometimes referred to as a boost stage of the engine driven pump.

The second or main stage of the engine-driven fuel pump for turbine engines is generally a positive displacement type of pump. The term "positive displacement" means that the gear supplies a fixed quantity of fuel to the engine for every revolution of the pump gears. Gear type pumps have approximately straight line flow characteristics, whereas fuel requirements fluctuate with flight or ambient air conditions. Hence, a pump of adequate capacity at all engine operating conditions has excess capacity over most of the range of operation. This is the characteristic that requires the use of a pressure relief valve for bypassing excess fuel back to the inlet. A typical two stage turbine engine driven pump is illustrated in ***Figure 1-21.*** The impeller, which is driven at a greater speed than the high pressure elements, increases the fuel pressure depending upon engine speed.

The fuel is discharged from the boost element (impeller) to the two high pressure gear elements. A relief valve is incorporated in the discharge port of the pump. This valve opens at a predetermined pressure and is capable of bypassing the total fuel flow. This allows fuel in excess of that required for engine operation at the time to be recirculated. The bypass fuel is routed to the inlet side

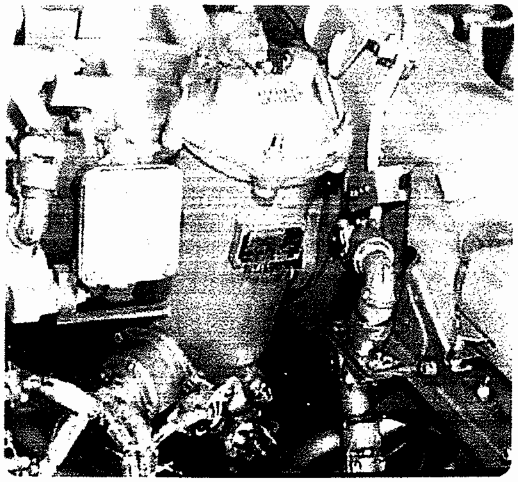


Figure 1-21. Dual element fuel pump.

of the second stage pump. Fuel flows from the pump to the fuel metering unit or fuel control. The fuel control is often attached to the fuel pump. The fuel pump is also lubricated by the fuel passing through the pump, and it should never be turned without fuel flow supplied to the inlet of the pump. As the engine coasts down at shutdown, the fuel pump should be provided with fuel until it comes to a stop.

FUEL HEATER

Gas turbine engine fuel systems are very susceptible to the formation of ice in the fuel filters. When the fuel in the aircraft fuel tanks cools to 32°F or below, residual water in the fuel tends to freeze, forming ice crystals. When these ice crystals in the fuel become trapped in the filter, they block fuel flow to the engine, which causes a very serious problem. To prevent this problem, the fuel is kept at a temperature above freezing. Warmer fuel also can improve combustion, so some means of regulating the fuel temperature is needed.

One method of regulating fuel temperature is to use a fuel heater which operates as a heat exchanger to warm the fuel. The heater can use engine bleed air or engine lubricating oil as a source of heat. The bleed air type is called an air to liquid exchanger and the oil type is known as a liquid to liquid heat exchanger. The function of a fuel heater is to protect the engine fuel system from ice formation. However, should ice form in the filter, the heater can also be used to thaw ice on the fuel screen to allow fuel to flow freely again. On most installations, the fuel filter is fitted with a pressure drop warning switch, which illuminates a warning light on the cockpit instrument panel. If ice begins to collect on the filter surface, the pressure across the filter slowly decreases. When the pressure reaches a predetermined value, the warning light alerts the flight deck personnel.

Fuel deicing systems are designed to be used intermittently. The control of the system may be manual, by a switch in the cockpit, or automatic, using a thermostatic sensing element in the fuel heater to open or close the air or oil shutoff valve. A fuel heater system

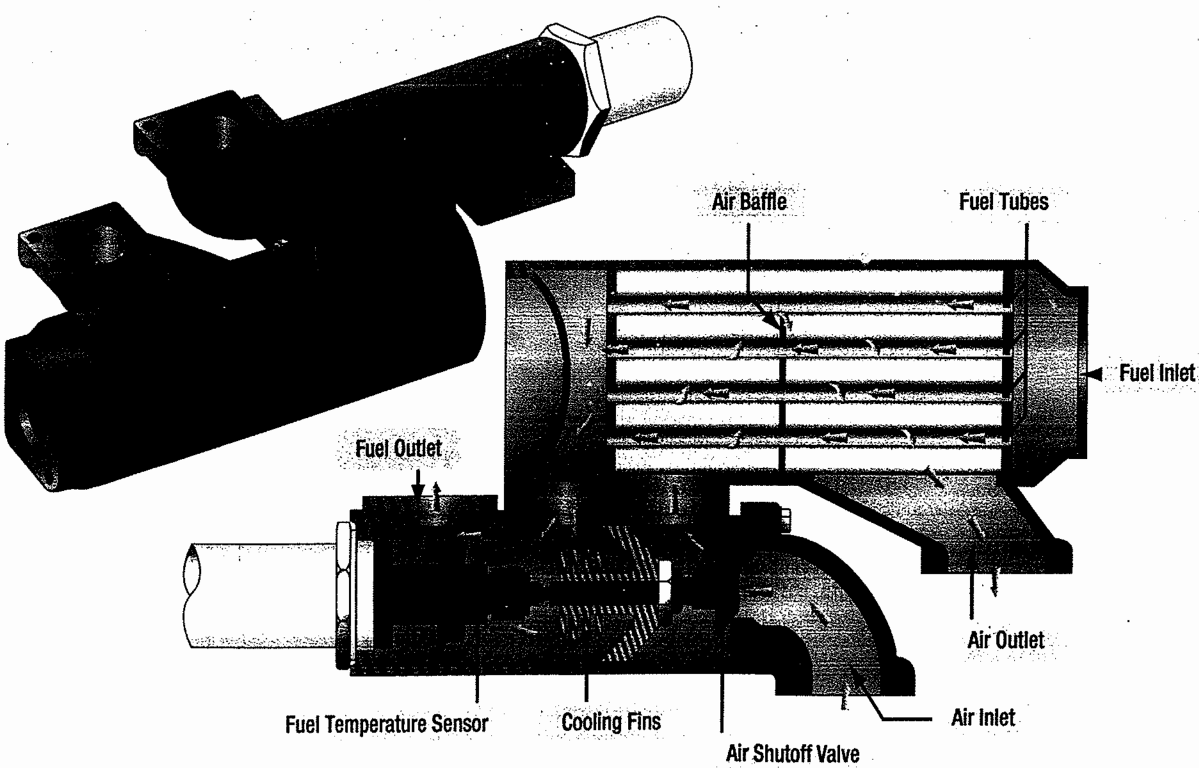


Figure 1-22. Fuel heater.

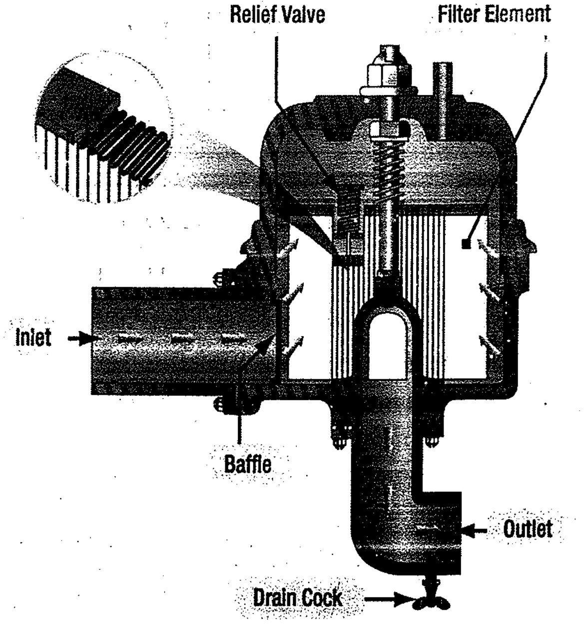


Figure 1-23. Aircraft fuel filter.

is shown in ***Figure 1-22.*** In a FADEC system, the computer controls the fuel temperature by sensing the fuel temperature and heating it as needed.

FUEL FILTERS

A low-pressure filter is installed between the supply tanks and the engine fuel system to protect the engine driven fuel pump and various control devices. An additional high pressure fuel filter is installed between the fuel pump and the fuel control to protect the fuel control from contaminants that could come from the low pressure pump.

The three most common types of filters in use are the micron filter, the wafer screen filter, and the plain screen mesh filter. The individual use of each of these filters is dictated by the filtering treatment required at a particular location. The micron filter has the greatest filtering action of any present day filter type and, as the name implies, is rated in microns. ***(Figure 1-23)*** (A micron is one thousandth of one millimeter.) The porous cellulose material frequently used in construction of the filter cartridges is capable of removing foreign matter measuring from 10–25 microns. The minute openings make this type of filter susceptible to clogging; therefore, a bypass valve is a necessary safety factor.

Since the micron filter does such a thorough job of removing foreign matter, it is especially valuable between the fuel tank and engine. The cellulose material also absorbs water, preventing it from passing through the pumps. If water does seep through the filter, which happens occasionally when filter elements become saturated with water, the water can and does quickly damage the working elements of the fuel pump and control units, since these elements depend solely on the fuel for their lubrication. To reduce water damage to pumps and control units, periodic servicing and replacement of filter elements is imperative. Daily draining of fuel tank sumps and low pressure filters eliminates much filter trouble and undue maintenance of pumps and fuel control units.

The most widely used filters are the 200-mesh and the 35-mesh micron filters. They are used in fuel pumps, fuel controls, and between the fuel pump and fuel control where removal of micronic particles is needed.

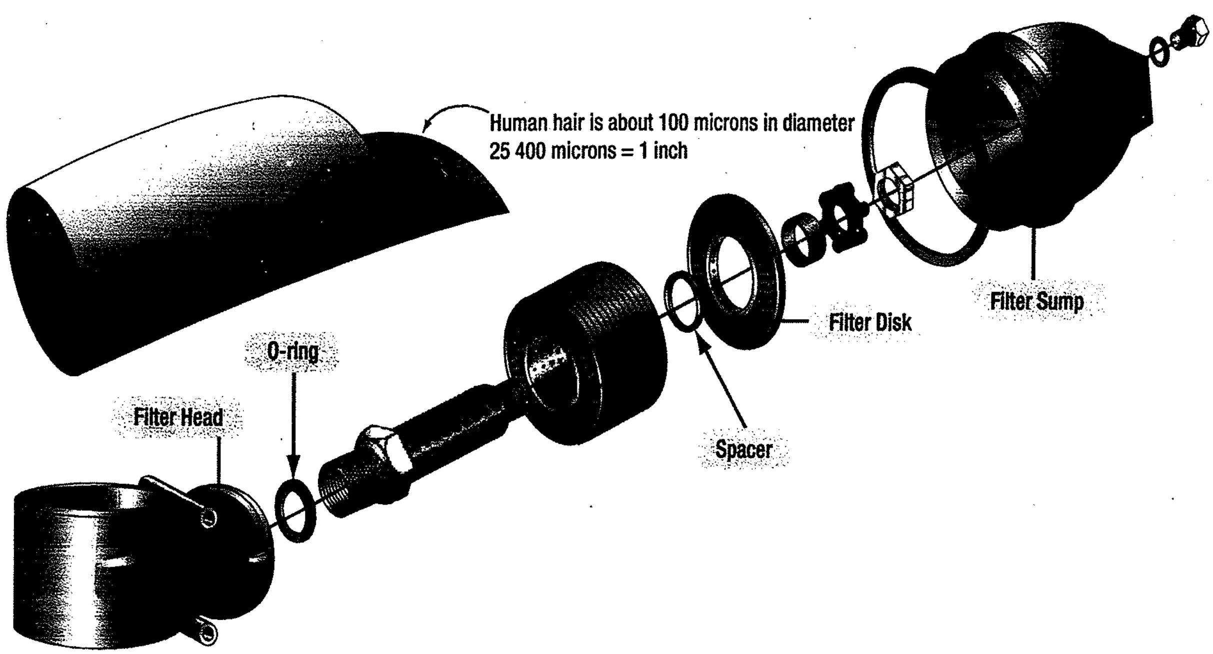


Figure 1-24. Wafer screen filter.

These filters, usually made of fine-mesh steel wire, are a series of layers of wire. The wafer screen type of filter has a replaceable element, which is made of layers of screen disks of bronze, brass, steel, or similar material. ***(Figure 1-24)*** This type of filter is capable of removing micronic particles. It also has the strength to withstand high pressure.

FUEL SPRAY NOZZLES AND FUEL MANIFOLDS

Although fuel spray nozzles are an integral part of the fuel system, their design is closely related to the type of combustion chamber in which they are installed. The fuel nozzles inject fuel into the combustion area in a highly atomized, precisely patterned spray so that burning is completed evenly, in the shortest possible time, and in the smallest possible space. It is very important that the fuel be evenly distributed and well centered in the flame area within the liners. This is to preclude the formation of any hot spots in the combustion chambers and to prevent the flame burning through the liner.

Fuel nozzle types vary considerably between engines, although for the most part fuel is sprayed into the combustion area under pressure through small orifices in the nozzles. The two types of fuel nozzles generally used are the simplex and the duplex configurations. The duplex nozzle usually requires a dual manifold and a pressurizing valve or flow divider for dividing primary and secondary (main) fuel flow, but the simplex nozzle requires only a single manifold for proper fuel delivery.

The fuel nozzles can be constructed to be installed in various ways. The two methods used quite frequently are:

1. External mounting wherein a mounting pad is provided for attachment of the nozzles to the case or the inlet air elbow, with the nozzle near the dome; or
2. Internal mounting at the liner dome, in which the chamber cover must be removed for replacement or maintenance of the nozzle.

The nozzles used in a specific engine should be matched so that they flow equal amounts of fuel. Even fuel distribution is important to efficient combustion in the burner section. The fuel nozzle must present a fine spray with the correct pattern and optimum atomization.

SIMPLEX FUEL NOZZLE

The simplex fuel nozzle was the first nozzle type used in turbine engines and was replaced in most installations with the duplex nozzle, which gave better atomization at starting and idling speeds. The simplex nozzle is still being used in several installations. ***(Figure 1-25)*** Each of the simplex nozzles consists of a nozzle tip, an insert, and a strainer made up of fine-mesh screen and a support.

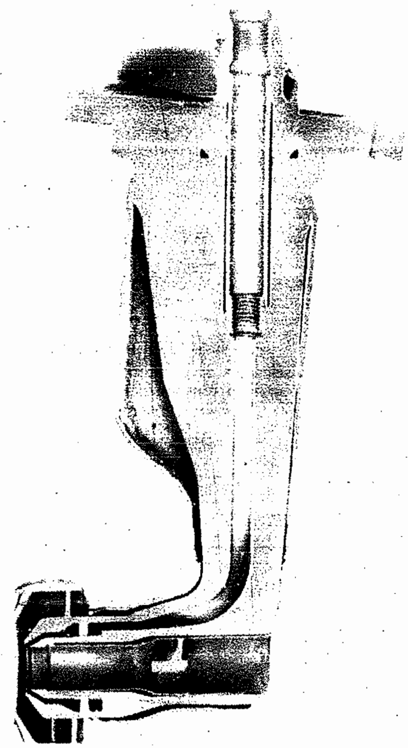


Figure 1-25. Simplex airblast nozzle cutaway.

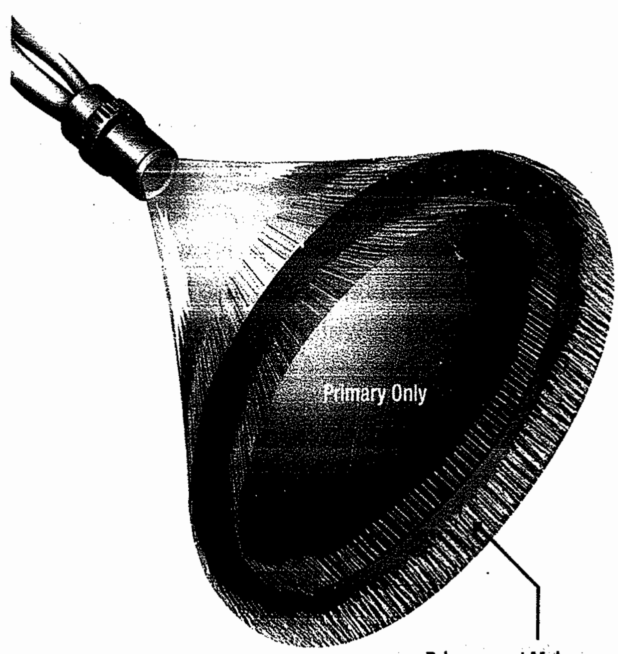


Figure 1-26. Duplex nozzle spray pattern.

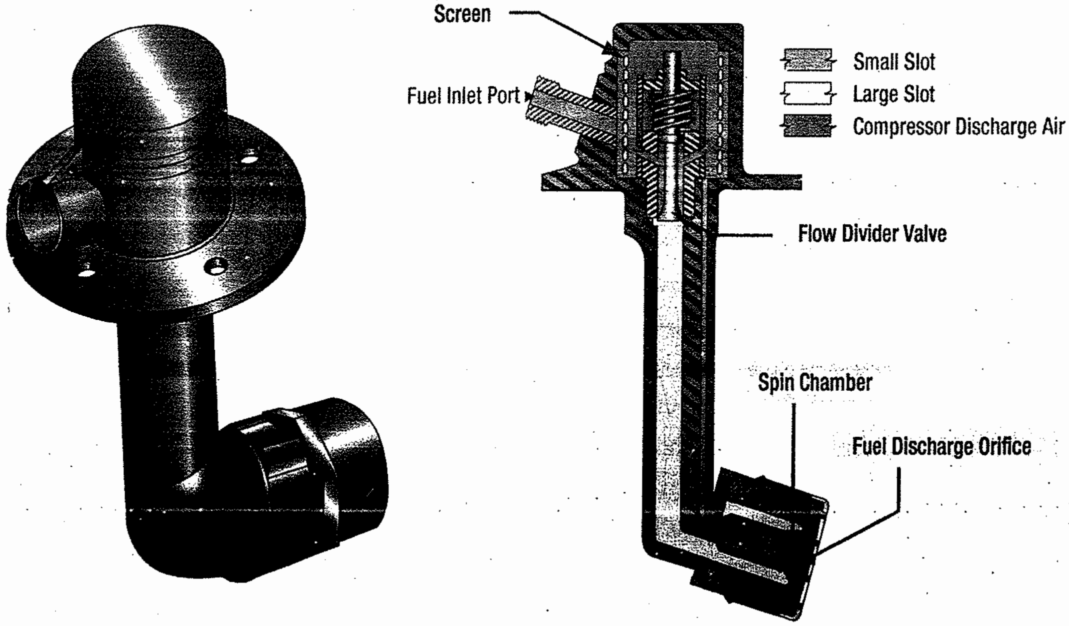


Figure 1-27. Duplex fuel nozzle.

DUPLEX FUEL NOZZLE

The duplex fuel nozzle is widely used in present day gas turbine engines. As mentioned previously, its use requires a flow divider, but at the same time it offers a desirable spray pattern for combustion over a wide range of operating pressures. ***(Figure 1-26)*** A nozzle typical of this type is illustrated in ***Figure 1-27***.

AIRBLAST NOZZLES

Airblast nozzles are used to provide improved mixing of the fuel and airflow to provide an optimum spray for combustion. Squirrel vanes are used to mix the air and fuel at the nozzle opening. By using a proportion of the primary combustion airflow in the fuel spray, locally rich fuel concentrations can be reduced. This type of fuel nozzle can be either simplex or duplex, depending upon the engine. This nozzle type can operate at lower working pressures than other nozzles which allows for lighter pumps. This airblast nozzle also helps in reducing the tendency of the nozzle to carbon up which can disturb the flow pattern.

FLOW DIVIDER

A flow divider creates primary and secondary fuel supplies that are discharged through separate manifolds, providing two separate fuel flows. ***(Figure 1-28)***

Metered fuel from the fuel control enters the inlet of the flow divider and passes through an orifice and then on to the primary nozzles. A passage in the flow divider directs fuel flow from both sides of the orifice to a chamber. This chamber contains a differential pressure bellows, a viscosity compensated restrictor (VCR), and a surge dampener. During engine start, fuel pressure is applied to the inlet port and across the VCR, surge dampener, and on to the primary side of the nozzles. Fuel is also applied under pressure to the outside of the flow divider bellows and through the surge dampener to the inside of the flow divider bellows. This unequal pressure causes the flow divider valve to remain closed.

When fuel flow increases, the differential pressure on the bellows also increases. At a predetermined pressure, the bellows compresses, allowing the flow divider valve to open. This action starts fuel flow to the secondary manifold, which increases the fuel flow to the engine. This fuel flows out of the secondary opening in the nozzles.

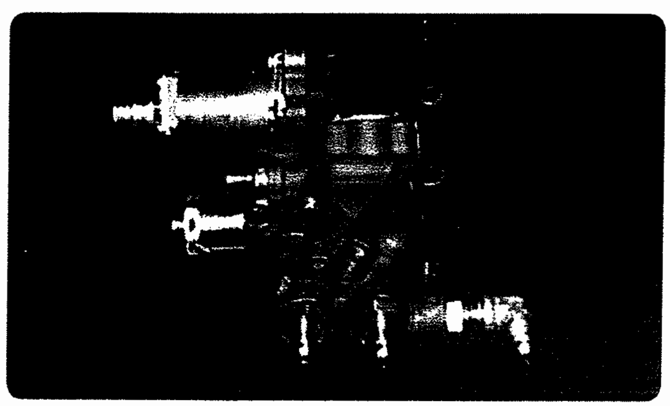


Figure 1-28. Flow divider.

FUEL PRESSURIZING AND DUMP VALVES

The fuel pressurizing valve is usually required on engines incorporating duplex fuel nozzles to divide the flow into primary and secondary manifolds. At the fuel flows required for starting and altitude idling, all the fuel passes through the primary line. As the fuel flow increases, the valve begins to open the main line until at maximum flow the secondary line is passing approximately 90 percent of the fuel. Fuel pressurizing valves usually trap fuel forward of the manifold, giving a positive cutoff. This cutoff prevents fuel from dribbling into the manifold and through the fuel nozzles, limiting afterfires and carbonization of the fuel nozzles. Carbonization occurs because combustion chamber temperatures are lowered and the fuel is not completely burned.

A flow divider performs essentially the same function as a pressurizing valve. It is used, as the name implies, to divide flow to the duplex fuel nozzles. It is not unusual for units performing identical functions to have different nomenclature between engine manufacturers.

COMBUSTION DRAIN VALVES

The drain valves are units used for draining fuel from the various components of the engine where accumulated fuel is most likely to present operating problems. The possibility of combustion chamber accumulation with the resultant fire hazard is one problem. A residual problem is the deposit of lead and/or gum, after evaporation, in such places as fuel manifolds and fuel nozzles.

In some instances, the fuel manifolds are drained by an individual unit known as a drip or dump valve. This type of valve may operate by pressure differential, or it may be solenoid operated. The combustion chamber drain valve drains fuel that accumulates in the combustion chamber after each shutdown and fuel that may have accumulated during a false start. If the combustion chambers are the can type, fuel drains by gravity down through the flame tubes or interconnecter tubes until it gathers in the lower chambers, which are fitted with drain lines to the drain valve. If the combustion chamber is of the basket or annular type, the fuel merely drains through the air holes in the liner and accumulates in a trap in the bottom of the chamber housing, which is connected to the drain line.

After the fuel accumulates in the bottom of the combustion chamber or drain lines, the drain valve allows the fuel to be drained whenever pressure within the manifold or the burner(s) has been reduced to near atmospheric pressure. A small spring holds the valve off its seat until pressure in the combustion chamber during operation overcomes the spring and closes the valve. The valve is closed during engine operation. It is imperative that this valve be in good working condition to drain accumulated fuel after each shutdown. Otherwise, a hot start during the next starting attempt or an afterfire after shutdown is likely to occur.

FUEL QUANTITY INDICATING UNITS

Fuel quantity units vary from one installation to the next. A fuel counter or indicator, mounted on the instrument panel, is electrically connected to a flowmeter installed in the fuel line to the engine.

The fuel counter, or totalizer, is used to keep record of fuel use. When the aircraft is serviced with fuel, the counter is manually set to the total number of pounds of fuel in all tanks. As fuel passes through the measuring element of the flowmeter, it sends electrical impulses to the fuel counter. These impulses actuate the fuel counter mechanism so that the number of pounds passing to the engine is subtracted from the original reading. Thus, the fuel counter continually shows the total quantity of fuel, in pounds, remaining in the aircraft. However, there are certain conditions that cause the fuel counter indication to be inaccurate. Any jettisoned fuel is indicated on the fuel counter as fuel still available for use. Any fuel that leaks from a tank or a fuel line upstream of the flowmeter is not counted.

Question: 1-1
Potential energy may be classified as stored energy due to the position of a body, due to distortion of an elastic body, or due to work produced by ________________ action.

Question: 1-2
What is the formula for calculating the kinetic energy for something in motion?

Question: 1-3
For work, power, or torque to exist, there has to be a ________________ that initiates the process.

Question: 1-4
Work can be calculated by multiplying the force × distance. To calculate power, what consideration is added to this formula?

Question: 1-5
________________ may be defined as a continuing change of position or place, or as the process in which a body undergoes displacement

Question: 1-6
Acceleration is defined as the rate of change of ________________.

Question: 1-7
A reciprocating engine is rated in brake horsepower (bhp), the gas turbine engine is rated in ________________.

Question: 1-8
A significant feature of the gas turbine engine is that separate sections are devoted to each function, and all functions are performed ________________ without interruption.

Answer: 1-1
chemical.

Answer: 1-2
Kinetic Energy = ½ Mass × Velocity2.

Answer: 1-3
force.

Answer: 1-4
Time.

Answer: 1-5
Motion.

Answer: 1-6
velocity.

Answer: 1-7
thrust horsepower (thp).

Answer: 1-8
simultaneously.

Question: 1-9
The amount of air that is bypassed around the core of the engine determines the ________________.

Question: 1-10
In a mixed exhaust nozzle, fan air mixes with ________________.

Question: 1-11
What two controllable variables affect the selection of thrust on a turboprop aircraft?

Question: 1-12
FADEC stand for ____________________.

Question: 1-13
A ________________ supplies a signal to the EEC that indicates an almost clogged filter condition.

Question: 1-14
The main fuel pump on a turbine engine is ________________ driven.

Question: 1-15
The minute openings of turbine engine fuel filters make it susceptible to clogging; therefore, a ________________ is incorporated as a safety factor.

Question: 1-16
To prevent hot starts or an after fire after engine shutdown, a ________________ is located in the combustion section of a turbine engine.

Answer: 1-9
bypass ratio.

Answer: 1-10
core engine exhaust.

Answer: 1-11
fuel flow;
propeller blade angle.

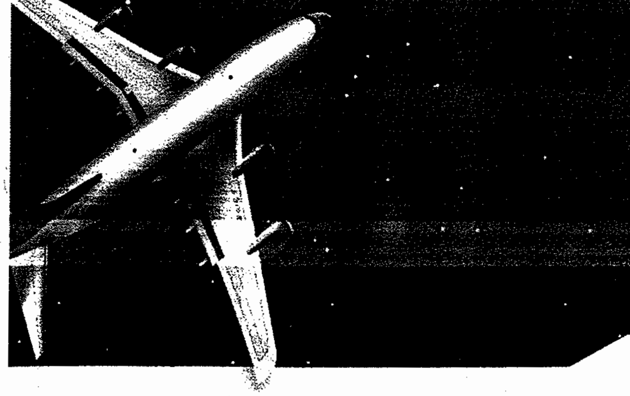
Answer: 1-12
Full Authority Digital Electronic Control.

Answer: 1-13
fuel filter differential pressure switch.

Answer: 1-14
engine.

Answer: 1-15
bypass valve.

Answer: 1-16
drain valve.



SUB-MODULE 02

PART-66 SYLLABUS LEVELS

CERTIFICATION CATEGORY → B2

Sub-Module 02
ENGINE INDICATING SYSTEMS
Knowledge Requirements

14.2 Engine Indicating Systems

Exhaust gas temperature/interstage turbine temperature systems; 2

Engine speed;

Engine thrust indication: engine pressure ration, engine turbine discharge pressure or jet pipe pressure systems;

Oil pressure and temperature;

Fuel pressure, temperature and flow;

Manifold pressure;

Engine torque:

Propeller speed.

Level 2

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

Objectives:

(a) The applicant should be able to understand the theoretical fundamentals of the subject.

(b) The applicant should be able to give a general description of the subject using, as appropriate, typical examples.

(c) The applicant should be able to use mathematical formula in conjunction with physical laws describing the subject.

(d) The applicant should be able to read and understand sketches, drawings and schematics describing the subject.

(e) The applicant should be able to apply his knowledge in a practical manner using detailed procedures.

ENGINE PARAMETERS

PURPOSE

Engine instrumentation displayed in the cockpit (flight deck) can be categorized into two areas:

- Engine Operation;
- Engine Monitoring.

Where each specific engine instrument fits into these categories can vary, depending on engine and aircraft manufactures requirements and their recommendations in determining the order of data, or parameters, that are to be displayed. However there are common accepted standards for the layout or order of engine instruments.

The ***engine operation*** (sometimes referred as the operating or primary parameters) instruments represent engine performance.

Different engine types will display varied combinations of operating instruments; e.g. EPR, N1, EGT and N2; or e.g. N1, EGT and N2.

These instruments are essential for the flight crew to determine the power operating data of an engine.

The following example shows four instruments in this category:

The first is the thrust or engine power instrument.

The ***engine monitoring*** (sometimes referred to as the control parameters) instruments assist the crew to ensure proper control of the engine is maintained.

Common examples of these instruments are: oil pressure, temperature and quantity; fuel pressure, temperature and quantity; and nacelle temperature.

Two typical monitoring instruments are show here in ***Figure 2-1.***

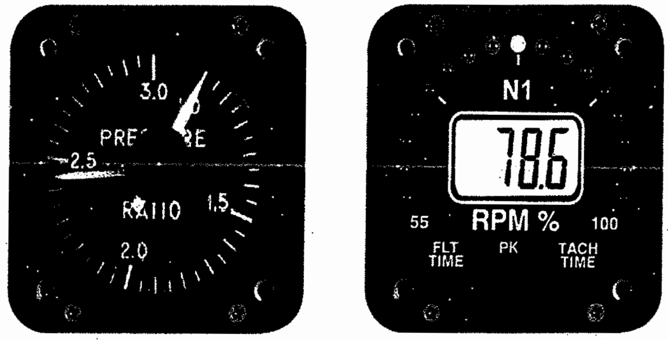


Figure 2-1. Engine Pressure (thrust) and N1 indicators.

All engine instrumentation must be ***reliable***, as they are the interface between the engine and the crew who rely on them completely to evaluate engine performance, operation and control.

They must also be ***accurate*** within the tolerances given for each instrument. An out of tolerance reading can sometimes result in a more damaging situation than no reading at all.

Engine instrumentation must be displayed ***instantaneously***. A slow display time or a lag between the change in values of data or parameters, and the reading displayed in the cockpit can have serious consequences.

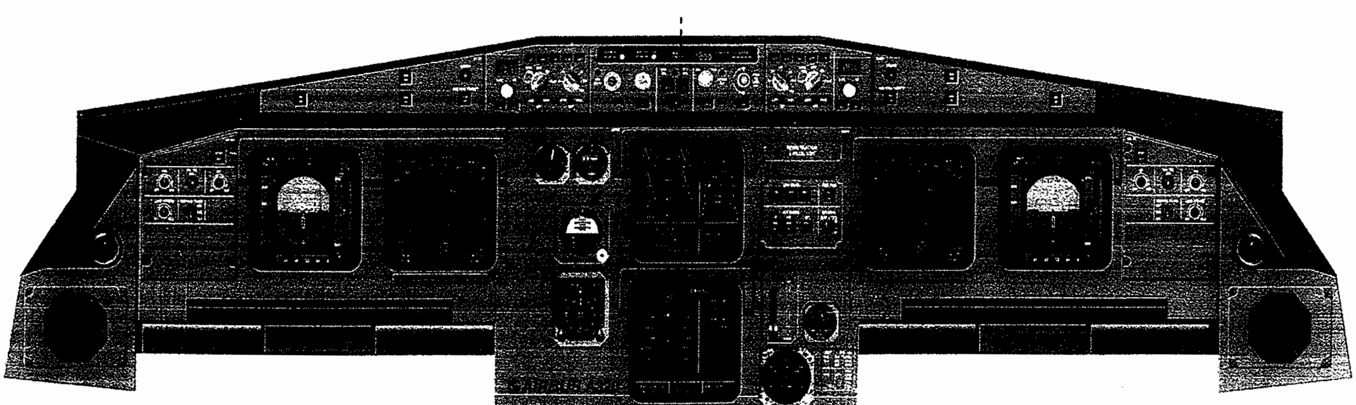


Figure 2-2. Left and right hand Engine Parameter indicators.

Example: When the pilot is monitoring a rising EGT (exhaust gas temperature), a lag in the reading could be interpreted that the maximum EGT has not been reached, whereby in reality, the engine is already overheating.

POSITION

Engine instrumentation is always in the center of the instrument panel, or if is slightly off center, favoring the Captains side. This enables reading for both the Pilot in Command and the First Officer (FO). ***(Figure 2-2)***

Engine operating instrumentation is shown at the top of the panel, with the engine monitoring instrumentation below.

Thrust is the most important operating instrument; so the EPR or N1 indicator is found at the very top. This standard layout position always applies, no matter what type of indicator is used, whether an old dial and pointer display, or new electronic display (Cathode Ray Tube - CRT and Liquid Crystal Display - LCD). ***(Figure 2-3)***

Note: Certain aircraft having an Electronic Flight Information System (EFIS or EIS), have a "backup" display for engine operating instruments on an additional indicator (standby indicator). An example is the Boeing 767.

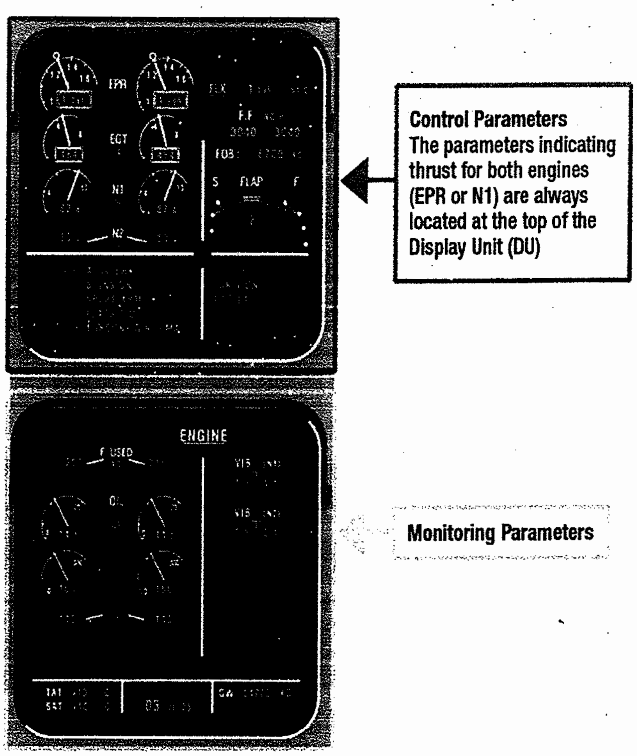


Figure 2-3. Operating Parameter indicators.

Aircraft having a Flight Engineer (FE) station, have repetition of all engine monitoring instruments and some operating instruments on the FE instrument panel. These are direct duplication of respective instruments situated on the main cockpit instrument panel.

DESCRIPTION

Engine instrumentation data can be displayed on analog or digital indicators.

The displays can have pointers or numerical characters; some instruments have a mixture, or combination, of both.

An analog indicator (gauge) has a pointer, or needle, which moves to indicate a value, graduated around the edge of the dial.

Numerical displays use a dial indicator; small drums, graduated from 0 to 9 around their edges turn on themselves to form a legible number in one window of the dial. The same analog signals which drives the needle or the pointer of an analog gauge indicator, also drives the numerical display drums of a dial indicator.

Analog and numerical displays can also be produced using electronic indicators – the displayed data being produced by digital circuits rather than conventional mechanical means. ***(Figure 2-4)***

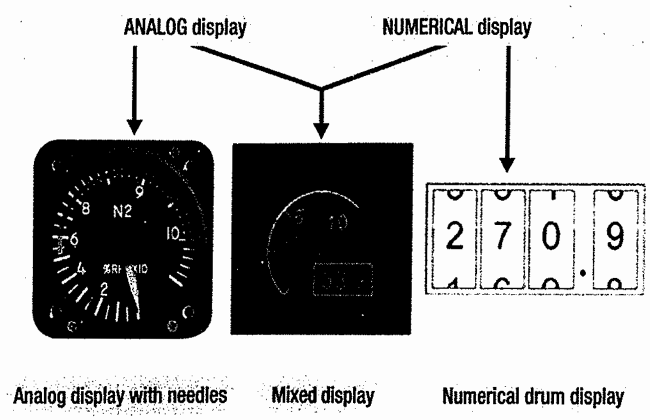


Figure 2-4. Analog, numerical and mixed displays.

These electronic indicators, used for instrumentation, can be either Cathode Ray Tubes (CRT) or Liquid Crystal Displays (LCD).

Electronic instrumentation is widely used on modern aircraft, being more reliable and accurate than the conventional mechanical gauges. The electronic indicators receive video signals and can replace several

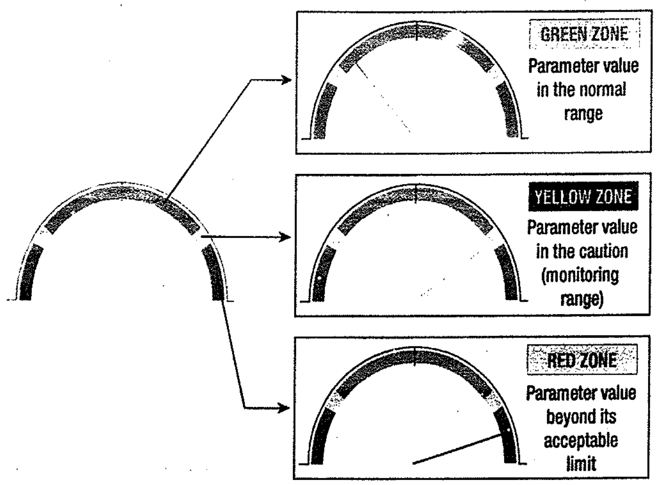


Figure 2-5. Colored indicator zones.

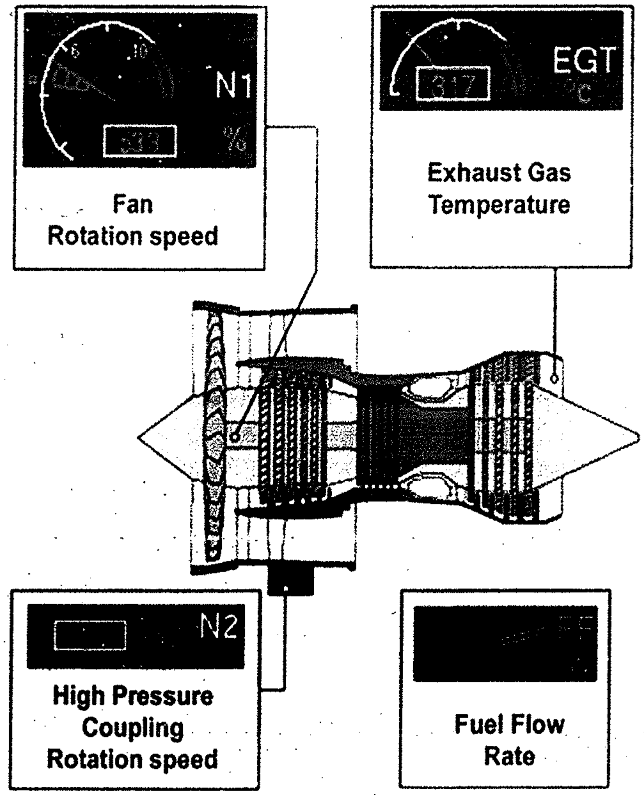


Figure 2-6. Rotational Speed and Fuel Flow indicators.

conventional indicators with a single instrument. However, electronic displays require air cooling, which is not necessary for conventional instruments.

Some engine instrumentation indicators can have colored zones. Theses specific zones allow the pilot to determine the state of the engine parameter, or data, at a glance. These colored zones can be found on both conventional analog indicators and modern electronic indicators, where data is displayed in an analog form. (***Figure 2-5***)

Example:

- The needle in the green zone means that the value of this parameter is in the normal range.
- The needle in the yellow zone means that the value of this parameter is in a range which requires careful monitoring by the crew.
- The needle in the red zone means that the value of this parameter has reached an unacceptable range, which is very irregular or hazardous, and requires immediate action by the crew.

OPERATION

OPERATING PARAMETERS

Engine Thrust Indication

EPR (Engine Pressure Ratio). This parameter is the ratio of the total pressure in the engine air intake to the total pressure at the turbine outlet. Two sensors are used to detect the two respective pressures; this data is fed to a device for computation of the pressure ratio and fed to the EPR instrument. Pt is the designated "point" the inlet and outlet pressures are taken. An engine may have e.g., Pt7 and Pt2 as the pressure detect points. (***Figure 2-6***)

Examples of engines that use EPR instruments to indicate thrust are: P&W and RR turbojet engines.

N1 is the symbol for the rotation speed of the low pressure compressor turbine.

Examples of engines using N1 are GE and CFM turbojets to indicate thrust.

On a double flow turbojet, the N1 reading represents, as a percentage, the RPM of the fan. A speed sensor sends a signal to the parameter display system.

Comparison of EPR and N1

EPR is generally accepted to be the better indication of thrust in terms of accuracy, however it has small delay times, and is dependent on prevailing temperature. Also the pressure probes can be prone to damage and contamination.

N1 has relatively better response and thus is a more reliable and stable indication of thrust.

EGT (Exhaust Gas Temperature)

EGT represents the turbine temperature. This is a very important parameter, alerting the crew when the temperature approaches the limits of mechanical integrity for the turbine and the combustion chamber.

Several temperature sensors are used, called thermocouples, usually made of chrome/nickel and nickel/aluminum, commonly trade named chromel and alumel, respectively; known as "K" Type thermocouples.

Thermocouples are located around the edge of the outlet pipe, close to the turbine outlet. These sensors, together with their interconnection leads, are of a specific high tolerance resistance.

The thermocouples and connecting wiring is usually made up of one assembled harness for ease of installation and reliability.

Average EGT indications of jet engines are determined by such factors as: operating conditions; the condition of the engine; type of engine (high or low bypass); and materials used.

The hot and cold junction principle of dissimilar metals producing a voltage, that is proportional to the temperature at the hot junction, is displayed on the EGT indicator, graduated in degrees Celsius.

Several temperature sensors, thermocouples generally made of chrome/nickel and nickel/aluminum, are located around the edge of the outlet pipe, close to the turbine outlet. These sensors transmit an average temperature to the EGT indicator on the instrument panel, graduated in degrees Celsius.

N2

N2, the rotational speed of the high pressure compressor rotor, is used by the pilot to check engine performance. N2 is expressed as a percentage of the nominal rpm. The transmitter is usually a tachometer generator driven by the accessory gearbox.

Flowmeter (FF: Fuel Flow)

This instrument provides the crew with important information on the performance and efficiency of the engine. It displays the instantaneous fuel flow rate (consumption) in kilo per hour (kph) or in pound per hour (pph). A fuel flow transmitter, usually located after the HP valve, measures the fuel flow rate and sends it to the indicator. This same information is used by the total fuel consumption indicator (Fuel Used Indicator)

MONITORING PARAMETERS

LUBRICATION SYSTEM

This system is very important to the operation of the turbojet (powerplant).

Certain parameters must be available on the instrument panel for close monitoring by the crew. ***(Figure 2-7)***

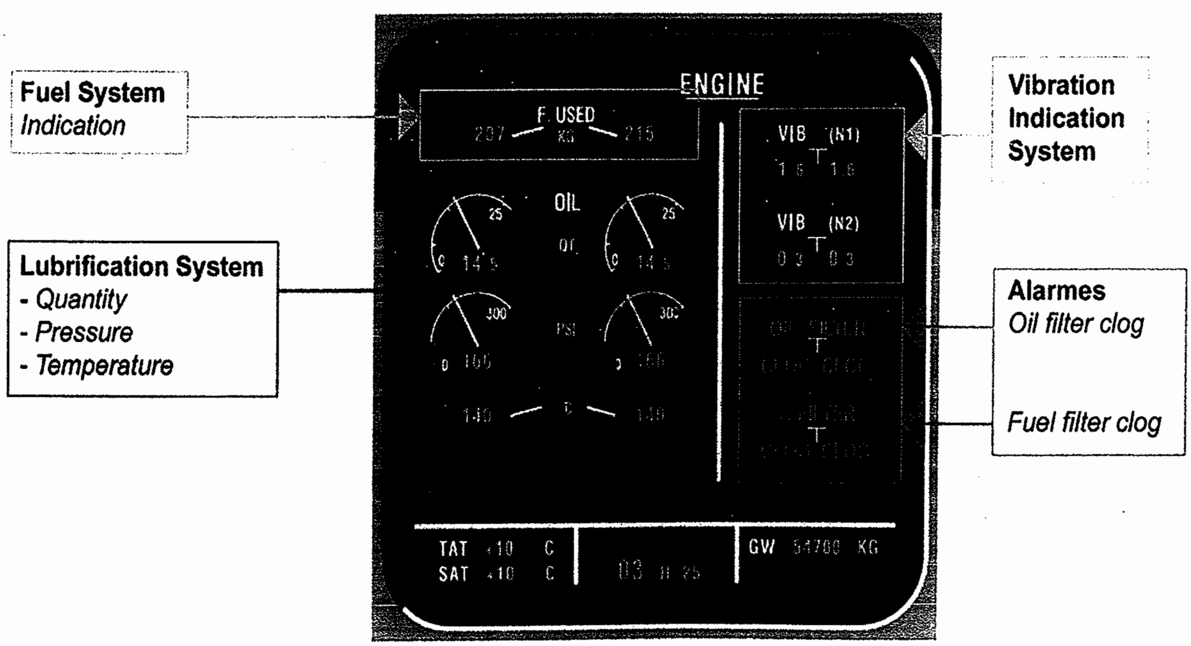


Figure 2-7. Nacelle Temperature indicator.

Oil Quantity
An indicator graduated in quarts (QT) displays the amount of oil remaining in the reservoir. This indication allows the crew to monitor oil consumption.

Oil Pressure
This parameter makes it possible to assess the lubrication of the bearings and other engine parts. The oil pressure is usually measured at the oil pump outlet and is indicated in PSI (pounds per square inch) or in PSID (pounds per square inch differential) which is used to determine any pressure difference across, for example, an oil filter, to provide indications of a clogged filter.

Engine oil pressure is the most important parameter for oil.

Oil Temperature
In addition to the oil pressure, which determines the amount of oil delivered to the bearing lubrication injectors, the oil temperature is one factor which determines its ability to lubricate, and also its cooling capacity. It is an important parameter.

The indicator, graduated in degrees celsius, indicates to the crew if the lubrication system is working properly and effectively within a normal temperature range.

Low Oil Pressure Alert
In addition to the oil pressure indication most aircraft also have a "*low pressure*" alert. This can be in the form of a red indicator light, a red "*oil press*" legend light or a message written on an electronic display.

This alert light illuminates when the oil pressure drops below a set value and is activated by a pressure switch, usually situated near the engine oil pressure transmitter at the oil pump outlet.

Filter Pre-Clogging Alert
On some oil pressure circuits, the oil filter is equipped with a differential pressure switch. It illuminates an alert light or generates an alert message to indicate that the oil filter is starting to clog when the differential pressure reaches a preset value.

ENGINE VIBRATION INDICATION
This system can allow the crew to identify an imminent failure before it is detected using indications from other engine parameters.

Detecting vibrations as soon as they start can limit the damage caused by abnormal engine wear. The vibration sensors are installed in specific areas of the engine and send signals to a "signal conditioner" which modifies them so they can be used by the engine parameter display system (ECAM/EICAS).

On some aircraft, the detection and display system for engine vibrations is called the "AVM System" for "Airborne Vibration Monitoring".

The first vibration analysis system for Rotorcraft, developed by Bristow Helicopters, was called: IHUMS (Integral Health and Usage Monitoring). This term is still currently used for many aircraft vibration systems.

NACELLE TEMPERATURE
Even though it cannot be considered an engine operating or monitoring parameter, the nacelle temperature indication, when available, is displayed with the engine parameters.

The engine nacelles are ventilated and cooled by the fan air. Even though they are equipped with fire and overheat detectors, a nacelle temperature indication would alert the crew of an abnormal temperature increase which could be caused by, for example, a small leak in the air bleed system and which had not set off the overheat alert.

The nacelle temperature indicator is graduated in degrees celsius.

MAINTENANCE
The accuracy of engine parameter indications is important for the proper and effective monitoring of the engines by the crew. When the pilot reports that a parameter is not within the normal operation range, the maintenance technician must determine the source of the anomaly: for example: is it a true engine problem which has been correctly indicated or is it a false reading? First, a technician should analyze the parameter(s) that are related to the parameter that is in a failure state; for example, N1 and N2 are linked, EGT and FF are linked, N2 and FF are linked, and EPR and N1 are linked.

This enables a technician to more easily assess and diagnose the problem reported by the crew to assist in determining if the defect is really an engine problem, or is in fact a problem with the readings.

If it is a problem with the readings, the problem may be at the source of the signal; e.g. probe, sensor, detector or transmitter, or related to the indicator, or between two of them when the signal passes through intermediate components (amplifier, etc.).

Finally, a wiring problem is always a possibility (bad connection, break, etc.)

Only through systematic research of the cause of the failure is it possible to quickly identify the source of the problem reported by the pilot.

With the various electronic display systems modern aircraft are equipped with today, the indication itself is rarely the source of the problem. The same cannot be said for conventional mechanical gauge indicators which can contain synchronous motors, micro-mechanisms involving pointers, needles and many other moving parts.

On some conventional dial indicators an electrical power failure can be indicated by the appearance of a red indicator through the dial. With an electronic display the indication of the parameter can disappear (leaving a gap) or a red cross through the indication can appear to indicate that there is no signal or that the signal is malfunctioning.

Most aircraft Maintenance Manuals have flow charts, or similar fault diagnostic data to aid the technician in fault finding, given specific failed symptoms.

ENGINE PARAMETERS - DETAILED OPERATION

OPERATION AND CONTROLS

All instruments which display engine parameters receive data gathered by various sensors, probes, detectors or transmitters located on the engine.

There are three types of data which are important to monitoring the engine and ensuring its proper operation and performance: pressure, temperature and mechanical moving parts.

Pressure Data
Required for the EPR, oil pressure, low oil pressure alert, fuel filter pre-clogging and fuel pressure alert.

Temperature Data
Required for the EGT, oil temperature, fuel temperature and nacelle temperature.

Mechanical Movement Data
Required for speed N1, N2, fuel flow and engine vibrations.

PRESSURE DATA

EPR (Engine Pressure Ratio)
This parameter measures the thrust produced by the engine (as previously mentioned, on some engines, N1 is the thrust parameter).

The EPR is the ratio of the total pressure at the turbine outlet to the total pressure in the turbojet air intake. Several sensors provide an average of total pressure at these two engine locations. Pipes send these total pressures to the electronic Engine Control Unit (EEC/ECU).

Depending on the engine manufacturer, these respective pressure detection areas (inlet and outlet turbines) of the engine can have designations such as: Pt2, Pt7 etc.

The numbers usually refer to the turbine staging of the engine.

An analog to digital in the EEC/ECU converts these pressure readings into electric signals, calculates the "EPR" value and sends it to the engine parameter display system known as the Electronic Centralized Aircraft Monitor or Engine Indicating and Crew Alert System (ECAM/EICAS).

Note: On some engines, the same sensor combines the total air intake pressure and the total air intake temperature. Similarly, some engines may have a single sensor that detects total pressure measurement and the EGT temperature sensor at the turbine exhaust.

Ambient temperature is required for correction to the EPR for accurate power settings; this is accomplished in the ECAM/EICAS.

Oil Pressure

Oil pressure and oil temperature parameters are crucial to engine monitoring and are therefore always indicated.

A pressure transmitter sends an analog signal to the electronic calculator (EEC/ECU) where it is digitized before being used by the electronic display system - ECAM or EICAS

On some modern systems, an engine may have dual EEC/ECU's for redundancy purposes. The oil pressure transmitter would have two detectors; for example, LVDT's (Linear Variable Differential Transformers) which send oil pressure signals to each of the two EEC/ECU's.

Low Oil Pressure Alert

An oil "low pressure" switch operates when oil pressure falls below a certain value; this enables an alert signal to be displayed on the ECAM or EICAS.

Depending on the aircraft's system, an audible alert in the cockpit can also be triggered; the oil pressure indicator on the electronic display may also start flashing and/or will change color (red).

Fuel Filter Pre-Clogging Alert

A differential pressure switch detects the fuel pressure at the fuel filter inlet and outlet.

The switch operates when the differential pressure exceeds a certain value and provided a caution alert indication.

Some systems have a two stage caution for fuel filters. The first is a "*fuel filter clog*" (clogging) message which is indicated at a relatively low differential pressure. At this stage, the fuel filter bypass valve is not open. If the differential pressure continues to rise, meaning the filter is becoming more clogged, then a "*fuel filter bypass*" alert (bypass) will be triggered as the fuel filter bypass valve operates. This ensures continual fuel flow to the engine, but with no filtering.

Fuel Pressure

On some aircraft (usually with engines which do not have Electronic Engine Control – EEC) a fuel pressure reading is provided in the cockpit. A pressure transmitter is located at the fuel centrifugal pump outlet (boost pump) and sends this information which is then displayed in an analog or digital format.

This pressure indication is sometimes related to a low pressure alert built into the instrumentation; the fuel pressure display flashes when its value is lower than a predetermined level.

TEMPERATURE DATA

EGT (EXHAUST GAS TEMPERATURE)

This is a critically important engine parameter which is always indicated in the cockpit.

It is interesting to note that the highest turbojet/ powerplant temperature is located at the inlet of the high pressure turbine. However, the measured temperature is down flow: either between the HP and LP turbine stages, or more commonly, at the LP turbine outlet. ***(Figure 2-8)***

Engine manufacturers have adopted this design because, by exposing thermocouple sensors to very high temperatures would have been impractical and difficult to achieve. As the drop in temperature across the various turbine stages is determined in the engine design with great accuracy, the "measured" temperature down flow of the turbines represents the inlet temperature of the turbine.

According to the manufacturers, there can be any number of thermocouple sensors placed around the outer edge of the pipe; usually ranging from two to 12. These thermocouple sensors, which are a bi-metallic junction welded together, are composed of two different metals. One is usually nickel chrome alloy and the other nickel aluminum, they are the "K" type, and are capable of measuring temperatures from -200 to +1 250 degrees celsius. The wiring harness for the sensors are made from the same respective metals, and can be secured to the outside casing of the engine, or

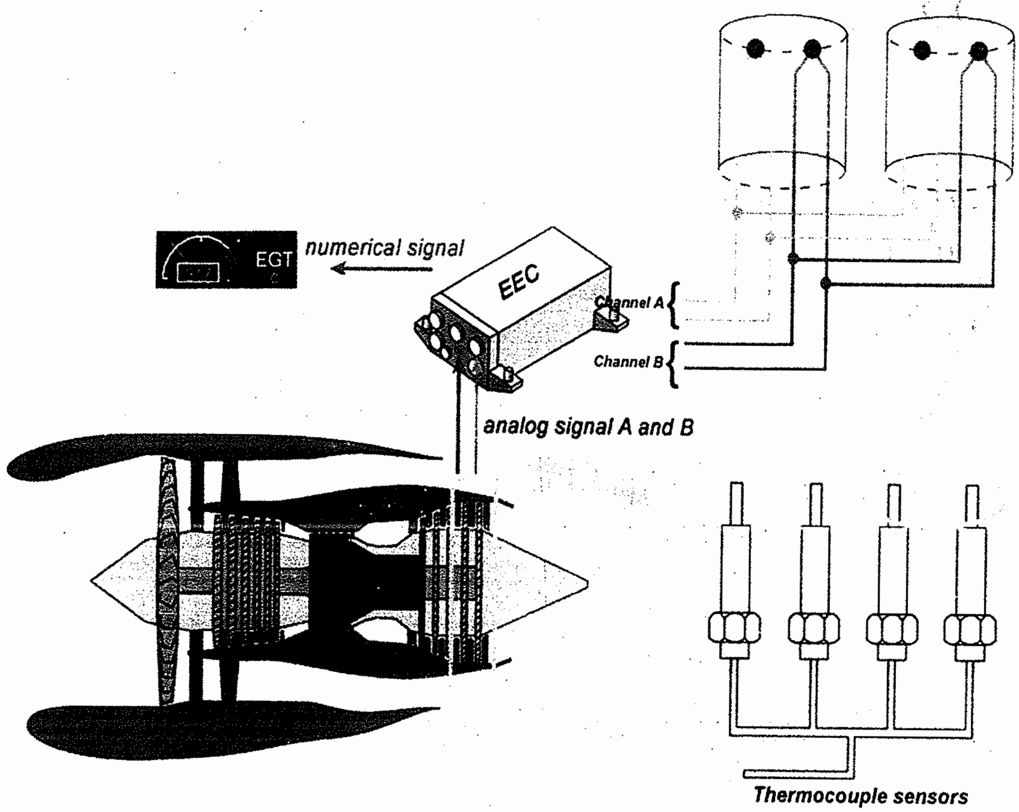


Figure 2-8. Exhaust Gas Temperature (EGT) measurement indicator.

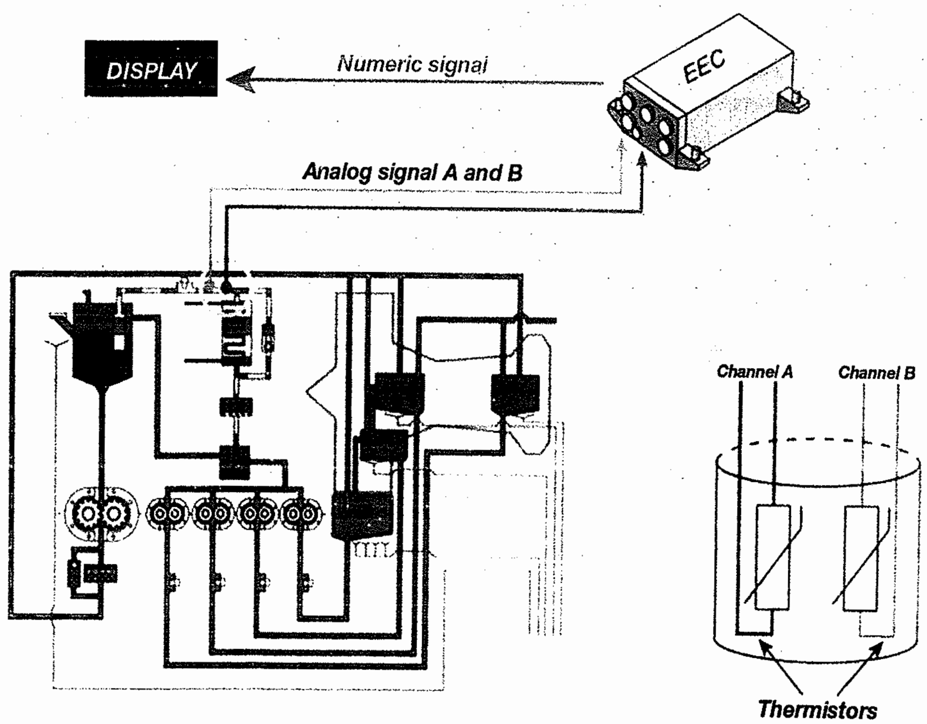


Figure 2-9. Oil Temperature measurement sensors.

situated in a perforated tube inside the casing through which hot gases can pass through. Facilities are made for connection of the harness to normal aircraft wiring. All the thermocouples are connected parallel to each other in order to transmit an average temperature signal. If the thermocouples were in series, there would be no facility for redundancy, and much more wiring would be required. The total resistance of the sensors, and the associated immediate wiring is critical for accurate temperature measurement. The resistance of an assembled thermocouple harness will vary slightly with the operation and temperature of the engine. Resistance measurements, for calibration and fault diagnosis, are ideally carried out when the engine is cold.

On modern engines with EEC/ECU calculators, there may be EGT sensors with two thermocouple layouts; one for each channel. For example there maybe a total of eight EGT sensors; four sensors for each channel.

The EEC/ECU converts the EGT signal into digital data which is sent to the engine parameter display system (ECAM – Electronic Centralized Aircraft Monitor or EICAS – Engine Indication and Crew Alerting System).

OIL TEMPERATURE

Depending on the type of system used, the oil temperature sensors can be located on the "*pressure*" circuit or on the "*recuperation*" circuit of the engine lubrication circuit.

Sensors can thermocouples, but more commonly are thermistors. The figure shows two thermistors, one for each channel of the EEC/ECU calculator which transforms the temperature signal into digital data for display on the ECAM/EICAS system. ***(Figure 2-9)***

Note: Many systems have changes in the display color, or sections, on indicators, with different colors correspond to the different temperature ranges

FUEL TEMPERATURE

This engine parameter is rarely displayed in modern aircraft. However, maintenance technicians can find this information by accessing specific maintenance pages via the electronic display system, where aircraft have this facility. A two channel sensor measures fuel temperature at the outlet of a fuel/oil heat exchanger; each channel providing a temperature signal to each of two channels in the EEC/ECU calculator.

NACELLE TEMPERATURE

When this parameter is measured, a temperature sensor placed at an appropriate location inside the nacelle sends a temperature signal to the display system.

This sensor has a single channel and contrary to most sensors, the temperature signal is not sent to the ECU/EEC calculator.

In aircraft where the ECU/EEC controls the cooling of the nacelle, an altitude signal is compared with the nacelle temperature signal, for temperature control.

MECHANICAL MOVEMENT DATA

N1

When EPR is not used for determining thrust, an N1 speed transmitter provides a fan rotation speed signal, which has a linear relationship to engine thrust.

N1 indication is displayed as a percentage of nominal rotation speed.

No matter what the purpose of the parameter is (operation or monitoring), the rotation speed signal is transmitted via an electromagnetic speed sensor with a phonic wheel.

This pickoff is an electromagnetic coil can be located on the fan casing, in the fan blade shaft, or on the compressor casing, to the right of a phonic wheel, an integral part of the LP compressor rotor.

The teeth on the outer edge of the phonic wheel pass in front of the sensor once per rotation thereby inducing an electric current by altering the magnetic flux through the sensor pickup coil. The magnitude of this current depends on the magnetic flux variation rate and is therefore directly proportional to the speed of shaft rotation.

On modern aircraft, the speed sensor sends two analog signals; one for each detector channel, which digitizes them before transmitting them to the ECAM/EICAS display system.

N2

The rotation speed of the HP (high pressure) turbine is always indicated: N2 for double spool turbojets, N3 for triple spool turbojets (Rolls Royce).

The speed signal can come from a small tachometer driven by the AGB (Accessory Gear Box), or can come from a phonic wheel sensor located on the AGB. In both cases the analog signals are produced; as with N1 they are digitized by the ECU/EEC calculator before being used by the ECAM/EICAS display system. ***(Figure 2-10)***

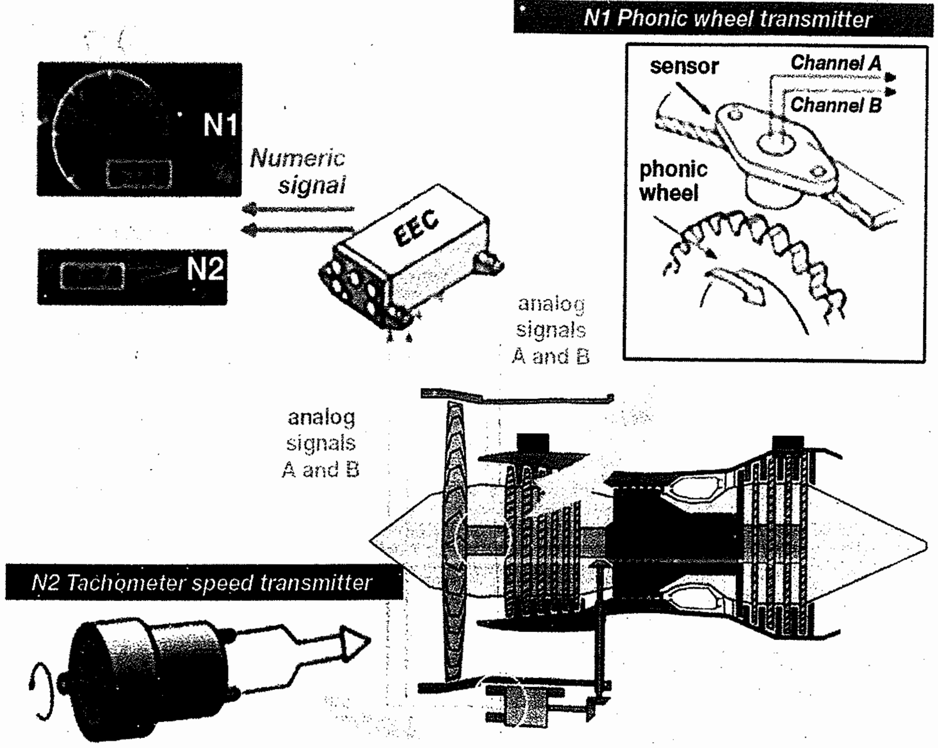


Figure 2-10. Analog signal digitizer.

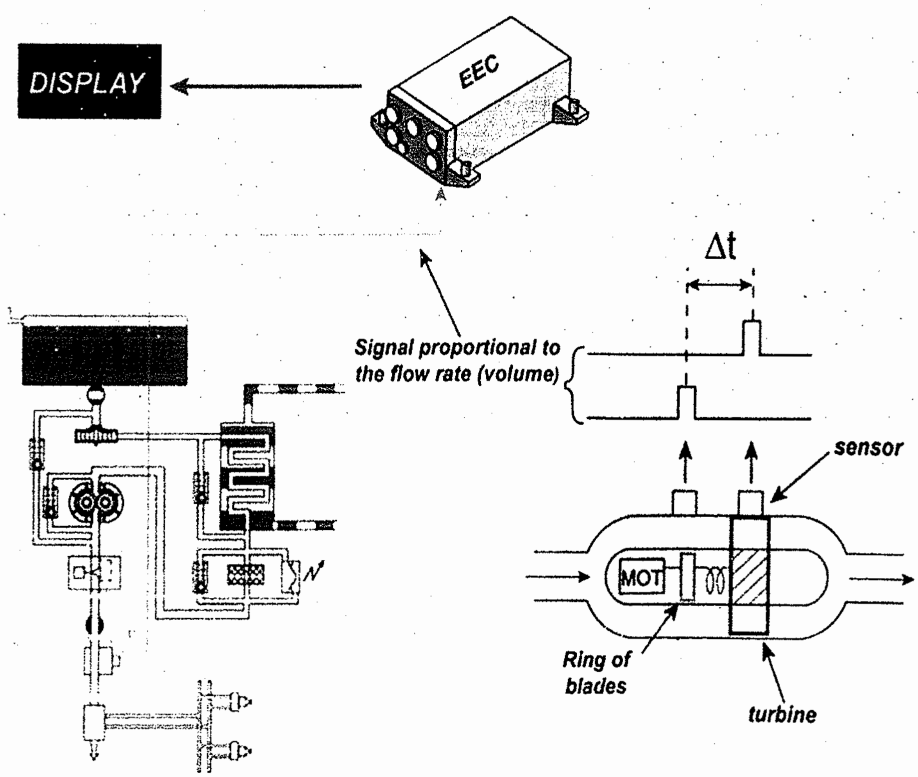


Figure 2-11. Fuel Flow Rate calculator.

FUEL FLOW RATE (FF OR FUEL FLOW)

The fuel flow transmitter is normally located between the HP fuel valve and distribution lines to fuel injectors. There are several types: the most common is a constant speed propeller driven by an electric alternating triphase motor. The propeller rotation causes a spiraling movement in the fuel passing through the line. This spinning motion creates deflection on a turbine located down flow that is secured by one or more calibrated springs.

The deflection angle of this turbine is directly proportional to the flow rate and the density of the fuel; an analog electrical signal is produced that is proportional to the fuel mass flow rate.

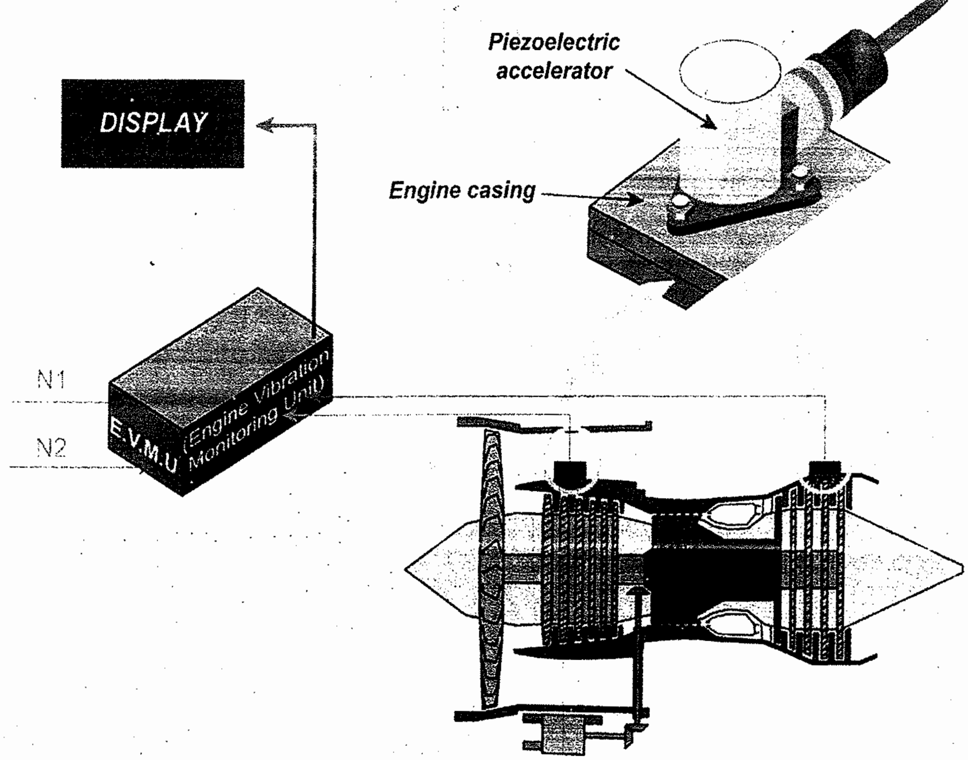


Figure 2-12. Engine Vibration Monitoring Unit.

Another type of fuel flow transmitter does not have a propeller driven by an electric motor, but only a turbine maintained in rotation by one or more calibrated springs whose angular deflection is measured by the fuel flow.

In both types, the analog signal is fed to the EEC/ECU which determines the mass flow rate (expressed in lbs/h or in kg/h); this is fed to the ECAM/EICAS system for display. The same data is also used to calculate the total fuel consumption rate (fuel used). ***(Figure 2-11)***

Note: A given quantity of fuel's volume will vary with temperature, but the fuel will still have the same potential energy; the fuel density changes with corresponding change in temperature. The fuels mass remains constant, and it's this parameter that the fuel flow transmitter measures.

ENGINE VIBRATIONS

The engine vibration monitoring system is made up of three main components:

- One to three vibration sensors,
- A signal conditioner (or engine vibration calculator);
- An indication in the cockpit.

Engine manufacturers determine proper placement of vibration sensors on engine structures with respect to different engine types sensitivity to vibrations and certain environmental considerations.

Sensors currently used on engines are accelerometers made up with a piezoelectric crystal; an electric signal which is proportional to the forces applied by the vibrations is generated and sent to the engine vibration analyzer.

EVMU: ***Engine Vibration Monitoring Unit.*** This unit receives signals from all the sensors as well as the analog signals of speeds N1 and N2. It integrates the data and calculates vibration levels, which are displayed in the cockpit.

The EVMU can also have other functions: It can calculate the vibration limits based on the engine systems N1 and N2 and set off "caution" or "advisory" level alerts on the ECAM/EICAS screens. It can also carry out calculations in relation to the fan balance and keep all the data related to vibrations detected in its memory (to be downloaded) for the purpose of conducting failure research and trend analysis at a later time. ***(Figure 2-12)***

The vibration display in the cockpit can vary depending on the type of equipment installed. The N1 and N2 vibrations can either be indicated simultaneously, or a selector switch can allow the user to choose to display one or the other on a single indicator, or there can even be a single indicator which automatically displays whichever vibration reading is the greatest.

ENGINE TORQUE

The "coupling" (torque) of a turboprop is the ratio between the power delivered and the rotation speed of the drive shaft, i.e. torque equals power divided by RPM.

Torque is a very important parameter (similar to EPR or N1); it is an exact power level indication of an engine, turboprop, or rotorcraft gearbox at any phase of flight. All engines, power plants, and associated gearbox systems have a maximum torque limit relative to the phase of flight and environmental conditions. Any exceeded instances of manufacturers torque data invariably results in mandatory inspections for damage.

Available torque performance can be obtained from torque data, by comparing the actual torque obtained to the theoretical torque provided by the manufacturer.

Current atmospheric pressure and temperature influence torque performance; diagrams are commonly used to compare actual torque computations.

Manufacturers torque data enables flight crew to operate aircraft within stipulated limitations.

Measuring torque is usually done by measurement at the gearbox. The detecting, or sensing arrangement, can be a process of determining oil pressure that is varied by helical gearing in a mechanism (hydraulic torque meter). The varying oil pressure is a direct function of torque. An indicator in the cockpit displays a value in units of oil pressure (bar) or in percentage of torque in relation to maximum torque (%).

Torque can also be measured by determining the torsion movement, over any distance, of any power drive shaft. One way is by detecting the magnetic reluctance of the engine output shaft from the torsional induced forces. A ferromagnetic sleeve is welded to the output shaft; stationary primary coils induce a control AC signal, which is then detected by electromagnetic pickoffs at various points on the shaft to determine the resultant twisting, or torsion force (torque) produced.

The actual power measured in horsepower is a function of the torque and the number of rotations per minute (rpm) multiplied by a constant of

$$K\ (K = 2\pi/33.000)$$

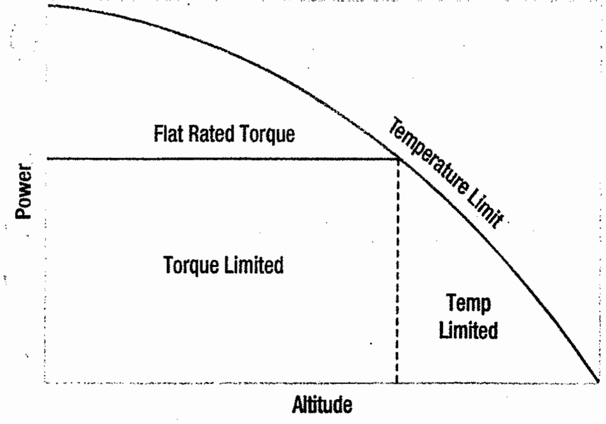


Figure 2-13. Torque and temperature limits.

Exceeding engine operating temperature or torque limitations can damage engines, powerplants, or gearboxes.

On the graph shown in ***Figure 2-13***, we can see that up to a certain point the temperature limit will take priority over the torque limit, when the aircraft reaches a certain altitude.

The diagram shows an example of torque measurement for the Garrett TPE-331 engine. The torque output signal, from the detector position in the accessory gear box is sent to an electronic conditioner (usually situated in an Engine Control Unit), which feeds an indicator in the cockpit, and a torque limiter. ***(Figure 2-14)***

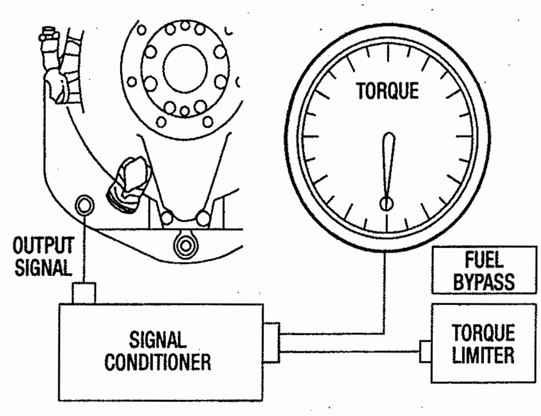


Figure 2-14. Torque annunciator circuit.

The torque limiter controls power output so that power is not exceeded.

MANIFOLD PRESSURE

On aircraft equipped with a constant speed propeller system, power output is controlled by the throttle and is indicated by a manifold absolute pressure gauge. ***(Figure 2-15)***

Figure 2-15. Manifold Pressure indicator.

A manometer measures the absolute pressure of fuel/ air mixture inside the intake manifold (MAP Manifold Absolute Pressure). At a given number of revolutions per minute (RPM) and a constant altitude, the amount of energy produced is directly related to the flow of fuel/air sent to the combustion chamber.

By "opening" the throttle, more fuel and air is sent to the engine, which increases the absolute pressure (MAP). At rest, the manifold pressure gauge indicates the ambient air pressure. When the engine starts up, the intake pressure indication will be less than the ambient pressure. Failure or loss of engine power is indicated by an increase in the intake pressure up to the value corresponding to the ambient air pressure at the altitude at which the failure occurred.

For a given number of revolutions per minute (RPM) there is an intake pressure, which should not be exceeded to avoid damage to an engine. The data is provided by aircraft and engine manufacturers and is as part of flight crew operating limitations.

Manifold pressure gauge readings for non-turbocharged aspiring engines generally range between 10 – 40 inches of Hg. Engine manufacturers of turbo charged engines have specific limitations of maximum manifold pressures for the type of engine.

MAP is a direct indication of the performance of an engine.

Damage from excessive MAP usually results in damage to piston cylinders.

PROPELLER ROTATIONAL SPEEDS

A tachometer generator (or alternator), connected, for example, to an auxiliary drive, provides DC single or variable phase AC voltage based on the rotation speed. This voltage is measured in the cabin by a graduated indicator in revolutions per minute (RPM) or by percentage (%). This type requires no power supply, and so is independent.

Alternative types can measure rotation speed can also be read by means of a phonic wheel and a sensor.

INTERFACES

In addition to the display of engine parameters which allow the crew to control and monitor the engine, some engine parameters can be used for other functions on the engine itself or the aircraft. Some examples are provided here.

ENGINE INTERFACES

- **The fuel and oil temperature signals:** These are sometimes used by the ECU/EEC to control the fuel/oil heat exchanger.
- **N1 signal:** It can be used by the EEC/ECU to replace the EPR signal when the electronic calculator operates in an "alternate" or "standby" mode and where the EPR is the thrust parameter.
- **Vibration signals:** These can be used by the engine balancing system (when it is installed) to calculate the balance correction for vibrations in shaft N1.
- **N2 signal:** This is mainly used by the ECU/EEC for fuel control (metering), but is also used to close the start valve and cut the ignition circuit during startup sequence. This signal can also be used to manage the turbine casing cooling (Turbine Clearance Control TCC) and to automatically trigger a reignition of the engine in flight when abnormal engine deceleration has been detected.

AIRCRAFT INTERFACES

- **Fuel Flow Rate signal (FF)**: This is used to calculate the total consumption (fuel used) which can be displayed continuously on a Control Display Unit (CDU), and is part of the Flight Management System (FMS)."Total consumption" data is used to calculate how much fuel is left onboard (fuel remaining).
- **Low oil pressure signal:** This can be used on certain aircraft by some systems to determine if the engine is running properly or not. When the low oil pressure signal is not used, these systems use the N2 signal for the same functions.

- **N2 signal:** This is widely used by many aircraft systems which need to know if the engine is operating normally (greater than idle speed) or is not running (below idle speed).

Here are some examples of aircraft systems which can use the N2 signal:

- The air cooling system for electronic and electrical air flow control in air conditioners/climate control systems.
- The electrical power system to control the load shedding circuit.
- The fuel system to control the DC fuel pump.
- The hydraulic system to control the Ram Air Turbine (RAT)
- The deicing system to control the heating of exterior sensors.
- The APU to control the Pneumatic System Isolation Valves.

***Note:** Because each engine and each aircraft has its own specific characteristics, the examples above are far from being exhaustive. They only serve to provide an idea of the multiple uses for certain engine parameters.*

MONITORING AND ALERT

Alert systems are designed to alert flight crew to a possible failure or potentially dangerous situation. Although the aircraft and the engine are often equipped with safety features, in the case of malfunctions, it is important that the crew be immediately informed of the situation so that action can be taken to ensure the safety of the aircraft or the engine.

ANALOG DIAL INDICATORS (GAUGES)

Some traditional indicators (electromechanical) include an integrated alert system: when the pointer exceeds a given value, an amber light (or red) illuminates on the dial.

For certain parameters where it is important to know the maximum exceeded value (example: engine overspeed), an additional pointer can be used, remaining at the maximum value reached. A push button makes it possible to turn off the amber light (or red) and to return the pointer to zero.

Modern digital instrumentation can have a memory function, as part of their design, so that exceeded data can be recalled at a later time.

Dial indicators often have colored zones, specific to each parameter. This allows the pilot to determine with a glance if the engine is operating within a range that normal and safe range or one that is abnormal and dangerous.

- A **green** colored zone corresponds to a zone of normal engine operation.
- A **yellow** colored zone corresponds to a zone where caution and careful monitoring are required.
- A **red** colored zone corresponds to a danger zone requiring immediate action by the pilot to get out of this operation zone.
- A red radial line indicates a maximum acceptable value (maximum temperature, maximum rpm)

These indicator markings can be present in addition to other audible or visual alerts whose purpose is to get the attention of the pilot. Therefore, a specific audible signal (gong, horn, ring tone) warns the crew that a parameter is in the "red" zone.

Most medium and large sized aircraft have a centralized alert panel, which brings together all the failure or exceeded limit lights (fault lights/exceeded lights) for certain engine parameters and other advisory/cautions/warnings. A MASTER Warning/Caution resettable (momentarily push), and usually flashing, light is displayed at a prominent place on the instrument panel in front of each pilot. This provides a means of acknowledging each warning/caution alert – the MASTER light will cancel, but the specific alert will remain displayed on the Central panel until the failure or exceeded value is returned to normal.

ELECTRONIC INDICATORS

These video displays are "Cathode Ray Tubes" (CRT) or "Liquid Crystal Displays" (LCD).

They are widely used onboard modern aircraft by display systems like ECAM or EICAS. These electronic display screens are sometimes called "Multifunction Displays" or MFD (Multifunction Display). ***(Figure 2-16)***

They are well adapted to monitoring engines by bringing together a large number of primary indications as well as alert and monitoring functions into a single display or two displays.

In addition, on certain aircraft with MFD displays, monitoring parameters (sometimes called secondary

AIRBUS A330 ECAM

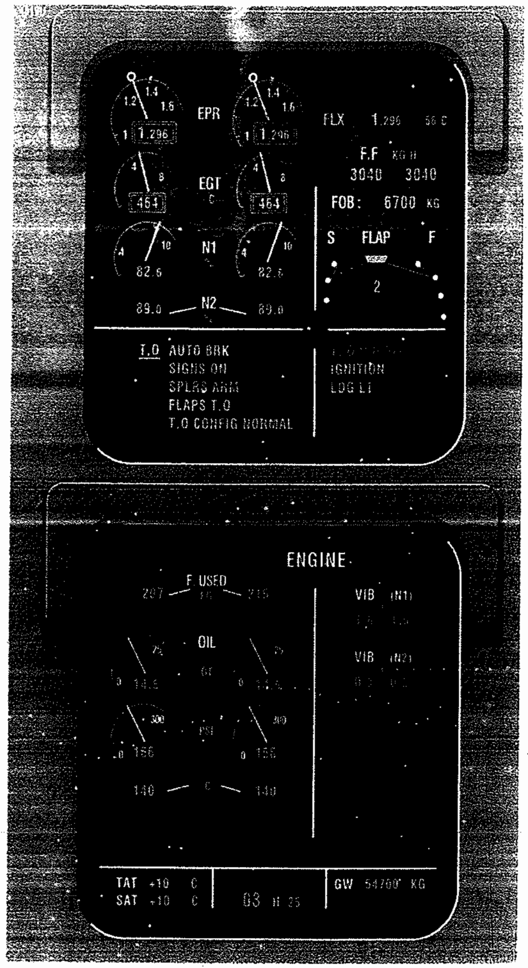


Figure 2-16. Multifunction Display.

parameters) can be displayed upon request, or automatically when one parameter approaches an operation range requiring specific monitoring.

Alert messages can be displayed in the margin of electronic displays or below the display of engine parameters. These messages appear in three colors depending on their level of importance:

- **White or green** for an "advisory" message: No immediate action from the crew is required.
- **Amber or yellow** for a "caution" message: For immediate crew awareness, followed by further action.
- **Red** for an "alert" message: For immediate action by the crew.

Note: Depending on the importance of the "alert", when it is displayed, an audible is simultaneously triggered. Examples can be "Engine low RPM"; "Engine fire".

MAINTENANCE

The modern electronic display systems reduce the workload for the crew thanks to the integration of automatic monitoring systems and the centralization of alerts. They are usually useful for maintenance personnel when these kinds of systems have automatic "*out of tolerance*" parameter logging features in a non-volatile memory to analyze after the flight.

The maintenance technician may access such information as: what moment one or the other parameter exceeded maximum permissible; how long it lasted; and what the maximum value reached was.

The electronic display systems are very reliable and therefore require very little maintenance work. The same cannot be said for the other end of the process: The sensors, switches, transmitters are exposed to a hostile environment (pressure, temperature, vibrations) which can result in the need for action to be taken by maintenance personnel.

THERMOCOUPLE TEMPERATURE SENSOR

The EGT temperature sensors have terminal contacts to connect, for example, Chromel and Alumel, wires to the wiring harness. These terminal contacts have different diameters to prevent inadvertent crosswiring of the two wires, which is very important in a thermocouple system.

In addition, the terminals must be correctly clamped to the terminal contacts in accordance with relevant instructions in the Maintenance Manual, ATA 77.

EPR THRUST INDICATION

On engines which do not have the N1 as a main operating parameter, the lines which come from sensors, for example, Pt2 and Pt7 (or Pt5) can be a source of problems.

These lines transmit the total air intake pressure and the total pressure at the turbine outlet to the EPR calculator, and a leak in these circuits would have a direct effect on the EPR indication. A leak on the turbine outlet circuit will give a lower EPR reading and a leak on the air intake circuit will give a higher EPR reading.

VIBRATION SENSOR

Modern "piezoelectric" type accelerometer sensors are more reliable than the sensors previously used with an "electromagnetic" accelerometer because they do not have any moving parts. However, it is important that the maintenance technician apply certain procedures if he is going to work on this system.

The sensor(s) must be securely attached to the engine structure: An incorrectly installed sensor generates false vibration indications. This also applies to the electric connection which should be correctly tightened to the correct torque. The electric harness which should be securely attached by attachment clam.

N1, N2 SPEED SENSORS

These phonic wheel sensors do not usually require specific work by maintenance personnel. However, for certain types of equipment the maintenance manual can require that the space between the sensor and the teeth of the phonic wheel be measured. Usually this spacing can be adjusted by adding or removing the adjustment shims under the sensor base.

Question: 2-1
Engine instrumentation falls into two basic categories called: engine ____________ and engine ____________.

Question: 2-2
List three essential requirements for engine instrumentation.

Question: 2-3
What is the most important operating engine instrument?

Question: 2-4
What are the two types of engine instrumentation displays?

Question: 2-5
The state of detected engine parameters can be displayed with colored zones on indicators.

What are the three colors depicting the operating conditions of: normal, caution, and alert?

Question: 2-6
EPR measures air pressure at the ____________ and ____________ of a turbine engine.

Question: 2-7
N1 represents the rotational speed of a turbine engine at the ____________ pressure compressor.

Question: 2-8
EGT thermocouples for turbine engines are commonly made from ____________ and ____________.

Answer: 2-1
operation;
monitoring.

Answer: 2-2
reliability, accuracy and instant display.

Answer: 2-3
thrust

Answer: 2-4
analog or digital.

Answer: 2-5
green, yellow and red.

Answer: 2-6
inlet;
outlet.

Answer: 2-7
low

Answer: 2-8
chromel and alumel.

Question: 2-9
Engine oil pressure is commonly measured in
____________________.

Question: 2-10
Oil pressure measured as PSID means
____________________.

Question: 2-11
In determining most defects, a maintenance technician would initially determine any ____________________ between the failed indicated parameters.

Question: 2-12
In determining accurate EPR, corrections are made to pressure measurements by measuring the
____________________.

Question: 2-13
A differential pressure switch placed across a fuel filter could be set to provide two alerts at two distinct pressure differentials; the first alert would be a fuel filter ____________________, and the other alert would be a fuel filter ____________________.

Question: 2-14
EGT thermocouples for turbine engines are capable of measuring temperatures from approximately
____________________ to ____________________
degrees Celsius. They are connected in
____________________.

Question: 2-15
An ECU that controls nacelle temperature, uses an ____________________ signal for comparison purposes.

Question: 2-16
N1 parameters are normally detected by an ____________________coil and a
____________________ wheel

Answer: 2-9
pounds per square inch (PSI).

Answer: 2-10
pounds per square inch differential (PSID).

Answer: 2-11
relationship

Answer: 2-12
ambient temperature.

Answer: 2-13
clog;
bypass.

Answer: 2-14
-200;
+1 250;
parallel.

Answer: 2-15
altitude

Answer: 2-16
electromagnetic;
phonic.

Question: 2-17
N2 rotational speed is measuresd at the ____________________ pressure turbine.

Question: 2-18
Fuel flow rate detectors measure fuel ____________________ flow rate.

Question: 2-19
Engine vibration detectors use the ____________________ principle.

Question: 2-20
Coupling torque of a turboprop is equal to delivered ____________________ divided by the shaft ____________________.

Question: 2-21
Torque is usually measured at a ____________________-box. Torque is the ____________________movement of a shaft over a certain ____________________.

Question: 2-22
Manifold pressure is measured by a ____________________ and is an ____________________ pressure.

Answer: 2-17
high.

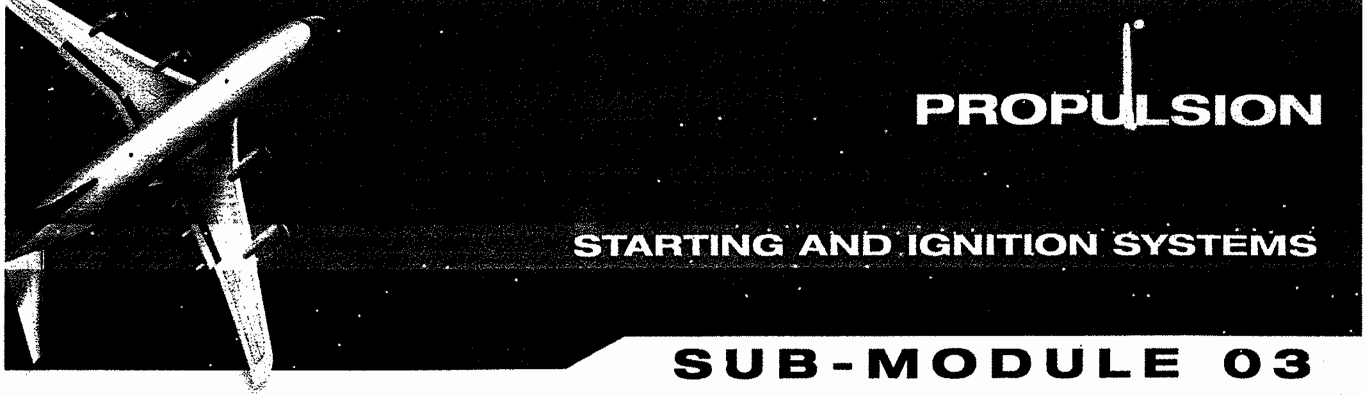
Answer: 2-18
mass.

Answer: 2-19
piezo-electric.

Answer: 2-20
power;
RPM.

Answer: 2-21
gear;
torsion;
distance.

Answer: 2-22
manometer;
absolute.



SUB-MODULE 03

PART-66 SYLLABUS **LEVELS**

CERTIFICATION CATEGORY → **B2**

Sub-Module 03
STARTING AND IGNITION SYSTEMS
Knowledge Requirements

14.3 Starting and Ignition Systems	2
Operation of engine start systems and components;	
Ignition systems and components;	
Maintenance safety requirements.	

Level 2
A general knowledge of the theoretical and practical aspects of the subject and an ability to apply that knowledge.

Objectives:
- (a) The applicant should be able to understand the theoretical fundamentals of the subject.
- (b) The applicant should be able to give a general description of the subject using, as appropriate, typical examples.
- (c) The applicant should be able to use mathematical formula in conjunction with physical laws describing the subject.
- (d) The applicant should be able to read and understand sketches, drawings and schematics describing the subject.
- (e) The applicant should be able to apply his knowledge in a practical manner using detailed procedures.

IGNITION SYSTEM MAINTENANCE SAFETY

It is absolutely necessary to use caution and follow all manufacturer's instructions when working with turbine engine ignition systems. Residual high voltage and current in the ignition exciter can be present and injury or death may occur if it is released into the human body. The most likely way for an accidental discharge to occur is by touching the igniter. To perform igniter maintenance, standard procedure calls for disconnection of the igniter lead coupling nuts at the exciter end first. Insulated tools must be used and coupling nuts or connectors should not be touched with bare hands. Again, follow all manufacturer's procedures whenever working on a turbine engine ignition system.

GAS TURBINE ENGINE STARTERS

Gas turbine engines are started by rotating the high pressure compressor. On dual spool, axial flow engines, the high pressure compressor and N1 turbine system is only rotated by the starter. To start a gas turbine engine, it is necessary to accelerate the compressor to provide sufficient air to support combustion in the combustion section, or burners. Once ignition and fuel has been introduced and the liftoff has occurred, the starter must continue to assist the engine until the engine reaches a self sustaining speed. The torque supplied by the starter must be in excess of the torque required to overcome compressor inertia and the friction loads of the engine's compressor.

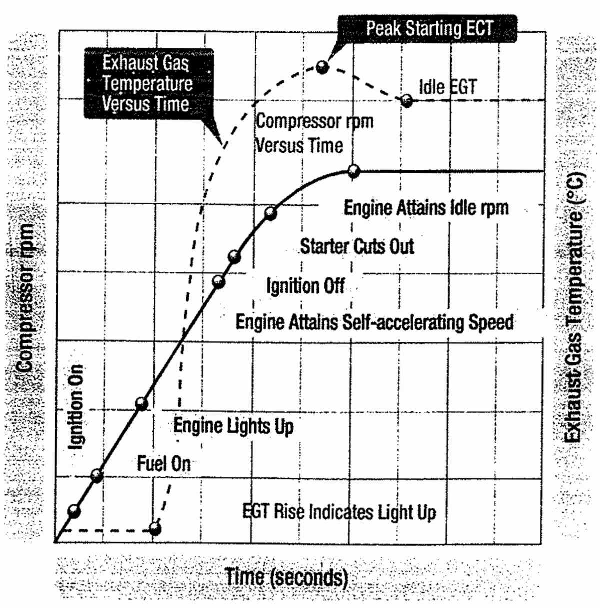


Figure 3-1. Typical gas turbine engine starting sequence.

Figure 3-1 illustrates a typical starting sequence for a gas turbine engine, regardless of the type of starter employed. 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; for this reason, the starter continues to crank the engine until after self accelerating speed has been attained. If assistance from the starter were cut off below the self accelerating speed, the engine would either 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. The starter must continue to assist the engine considerably above the self accelerating speed to avoid a delay in the starting cycle, which would result in a hot or hung false start or a combination of both. At the proper points in the sequence, the starter and ignition are automatically cut off. The basic types of starters that are in current use for gas turbine engines are direct current (DC) electric motor, starter/generators, and the air turbine type of starters.

Many types of turbine starters have included several different methods for turning the engine for starting. Several methods have been used but most of these have given way to electric or air turbine starters. An air impingement starting system, which is sometimes used on small engines, consists of jets of compressed air piped to the inside of the compressor or turbine case so that the jet air blast is directed onto the compressor or turbine rotor blades, causing them to rotate.

A typical cartridge/pneumatic turbine engine starter may be operated as an ordinary air turbine starter from a ground operated air supply or an engine cross-bleed source. It may also be operated as a cartridge starter. ***(Figure 3-2)*** To accomplish a cartridge start, a cartridge is first placed in the breech cap. The breech is then closed on the breech chamber by means of the breech handle and then rotated a partial turn to engage the lugs between the two breech sections. The cartridge is ignited by applying voltage through the connector at the end of the breech handle.

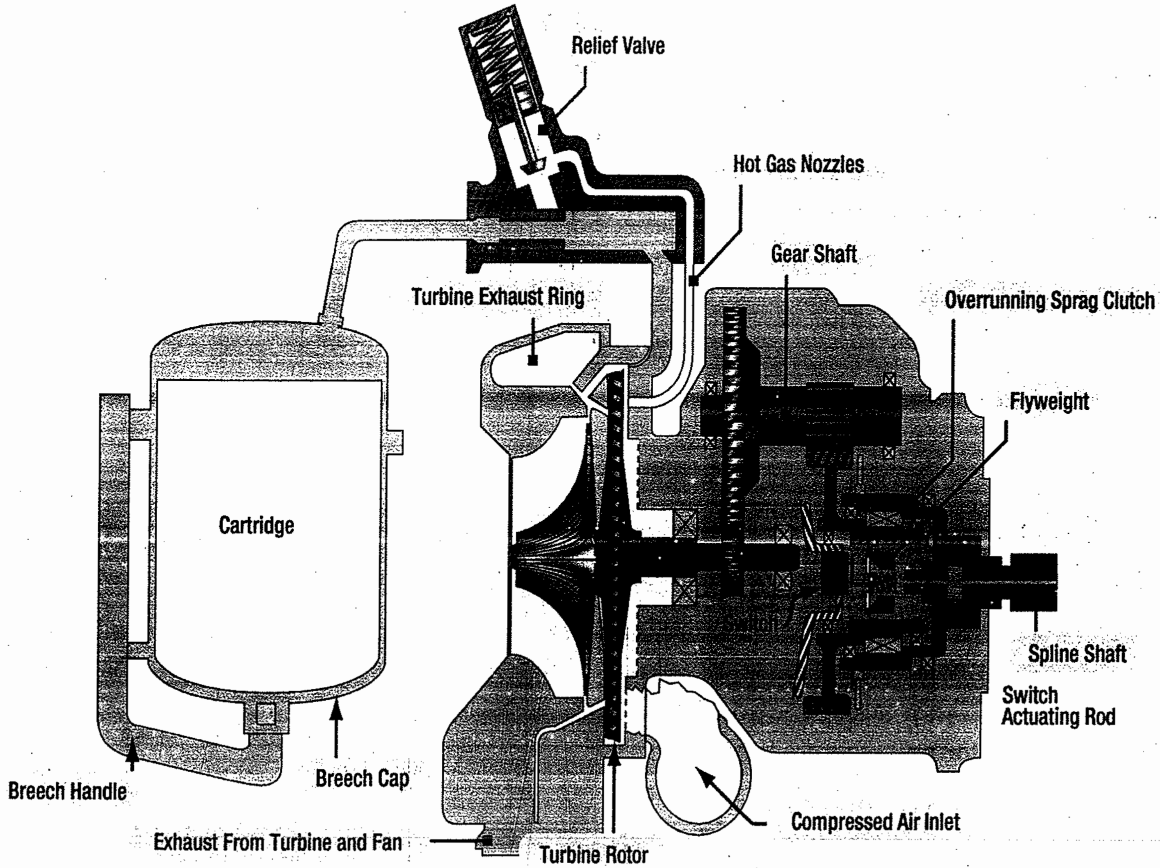


Figure 3-2. Cartridge/pneumatic starter schematic.

Upon ignition, the cartridge begins to generate gas. The gas is forced out of the breech to the hot gas nozzles that are directed toward the buckets on the turbine rotor, and rotation is produced via the overboard exhaust collector. Before reaching the nozzle, the hot gas passes an outlet leading to the relief valve. This valve directs hot gas to the turbine, bypassing the hot gas nozzle, as the pressure rises above the preset maximum. Thus, the pressure of the gas within the hot gas circuit is maintained at the optimum level.

The fuel/air combustion starter was used to start gas turbine engines by using the combustion energy of jet A fuel and compressed air. The starter consists of a turbine driven power unit and auxiliary fuel, air, and ignition systems. Operation of this type starter is, in most installations, fully automatic; actuation of a single switch causes the starter to fire and accelerate the engine from rest to starter cutoff speed.

Hydraulic pumps and motors have also been used for some smaller engines. Many of these systems are not often used on modern commercial aircraft because of the high power demands required to turn the large turbofan engines during the starting cycle on transport aircraft.

ELECTRIC STARTING SYSTEMS AND STARTER GENERATOR STARTING SYSTEMS

Electric starting systems for gas turbine aircraft are of two general types: direct cranking electrical systems and starter generator systems. Direct cranking electric starting systems are used mostly on small turbine engines, such as Auxiliary Power Units (APUs), and some small turboshaft engines. Many gas turbine aircraft are equipped with starter generator systems. Starter generator starting systems are also similar to direct cranking electrical systems except that after functioning as a starter, they contain a second series of windings that allow it to switch to a generator after the engine has reached a self-sustaining speed. This saves weight and space on the engine.

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. The starter generator unit is basically a shunt generator with an additional heavy series winding. ***(Figure 3-3)*** This series winding is electrically connected to produce a strong field and a resulting high torque for

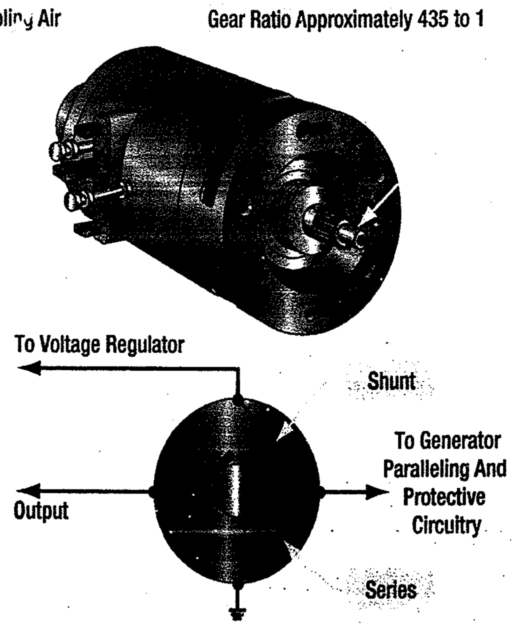


Figure 3-3. Typical starter generator.

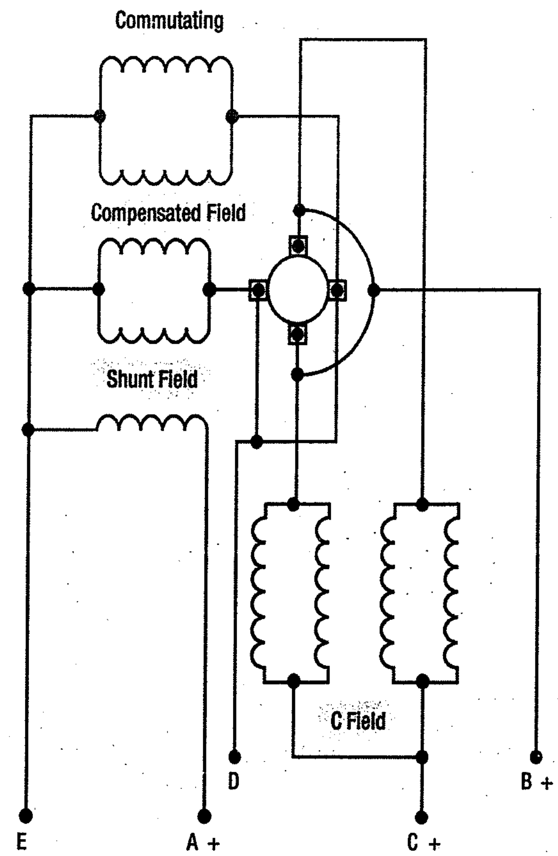


Figure 3-4. Starter generator internal circuit.

starting. Starter generator units are desirable from an economical 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.

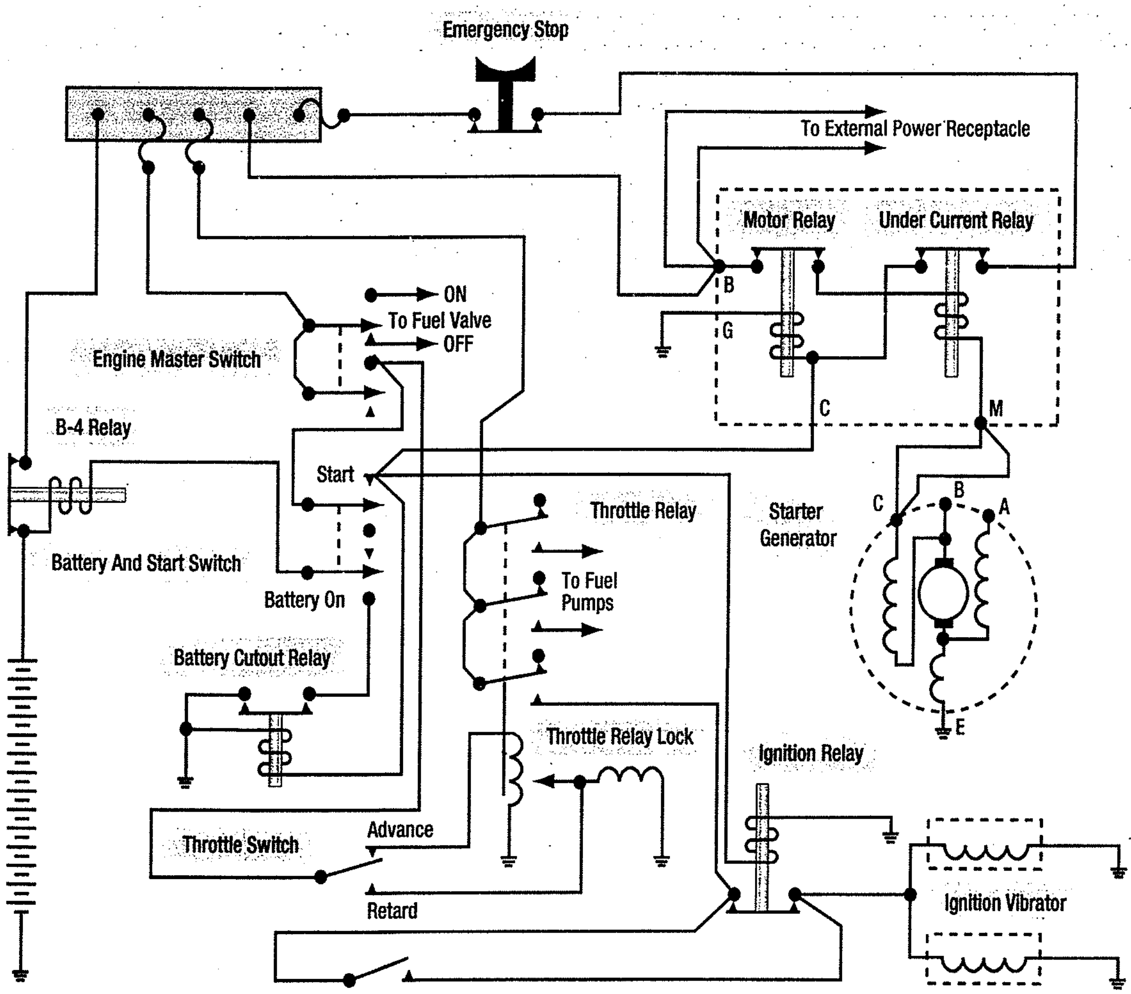


Figure 3-5. Starter generator circuit.

The starter generator internal circuit has four field windings: a series field (C field), a shunt field, a compensating field, and an interpole or commutating winding. ***(Figure 3-4)*** During starting, the C field, compensating, and commutating windings are used. 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 practical use of its shunt field. A source of 24 volts and 1 500 peak amperes is usually required for starting.

When operating as a generator, the shunt, compensating, and commutating windings are used. The C field is used only for starting purposes. The shunt field is connected in the conventional voltage control circuit for the generator. Compensating and commutating or interpole windings provide almost sparkless commutation from no load to full load. ***Figure 3-5*** illustrates the external circuit of a starter generator with an undercurrent controller. This unit controls the starter generator when it is used as a starter. Its purpose is to assure positive action of the starter and to keep it operating until the engine is rotating fast enough to sustain combustion. The control block of the undercurrent controller contains two relays. One is the motor relay that controls the input to the starter; the other, the undercurrent relay, controls the operation of the motor relay.

The sequence of operation for the starting system is discussed in the following paragraphs. ***(Figure 3-5)*** To start an engine equipped with an undercurrent relay, it is first necessary to close the engine master switch. This completes the circuit from the aircraft's bus to the start switch, to the fuel valves, and to the throttle relay. Energizing the throttle relay starts the fuel pumps, and completing the fuel valve circuit gives the necessary fuel pressure for starting the engine. As the battery and start switch is turned on, three relays close: the motor relay, ignition relay, and battery cutout relay. The motor relay closes the circuit from the power source to the starter motor; the ignition relay closes the circuit to the ignition units; the battery cutout relay disconnects the battery.

Opening the battery circuit is necessary because the heavy drain of the starter motor would damage the battery. Closing the motor relay allows a very high current to flow to the motor. Since this current flows through the coil of the undercurrent relay, it closes.

Starter Generator Starting System Troubleshooting Procedures		
Probable Cause	**Isolation Procedure**	**Remedy**
Engine Does Not Rotate During Start Attempt		
• Low supply voltage to the starter • Power switch is defective • Ignition switch in throttle quadrant • Start-lockout relay is defective • Battery series relay is defective • Starter relay is defective • Defective starter • Start lock-in relay defective • Starter drive shaft in component drive gearbox is sheared	• Check voltage of the battery or external power source. • Check switch for continuity. • Check switch for continuity. • Check position of generator control switch. • With start circuit energized, check for 48 volts DC across series relay coil. • With start circuit energized, check for 48 volts DC across starter relay coil. • With start circuit energized, check for proper voltage at the starter. • With start circuit energized, check for 28 volts DC across the relay coil. • Listen for sounds of starter rotation during an attempted start. If the starter rotates but the engine does not, the drive shaft is sheared.	• Adjust voltage of the external power source or charge batteries. • Replace switch. • Replace switch. • Place switch in OFF position. • Replace relay if no voltage is present. • Replace relay if no voltage is present. • Replace the starter if voltage is present. • Replace relay if voltage is not present. • Replace the engine.
Engine Starts But Does Not Accelerate To Idle		
• Insufficient starter voltage	• Check starter terminal voltage.	• Use larger capacity ground power unit or charge batteries
Engine Fails To Start When Throttle Is Placed In Idle		
• Defective ignition system	• Turn on system and listen for spark-igniter operation.	• Clean or replace spark igniters, or replace exciters or leads to igniters.

Figure 3-6. Starter generator starting system troubleshooting procedures.

Closing the undercurrent relay completes a circuit from the positive bus to the motor relay coil, ignition relay coil, and battery cutout relay coil. The start switch is allowed to return to its normal off position, and all units continue to operate.

As the motor builds up speed, the current draw of the motor begins to decrease. As it decreases to less than 200 amps, the undercurrent relay opens. This action breaks the circuit from the positive bus to the coils of the motor, ignition, and battery cutout relays. The deenergizing of these relay coils halts the start operation. After these procedures are completed, the engine should be operating efficiently and ignition should be self-sustaining. If, however, the engine fails to reach sufficient speed to halt the starter operation, the stop switch may be used to break the circuit from the positive bus to the main contacts of the undercurrent relay.

Troubleshooting a Starter Generator Starting System
The procedures listed in ***Figure 3-6*** are typical of those used to repair malfunctions in a starter generator starting system similar to the system described in this section. These procedures are presented as a guide only. The appropriate manufacturer's instructions and approved maintenance directives should always be consulted for the aircraft involved.

AIR TURBINE STARTERS

Air turbine starters are designed to provide high starting torque from a small, lightweight source. The typical air turbine starter weighs from ¼ to ½ as much as an electric starter capable of starting the same engine. It is capable of developing considerable more torque than the electric starter.

The typical air turbine starter consists of an axial flow turbine that turns a drive coupling through a reduction gear train and a starter clutch mechanism. The air to operate an air turbine starter is supplied from either a ground-operated air cart, the APU, or a cross-bleed start from an engine already operating. ***(Figure 3-7)*** Only one

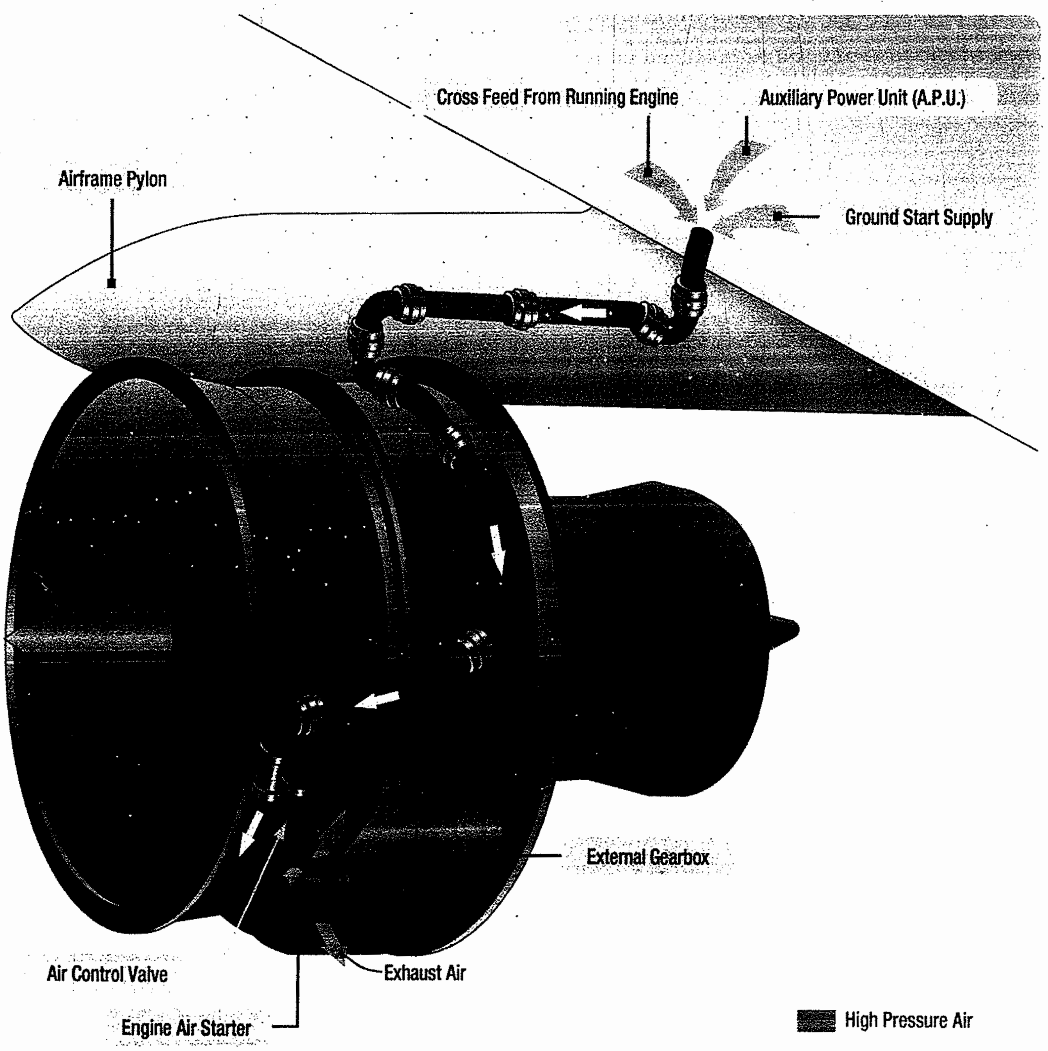


Figure 3-7. Air turbine starters are supplied by ground cart, APU, or another operating onboard engine.

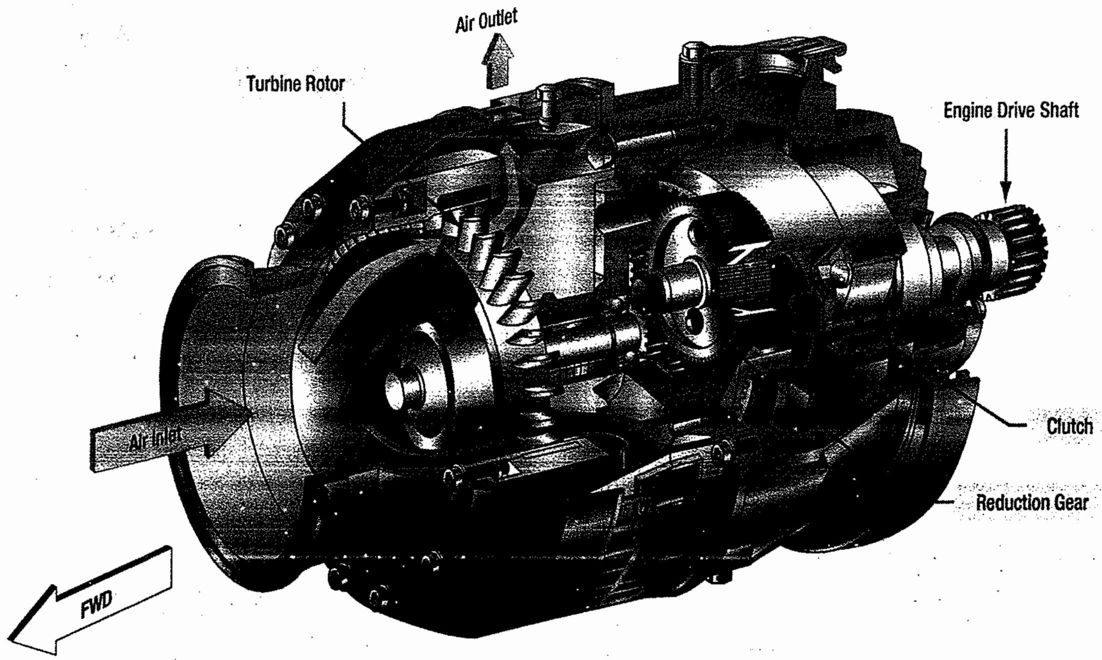


Figure 3-8. Cutaway view of an air turbine starter.

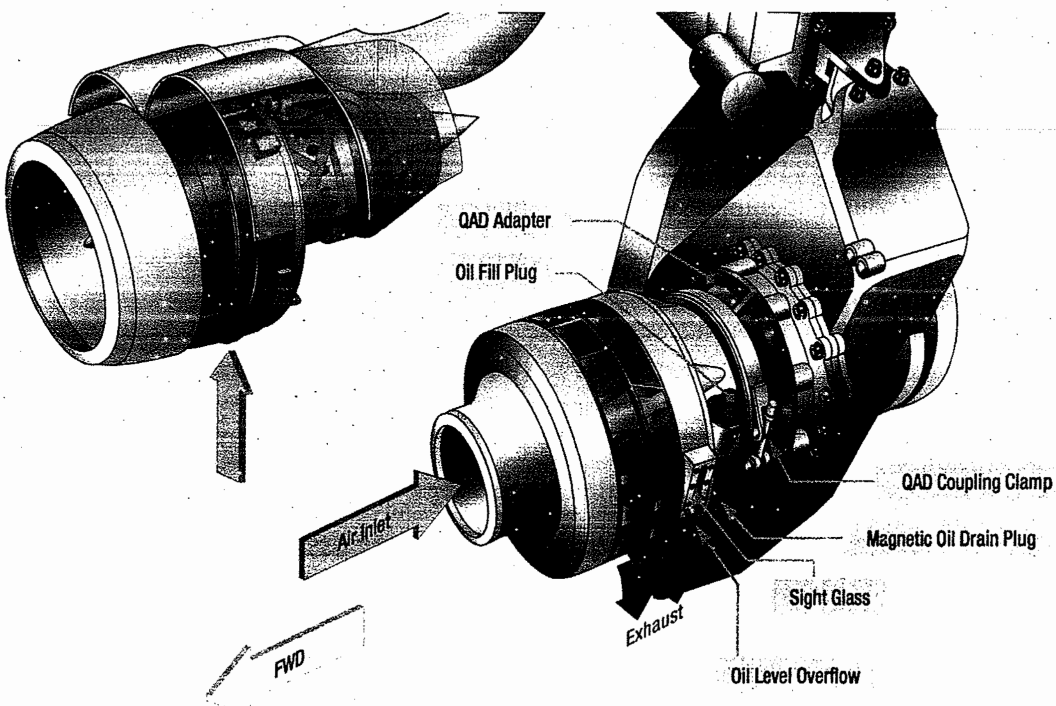


Figure 3-9. Air turbine starter.

source of around 30–50 pounds per square inch (psi) is used at a time to start the engines. The pressure in the ducts must be high enough to provide for a complete start with a normal limit minimum of about 30 psi. When starting engines with an air turbine starter, always check the duct pressure prior to the start attempt.

Figure 3-8 is a cutaway view of an air turbine starter. The starter is operated by introducing air of sufficient volume and pressure into the starter inlet. 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. 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 overrun 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. A rotor switch actuator, mounted in the turbine rotor hub, is set to open the turbine switch when the starter reaches cutout speed. Opening the turbine switch interrupts an electrical signal to the start valve. This closes the valve and shuts off the air supply to the starter.

The turbine housing contains the turbine rotor, the rotor switch actuator, and the nozzle components that 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 over speed.

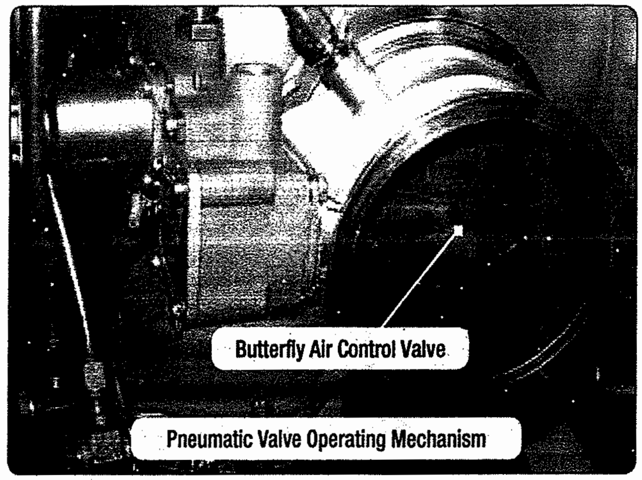


Figure 3-10. Start valve.

The transmission housing contains the reduction gears, the clutch components, and the drive coupling. The transmission housing also provides a reservoir for the lubricating oil. *(Figure 3-9)* Normal maintenance for air turbine starters includes checking the oil level, inspecting the magnetic chip detector for metal particles, and checking for leaks. Oil can be added to the transmission housing sump through a port in the starter. This port is closed by a vent plug containing a ball valve that allows the sump to be vented to the atmosphere during normal flight. The housing also incorporates a sight plug in the transmission drain opening attracts any ferrous particles that may be in the oil. The starter uses turbine oil, the same as the engine, but this oil does not circulate through the engine.

The ring gear housing, which is internal, contains the rotor assembly. The switch housing contains the turbine switch and bracket assembly. To facilitate starter installation and removal, a mounting adapter is bolted to the mounting pad on the engine. Quick-detach clamps join the starter to the mounting adapter and inlet duct. *(Figure 3-9)* 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.

The air path is directed through a combination pressure regulating and shutoff valve, or bleed valve that controls all duct pressure flowing to the starter inlet ducting.

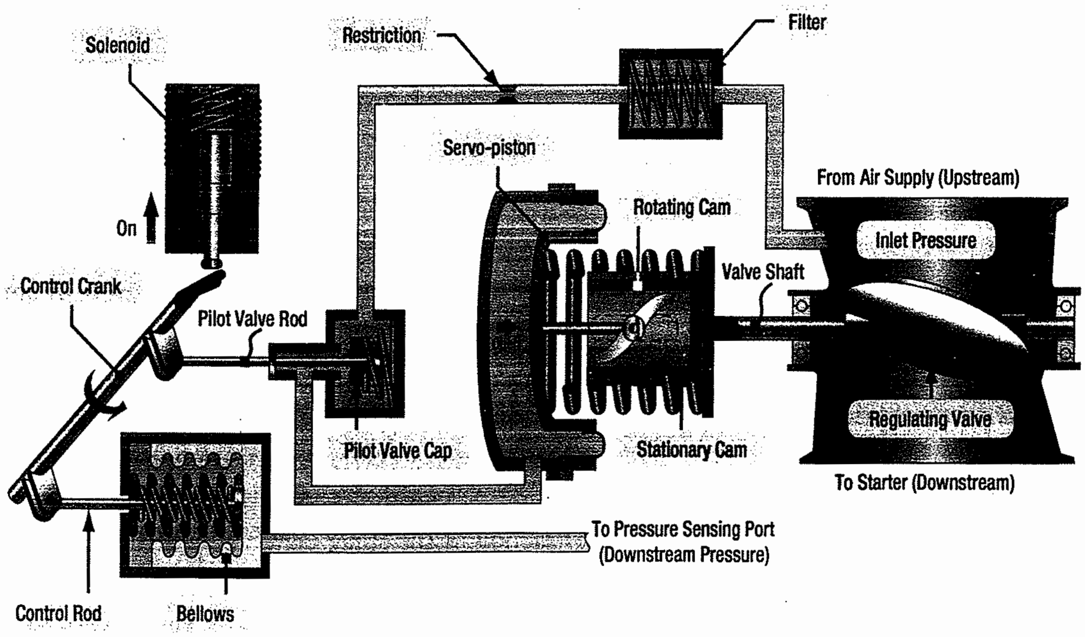


Figure 3-11. Pressure regulating and shutoff valve in ON position.

Air Turbine Starter System Troubleshooting Procedures		
Trouble	**Probable Cause**	**Remedy**
• Starter does not operate (no rotation).	• No air supply • Electrical open in cutout switch • Sheared starter drive coupling • Internal starter discrepancy	• Check air supply. • Check switch continuity. If no continuity, remove starter and adjust or replace switch. • Remove starter and replace drive coupling. • Remove and replace starter.
• Starter will not accelerate to normal cutoff speed.	• Low starter air supply • Starter cutout switch set improperly • Valve pressure regulated too low • Internal starter malfunction	• Check air source pressure. • Adjust rotor switch actuator. • Replace valve. • Remove and replace starter.
• Starter will not not cut off.	• Low air supply • Rotor switch actuator set too high • Starter cutout switch shorted	• Check air supply. • Adjust switch actuator assembly. • Replace switch and bracket assembly.
• External oil leakage.	• Oil level too high • Loose vent, oil filler, or magnetic plugs • Loose clamp band assembly	• Drain oil and re-service properly. • Tighten magnetic plug to proper torque. • Tighten vent and oil filler plugs as necessary and lock wire. Tighten clamp band assembly to higher torque.
• Starter runs, but engine does not turn over.	• Sheared drive coupling	• Remove starter and replace the drive coupling. If couplings persist in breaking in unusually short periods of time, remove and replace starter.
• Starter inlet will not line up with supply ducting.	• Improper installation of starter on engine, or improper indexing of turbine housing on starter	• Check installation and/or indexing for conformance with manufacturer's installation instructions and the proper index position of the turbine housing specified for the aircraft.
• Metallic particles on magnetic drain plug.	• Small fuzzy particles indicate normal wear • Particles coarser than fuzzy (chips, slivers, etc.) indicate internal difficulty	• No remedial action required. • Remove and replace starter.
• Broken nozzle vanes.	• Large foreign particles in air supply	• Remove and replace starter and check air supply filter.
• Oil leakage from vent plug assembly.	• Improper starter installation position	• Check installed position for levelness of oil plugs and correct as required in accordance with manufacturer's installation instructions.
• Oil leakage at drive coupling.	• Leaking rear seal assembly	• Remove and replace starter.

Figure 3-12. Air turbine starter system troubleshooting procedures.

This valve gauge that is used to check the oil quantity. A magnetic drain regulates the pressure of the starter operating air and shuts off the air supply to the engine when selected off. Downstream from the bleed valve is the start valve, which is used to control air flow into the starter. *(Figure 3-10)*

The pressure regulating and shutoff valve consists of two subassemblies: pressure regulating valve and pressure regulating valve control. *(Figure 3-11)* The regulating valve assembly consists of a valve housing containing a butterfly type valve. *(Figure 3-11)* 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 rotation of the butterfly valve.

The slope of the cam track is designed to provide small initial travel and high initial torque when the starter is actuated. The cam track slope also provides more stable action by increasing the opening time of the valve.

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 that meters pressure to the servo piston, with the bellows connected by an air line to the pressure sensing port on the starter.

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 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 upstream air, which is supplied to the pilot valve through a suitable filter and a 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 a preset value, the amount of air flowing into the servo through the restriction equals the amount of air being bled to the atmosphere through the servo bleed; the system is in a state of equilibrium.

When the bleed valve and the start valve are open, the regulated air passing through the inlet housing of the starter impinges on the turbine causing it to turn. As the turbine turns, the gear train is activated and the inboard clutch gear, which is threaded onto a helical screw, moves forward as it rotates; its jaw teeth engage those of the outboard clutch gear to drive the output shaft of the starter. The clutch is an overrunning type to facilitate positive engagement and minimize chatter. When starter cut-out speed is reached, the start valve is closed. When the air to the starter is terminated, the outboard clutch gear, driven by the engine, begins to turn faster than the inboard clutch gear; the inboard clutch gear, actuated by the return spring, disengages the outboard clutch gear allowing the rotor to coast to a halt. The outboard clutch shaft continues to turn with the engine.

Air Turbine Troubleshooting Guide

The troubleshooting procedures listed in ***Figure 3-12*** are applicable to air turbine starting systems equipped with a combination pressure regulating and shutoff valve. These procedures should be used as a guide only, and are not intended to replace the manufacturer's instructions.

TURBINE ENGINE IGNITION SYSTEMS

Since turbine ignition systems are operated mostly for a brief period during the engine starting cycle, they are, as a rule, more trouble free than the typical reciprocating engine ignition system. The turbine engine ignition system does not need to be timed to spark during an exact point in the operational cycle. It is used to ignite the fuel in the combustor and then it is switched off. Other modes of turbine ignition system operation, such as continuous ignition that is used at a lower voltage and energy level, are used for certain flight conditions.

Continuous ignition is used in case the engine were to flame out. This ignition could relight the fuel and keep the engine from stopping. Examples of critical flight modes that use continuous ignition are takeoff, landing, and some abnormal and emergency situations.

Most gas turbine engines are equipped with a high energy, capacitor type ignition system and are air cooled by fan airflow. Fan air is ducted to the exciter box, and then flows around the igniter lead and surrounds the igniter before flowing back into the nacelle area. Cooling is important when continuous ignition is used for some extended period of time. Gas turbine engines may be equipped with an electronic-type ignition system, which is a variation of the simpler capacitor type system.

The typical turbine engine is equipped with a capacitor type, or capacitor discharge, ignition system consisting of two identical independent ignition units operating from a common low voltage (DC) electrical power source: the aircraft battery, 115AC, or its permanent magnet generator. The generator is turned directly by the engine through the accessory gear box and produces power any time the engine is turning. The fuel in turbine engines can be ignited readily in ideal atmospheric conditions, but since they often operate in the low temperatures of high altitudes, it is imperative that the system be capable of supplying a high heat intensity spark. Thus, a high voltage is supplied to arc across a wide igniter spark gap, providing the ignition system with a high degree of reliability under widely

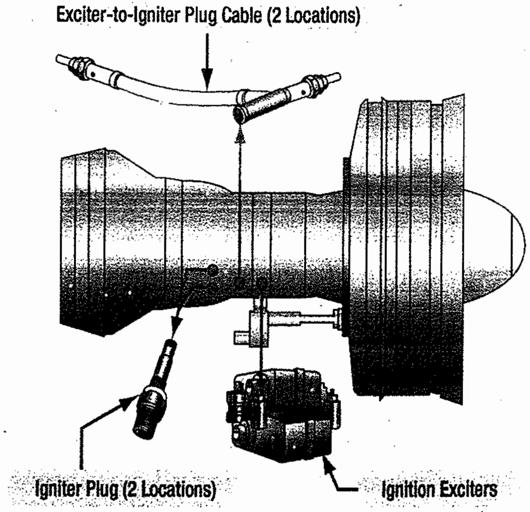


Figure 3-13. Turbine ignition system components.

varying conditions of altitude, atmospheric pressure, temperature, fuel vaporization, and input voltage.

A typical ignition system includes two exciter units, two transformers, two intermediate ignition leads, and two high tension leads. Thus, as a safety factor, the ignition system is actually a dual system designed to fire two igniter plugs. ***(Figure 3-13)***

Figure 3-14 is a functional schematic diagram of a typical older style capacitor type turbine ignition system. A 24-volt DC input voltage is supplied to the input receptacle of the exciter unit. Before the electrical energy reaches the exciter unit, it passes through a filter that prevents noise voltage from being induced into the aircraft electrical system. The low voltage input power operates a DC motor that drives one multilobe cam and one single lobe cam. At the same time, input power is supplied to a set of breaker points that are actuated by the multilobe cam.

From the breaker points, a rapidly interrupted current is delivered to an auto transformer. When the breaker closes, the flow of current through the primary winding of the transformer establishes a magnetic field. When the breaker opens, the flow of current stops, and the

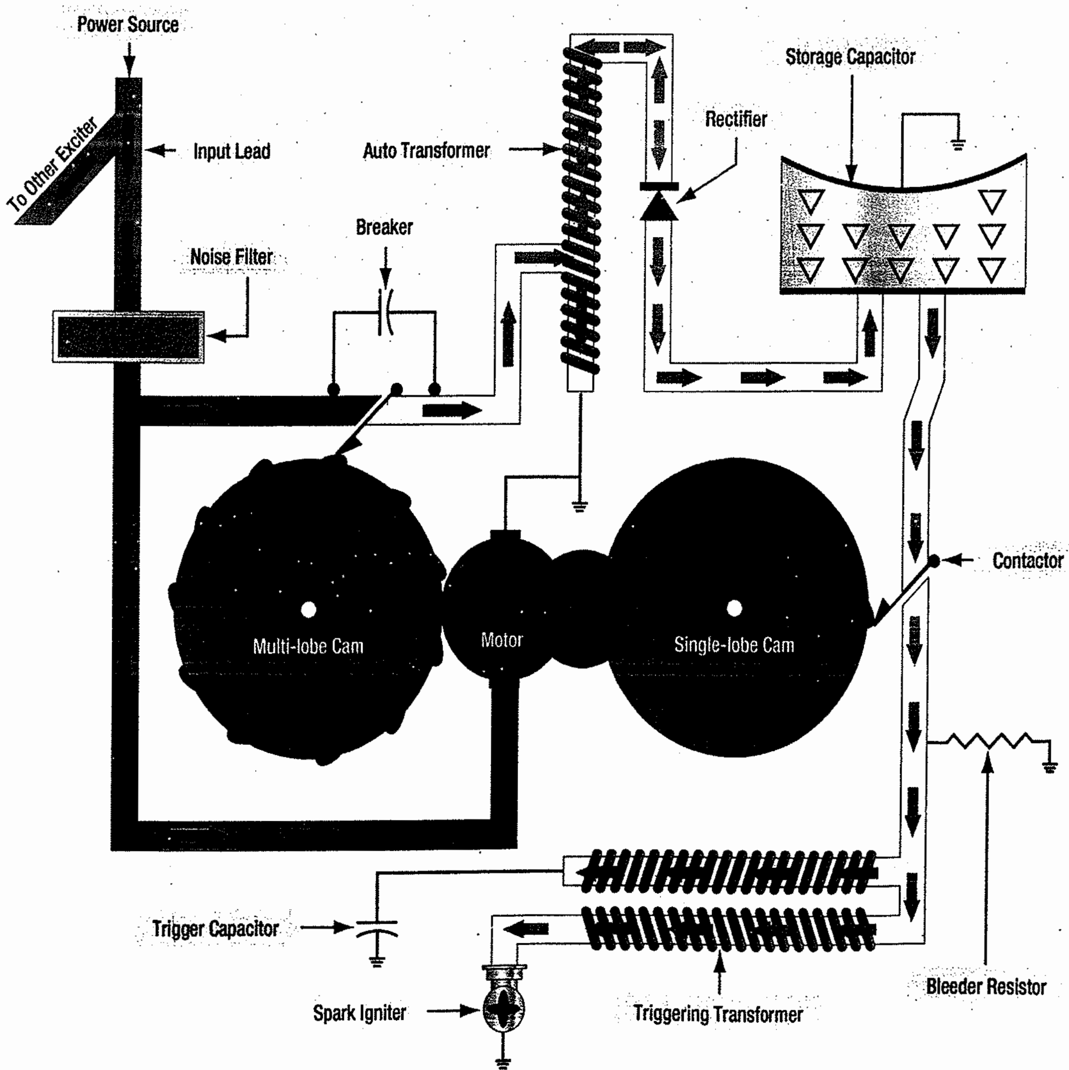


Figure 3-14. Capacitor type ignition system schematic.

collapse of the field induces a voltage in the secondary of the transformer. This voltage causes a pulse of current to flow into the storage capacitor through the rectifier, which limits the flow to a single direction. With repeated pulses, the storage capacitor assumes a charge, up to a maximum of approximately four joules. *(Note: one joule per second equals one watt.)* The storage capacitor is connected to the spark igniter through the triggering transformer and a contactor, normally open.

When the charge on the capacitor has built up, the contactor is closed by the mechanical action of the single lobe cam. A portion of the charge flows through the primary of the triggering transformer and the capacitor connected with it. This current induces a high voltage in the secondary, which ionizes the gap at the spark igniter.

When the spark igniter is made conductive, the storage capacitor discharges the remainder of its accumulated energy along with the charge from the capacitor in series with the primary of the triggering transformer. The spark rate at the spark igniter varies in proportion to the voltage of the DC power supply that affects the rpm of the motor. However, since both cams are geared to the same shaft, the storage capacitor always accumulates its store of energy from the same number of pulses before discharge. The employment of the high frequency triggering transformer, with a low reactance secondary winding, holds the time duration of the discharge to a minimum. This concentration of maximum energy in minimum time achieves an optimum spark for ignition purposes, capable of blasting carbon deposits and vaporizing globules of fuel.

All high voltage in the triggering circuits is completely isolated from the primary circuits. The complete exciter is hermetically sealed, protecting all components from adverse operating conditions, eliminating the possibility of flashover at altitude due to pressure change. This also ensures shielding against leakage of high frequency voltage interfering with the radio reception of the aircraft.

CAPACITOR DISCHARGE EXCITER UNIT

This capacity-type system provides ignition for turbine engines. Like other turbine ignition systems, it is required only for starting the engine; once combustion has begun, the flame is continuous. ***(Figure 3-15)***

The energy is stored in capacitors. Each discharge circuit incorporates two storage capacitors; both are located

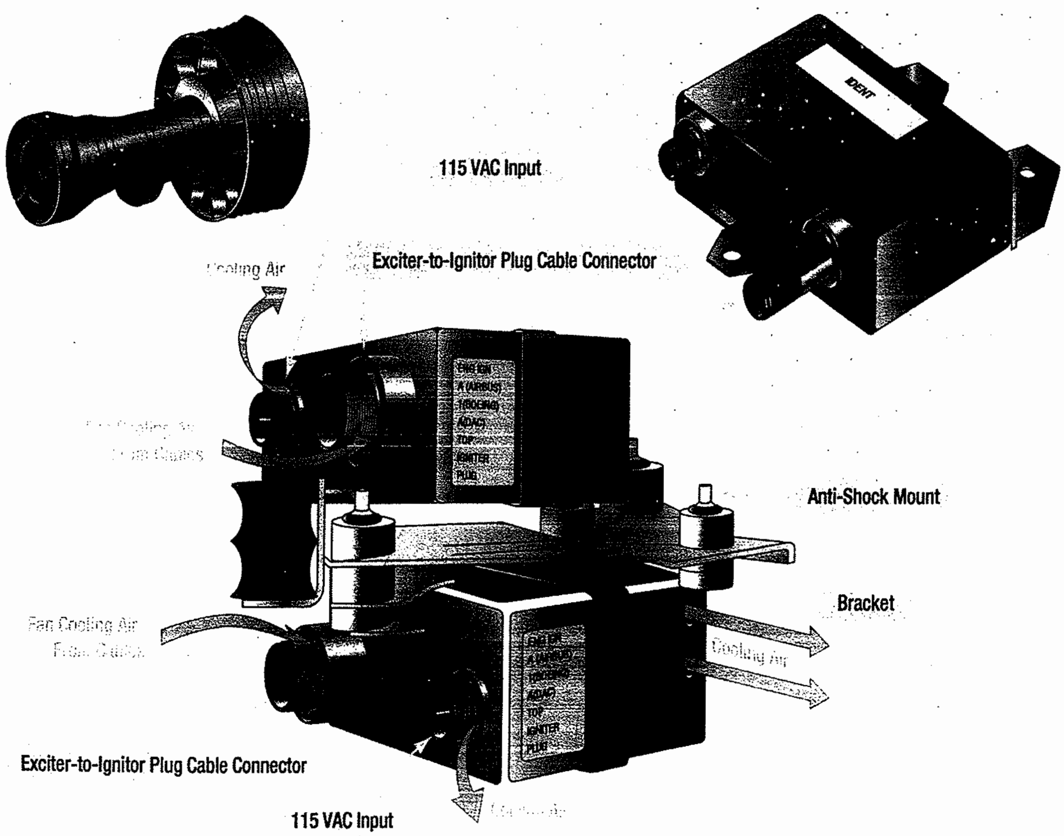


Figure 3-15. Fan air cooled exciter.

in the exciter unit. The voltage across these capacitors is stepped up by transformer units. At the instant of igniter plug firing, the resistance of the gap is lowered sufficiently to permit the larger capacitor to discharge across the gap. The discharge of the second capacitor is of low-voltage, but of very high energy. The result is a spark of great heat intensity, capable of not only igniting abnormal fuel mixtures but also burning away any foreign deposits on the plug electrodes.

The exciter is a dual unit that produces sparks at each of the two igniter plugs. A continuous series of sparks is produced until the engine starts. The power is then cut off, and the plugs do not fire while the engine is operating other than on continuous ignition for certain flight conditions. This is why the exciters are air cooled to prevent overheating during long use of continuous ignition.

IGNITER PLUGS

The igniter plug of a turbine engine ignition system differs considerably from the spark plug of a reciprocating engine ignition system. ***(Figure 3-16)*** Its electrode must be capable of withstanding a current of much higher energy than the electrode of a conventional spark plug. This high energy current can quickly cause electrode erosion, but the short periods of operation minimize this aspect of igniter maintenance. The electrode gap of the typical igniter plug is designed much larger than that of a spark plug since the operating pressures are much lower and the spark can arc more easily than in a spark plug. Finally, electrode fouling, common to the spark plug, is minimized by the heat of the high-intensity spark.

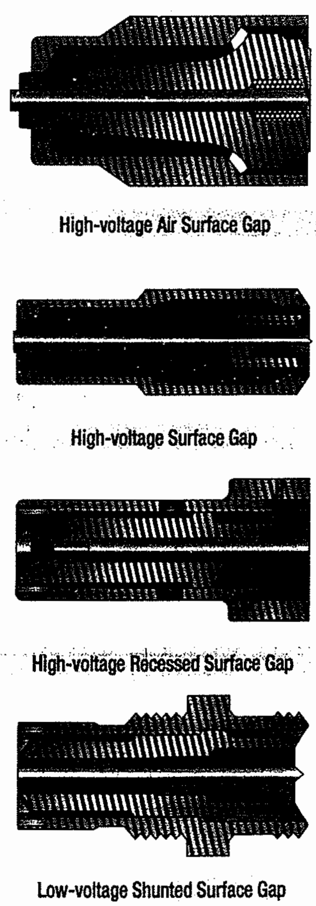


Figure 3-16. Ignitor plugs.

Figure 3-17 is a cutaway illustration of a typical annular gap igniter plug, sometimes referred to as a long reach igniter because it projects slightly into the combustion chamber liner to produce a more effective spark.

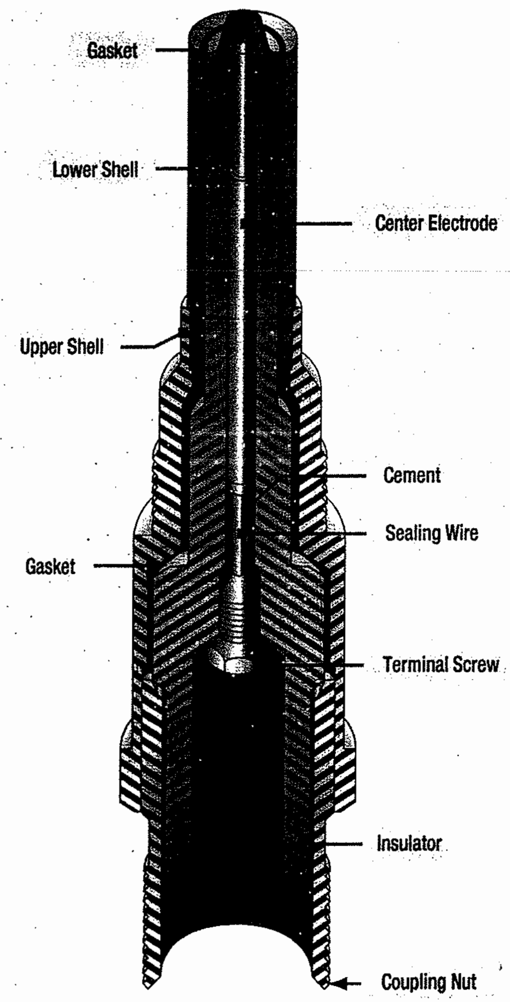


Figure 3-17. Typical annular gap igniter plug.

Another type of igniter plug, the constrained gap plug, is used in some types of turbine engines. ***(Figure 3-18)*** It operates at a much cooler temperature because it does not project into the combustion-chamber liner. This is possible because the spark does not remain close to the plug, but arcs beyond the face of the combustion chamber liner.

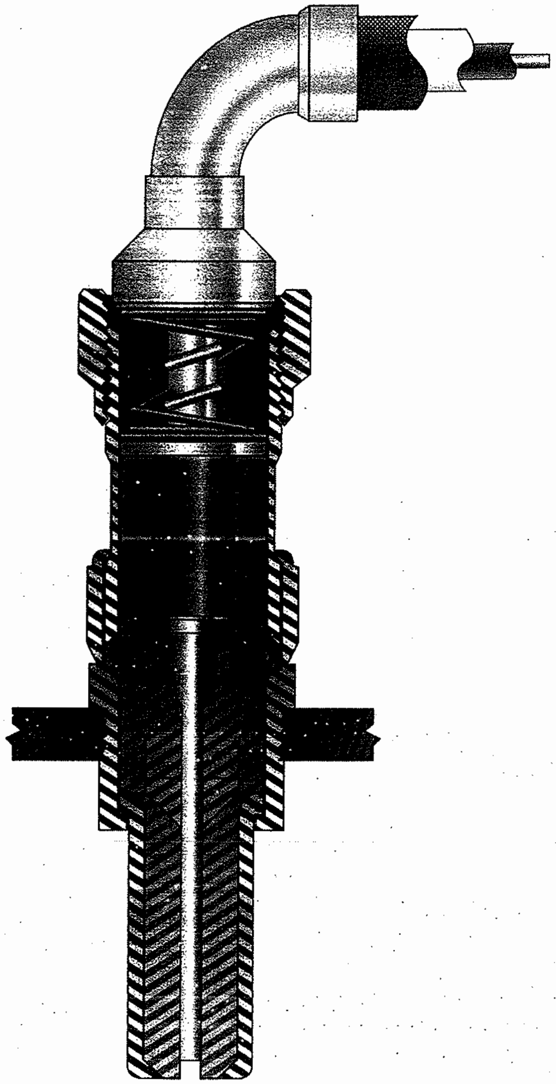


Figure 3-18. Constrained gap igniter plug.

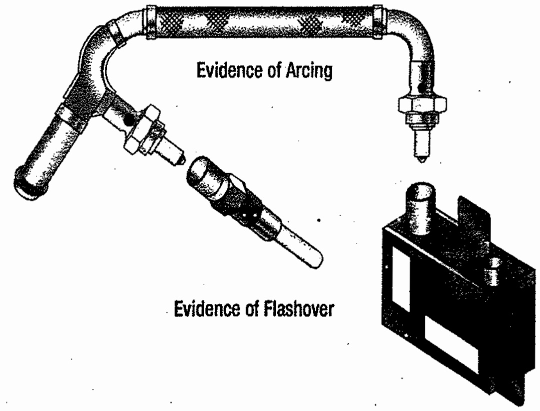


Figure 3-19. Flashover inspection.

TURBINE IGNITION SYSTEM INSPECTION AND MAINTENANCE

Maintenance of the typical turbine engine ignition system consists primarily of inspection, test, troubleshooting, removal, and installation.

INSPECTION

Inspection of the ignition system normally includes the following:

- Ignition lead terminal inspection; ceramic terminal should be free of arcing, carbon tracking and cracks.
- The grommet seal should be free of flashover and carbon tracking. *(Figure 3-19)*
- The wire insulation should remain flexible with no evidence of arcing through the insulation.
- Inspect the complete system for security of component mounting, shorts or high Voltage arcing, and loose connections.

CHECK SYSTEM OPERATION

The igniter can be checked by listening for a snapping noise as the engine begins to turn, driven by the starter. The igniter can also be checked by removing it and activating the start cycle, noting the spark across the igniter.

Caution: *The high energy level and voltage associated with turbine ignition systems can cause injury or death to personnel coming into contact with the activated system.*

REPAIR

Tighten and secure as required and replace faulty components and wiring. Secure, tighten, and safety as required.

REMOVAL, MAINTENANCE AND INSTALLATION OF IGNITION SYSTEM COMPONENTS

The following instructions are typical procedures suggested by many gas turbine manufacturers. These instructions are applicable to the engine ignition components. Always consult the applicable manufacturer's instructions before performing any ignition system maintenance.

IGNITION SYSTEM LEADS

1. Remove clamps securing ignition leads to engine.
2. Remove safety wire and disconnect electrical connectors from exciter units.
3. Remove safety wire and disconnect lead from igniter plug.
4. Discharge any electrical charge stored in the system by grounding and remove ignition leads from engine.
5. Clean leads with approved dry cleaning solvent.

6. Inspect connectors for damaged threads, corrosion, cracked insulators, and bent or broken connector pins.
7. Inspect leads for worn or burned areas, deep cuts, fraying, and general deterioration.
8. Perform continuity check of ignition leads.
9. Reinstall leads, reversing the removal procedure.

IGNITER PLUGS

1. Disconnect ignition leads from igniter plugs. A good procedure to perform before disconnecting the ignition lead is to disconnect the low-voltage primary lead from the ignition exciter unit and wait at least one minute to permit the stored energy to dissipate before disconnecting the high-voltage cable from the igniter.
2. Remove igniter plugs from mounts.
3. Inspect igniter plug gap surface material. Before inspection, remove residue from the shell exterior using a dry cloth. Do not remove any deposits or residue from the firing end of the low-voltage igniters. High-voltage igniters can have the firing end cleaned to aid in inspection. (*Figure 3-20*)
4. Inspect for fretting of igniter plug shank.
5. Replace an igniter plug whose surface is granular, chipped, or otherwise damaged.
6. Replace dirty or carbonized igniter plugs.
7. Install igniter plugs in mounting pads
8. Check for proper clearance between chamber liner and igniter plug.
9. Tighten igniter plugs to manufacturer's specified torque.
10. Safety wire igniter plugs.

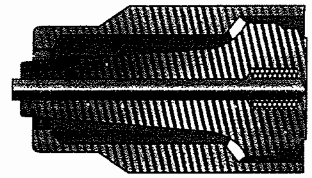
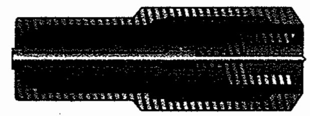
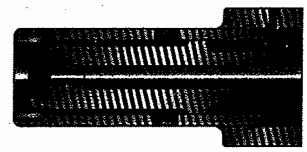
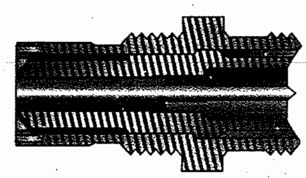
Gap Description	Typical Firing End Configuration	Clean Firing End
High-voltage Air Surface Gap		Yes
High-voltage Surface Gap		Yes
High-voltage Recessed Surface Gap		Yes
Low-voltage Shunted Surface Gap		No

Figure 3-20. Firing end cleaning.

Question: 3-1
On a turbine engine, once ignition and fuel has been introduced and light-off has occurred, the starter must continue to assist the engine until the engine reaches ________________ speed.

Question: 3-2
________________ starting systems are used mostly on small turbine engines, such as Auxiliary Power Units (APUs), and some small turboshaft engines.

Question: 3-3
The typical air turbine starter consists of an axial flow turbine that turns a drive coupling through a ________________ and a starter clutch mechanism.

Question: 3-4
Bleed air is delivered to the air starter turbine rotor through the ________________.

Question: 3-5
Most gas turbine engines are equipped with a high energy, ________________ ignition system and are air cooled by fan airflow.

Question: 3-6
The igniter plug of a turbine engine ignition system carries ________________ current than a spark plug of a reciprocating engine ignition system.

Question: 3-7
The turbine engine igniter can be checked by listening for ________________ as the engine begins to turn, driven by the starter.

ANSWERS

Answer: 3-1
self sustaining.

Answer: 3-2
Direct cranking electric.

Answer: 3-3
reduction gear train.

Answer: 3-4
start valve.

Answer: 3-5
capacitor type.

Answer: 3-6
more.

Answer: 3-7
a snapping noise.

AGB	/	Accessory Gear Box
APU	/	Auxiliary power unit
AVM	/	Airborne Vibration Monitoring
BHP	/	Brake horsepower
BTC	/	British Thermal Unit
CRT	/	Cathode Ray Tube
DC	/	Direct current
ECAM	/	Electronic Centralized Aircraft Monitor
EEC	/	Electronic Engine Control
EEC/ECU	/	Engine Control Unit
EFCU	/	Electronic Fuel Control Unit
EGT	/	Exhaust Gas Temperature
EICAS	/	Engine Indicating and Crew Alert System
EPR	/	Engine Pressure Ratio
EVMU	/	Engine Vibration Monitoring Unit
FADEC	/	Full Authority Digital Electronic Control
FE	/	Flight Engineer
FF	/	Fuel Flow
FMS	/	Flight Management System
FMU	/	Fuel metering unit
FO	/	First Officer
FOC	/	Fuel/Oil Cooler
FPS	/	Feet per second
FPS/S	/	Feet per second per second
HP	/	Horsepower
IHUMS	/	Integral Health and Usage Monitoring
KPH	/	Kilo per hour
LCD	/	Liquid Crystal Display
LVDT	/	Linear Variable Differential Transformer
MAP	/	Manifold Absolute Pressure
MFD	/	Multifunction Display
MPH	/	Miles per hour
PLA	/	Power Level Angle
PMA	/	Permanent magnet alternator
PPH	/	Pound per hour
PSI	/	Pounds per square inch
PSID	/	Pounds per square inch differential
QT	/	Quart
RAT	/	Ram Air Turbine
RPM	/	Revolutions Per Minute
TBO	/	Time between overhauls
TCC	/	Turbine Clearance Control
THP	/	Thrust horsepower
VCR	/	Viscosity compensated restrictor

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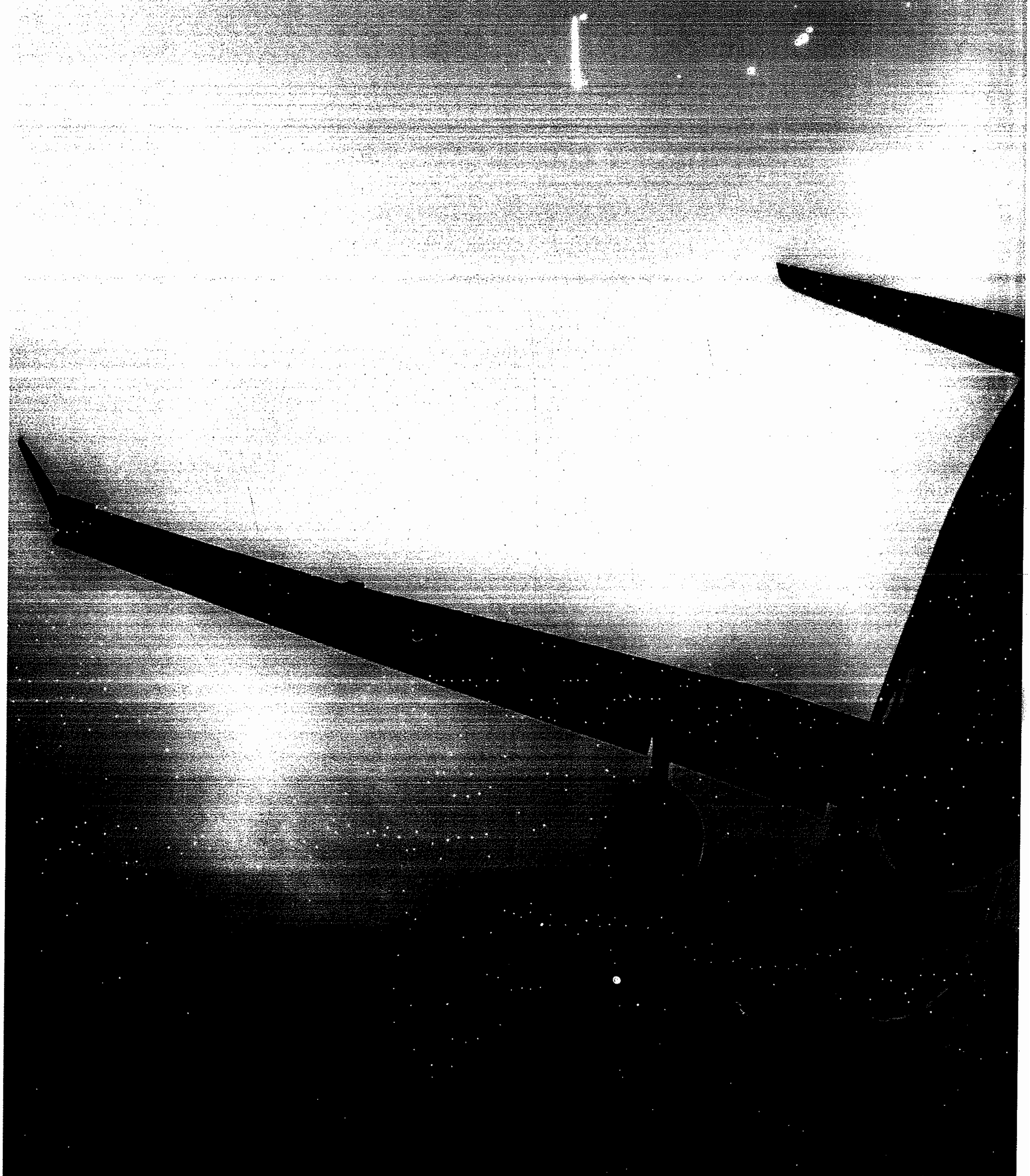

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