FM 1-506

FUNDAMENTALS OF AIRCRAFT POWER PLANTS

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HEADQUARTERS, DEPARTMENT OF THE ARMY

FIELD MANUAL
NO 1-506

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DEPARTMENT OF THE ARMY
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FUNDAMENTALS OF AIRCRAFT POWER PLANTS

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PREFACE

This manual provides information on the operation, components, and systems of aircraft power plants. The turbine engine is relatively new to the aviation field and its technology is growing rapidly. This manual will bring users up-to-date on new developments in the field.

Propellers have been deleted from this manual since the Army no longer works on them.

This manual is for use by Army aviation mechanics worldwide.

For specific instructions on the aircraft power plants in particular types and models of aircraft, refer to applicable maintenance manuals. Should the information in this field manual and that in a specific aircraft maintenance manual conflict, the latter takes precedence.

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PART ONE. FUNDAMENTALS OF POWER PLANTS

CHAPTER 1

BASIC REQUIREMENTS

Aircraft power plants must meet exacting requirements for dependability and endurance. Many difficult engineering problems have been overcome in an effort to satisfy these requirements with further advances being made each day. Requirements imposed on aircraft power plants in an effort to obtain engines suitable for aircraft include –

- Reliabtity.
- Durability.
- Compactness.
- Low weight per horsepower.
- High specific power output.
- Reasonable cost.
- High thermal efficiency.
- Freedom from vibration.
- Ease of maintenance.
- Operating flexibility.

DEFINITION OF TERMS

Reliability

Reliability is the most important fundamental power plant requirement. In the air each working part, no matter how small is important. Only by careful attention to the smallest detail can aircraft power plant manufacturers and mechanics assure power plant reliability.

Durability

Durability is the measure of reliable engine life. The durability realized by an engine depends largely on the type or condition of operation. Intelligent application of operation and maintenance procedures results in greatly improved power plant durability.

Compactness

Compactness is essential to power plant design in order to lower parasitic drag and to attain higher speeds. The overall form an engine takes is determined to a high degree by the compactness required. The degree of compactness that may be achieved is limited by the physical requirements of the engine. For example, compactness is limited on radial air-cooled engines duet to the frontal area required for sufficient cooling of engine cylinders.

Low Weight per Horsepower

Minimum weight per horsepower (HP) is a primary requirement in aeronautics. The weight of a power plant must be kept as low as possible. This allows the aircraft to carry a large useful load with a satisfactory margin of safety in proportion to gross weight. The larger modern aircraft reciprocating engines have attained a horsepower-to-weight ratio of 1 horsepower to 1 pound weight. Gas turbine engines currently used by the Army have a greater horsepower-to-weight ratio. A good example is the T-55-L-712, which develops 4500 shaft horsepower (SHP) and weighs 750 pounds(dry) (6.0 HP per pound).

High Specific Power Output

Power output is based on engine size, RPM, and weight for the fuel-air mixture. Size and RPM are limited in the reciprocating engine. Therefore, an increase in the effective working pressure in the cylinders is one of the most valuable ways to increase the specific power output. Greater pressure increases are possible by supercharging the engine (comprising the mixture before it enters the cylinders). The limiting factors in increasing cylinder pressure are resistance of the fuel to detonation and the maximum allowable cylinder pressure.

Reasonable Cost

Despite perfection of design and quality of workmanship, no power plant will be desirable if it is too costly in a competitive market. A primary factor determining the usefulness of an engine is its cost. Because of the raw materials and the great number of man-hours involved, complex designs drive up the cost. The most satisfactory design is generally the simplest that will meet requirements.

High Thermal Efficiency

Thermal efficiency is a measure of the losses suffered in converting heat energy in the fuel into mechanical work; it is the ratio of the heat developed into useful work to the heating value of the fuel. High thermal effciency, therefore, means high fuel economy-something of great importance in aircraft engines. The less fuel required for a military mission, the greater the military load that can be carried and the lower the fuel cost.

Freedom From Vibration

A power plant that is free from vibration is important in the light, somewhat flexible aircraft structure since severe engine vibration will in some cases reduce the life of certain structural parts. The need for freedom from vibration is met usually by using a large number of cylinders to offset the vibration torque delivered by the individual cylinders. Counterweights are installed on crankshafts to balance rotating masses. These are usually hinged to provide dynamic damping of vibration which results from power impulses and to counteract undesirable torsional or twisting vibration. Also, flexible engine mount isolators are used to permit certain movements of the power plant that are harmful to aircraft structures.

Ease of Maintenance

The requirement of ease of maintenance is especially important to military operations in the field. Simplicity of design and use of standard parts, when possible, assist in keeping maintenance at a low level.

Operating Flexibility

Flexibility is the ability of a power plant to run smoothly and provide the desired performance at all speeds from idling to maximum power output. The wide range of operating requirements demanded of aircraft engines presents difficulties rarely encountered in other power plant fields. In addition to the requirement of unfailing reliability, the engine must operate in widely varying positions, altitudes, and atmospheric conditions.

FUELS

Requirements

An engine fuel must be tailored to an engine and vice versa since there must be enough quantities of fuel available to the engine. Some significant properties of aviation fuels are discussed below.

Heat Energy Content or Net Heating Value. The energy content or heating value of a fuel is expressed in heat units (British thermal units [BTUs]). A fuel satisfactory for aircraft engines must have a high heat energy content per unit weight. A high heat energy content causes the weight of fuel carried to be lower than a low heat energy content. Then more of the load-carrying capacity is available for the payload Aviation gasoline and JP fuels are very desirable from this standpoint. The heat energy content for aviation gasoline is about 18,700 BTUs/pound, and for JP fuels about 18,200 BTUs/pound. The various alcohols, which have maximum energy content of about 12,000 BTUs/pound, do possess some other desirable characteristics as an internal combustion engine fuel.

Volatility. A volatile liquid is one capable of readily changing from a liquid to a vapor when heated or when contacting a gas into which it can evaporate. Since liquid fuels must be in a vaporous state to burn volatility is an important property to consider when choosing a suitable fuel for an aircraft engine. Volatility determines the starting accelerating vapor-locking and distribution characteristics of the fuel. Gasoline and JP fuels are very satisfactory because they can be blended during the refining process to give the desired characteristics. Because of the nature of constant pressure combustion in gas turbine engines a highly volatile fuel is not necessary. JP fuels are of rather low volatility while aviation gasoline is highly volatile. Comparing a highly volatile fuel like aviation gasoline to a less volatile one like JP fuel the following effects become apparent. The highly volatile fuel –

- Starts easier in cold temperatures.
- Has a slightly better combustion efficiency.
- Leaves less deposit in the combustion chamber and on the turbine blades.
- Is a greater fire hazard.
- Creates a greater danger of vapor lock of the fuel system.
- Has high evaporation losses through the breather of the fuel tank at high altitudes.

NOTE: The last two difficulties are practically nonexistent with fuels having low volatility.

Stability. The fuels used in aircraft engines must be stable. Because aviation fuels are sometimes stored for long periods, they must not deposit sediment. The gums that are normally formed are insoluble in gasoline and JP fuels and may cause restrictions in fuel strainers and liners. Aviation fuel must also retain its original properties during storage.

Purity. Aviation fuel must be free from water, dirt, and sulfur. Small amounts of water will not usually cause any difficulty because water can be removed from the fuel system by draining. Large amounts of this impurity, however, can cause complete engine failure. It is very important that corrosive sulfur be eliminated from fuel. The sulfur content of fuel may form corrosive acids when brought in contact with the water vapor formed in the combustion process.

Flush Point. The flash point is the lowest temperature at which fuel will vaporize enough to forma combustible mixture of fuel vapor and air above the fuel. It is found by heating a quantity of fuel in a special container while passing aflame above the liquid to ignite the vapor. A distinct hash of flame occurs when the flash point temperature has been reached.

Fire Point. The fire point is the temperature which must be reached before enough vapors will rise to produce a continuous flame above the liquid fuel. It is obtained in much the same manner as the flash point.

Reid Vapor Pnessure. Reid vapor pressure is the approximate vapor pressure exerted by a fuel when heated to 100% This is important because it is used to determine when a fuel will create a vapor lock.

Specific Gravity. Specific gravity is the ratio of the density (weight) of a substance (fuel) compared to that of an equal amount of water at 60°F. Specific gravity is expressed in terms of degrees API. Pure water has a specific gravity of 10. Liquids heavier than water have a number less than 10. Liquids lighter than water have a number greater than 10. An example is JP-4, whose specific gravity in degrees API is 57. The American Petroleum Institute (API) has chosen pure water by which to measure the specific gravity of fuels.

NOTE: Both flash and fire points give a relative measure of the safety properties of fuel a high flash point denotes that a high temperature must be reached before dangerous handling conditions are encountered. The minimum flash point permitted in a fuel is usually written into the specifications.

Grades

Turbine fuels are high-quality fuels covering the general heavy gasoline and kerosene boding range. They do not contain dyes or tetraethyl lead.

One of the major differences between the wide-boiling and kerosene types is the fuel volatility. JP-4 fuels have a wider boding range with an initial boiling point considerably below that of kerosene. As a group these fuels have lower specific gravities than kerosene types. Wide-boil-range fuels have Reid vapor pressures of 2 to 3 pounds and flash points below room temperature. Kerosene-type fuels have Reid vapor pressures of less than 0.5 pound and flash points higher than l00°F (38°C). Wide-boiig-range fuels generally have lower freezing points than kerosene fuels.

The fuel authorized for Army aircraft gas turbine engines is JP-4. The letters “JP" stand for jet propulsion; the number 4 indicates fuel grade.

Military specification MIL-T-5624 covers JP-4, JP-5, and JP-8 fuels. Jet A, Jet Al, and Jet B are commercial fuels which conform to the American Society for Tinting Materials specification ASTM-D-1655.

Jet B is a JP-4 type fuel; its freezing point is -56°F (-49°C) instead of -72°F (-58°C) for JP-4.

JP-5, Jet 4 and Jet A-1 are kerosene-type fuels.

ASTM Jet A and A-1 differ primarily in their fuel freezing points. Jet A is considered suitable down to fuel temperatures of -36°F (-38°C); Jet A-1, to -54°F (48°C).

JP-4 is a fuel consisting of approximately 65 percent gasoline and 35 percent light petroleum distillate, with rigidly specified properties. JP-4 is currently the Army standard fuel for turbine engines.

JP-5 is a specially refined kerosene having a minimum flash point of 140°F and a freezing point of -51°F (-46°C).

JP-8 is a specially refined kerosene with a minimum flash point of 110°F and a freezing point of -54°F (-48°C). This fuel is being classified as a total replacement fuel for all of NATO. It will replace all fuels currently used in military equipment from generators to tanks to aircraft and even to trucks. This classification will ease logistics in combat. Having only one fuel for all equipment prevents accidentally mixing or using the wrong fuels. To date testing of JP-8 is proceeding well with the total single-fuel concept on its way to full fielding.

JP fuels vary from water white to light yellow; color coding, however, does not apply to these fuels.

Additives in JP fuels include oxidation and corrosion inhibitors, metal deactivators, and icing inhibitors. Icing inhibitors also function as biocides to kill microbes in aircraft fuel systems.

Should mixing of JP fuels become necessary, there is no need to drain the aircraft fuel system before adding the new fuel. Due to the different specific gravities of these fuels, mixing them will affect the turbine engine's performance. Be sure to consult appropriate technical manuals for additional information and procedures.

When changing to a fuel with a different specific gravity, externally adjusted fuel controls and fuel flow dividers on some engines may require retrimming or readjustment for optimum performance.

COMBUSTION

Mixing fuel with air and burning it would seem to be a very simple process, but this apparent simplicity is deceptive. Problems encountered are with distribution knot.kj ignition timing, and so forth. In an internal combustion engine, the combustion process is the rather rapid reaction between fuel and oxygen. This process liberates the potential energy contained in the fuel supplied to the engine. In a gas turbine engine atmospheric air is taken in and compressed; fuel is then burned in the compressed air, which then expands through a turbine that drives a compressor.

The combustion problem would not be so great if weight and space were not so important in aircraft gas turbine engines. Without such limitation the air supply for the compressors could be divided. A portion suitable to the desired power output could be burned at approximately the chemically correct fuel-air ratio in a low-velocity combustion chamber. Design of the combustion chamber is such that less than a third of the total volume of air entering the chamber is permitted to mix with the fuel. The excess air bypasses the fuel nozzles and is used to cool the hot surfaces and to mix with and cool the burned gases before they enter the turbines.

Temperature Limitations

Gas turbine engines produce work in proportion to the amount of heat released internally. Most of this heat is obtained by burning fuel although some heat originates when air is compressed in the compressor. Low fuel-air ratio is required to keep the temperature of the gases delivered to the turbine down to a value which the turbine wheel can tolerate. With present materials of construction, the highly stressed blades or buckets of the turbine wheel cannot stand a temperature of more than about 1500°F (815°C); therefore, the gases at entrance to the turbine vanes cannot exceed about 1600°F (898°C) for more than brief periods.

Fuel-Air Ratio

The fuel-air ratio is so low in gas turbine engines that if fuel and air were uniformly mixed, the mixture would not ignite. Complete combustion of both fuel and air is obtained with isooctane at a fuel-air ratio of 0.066. This is the theoretical value which would produce complete combustion if given sufficient time to reach equilibrium. In practice, complete combustion of either fuel or air requires an excess of one or the other. Thus, if all of the air is to be burned excess fuel must be present and a fuel-air ratio of about 0.080 is required. Control of power output is largely determined by means of fuel-air ratio. Increasing fuel-air ratio increases the quantity of air and the temperature at which it is discharged at the exhaust jet pipe.

Rich-Mixture Blowout

Combustion efficiency in a well-designed combustion chamber using the most favorable fuel may be as high as 98 percent at sea level. On the other hand, it may fall to as low as 40 percent at extremely high altitudes with a badly designed combustion chamber and unsuitable fuel As combustion efficiency is reduced, a point is reached when the turbine does not develop enough power to drive the compressor. Increasing the fuel supply in order to maintain or increase engine speed may not result in increased engine RPM, and the unburned fuel may extinguish the flame. This is known as rich-mixture blowout.

Lean-Mixture Die-Out

In contrast to rich-mixture blowout, lean-mixture die-out occurs when the mixture is too lean to bum under conditions of efficient combustion. When combustion efficiency is very low, the mixture may be ignited from an external source (such as an igniter plug). It will then either be extinguished when the spark ceases or may bum so slowly that the flame is carried out through the turbine. Lean-mixture die-out can also occur when the fuel supply is reduced in order to decrease engine speed.

Rich mixture blowout and lean mixture die-out have been virtually eliminated through the refinement of fuel delivery systems.

LUBRICATION

Lubrication is a very important part of power plant operation. An engine allowed to operate without lubrications certain to fail. Lubrication not only combats friction but also acts as a cooling agent.

WARNING

Never mix reciprocating engine oils and gas turbine engine oils; they are not compatible. Mixing them causes engine failure!.

The primary purpose of a lubricant is to reduce friction between moving parts. Because liquid lubricants (oils) can be circulated readily, they are used universally in aircraft engines. In theory, fluid lubrication is based on actual separation of the surfaces so that no metal-to-metal contact occurs. As long as the oil film remains unbroken, metallic fiction is replaced by the internal fluid friction of the lubricant. Under ideal conditions friction and wear are held to a minimum. In addition to reducing friction, the oil film acts as a cushion between metal parts. This cushioning effect is particularly important for such parts as reciprocating engine crankshaft and connecting rods, which are subject to shock loading. As oil circulates through the engine, it absorbs heat from the parts. Pistons and cylinder walls in reciprocating engines especially depend on oil for cooling. Oil also aids in forming a seal between the piston and cylinder wall to prevent gas leaks from the combustion chamber. Oils also reduce abrasive wear by picking up foreign particles and carrying them to a filter to be removed

Friction Reduction

Lubricating oil decreases friction by preventing metal-to-metal contact at bearing points throughout the engine. Separating mating surfaces of moving parts by a thin film of oil changes dry or solid friction to fluid friction. The result is less heat generated in the moving parts and decreased wear on the parts.

Cushioning Effect

Lubricating oil cushions bearing surfaces by absorbing the shock between them.

Cooling

It has been noted that reducing friction results in less heat being generated. Also, as oil is circulated through bearings and splashed on various engine parts, it absorbs a great amount of heat. Lubrication is particularly important in reciprocating engines to cool the piston and cylinder. An efficient lubrication system will absorb as much as 10 percent of the total heat content of fuel consumed by the engine. By carrying away this heat, the oil flow reduces operating temperatures of internal parts not directly cooled by the engine cooling system.

Sealing Action

Oil helps seal mating surfaces in the engine, and the film of oil on various surfaces is an effective pressure seal. In reciprocating engines the oil film between the cylinder wall and piston and piston rings is important in retaining the high gas pressure in the cylinder.

Cleaning Effect

Oil cleans the engine by picking up carbon and other foreign particles as it passes through and around engine parts. It carries these particles through the system to a strainer where they are filtered from the oil.

LUBRICATING OIL REQUIREMENTS

The conditions which the engine operates under determine the requirements for lubricating oil. Conditions like temperature, contact pressure, and type and rate of motion vary so much that one lubricant cannot provide ideal lubrication for all components. Using a lubricating oil with all the desirable properties in* degrees will provide satisfactory results. TB 55-9150-200-24 specifies engine oils for use in Army aircraft. Some desirable lubrcating oil qualities are –

- Viscosity.
- Antifriction ability.
- Cooling ability.
- Chemical stability.

Viscosity

The degree of resistance of an oil flow at a specified temperature indicates its viscosity. An oil that flows slowly is described as a viscous oil or an oil of high viscosity. An oil that flows readily is said to possess a low viscosity. The viscosity of all oils is affected by temperature. AS the temperature increases, oil becomes thinner. The rate at which an oil resists viscosity changes through a given temperature range is called its viscosity index The viscosity of aircraft engine oil is fairly high because of high operating temperatures high bearing pressures, and relatively large clearances inside an aircraft engine. Since aircraft engines are also subjected to a wide range of temperatures, an oil with a high viscosity index is required.

Antifriction

The theory of fluid lubrication is based on the actual separation of metallic surfaces by an oil film. Lubricants should have high antifriction characteristics to reduce frictional resistance of the moving parts and high antiwear properties to resist the wearing action that occurs during engine operation.

Cooling Ability

Lubricating oil should have maximum cooling ability in order to absorb as much heat as possible from all lubricated surfaces.

Chemical Stability

The extreme operating conditions and high dollar value of aircraft engines make it necessary to use lubricating oil of the very best quality. The following chemical transformations can occur in a lubricating oil and make it unfit for service.

Acidity. Acidity in oils is dangerous chiefly when high temperatures and moisture are present as is the case in aircraft engines. The results of a high acid content are corrosion of metal and the formation of sludges, emulsions, and deposits in the oil system.

Oxidation. All lubricating oils tend to oxidize when in contact with air. The compounds formed by oxidation are undesirable and harmful since they are generally of a gummy or acid character.

Sulfur. Sulfur may occur in lubricating oil as free sulfur or as sulfonates. Free sulfur may be present through careless or improper refining or by actual addition. Free sulfur is corrosive in nature and impairs the stability of the oil. The presence of sulfonates indicates overtreatment with sulfuric acid or inadequate washing of the oil to free it of chemicals during the refining process. Sulfonates are strong emulsifying agents that tend to promote sludge formation in the oil system. Lubricating oils containing high percentages of sulfur oxidize more easily than those with low sulfur content.

Carbon Residue. Petroleum lubricating oils are complex mixtures of hydrocarbons that vary widely in their physical and chemical properties. Owing to these difference some oils may vaporize under atmospheric conditions without leaving any appreciable residues. Other oils leave a nonvolatile carbon residue upon vaporization. This carbon residue is the result of a partial breakdown of the oil by heat, which is caused by destructive distillation of the oil without air entering into the reaction. Many parts in the engine operate at a temperature high enough to cause this reaction and to form carbon deposits. These deposits are undesirable as they may restrict passages. In reciprocating engines they may cause sticking piston rings and sticking valves.

Moisture. Corrosion of bearing metals is almost always due to moisture in the oil. Although it is possible for corrosion to occur from acidity, it is unlikely unless moisture is also present. Therefore, to prevent corrosion, it is important to eliminate moisture from the oil as much as possible. This is especially true at high temperatures because they increase the rate of corrosion.

Because of the accumulation of these harmful substances common practice is to drain the entire lubrication system at regular intervals and refill it with new oil. The time between oil changes varies with each make and model aircraft and engine combination.

WARNING

When handling oil used in gas turbine engines, do not allow oil to remain on skin any longer than necessary. It contains a toxic additive that is readily absorbed through skin.

GAS TURBINE ENGINE LUBRICANTS

There are many requirements for turbine engine lubricating oils; but because of the small number of moving parts and the complete absence of reciprocating motion, lubrication problems are less complex in the turbine engine. This, together with the use of ball and roller bearings, requires a less viscous lubricant. The turboprop engine, while using essentially the same type of oil as the turbojet, must use a higher-viscosity oil because of the higher bearing pressures introduced by the highly loaded propeller reduction gearing.

Gas turbine engine oil must have high viscosity for good load-carrying ability but must also have viscosity low enough to provide good flow ability. It must also be of low volatility to prevent loss by evaporation at the high altitudes at which the engine operates. In addition, the oil should not foam and should be essentially nondestructive to natural or synthetic rubber seals in the lubricating system. Also, with high-speed antifriction bearings, the formation of carbons or varnishes must be held to a minimum.

The many requirements for lubricating oils are met in the synthetic oils developed specifically for turbine engines. Synthetic oil has two principal advantages over petroleum oil: it tends to deposit less lacquer and coke and evaporates less at high temperatures. Its principal disadvantage is that it tends to blister or remove paint wherever it is spilled Painted surfaces should be wiped clean with petroleum solvent after spills.

Oil-change intervals for turbine engines vary widely from model to model. They depend on the severity of oil temperature conditions imposed by the specific airframe installation and engine configuration. Follow the applicable manufacturer's instructions.

Synthetic oil for turbine engines is usually supplied in sealed l-quart or l-gallon metal cans. Although this type of container was chosen to minimize contamination, it is often necessary to filter the oil to remove metal slivers, can sealants, and so forth, which may occur when opening the can.

Some oil grades used in turbojet engines may contain oxidation preventives, load-carrying additives and substances that lower the pour point, in addition to synthetic chemical-base materials.

BEARINGS

In Army aircraft bearings are found throughout the power train system from the engine to the rotor or propeller. The failure of anyone of these bearings would place the entire aircraft in jeopardy. It is crucial that they be properly serviced and maintained. In fact, bearings are considered so important that a major air raid was conducted at considerable sacrifice during World War II in an attempt to eliminate one of Germany's principal bearing manufacturing centers. If the Allies could have destroyed Germany's capacity to produce antifriction bearings, its entire aviation effort would have come to an immediate standstill. Today, our economy could not function without bearings.

Bearings have the following functions. They–

- Support the load on a shaft. The load may be a wheel, pulley, or gear, or it may be the turning shaft itself.
- Reduce friction created by turning. This is accomplished both by design and by lubrication and is one of the most important functions of bearings.
- Reduce friction created by thrust. A specially designed bearing is required for this purpose.
- Hold a shaft in rigid alignment. A high-speed rotating shaft has a tendency to "whip" unless adequately supported by bearings.
- Provide a place for adjustment.

Bearings are classified into two broad categories

- Friction– also commonly known as a plain or babbitt type; it makes a sliding contact with the shaft.
- Antifriction– contains rollers or balls; it makes a rolling contact with the shaft.

The term "antifriction" has long been used to differentiate rolling and sliding bearings. The word is gradually being dropped in deference to the word "rolling" to describe ball and roller bearings. The term"rolling bearings'' will be used in this manual to describe all bearings consisting of ball or roller elements that roll between concentric inner and outer rings. The term "plain or journal bearings" will be used to describe two-piece bearings where the two rotating surfaces are sliding with respect to each other.

Rolling Bearings

A brief review of history reveals the long gradual development of rolling bearing. They were developed to reduce friction, thereby increasing work output while reducing energy input. Rolling-type bearings changed sliding friction into rolling motion with a greatly reduced friction level.

Assyrians and Babylonians as far back as 1100 BC used round logs as rollers to move huge monuments and stones. With the rollers placed under the load, it could more easily be pulled. AS the rollers came out of the rear of the load, they were carried around to the front and placed in the oncoming path of the load

The wheel was an extremely important development; however, it was based on sliding friction. The use of lubricants did reduce friction and increase load and life expectancy of the wheel. But it was not until the axle rested on balls or rollers that sliding friction was finally changed to rolling motion and the fiction level significantly reduced.

Modern rolling bearing had their origin with the great inventor, Leonardo da Vinci, about 1500 AD. Many of his drawings show the use of balls and rollers and foreshadow such modem technology as surface finish, raceway grooves, and conical pivots.

Rolling bearings are also classified into two types ball and roller.

Ball Bearings. The ball bearing is one of the most common used in aircraft. With relatively minor variations it can be adapted to many different uses. It creates the least amount of friction of any common bearing because the ball itself is the best antifriction rolling device known. The ball maintains point contact with the surface it rolls on and reduces friction to a minimum. It is, therefore, best suited to high-speed applications.

Roller Bearing. The roller bearing makes use of a cylindrical-shaped roller between the fiction surfaces.

Since it is a cylinder, it will make line contact rather than point contact. It is therefore more suited to heavy loads because the weight is distributed over a larger cotact area.

Construction Features. Refer to Figuree 1-1. The rolling elements in rolling bearings are provided with both an inner track and an outer track on which to roll. These tracks are known as "races." The races form a precision, hardened, and true surface for the balls or rollers to ride in. The balls or rollers are held together and spaced evenly around the bearing by means of a cage or separator. Seals are used on some bearings to keep out dirt and to keep grease in.

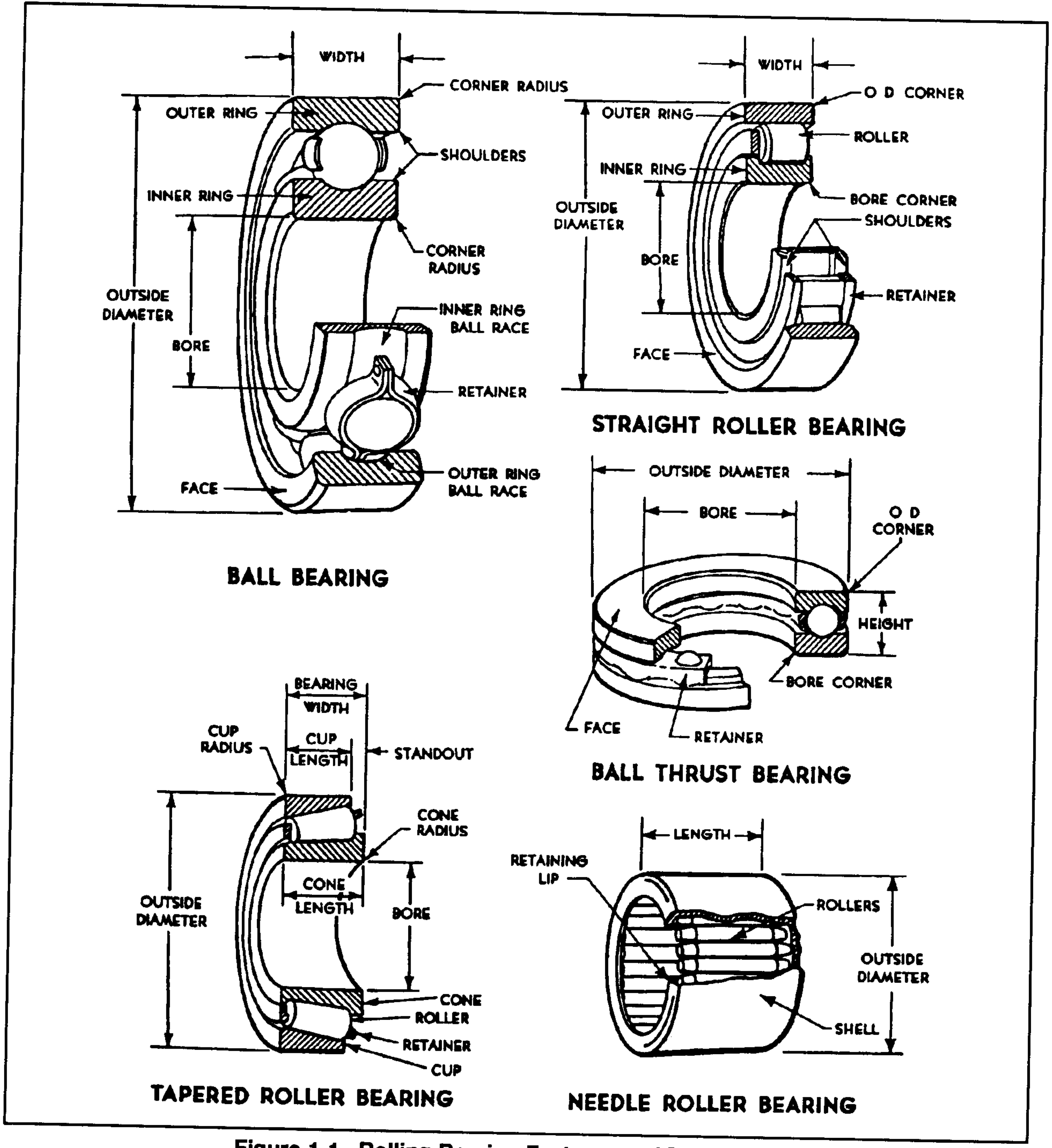


Figure 1-1. Rolling Bearing Features and Terminology

Dimensional interchangeability does not necessarily indicate functional interchangeability. Therefore, some bearings may be suited for thrust or axial loads while others are not. Bearing design (size and number of balls, depth and type of groove, width and thickness of races, construction of the separators) will determine the load and speed for which the bearing can be used. Bearings made to take both radial and thrust loads will be increased on one side of the outer race and will usually be stamped "thrust."

Plain Bearings

Plain bearings are classified as split type or solid type.

Split Type. The lower end of an engine connecting rod is a good example of a split bearing. It may be installed and used on a shaft in locations that preclude use of other bearing types. Another example of split bearings is the main bearing mounts supporting the engine crankshaft.

Solid Type. An engine connecting rod also furnishes a good example of a solid friction bearing the piston pin bearing or bushing. Bearings of this type can be used only where it is possible to slip them over the end of the shaft on which they run.

Construction Features. Refer to Figure 1-2. A basic requirement for the plain bearing is that it and the shaft be made of dissimilar metals. A steel bearing surface could never be used with a steel shaft. The bearing metal is always softer than the steel shaft, yet it must be hard enough to provide adequate heat transfer and possess good wear qualities. The metal used in bearing is known as babbitt.

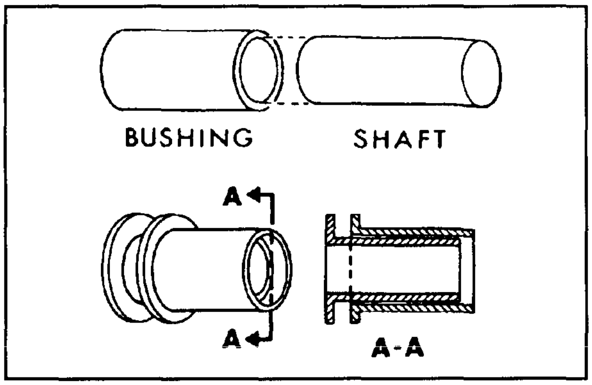


Figure 1-2. Types of Sliding/Plain Bearings

A typical friction bearing contains babbitt metal inserts in the bearing housing. A bearing insert consists of a steel shell on which a layer of babbitt has been applied The shell is actually two half shells that when placed in a split-type bearing housing produce a unit which is both efficient and easily maintained. Bearing inserts can be mass-produced to very close tolerances and require little or no fitting during assembly. The bearing is renewed by merely taking the housing apart, replacing the inserts, and bolting it up again.

Inserts on aviation engines are often of the tri-metal variety. The steel shell will have a layer of silver on its inner surface and a layer of babbitt on top of the silver. This bearing is durable and provides excellent heat transfer. It is typically used for crankshaft and rod end bearings (Figure1-3).

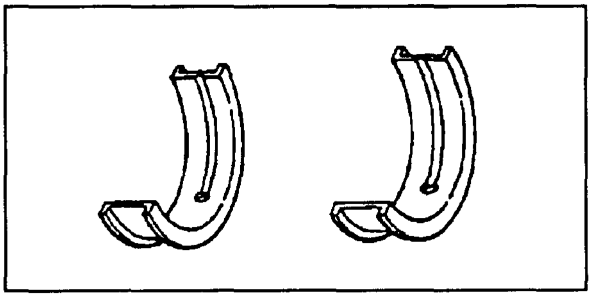


Figure 1-3. Commonly Used Plain Bearings

Bearing inserts must always be secured in the housing they must never turn with the shaft. Split-type inserts will have a tang on each half which will fit into a notch in the housing. Solid-type inserts (bushings) are pressed into the housing. Either method will preclude the chance of turning in the housing. Inserts that must absorb thrust or axial loads are designed with flanges along the sides to take this side load. Bearings without this side flange must never be subjected to thrust or axial loads.

Teflon-Lined Bearings

A new type of bearing finding increasing use is the Teflon-lined bearing. It offers high reliability and easy maintenance. It is self-lubricating, chemically inert, and shock-resistant; and it has a low coefficient of friction. It is designed as a spherical or as a journal bearing and also as a rod end bearing. Refer to Figures 1-4 and 1-5.

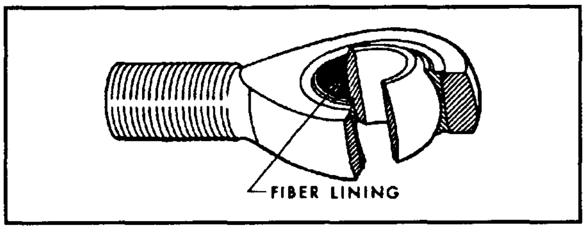


Figure 1-4. Fiber-Lined, Self-Lubricating Spherical Bearing

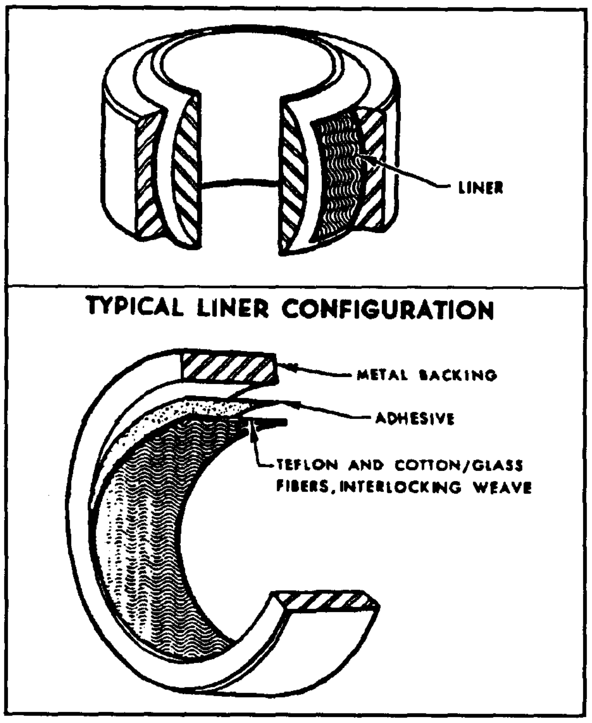


Figure 1-5. Fiber-Lined, Self-Lubricating Spherical Rod End Bearing

Bearing Loads

The two types of bearing loads are –

- Radial. When a wheel turns, it produces centrifugal force. When this force is 90° from the shaft, it is known as radial loading.
- Axial/Thrust. When the force or load on a bearing is in a direction parallel to the shaft, it is known as axial/thrust loading

NOTE: Thrust loads are the same as axial loads. Whenever the term "thrust load" is used throughout this manual, it will also refer to axial loads.

Many times a bearing is subject to a combination of both radial and thrust leak; for example, the engine crankshaft main bearings. The throws on the crankshaft produce radial load while the pull of the propeller produces thrust load. On high-horsepower engines the thrust load produced by the propeller is so great that the prop shaft could not turn unless this load (and the resulting friction) were absorbed by a special thrust bearing in the engine front section.

CHAPTER 2

BACKGROUND, DEVELOPMENT, AND THEORY

In their early attempts at flight humankind soon learned that the human body was totally inadequate as a propulsion device. They also learned that heavier-than-air aircraft would need power to attain and sustain flight. Early efforts to develop a satisfactory engine included rocket, steam, jet, and reciprocating engines, but it was the reciprocating engine that first pushed the Wright brothers aloft. Today's Army aircraft are propelled by gas turbine and reciprocating engines. While the technology which led to these engines is relatively new, the idea is not.

EARLY DEVELOPMENT

The Aeolipile

Hero, an Egyptian scientist from Alexandria, developed the first "jet engine" about the year 100 BC. Known as the "aeolipile" (Figure 2-1), it consisted of a boiler, two hollow bent tubes mounted to a sphere, and the sphere. Steam coming from the boiler entered through the two hollow tubes supporting the sphere. The steam then exited through the bent tubes on the sphere, causing it to spin. Hero is said to have used this invention to pull-open temple doors.

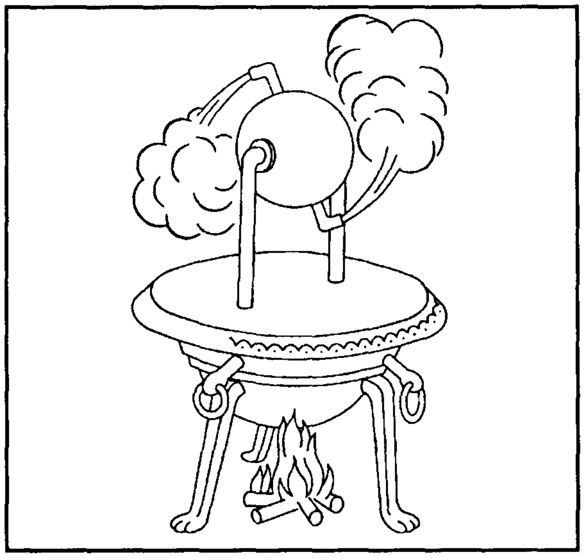


Figure 2-1. Hero's Aeolipile

The Chimney Jack

Leonardo Da Vinci designed a device called the "chimney jack" around the year 1500 AD. The chimney jack was used to turn a roasting skewer. This reaction-type turbine worked on the principle of heat raising gases from the roasting tire. As the hot air rose, it passed through fanlike blades that turned the roast through a series of gears.

Rockets

With the discovery of gunpowder around 1000 AD the Chinese, probably accidentally through a defective firecracker developed the rocket. Rockets were used as early as 1232 by the Mongols to create fear among enemy troops. A Chinese scholar, Wan Hu attempted to propel his sled with rockets. He became the first martyr in humankind's attempts to fly. Rockets were used in the Napoleonic Wars and the War of 1812. The Germans used V-2 rockets in World War II The most noted use of rockets is to launch space vehicles.

Branca's Stamping Mill

In 1629 an Italian engineer, Giovanni Branca, was probably the first to invent an actual impulse turbine. This device, a stamping mill (Figure 2-2), was generated by a steam-powered turbine. A jet nozzle directed steam onto a horizontality mounted turbine wheel, which then turned an arrangement of gears that operated his mill.

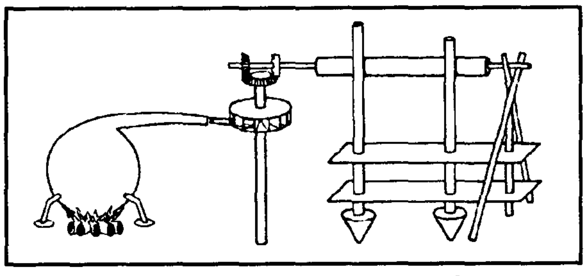


Figure 2-2. Branca's Jet Turbine

The Steam Wagon

In 1687 Isaac Newton attempted to put his newly formulated laws of motion to the test with his "steam wagon" (Figure 2-3). He tried to propel the wagon by directing steam through a nozzle pointed rearward Steam was produced by a boiler mounted on the wagon. Due to lack of power from the steam, this vehicle didn't operate.

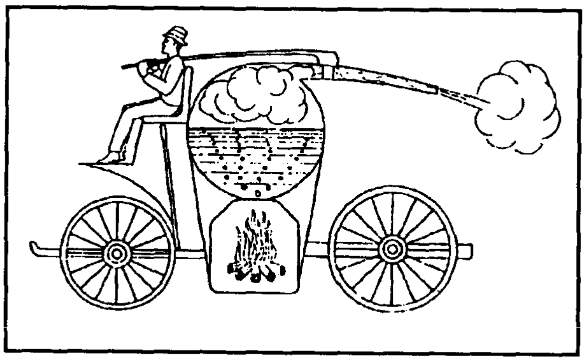


Figure 2-3. Newton's Steam Wagon

The First Gas Turbine

In 1791 John Barber, an Englishman. was the first to patent a design that used the thermodynamic cycle of the modem gas turbine. His design (Figure 2-4) contained the basics of the modem gas turbine it had a compressor, a combustion chamber, and a turbine. The main difference in his design was that the turbine was equipped With a chain-driven reciprocating type of compressor. He intended its use for jet propulsion.

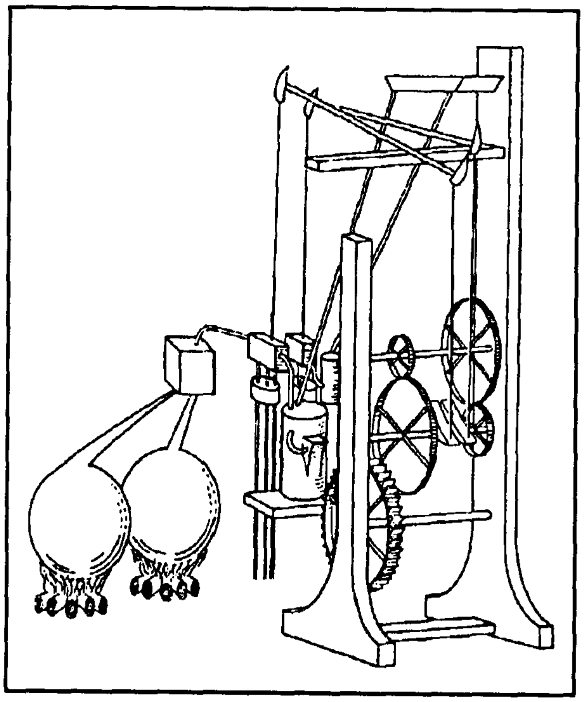


Figure 2-4. Barber's British Patent – 1791

MODERN AVIATION

English

In January 1930 an Englishman, Frank Whittle, submitted a patent application for a gas turbine for jet propulsion. It wasn't until the summer of 1939 that the Air Ministry awarded Power Jets Ltd a contract to design a flight engine. In May 1941 the Whittle W1 engine (Figure 2-5) made its first flight mounted in the Gloster Model E28/39 aircraft. This airplane would later achieve a speed of 370 MPH in level flight with 1000 pounds of thrust.

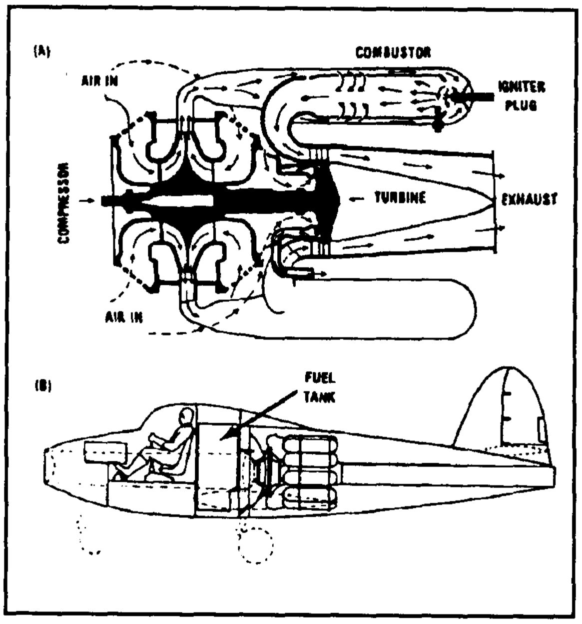


Figure 2-5. A – Whittle's Reverse-Flow Combustion Chamber. B – Fuselage Arrangement of the E28/39 Experimental

German

The Germans, Hans von Ohain and Max Hahn, students at Gottingen, seemingly unaware of Whittle's work patented a jet propulsion engine in 1936. Ernst Heinkel Aircraft Company adapted their ideas and flew the second aircraft engine of this development in an HE-178 aircraft (Figure 2-6) on August 27, 1939. This was the first true jet-propelled aircraft. The engine, known as the Heinkel HES-36, developed 1100 pounds of thrust and hurled the HE-178 to speeds of over 400 MPH. This engine used a centrifugal flow compressor. Later development produced a more advanced turbine engine that used an axial flow compressor. This turbine was used to power the ME262 jet fighter to 500 MPH. These planes were introduced in the closing stages of

World War II. The more modern engine features of blade cooling, ice prevention, and the variable-area exhaust nozzle were incorporated into the ME262 aircraft engine. On September 30, 1929, using a modified glider and Opel rockets, the Germans were the first to achieve flight using a reaction engine.

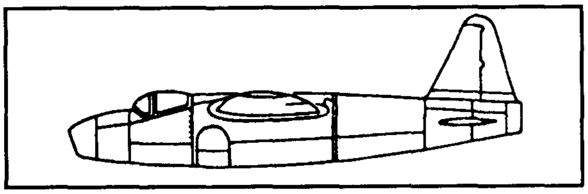


Figure 2-6. The German Heinkel HE-178

Italian

An Italian, Secundo Campiri of the Caproni Company, developed a turbine engine that used a 900-HP reciprocating engine to drive its three-stage compressor. This turbine was installed in the Caproni-Campiri CC-2, but it only achieved a disappointing 205 MPH. In August 1940 the CC-2 made its first flight, with the whole project ending just eight years later.

American

With the help of the British, America entered the jet propulsion field in September 1941. The W.lX engine, a complete set of plans for the W.2B engine, and a group of Power Jets engineers were flown to the United States from Britian. A contract was awarded General Electric Corporation to develop an American version of The W.IX. One year later (October 1942) the Bell XP-59A (Figure 2-7), fitted with two General Electric l-A engines (rated at 1300 pounds of thrust each) made this country's first jet propulsion flight.

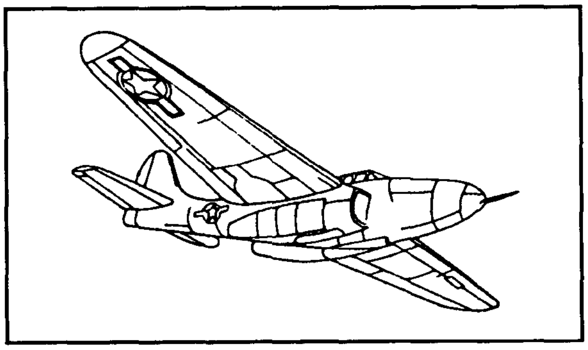


Figure 2-7. The Bell XP-59A Airacomet

Although General Electric introduced America to jet propulsion with its modified Whittle design, Westinghouse Corporation gave America its own gas turbine engine. The Westinghouse engine included an axial compressor and an annular combustion chamber. These two Westinghouse designs (axial compressor and annular combustion chamber) or variations thereof are still being used in turbine engines.

NEWTON'S LAWS OF MOTION

First Law

Newton's first law states a body in a state of rest remains at rest; a body in motion tends to remain in motion at a constant speed and in a straight line unless acted upon by some external force.

The first part of this law is evident from everyday experience for instance, a book placed on a table stays on the table. The second part of the law is more difficult to visualize. It states that if a body is set in motion and left to itself, it virtually keeps on moving without the action of any further force. The statement is correct; the body would continue to move without any reduction in velocity if no force actcd upon it. However, experience shows that a retarding force (friction) is always present. A block of wood thrown to slide along a cement-paved road comes to rest after sliding only a short distance because the friction is great; along a waxed floor it would slide farther because the friction is less, along a sheet of ice it would slide much farther because the fiction is much less. From examples like these it is theorized that if friction were eliminated entirely, a body once set in motion on a level surface would continue to move indefinitely with undiminished velocity.

Second Law

Newton's second law states: an unbalance of forces on a body produces or tends to produce an acceleration in the direction of the greater force; the acceleration is directly proportional to the force and inversely proportional to the mass of the body.

The meaning of the second law is illustrated by the example of two identical boxes being moved across a floor. If more force is applied to one box than to the other, the one subjected to the greater force will have greater acceleration. Or if a full box and an empty one are drawn across the floor with exactly equal forces, the empty box has the greater acceleration. In general, the greater the unbalanced force and the smaller the mass, the greater the acceleration.

Third Law

Newton's third law states: for every action there is an equal and opposite reaction; the two actions are directed along the same straight line. In this statement the term "action" means the force that one body exerts on a second, and "reaction" means the force that the second body exerts on the first. That is, if body A exerts a force on body B, then B must exert an equal and opposite force on A. Note that action and reaction, though equal in magnitude and opposite in direction, never neutralize or cancel each other for they always act on different objects.

The recoil of a rifle demonstrates this law of action-reaction. The gunpowder in a charge is ignited by the ignition cap, combustion takes place, and the bullet is rapidly accelerated from the rifle. As a result of this action, the rifle is accelerated rearward against the shoulder of the person firing it. The recoil felt by the person is the reaction to the action which ejected the bullet.

The principle of jet propulsion can be illustrated by a toy balloon (Figure 2-8). When inflated with the stem sealed, pressure is exerted equally on all internal surfaces. Since the force of this internal pressure is balanced, there is no tendency for the balloon to move. If the stem is released, the balloon will move in a direction away from the escaping jet of air. Although the flight of the balloon may appear erratic, it is moving in a direction away from the open stem at all times.

The balloon moves because of an unbalanced condition existing in it. The jet of air does not have to push against the outside atmosphere it could function better in a vacuum. When the stem area of the balloon is released, a convergent nozzle is created. As the airflows through this area, velocity is increased accompanied by a decrease in air pressure. In addition, an area of the balloon's skin against which the internal forces had been pushing removed. On the opposite internal surface of the balloon, an equal area of skin still remains. The higher internal pressure acting on this area moves the balloon in a direction away from the open stem. The flight of the balloon will be of short duration, though, due to the amount of air contained within it. If a source of pressurized air were provided, it would be possible to sustain the balloon's flight.

THE BRAYTON CYCLE

The "Brayton cycle" (Figure 2-9) is the name given to the thermodynamic cycle of a gas turbine engine to produce thrust. This is a varying-volume, constant-pressure cycle of events and is commonly called the "constant-pressure cycle" or "open cycle." A more recent term is "continuous-combustion cycle."

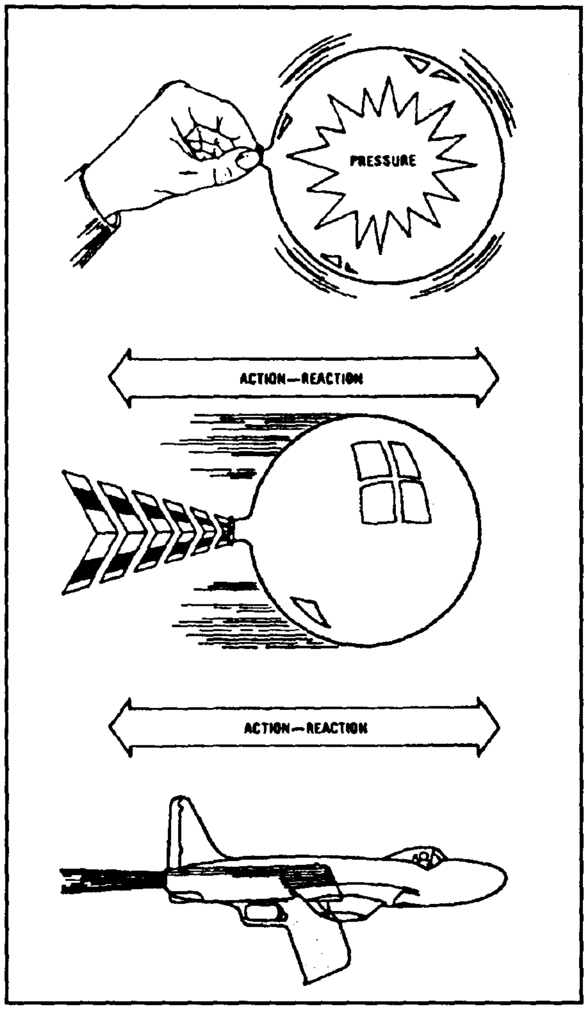


Figure 2-8. The Jet Propulsion Principle (Newton's Third Law of Motion)

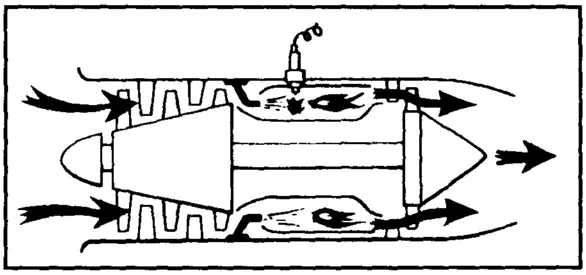


Figure 2-9. The Brayton Cycle

The four continuous and constant events are: intake, compression, expansion (includes power), and exhaust. These cycles will be discussed as they apply to a gas turbine engine.

In the intake cycle air enters at ambient pressure and in a constant volume and leaves at an increased pressure and decreased volume. In the compressor section air is received from the intake at increased pressure slightly above ambient and slightly decreased volume. Air enters the compressor where it is compressed, leaving with a large increase in pressure and decrease in volume. This is caused by the mechanical action of the compressor. The next step (expansion) takes place in the combustion chamber by burning fuel, which expands the air. Pressure remains relatively constant, but a marked increase in volume takes place. The expanding gases move rearward through the turbine assembly and are converted from velocity energy to mechanical energy by the turbine.

BERNOULLI'S THEOREM

Bernoulli's theorem states: when a gas or fluid is flowing through a convergent duct (as in nozzle stator vanes or venturi), its speed will increase and its temperature and pressure will decrease (Figure 2-10). If this area is a divergent duct (as in a diffuser or rotor blade), its speed will slow, and its temperature and pressure will increase. The total energy in a flowing gas is made up of static and dynamic temperatures and pressures. A nozzle or a diffuser does not change the total energy level but rather changes one form of energy to another. By varying the area of a pipe, velocity can be changed into pressure and pressure into velocity. A turbine engine is just such a pipe, with areas where air pressure and velocity are constantly being changed to achieve desired results.

To state this principle simply: the convergent duct increases velocity and decreases pressure. The divergent duct can be associated with the compressor where the air is slowing and pressurizing. In the combustion area the opposite is true. There, the velocity is increasing and the pressure is decreasing.

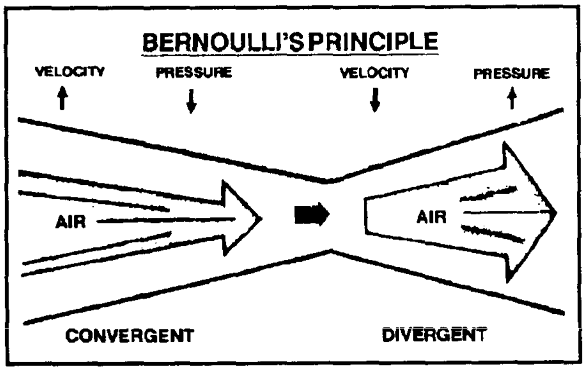


Figure 2-10. Bernoulli's Principle

BOYLE'S LAW

This law states that if the temperature of a confined gas is not changed, the pressure will increase in direct relationship to a decrease in volume. The opposite is also true – the pressure will decrease as the volume is increased. A simple demonstration of how this works may be made with a toy balloon. If you squeeze the balloon, its volume is reduced, and the pressure of air inside the balloon is increased. If you squeeze hard enough, the pressure will burst the balloon.

CHARLES' LAW

This law states that if a gas under constant pressure is so confined that it may expand, an increase in the temperature will cause an increase in volume. If you hold the inflated balloon over a stove, the increase in temperature will cause the air to expand and, if the heat is sufficiently great, the balloon will burst. Thus, the heat of combustion expands the air available within the combustion chamber of a gas turbine engine.

PRESSURE AND VELOCITY

Air is normally thought of in relation to its temperature, pressure, and volume. Within a gas turbine engine the air is put into motion and another factor must be considered, velocity. Consider a constant airflow through a duct. As long as the duct cross-sectional area remain unchanged, air will continue to flow at the same rate (disregard frictional loss). If the cross-sectional area of the duct should become smaller (convergent area), the airflow must increase velocity if it is to continue to flow the same number of pounds per second of airflow (Bernoulli's Principle). In order to obtain the necessary velocity energy to accomplish this, the air must give up some pressure and temperature energy (law of conservation of energy). The net result of flow through this restriction would be a decrease in pressure and temperature and an increase in velocity. The opposite would be true if air were to flow from a smaller into a larger duct (divergent area); velocity would then decrease, and pressure and temperature would increase. The throat of an automobile carburetor is a good example of the effect of airflow through a restriction (venturi); even on the hottest day the center portion of the carburetor feels cool. Convergent and divergent areas are used throughout a gas turbine engine to control pressure and velocity of the air-gas stream as it flows through the engine.

GAS TURBINE ENGINE VS RECIPROCATING ENGINE

A cycle is a process that begins with certain conditions and ends with those same conditions. Reciprocating and turbine engines have similiarties. Both power plants are air-breathing engines. Both engines have the same series of events (intake, compression, power, and exhaust). The difference is that in a turbine engine all of these events happen simultaneously, whereas in the reciprocating engine each event must follow the preceding event. Another difference is that in a turbine engine each operation in the cycle is performed by a separate component designed for its particular function; in the reciprocating engine all of the functions are performed in one component.

Note that the reciprocating engine obtains its work output by employing very high pressures (as much as 1000 pounds per square inch [psi]) in the cylinder during combustion. With these high pressures a greater amount of work can be obtained from a given quantity of fuel, thereby raising the thermal efficiency of this type engine. On the other hand, a turbine engine's thermal efficiency is limited by the ability of its compressor to build up high pressures without excesive temperature rises. Ideally, a turbine engine should burn as much fuel as possible in order to raise the gas temperature and increase the useful output.

Energy added in the form of fuel is more than enough to drive the compressor. The remaining energy produces the thrust or power for useful work.

NOTE: Thermal efficiency is defined as the relationship between the potential heat energy in the fuel and the actual energy output of the engine.

PART TWO. GAS TURBINE ENGINES

CHAPTER 3

PRINCIPLES, OPERATION, AND CONSTRUCTION

A gas turbine engine is an air-dependent, thermal jet propulsion device that uses exhaust-gas-driven turbine wheels to drive a compressor, making continuous operation of the engine possible.

PRINCIPLES

Although the gas turbine engine differs radically in construction from the conventional four-stroke, five-event cycle reciprocating engine, both operate on the same principle. In the piston (reciprocating) engine, the functions of intake, compression, combustion, and exhaust all take place in the same combustion chamber therefore, each must completely occupy the chamber during its respective part of the combustion cycle. In the gas turbine engine, a separate section is devoted to each function; all functions are performed at the same time without interruption. These sections are the air-inlet section the compressor section, the combustion section, and a turbine and exhaust section. The compressor brings in compresses, and forces air into the combustion section. Fuel is then injected into the combustion area, where it mixes with the compressed air. The fuel and air mixture is ignited by an electrical ignition plug; however, once started, ignition is shut off and combustion is continuous and self-supporting. In gas turbine engines designed for Army use, nearly two-thirds of the energy available from the products of combustion is necessary to drive the compressor. The power turbine is designed to extract as much of the remaining energy as possible from the gases and transform it into shaft horsepower which is used to drive an output shaft or propeller from a power shaft.

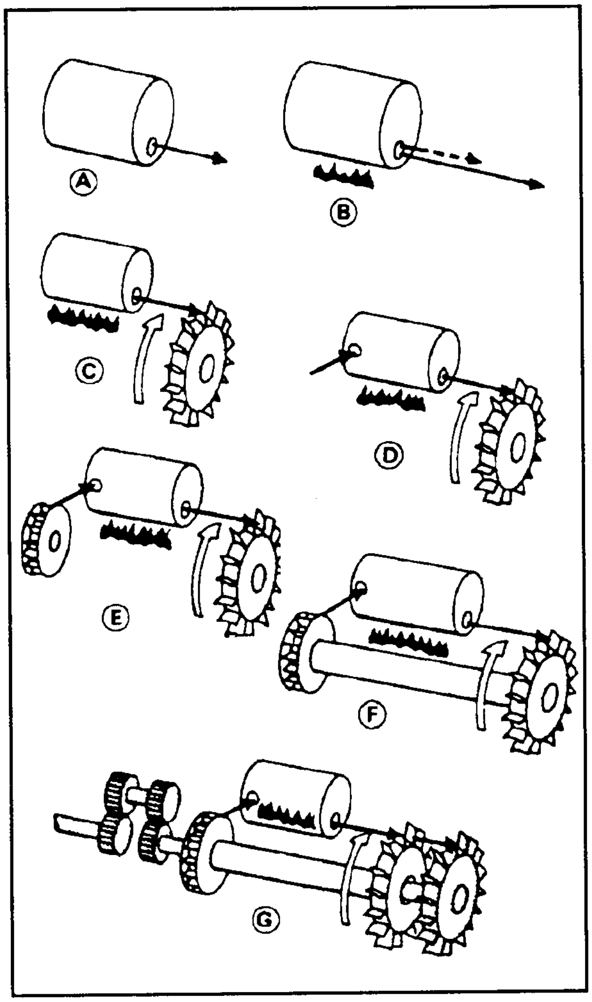


Figure 3-1. Basic Gas Turbine Engine (Thrust)

A basic gas turbine engine is illustrated in Figure 3-1. A container of compressed air has been provided with an opening (nozzle) through which the air passes off into the atmosphere until the pressure is exhausted (A). This brief high-speed airflow (velocity) through the node produces a mild momentary reaction force (solid arrow). The density of the air can be increased by heating (B). The result of this increased volume is a greater velocity as indicated by the long arrow (heated air) as compared to the short broken arrow. In (C) the heated air (solid arrow) is directed (impinged) onto the airfoil-shaped blades attached to the rim of the disc (turbine) causing the turbine to rotate on its shaft. To provide for the continuous airflow, an opening is placed in the forward end of the container(D). A mechanical pump (compressor) forces air (solid arrow) into the container (E).With high-velocity air driving the turbin, the rotating motion of the turbine can be used to drive the compressor by joining the two rotating parts with a shaft (F). Up to this point the air container has only provided for the heating of the air by an outside means. The container becomes an engine combustion chamber when fuel is introduced mixed with the air, and ignited internally. Not all of the air entering the combustion chamber is needed for combustion. However, all of it is heated and expands rapidly. It exhausts as hot, high-velocity gas through the nozzle and is directed (impinged) onto the turbine. As the gases pass across the turbine, approximately two-thirds of the available energy is used The remaining energy still possesses a high work potential. Therefore, a second turbine is placed in the flow path of the hot, high-velocity gases and is driven in the same manner as the comprcssor-driven turbine. The second turbine (power turbine), by means of a shaft system mechanically independent of the compressor turbine system drives a system of reduction gears and the output shaft. The output shaft is externally splined for turboprop application or internallys splined for helicopter application (G).

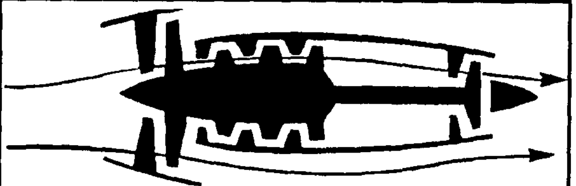
ENGINE OPERATION

The front or inlet duct is almost entirely open to permit outside air to enter the front of the engine. The compressor works on the incoming air and delivers it to the combustion section with as much as twelve times or more the pressure the air had when it entered the engine. In the combustion section fuel is sprayed and mixed with the compressed air. The air-fuel mixture is then ignited by igniter or spark plugs. Once the mixture is lighted the igniter is turned off as the burning process will continue without further assistance, providing the engine is supplied with the right air-fuel mixture. This air-fuel mixture bums at a relatively constant pressure with only about 25 percent of the air taking part in the actual combustion process The rest of the air is used for cooling some of the components of the combustion section, This heated expanding air is then directed to the turbine. The turbines are connected to the compressor and accessories They will extract a major portion (nearly two-thirds) of the energy to drive them. The remaining energy will be used to either propel the aircraft through a jet nozzle or to turn other times (power turbines). Power turbines will take this energy and transform it into shaft horsepower, which in turn drives an output shaft or propeller from a power shaft.

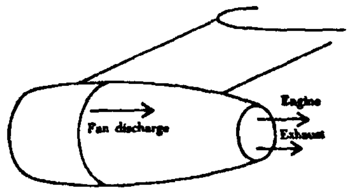
TYPES OF GAS TURBINE ENGINES

The gas turbine engines most commonly used today are divided into four types:

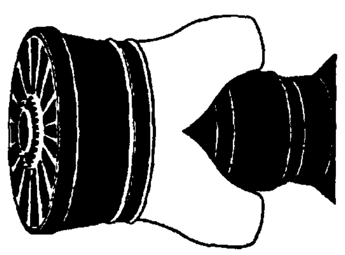
- Turbojet engine – a gas turbine engine in which the net energy available is used by the air or hot gas solely in the form of the jet issuing through a propelling nozzle or nozzles or a jet engine whose air is supplied by aturbine-driven compressor, the turbine being driven by exhaust gases.
- Turboshaft engine– an engine in which the net energy available is transmitted from the exhaust gas-driven turbine wheel through a planetary gear, which may be integral to the engine or externally provided by the aircraft manufacturer, to turn a helicopter transmission-driven powertrain system.
- Turboprop engine – a turboshaft engine in which power is transferred from the power shaft through reduction gearing to a propeller. The major difference between the two engines is the gear reduction.
- Turbofan engine – in principle, the same as a turboprop, except that the geared propeller is replaced by a duct-enclosed axial-flow fan driven at engine speed (Figure 3-2).



Airflow through a forward-fan engine.



Typical forward-fan turbofan engine installation.



Bifurcated duct configuration.

Figure 3-2. Turbofan Engines

The term "turbo" means "turbine." Therefore, a truboshaft engine is an engine that delivers power through a shaft, which, in turn is powered by a turbine wheel. Army aircraft gas turbine engines are generally the free-type power turbine turboprop or turboshaft engines. Having a free power turbine enables the power output shaft to turn at a constant speed while the power-producing capability of the engine can be varied to accommodate the increased loads applied to the power output shaft. Turbine engines may also be classified into two general groups, centrifugal-flow and axial-flow, depending on the type of compressor used. However, most gas turbine engines in Army aircraft employ a combination of both types.

AIR INLET SECTION

The amount of intake required by a gas turbine engine is approximately 10 times that required by a reciprocating engine. The air entrance is designed to conduct incoming air to the compressor with minimum energy loss resulting from drag or ram pressure loss, that is, the flow of air into the compressor should be free of turbulence to achieve maximum operating efficieney. Proper design contributes materially to aircraft performance by increasing the ratio of compressor discharge pressure to duct inlet pressure.

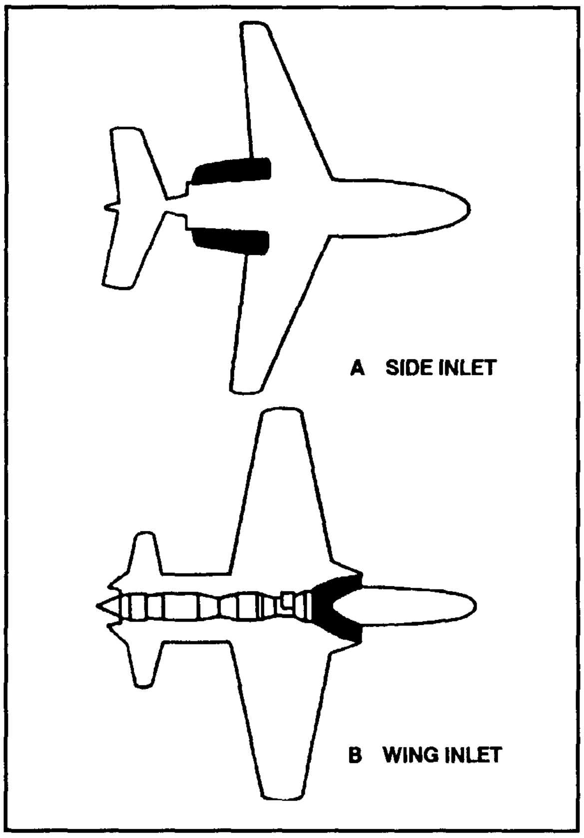


Figure 3-3. Types of Entrance Ducts

The amount of air passing through the engine depends on the–

- Speed of the compressor RPM.
- Forward speed of the aircraft.
- Density of the ambient air.

Inlets (Figures 3-3, 3-4) are classified as–

- Nose inlets located in the nose of the fuselage, power lant Pod, or nacelle.
- Winq inlets– located along the leading edge of the wing usually at the root for single-engine installations.
- Annular inlets – encircling in whole or in part the fuselage or power plant pod or nacelle.
- Scoop inlets -projecting beyond the immediate surface of the fuselage or nacelle.
- Flush inlets – recessed in the side of the fuselage, power plant or or nacelle.
- Bellmouth inlets– a bell-shaped funnel with carefully rounded Shoulders, mounted to front of engine.

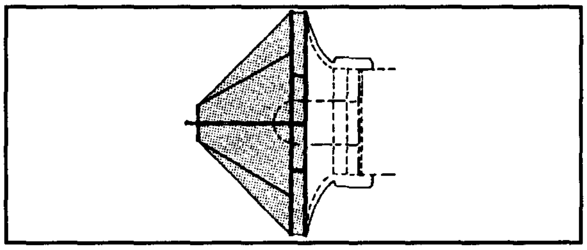


Figure 3-4. Bellmouth Compressor Inlet

There are two basic types of air entrances in use: single entrance and divided entrance. Generally, it is best to use a single entrance with an axial-flowengine to obtain maximum ram pressure through straight flow. Single entrance is used almost exclusively on wing or external installations where the unobstructed entrance lends itself readily to a single short, straight duct (Figure 3-5).

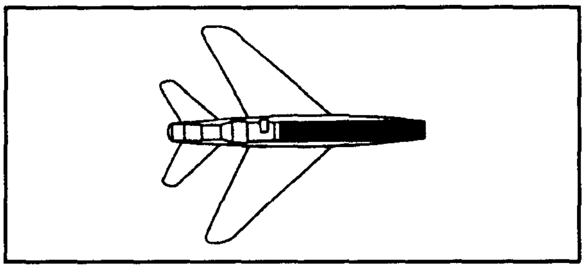


Figure 3-5. Aircraft With Single-Entrance Duct

A divided entrance offers greater opportunity to diffuse the incoming air and enter the plenum chamber with the low velocity required to utilize efficiently a double-entry compressor (refer back to Figure 3-3). (The plenum chamber is a storage place for ram air, usually associated with fuselage installations.) It is also advantageous when the equipment installation or pilot location makes the use of a single or straight duct impractical. Inmost cases the divided entrance permits the use of very short ducts with a resultant small pressure drop through skin fiction.

The air inlet section of turboprop and turboshaft engines (Figure 3-6) also incorporates some type of particle separator or inlet screens to protect compressors from foreign object damage (FOD). Systems will vary among manufacturers. Consult the aircraft or engine technical manuals for a description of the inlet duct and its particular air inlet protective device.

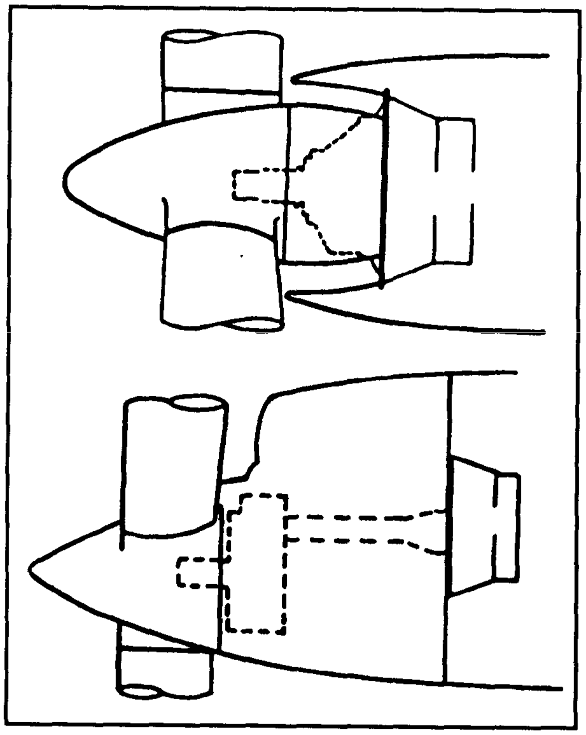


Figure 3-6. Turboprop Compressor Inlets

Air inlet ducts have an anti-icing system. Turbine engine air inlets use hot engine oil, hot bleed air, or a combination of both These systems prevent icing in a turbine engine air inlet. They are not designed to melt ice that has already formed on or in the inlets.

Guide vanes are included in some turbine engines These vanes direct air coming through the inlet into the compressor at the most efficient angle. The angle depends on the speed of the engine. On most engines the vanes are hollow to allow hot air or oil to flow through to prevent ice buildup.

COMPRESSOR SECTION

The compressor section of the turbine engine has many functions. Its primary function is to supply enough air to satisfy the requirements of the combustion burners. The compressor must increase the pressure of the mass of air received from the air inlet duct and then discharge it to the burners in the required quantity and pressure.

A secondary function of the compressor is to supply bleed air for various purposes in the engine and aircraft. The bleed air is taken nom any of the various pressure stages of the compressor. The exact location of the bleed port depends on the pressure or temperature required for a particular job. The ports are small openings in the compressor case adjacent to the particular stage from which the air is to be bled. Varying degrees of pressure and heat are available simply by tapping into the appropriate stage. Air often bled from the final or highest pressure stage because at this point pressure and air temperature are at a maximum. At times it may be necessary to cool this high-pressure air. If it is used for cabin pressurization or other purposes where excess heat would be uncomfortable or detrimental the air is sent through a refrigeration unit.

Bleed air has various uses including driving the remote-driven accessories. Some current applications of bleed air are–

- In cabin pressurization heating and cooling.
- In deicing and anti-icing equipment.
- For pneumatic starting of engines.
- In auxiliary drive units (ADUs).
- In control booster servo systems.
- As power for running instruments.

Compressor section location depends on the type of compressor. In the centrifugal-flow engine the compressor is between the accessory section and the combustion section; in the axial-flow engine the compressor is between the air inlet duct and the combustion section.

Centrifugal-Flow Compressor

The centrifugal-flow compressor basically consists of an impeller (rotor), a diffuser (stator), and a compressor manifold. The impeller and the diffuser are the two main functional elements. Although the diffuser is a separate component positioned inside and secured to the manifold, the entire assembly (diffuser and manifold) is often referred to as the diffuser.

The impeller's function is to pick up and accelerate air outward to the diffuser. Impellers may be either of two types – single entry or double entry. Both are similar in construction to the reciprocating engine supercharger impeller. The double-entry type is similar to two back-to back impellers. However, because of much greater combustion air requirements in turbine engines, these impellers are larger than supercharger impellers.

The principal differences between the two types of impellers are size and ducting arrangement. The double-entry type has a smaller diameter but is usually operated at a higher rotational speed to ensure enough airflow. The single-entry impeller permits convenient ducting directly to the impeller eye (inducer vanes) as opposed to the more complicated ducting necessary to reach the rear side of the double-entry type. Although slightly more efficient in receiving air, the single-entry impeller must be large in diameter to deliver the same quantity of air as the double-entry type. This of course, increases the overall diameter of the engine.

Included in the ducting for double-entry compressor engines is the plenum chamber. This chamber is necessary for a double-entry compressor because air must enter the engine at almost right angles to the engine axis. To give a positive flow, air must surround the engine compressor at a positive pressure before entering the compressor.

Multistage centrifugal compressors consist of two or more single compressors mounted in tandem on the same shaft. The air compressed in the first stage passes to the second stage at its point of entry near the hub. This stage will further compress the air and pass it to the next stage if there is one. The problem with this type of compression is in turning the air as it is passed from one stage to the next.

The diffuser is an annular chamber provide with a number of vanes forming a series of divergent passages into the manifold. The diffuser vanes direct the flow of air from the impeller to the manifold at an angle designed to retain the maximum amount of energy imparted by the impeller. They also deliver the air to the manifold at a velocity and pressure satisfactory for combustion chambers.

The compressor manifold diverts the flow of air from the which, which is an integral part of the manifold, into the combustion chambers. The manifold will have one outlet port for each chamber so that the air is evenly divided. A compressor outlet elbow is bolted to each of the outlet ports. These air outlets are constructed in the form of ducts and are known by a variety of names including "air outlet ducts", "outlet elbows," and "combustion chamber inlet ducts." These outlel ducts perform avery important part of the diffusion process. They change the airflow direction from radial to axial. The diffusion process is completed after the turn. To help the elbows perform this function efficiently, turning vanes (cascade vanes) are sometimes fitted inside the elbows. The vanes reduce air pressure losses by presenting a smooth, turning surface.

The centrifugal compressor is used best on smaller engines where simplicity, flexibility, and ruggedness are primary requirements. These have a small frontal area and can handle high airflows and pressures with low loss of efficiency.

Centrifugal-flow compressors have the following advantages:

- High pressure rise per stage.
- Efficiency over wide rotational speed range.
- Simplicity of manufacture with resulting low cost.
- Low weight.
- Low starting power requirements.

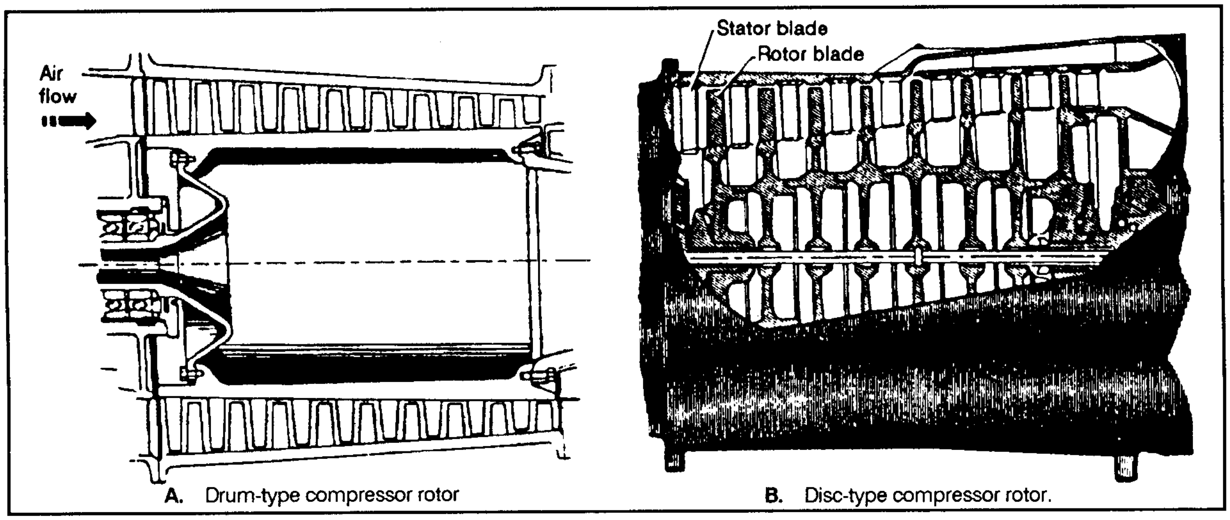
They have the following disadvantages:

- Large frontal area for given airflow.
- Impracticality if more than two stages because of losses in turns between stages.

Axial-Flow Compressor

Axial-flow compressors have have main elements a rotor (drum or disc type) and a stator. These compressors are constructed of several different materials depending on the load and operating temperature. The drum-type rotor consists of rings that are flanged to fit one against the other so that the entire assembly can be held together by through bolts. This type of construction is satisfactory for low-speed compressors where centrifugal stresses are low (Figure-3-7). The rotor (disc-type) assembly consists of—

- Stub shafts.
- Discs.
- Blades.
- Ducts.
- Air vortex spoilers.
- Spacers.
- Tie bolts.
- Torque cones.



A. Drum-type compressor rotor

B. Disc-type compressor rotor.

Figure 3-7. Axial-Flow Compressors

Rotor blades are generally machined from stainless steel forgings, although some maybe made of titanium in the forward (colder) section of the compressor (Figure 3-8). The blades are attached in the disc rim by different methods using either the fir-tree-type, dovetail-type, or bulb-type root designs. The blades are then locked into place with screws, peening, locking wires, pins, keys, or plates (Figure 3-9). The blades do not have to fit too

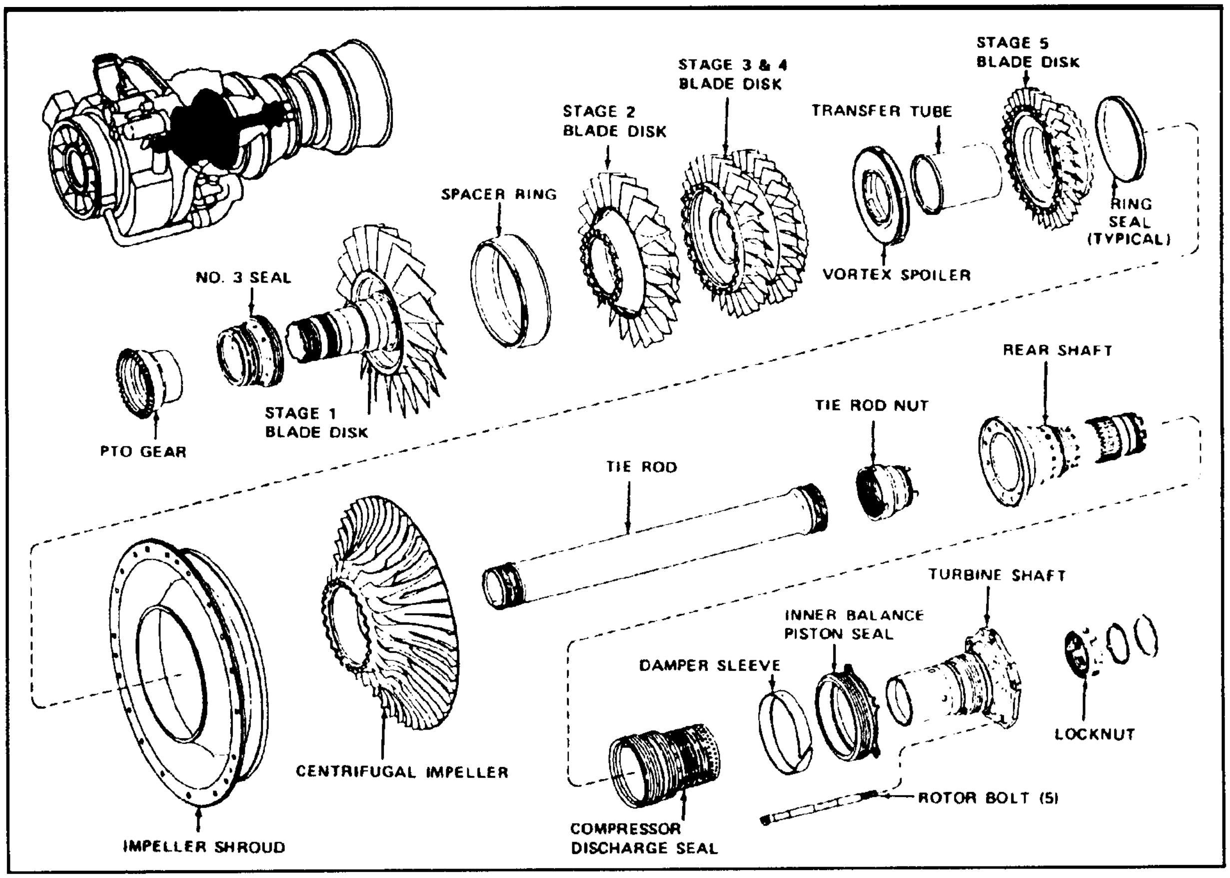


Figure 3-8. Axial-Flow Compressor Components

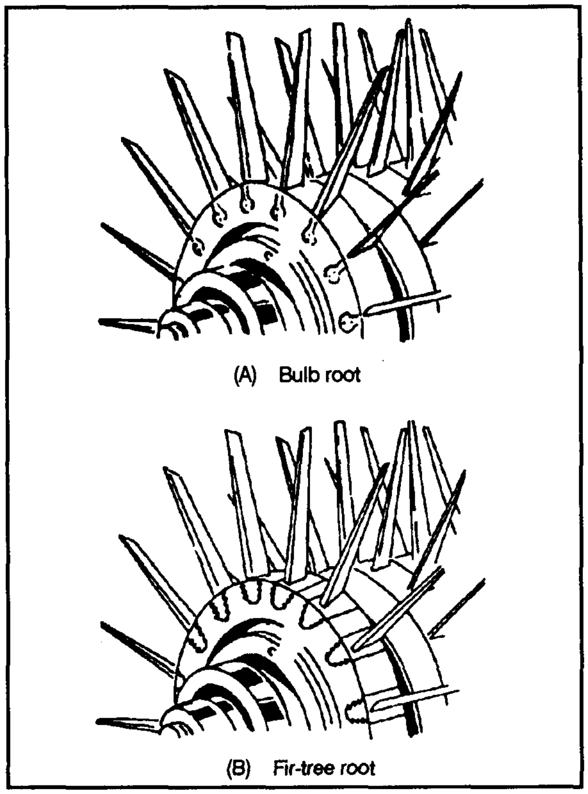


Figure 3-9. Common Retention Methods Used on Compressor Rotor Blades

tightly in the disc because centrifugal force during engine operation causes them to seat. Allowing the blades some movement reduces the vibrational stresses produced by high-velocity airstreams between the blades. The newest advance in technology is a one-piece design machined blade disc (combined disc and blade);both disc and rotor blade are forged and then machined into one (refer to Figure 3-8 again).

Clearances between rotor blades and the outer case are very important to maintain high efficiency. Because of this, some manufacturers use a "wear fit" design between the blade and outer case. Some companies design blades with knife-edge tips that wear away to form their own clearances as they expand from the heat generated by air compression. Other companies coat the inner surface of the compressor case with a soft material (Teflon) that can be worn away without damaging the blade. Rotor discs that are joined together by tie bolts use serration splines or curve coupling teeth to prevent the discs from turning in relation to each other. Another method of joining rotor discs is at their rims.

Axial-flow compressor casings not only support stator vanes and provide the outer wall of the axial paths the air follows but also provide the means for extracting compressor air for various purposes. The stator and compressor cases show great differences in design and construction. Some compressor cases have variable stator vanes as an additional feature. Others (compressor cases) have fixed stators. Stator vanes may be either solid or hollow and mayor may not be connected at their tips by a shroud. The shroud serves two purposes. First, it provides support for the longer stator vanes located in the forward stages of the compressor second, it provides the absolutely necessary air seal between rotating and stationary parts. Some manufacturers use split compressor cases while others favor a weldment, which forms a continuous case. The advantage of the split case is that the compressor and stator blades are readily available for inspection or maintenance. On the other hand the continuous case offers simplicity and strength since it requires no vertical or horizontal parting surface.

Both the case and the rotor are very highly stressed parts. Since the compressor turns at very high speeds the discs must be able to withstand very high certrifugal forces. In addition the blades must resist bending loads and high temperatures. When the compressor is constructed each stage is balanced as a unit. The compressor case in most instances is one of the principal structural, load-bearing members of the engine. It may be constructed of aluminum steel, or magnesium.

Axial-flow compressors have the following advantages:

- High peak efficiency.
- Small frontal area forgiven airflow.
- Straight-through flow, allowing high ram efficiency.
- Increased pressure rise due to increased number of stages with negligible losses.

They have the following disadvantages:

- Good efficiency over narrow rotational speed range.
- Difficulty of manufacture and high cost.
- Relatively high weight.
- High starting power requirements (this has been partially overcome by split compressors).

The air in an axial compressor flows in an axial direction through a series of rotating (rotor) blades and stationary (stator) vanes that are concentric with the axis of rotation. Unlike a turbine, which also employs rotor blades and stator vanes the flow path of an axial compressor decreases in cross-sectional area in the direction of flow. This reduces the volume of air as compression progresses from stage to stage.

After being delivered to the face of the compressor by the air inlet duct incoming air passes through the inlet guide vanes. Upon entering the first set of rotating blades, the air, which is flowing in a general axial direction is deflected in the direction of rotation. The air is arrested and turned as it is passed on to a set of stator vanes. Following that it is picked up by another set of rotating blades and soon through the compressor. Air pressure increases each time it proses through a set of rotors and stators.

The rotor blades increase the air velocity. When air velocity increases, the ram presure of air passing through a rotor stage also increases. This increase in velocity and pressure is somewhat but not entirely mullified by diffusion. When air is forced past the thick sections of the rotor blades static pressure also increases. The larger area at the rear of the blades (due to its airfoil shape) acts as a diffuser.

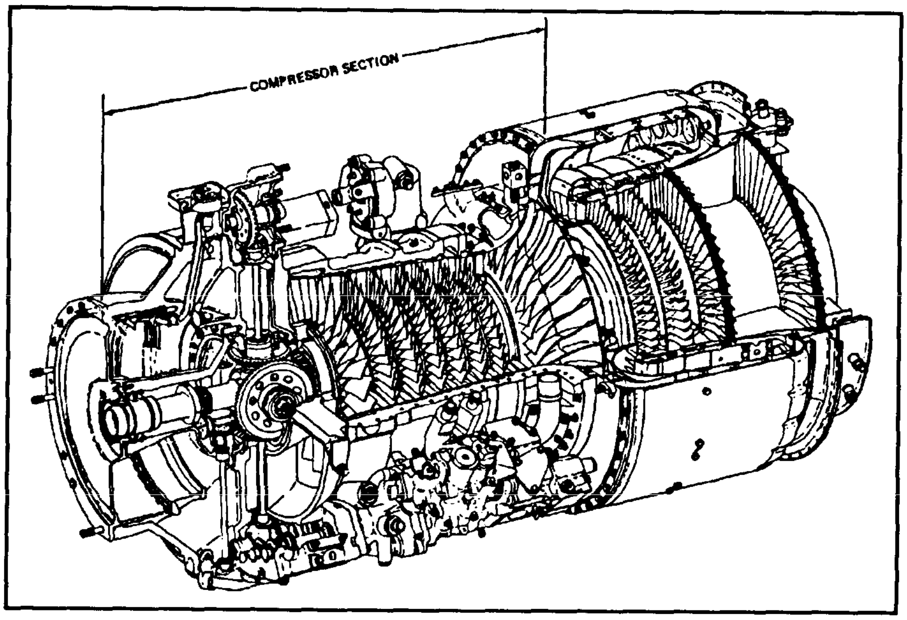
In the stators velocity decreases while static pressure increases. As air velocity decreases, the pressure due to velocity or ram that has just been gained in Passing through preceding rotor stage decreases somewhat; however, the total pressure is the sum of static pressure and pressure due to ram. Successive increases and decreases in velocity as air leaves the compressor are usually only slightly greater than the velocity of the air at the entrance to the compressor. As the pressure is built up by successive sets of rotors and stators, less and less volume is required. Thus, the volume within the compressor is gradually decreased. At the exit of the compressor, a diffuser section adds the final stage to the compression process by again decreasing velocity and increasing static pressure just before the air enters the engine burner section.

Normally, the temperature change caused by diffusion is not significant by itself. The temperature rise which causes air to get hotter and hotter as it continues through the compressor, is the result of the work being done on the air by the compressor rotors. Heating of the air occurs because of the compression process and because some of the mechanical energy of the rotor is converted to heat energy.

Because airflow in an axial compressor is generally diffusing it is very unstable. High efficiency is maintained only at very small rates of diffusion. Compared to a turbine, quite a number of compressor stages are needed to keep the diffusion rate small through each individual stage. Also, the permissible turning angles of the blades are considerably smaller than those which can be used in turbines. These are the reasons why an axial compressor must have many more stages than the turbine which drives it. In addition, more blades and consequently more stages are needed because the compressor, in contrast to a turbine, is endeavoring to push air in a direction that it does not want to go in.

Dual Compressor

The dual compressor is a combination either of two axial compressors or of an axial and a centrifugal compressor (Figure 3-10). The dual-axial compressor consists of



a low-pressure compressor in front and a high-pressure compressor in the rear. Both compressors(lowand high) are driven by two different shafts that connect to different turbines. The starter is usually connected to the high-pressure compressor because it reduces the torque required to start the engine. With the rear (high-pressure) compressor turning at governed speed, the front (low-pressure) compressor (not governed) is automatically rotated by its turbine. Rotation speed is whatever speed will ensure an optimum flow of air through the compressor. With the front and rear compressor rotors working in harmony instead of interfering with each other, compression rates can be increased without decreasing efficiency. Due to the added length of the engine this type of compressor is found on turbojet aircraft.

Most gas turbines in Army aircraft have a combination of an axial compressor (front) and a centrifugal compressor (rear). The usual combination is a five- or seven-stage axial- flow compressor and a centrifugal-flow compressor. The axial compressor and centrifugal compressor combination is mounted on the same shaft; the compressors turn in the same direction and at the same speed. By combining the the manufacturer makes the most of the advantages of both compressors small frontaI area, increased compression ratios, and shortened overall engine length. Using the centrifugal-flow compressor boosts compression and increases efficiency of the turbine engine. The centrifugal compressor also shortens the length of the engine. If the centrifugal compressor were not added, the manufacturer would have to add more stages of axial compression to equal that of the centrifugal compressor.

COMBUSTION SECTION

The combustion section contains the combustion chambers, igniter plugs, and fuel nozzle or fuel injectors. It is designed to burn a fuel-air mixture and to deliver combusted gases to the turbine at a temperature not exceeding the allowable limit at the turbine inlet. Theoretically, the compressor delivers 100 percent of its air by volume to the combustion chamber. However, the fuel-air mixture has a ratio of l5 parts air to l part fuel by weight. Approximately 25 percent of this air is used to attain the desired fuel-air ratio. The remaining 75 percent is used to form an air blanket around the burning gases and to dilute the temperature, which may reach as high as 3500°F, by approximately one-half. This ensures that the turbine section will not be destroyed by excessive heat.

The air used for burning is known as primary air; that used for cording is secondary air. Secondary air is controlled and directed by holes and louvers in the combustion chamber liner. Igniter plugs function during starting only; they are shut off manually or automatically. Combustion is continuous and self-supporting. After engine shutdown or failure to start, a pressure-actuated valve automatically drains any remaining unburned fuel from the combustion chamber. The most common type used in Army gas turbine engines is the external annular reverse-flow type.

The primary function of the combustion section is, of course, to bum the fuel-air mixture, thereby adding heat energy to the air. To do this efficiently, the combustion chamber must–

- Provide the means for mixing the fuel and air to ensure good combustion.
- Bum this mixture efficiently.
- Cool the hot combustion products to a temperature which the turbine blades can withstand under operating conditions.
- Deliver the hot gases to the turbine section.

The location of the combustion section is directly between the compressor and turbine sections. The combustion chambers are always arranged coaxially with the compressor and turbine, regardless of type, since the chambers must be in a through-flow position to function efficiently.

All combustion chambers contain the same basic elements:

- A casing
- A perforated inner liner.
- A fuel injection system.
- Some means for initial ignition.
- A fuel drainage system to drain off unburned fuel after engine shutdown.

There are currently three basic types of combustion chambers, varying in detail only:

- The multiple-chamber or can type.
- The annular or basket type.
- The can-annular type.

Can-Type Combustion Chamber

The can-type combustion chamber is typical of the type used on both centrifugal and axial-flow engines (Figure 3-11). It is particularly well suited for the centrifugal compressor engine since the air leaving the compressor is already divided into equal portions as it leaves the diffuser vanes. It is then a simple matter to duct the air from the diffuser into the respective combustion chambers arranged radially around the axis of the engine. The number of chambers will vary; in the past as few as 2 and as many as 16 chamber's have been used. The present trend is about 8 or 10 combustion chambers. Figure 3-11 illustrates the arrangement of can-type combustion chambers. On American-built engines these chambers are numbered in a clockwise direction facing the rear of the engine with the No. 1 chamber at the top.

Each can-type combustion chamber consists of an outer case or housing with a perforated stainless steel (highly heat-resistant) combustion chamber liner or inner liner (Figure 3-12). The outer case is divided for ease of

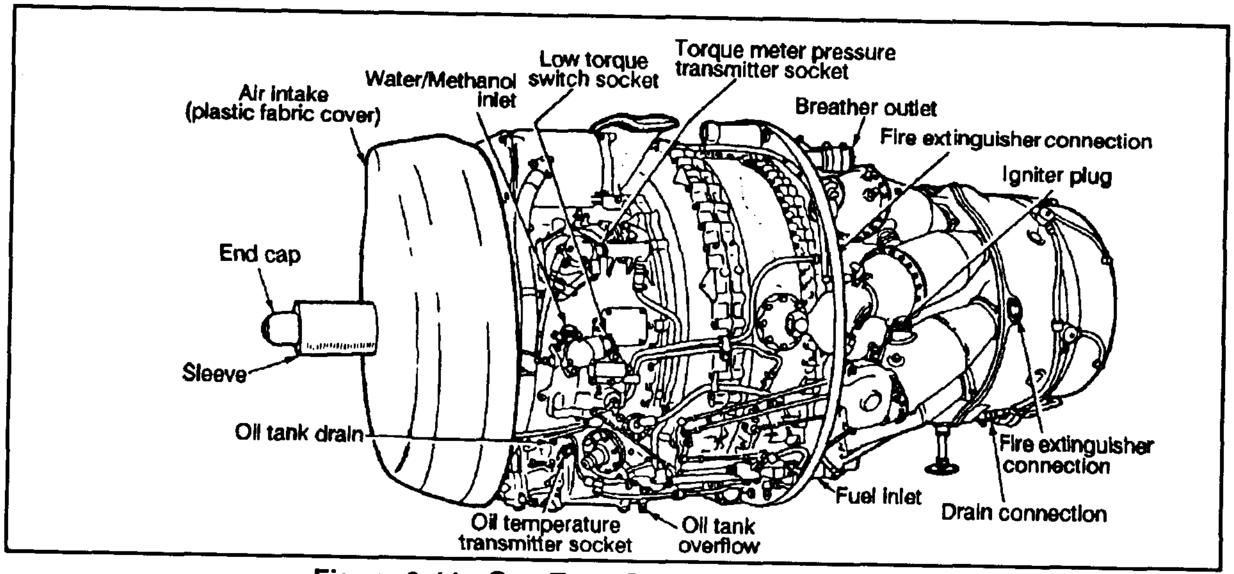


Figure 3-11. Can-Type Combustion Chamber

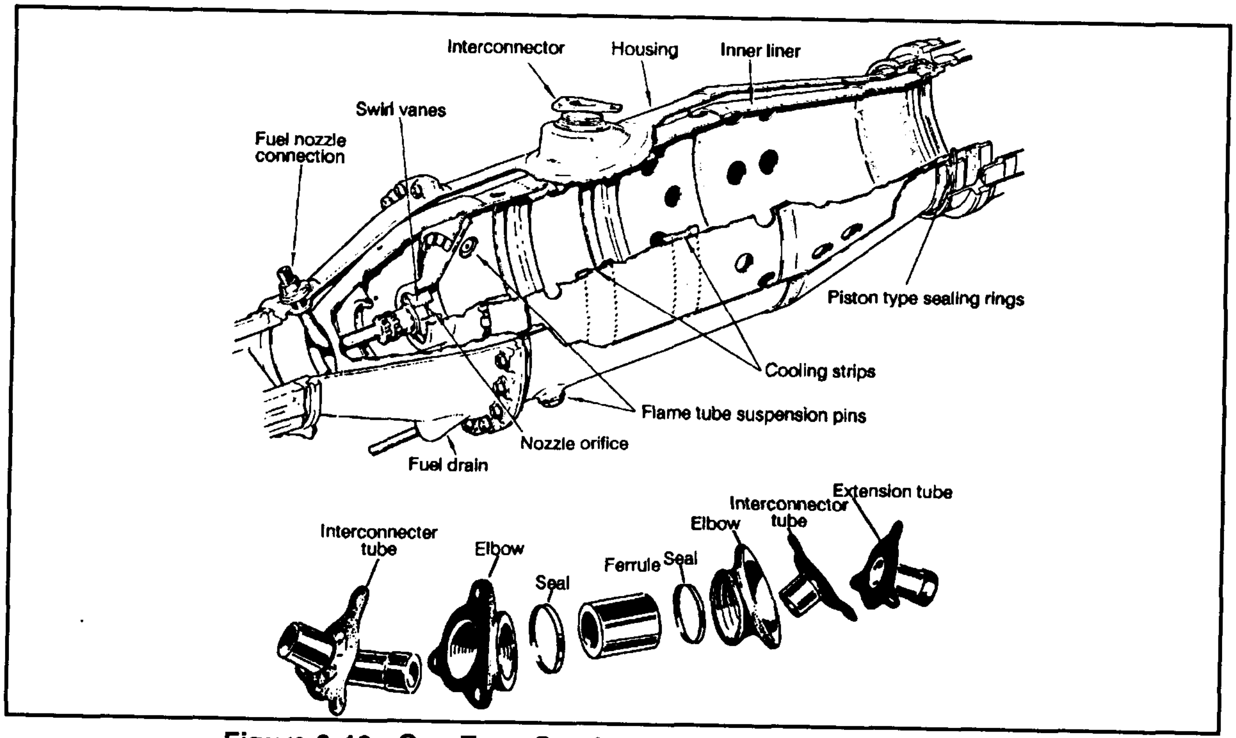


Figure 3-12. Can-Type Combustion Chamber Components

liner replacement. The larger section or chamber body encases the liner at the exit end; the Smaller chamber cover encases the front or inlet end of the liner.

The interconnector (flame propagation) tubes area necessary part of can-type combustion chambers. Since each can is a separate burner operating independently of the others, there must be some way to spread combustion during the initial starting operation. This is done by interconnecting all the chambers. The flame is started by the spark igniter plugs in two of the lower chambers; it passes through the tubes and ignites the combustible mixture in the adjacent chamber. This continues until all chambers are burning. The flame tubes will vary in construction details from one engine to another although the basic components are almost identical.

The interconnector tubes are shown in Figure 3-12. Bear in mind that not only must the chambers be interconnected by an outer tube (in this case, a ferrule), but there must also be a slightly longer tube inside the outer one to interconnect the chamber liners where the flame is located The outer tubes or jackets around the interconnecting flame tubes not only afford airflow between the chambers but also fulfill an insulating function around the hot flame tubes.

The spark igniters are normally two in number. They are located in two of the can-type combustion chambers.

Another very important requirement in the construction of combustion chambers is providing the means for draining unburned fuel. This drainage prevents gum deposits in the fuel manifold, nozzles, and combustion chambers. These deposits are caused by the residue left when fuel evaporates. If fuel is allowed to accumulate after shutdown there is the danger of afterfire.

If the fuel is not drained, a great possibility exists that at the next starting attempt excess fuel in the combustion chamber will ignite and tailpipe temperature will go beyond safe operating limits.

The liners of can-type combustors have perforations of various sizes and shapes, each hole having a specific purpose and effect on flame propagation in the liner. Air entering the combustion chamber is divided by holes, louvers, and slots into two main streams – primary and secondary air. Primary (combustion) air is directed inside the liner at the front end where it mixes with the fuel and bums. Secondary (cooling) air passes between the outer casing and the liner and joins the combustion gases through larger holes toward the rear of the liner, cooling the combustion gases from about 3500ºF to near 1500ºF. Holes around the fuel nozzle in the dome or inlet end of the can-type combuster liner aid in atomization of the fuel. Louvers are also provided along the axial length of the liners to direct a cooling layer of air along the inside wall of the liner. This layer of air also tends to control the flame pattern by keeping it centered in the liner, preventing burning of the liner walls.

Annular- or Basket-Type Combustion Chamber

Figure 3-13 illustrates the flow of air through the louvers in the double-annular combustion chamber.

Some provision is always made in the combustion chamber case or in the compressor air outlet elbow for installation of a fuel nozzle. The fuel nozzle delivers the fuel into the liner in a freely atomized spray. The freer the spray, the more rapid and efficient the burning process. Two types of fuel nozzles currently being used in the various types of combustion chambers are the simplex nozzle and the duplex nozzle.

The annular combustion chamber consists basically of a housing and a liner, as does the can type. The liner consists of an undivided circular shroud extending all the way around the outside of the turbine shaft housing. The chamber may be constructed of one or more baskets. If two or more chambers are used, one is placed outside the other in the same radial plane; hence, the term "double-anmular chamber."

The spark igniter plugs of the annular combustion chamber are the same basic type used in the can combustion chambers, although construction details may vary. There are usually two plugs mounted on the boss provided on each of the chamber housings. The plugs must be long enough to protrude from the housing into the outer annulus of the double-annular combustion chamber.

The annular-type combustion chamber is used in many engines designed to use the axial-flow compressor. It is also-used by engines incorporating dual-type compressors (combinations of axial flow and centrifugal flow). Its use permits building an engine of small diameter. Instead of individual combustion chambers, the compressed air is introduced into an annular space formed by a combustion chamber liner around the turbine shaft. Usually, enough space is left between the outer liner wall and the combustion chamber housing to permit the flow of cooling air from the compressor. Fuel is introduced through nozzles or injectors connected to a fuel manifold. The nozzle opening may face upstream or downstream to airflow depending on engine design. Various means are provided to introduce primary (compressed) air to

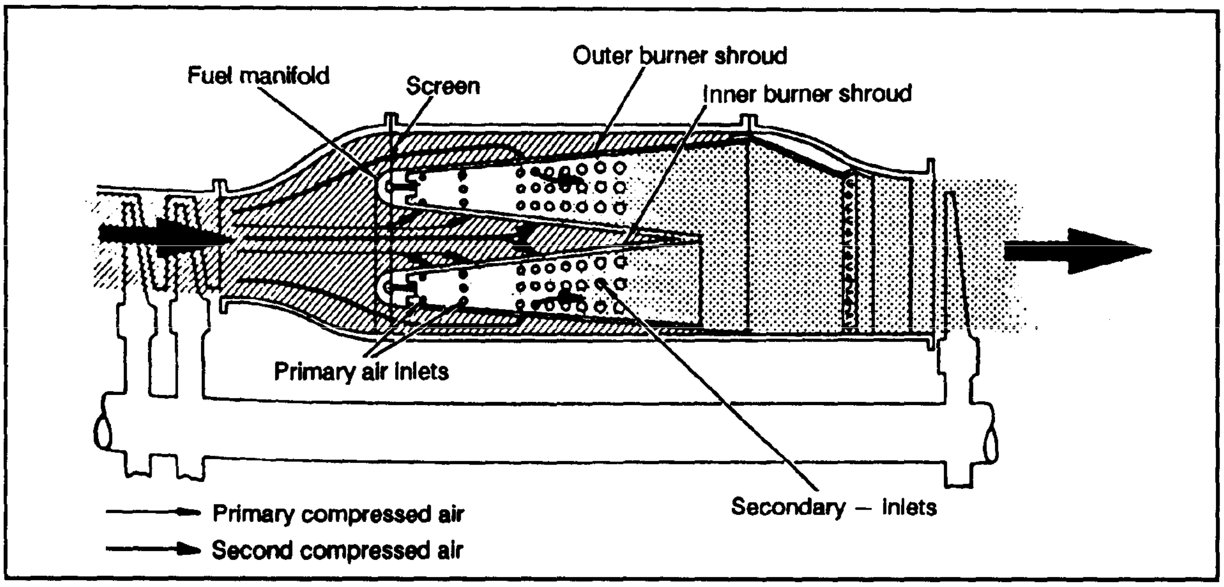


Figure 3-13. Components and Airflow of a Double-Annular Chamber

the vicinity of the nozzle or injectors to support combustion and additional air dowmstream to increase the mass flow. Secondary cooling air reduces the temperature of gases entering the turbine to the proper level,

Some axial compressor engines have a single annular combustion chamber similar to that shown in Figure 3-14. The liner of this type of burner consists of continuous, circular, inner and outer shrouds around the outside of the compressor drive shaft housing. Holes in the shrouds allow secondary cooling air to enter the center of the combustion chamber. Fuel is introduced through a series of nozzles at the upstream end of the liner. Because of their proximity to the flames all types of burner liners are short-lived in comparison to other engine components; they require more frequent inspection and replacement.

This type of burner uses the limited space available most effectively, permitting better mixing of the fuel and air within a relatively simple structure. An optimum ratio of burner inner surface area to volume is provided; this ensures maximum cooling of the gases as combustion occurs. The design also tends to prevent heat warping However, the burner liner on some engines cannot be disassembled without removing the engine from the aircraft – a distinct disadvantage.

The latest annular combustion system for military use is a low-pressure fuel injection system with vortex air swirlers to mix fuel and compressor discharge air before combustion. The fuel injector is positioned into the center of an air swirler in the dome of the liner. Fuel leaving the injectors (which has been swirled) is surrounded by a concentric air vortex pattern. **This** breaks fuel particles down to an extremely small size before they reach the combustion zone, This creates excellent fuel-air mixing that ensures a low smoke level in the exhaust. The low-pressure fuel system does not have tine nozzle orifices and can handle contaminated fuel without clogging.

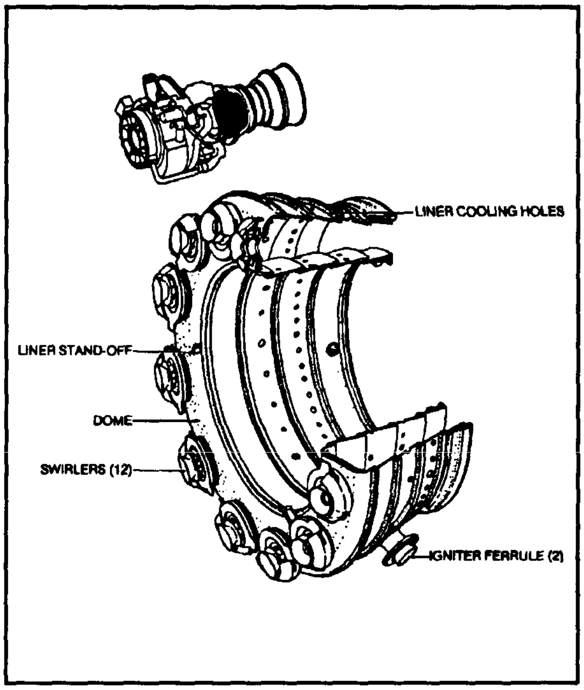


Figure 3-14. Annular Combustion Chamber Components

Can-Annular-Type Combustion Chamber

The can-annular-type combustion chamber was developed by Pratt and Whitney for use in their JT3 axial-flow turbojet engine. Since this engine features the split-spool compressor, it needed a combustion chamber capable of meeting the stringent requirements of maximum strength and limited length plus high overall efficiency. These were necessary because of the high air pressures and velocities in a split-spoolcompresmr along with the shaft length limitations explained below.

The split compressor requires two concentric shafts to join the turbine stages to their respective compressors. The front compressor joined to the rear turbine stages requires the longer shaft. Because this shaft is inside the other, a limitation is imposed on diameter. The distance between the front compressor and the rear turbine must be limited if critical shaft lengths are to be avoided.

Since the compressor and turbine are not susceptible to appreciable shortening the necessary shaft length limitation had to be absorbed by developing a new type of burner. A design was needed that would give the desired performance in much less relative distance than had previously been assigned.

Can-annular combustion chambers are arranged radially around the axis of the engine in this instance the rotor shaft housing. The combustion chambers are enclosed in a removable steel shroud that covers the entire burner section. This feature makes the burners readily available for any required maintenance.

The burners are interconnected by projecting flame tubes. These tubes make the engine-starting process easier. They function identically with those previously discussed but differ in construction details.

Each combustion chamber contains a central bullet-shaped perforated liner. The size and shape of the holes are designed to admit the correct quantity of air at the correct velocity and angle. Cutouts are provided in two of the bottom chambers for installation of the spark igniters. The combustion chambers are supported at the aft end by outlet duct clamps. These clamps secure them to the turbine nozzle assembly.

The forward face of each chamber presents six apertures which align with the six fuel nozzles of the corresponding fuel nozzle duster. These nozzles are the dual-orifice (duplex) type. They require a flow divider (pressurizing valve) as was mentioned above in the can-type combustion chamber discussion. Around each nozzle are preswirl vanes for imparting a swirling motion to the fuel spray. This results in better atomization burning- and efficiency.

Swirl vanes perform two important functions. They cause—

- High flame speed-provides better nixing of air and fuel and ensures spontaneous burning.
- Low air velocity axially-swirling prevents the flame from moving axially too rapidly.

Swirl vanes greatly aid flame propagation because a high degree of turbulence in the early combustion and cooling stagea is desirable. Virous mechanical mixing of fuel vapor with primary air is necessary; mixing by diffusion alone is too slow. Mechanical mixing is also done by other measure; for example,placingcoarse screens in the diffuser outlet as is done in most axial-flow engines.

Can-annular combustion chambers must also have fuel drain valves in two or more of the bottom chambers. This ensures drainage of residual fuel to prevent its being burned at the next start.

The flow of air through the holes and louvers of the can-annular chambers is almost identical with the flow through other types of burners. Special baffling is used to swirl the combustion airflow and to give it turbulence.

Performance Requirements

Performance requirements include–

- High combustion efficiency. This is necessary for long range.
- Stable operation. Combustion must be free from blowout at airflows ranging from idle to maximum power and at pressures representing the aircraft’s entire altitude range.
- Low pressure loss. It is desirable to have as much pressure as possible available in the exhaust nozzle to accelerate the gases rearward High pressure losses will reduce thrust and increase specific fuel consumption.
- Uniform temperature distribution. The average temperature of gases entering the turbine should be as close as possible to the temperature limit of the burner material to obtain maximum engine performance. High local temperatures or hot spots in the gas stream will reduce the allowable average turbine inlet temperature to protect the turbine. This will result in a decrease in total gas energy and a corresponding decrease m engine performance.
- Easy starting. Lowpressures and high velocities in the burner make starting difficult. A poorly designed burner will start only within a small

range of light speeds and altitudes, whereas a well designed burner will permit easier air restarts.

- Small size. A large burner requires a large engine housing with a corresponding increase in the airplane's frontal area and aerodynamic drag. This will result in a decrease in maximum flight speed Excessive burner size also results in high engine weight, lower fuel capacity and payload, and shorter range. Modem burners release 500 to 1000 times the heat of a domestic oil burner or heavy industrial furnace of equal unit volume. Without this high heat release the aircraft gas turbine could not have been made practical.
- Low-smoke burner. Smoke not only annoys people on the ground, it may also allow easy tracking of high-flying military aircraft.
- Low carbon formation. Carbon deposits can block critical air passages and disrupt airflow along the liner walls, causing high metal temperatures and low burner life.

All of the burner requirements must be satisfied over a wide range of operating conditions. For example, airflows may vary as much as 50:1, fuel flows as much as 30:1, and fuel-air ratios as much as 5:1. Burner pressures may cover a ratio of 100:1, while burner inlet temperatures may vary by more than 700°F.

The effect of operating variables on burner performance is—

- Pressure.
- Inlet air temperature.
- Fuel-air ratio.
- Flow velocity.

TURBINE SECTION

All turbines in modern jet engines, regardless of the type of compress used, are of of axial-flow design. They consist of one or more stages located immediately to the rear of the engine burner section. Turbines extract kinetic energy from the expanding gases as the gases come from the burners. They convert this energy in to shaft horsepower to drive the compressor and engine accessories. In a turboshaft or turboprop engine one or more turbines will also furnish the power required to turn the engine drive or propeller shaft. Nearly three-fourths of all of the energy available from combustion is needed to drive the compressor or compressors in the case of a dual-compressor engine. This includes the fan of a turbofan engine. If the engine is a turboshaft or turboprop, the turbines are designed to extract as much energy as possible from the gases passing through the engine. So efficient are the turbines in such engines that the propeller in a turboprop aircraft provides approximately 90 percent of the propulsive force with only 10 percent supplied by jet thrust.

The axial-flow turbine has two main elements: turbine rotors (or wheels, as they are sometimes called) and stationary vanes. The stationary part of the assembly consists of a plane of contoured vanes, concentric with the axis of the turbine and set at an angle to form a series of small nozzles. These nozzles discharge the gases onto the blades in the turbine rotors. The stationary vane assembly of each stage in the turbine is usually referred to as the turbine nozzle guide vanes. The turbine nozzle area is the most critical part of the turbine design. If the nozzle area is too large, the turbine will not operate at its best efficiency. If the area is too small the nozzle will have **a** tendency to choke and lose efficiency under maximum thrust conditions. The turbine nozzle area is defined as the total cross-sectional area of the exhaust gas passages at their narrowest point through the turbine nozzle. It is calculated by measuring and adding the areas between individual nozzle guide vanes.

There are three types of turbines: impluse reaction and a combination of these two known as reaction-impulse. In the impulse type there is no net change in pressure between the rotor inlet and the rotor exit. The blade's relative discharge velocity will be the same as its relative inlet velocity. The nozzle guide vanes are shaped to form passages which increase the velocity and reduce the pressure of the escaping gases. In the reaction type, the nozzle guide vanes do little more in relation to the rotor than alter flow direction. The decrease in pressure and increase in velocity of gases are caused by the convergent shape of the passage between the rotor blades. In a jet engine the turbine is usually a balanced combination of both types known as a reaction-impulse turbine. Its design is intended to achieve both a small diameter and a proper match with the compressor.

Turbines may be either single or multiple stage. When the turbine has more than one stage, stationary vanes are inserted between each rotor wheel and the rotor wheel downstream. They are also placed at the entrance and exit of the turbine unit. Each set of stationary vanes forms a nozzle-vane assembly for the turbine wheel that follows. The exit set of vanes serves to straighten the gas flow before passage through the jet nozzle. The wheels may or may not operate independently of one another, depending on engine type and turbine power requirements.

Shaft RPM, gas flow rate, turbine inlet and outlet temperature and pressure, turbine exhaust velocity, and required power output must all be considered by the designer of the turbine. If the engine is equipped with a dual compressor, the turbine must also be dual or "split." In this event, the forward part of the turbine (which drives the high-pressure compressor) can be single-stage because it receives high-energy gases directly from the burner and turns at a higher RPM than the turbine for the low-presssure compressor. By the time the gases reach the rear part of the turbine (which drives the low-pressure compressor), they have expanded. Considerably more blade area is needed if work or energy balance is to be maintained. To do a multistage turbine is used for the second part of the turbine (Figure 3-15). high expansion ratio. This results in a large temperature drop in gases passing through the turbine and a cool turbine exhaust. If the engine is equipped with an afterburner, a cool exhaust enables more fuel to be burned in the afterburner without exceeding the temperature limit of the construction materials used in the afterburner.

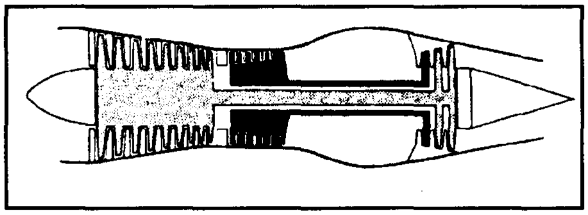


Figure 3-15. Dual-Rotor Turbine for Split-Spool Compressor

The turbine wheel is a dynamically balanced unit consisting of super alloy blades attached to a rotating disc. The base of the blade is usually a "fir tree" design to enable it to be firmly attached to the disc and still allow room for expansion. In some turbines the rotating blades are open at their outer perimeter. More commonly, the blade is shrouded at the tip. The shrouded blades form a band around the perimeter of the turbine wheel, which serves to reduce blade vibrations. The weight of the shrouded tips is offset because the shrouds permit thinner, more efficient blade sections than are otherwise possible because of vibration limitations. Also, by acting in the same manner as aircraft wing tip fences, the shrouds improve the airflow characteristics and increase the efficiency of the turbine. The shrouds also serve to cut down gas leakage around the tips of the turbine blades.

Turbines are subjected to high speeds and high temperatures. High speeds result in high centrifugal forces. Turbines must operate close to temperature limits that, if exceeded, lower the strength of the materials they are constructed of. Turbine blades undergo distortion or lengthening known as "creep." Creep means that the blade stretches or elongates. This condition is cumulative. The rate of creep is determined by the load imposed on the turbine and the strength of the blade. The strength of the blade is determined by the temperature within the turbine. Since changes in pitch and creep are more pronounced if engine operating limits are not respected the pilot or flight engineer must closely observe the temperature and RPM limits stipulated by the manufacturer.

Construction

The turbine wheel is one of the most highly stressed engine parts. Not only must it operate at temperatures up to approximately 1700°F, but it must do sounder severe centrifugal loads imposed by high rotational speeds of over 40,000 RPM for small engines and 8000 RPM for larger ones. Consequently, engine speed and turbine inlet temperature must be accurately controlled to keep the turbine within safe operating limits.

The turbine assembly is made of two main parts: the disc and blades. This disc or wheel is a statically and dynamically balanced unit of specially alloyed steel. It usually contains large percentages of chromium, nickel, and cobalt. After forging, the disc is machined all over and carefully inspected using X rays, magnetism, and other inspection methods for structural integrity. The blades or buckets are attached to the disc by means of a fir tree design to allow for different rates of expansion between the disc and the blade while still holding the blade firmly against centrifugal loads. The blade is kept from moving axially either by rivets, special locking tabs or devices, or another turbine stage.

Some turbine blades are open at the outer perimeter (Figure 3-16); in others a shroud is used. The shroud acts to prevent blade-tip losses (gas leakage around the tips of the turbine blade) and excessive vibration. By acting in the same manner as aircraft wing tip fence, the shrouds improve airflow characteristics and increase turbine efficiency.

Shrouds reduce resistance to distortion under high loads, which tend to twist the blade toward low pitch. The shrouded blade has an aerodynamic advantage; thinner blade sections can be used and tip lines can be reduced by using a knife-edge or labyrinth seal at this point.

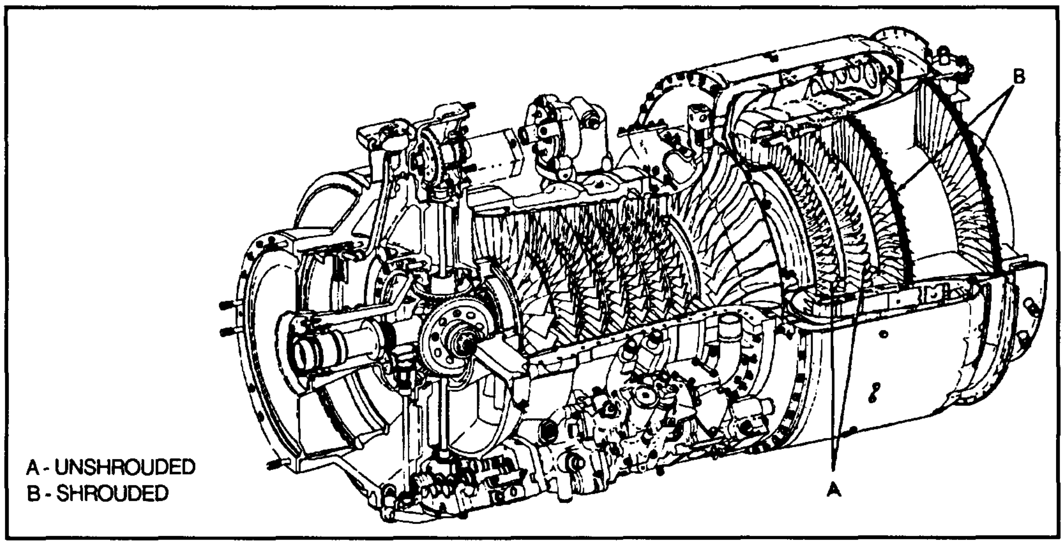


Figure 3-16. Turbine Blade Tips

Shrouding however, **requires that the** turbine run cooler or at reduced RPM because of the extra mass at the tip. On blades that are not shrouded, the tips are cut or recessed to a knife-edge to permit a rapid "wearing-in" of the blade tip to the turbine casing with am-responding increase in turbine efficiency.

Blades are forged from highly alloyed steel. They are carefully machined and inspected before being certified for use. Many engine manufacturers will stamp a moment weight number on the blade to retain rotor balance when replacement is necessary.

Another method for increasing efficiency is the use of honeycomb shrouding (Figure 3-17). This shroud works as a labyrinth sealing the unshrouded turbine tips. These shrouds are all housed by a stator support, which, in turn, is supported by the engine outer casing. This design is currently in use in the new General Electric turboshaft engines.

Nozzle vanes may be either case or forged. Some vanes are hollow (Figure 3-18) to allow a degree of cooling by compressor bleed air. In all cases the nozzle assembly is made of very high-temperature, high-strength steel to withstand the direct impact of the hot high-pressure, high-velocity gas flowing from the combustion chamber.

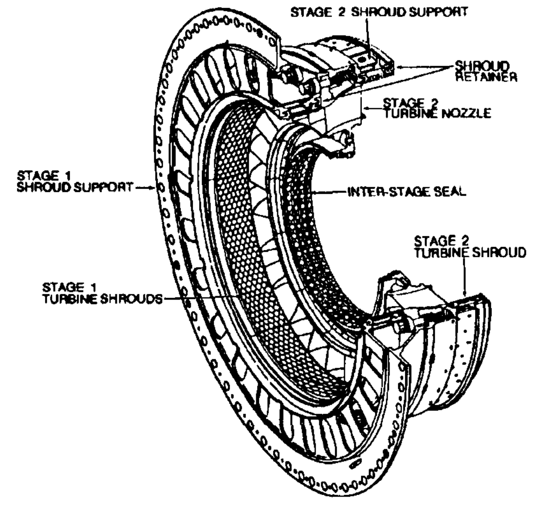


Figure 3-17. Honeycomb Shroud

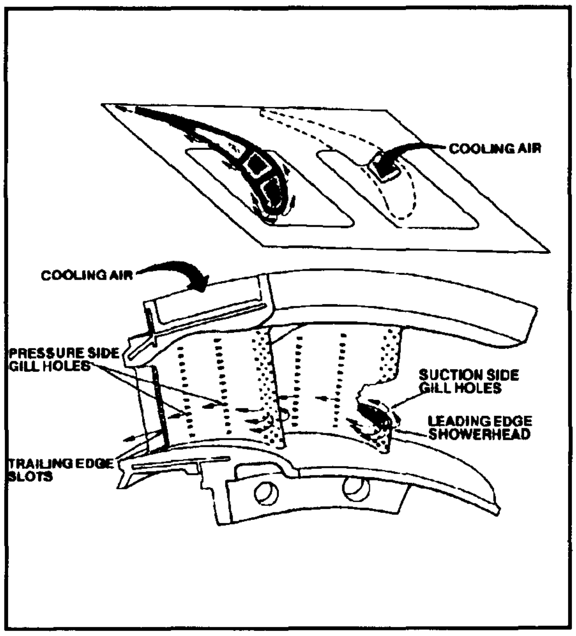


Figure 3-18. Turbine Nozzle Cooling

Some manufacturers are experimenting with transpiration-cooled nozzle and turbine blading in which the airflows through thousands of small holes in a porous airfoil made from a sintered wire mesh material (Figure 3-19). The performance of the gas turbine engine depends largely on the temperature at the inlet. Increasing this temperature from the present limit of about 1750°F to the 2500°F possible with transpiration-cooled blades will result in about a 100 percent increase in specific horsepower. Transpiration cooling may be a promising development in gas turbine design.

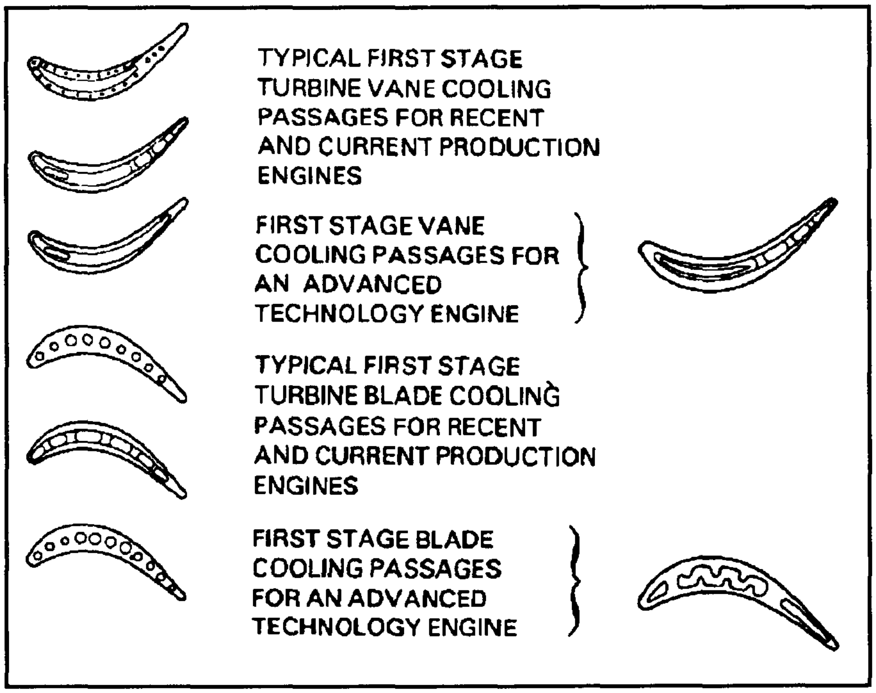


Figure 3-19. Examples of Typical Transpiration-Cooling Blades

Cooling

Design engineers use every device at their command to increase the allowable inlet temperature. On practically all large engines, one such device is to cool the fret-stage turbine inlet guide vanes and the first-stage rotor blades. This is done by conducting compressor bleed air through passages inside the engine to the turbine area. There, the air (the coolant) is led to the longitudinal holes, tubes or cavities in the first-stage vanes and blades.

After entering the vane and blade passages, the air (coolant) is distributed through holes at the leading and trailing edges of the vanes and blades. The air impinges along the vane and blade surfaces and then passes out of the engine with the exhaust. Although bleed air coming from the compressor may be hot, it is cool in relation to the temperature at the turbine inlet. This air, therefore serves to cool the vanes and blades. This permits gases coming from the burner section to enter the turbine at higher temperatures than would otherwise be permissible. Cooling is necessary only in the turbine inlet area because enough energy is extracted from the exhaust gases by the first or first and second stages of the turbine to reduce the temperature to a tolerable level.

EXHAUST SECTION

The term “exhaust duet” applies to the engine exhaust pipe or tail pipe including the jet nozzle of a non-after-burning engine (Figure 3-20). Altough an afterburner might also be considered a type of exhaust duct, after burning is a subject in itself.

If the engine exhaust gases could be discharged directly to the outside air in an exact axial direction at the turbine exit, an exhaust duct might not be necessary. This, however, is not practical. A larger total thrust can be obtained from the engine if the gases are discharged from the aircraft at a higher velocity than that permissible at the turbine outlet. An exhaust duct is added to collect and straighten the gas flow as it comes from the turbine. It also increases the velocity of the gases before they are discharged from the exhaust nozzle at the rear of the duct. Increasing gas velocity increases its momentum and the thrust produced.

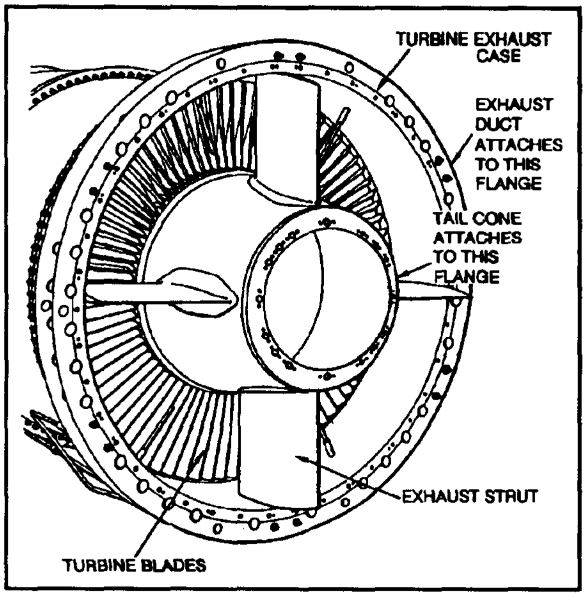
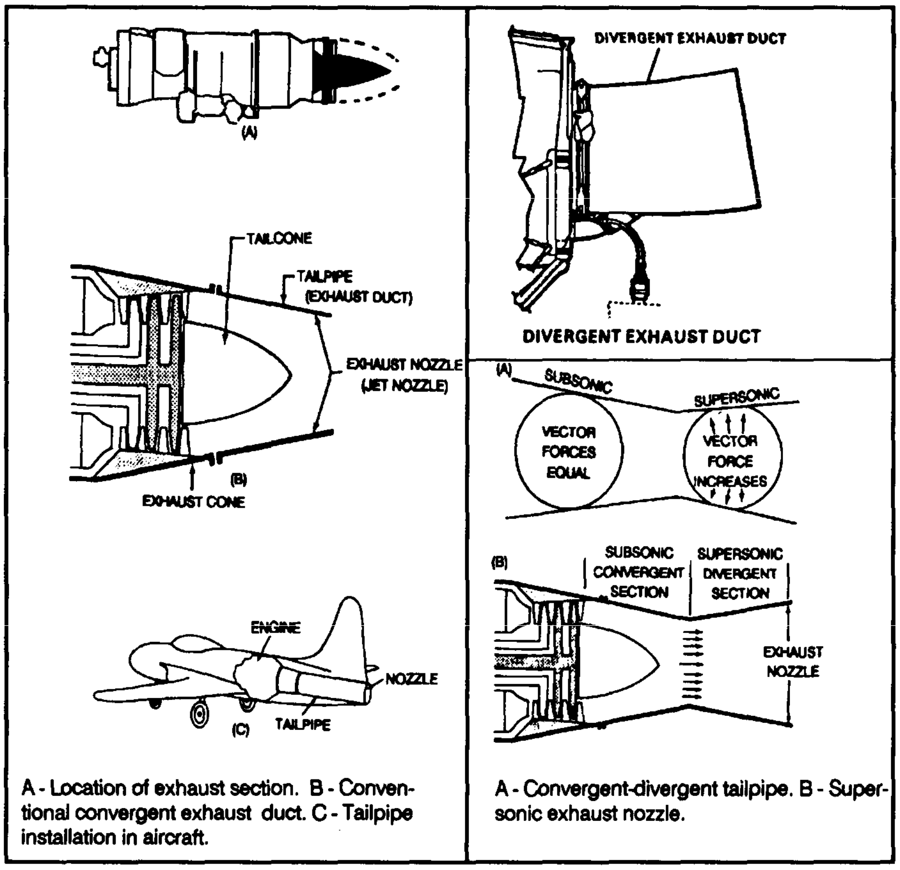


Figure 3-20. Exhaust Duct

An engine exhaust duct is often referred to as the engine tail pipe. The duct is essentially a simple, stainless steel, conical or cylindrical pipe. The engine tail cone and struts (Figure 3-21) are usually included at the rear of the turbine. The struts support the rear bearing and impart an axial direction to the gas flow, the tail cone helps smooth the flow. Immediately aft of the turbine outlet and usually just forward of the flange to which the exhaust duct is attached, the engine has a sensor for turbine discharge pressure. In large engines, it is not practical to measure internal temperature at the turbine inlet. Therefore, the engine is usually also instrumented for exhaust gas temperature at the turbine outlet. One or more thermocouples preinserted in the exhaust case to provide adequate sampling of exhaust gases. Pressure probes are also inserted in this case to measure pressure of gases coming from the turbine. The gradually diminishing cross-seclional area of a conventional convergent type of exhaust duct is capable of keeping the flow through the duct constant at velocities not exceeding Mach 1.0 at the exhaust nozzle.



A - Location of exhaust section. B - Conventional convergent exhaust duct. C - Tailpipe installation in aircraft.

A - Convergent-divergent tailpipe. B - Supersonic exhaust nozzle.

Figure 3-21. Exhaust Duct Nozzles

Exhaust Ducts

Turboshaft engines in helicopters do not develop thrust using the exhaust duct. If thrust were developed by the engine exhaust gas, it would be impossible to maintain a stationary hover; therefore, helicopters use divergent ducts. These ducts reduce gas velocity and dissipate any thrust remaining in the exhaust gases. On find-wing aircraft, the exhaust duct may be the convergent type, which accelerates the remaining gases to produce thrust. This adds additional SHP to the engine rating. Equivalent shaft horsepower (ESHP) is the combination of thrust and SHP.

Conventional Convergent Exhaust Nozzle

The rear opening of the exhaust duct is the jet nozzle, or exhaust nozzle as it is often called The nozzle acts as an orifice, the size of which determines velocity of gases as they emerge from the engine. In most non-after-burning engines, this area is critical; for this reason, it is fixed at the time of manufacture. The exhaust (jet) nozzle area should not be altered in the field because any change in the area will change both the engine performance and the exhaust gas temperature. Some early engines, however, were trimmed to their correct RPM or exhaust gas temperature by altering the exhaust-nozzle area. When this is done, small tabs that may be bent as required are provided on the exhaust duct at the nozzle opening. Or small, adjustable pieces called "mice" are fastened as needed around the perimeter of the nozzle to change the area. Occasionally, engines are equipped with variable-area nozzles which are opened or closed, usually automatically, with an increase or decrease in fuel flow. The velocity of the gases within a convergent exhaust duct is usually held to a subsonic speed. The velocity at the nozzle approaches Mach 1.0 (the velocity at which the nozzle will choke) on turbojets and low-bypass-ratio turbofans during most operating conditions.

Convergent-Divergent Exhaust Nozzle

Whenever the pressure ratio across an exhaust nozzle is high enough to produce gas velocities which might exceed Mach 1.0 at the engine exhaust nozzle, more thrust can be gained by using a convergent-divergent type of nozzle (refer back to Figure 3-21). This can be done provided the weight penalty is not so great that the benefit of the additional thrust is nullified. The advantage of a convergent-divergent nozzle (C-D nozzle) is greatest at high Mach numbers becausce of the resulting higher pressure ratio across the engine nozzle. If the pressure ratio through a subsonic exhaust duct is great enough (this will be the case when the pressure at the entrance to the exhaust duct becomes approximately twice that at the exhaust nozzle), the change in velocity through the duct will be enough to cause sonic velocity (Mach 1.0) at the nozzle. At very high flight Mach numbers, the pressure ratio becomes much more than 20. If a C-D nozzle is used, the velocity at the exhaust nozzle becomes correspondingly greater than Mach 1.0. This is a distinct advantage, provided the nozzle can effectively handle these high velocities.

When a divergent duct is employed in combination with a conventional exhaust duct, it is called a convergent-divergent exhaust duct (Figure 3-21). In the C-D nozzle, the convergent section is designed to handle the gases while they remain subsonic and to deliver them to the throat of the nozzle just as they attain sonic velocity. The divergent section handles the gases after they emerge from the throat and become supersonic further increasing their velocity.

Pressure generated within an engine cannot be converted to velocity, particularly when a convergent nozzle is used. The additional pressure results in additional thrust which, as has been shown, must be added when the total thrust developed by the engine is computed. The additional thrust is developed inefflciently. It would be much better to convert all of the pressure within the engine to velocity and develop all of the engine thrust by means of changes in momentum. In theory, a C-D nozzle does this. Becuase it develops this additional part of the total thrust more efficiently, it enables an engine to produce more total net thrust than the same basic engine would generate if it were equipped with a conventional convergent duct and nozzle. The C-D nozzle would be nearly ideal if it could always be operated under the exact conditions for which it was designed. However, if the rate of change in the duct area is either too gradual or too rapid for the calculated increase in weight of the gases, unsteady flow downstream of the throat will occur with an accompanying loss of energy. This ultimately means loss of thrust. If the rate of increase in area of the duct is too little, the maximum gas velocity that can be reachcd will be limited. If the rate of increase is too great, the gas flow will break away from the surface of the nozzle, and the desired increase in velocity will not be obtained. As exhaust gases accelerate or decelerate with changing engine and flight **conditions, their pressure fluctuates above or below the pressure ratio for which the nozzle** was designed When this occurs, the nozzle no longer converts all of the pressure to velocity, and the nozzle begins to lose efficiency.

The solution to this dilemma is a C-D nozzle with a variable cross-sectional configuration which can adjust itself to changing pressure conditions. Several types of C-D nozzles have been tried, and a few have been used successfully on production aircraft. As the actual design and operation of such nozzles is usually either classified military information or proprietary information of the manufacturer, the nozzles cannot be described here.

THRUST REVERSERS

The difficult problem of stopping an aircraft after landing increases many times with the greater gross weights common to large, modern aircraft with their higher wind loadings and increased landing speeds. Wheel brakes alone are no longer the beat way to slow the aircraft immediately after touchdown. The reversible-pitch propeller solved the problem for piston engine and turboprop-powered airplanes. Turbo rbojet and turbofan aircraft, however, must rely on some device such as a parabrake or runway arrester gear or some means of reversing the thrust produced by their engines.

Although sometimes used on military aircraft, the parabrake or drag parachute has distinct disadvantage The parabrake is always subject to either a premature opening or a failure to open at all. The parabrake must be recovered and repacked after each use and, if damaged or lost must be repaired or replaced. Once the parabrake has opened, the pilot has no control over the amount of drag on the aircraft except to release the parachute completely.

Arrester gears are primarily for aircraft carrier deck operation although they are sometimes used by military bases as overshoot barriers for land runways. They would hardly be suitable for commercial airline operation at a busy municipal airport.

OIL SYSTEM SEALS

The significance of oil system seals in aircraft engines is great. A leaking seal in a turbine engine could cause tire, bearing failure, or cockpit fumes, to name a few dangers. There are three main types of oil system seals: synthetic, labyrinth, and carbon.

Synthetic

Synthetic seals (neoprene, silicone, Teflon, and synthetic rubber) are used throughout the engine's oil system. They are used where metal-to-metal contact would not provide satisfactory sealing to withstand pressures in such items as filters, turbine, and fittings. Seals come in many sizes and shapes and are not normally reused. New replacement seals are received from supply channels **usually** in a package that prevents damage. In most cases the packages will have a "cure date" stamped on the outside. (Cure date is the date of manufacture of the seals.) This date is particularly important when installing seals retie of rubber, which has a tendency to deteriorate more rapidly than synthetic material. Just as important is to use the proper seal with the correct part number for a specific installation. Never use a seal from another system just because it looks like the right seal. The composition or military specifications may be entirely different which could cause the seal to fail at a crucial moment.

Some synthetic seals coming into contact with synthetic oils such as MIL-7808 or ML-23609, have a tendency to swell; others might deteriorate completely. Occasionally, seals are referred to as "packings" or "gaskets." However, there is a difference between the two. Packing is used to provide a running seal; a gasket is used between two stationary parts to create a static seal. Some manufacturers refer to a gasket as a packing and vise versa. These terms should not be taken literally, Always go strictly by the part number when using seals.

Labyrinth

Labyrinth or air seals are designed to allow a small amount of air to flow across the sealing surface. This helps prevent oil (or lower-pressured air) seepage across the same surface (Figure 3-22). Air seals have two separate parts. One part forms a plain or honeycomb surface; the corresponding part is a circular seal with annular grooves. These grooves may use a soft metal as the basic composition or be machined into a surface. Matching the two together (one rotating portion or race with one stationary) forms an air pressure seal. A series of soft metal knifelike edges rides very close to the seal surface or cuts a path into a stationary honeycomb or silver alloy air seal (Figure 3-23).

NOTE: When honeycomb or silver alloy is used, it is bonded to the stationary portion of the air seal.

Air for this seal is normally bled from the compressor and then forced between the sealing surface and the seal. The effect of pressurization prevents oil (or lower-pressured air) from seeping from one section to another during engine operation. Air seals work only when the engine is operating when the engine is shut down seal leakage will occur. Be extremely careful when working in or around the seal area because seals are composed of very soft metal. Avery small nick or groove in a seal may cause a serious oil leak which may require a premature engine change.

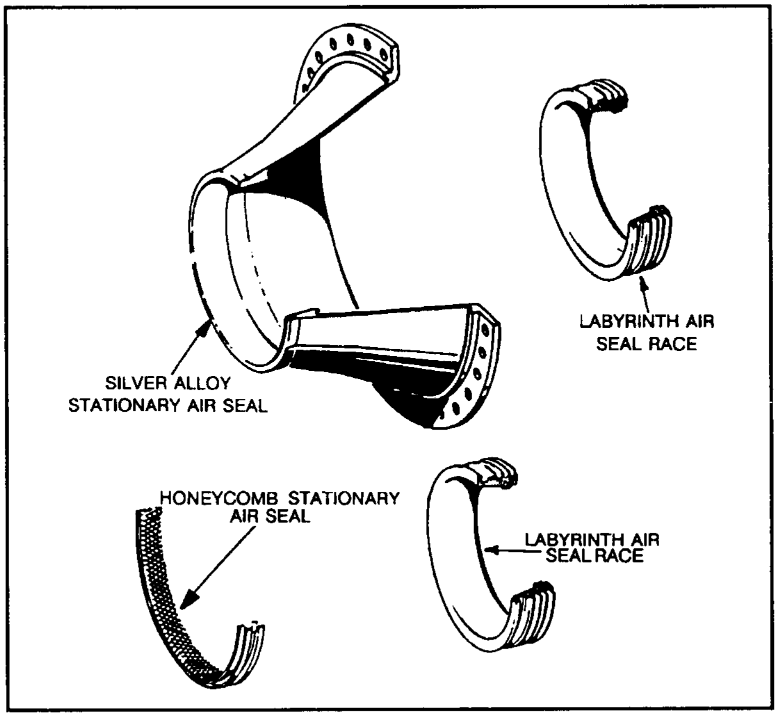


Figure 3-22. Labyrinth Air Seals and Races

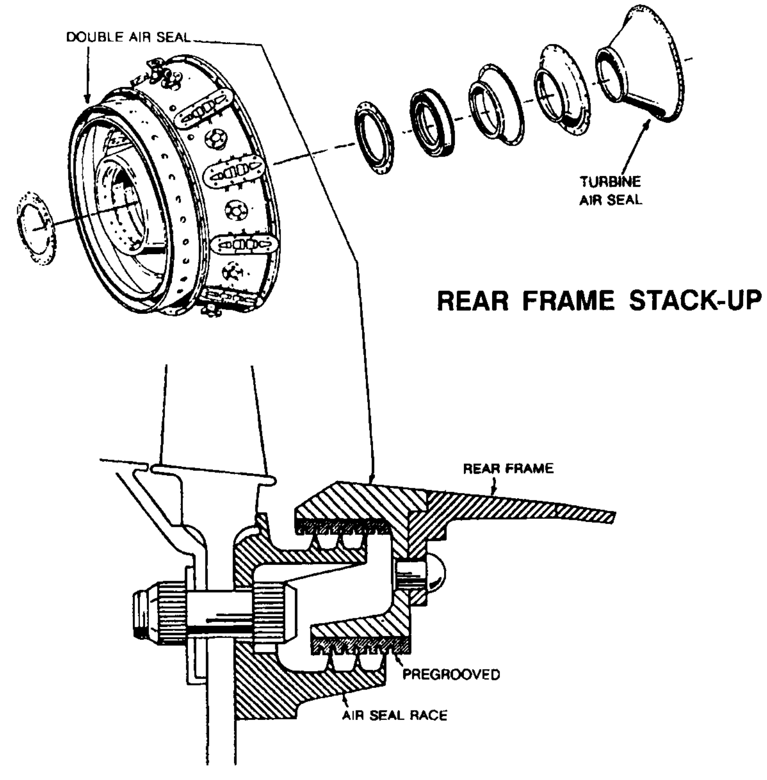


Figure 3-23. Double Air Seal

Carbon

Carbon oil seals are used to contain the oil within the bearing areas on most jet turbine engines. All carbon seals form a sealing surface by having a smooth carbon surface rub against a smooth steel surface. The steel surface is called a “seal race” or "faceplate," depending on the engine manufacturer. All carbon seals are preloaded. That is, the carbon must in some way be pressed against the steel surface. Three common preload methods are spring tension, centrifugal force, and air pressure. During operation, the seal may be aided by allowing a small amount of oil to flow into the rubbing surface. The oil also cools the seal as a certain amount of heat is built up by the carbon rubbing on the steel surface.

The carbon oil seal shown in Figure 3-24 consists of two rows of carbon segments (seal ring and back ring) mounted in a housing and held together around their circumference by extension springs. These springs not only hold the segments together by circling the outside but also serve as the preload necessary to press the seals inward. The seal segments nearest the bearing have a lip that forms the seal; the positioning pads contact the steel race and maintain the proper sealing positions of the segments. These positioning pads are sometimes referred to as “wear blocks” because the seal lip is very thin and without the pads would have a short wear life. The grooves between the pads are staggered to reduce airflow toward the sump. On this particular seal, the seal race contact surface is cooled by a spray of oil. The key and spiral pin shown in the figure keep the carbon segments from turning within the seal housing the compression springs press the seal segments into the housing. The entire assembly is held together by the spring retainer and snap ring. This type of seal is stationary and rubs against an inner, rotating seal race.

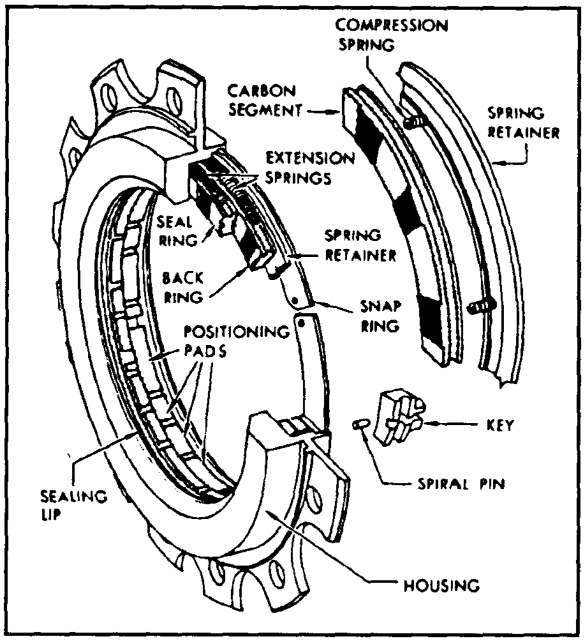


Figure 3-24. Carbon Oil Seal

Other configurations of carbon seals may have several seals on each side of the bearing. They may also rub on the side or outer surface of the seal rather than the inner surface as the one illustrated does. Seals such as the one in Figure 3-25 can be rebuilt by replacing the segments in groups; other seals however, must be returned to an overhaul facility when they are damaged and must be replaced with a complete seal assembly.

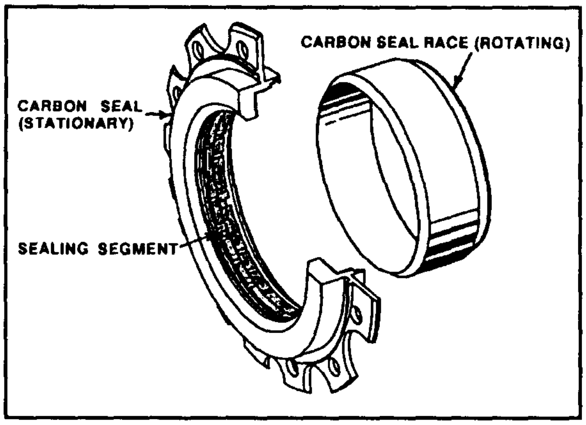


Figure 3-25. Carbon Rubbing Seal and Race

MATERIALS AND METHODS OF CONSTRUCTION

High-temperature, high-strength materials and unique methods of manufacture have made the gas turbine engine a practical reality in a few decades. The performance of turbojet and turboprop engines depends largely on the temperature at the inlet to the turbine. Increasing the turbine inlet temperature from the present limit (for most highly produced engines) of approximately 1700°F to 2500°F will result in a specific thrust increase of approximately 130 percent along with a corresponding decrease in specific fuel consumption. For this reason high cycle temperatures are desirable. Not all materials can withstand the hostile operating conditions found in parts of the gas turbine engine.

Properties and Characteristics

Metallurgists have been working for almost 50 years improving metals for use in aircraft construction. Each type of metal or alloy has certain properties and characteristics which make it desirable for a particular use, but it may have other qualities which are undesirable. The metallurgist's job is to build up the desirable qualities and tone down the undesirable ones. This is done by the alloying (combining) of metals and by Various heat-treating processes. It is not necessary for the airframe repairer to be a metallurgist, but it is advantageous to have a general knowledge of the properties used in their development. The repairer should be familiar with a few metallurgical terms. The following terms are used in describing the physical properties and characteristics of metals.

- Hardness. Hardness refers to the ability of a metal to resist abrasion, penetration, cutting action, or permanent distortion. Hardness may be increased by working the metal and, in the case of steel and certain aluminumalloys, by heat-treatment and cold-working. Structural parts are often formed from metals in their soft state and are ***then*** heat-treated to harden them so the finished shape is retained. Hardness and strength are closely associated properties of metals.
- Brittlemem. Brittleness is the property of a metal which allows little bending or deformation without shattering. A brittle metal is apt to break or crack without change of shape. Because structural metals are often subjected to shock loads, brittleness is not a desirable property. Cast iron or cast aluminum and very hard steel are brittle metals.
- Malleability. A metal which can be hammered, rolled, or pressed into various shapes without cracking breaking or other detrimental effects is said to be malleable. This property is necessary in sheet metal which is worked into curved shapes such as cowling, and wingtips. Copper is an example of a malleable metal.
- Ductility. Ductility is the property of a metal which permits it to be permanently drawn, bent, or twisted into various shapes without breaking. This property is essential for metals used in making wire and tubing. Ductile metals are preferred for aircraft use because of their ease of forming and resistance to failure under shock loads. For this reason, aluminum alloys are used for cowl rings, fuselage and wing skin, and formed or extruded parts such as ribs, spars, and bulkheads. Chrome-molybdenum steel is also easily formed into desired shapes. Ductility is similar to malleability.
- Elasticity. Elasticity is that property which enables a metal to return to its original shape when the force which causes the change of shape is removed. This property is extremely valuable, as it would not be desirable to have a part permanently distorted after an applied load was removed. Each metal has a point known as the elastic limit beyond which it cannot be loaded without causing permanent distortion. In aircraft construction, members and parts are so designed that the maximum loads to which they are subjected will never stress them beyond their elastic limits. This desirable property is present in spring steel.
- Toughness. A material which possesses toughness will withstand tearing or shearing and may be stretched or otherwise deformed without breaking. Toughness is a desirable property in aircraft materials.
- Conductivity. Conductivity is the property which nables a metal to carry heat or electricity. The heat conductivity of a metal is especially important in welding as it governs the amount of heat that will be required for proper fusion. Conductivity of the metal, to a certain extent, determines the type of jig to be used to control expansion and contraction. In aircraft, electrical conductivity must also be considered in conjunction with bonding to eliminate radio interference. Metals vary in their capacity to conduct heat. Copper, for instance, has a relatively high rate of heat conductivity and is a good electrical conductor.
- Fusibility. Fusibility is the ability of a metal to become liquid by the application of heat. Metals are fused in welding. Steels fuse at approximately 2500°F (1371°C), and aluminum alloys fuse at approximately 1100°F (593°C).
- Density. Density is the weight of a unit volume of a material. In aircraft work, the actual weight of a material per cubic inch is preferred, as this figure can be used in determining the weight of apart before actual manufacture. Density is an important consideration when choosing a material to be used in the design of a part in order to maintain the proper weight and balance of the aircraft.

- Contraction and expansion. contraction and expansion are reactions produced in metals as the result of heating or cooling. A high degree of heat applied to a metal will cause it to expand or become larger. Cooling hot metal will shrink or contract it. Contraction and expansion affect the design of welding jigs, castings, and tolerances necessary for hot rolled material.
- Strength. Strength refers to the ability of a metal to hold loads (or forces) without breaking Strength is a property that sums up many of the desirable qualities of metals. Strength with toughness is the most important combination of properties a metal can possess. Metals having this combination of properties are used in vital structural members that may become overloaded in service.

In a discussion of metal properties, stress and strain should be mentioned. Stress is a force placed upon a body and is measured in terms of force per unit area, the force being expressed in pounds and the unit of area in square inchs; in other words, pounds per square inch (psi). Stress may be in the form of compression, tension, torsion, bending, shearing loads, or a combination of two or more of these. All parts of an aircraft are subjected to stresses. When a part fails to return to its original form after being stressed, it is said to be strained. The various stresses acting on parts of an aircraft, while in flight, have an important&wing on the metals used:

- Tension. Tension is the resistance to pulling apart or stretching produced by two forces pulling in opposite directions along the same straight line. The cables of a control system are placed under tension when the controls are operated.
- Compression. Compression is the resistance to pushing together or crushing produced by two forces pushing toward each other in the same straight line. The landing struts of an aircraft are under compression when landing and, to a smaller degree, when supporting the weight of the aircraft as it rests on the ground.
- Torsion. Torsion is the resistance to twisting. A torsional force is produced when an engine turns a crankshaft. Torque is the force that produces torsion.
- Bending. Bending is a combination of tension and compression. The inside curve of the bent object is under compression, and the outside curve is under tension. The main spars of the main rotor blades are subjected to bending. The blades droop while the rotor head is at rest and bend upward when rotating.
- Shear. Shear is the stress exerted when two pieces of metal fastened together are separated by sliding one over the other in opposite directions. The stress cuts off a bolt or a rivet like a pair of shears. In general, rivets are subjected to shear only; bolts, to both shear and tension. There is internal shear in most bending elements and in the skin of sheet metal structures.

Metallurgical and Metalworking Terms

Some of the more commonly used terms in the field of mettalurgy are listed below:

Strength.

- Creep strength-the only ability of a metal to resist slow deformation due to stress, but less than the stress level needed to reach the yield point. Creep strength is usually stated in terms of time, temperature, and load.
- Yield strength – the point reached when metal exhibits a permanent set under load.
- Rupture strength– the point where metal will break under a continual load applied for periods of l00 and 1000 hours. Metals are usually tested at several temperatures.
- Ultimate tensile strength– the load under which metal will break in a short time.

- Ductility– the ability of a metal to deform without breaking.
- Coefficient of expansion – a measure of how much a metal will expand or grow with the application of heat.
- Thermal conductivity-a measure of the ability of a metal to transmit heat.
- Corrosion and oxidation resistance– indicates how well a metal can resist the corrosive effects of the hot exhaust stream.
- Melting point-the temperature at which metal becomes a liquid.
- Critical temperature – point where as it is cooled a metal's internal structure and physical properties are altered. The rate of cooling will greatly influence the ultimate properties of the metal.
- Heat treatability– a measure of how the metal's basic structure will vary under an operation or series of operations involving heating and cooling of the metal while it is in a solid state. Ferritic, austenitic, and martensitic steels all vary in heat treatability.

- Thermal shock resistance—the ability of a metal to withstand extreme changes in temperature in short periods of time.
- Hardness—the ability of a metal to resist abrasion penetration cutting action or permanent distortion. Hardness may be increased by working the metal or by heat treatment.
- Alloying—the combining of metals in their molten state to create desirable qualities or reduce or eliminate undesirable qualities.

Common metal working terms include the following:

- Casting—a process whereby molten metal solidifies in a mold.
- Forging—a process of plastic deformation under pressure that may be slowly or quickly applied
- Electrochemical machining (ECM)—controlled high-speed deplating using a shaped tool (cathode), an electricity-conducting solution and the workpiece (anode).
- Machining—any process where metal is formed by cuttin,- hot or cold rolling pinching, punching, grinding, or by laser beams.
- Extrusion—pushing through a die to form various cross-sectional shapes.
- Welding—a process of fusing two pieces of metal together by locally melting part of the material by arc welders, plasmas, lasers, or electron beams.
- Pressing—a process of blending, pressing, sintering (fusing the power particles together through heat), and coining metals out of prealloyed powders.
- Protective finish and surface treatment—includes plating by electrical and chemical processes ceramic coatings, or painting. Surface treatments for increased wear may take the form of nitriding, cyaniding, carburizing, diffusion coating and flame plating.
- Shot peening—a plastic flow or stretching of a metal's surface by a rain of round metallic shot thrown at high velocity. Shot peening also serves to work-harden metals, especially aluminum alloy.
- Heat treatment—a series of operations involving the controlled heating and cooling of metals in the solid state. Its purposes is to change a mechanical property or combination of properties so that the metal will be more useful, serviceable, and safe for a specific purpose. It includes normalizing annealing stress relieving-tempering and hardening.
- Inspection (strictly speaking not a part of the metalworking process but integrally associated with it) – includes magnetic particle and dye penetrant inspection, X-ray inspection dimensional and visual inspection, and inspection by devices using sound, light, and air.

Heat Ranges of Metals

The operating conditions inside a gas turbine engine vary considerably, and metals differ in their ability to satisfactorily meet these conditions.

Aluminum Alloys. Aluminum and its alloys are used in temperature ranges up to 500ºF. With low density and good strength-to-weight ratios, aluminum forgings and castings are used extensively for centrifugal compressor wheels and housings, air inlet sections, accessory sections, and for the accessories themselves.

Magnesium Alloys. Magnesium is the world's lightest structural metal. Aluminum is 15 times heavier, titanium 25 times heavier, steel 4 times heavier, and copper and nickel alloys are 5 times heavier. Magnesium is combined with small amounts of certain other metals, including aluminum, manganese, zinc, zirconium, thorium, and others, to obtain the strong lightweight alloys needed for structural purposes.

Titanium Alloys. Titanium and its alloys are used for axial-flow compressor wheels, blades, and other forged components in many large, high-performance engines. Titanium combines high strength with low density and is suitable for applications up to 100ºF.

Steel Alloys. This group includes high-chromium, molybdenum, high-nickel, and iron-base alloys in addition to low-alloy steels. Because of the relatively low material cost, ease of fabrication, and good mechanical properties, low-alloy steels are commonly used for both rotating and static engine components such as compressor rotor blades, wheels, spacers, stator vanes and structural members. Low-alloy steels can be heat-treated and can withstand temperatures up to 100°F. High nickel-chromium iron-base alloys can be used up to 1250ºF.

Nickel-Base Alloys. Nickel-base alloys are some of the best metals for use between 1200ºF and 1800ºF. Most contain little or no iron. They develop high-temperature strength by age hardening and are chacterized by long-time creep-rupture strength as well as high ultimate and yield strength combined with good ductility. Many of these materials, originally developed for turbine bucket applications, are also being used in turbione wheels, shafts, spacers, and other parts. Their use is somewhat restricted because of cost and because of their requirement for critical materials.

Cobalt-Base Alloys. Colbalt-base alloys form another important group of high-temperature, high-strength, and high-corrosion- resistant metals. They contain little or no iron. These alloys are used in afterburner and other parts of the engine subjected to very high temperatures.

Chemical Elements of Alloys

The number of materials used in alloys is large. Some of the most commonly used elements are listed below.

TABLE. CHEMICAL ELEMENTS USED IN ALLOYS

ELEMENT	CHEMICAL SYMBOL	ELEMENT	CHEMICAL SYMBOL
Aluminum	A	Manganese	Mn
Boron	B	Molybdenum	Mo
Carbon	C	Nitrogen	N
Chromium	Cr	Nickel	Ni
Cobalt	Co	Silicon	Si
Columbium	Cb	Tantalum	Ta
Copper	Cu	Titanium	T
Iron	Fe	Vanadium	V
		Zirconium	Zr

The percentages of elements used partially determines the physical and chemical charteristics of the alloy and its suitability to a particular application, Tempering and other processes determine the rest. Three characteristics that must be considered are—

- High-temperature strength.
- Resistance to oxidation and corrosion.
- Resistance to thermal shock.

High-Temperature Strength. The most highly stressed parts of the gas turbine engine are the turbine blades and discs. Centrifugal forces tending to break the disc vary with the square of the speed. For example, the centrifugal force on a disc rotating at 20,000 RPM will be four times that at 10,000 RPM. Blades weighing only 2 ounces may exert loads of over 4000 pounds at maximum RPM. Blades must also resist the high bending loads applied by the moving gas stream to produce the thousands of horsepower needed to drive the compressor. There is also a severe temperature gradient (difference) of several hundred degrees between the central portion of the disk and its periphery.

Many metals which would be quite satisfactory at room temperatures will lose much of their strength at the elevated temperatures encountered in the engine's hot section. The ultimate tensile strength of a metal at one temperature does not necessarily indicate its ultimate tensile strength at a higher temperature. For example, at 1000°F Inconel X has an ultimate tensile strength of approximately 160,000 psi; and S 816 at the same temperature has an ultimate tensile strength of 135,000 psi. At 1500°F their positions are reversed. Inconel X has an untimate tensile strength of 55,000 psi; S 816 has an ultimate tensile strength of 75,000 psi. The creep strength, which is closely associated with ultimate tensile strength, is probably one of the most important considerations in the selection of a suitable metal for turbine blades. Engine vibration and fatigue resistance will also have some influence on the selection and useful life of both discs and blades.

Many materials will withstand the high temperatures encountered in a gas turbine engine (carbon columbium, molybdenum, rhenium, tantalum, and tungsten all have melting points above 4000°F). However, the ability to withstand high temperatures while maintaining reasonable tensile strength is not the only consideration. All of the following qualities must be taken into account when selecting a particular metal:

- Critical temperature.
- Rupture strength.

- Thermal conductivity.
- Coefficient of expansion.
- Yield strength.
- Ultimate tensile strength.
- Corrosion resistance.
- Workability.
- Cost.

Resistance to Oxidation and Corrosion. Corrosion and oxidation are results of electrical and chemical reactions with other materials. The hot exhaust gas stream encountered in the engine speeds up this reaction. While all metals will corrode or oxidize, the degree of oxidation is determined by the base alloy and the properties of the oxide coating formed. If the oxide coating is porous or has a coefficient of expansion different from that of the base metal, the base metal will be continually exposed to the oxidizing atmosphere. One solution to oxidation at elevated temperatures is ceramic coatings. Ceramic-coated afterburner liners and combustion chambers are in use today. The ceramic coating has two basic functions:

- Sealing the base metal surface against corrosion.
- Insulating the base metal against high temperatures.

These coatings are not without disadvantages:

- They are more susceptible to thermal shock.
- They must have the same coefficient of expansion as the base metal.
- They are brittle.
- They have low tensile strength which restricts their use in the engine.

Some promising work is being done with various metal-ceramic combinations called Cermets or Ceramels. Materials being used with ceramics include aluminum, beryllium, thorium, and zirconium oxides, to name a few.

Resistance to Thermal Shock. Many materials which would otherwise be quite suitable must be rejectcd because of their poor thermal shock characteristics. Several engine failures have been attributed to thermal shock on the turbine disc. Ceramic coating in particular are vulnerable to this form of stress. Improved fuel controls, starting techniques, and engine design have lessened this problem.

Transpiration Cooling

The effort to achieve higher turbine inlet temperatures (and therefore higher thermal efficieney) has been approached from two directions: (1) high-temperature materials and (2) cooling methods. A common method of cooling the nozzle guide vanes on gas turbine engines is to pass compressor bleed air through the hollow blades to cool them by convective heat transfer. Some engines also use air bled from the compressor to cool the front and rear face of the turbine discs and the hollow turbine blades.

Transpiration cooling is a novel and efficient method of allowing the turbine blades and other parts within the hot section to operate at much higher turbine inlet temperatures. The Wright Corporation has constructed and run turbine blades at an inlet temperature of 2500ºF. In this type of cooled blade the air passes through thousands of holes in a porous airfoil made from a sintered wire mesh material. Since the sintered wire mesh is not strong enough by itself, an internal strut is provided as the main structural support carrying all air foil and centrifugal loads. Fabrication techniques involve rolling layers of woven wire mesh and then sintering these layers to forma porous metal sheet. The sheet is then rolled into an airfoil shape.

Porous materials have been tested for use in combustion chambers and for afterburner liners. A similar material called Rigimesh has also been used in rocket engines to help keep the fuel nozzles cool. Many manufacturers are experimenting with other types of porous materials for use in blades in an attempt to obtain higher turbine inlet temperatures.

Other Materials

Relatively new materials called composites are coming into use in both airframes and engines. In these products graphite, glass or boron filaments are embedded in an epoxy-resin matrix or base substance. Other types of filaments and materials are being tried to meet the demands of higher temperatures and stress The chief advantage of composite material is its very favorable strength-to-weight ratio, which can lead to lighter weight in many structural parts. For example, a lighter fan blade allows a lighter fan disc, which in turn permits a lightening of other parts all the way down the line. Composite materials may be used in conjuction with other load-bearing materials to provide a support function. Typical of this type of structure are fan blades with a steel spar and base and with an airfoil composite shell.

Manufacturing Techniques

Basic parts of the engine are produced by several casting and forging processes, literally dozens of machine operations, and fabrication procedures using a variety of metal-joining methods.

Casting. Several engine parts are cast in aluminum, magnesium, or steel alloys. These parts include intake and compressor housings, accessory- and blading. to name a few. Casting methods differ. They include –

- Sand casting.
- Spin Casting.
- Lost-wax or investment casting.
- Resin-shell mold casting.
- Slip casting.
- Mercasting.

Sand castings. Sand casting uses a wood or metal pattern around which a clay-he sand has been packed to form the mold. The mold is then split, the pattern removed, the mold reassembled, and any cores that are necessary added. Molten metal at a precise temperature is poured into the mold and allowed to cool. The mold is removed, and various heat treatments may be performed to obtain the desired physical characteristics. The casting may be spun while being poured.

Spin casting. Spin casting results in a denser, sounder casting. Spinning is normally performed on small ring sections. Cooling of the metal radially inward results in fewer stresses.

Lost-wax or investment casting. Basically, the investment casting process involves the use of heat-disposable wax or plastic patterns which are surrounded with a refractory material to form a monolithic mold Patterns are removed from the mold in ovens, and molten metal is poured into the hot mold. Sometimes this pouring is done in a vacuum furnace. After cooling the mold material is quite fragile and easily removed from the casings. Because the finished product duplicates the pattern exactly, the fabrication of patterns is critical. They are made by injecting molten wax or plastic into metal dies. The finished castings have an exceptionally smooth surface finishing and require very little further machining. Incidentally, this process is not new. It was used by the ancient Greeks and Egyptians to cast lightweight statues, intricate bowls, and pitchers.

Resin-shell mold casting. ***Resin-shell*** mold casting is a high-production method similar to investment casting except that the tolerances are not held as closely. In many ways it rivals sand casting in economy.

Slip casting. Slip casting (which was borrowed from the ceramics industry) is used for super heat-resistant materials. Often it is the only way certain materials can be shaped. Metal ceramics, silicon nitride, and refractory metals cast this way can withstand temperatures over 2200ºF.

Mercasting. The Mercast process is a precision casting technique. It is essentially the same kind of method as the lost-waxer investment process except that frozen mercury is used as a pattern instead of wax. Liquid mercury is poured into a master mold where it is frozen at temperatures below 40ºF. Then it is removed and created with a cold refractory slurry to a thickness of 1/8 inch or more. The refractory shell is dried at low temperature then the shell and mercury are brought to room temperature and the mercury is melted out. The refractory shell is fired to give it strength and then is used as the mold for a usual casting process. Complicated parts can be made with the Mercast process. Very close tolerances and excellent surface finish can be obtained The cost, however, is higher than that of some other methods.

Forging. Disks, drive Shafts, gears, vanes, blades, and numerous other parts of the gas turbine engine are manufactured by forging. This process allows the development of a grain structure and results in a finely grained, more ductile, strong dense product. Forging is by rapid hammering or slow pressing. The choice of technique depends on the resistance of metal to rapid deformation. The workpiece is generally heated to improve plasticity and reduce forging forces. It will often pass through several different dies before the final shape is obtained. All ductile materials can be forged but their forgeability varies considerably. Forgeability generally depends upon –

- Melting point.
- Ductility.
- Yield strength.
- Crystallographic structure.
- Recovery from forging stresses
- Surface reactivity.
- Die friction.
- Cost.

Machining. Common tools used to manufacture gas turbine parts include lathes, mills, broaches, grinders, shapers and planers, polishers and buffers, drills, saws, shears, filers, threaders, contour machines of all kinds, and a host of other devices to cut and form metal. Many of these devices use a numerical tape control or other automatic control devices to reduce human error and produce a more uniform, less expensive product. Robots equipped with computers also assist in machining parts.

Some nontraditional machining techniques for removing metal from super hard and super tough alloys and other materials whose complex shapes preclude conventional metal-cutting tools include—

- Chemical milling.
- Electrochemical machining (ECM).
- Electric-discharge machining (EDM).
- Electron-beam machining.
- Laser-beam machining.

Other nonconventional machining includes everything from abrasive jet cutting to ultrasonic machining.

Chemical milling. Chemical milling involves the removal of metal by dissolving it in a suitable chemical. Those areas that are not to be dissolved are masked with nonreactive materials. The process can be used on most metals, including aluminum, magnesium, titanium, steels, and superalloy for surface sculpturing. Both sides of the workpiece can be chemically milled simultaneously. In addition, the process can be used to machine very thin sheets.

Electrochemical machining. Electrochemical machining is basically a chemical deplating process in which metal, removed from a positively charged workpiece using high-amperage, low-voltage DC, is flushed away by a highly pressurized electrolyte before it can plate out on the cathode tool. The cathode tool is made to produce the desired shape in the workpiece; both must be electrically conductive. The work proceeds while the cathode and workpiece are both submerged in an electrolyte such as sodium chloride. A variation and extension of electrochemical machining is electro-stream drilling. In this process a negatively charged electrolyte, usually an acid, drills holes in a workpiece that has been positively charged Holes as small as 0.005 inch in diameter and 0.5 inch deep in superalloys can be drilled in this manner.

Electric-discharge machining. In electric-discharge machining high voltages are used to produce a high electrical potential between two conductive surfaces (the workpiece and electrode tool) both of which are immersed in a dielectric fluid. Material is removed from both the electrode and the workpiece by a series of very short electric discharges or sparks between the two and is swept away by the dielectric fluid. More material is removed from the workpiece than from the tool by proper selection of the two materials. This process can be used to shape complex parts to very close tolerances from refractory metals and alloys that were formerly impossible to machine. The use of electric-discharge machining is limited in that it is slower than electrochemical machining tool replacement can become expensive, and the surface of the workpiece is damaged as a result of the sparks. On the other hand, the EDM process is less expensive than the ECM process.

Electron- and laser-beam machining. Electron-beam machining and laser-beam machining are being used experimentally. They may find future use in the production of gas turbines and other aerospace components.

Fabrication. Welding is used extensively to fabricate and repair many engine parts. Fabricated sheet steel is used for combustion chambcrs, exhaust ducts, compressor casings, thrust reversers, silencers, and so forth. Common methods include resistance and inert-gas (usually argon) welding. Less common methods use plasmas and lasers. Electric resistance welding is used to make spot, stitch (overlapping spots), and continuous-seam welds. Inert-gas welding employs a nonconsumable electrode (tungsten-thorium alloy) surrounded by some inert gas such as argon or helium. The gas prevents an adverse reaction with the oxygen present in the normal atmosphere. The inert gas can be applied in the immediate area of the arc. In the case of production runs the workpiece or the entire welding machine can be enclosed in a thin plastic balloon, sometimes as large as a room. The entire plastic bubble is filled with and supported by the inert gas. The operator stands on the outside and works through specially designed armholes. After welding, many parts must be stress-relieved. Where temperature or working loads are not large, brazing or silver soldering may be used to join such parts as fittings and tube assemblies.

Electron-beam welding is showing great promise as a method of fabricating parts from heretofore difficult to weld or unweldable materials. Electron-beam welding uses a stream of focused electrons traveling at speeds approaching 60 percent of the speed of light. Even though the mass of electrons which form the beam is small they are traveling at such speeds that they contain a great amount of kinetic energy. When the beam strikes the workpiece, the kinetic energy is transformed into heat energy. The welding usually takes place in a vacuum, although nonvacuum techniques can be used. The following characteristics make this welding process a valuable one in the gas turbine manufacturing area:

- Deep narrow welds with a very narrow heat-affected zone in the base metal.

- The ability to weld materials as thin as 0.00025 inch and as thick as 4 inches of stainless steel.
- The ability to weld many different types of materials.

Finishing. The basic material, the properties desired in the finished product, and the kind of protection desired determine the type of surface and internal treatment received. The variety is considerable and includes the following:

- Chemical treatment. Chrome pickling is the most commonly used of all chemical treatments of magnesium. The part is dipped in a solution of sodium bichromate, nitric acid, and water.
- Electrochemical treatment. Anodizing is a common surface treatment for aluminum alloys in which the surface aluminum is oxidized to an adherent film of aluminum oxide.
- Painting. A thin preservative resin varnish coating is used to protect internal steel, aluminum, and magnesium parts. The characteristic color of this shiny, transparent coating is usually green or blue-green. A graphite powder may be mixed with the varnish to act as an antigellant. Grey, black, or aluminum enamel or epoxy paint is also used extensively as a protective finish.
- Shot peering. This procedure can increase the life of apart many times. It is essentially a plastic flow or stretching of a metal's surface by a rain of round metallic shot thrown at high velocity by either mechanical or pneumatic means. The 0.005- to 0.035-inch stretched layer is placed in a state of compression with the stress concentration uniformly distributed over the entire surface. This aids to increase surface hardness. Glass beads are sometimes used as the shot for cleaning purposes.
- Plating. A great number of plating materials and procedures are used. Plating materials involving the use of chemical or electrochemical solutions include cadmium, chromium, silver, nickel, tin and others. The exact procedure is determined by the plating and base metal.
- Aluminizing. This is another plating method whereby pure molten aluminum is sprayed onto the aluminum alloy base material to form a protective coating against oxidation and **corrosion.**

The Coating Service of Union carbide Corporation has developed and is producing machines for applying extremely wear-resistant and other **specialized coating** to gas turbine parts, tools, and other machines. The different coatings are applied by either of two methods– the detonation gun (D-gun) or the plasma gun. Four times a second, a spark ignites the mixture and creates a detonation which hurls the coating particles, heated to a plastic state by the 6000°F temperature in the gun, out of the barrel at a speed of 2500 feet per second. The part to be plated is kept below 300°F by auxiliary cooling streams. The high-level sound of 150 decibels necessitates housing the gun in a double-walled, sound-insulated construction. Operation is controlled from outside this enclosure.

The plasma gun or torch produces and controls a high-velocity, inert-gas stream that can be maintained at temperatures above 20,000°F. Unlike the D-gun process no combustion takes place. The high-temperature plasma is formed by ionizing argon gas in the extreme heat of an electric arc. Gas molecules absorb heat energy from the arc split into atoms, and then further decompose into electrically charged particles called ions. The hot gas stream can melt any known material, without decomposition. When the molten particles, which are introduced in powdered form, strike the part being coated, a permanent welded bond is formed. While the D-gun is a patented Union Carbide machine, other manufacturers make and distribute a variety of plasma-plating and cutting devices.

Heat Treatments. All of the following procedures alter the mechanical properties of steel to suit the end

- Normalizing– steel is heated to a temperature above the critical range and allowed to cool slowly. Normalizing promotes uniformity of structure and alters mechanical properties.
- Annealing-consists of heating to a point at or near the critical range, then cooling at a predetermined rate. It is used to develop softness, improve machine abliity, reduce stress, improve or restore ductility, and modify other properties.
- Stress relieving–metal is heated throughout to a point below the critical range and slowly cooled. The object of this treatment is to restore elastic properties or reduce stresses that may have been induced by machining cold working, or welding.
- Solution heat treatment – done with aluminum alloys. Consists of heating the metals to the highest temperature without melting and

holding the metals at that temperature long enough to produce a solid solution of the hardening components in the alloy. This is followed by rapid quenching to retain the produced condition.

- Hardening– involves heating the metal to a temperature above the critical range and then quenching The cooling rate will determine hardness.
- Tempering– steel is usually too brittle for use after quenching. Tempering restores some of the ductility and toughness of steel at the sacrifice of hardness or strength. The process is accomplished by heating the hardened steel to a specific point below the critical temperature, holding it at that temperature for a specific time, and then cooling material in a controlled area.

Nonmetallic Materials

Teflon, nylon, carbon, rubber, Bakelite, and a host of plastic materials are used in the gas turbine engine mainly as sealing and insulation materials. For example, nylon and Teflon are used to insulate and protect the shielded electrical wiring located on the outside of the engine. Teflon is also used on the J-79 F4 Phantom engine for the sealing the variable- stator-vane actuators. Carbon is used largely inside the engine in the form of carbon rubbing seals. Some of these “face” carbon rubbing seals must be flat to within two helium light bands, or approximately 23 millionths of an inch Rubber and rubberized fabric materials makeup the sealing edge of the fire seal which divides the hot and cold sections of the engine when mounted in the nacelle. Synthetic rubber is used extensively throughout the engine in the form of O-rings or other shaped seals.

CHAPTER 4

FUEL SYSTEM

The fuel system for gas turbine and reciprocating engines is the same. It delivers to the engine fuel metering system a uniform flow of clean fuel at the proper pressure and in the necessary quantity to operate the engine. Despite widely varying atmospheric conditions, the fuel supply must be adequate and continuous to meet the demands of the engine during flight.

DESCRIPTION

The fuel system is one of the more complex aspects of a gas turbine engine. The variety of methods used to meet turbine engine fuel requirements makes reciprocating engine carburetion seem simple by comparison.

Thrust

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, turboprop and turboshaft aircraft also use variable-pitch propellers or helicopter rotors; thus, the selection of thrust is shared by two controllable variables, fuel flow and propeller blade or rotor blade pitch.

Fuel Supply

The fuel supply must be adjusted automatically to correct for changes in ambient temperature or pressure. An excessive fuel supply in relation to mass airflow through the engine can cause the limiting temperature of the turbine blades to be exceeded. It can produce compressor stall and surge.

Fuel Delivery

The fuel system must deliver fuel to the combustion chambers in the right quantity and in the right condition for satisfactory combustion. Fuel nozzles form part of the system and atomize or vaporize the fuel so that it tiff ignite and burn efficiently. The fuel system must also supply fuel so that the engine can easily be started on the ground and in the air. This means fuel must be injected into the combustion chambers in a combustible condition when the engine is being turned over slowly by the starting system. Combustion must be sustained while the engine is accelerating to its normal running speed.

Acceleration

Another critical condition to which the fuel system must respond occurs during a quick 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 overrich mixture maybe produced causing a surge.

Fuel Control

Turbojet, turbofan, turboprop, and turboshaft 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. Each fuel control manufacturer has its own way of meeting the engine demands.

TURBINE ENGINE FUEL SYSTEM COMPONENTS

Main Fuel Pumps, Engine-Driven

Main fuel pumps deliver a continuous supply of fuel at the proper pressure during operation of the aircraft engine. Engine-driven fuel pumps must be able to deliver the maximum flow needed at high pressure to obtain satisfactory nozzle spray and accurate fuel regulation.

Fuel pumps for turbojet engines are generally positive displacement gear or piston types. The term “positive displacement” means that the gear or piston will supply a fixed quantity of fuel to the engine for every revolution of the pump gears or for each stroke of the piston.

These fuel pumps may be divided into two distinct system categories constant displacement and variable displacement. Their use depends on the system used to regulate the flow of fuel. This maybe a pressure relief valve (barometric unit) for constant displacement (gear) pump or a method for regulating pump output in the variable displacement (piston) pumps.

Constant-Emplacement Pump

Gear-type pumps have approximately straight-line flow characteristics, whereas fuel requirements fluctuate with flight or ambient air conditions. A pump of adequate capacity at all engine operating conditions will have excess capacity over most of the range of operation. This is the characteristic which requires the use of a pressure relief valve for disposing of excess fuel. The impeller, which is driven at a greater speed than the high-pressure elements, increases the fuel pressure from 15 to 45 psi, depending on engine speed.

This fuel is discharged from the boost element (impeller) to the two high-pressure gear elements. Each of these elements discharges fuel through a check valve to a common discharge port. High-pressure elements deliver approximately 51 **gallons** per minute at a discharge pressure of 850 psig.

Shear sections are incorporated in the drive systems of each element. If one element fails, the other element continues to operate. Check valves prevent circulation through the inoperative element. One element can supply enough fuel to maintain moderate aircraft speeds.

A relief valve is incorporated in the discharge port of the pump. This valve opens at approximately 900 psi and is capable of bypassing the total flow at 960 psi. Excess fuel is recirculated. The bypass fuel is routed to the inlet side of the two high-pressure elements.

Variable-Displacement Pump

The variable-displacement pump system differs from the constant-displacement pump system. Pump displacement is changed to meet varying fuel flow requirements; that is, the amount of fuel discharged from the pump can be made to vary at anyone speed. With a pump; of variable flow, the applicable fuel control unit can automatically and accurately regulate the pump pressure and delivery to the engine.

Where variable-displacement pumps are installed two similar pumps are provided and connected in parallel. Each pump can carry the bad if the other fails during normal parallel operations. At times one pump maybe insufficient to meet power requirements. Pump duplication increases safety in operation, especially during takeoff and landing

The positive-displacement, variable-stroke-type pump incorporates a rotor, piston, maximum speed governor, and relief valve mechanism.

Fuel Filters

All gas turbine engines have several fuel filters at various points along the system. It is common practice to install at least one filter before the fuel pump and one on the high-pressure side of the pump. In most cases the filter will incorporate a relief valve set to open at a specified pressure differential to provide a bypass for fuel when filter contamination becomes excessive.

Paper Cartridge. This filter is usually used on the low-pressure side of the pump (Figure 4-1). It incorporates a replaceable paper filter element which is capable of filtering out particles larger than 50 to 100 microns (the size of a human hair). (One micron equals 0.000039 inch, or 25,400 microns equal one inch.) The cartridge protects the fuel pump from damage due to fuel contamination.

Screen Disc. This disc (Figure 4-2) is located on the outlet side of the pump. This filter is composed of a stack of removable fine wire-mesh screen discs which must be dissassembled and cleaned periodically in an approved solvent.

Screen. This screen is generally used as a low-pressure fuel filter. Some of these filter screens are constructed of sinter-bonded stainless steel wire cloth and are capable of filtering out particles larger than 40 microns (Figure 4-3).

In addition to the mainline filters, most fuel systems will incorporate several other filtering elements. They may be located in the fuel tank, fuel control, fuel nozzles, and any other place deemed desirable by the designer.

Pressurizing and Drain (Dump) Valves

The pressurizing and drain valve prevents flow to the fuel nozzles until sufficient pressure is reached in the main fuel control. Once pressure is attained, the servo assemblies compute the fuel-flow schedules. It also drains the fuel manifold at engine shutdown to prevent post-shutdown fires. But it keeps the upstream portion of the system primed to permit faster starts.

Flow Divider. The pressurizing and dump valve used on some engines has a somewhat different function. In addition to the draining or dumping function, this unit also serves as a flow divider. At the beginning of an engine start, the fuel control supplies a pressure signal to the pressurizing and dump valve. This causes the valve to close the manifold drain and open a passage for fuel flow to the engine. On engine shutdown, fuel flow is cut off immediately by a valve in the fuel control. The pressure signal drops, the dump valve opens, and fuel drains from

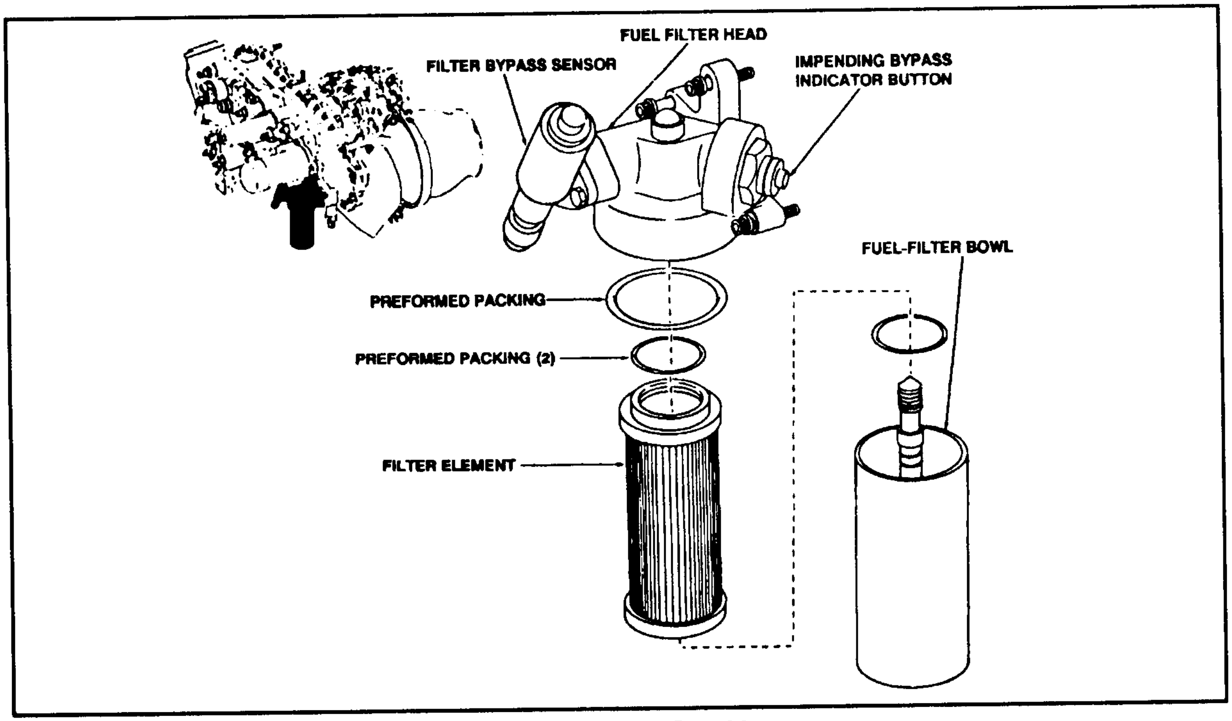


Figure 4-1. Paper Cartridge

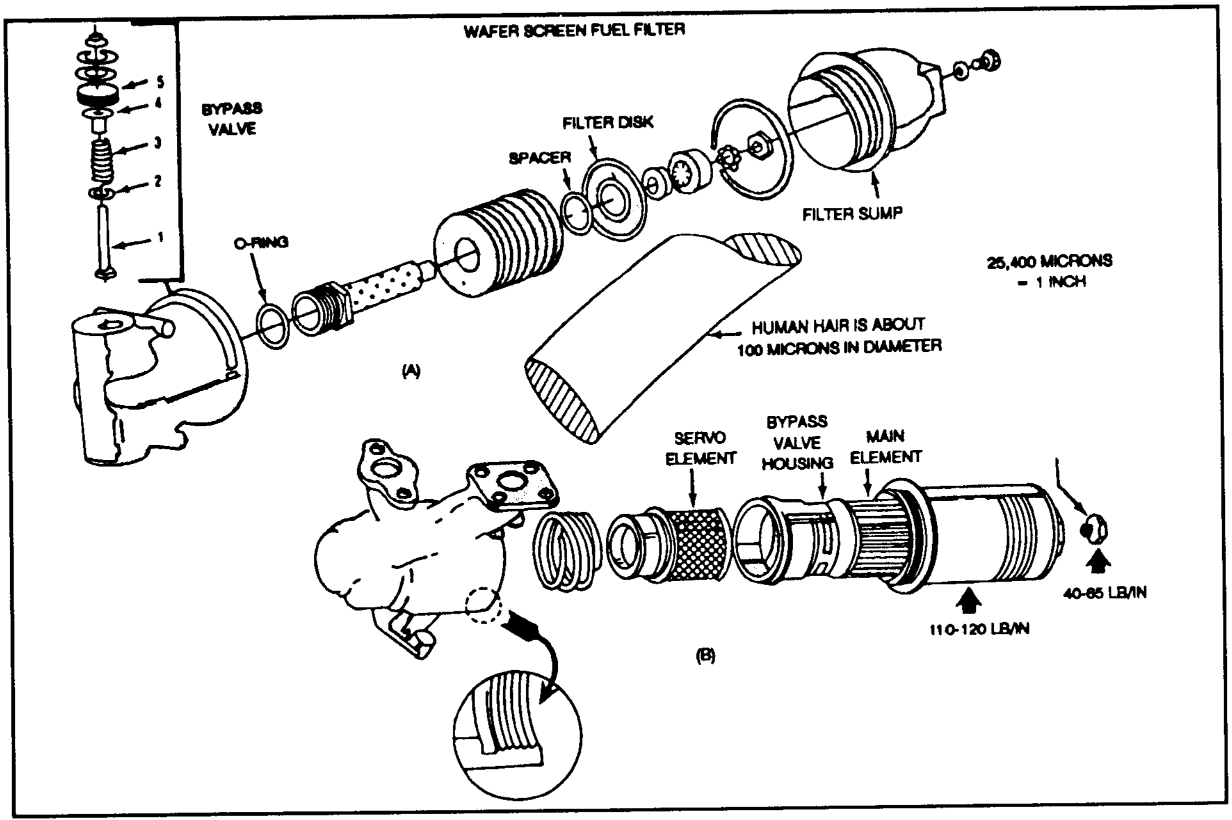


Figure 4-2. Wafer and Pleated Screen Fuel Filter

the manifold. The flow divider allows fuel to flow to the primary and secondary manifolds depending on fuel pressure. (See Figure 4-3.)

Pressure-Operated Valve. Some manufacturers, such as Allison and Lycoming, install a pressure-operated valve in the combustion chamber section. When the pressure in the burners drops below a specified minimum, usually a few pounds per square inch, this valve will open and drain any residual fuel remaining after a false start or normal shutdown. (Refer to Figure 4-4 to see where this drain valve fits into the system.)

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 when it contacts the filter screen.

A fuel heater operates as a heat exchanger to warm the fuel. The heater can use engine bleed air, an air-to-liquid exchanger, or an engine lubricating oil, a liquid-to-liquid exchanger, as a source of heat.

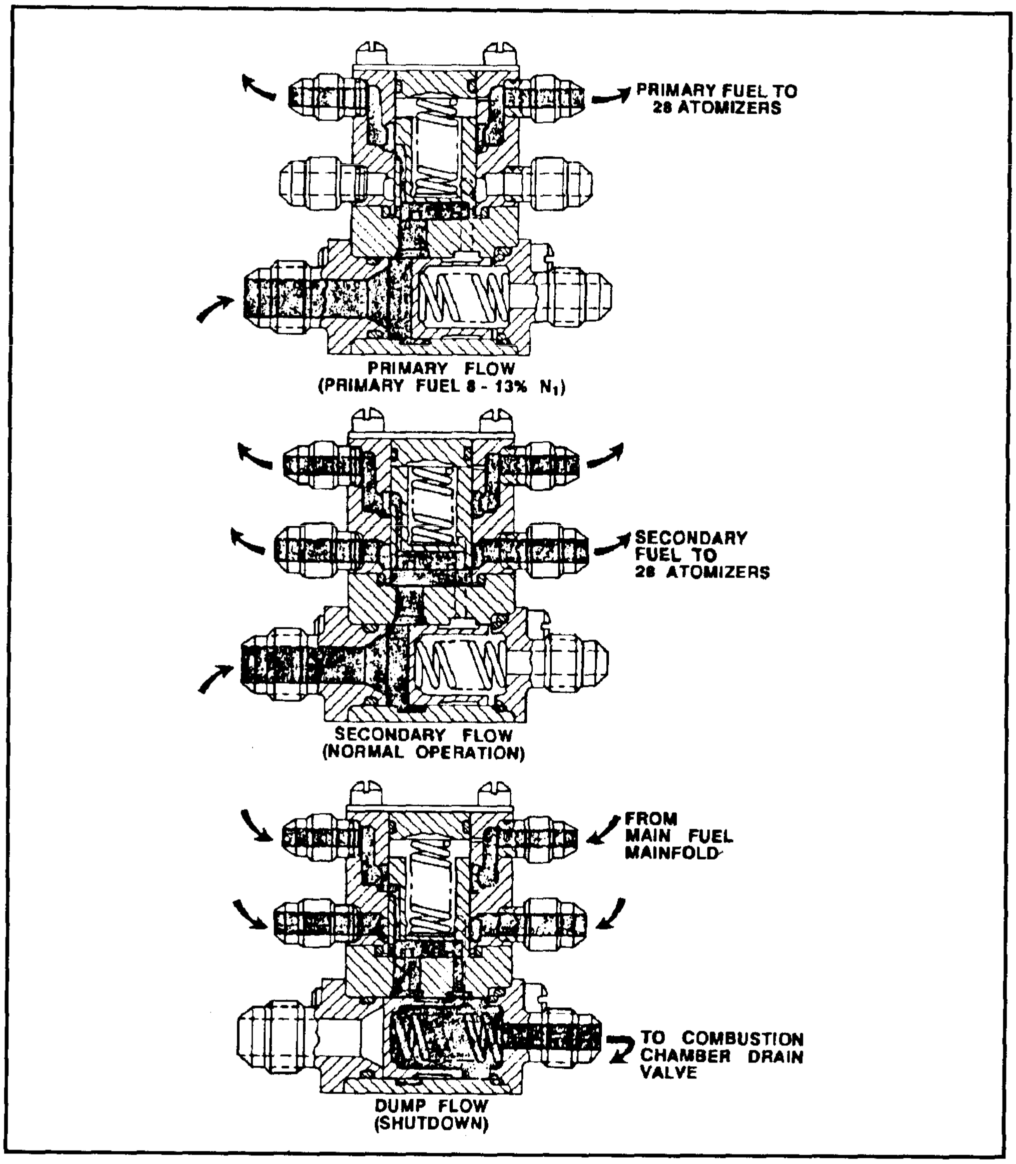


Figure 4-3. Flow Divider and Dump Valve

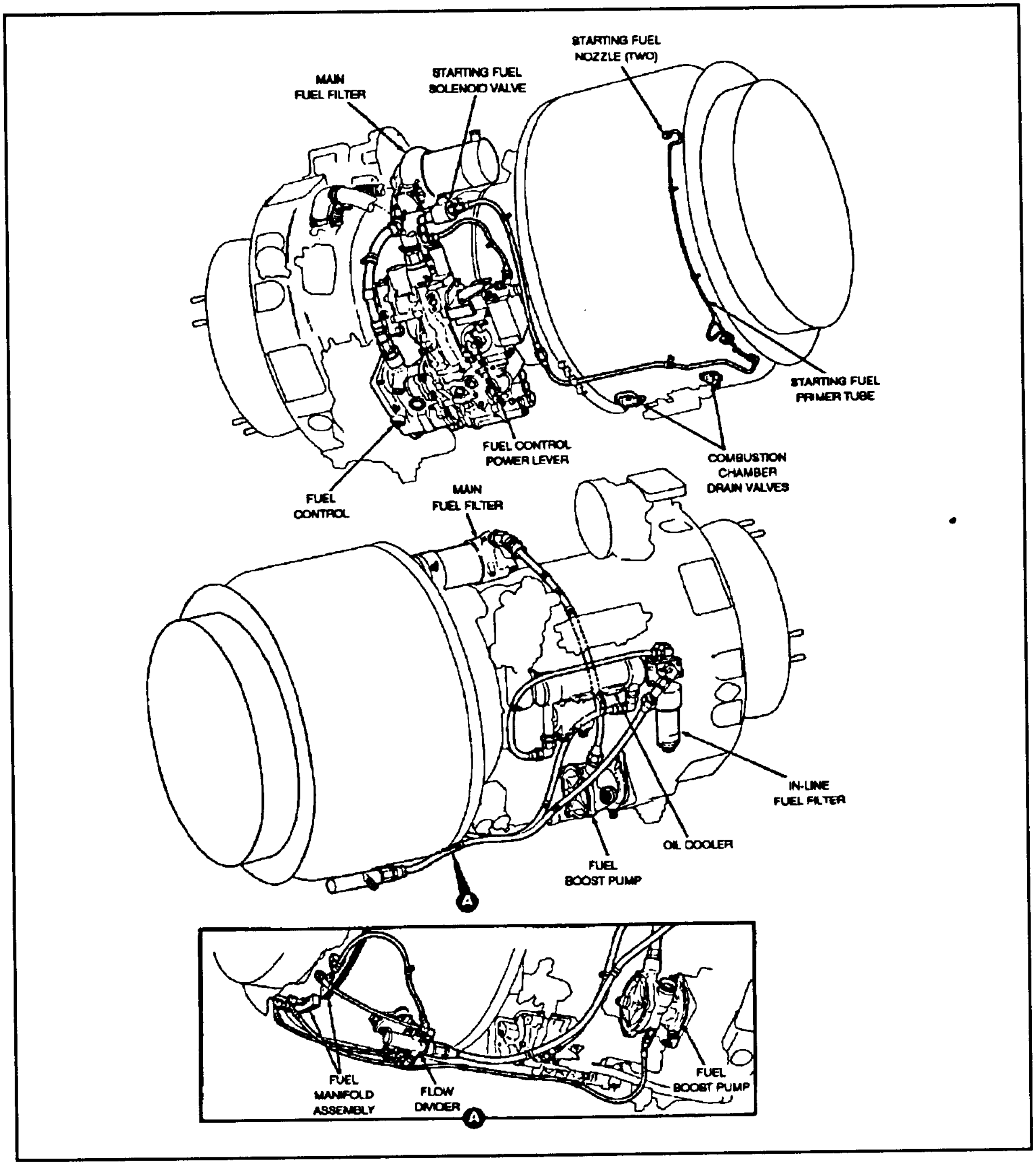


Figure 4-4. Fuel System Components

A fuel heater protects the engine fuel system from ice formation. However, should ice form, the heater can also be used to thaw ice on the fuel screen.

In some 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 will slowly decrease. When the pressure reaches a predetermined value, the warning light flashes on.

Fuel deicing systems are designed to be used intermittently. The system may be controlled manually by a switch in the cockpit or automatically using a thermostatic sensing element in the fuel heater to open or close the air or oil shutoff valve. An automatic fuel heater is illustrated in Figure 4-5.

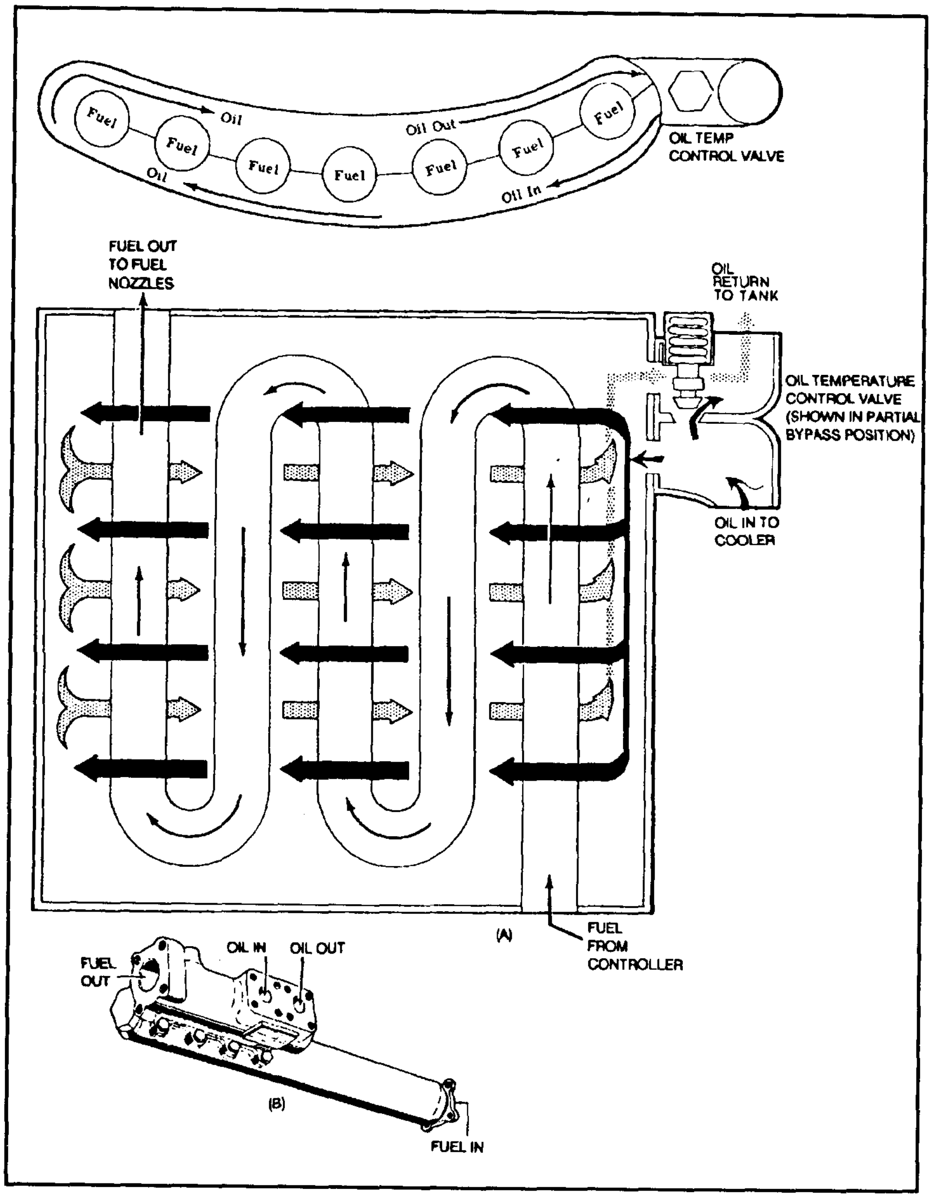


Figure 4-5. Typical Fuel-Oil Cooler

Fuel Nozzles

On most gas turbine engines, fuel is introduced into the combustion chamber through a fuel nozzle. This nozzle creates a highly atomized, accurately shaped spray of fuel for rapid mixing and combustion with the primary airstream under varying conditions of fuel and airflow. Most engines use either the single (simplex) or the dual (duplex) nozzle.

Simplex Nozzle Figure 4-6(A) illustrates a typical simplex nozzle. Its chief disadvantage is that it is unable to provide a satisfactory spray pattern in bigger engines because of the large changes in fuel pressures and airflows.

Duplex Nozzle. The chief advantage of the duplex nozzle is its ability to provide good fuel atomization and proper spray pattern at all rates of fuel delivery and airflow. At starting and low RPM and at low airflow, the spray angle needs to be fairly wide to increase the chances of ignition and good mixing of fuel and air. At higher

RPM and airflow, a narrow pattern is required to keep the flame of combustion away from the walls of the combustion chamber (Figure 4-6{B]). The small fuel flow used in idling is broken up into a fine spray after being forced through a small outlet formed by the primary holes. The secondary holes are larger but still provide a fine spray at higher RPM because of the higher fuel pressure.

For the duplex nozzle to function, there must be a device to separate the fuel into low- (primary) and high- (secondary) pressure supplies. This flow divider maybe incorporated in each nozzle, as with the single-entry duplex type (Figure 4-6[C]), or a single-flow divider may be used with the entire system (Figure 4-6[D]).

Single-entry duplex nozzles incorporating an internal flow divider require only a single fuel manifold

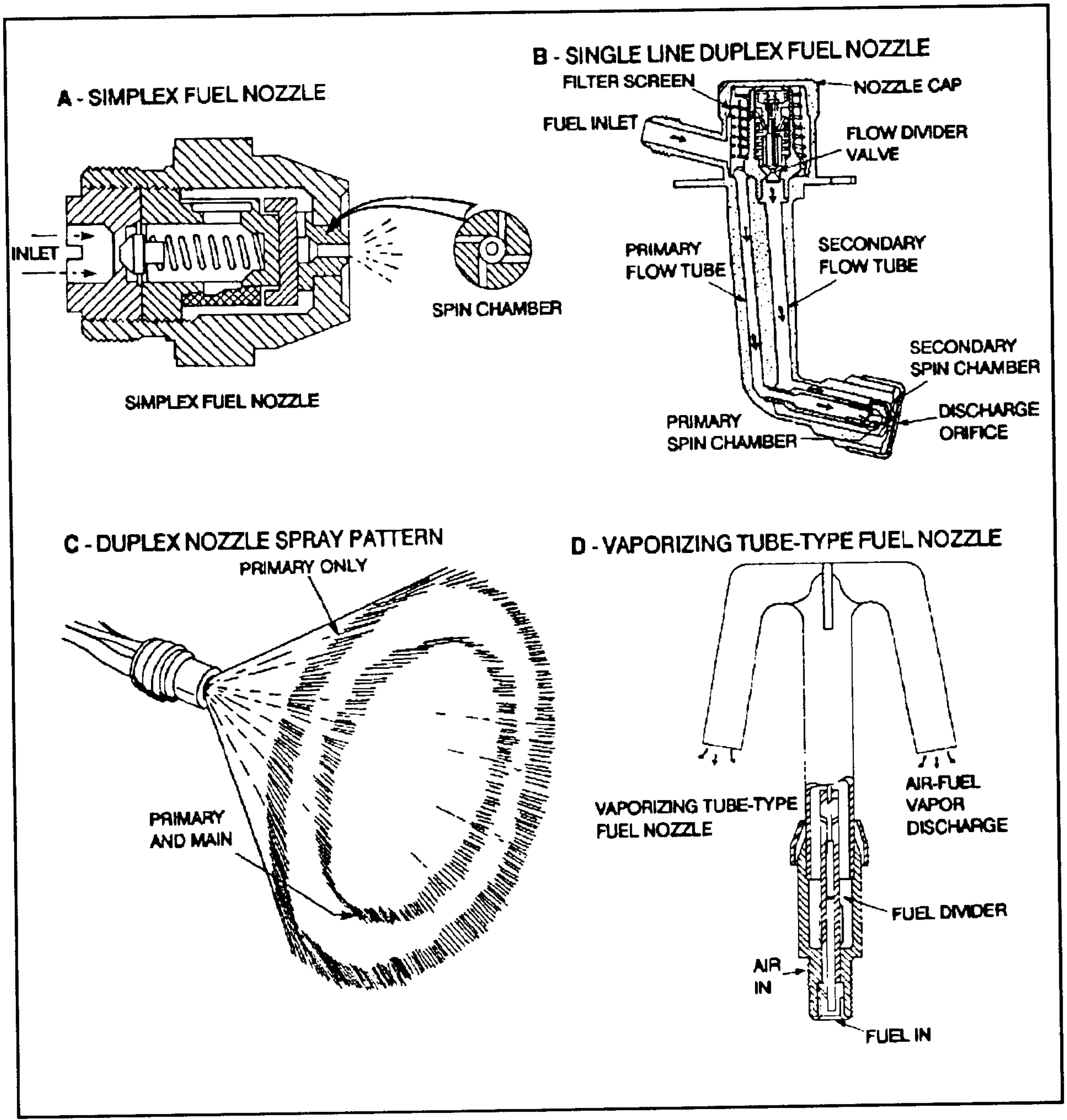


Figure 4-6. Fuel Nozzles

(Figure 4-7). Dual-entry fuel nozzles require a double fuel namifold. Some dual fuel manifolds may not be apparent as such.

Extreme care must be exercised when cleaning, repairing, or handling the nozzles. Even fingerprints on the metering parts may produce a fuel flow which is out of tolerance.

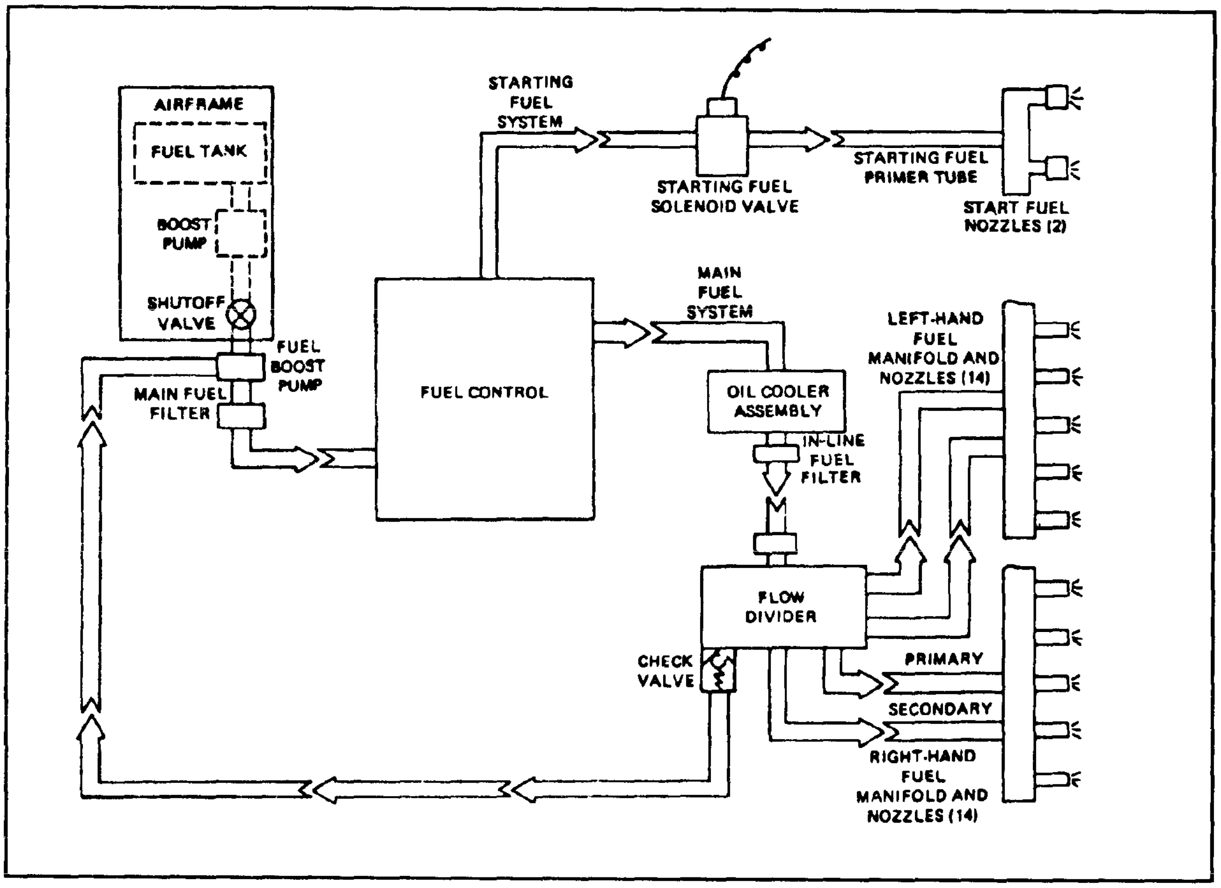


Figure 4-7. Typical Fuel Flow

The flow divider, whether self-contained in each nozzle or installed in the manifold, is usually a spring-loaded valve set to open at a specific fuel pressure. When the pressure is below this value, the flow divider directs fuel to the primary manifold or nozzle orifice. Pressures above this value cause the valve to open, and fuel is allowed to flow in both manifolds or nozzle orifices.

Most modern nozzles have their passages drilled at an angle. The fuel is discharged with a swirling motion to provide low axial air velocity and high flame speed. In addition, an air shroud surrounding the nozzle cools the nozzle tip. It also improves combustion by retarding the accumulation of carbon deposits on the face. The shroud also provides some air for combustion and helps to contain the flame in the center of the liner (Figure 4-8).

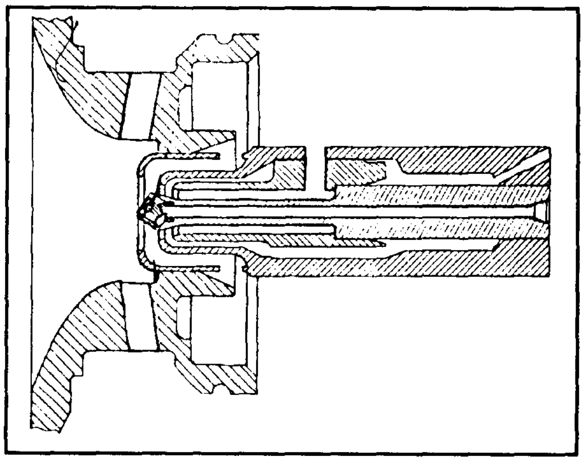


Figure 4-8. Fuel Injector Nozzle (Air Blast)

Fuel Shutoff Valves

The engine fuel shutoff valve is installed in the main fuel supply line or tank outlet to the engine. It is controlled from the pilot's compartment. A fuel shutoff valve is usually installed between the fuel control unit and the fuel nozzles. When the throttle is placed in the closed position, this ensures positive shutoff of fuel to the engine.

T-700/701 FUEL SYSTEM

The fuel system consists of the fuel boost pump, fuel filter, hydromechanical unit (HMU), and overspeed and drain valve. Integral to the HMU are the high-pressure vane pump, variable geometry (VG) actuator, and compressor inlet temperature sensor. These fuel system components are mounted on the accessory gearbox (AGB) and oriented as shown in Figure 4-9. At a 100 percent gas generator speed (Ng) of 44,700 RPM, the fuel boost pump is driven at 10,678 RPM and the HMU at 9947 RPM. This fuel-oil heat exchanger is located in the metered fuel flow path to the engine between the HMU discharge and the overspeed and drain valve inlet. Except for one external line between the HMU discharge (metered fuel) and the fuel-oil heat exchanger inlet passage, all the fuel transfer is through cored passages within AGB. This includes the boost pump inlet flange (engine-aircraft interface) to the overspeed and drain valve where the fuel discharges into the primer and the main manifolds.

A schematic diagram of the fuel system component arrangement is shown in Figure 4-10. An aircraft fuel system is depicted to show the overall aircraft-engine fuel-handling systems.

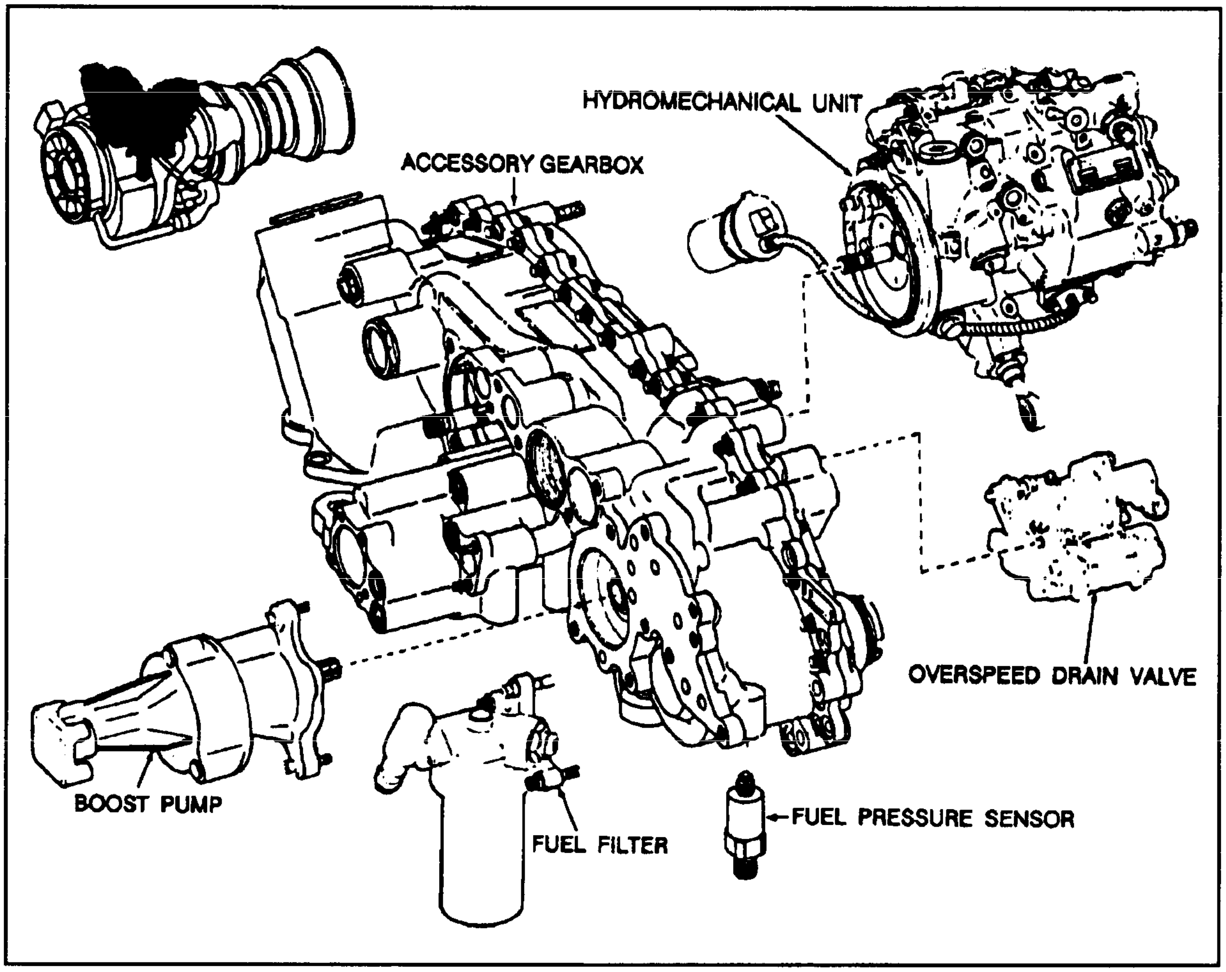


Figure 4-9. Fuel System Components

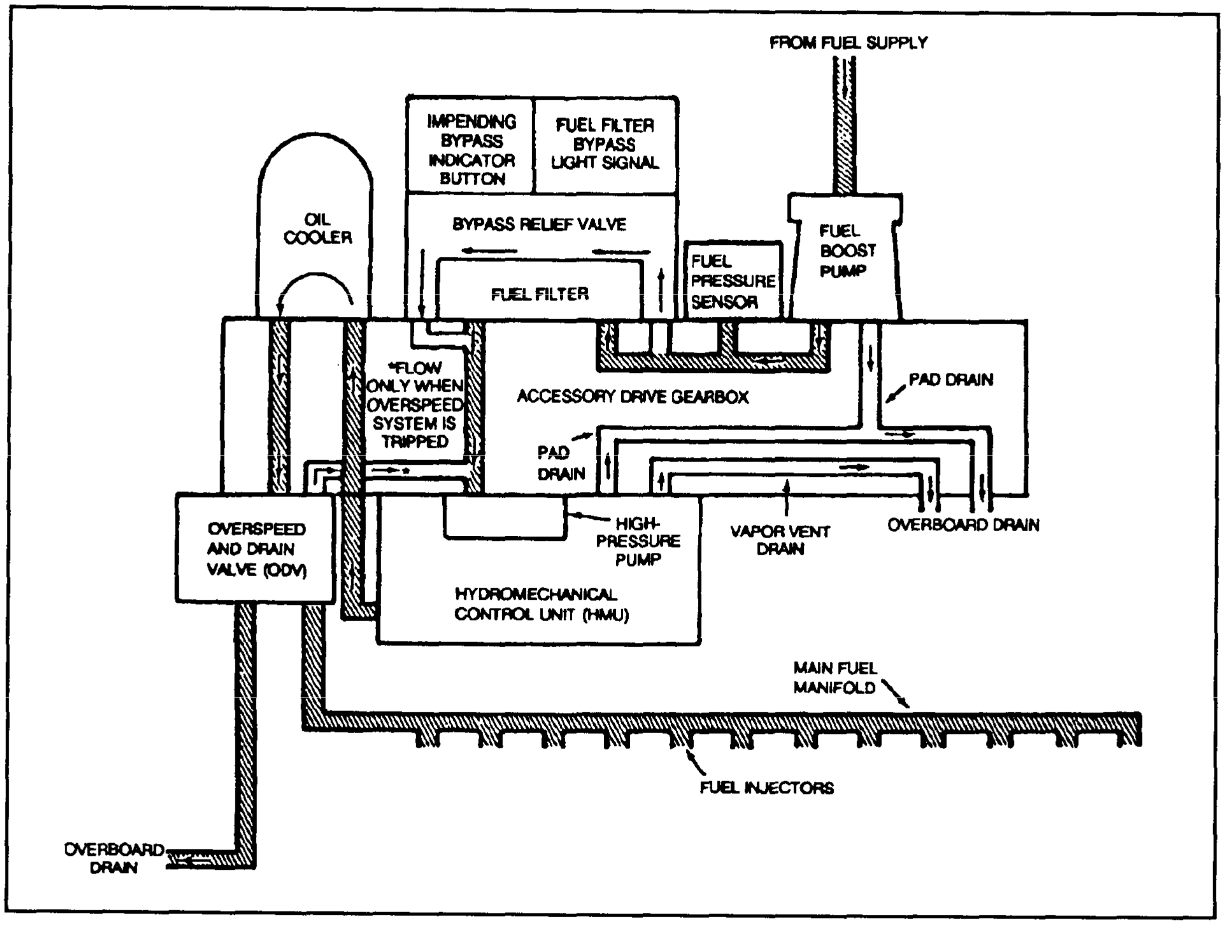


Figure 4-10. (T-701) Fuel System Schematic

Requirements

The primary requirements of the fuel system are —

- To control accurate and stable engine speed for steady-state operations and to provide transient control to achieve rapid power changes. This system pumps, filters, and meters fuel in response to power-available spindle (PAS) position, load-demand spindle (LDS) position, sensed engine variables, and torque motor input from the electrical control unit.
- To position the compressor variable stator vanes throughout the engine operating range to achieve the required airflow and stall margin performance by the compressor.
- To provide a schedule for starting bleed valve.
- To provide automatic start schedules from sea level to 20,000 feet altitude.
- To protect the engine against destructive gas generator and power turbine overspeed.

These requirements must be met over the full engine operating envelope and environment.

Fuel Boost Pump

The fuel boost pump is mounted on the AGB forward side (Figure 4-11). It is designed —

- To provide reliable suction feed from the aircraft fuel boost pump to the engine.
- To minimize vulnerability and fire hazard by continuous operation with fuel pressure in the lines from tank to engine at a pressure less than atmospheric.
- To provide discharge pressure for high-pressure vane pump minimum inlet pressure requirements.

At 100 percent Ng (44,700 RPM) the fuel boost pump operates at 10,678 RPM. Pump discharge pressure ranges from 45 to 90 psi at maximum continuous speed and 20 psi minimum at ground idle speed.

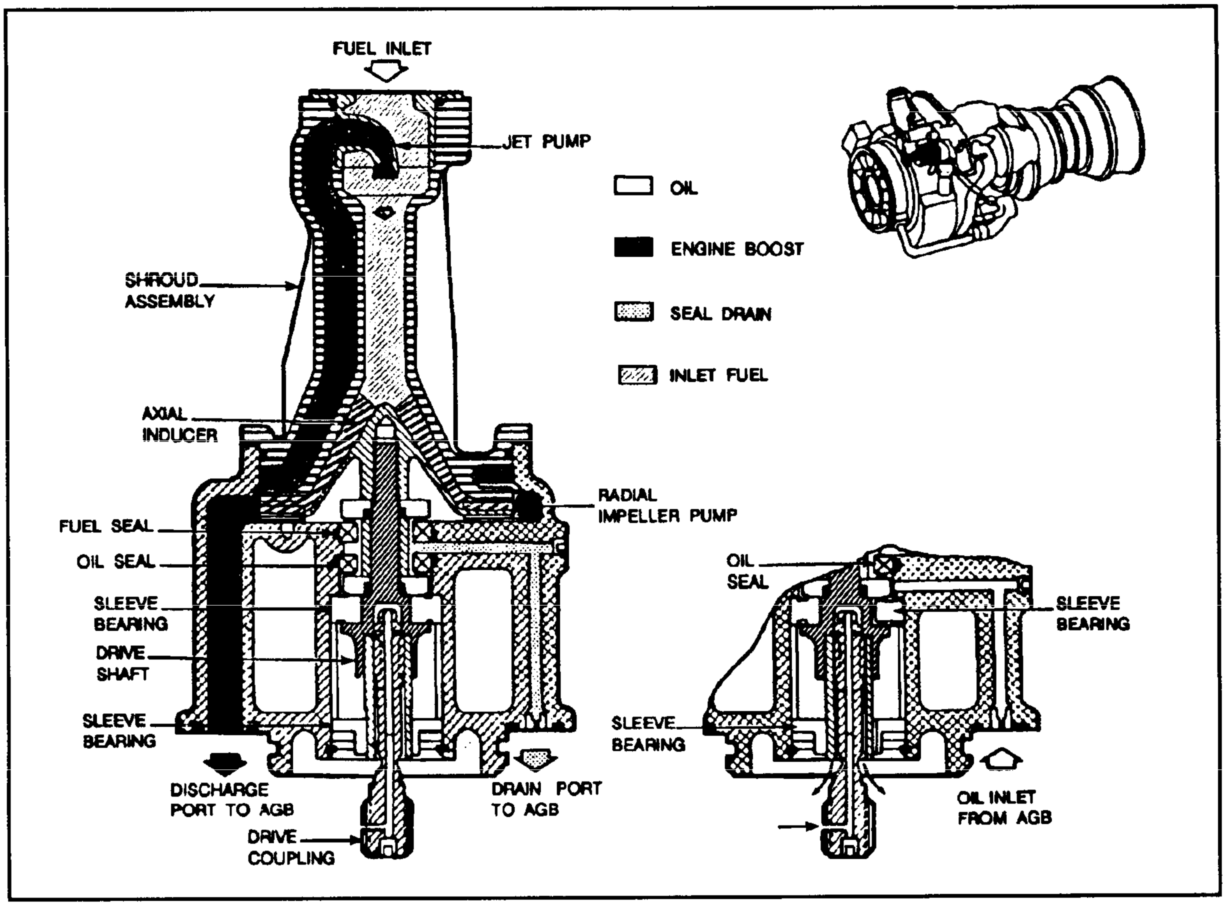


Figure 4-11. Fuel Boost Pump Cross-Section

Pump Inlet

The pump inlet is the engine-airframe fuel interface. The pump is mechanically designed as a cantilevered pumping element on a rigid shaft running in two oil-lubricated sleeve bearings. Oil is supplied from the engine oil system through a face port mating with gearbox forbearing lubrication. Oil and fuel are separated by two dynamic carbon seals with a center vent to the engine overboard drain manifold. Shaft splines are lubricated by oil mist which is pumped through the splints by radial pumping holes in the pump quill shaft and the mating engine gearbox shaft.

Pump Elements

The pumping elements are an ejector or jet pump, a mixed-flow centrifugal inducer, and a radial-flow impeller with a flow path from impeller discharge to provide ejector pump motive flow. This bypass flow is approximately equal to twice maximum engine flow at pump rated speed.

Fuel Filter

Refer to Figures 4-12 and 4-13 and refer back to 4-1. The fuel filter provides 30-micron absolute filtration for engine fuel prior to entering the high-pressure valve pump in the HMU. After passing through a core in the accessory gearbox, engine fuel flows to the filter through its inlet port from the engine boost pump discharge. The flow then is directed across the 30-micron pleated, barier-type filter element (outside to inside direction), out the discharge port through another gearbox core, and to the HMU vane pump inlet.

The fuel differential pressure across the element is sensed across a magnet assembly piston on both the impending and actual bypass indicators. At 8-10 psi of pressure differential, the impending button piston assembly moves, carrying the magnet with it. As the magnet of the impending indicator moves away from the button, the magnetic field holding the red button in the inward position is reduced, allowing the button to pop out aided by a spring.

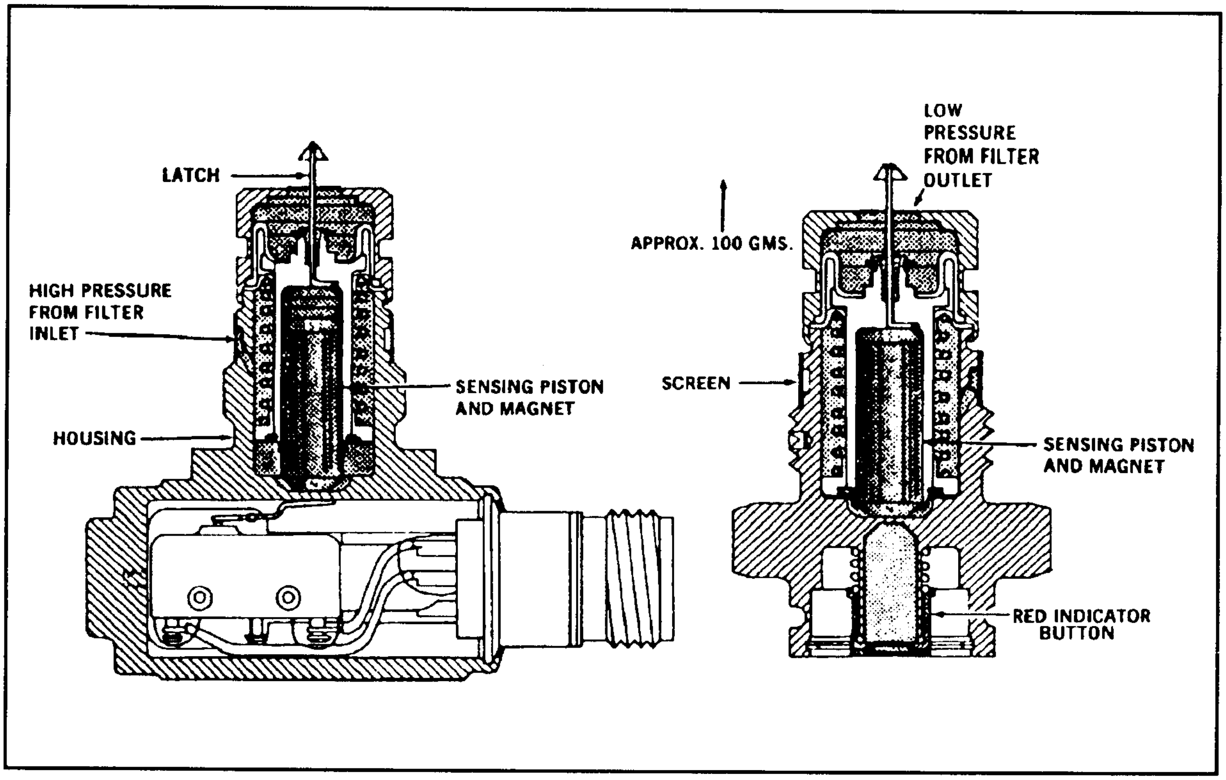


Figure 4-12. Fuel Filter Bypass Indicator Systems (Normal Position)

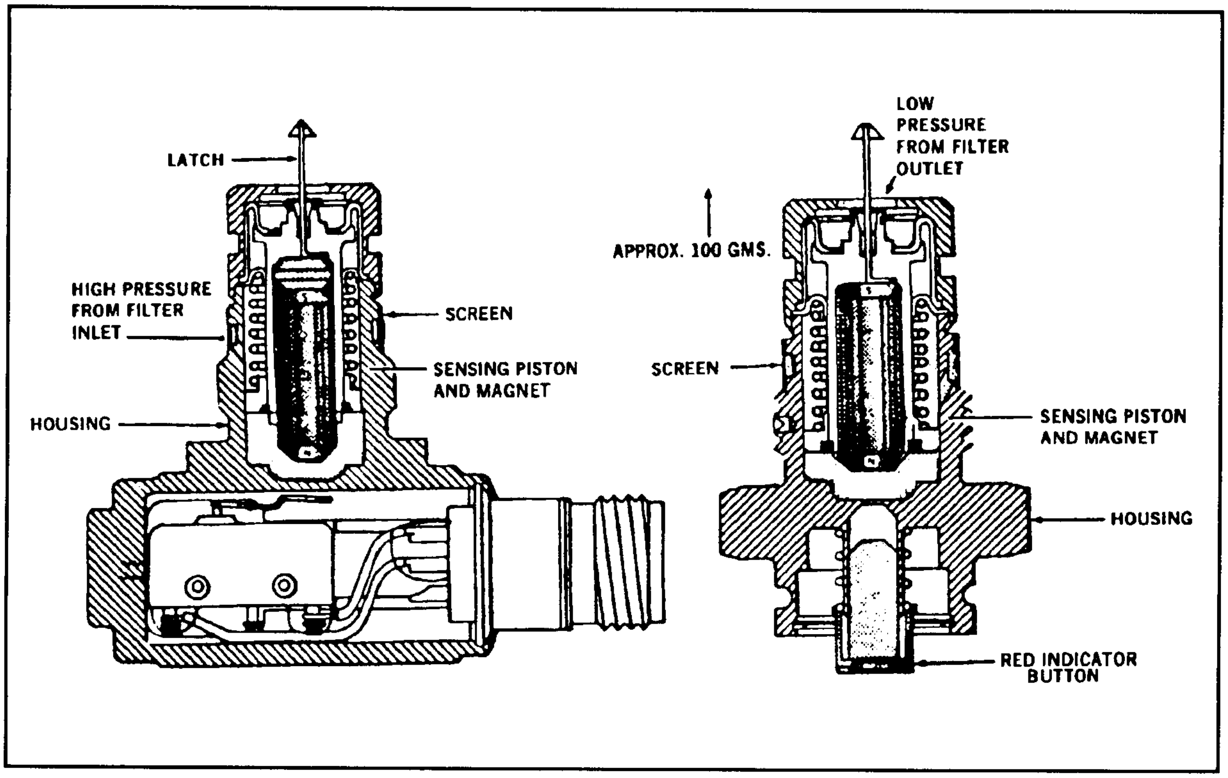


Figure 4-13. Fuel Filter Bypass Indicator Systems (Tripped Position)

The electrical filter bypass sensor (or actual bypass indicator) is activated by a pressure signal as the bypass valve opens at 18-22 psi differential pressure. However, in this case the reduced magnetic field allows the button return spring inside the microswitch to actuate the switch button through the action of the pivoted stitch lever arm. This provides a cockpit indication of filter bypass.

Impending indicator mechanisms are locked when the wire and half-ball element and the magnet piston assembly move towards the center of the filter. This causes the half ball to drop and catch on the edge of the ramp. This latching prevents the magnet piston assembly from returning to its original position. In the impending by-pass position, the button can be pushed in its recessed position but will not remain since the magnet has not returned to provide the necessary magnetic field. The filter bypass sensor does not latch.

The impending bypass button cannot be reset until the filter element and bowl assembly are removed and the reset piston pushed upwards. The reset piston upper land then trips the half-spherical ball at the end of the locking wire, allowing the spriig-loaded piston to return the magnet piston assembly to its original position.

The filter bypass valve is a poppet type. As the filter differential pressure reaches 18-22 psi, the bypass valve opens, and the sensor is activated for remote indication of filter bypassing. The filter element is disposable when loaded.

Hydromechanical Unit (HMU)

The HMU is mounted on the aft center of the AGB (Figure 4-14). It provides fuel pumping, fuel metering fuel flow computation, fuel pressurization, and fuel shutoff. It also provides gas generator speed control, compressor VG scheduling and actuation, and anti-icing and starting bleed valve actuation. The unit responds to PAS input for fuel shutoff, start, ground idle, up to maximum permissible gas generator speed, vapor venting, and electrical control unit override capability. The HMU also responds to an externally supplied load demand input via the LDS which is proportional to the power absorber load. This initially and directly coordinates gas generator speed and power to closely approximate the power required for the rotor or shaft power absorber. The HMU then responds to input from an electrical control unit (ECU) via the HMU torque motor. This trims gas generator speed as directed for both power turbine speed control and turbine temperature limiting for more exact load share control. In the event of an ECU failure, the HMU has the capability to mechanically deactivate the ECU. It also vents the unit case to the overboard drain in the event of excessive air or vapor at the inlet because of overtravel in the PAS. The HMU responds to sensed engine parameters (T_2, P_3 and N_3) which influence fuel flow and VG position.

The HMU provides three major engine functions: fuel pumping fuel metering and VG positioning.

Fuel Pumping System (High Pressure). The main fuel pump is housed within the HMU. It is a vane-type, pressure-balanced pump which is self-priming, contamination-resistant, and interchangeable (at depot-level maintenance). The gearbox drives the pump spline at 9947 RPM at 100 percent N_g The opposite end of the drive shaft serves as the rotational input to the HMU. The vane pump design was specifically developed with tungsten carbide vanes, pressure plates, and cam ring for contamination resistance.

The vane inlet pressure is internally boosted above engine boost discharge pressure by a fuel injector and injector bypass valve. This ensures positive charging of the vane element under all normal operating conditions and allows limited operation with a failed engine boost pump. The injector bypass valve maintains a differentail pressure across the injector of 12.5-135 psi. This results in a vane pump innlet pressure up to 30 psi above boost pump discharge.

A spring-loaded, high-pressure relief valve on the vane pump discharge prevents system overpressurization by limiting vane pump differential pressure to 832 psi.

Fuel Metering System. The HMU fuel metering system controls fuel flow to the engine. The components in this system are the —

- High-pressure fuel pump.
- Servo supply filter.
- Metering valve.
- Pressure-regulating valve.
- Shutoff valve.
- Minimum pressure valve.

High-pressure fuel from the pump passes around the outside of the servo supply wash filter and goes to the metering valve. The metering valve, in conduction with the pressure-regulating valve, meters required engine flow proportionally to the metering valve area and bypasses excess fuel through the PRV back to the pump inlet.

Variable Geometry Positioning System. A stator vane actuator is an integral part of the HMU. It provides positioning of the variable stator vanes and the anti-ice and the start bleed valve for efficient engine operation throughout the engine speed (N_g) range. A servo piston within the HMU provides an external output (force and position) to set the engine VG as a function of N_g and T_2 This schedule is contoured on the N_g speed servo 3D cam. Motion of the schedule-follower lever moves a link pivoted on the actuator piston. This action strokes a double-acting, spring-loaded, rotating pilot valve. The valve then provides high- and low-fuel pressure signals to opposite sides for the VG actuator piston. Motion of the actuator returns the pilot valve to a null position, which cm-responds to the input position being scheduled. The actuator provides minimum force output of 280 pounds and is positioned as a function of corrected speed.

Engine Start

With the engine shut down, the pressure in the overspeed and drain valve is equal to ambient pressure, and the inlet and pressurizing valve is spring-loaded closed. When the engine is cranked over and the PAS is advanced to the stopcock in the HMU, the HMU delivers, metered flow to the overspeed drain valve inlet. This metered flow passes through awash-flow filter, and line pressure builds up until the inlet and pressurizing valve opens. Fuel boost pressure is directed to the top of a selector valve. Higher-pressure W_f passes through the open selector valve and flows to the 12 fuel injectors for engine lightoff and normal operation.

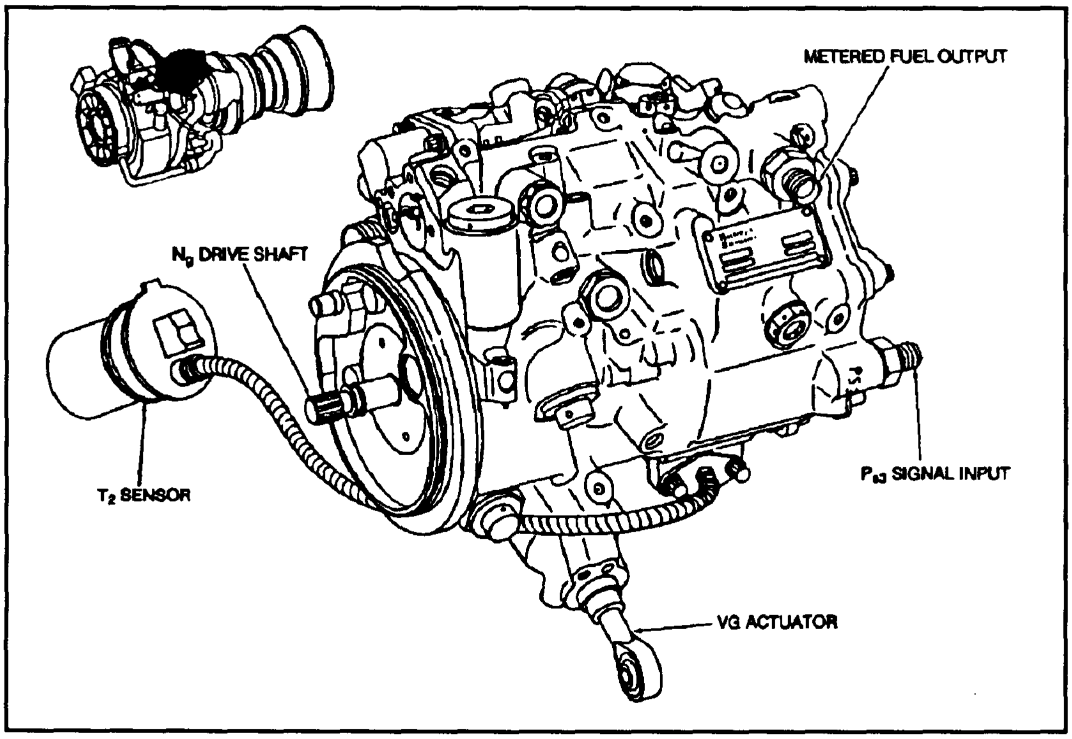


Figure 4-14. Hydromechanical Unit

Overspeed and Drain Valve. The T7-GE-701 valve controls the sequencing of fuel between the main manifold and the primer manifold (Figure 4-15). The valve also provides shutoff, drain, primer manifold purge functions, and N_p overspeed protection. The assembly consists of the following components

- Shutoff and drain valve.
- Pressurizing valve.
- Wash flow filter.
- Bypass valve (N_p overspeed).
- Fuel servo solenoid valve (N_p overspend).

Engine Shutdown

When the PAS is moved to the OFF position, the HMU is stopcocked, fuel flow to the overspeed and drain valve is stopped, and the inlet and pressurization valve is forced down by spring action. This opens the main fuel line in the overspeed and drain valve to overboard drain pressure. The residual P_3 pressure in the combuster forces the fuel injectors and main manifold back through the overspeed and drain valve and out the overboard drain line.

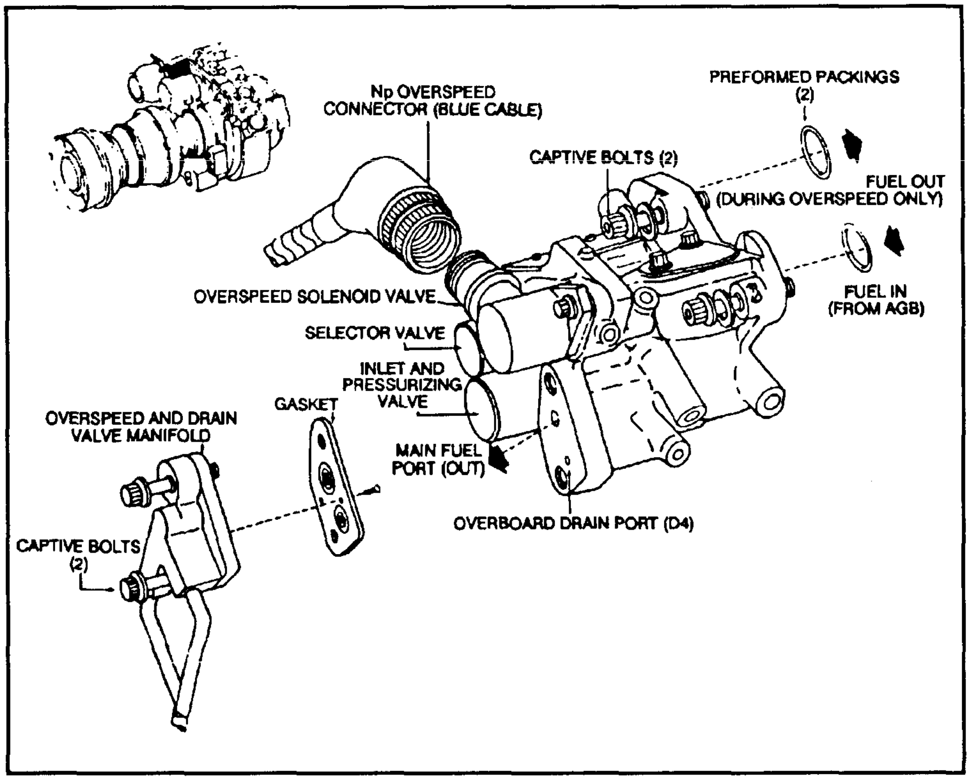


Figure 4-15. Overspeed and Drain Valve

Power Turbine (N_g) Overspeed Protection

The turbine overspeed function is designed to divert fuel flow from the combustor and flameout the engine to protect against destructive N_p overspeed (Figure 4-16). When N_p reaches 25,000 RPM (119.6 percent), the solenoid valve in the ODV is energized and opens a ball valve. This causes a bleed-off of equalizing fuel pressure on the bottom part of the selector valve. The high pressure W4 causes the selectro valve to move down and all W4 to bypass back to the HMU inlet. The instantaneous loss of W4 to the combustor causes the engine to flameout.

Fuel Injectors

Twelve fuel injectors, installed in the midframe, receive fuel from the main fuel manifold and supply it to the combustion liner swirl cup (swirler) subassemblies (Figure 4-17). The swirlers consist of counter-rotating-flow primary and secondary vanes with venturi sleeves between the two radial inflow swirler vanes. Fuel from the injector is forced into these sleeves, and the counter-rotating flow creates shear layers which break up the fuel film into finely atomized sprays.

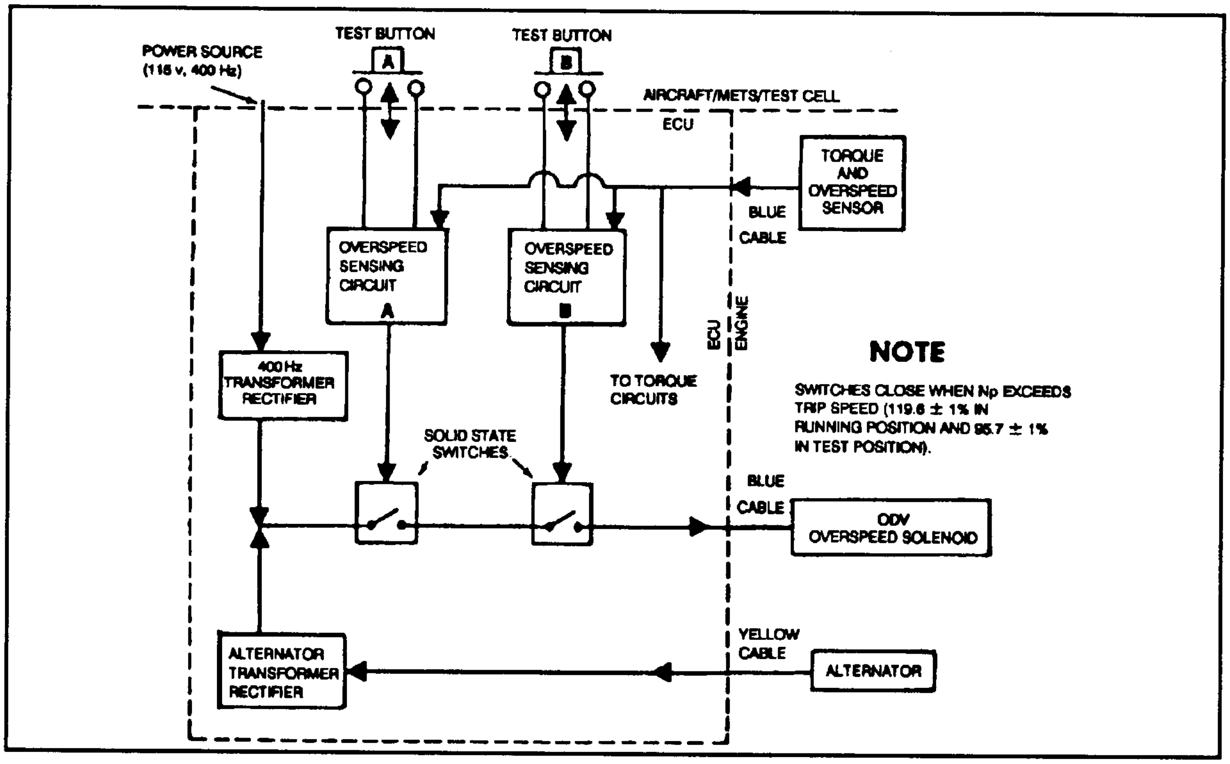
The injector is a simplex nozzle with a single spin chamber fed by two spin holes. The swirled fuel from the spin holes exits through an orifice and discharges onto a 30° primary cone. This cone flares outward at the exit. The contoured exit provides a good-quality fuel spray at very low fuel pressure in the starting regime. The primary cone is housed in an air shroud which has six air holes. These six air holes feed air to augments the atomization of the fuel. This hydraulic design is simple; contains no valves, flow dividers, or secondary orifices and is purged by compressor discharge air during shutdown to prevent plugging.

The injector has a military standard fitting at the inlet with a last-chance, 0.009-inch diameter mesh screen to protect the orifice spin slots. A locating pin in the mounting flange assures correct orientation of the injector within the midframe casing. It is not necessary to remove the injectors before removing or replacing the combustion liner.

FUEL CONTROL UNIT

Types

Modern fuel controls can be divided into two basic groups: hydromechanical and electronic. Hydromechanical controls are used most often. Fuel controls are extremely complex devices composed of speed governors, servo systems and feedback loops, valves,



NOTE

SWITCHES CLOSE WHEN Np EXCEEDS TRIP SPEED (119.6 ± 1% IN RUNNING POSITION AND 95.7 ± 1% IN TEST POSITION).

Figure 4-16. (T-701) N_p Overspeed Protection System

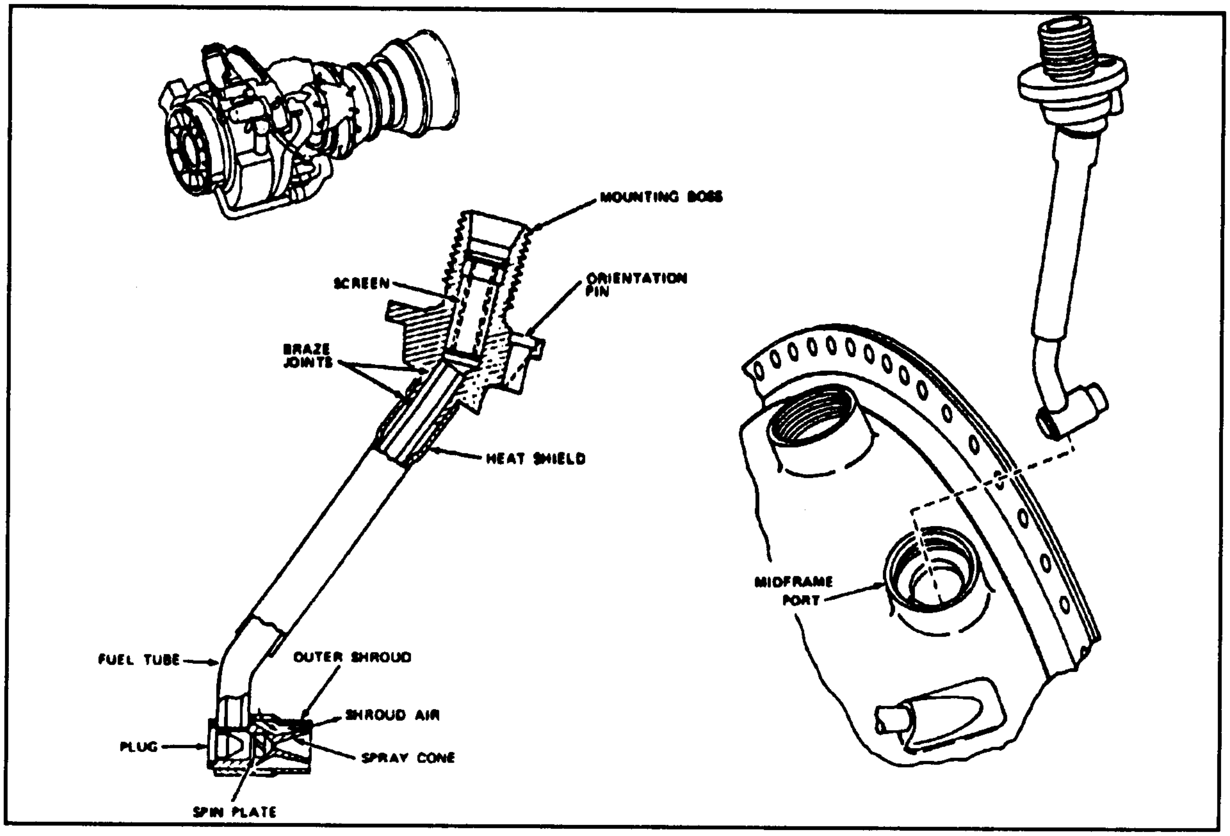


Figure 4-17. Fuel Injector

metering systems and various sensing mechanisms. Electronic fuel controls contain thermocouples, amplifiers, relays, electrical servo system switches, and solenoids. The discussion of fuel-control theory will address mainly the hydromechanical type. The simplest control is a plain metering valve to regulate fuel flow to the engine. This type of control could be installed on an engine used for thrust or gas generation.

Fuel controls may sense some or all of the following engine operating variables:

- Pilots demands.
- Compressor inlet temperature.
- Compressor discharge pressure.
- Burner pressure.
- Compressor inlet pressure.
- RPM.
- Turbine temperature.

Some refinements might include a —

- Pump to pressurize the fuel.
- Shutoff valve to stop fuel flow.
- Relief valve to protect the control when the shutoff valve is closed.
- Minimum fuel control adjustment to prevent complete stoppage of fuel by the metering valve.

Turboprop and Turboshaft Engine Fuel Controls

Like fuel controls for turbojet and turbofan engines, the fuel control for a turboprop or a turboshaft engine receives a signal from the pilot for a given level of power. The control then takes certain variables into consideration. It adjusts the engine fuel flow to provide the desired power without exceeding the RPM and turbine inlet temperature limitations of the engine. But the turboprop or turboshaft engine control system has an additional job to do that is not shared by its turbojet and turbofan counterparts. It must control the speed of the propeller or the free turbine, and it usually governs the pitch angle of the propeller blades.

Many turboprop and turboshaft engines in production today are the free turbine type. Engines of this kind act principally as gas generators to furnish high-velocity gases that drive a freely rotating turbine mounted in the exhaust gas stream. The free turbine turns the propeller through a system of reduction gears. If the engine is a turboshaft model, the free turbine rotates (also through reduction gears) a helicopter rotor or powers a machine. The General Electric T-700 and the Lycoming T-55-L-712 fuel control system follow.

T-700 CONTROL SYSTEM

The engine control system incorporates all control units necessary for complete control of the engine. The system provides for the more common functions of fuel handling, computation, compressor bleed and VG control, power modulation for rotor speed control, and overspeed protection. The system also incorporates control features for torque matching of multiple engine installations and overtemperature protection.

The T-700 control system was designed for simple operation requiring a low level of pilot attention. The system performs many of the controlling functions formerly performed by the pilot. This has been done by providing —

- Isochronous power turbine and helicopter rotor (N_p / N_r) governing.
- Automatic load sharing.
- Automatic limiting of power turbine inlet temperature.
- Rapid engine transient response through collective compensation.
- Automatic starting
- Contingency power.

Basic system operation is governed through the interaction of the electrical and hydromechanical control units. In general, the HMU provides for gas generator control in the areas of acceleration limiting, stall and flameout protection, gas generator speed limiting rapid response to power demands, and VG actuation. The ECU trims the HMU to satisfy the requirements of the load to maintain rotor speed, regulate load sharing, and limit engine power turbine inlet temperature.

Component Arrangement and Interconnection

Metering of fuel to the engine and basic engine control computations are performed in the hydromechanical control unit (Figure 4-18). The electrical and hydromechanical control units compute the fuel quantity to satisfy power requirements of the engine. The fuel and control system contains the following components:

- Hydromechanical control unit which includes a 9947 RPM (at 100 percent of Ng) high-pressure vane pump package and a closed-loop VG servo-acutator. The basic unit meters the required fuel to the engine as a function of $N_g T_2$, P_3, an electrical trimming signal from the engine-mounted electrical control unit, and cockpit inputs of PAS and LDS.

- Electrical control unit which resets the hydromechanical control unit within acceptable engine limits to maintain isochronous N_p governing while automatically limiting TGT. The unit exchanges torque signals to provide automatic load sharing for multiengine use. The ECU provides —

— A separate signal to the overspeed and drain valve for N_P overspeed protection.

— The required signals to an engine-mounted recorder to provide a record of engine operational history.

— The desired cockpit signals needed for proper engine operation.

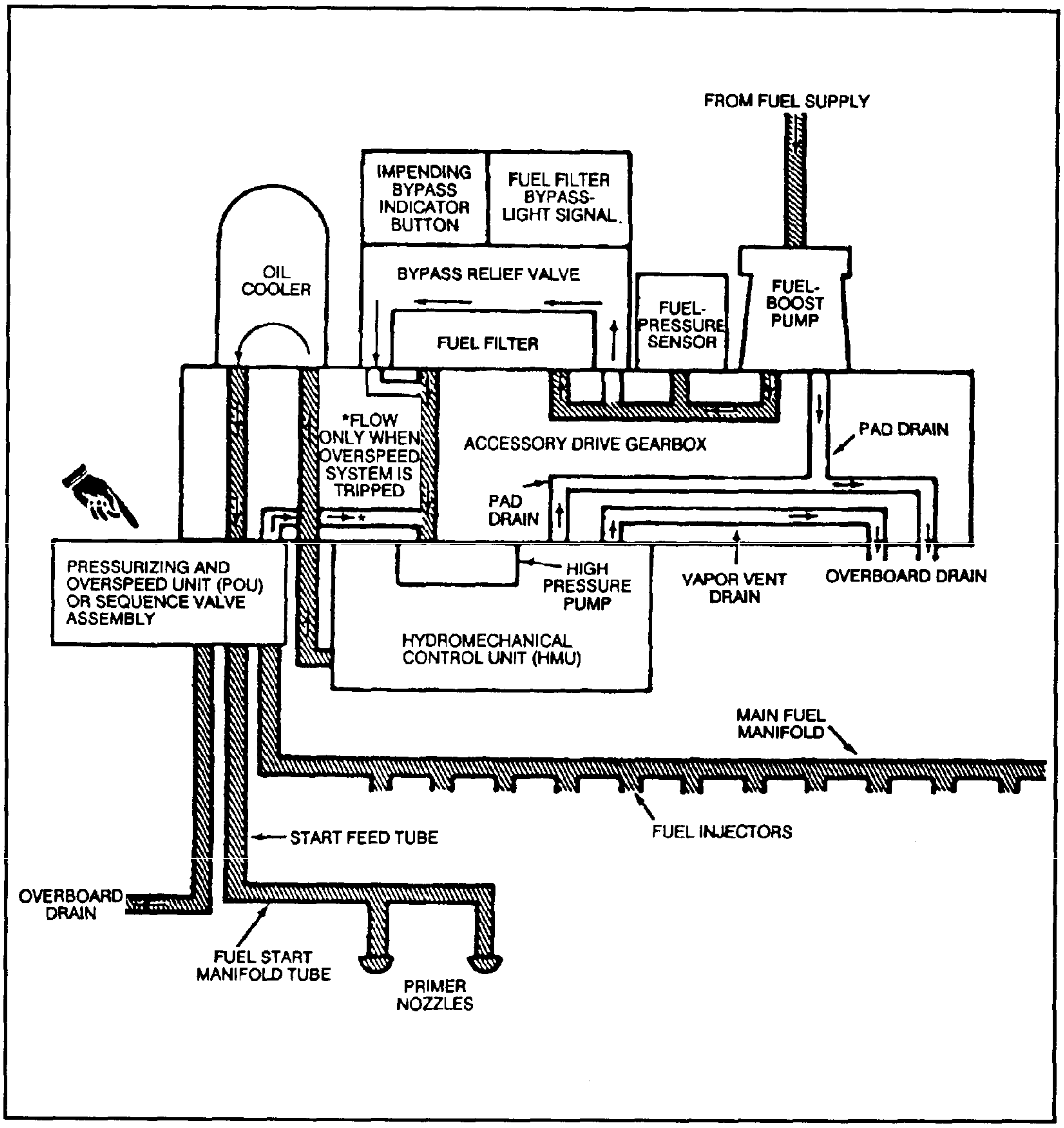


Figure 4-18. (T-700) Fuel System Schematic

For the T-700-GE-701/701A engines in a one-engine inoperative (OEI) condition, the automatic contingency power switch, located in the ECU, resets the temperature limit amplifier to allow for more power is required for the operating engine.

Figure 4-19 lists the functional split between the two units mentioned above.

HYDROMECHANICAL UNIT

- FUEL PUMPING
- FUEL FLOW METERING
- COLLECTIVE PITCH COMPENSATION THROUGH LDS
- ACCELERATION AND DECELERATION FLOW LIMITING (INCLUDING STARTING)
- N_g LIMITING
- VARIABLE GEOMETRY POSITIONING
- TORQUE MOTOR TO TRIM N_g GOVERNOR
- PAS OVERRIDE AND CONTROL WITH ELECTRICAL UNIT INOPERATIVE
- VAPOR VENT ON PAS OVERTRAVEL FOR FUEL SYSTEM PRIMING

ELECTRICAL CONTROL UNIT

- HMU TRIMMING OF N_g GOVERNOR AS DETERMINED BY:
  - a. ISOCHRONOUS N_p GOVERNING
  - b. TGT LIMITING
  - c. LOAD SHARING ON TORQUE
  - d. N_p REFERENCE INPUT FROM COCKPIT
- REDUNDANT N_p OVERSPEED LIMIT
- COCKPIT SIGNAL GENERATION OF N_p, TGT AND TORQUE
- HISTORY RECORDER SIGNALS

Figure 4-19. Control System Functional Split

Fully integrated operation of the engine results from three inputs:

- Power-available spindle. This input has a function similar to the throttle or power lever of other engine controls. It mechanically stopcocks fuel and sets permissible gas generator speeds for operating condtions from ground idle through intermediate power. Overtravel beyond 120° to 130° actuates an electrical unit interface lockout, used in the event of an electrical unit failure. It vents the hydromechanical unit ease to overboard drain to facilitate priming of the fuel system.
- Load-demand spindle. This input is a function of collective pitch. It provides collective compensation reduce rotor transient droop.
- Rotor speed referenee. A cockpit mounted electric potentiometer sets desired power turbine speed.

Hydromechanical Unit Operation

The HMU operates as a conventional gas generator power control when there is no input to the torque motor and with the load demand spindle set for maximum load (Figure 4-20). Engine schedules such as acceleration fuel flow and compressor VG position, are controlled by N_g and T_2. The acceleration (or stall) limit is immposed by a maximum can schedule of Wf/P_3 versus N_g and T_2. A minimum flow schedule controls engine deceleration. Maximum and minimum metering valve stops provide absolute fuel-flow limits. An intermediate topping line controls maximum N_g speed. The topping line also limits excessive $T_{4.5}$ in event of an electrical $T_{4.5}$ control-system failure. Since these features are incorporated in the HMU, any power-available spindle motion will result in safe engine operation and will not cause engine damage. Except for intentional stopcocking of the control, no inadvertent shutdowns will occur from PAS motion.

A load-demand signal is introduced to the HMU through the LDS. When the LDS is reduced for its maximum setting with a reduction of aircraft rotor collective pitch setting the desired N_g is reset down from the prevailing PAS setting to provide immediate and accurate gas generator response. This new setting is trimmed by the ECU to satisfy the N_p and load control functions established by the ECU.

The PAS sets a maximum available gas generator speed. The pilot usually sets this 120° PAS angle allowing the gas generator speed to reach a value which gives intermediate power. Through this collective pitch setting, the pilot positions the LDS to adjust available N_g to power level approximately equal to the rotor load demand power. The actual level of horsepower at 120° PAS angle will be more than required by the helicopter. This is intentionally done for two reasons:

- Fail-safe to high power. By placing the schedule high, the torque motor is designed to reduce the schedule to the desired level when it is energized. Because loss of torque motor current causes the schedule to return to the highest level, this provides failure protection to a high power. A schedule that is biased high due to electrical failure does not cause power limiting. In the event of an electrical system failure, it can be manually retarded to a more desirable level using the PAS. With all engine protection functions in the HMU, no engine damage or stall can occur during or following any loss of electrical signal to the torque motor.
- Power available with one engine out. The schedule is placed high enough that, in the event of failure of one engine, the remaining engine's gas generator can increase power enough (automatic contingency power) to carry the load at the given LDS (collective pitch) setting. Without this arrangement of schedules, a single-engine failure could not be compensated for by the remaining engine and would result in a significant loss of available power.

Electrical Control Unit Operation

The ECU, powered from an engine-mounted alternator (Figures 4-21, 4-22)—

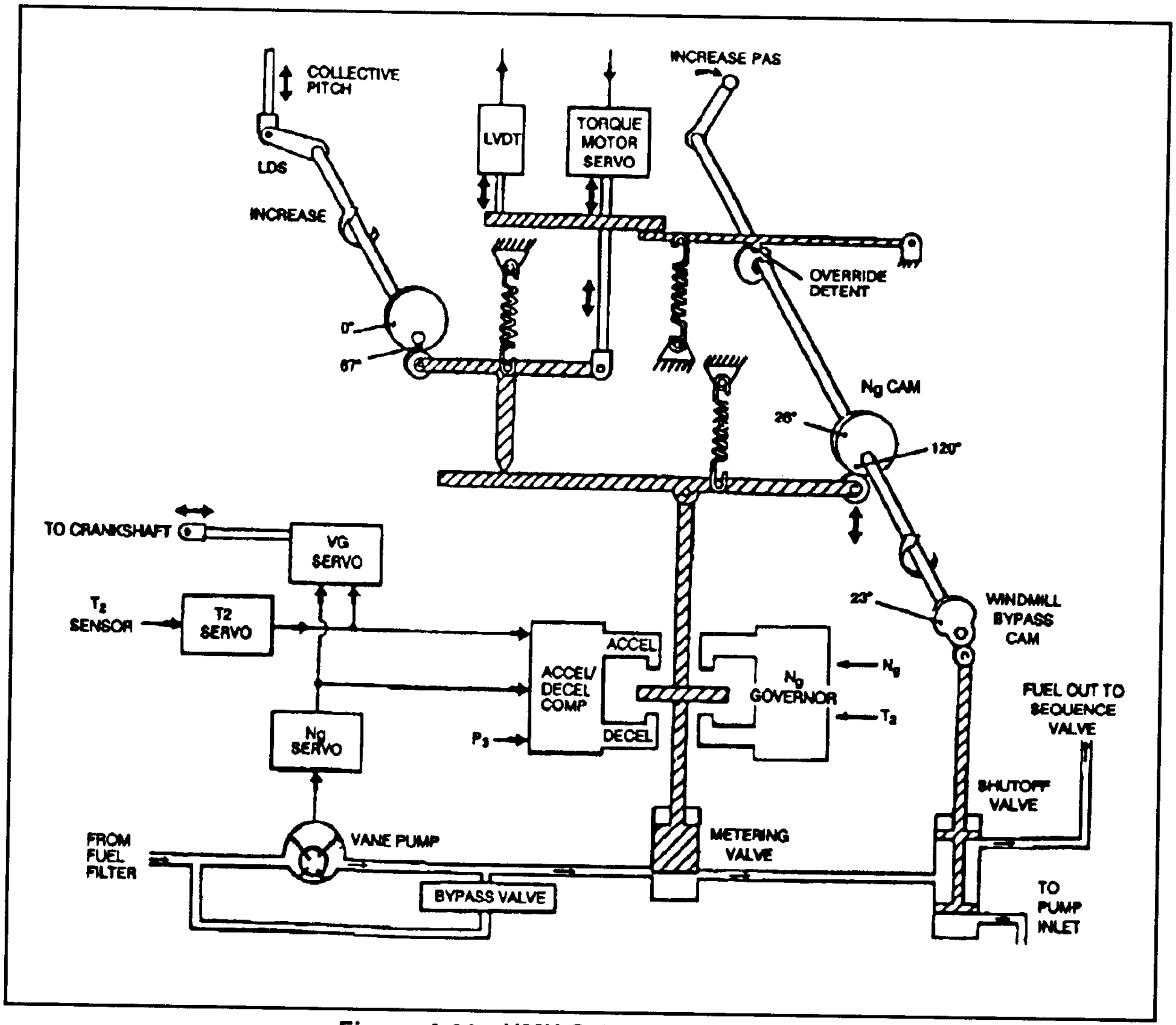


Figure 4-20. HMU Schematic Diagram

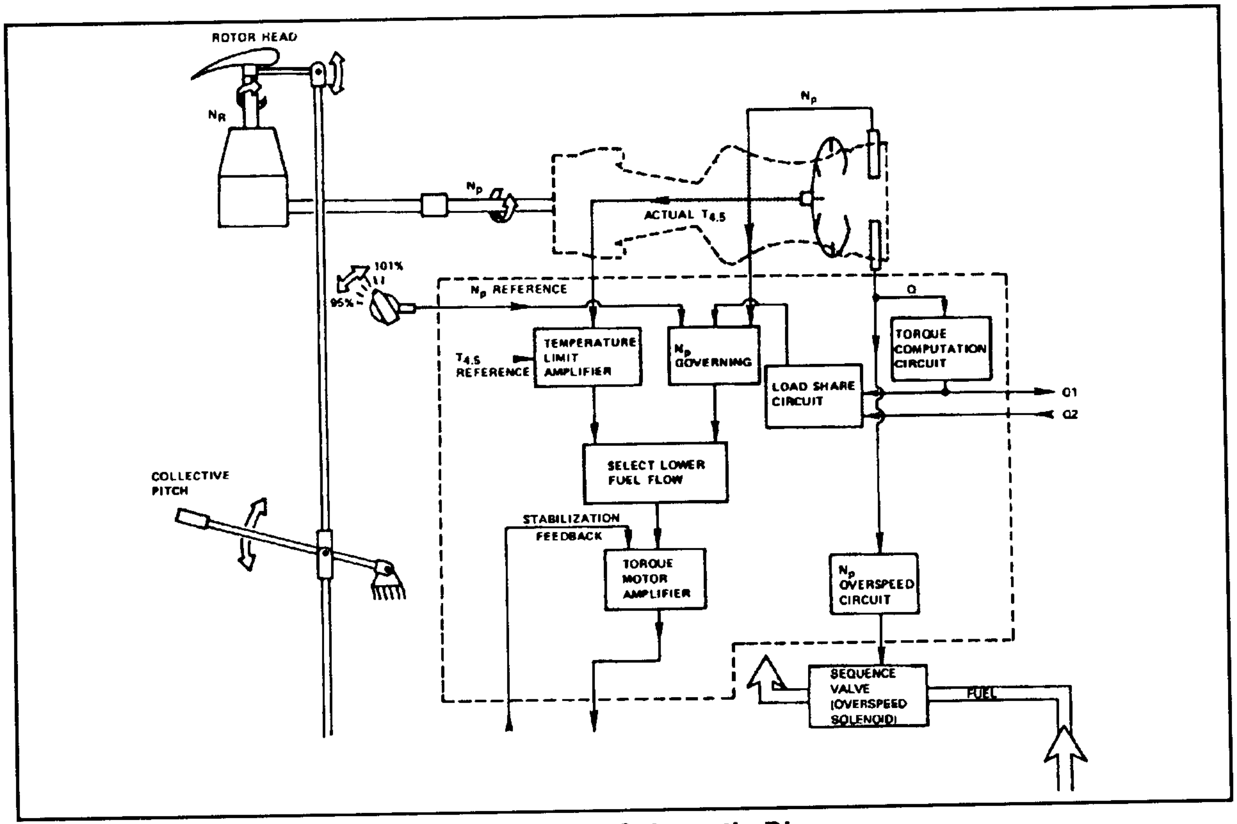


Figure 4-21. ECU Schematic Diagram

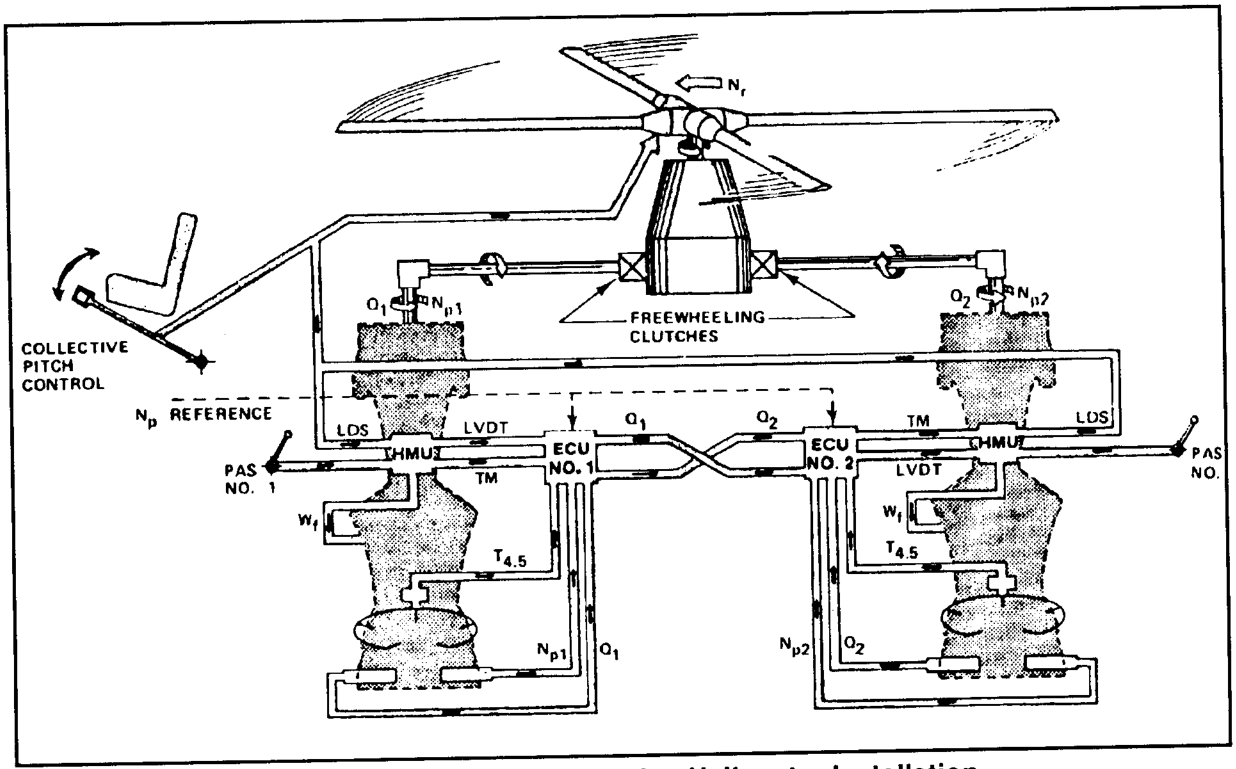


Figure 4-22. T-700 Twin-Engine Helicopter Installation

- Compares actual N_p to a reference N_p to compute a speed error input signal for use in electrical control computation.
- Compares actual torque of the engine to torque of the other engine for load sharing. If the engine torque (Q_1) is less than that of the other engine (Q_2), supplies a torque error signal to the computer. No error signal appears if Q_1 is greater then Q_2. This arrangement (frequently reffered to as a match-the-maxixmun principle) prevents the load-sharing circuit from causing a good engine to reduce power to match a power-limited engine. The torque error signal is added to the N_p speed reference signal and can increase up to 3 percent over the selected N_p.
- Compares measured engine TGT to a fixed-reference TGT. When (and only when) temperature is above the reference, develops a signal to reduce fuel flow to correct the overtemperature.
- Compares the combined speed error and load-sharing signal to the overtemperature signal in the selector circuit of the ECU. Selects the signal calling for the lowest N_g and passes it to the HMU to reduce gas generator power as required.
- Sends an electrical output from the selector drives to a torque motor in the HMU. The torque motor can shift the load demand scheduled as if the PAS were moved in a reduced power demand direction. The torque motor can retard N_g no further than ground idle and can only allow power to increase to the PAS setting. The ECU may be overridden at any time by advancing PAS beyond the normal (120°) flight position to the 130° stop. PAS may then be retarded to trim the engine manually. Note that this has no effect on the N_p overspeed system, which remains fully operational.

Takeoff and Climb

Before takeoff, the PAS lever is advanced from ground idle to 120°, which is the normal flight position. This allows the rotor head to accelerate to 100 percent N_p / N_r with the collective still in flat pitch. N_g will rise as the PAS is advanecd but will cut back after the N_p governing speed of 100 percent is reached. (N_p governing can be selected at 95-101 percent, but 100 percent is considered standard.)

To take off, collective pitch is increased, increasing the torque load on the power turbine. Simultaneously, the LDS rotates, calling for an increase in gas generator speed to keep N_p / N_r from falling below 100 percent. The ECUs of each engine perform a fine trim of fuel flow to match torques and trim N_p / N_r to 100 percent.

As N_g inereases, the HMU schedules the bleed valve closed and the variable stators open to increase airflow through the combustor and turbine.

If collective pitch is increased to a very high angle, TGT may approach the temperature limiting value. When this occurs, the ECU prevents any further increase in fuel to the engine. If torque load is increased further, N_p / N_r will droop below 100 percent because power turbine governing must be sacrificed to protect the engine against overtemperature.

Cruise and Descent

At the end of the climb segment, less rotor lift is required and collective pitch is recked. The LDS rotates to reduce fuel flow and N_g; the variable stators will close slightly to optimize part-power fuel consumption and preserve stall margin.

Again, ECUs trim fuel flow. Upon entering a descent, the same sequence of events reduces N_g to the point that the bleed valve maybe opened. If the collective pitch is fully lowered, autorotation (power-off descent) is reached, and the torque drops to zero; overrunning clutches in the airframe transmission preclude a negative torque situation. Once the engines are uncoupled from the rotor, N_r is free to accelerate above 100 percent; and both engines will continue to govern N_p at 100 percent. N_r and N_p rotor speeds are held in reserve to pick up the rotor load when collective is again increased. This condition (100 percent N_p zero torque) is known as flight idle.

T-55-L-11E/T55-L-712 FUEL CONTROL SYSTEM

The fuel control for the Lycoming T55-L-712 free power turbine engine is a hydromechanical type designated by Hamilton Standard as the JFC 31-22. It consists of the following main units:

- Single-element fuel pump.
- Gas producer speed governor.
- Power turbine speed governor.
- Acceleration and deceleration control.
- Air bleed signal mechanism.
- Maximum flow limiter.
- Fuel shutoff valve.
- Temperature compensator.

Figure 4-23 schematically describes the fuel control system. Fuel control can be divided on a functional basis into two sections: the flow control section, consisting of the valving which meters engine fuel flow, and the computer section. The computer section includes the elements which schedule position of the flow control section metering valves as a function of the control input signals. The computer section also signals the closure of the compressor bleed valve.

This computer operates primarily on four engine parameters gas producer speed (Ng), power turbine speed (Np), compressor discharge total pressure (Pt3), and compressor inlet total temperature (Tt2) for a given power Iever position and power turbine speed-setting lever position. The ratio of engine fuel flow to compressor discharge total pressure is the manipulated variable used to control engine power output. This variable is biased by Tt2 during acceleration and Ng topping.

The position of the engine fuel flow metering valve is established by a multiplication of two positions representing compressor discharge pressure (P3) and fuel flow (Wf). The (Wf) engine fuel flow is made proportional to the metering valve position by maintaining a constant differential pressure across the valve flow area, which varies linearly with valve position. This constant pressure in maintained by the pressure regulating valve. This valve is positioned as necessaryto maintain a 40-psi differential across the metering area. To accomplish this, all pump output not required to operate servos and supply engine flow requirements is bypassed back to the pump inlet.

The P3 servo (motor) is positioned by directing compressor discharge (P3) to a bellows, which positions the servo directly proportional to P3 air pressure. The servo is connected to the P3 ramp, which moves proportional to servo inputs. The ramp works directly against the ratio servo and in turn positions the metering valve.

The ratio servo maybe positioned by anyone of four inputs: the Np governing linkage, the Ng governing linkage, acceleration limiting linkage, or the maximum flow limiter. The inputs, which schedule the lowest fuel flow, determine the position of the metering valve. The ratio servo and the Ng servo provide an input to the compressor bleed air signal mechanism.

The Np governor linkage input to the ratio servo is controlled by the Np servo piston whose position is established by a flyball-operated pilot valve. It functions as a droop-type governor, limiting fuel flow proportional to speed over its operating range, which is set by the power turbine speed setting lever position. The Np governing linkage input to the ratio servo is biased by Ng speed such that Np governing droop line position increases in speed as Ng speed decreases.

The Ng governing linkage input to the ratio servo is controlled by the Ng servo piston whose position is established in the same manner as the Np servo. It functions as a droop-type governor, limiting the ratio servo inversely proportional to Ng speed over its operating range. Its operating range (ground idle to maximum speed) is established by the power and shutoff lever position. This linkage is also biased by T2 through the speed reset linkage.

The acceleration limiting linkage input to the ratio servo is controlled by a contour on the 3D cam. The 3D cam is positioned longitudinally by the Ng servo piston and rotated by the T2 servo piston. This provides a unique cam positioned for each set of NG speeds and T2 conditions. The acceleration finding cam contour schedules the maximum allowable fuel of low P3 ratio at each speed and temperature setting. The 3D cam also positions the speed reset linkage through the speed reset contour and provides an input to the bleed air signal mechanism.

The position of the T2 servo is established by the liquid-filled bellows which positions the servo directly proportional to the compressor inlet temperature.

The maximum flow limiter input to the ratio servo limits the engine shaft torque by limiting fuel flow. This is done by positioning the ratio servo as necessary to reduce fuel flow at a safe value.

The control computer section also provides a pneumatic signal to the bleed air acutator which is used to open or close the bled air during appropriate phases of engine operation.

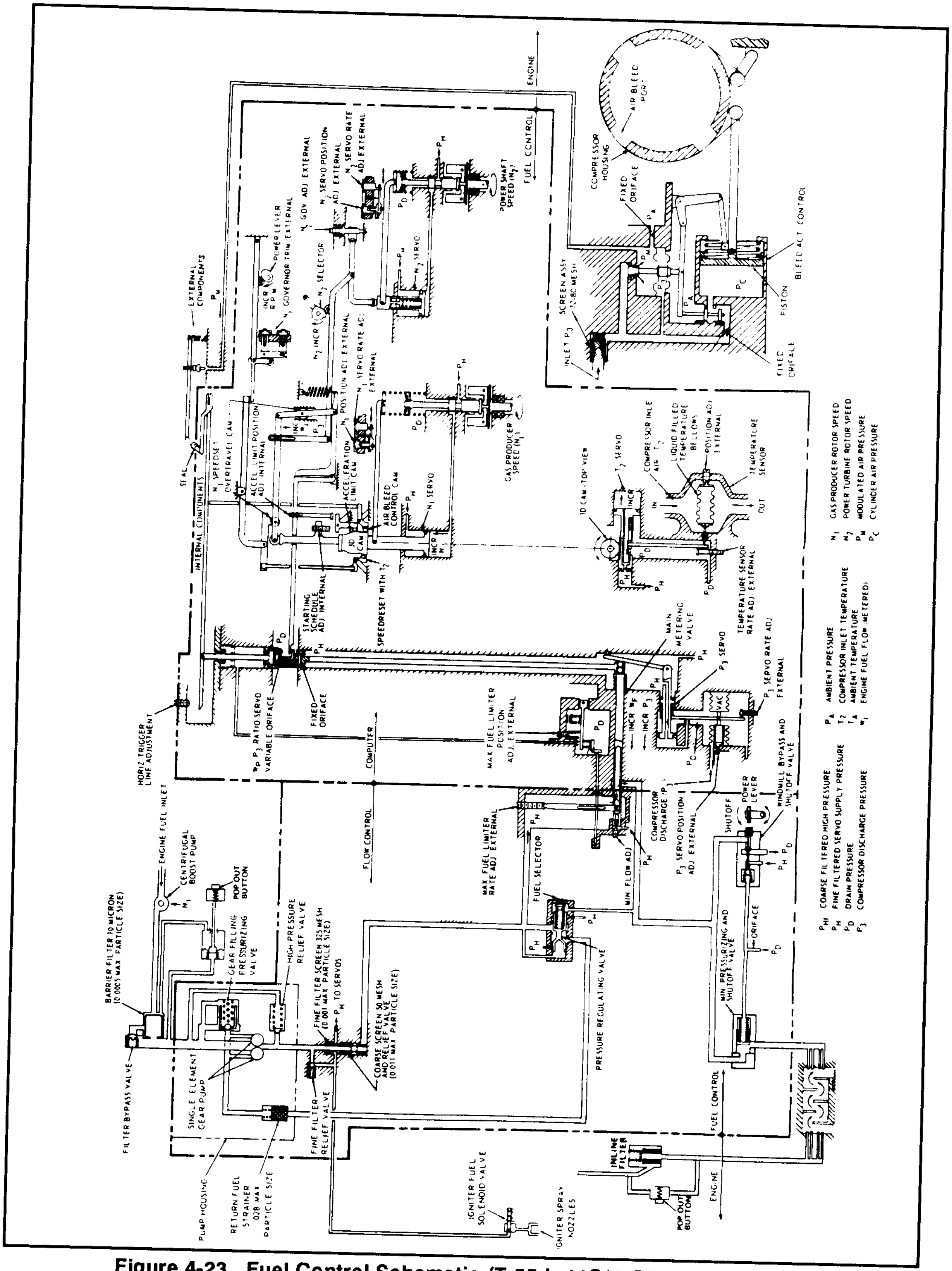


Figure 4-23. Fuel Control Schematic (T-55-L-11C/11D/11E/T55-L-712)

CHAPTER 5

LUBRICATING SYSTEMS

Although the oil system of the modern gas turbine engine is varied in design and plumbing most have units which perform similar functions. In most cases a pressure pump or system furnishes oil to the engine to be lubricated and cooled. A scavenging system returns the oil to the tank for reuse. The problem of overheating is more severe after the engine has stopped than while it is running. Oil flow which would normally have cooled the bearings has stopped. Heat stored in the. turbine wheel will raise the bearing temperature much higher than that reached during operation. Most systems will include a heat exchanger (air or fuel) to cool the oil. Many are designed with pressurized sumps. Some incorporate a pressurized oil tank. This ensures a constant head pressure to the pressure- lubrication pump to prevent pump cavitation at high altitude.

Oil consumption in a gas turbine engine is low compared to that in a reciprocating engine of equal power. Oil consumption on the turbine engine is affected by the efficiency of the seals. However, oil can be lost through internal leakage and on some engines by malfunction of the pressurizing or venting system. Oil scaling is very important in a jet engine. Any wetting of the blades or vanes by oil vapor will encourage the accumulation of dust and dirt. A dirty blade or vane represents high friction-to-airflow. This decreases engine efficiency, and results in a noticeable decrease in thrust or increase in fuel consumption. Since oil consumption is so low, oil tanks can be made relatively small. This causes a decrease in weight and storage problems. Tanks may have capacities ranging from 1/2 to 8 gallons. System pressures may vary from 15 psig at idle to 200 psig during cold starts. Normal operating pressures and bulk temperatures are about 50 to 100 psig and 200°F, respectively.

GENERAL

In general the parts to be lubricated and cooled include the main bearings and accessory drive gears and the propeller gearing in the turboprop. This represents again in gas turbine engine lubrication simplicity over the complex oil system of the reciprocating engine. The main rotating unit can be carried by only a few bearings. In a piston power plant there are hundreds more moving parts to be lubricated. On some turbine engines the oil may also be uscd–

- To operate the servo mechanism of some fuel controls.
- To control the position of the variable area exhaust-nozzle vanes.
- To operate the thrust reverser.

Because each bearing in the engine receives its oil from a metered or calibrated orifice, the system is generally known as the calibrated type. With a few exceptions the lubricating system used on the modem turbine engine is of the dry-sump variety. However, some turbine engines are equipped with a combination dry- and wet-type lubrication system. Wet-sump engines store the lubricating oil in the engine proper. Dry-sump engines utilize an external tank usually mounted on or near the engine. Although this chapter addresses dry-sump systems, an example of the wet-sump design can be seen in the Solar International T-62 engine. In this engine the oil reservoir is an integral part of the accessory-drive gear case. An example of a combination dry- and wet-sump lubrication can be found in the Lycoming T-55-series engines.

TURBINE ENGINE DRY-SUMP LUBRICATION

In a turbine dry-sump lubrication system, the oil supply is carried in a tank mounted externally on or near the engine. With this type of system, a larger oil supply can be carried and the oil temperature can be controlled An oil cooler usually is included in a dry-sump oil system (Figure 5-l). This cooler may be air-cooled or fuel-cooled. The dry-sump oil system allows the axial-flow engines to retain their comparatively small diameter. This is done by designing the oil tank and the oil cooler to conform to the design of the engine.

The following component descriptions include most of those found in the various turbine lubrication systems. However, not all of these components will be found in any one system.

The dry-sump systems use an oil tank which contains most of the oil supply. However, a small sump usually is included on the engine to hold a supply of oil for an emergency system. The dry-sump system usually contains –

- Oil pump.
- Scavenge and pressure inlet strainers.
- Scavenge return connection.
- Pressure outlet ports.
- Oil falter.
- Mounting bosses for the oil pressure transmitter.
- Temperature bulb connections.

A typical oil tank is shown in Figure 5-2. It is designed to furnish a constant supply of oil to the engine. This is done by a swivel outlet assembly mounted inside the tank a horizontal baffle mounted in the center of the tank, two flapper check valves mounted on the baffle, and a positive-vent system.

The swivel outlet fitting is controlled by a weighted end, which is free to swing below the baffle. The flapper valves in the baffle are normally open. They close only when the oil in the bottom of the tank rushes to the top of the tank during deceleration. This traps the oil in the bottom of the tank where it is picked up by the swivel

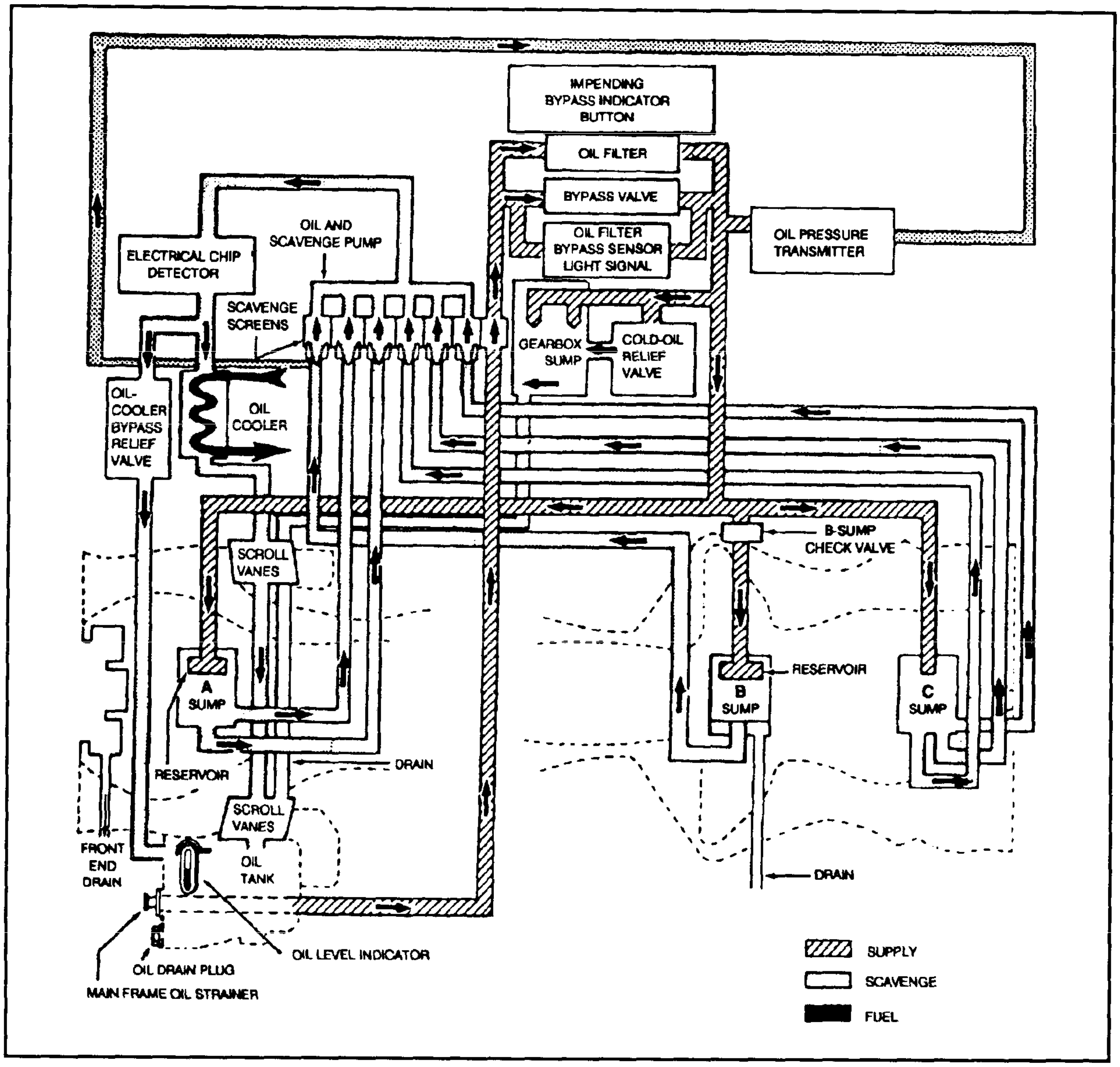


Figure 5-1. Oil System Schematic

fitting A sump drain is located in the bottom of the tank. The airspace is vented at all times.

All oil tanks have expansion space. This allows for oil expansion after heat is absorbed from the bearings and gears and after the oil foams after circulating through the system. Some tanks also incorporate a deaerator tray. The tray separates air from the oil returned to the top of the tank by the scavenger system. Usually these deaerators are the "can" type in which oil enters a tangent. The air released is carried out through the vent system in the top of the tank. Inmost oil tanks a pressure buildup is desired within the tank. This assures a positive flow of oil to the oil pump inlet. This pressure buildup is made possible by running the vent line through an adjustable check-relief valve. The check-relief valve normally is set to relieve at about 4 psi pressure on the oil pump inlet.

There is little need for an oil-dilution system. If the air temperature is abnorrnally low, the oil may be changed to a lighter grade. Some engines may provide for the installation of an immersion-type oil heater.

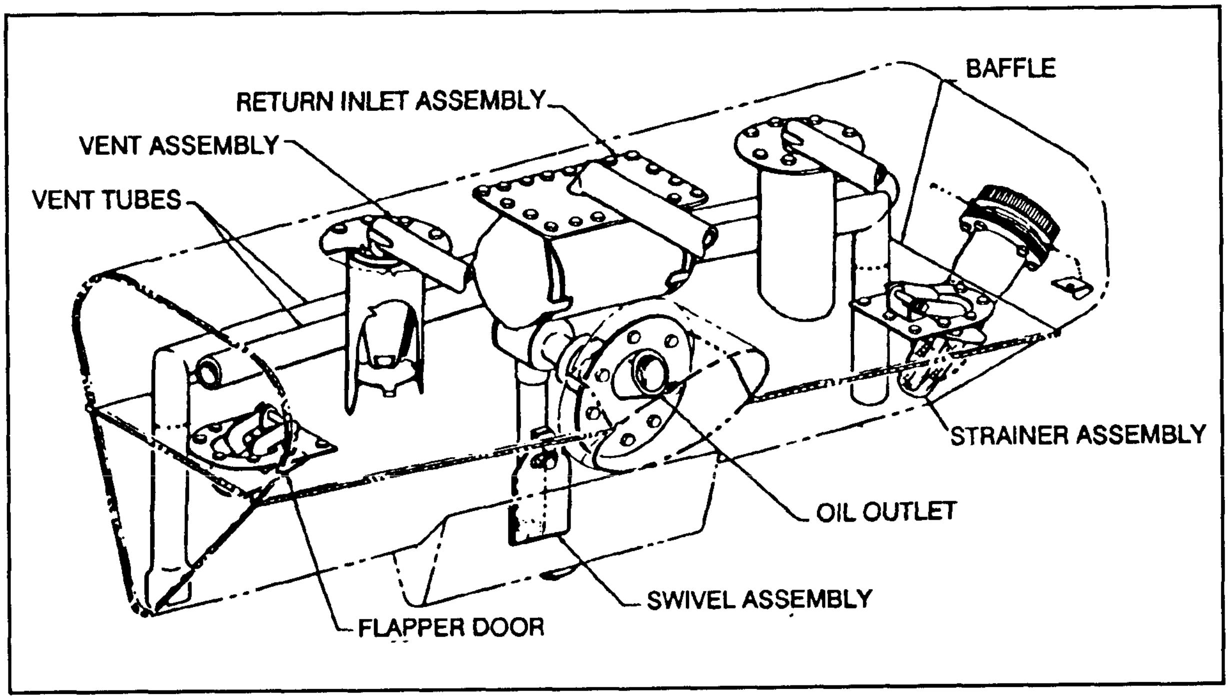


Figure 5-2. Oil Tank

TURBINE ENGINE WET-SUMP LUBRICATION

In some engines the lubrication system is the wet-sump type. Because only a few models of centrifugal-flow engines are in operation, there are few engines using a wet-sump type of oil system.

The components of a wet-sump system are similar to many of a dry-sump system. The oil reservoir location is the major difference.

The reservoir for the wet-sump oil system may be the accessory gear case, which consists of the accessory gear casing and the front compressor bearing support casing. Or it may be a sump mounted on the bottom of the accessory case. Regardless of configuration reservoirs for wet-sump systems are an integral part of the engine and contain the bulk of the engine oil supply.

The following components are included in the wet-sump reservior:

- A bayonet-type gage indicates the oil level in the sump.
- Two or more finger strainers (filters) are inserted in the accessory case for straining pressure and scavenged oil before it leaves or enters the sump. These strainers aid the main oil strainer.
- A vent or breather equalizes pressure within the accessory casing.
- A magnetic drain plug may be provided to drain the oil and to trap any ferrous metal particles in

the oil. This plug should always be examined closely during inspections. The presence of metal particles may indicate gear or bearing failure.

- A temperature bulb and an oil pressure fitting may be provided.

This system is typical of all engines using a wet-sump lubrication system. The bearing and drive gears in the accessory drive casing are lubricated by a splash system. The oil for the remaining points of lubrication leaves the pump under pressure. It passes through a falter to jet nozzles that direct the oil into the rotor bearings and couplings. Most wet-sump pressure systems are variable-pressure systems in which the pump outlet pressure depends on the engine RPM.

The scavenged oil is returned to the reservior (sump) by gravity and pump suction. Oil from the front compressor bearing in the accessory-drive coupling shaft drains directly into the reservoir. Oil from the turbine coupling and the remaining rotor shaft bearings drains into a sump. The oil is then pumped by the scavenge element through a finger screen into the reservoir.

OIL SYSTEM COMPONENTS

The oil system components used on gas turbine engines are–

- Tanks.
- Pressure pumps.
- Scavenger pumps.
- Filters.
- Oil coolers.
- Relief valves.
- Breathers and pressurizing components.
- Pressure and temperature gages and warning lights.
- Temperature-regulating valves.
- Oil-jet nozzle.
- Fittings, valves, and plumbing.
- Chip detectors.

Not all of the units will be found in the oil system of any one engine. But a majority of the parts listed will be found in most engines.

Oil Tanks

Tanks can be either an airframe or engine-manufacturer-supplied unit. Usually constructed of welded sheet aluminum or steel, it provides a storage place for the oil. Inmost engines the tank is pressurized to ensure a constant supply of oil to the pressure pump. The tank can contain–

- Venting system.
- Deaerator to separate entrained air from the oil.
- Oil level transmitter or dipstick.
- Rigid or flexible oil pickup.
- Coarse mesh screens.
- Various oil and air inlets and outlets.

Pressure Pumps

Both gear- and Gerotor-type pumps are used in the lubricating system of the turbine engine. The gear-type pump consists of a driving and a driven gear. The engine-accessory section drives the rotation of the pump. Rotation causes the oil to pass around the outside of the gears in pockets formed by the gear teeth and the pump casing. The pressure developed is proportional to engine RPM up to the time the relief valve opens. After that any further increase in engine speed will not result in an oil pressure increase. The relief valve may be located in the pump housing or elsewhere in the pressure system for both types of pumps.

The Gerotor pump has two moving parts: an inner-toothed element meshing with an outer-toothed element. The inner element has one less tooth than the outer. The missing tooth provides a chamber to move the fluid from the intake to the discharge port. Both elements are mounted eccentrically to one another on the same shaft.

Scavenger Pumps

These pumps are similar to the pressure pumps but have a much larger total capacity. An engine is generally provided with several scavenger pumps to drain oil from various parts of the engine. Often one or two of the scavenger elements are incorporated in the same housing as the pressure pump (Figure 5-3). Different capacities can be provided for each system despite the common driving shaft speed. This is accomplished by varying the diameter or thickness of the gears to vary the volume of the tooth chamber. A vane-type pump may sometimes be used

Oil Filters and Screens or Strainers

To prevent foreign matter from reaching internal parts of the engine, falters and screens or stainers are provided in the engine lubricating system. The three basic types of oil falters for the jet engine are the cartridge screen-disq and screen (Figures 5-4, 5-5 and 5-6). The cartridge falter is most commonly used and must be replaced periodically. The other two can be cleaned and

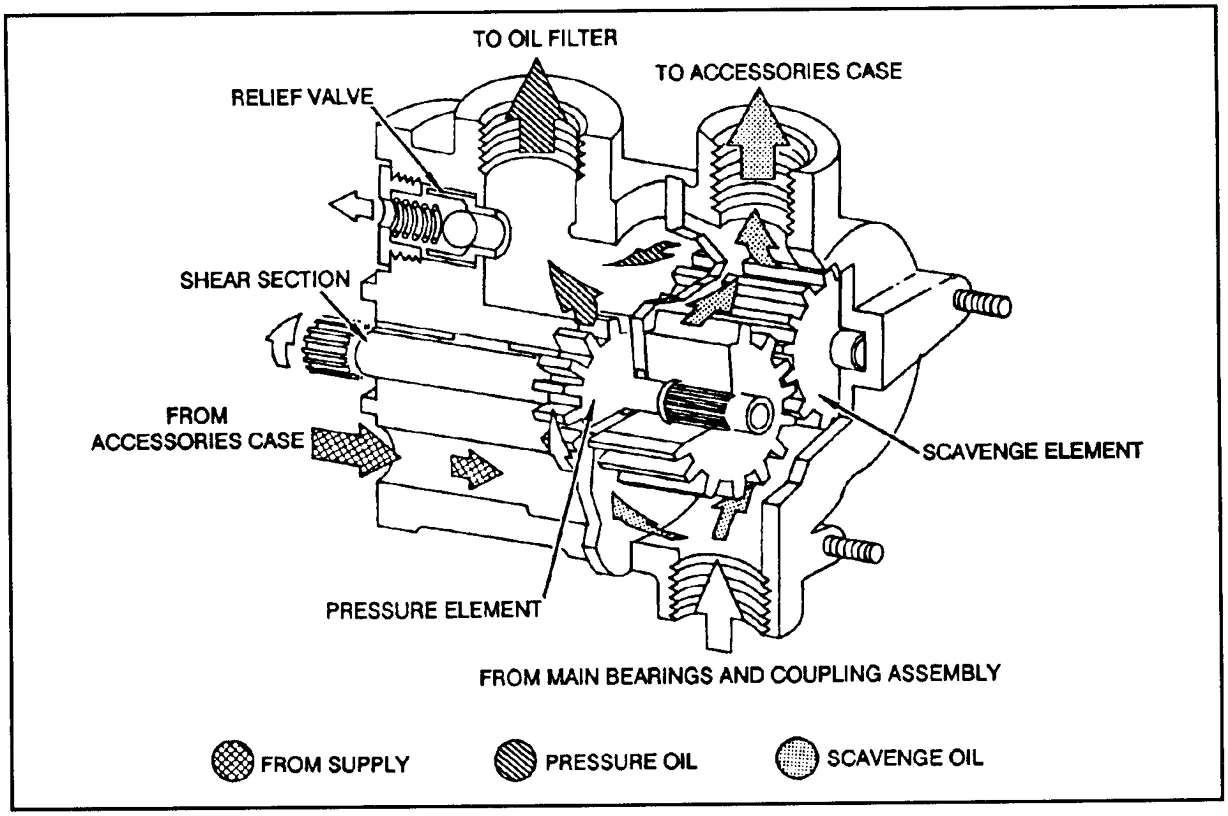


Figure 5-3. Cutaway View of Gear Oil Pump

reused. In the screen-disc falter there are a series of circular screen-type falters. Each falter is comprised of two layers of mesh forming a chamber between mesh layers. The filters are mounted on a common tube and arranged to provide a space between each circular element. Lube oil passes through the circular mesh elements and into the chamber between the two layers of mesh. This chamber is ported to the center of a common tube which directs oil out of the falter. Screens or strainers are placed at pressure oil inlets to bearings in the engine. This aids in preventing foreign matter from reaching the bearings.

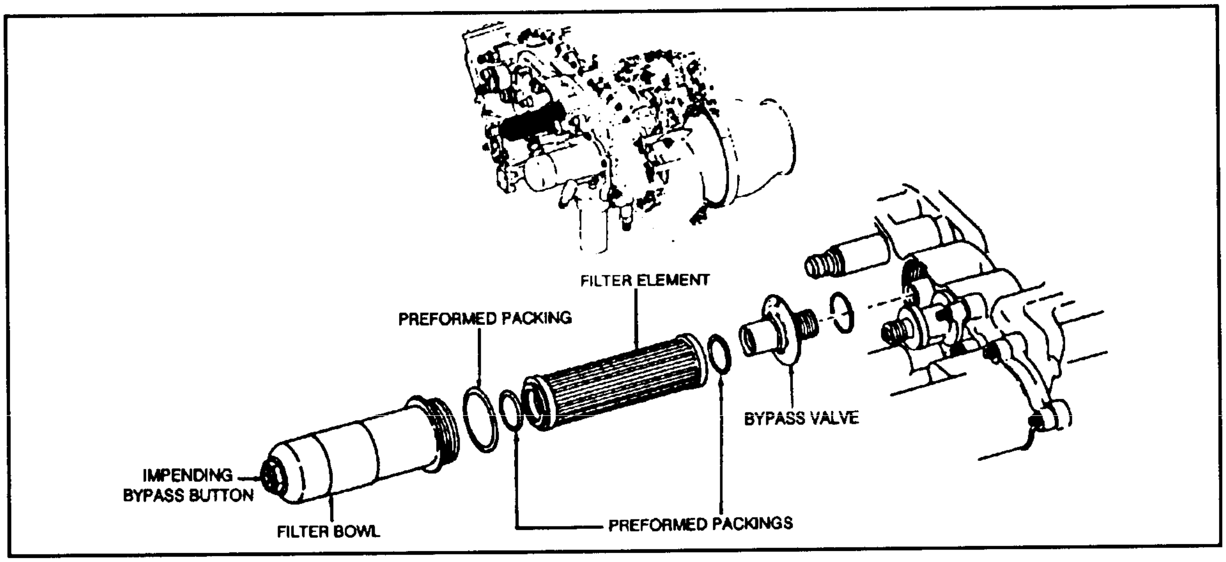


Figure 5-4. Cartridge-Type Filter Assembly

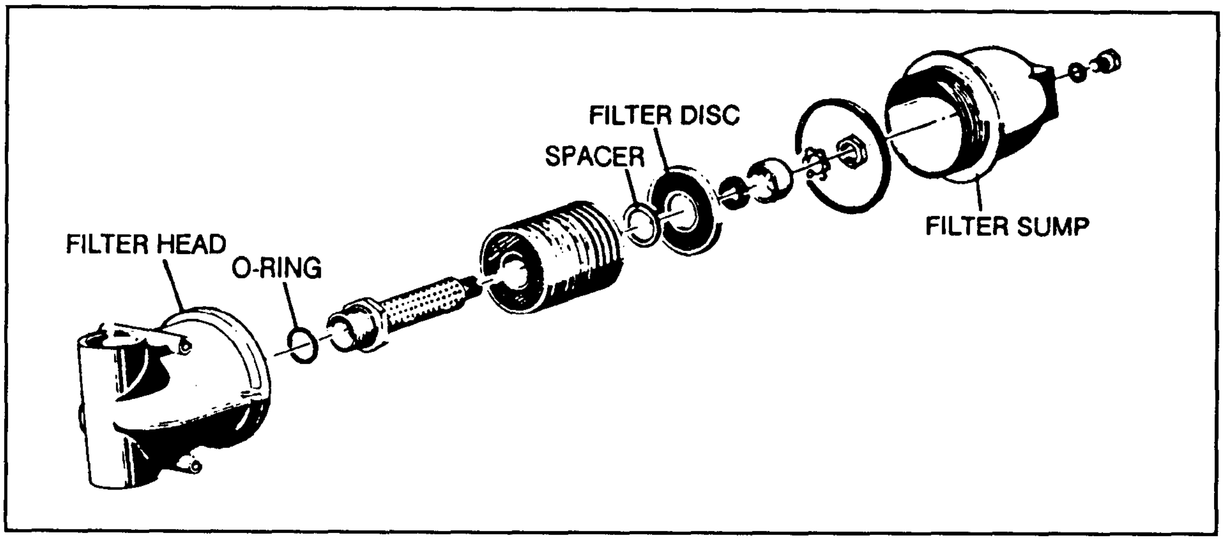


Figure 5-5. Disc-Type Filter Assembly

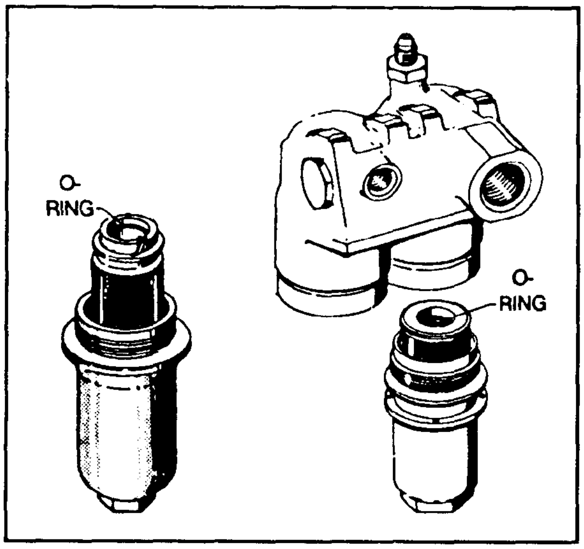


Figure 5-6. Filtering Assembly Screen or Strainer Type

To allow for oil flow in the event of filter blockage, all falters incorporate a bypass or relief valve as part of the falter or in the oil passages. When the pressure differential reaches a specified value (about 15 to 20 psi), the valve opens and allows oil to bypass the filter. Some falters incorporate a check valve. This prevents reverse flow or flow through the system when the engine is stopped Filtering characteristics vary, but most falters will stop particles of approximately 50 microns.

Magnetic Chip Detector

One or more magnetic chip detectors are installed on gas turbine engines. They are used to detect and attract ferrous material (metal with iron as its basic element) which may come from inside the engine. This ferrous material builds up until it bridges a gap. Whenever there is a requirement, the chip detectors may be collected and analyzed to determine the condition of the engine. Most engines utilize an electrical chip detector, located in the scavenger pump housing or in the aceessory gearbox. Should the engine oil become contaminated with metal particles, the detector will catch some of them. This causes the warning light on the caution panel to come on.

Tubing, Hose, and Fittings

Tubing hose, and fittings are used throughout the lubricating system. Their purpose is to connect apart into a system or to connect one part to another to complete a system.

Oil Pressure Indicating System

In a typical engine oil pressure indicating system the indicator receives inlet oil pressure indications from the oil pressure transmitter and provides readings in pounds per square inch Electrical power for oil pressure indicator and transmitter operation is supplied by the 28-volt AC system.

Oil-Pressure-Low Caution Light

Most gas turbine engine lubricating systems incorporate an engine oil-pressure-low caution light warning device into the system for safety purposes. The light is connected to a low-pressure switch. When pressure drops below a safe limit, the switch closes an electrical circuit causing the caution light to bum. Power is supplied by the 28-volt DC system.

Oil Temperature Indicating System

In a typical engine oil temperature indicating system, the indicator is connected to and receives temperature indications from an electrical resistance-type thermocouple or thermobulb. These are located in the pressure pump oil inlet side to the engine. Power to operate this circuit is supplied by the 28-volt DC system.

Oil Coolers

The oil cooler is used to reduce oil temperature by transmitting heat from the oil to another fluid usually fuel. Since the fuel flow through the cooler is much greater than the oil flow, the fuel is able to absorb a considerable amount of heat. This reduces the size and weight of the cooler. Thermostatic or pressure-sensitive valves control the oil temperature by determining whether the oil passes through or bypasses the cooler. Oil coolers are also cooled by air forced through them by a blower/fan.

Breathers and Pressurizing Systems

Internal oil leakage is kept to a minimum by pressurizing the bearing sump areas with air that is bled off the compressor (Figure 5-7). The airflow into the sump minimizes oil leakage across the seals in the reverse direction.

The oil scavenge pumps exceed the capacity of the lubrication pressure pump They are capable of handling considerably more oil than actually exists in the bearing sumps and gearboxes. Because the pumps area constant-displacement type, they make up for the lack of oil by pumping air from the sumps. Large quantities of air are delivered to the oil tank. Sump and tank pressures are maintained close to one another by a line which connects the two. If the sump pressure exceeds the tank pressure, the sump vent check valve opens, allowing the excess sump air to enter the oil tank. The valve allows flow only into the tank; oil or tank vapors cannot back up into the sump areas. Tank pressure is maintained little above ambient.

The scavenge pumps and sump-vent check valve funtions result in relatively low air pressure in the sumps and gearboxes. These low internal sump pressures allow air to flow across the oil seals into the sumps. This airflow minimizes lube oil leakage across the seals. For this reason it is necessary to maintain sump pressures low enough to ensure seal-air leakage into the sumps. Under some conditions, the ability of the scavenge pumps to pump air forms a pressure low enough to cavitate the pumps or cause the sump to collapse. Under other conditions, too much air can enter the sump through worn seals.

If the seal leakage is not sufficient to maintain proper internal pressure, check valves in the sump and tank pressurizing valves open and allow ambient air to enter the system. Inadequate internal sump and gearbox pressure may be caused by seal leakage. If that occurs, air flows from the sumps, through the sump-vent check valve, the oil tank, the tank and sump pressurizing valves to the atmosphere. Tank pressure is always maintained a few pounds above ambient pressure by the sump and tank pressurizing valve.

The following adresses two types of lubrication systems used in the Army today the General Electric T-701 turboshaft engine and the International/Solar T-62-series engine.

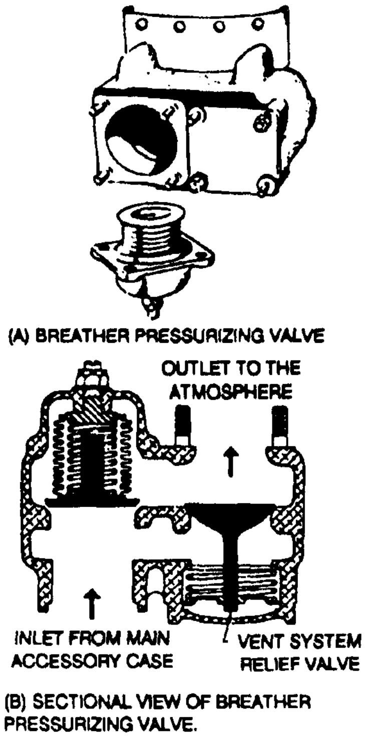


Figure 5-7. Breather Pressurizing Valve

TYPICAL OIL SYSTEM FOR T-701

The lubrication system in the T-700-GE-701 engine distributes oil to all lubricated parts (Figure 5-8). In emergencies it supplies an air-oil mist to the main shaft bearings in the A- and B-sumps. The system is a self-contained, recirculating dry-sump system. It consists of the following subsystems and components:

- Oil supply and scavenge pump.
- Seal pressurization and sump venting
- Emergency lube system.
- Oil filtration and condition monitoring.
- Tank and air-oil cooler.
- Oil cooler.
- Oil pressure monitoring.
- Cold oil-relief and cooler-bypas valves.
- Chip detector.
- Integral accessory gearbox

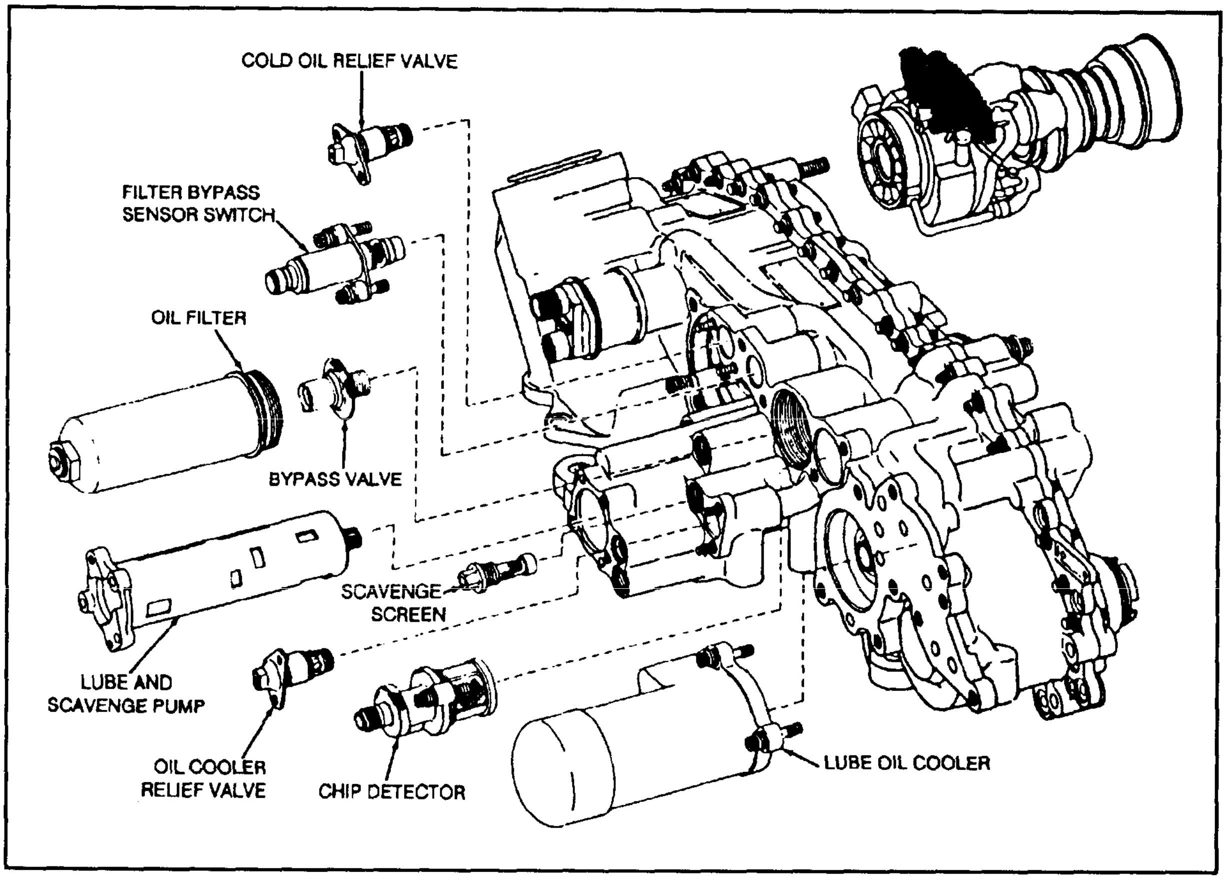


Figure 5-8. Lubrication System Components

Lube Supply System

The oil tank, integral with the mainframe, holds approximately 7.3 quarts of oil (Figure 5-9). This is a sufficient quantity to lubricate the required engine parts without an external oil supply. The tank is filled using a 3-inch, gravity-fill port on the right-hand side. Visual indication of oil level is supplied by a fluid level indicator installed on each side of the tank. A coarse pickup screen located near the tank bottom keeps sizable debris from entering the lube supply pump inlet. A drain plug is located at the bottom of the tank.

Oil from the pickup screen enters a east passage in the mainframe. It is then conducted to the top of the engine to a point beneath the lube supply pump. A short connector tube transfers the oil from the mainframe to the accessory gearbox pump inlet port. The connector tube contains a domed, coarse-debris screen. The screen keeps foreign objects out of the passage when the accessory module is not installed on the mainframe. Oil flows through the connector tube to the pump inlet. There it enters the pump tangentially in alignment with pump rotational direction.

The lube supply pump, a Geroter-type pumping element assembly, is comprised of an inner and outer element. The element assembly is located adjacent to the drive spline end of the pump. Six scavenge elements are also located in tandem on the common drive shaft. The stack of pump elements is retained in a cast tubular hosing having an integral end plate. The complete pump slides into a precision bore in the gearbox casing. Oil from the supply pump flows to the lube filter inlet and through the falter, a 3-micron falter element. Oil flow passes from outside to inside of the falter element. It then passes through the open bore of the bypass valve and into the gearbox outlet passage. Bypass valve opening occurs when filter differential pressure unseats a spring-loaded poppet from its scat. The filter bowl contains an impending bypass warning button which will provide an indication for filter servicing. An electrical bypass sensor for cockpit indication of falter bypass tits into an AGB boss adjacent to the lube falter. A differential pressure of 60-80 psi across the falter will actuate this sensor.

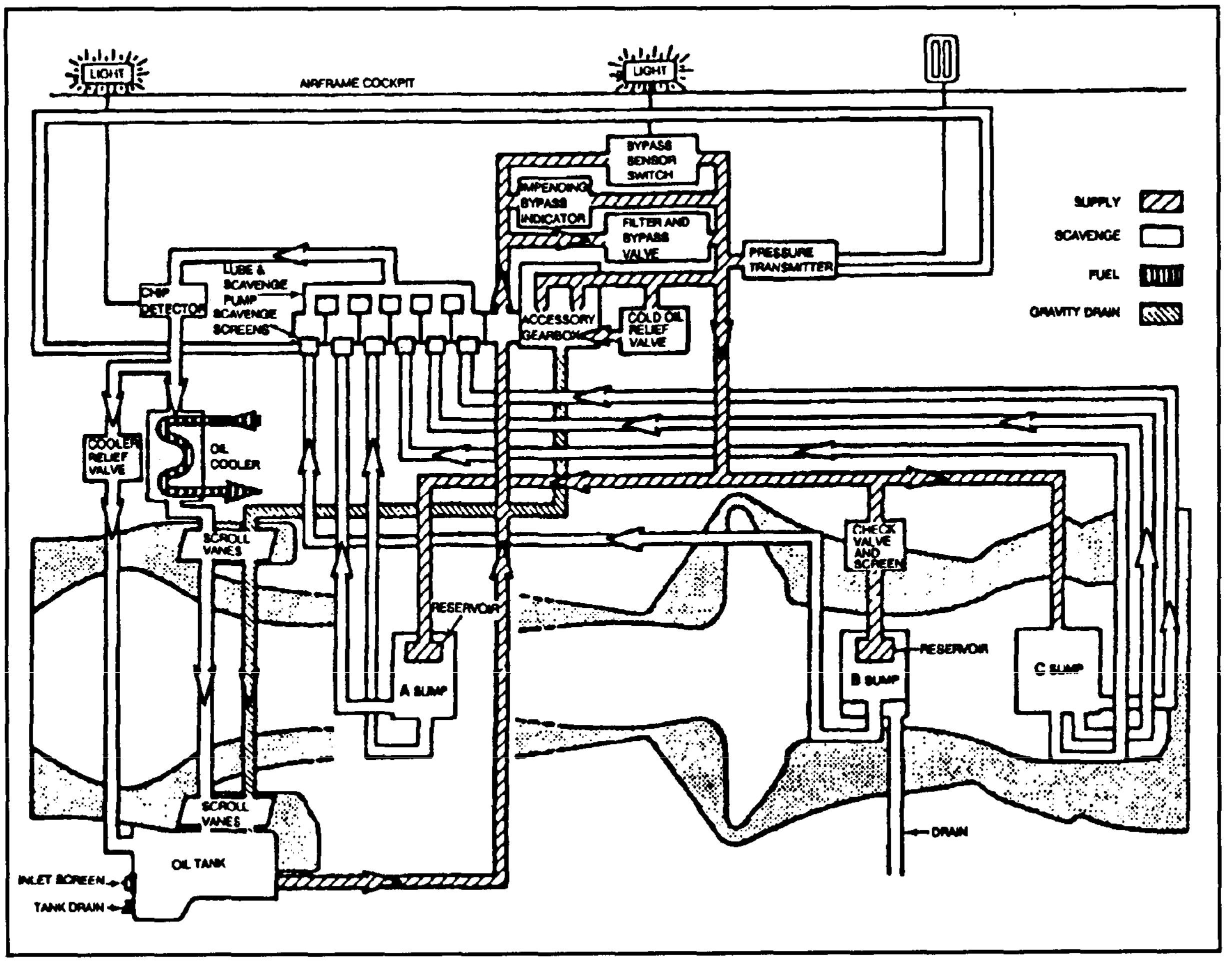


Figure 5-9. Lubrication System Schematic

A spring-loaded poppet-type, cold oil relief valve is incorporated in this sytem. This valve prevents excessive supply pressure during cold starts when high oil viscosity creates high line pressures. Cracking pressure is set for 120-180 psid and reset is 115 psid minimum. When open, apart of the lube flow is discharged into the AGB where churning in the gears will assist in reducing warm-up time.

Oil leaving the falter branches in three directions. It goes to the to of the emergency oil reservoirs in the A- and B-sumps, the AGB, and C-sump jets.

Scavenge System. After the oil has lubricated and cooled the parts, the scavenge system returns it to the oil tank (Figure 5-10). In addition, fuel-oil and air-oil coolers and a chip detector are located in the scavenge return path.

Scavenge Inlet Screens. Each scavenge pump inlet is fitted with a relatively coarse screen (Figure 5-11). This screen is designed to protect the pumps from foreign object damage and to provide for fault isolation. Scavenge oil (and air) enters the bore of each screen axially on the open inner end. It exits into a cast annulus which discharges directly into the scavenge pump inlet.

These screens may be removed for inspection if chip generation is suspected

Scavenge pumps. Six scavenge pumps are in line with the lube supply pump on a common shaft (Figure 5-10). Positioning of the pump elements is determined by these factors:

- The lube supply element is placed in the least vulnerable location and isolated from scavenge elements atone end
- The B-sump element is placed at the other end of the pump to help isolate it from the other scavenge elements. This element is the only one with an elevated inlet pressure.
- Pump windmilling experience on other engine scavenge pumps shows that adjacent pumps tend to cut each other off due to interelement leaks at very low speed Therefore, the two A-sump elements are placed adjacent, as are the three C-sump elements, to reduce the possibiity of both elements in a sump being inoperative simultaneously.
- Porting simplification for the gearbox coring determines relative positions of A-sump, B-sump, and C-sump elements.

Scavenge Discharge Passage. The common discharge of all six scavenge pumps is cast into the gearbox at the top of the pump cavity. Top discharge facilitates priming by clearing air bubbles and by wetting all pumping elements from the discharge of first pumps to prime. The discharge cavity is tapered to enlarge as each pump discharge enters the flow steam. This keeps discharge velocity relatively constant. It also tends to avoid air traps which could short-circuit pumping at windmilling speeds. This discharge plenum flows into the core to the chip detector. Flow leaving the chip detector passes to the fuel-oil cooler in series with the air-oil cooler. To promote faster warm-up and guard against plugged coolers, a bypass valve is provided which bypasses both coolers. Air-oil cooling is an integral part of the mainframe casting. Scavenge oil enters a manifold at the tank top. It then flows in a serpentine fashion in and out through the hollow scroll vanes and box-sectioned hub. Air for the particle separator is pulled across the vanes by the scavenge air blower providing the oil cooling process. Exit from the air-oil cooler is through three holes at the top of the tank. These outlets disperse the oil over the tank surfaces on both sides to settle in the tank. The oil tank vents to the AGB.

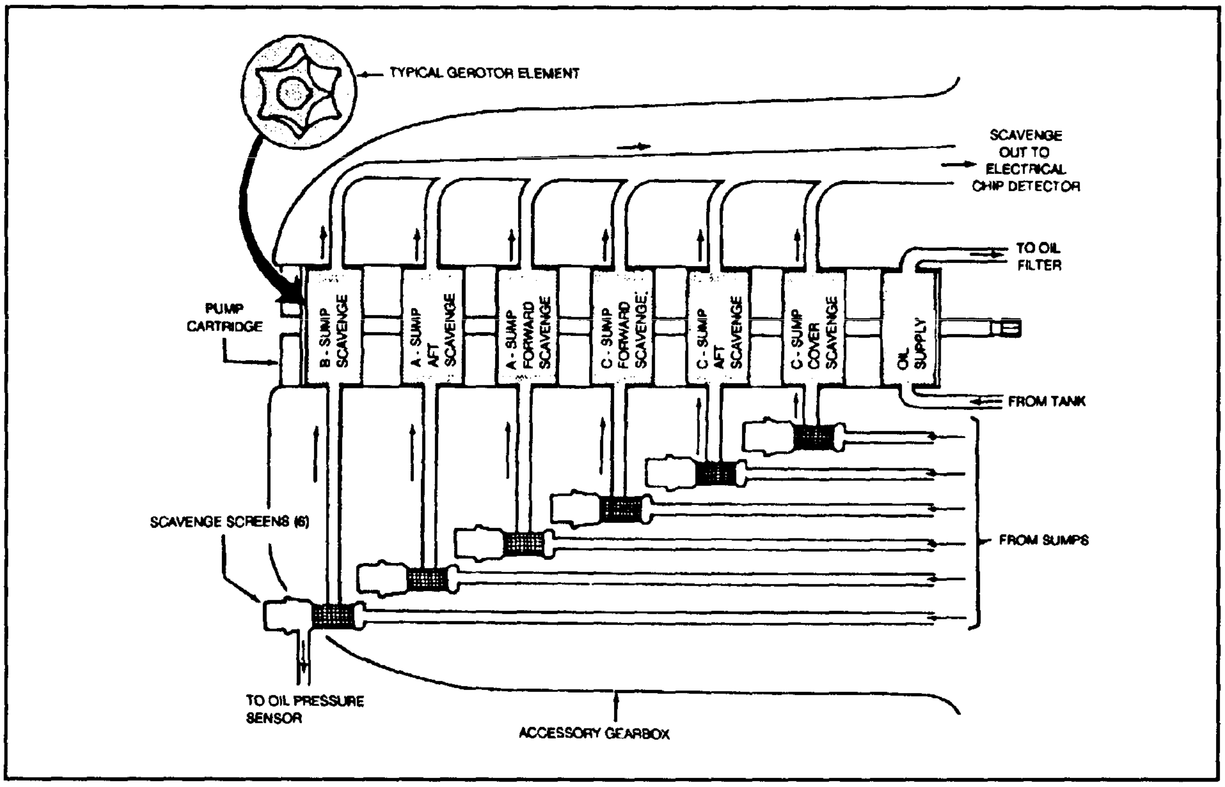


Figure 5-10. (T-701) Oil and Scavenge Pump

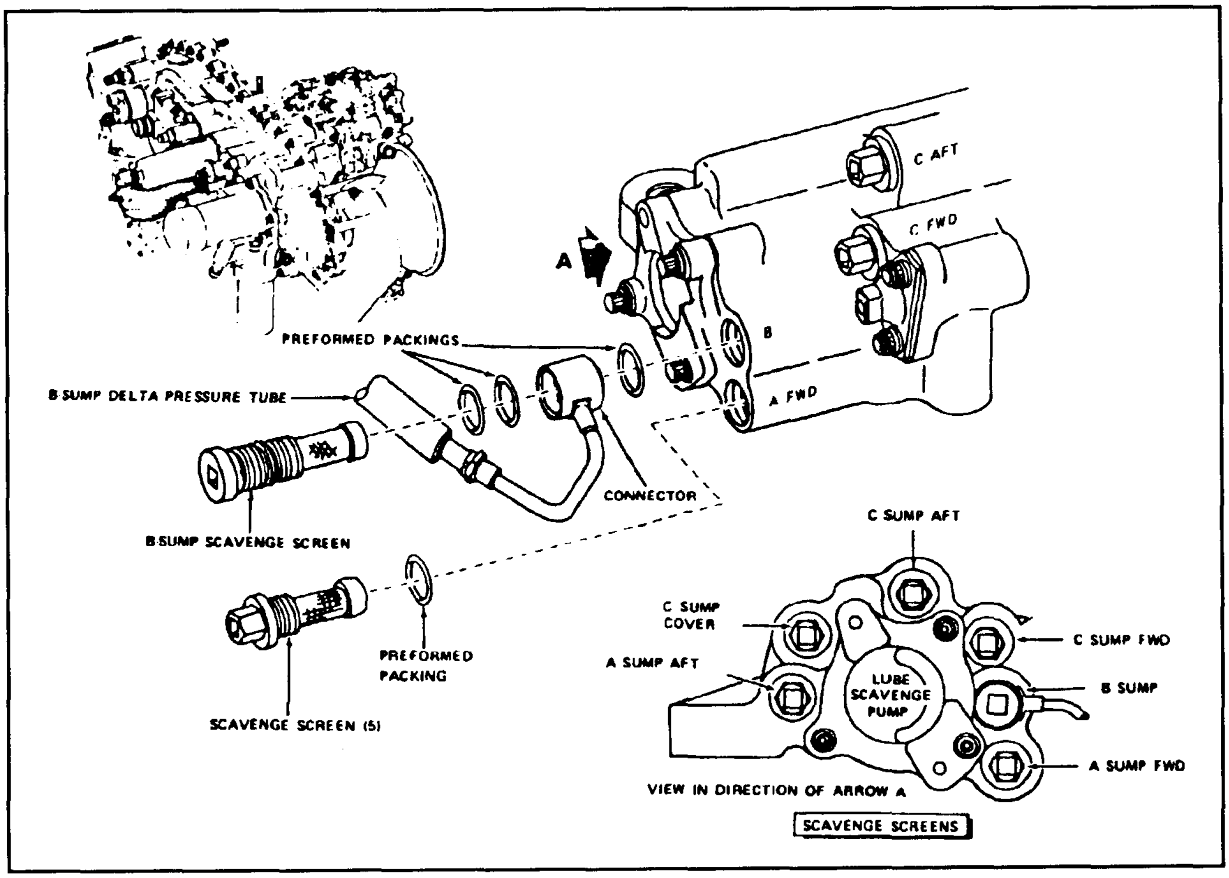


Figure 5-11. Scavenge Screens

Emergency Oil System

The T-700-GE-701 engine is designed to have two oil jets to provide each main bearing with oil for lubricating and cooling (Figure 5-12).

In addition to being designed for normal engine operation, the system provides for operation if the normal oil supply from the primary system is interrupted. The AGB and C-sump components can continue to operate at least 6 minutes with residual oil present. The No. 4 bearing in the B-sump and the bearings and gears in the A-sump are provided with emergency air-oil mist syterns located in each sump. The emergeney oil system forms part of the normal full-time lubrication system and incorporates one full set of main bearing oil jets operating in parallel with the primary jets. The dual-jet system also provides redundancy to minimize the effect of oil jet plugging.

A small reservoir, curved to tit the A- and B-sumps, retains a sufficient amount of oil to provide air-oil mist when normal lubrication is interrupted The total sump oil supply is fed into the reservoir at the top. Top feed prevents reservoir drainage if the supply line is damaged Primary oil jets, squeeze film damper, and uncritical lube jets are connected to a standpipe at the top of the tank. Secondary or emergency jets are similarly connected to the lowest point in the tank.

Secondary jets are only located at points where lubrication is vital for short-duration emergeney operation. Each secondary oil jet has a companion air jet or air source which flows over the end of the oil jet and impinges on the lubricated part. The air jets aspirate oil mist when normal oil supply pressure is lost. They are pressurized from the seal pressurization cavities and operate continuously with no valving required.

Component Description

The oil filter (Figure 5-13) consists of three subassemblies:

- Filter element.
- Bowl and impending bypass indicator.
- Bypass valve and inlet screen.

Filter Element. Media used in this falter are high-temperature materials em-staining organic and inorganic fibers. The layered media are faced on both sides with stainless steel mesh. This mesh provides mechanical support to resist collapse when pressure loads become high. Pleating of the faced media adds surface area and mechanical rigidity. A perforated steel tube in the bore also adds rigidity and retains the circular shape of the element.

The media and support tube are epoxy-bonded to formed sheet metal and caps. These end caps include an O-ring groove which seals inlet to outlet leak paths at each end

Filtration level selected is 100 percent of all particles three microns or larger and is disposable when saturated

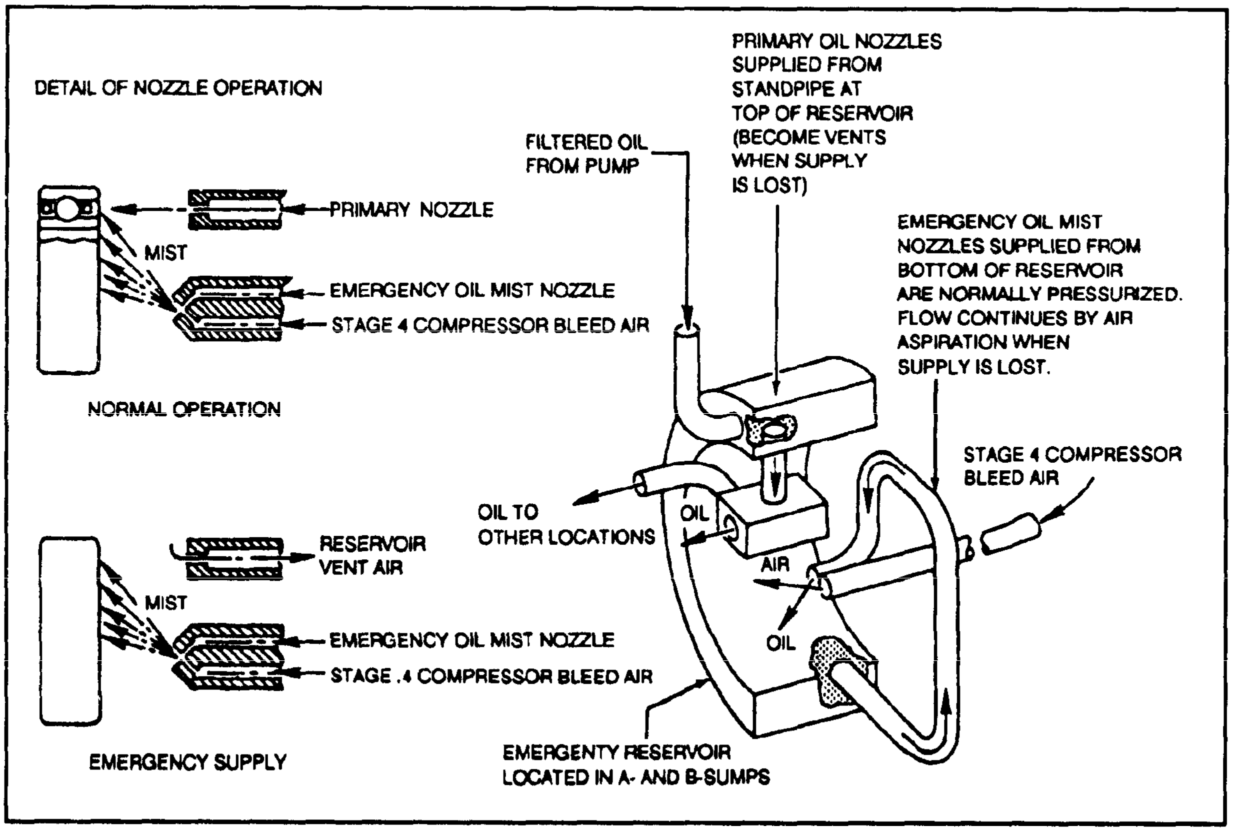


Figure 5-12. Emergency Oil System

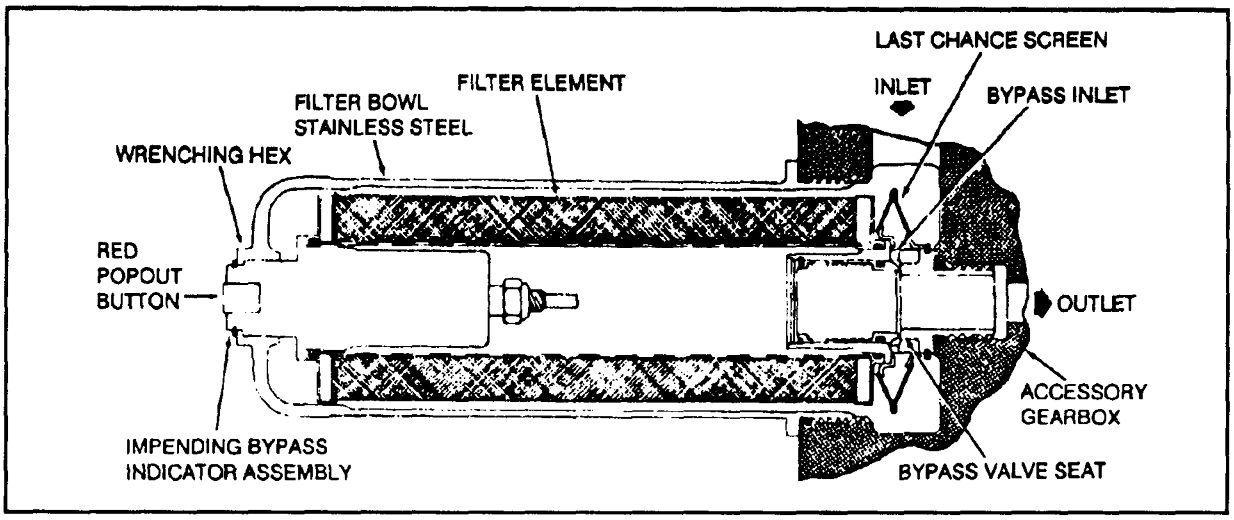


Figure 5-13. Lube Oil Filter (Cross Section)

with debris. Support of the falter element is provided by the bypass valve on one end and the impending bypass indicator on the other. The indicator end has a spring-loaded sleeve which restrains the filter axially.

Bowl and Bypass Indicator. An aluminum bowl houses the element and contains the impending bypass indicator at the end. Mounting is horizontal to fit the space available and provide ready access for servicing Impending bypass indication is provided by a small unit which is part of the bowl assembly. The indicator is installed from the inside of the bowl. It is retained in place with an external retaining ring. Basic mechanics of operation are as follows:

- Different pressure between filter inlet and outlet acts to move a piston against a spring at 44 to 60 psi.
- Piston contains a magnet which normally attracts a redbutton assembly and holds it seated against its spring. When the piston moves, the button is released. It extends 3/16 inch to visually indicate an impending bypass condition.
- Button is physically reattained from tripping by a cold lockout bimetallic latch if temperature is less than 100 to 130°F. This prevents a false trip during cold starts.
- As the button is released, a small spring-loaded ball also moves out of position to latch the button and block reset. The internal piston assembly automatically resets on shutdown; however, the indicator remains latched out.
- After removing the filter element and the bowl from the gearbox, a spring-loaded sleeve around the indicator moves aft and pulls the piston assembly to a tripped position. This causes the button to trip if operation is attempted with no filter in the bowl.
- To react the indicator, the bowl is held vertically so the button latch ball can roll out of the latched position. The button is then manually reset.

If the bowl is reassembled with no falter, the indicator will trip when the temperature exceeds the 100 to 130°F lock-out level. The internal latch mechanism prevents resetting the button without disassembling the bowl. Resetting must be done with the bowl removed from the accessory gearbox and held verically, button up, to release the latch.

Oil Filter Bypass Sensor. The oil filter bypass sensor is a differential-pressure switch which senses fiilter inlet minus outlet pressure.

The sensor consists of a spring-loaded piston which moves aft at high falter differential pressure (60 to 80 psi) and magnetically releases a microswitch lever. The switch is in a sealed cavity separated from the oil and is wired to a hermetically sealed electrical connector. The switch connects 28-VDC aircraft power when tripped and reopens the circuit at 15 psi minimum differential No latch is used in the sensor so resetting is automatic. Also, there is no cold lockout. The pilot will be informed of falter bypassing during cold start warm-ups. Sensor tolerance range is set slightly below the tolerance range of bypass valve cracking pressure. Therefore, bypassing will not occur without pilot warning. The impending bypass indicator will show need-to-change filter elements. This sensor provides backup warning if maintenance action is not taken.

Lubrication and Scavenge Pump. The lube and scavenge pump is a Gerotor-type pump of cartridge design, located on the forward side of the accessory gearbox (refer back to Figure 5-10). It fits into a precision bore in the gearbox casing. The Gerotor-type pump was chosen because of its wear resistance and efficiency. Gerotor elements are similar to male gear inside a female (internal) gear with one less tooth on the inner member.

The inner Gerotors are keyed to the drive shaft, and the outer Gerotors are pocketed in individual eccentric rings. AS the assembly rotates, oil is drawn into an expanding cavity between teeth on one side. The oil is expelled when the cavity contracts approximately 180° away. Inlet and discharge ports are cast into the port plates. They are shaped and positioned to fill and empty at proper timing for maximum volumetric efficiency and resistance to inlet cavitation.

There are seven different elements in the pump from the spline end forward. They are the lube supply element, C-sump cover, C-sump aft, C-sump forward, A-sump forward, A-sump aft, and B-sump Delta scavenge elements.

The port plate eccentric rings and Gerotors are assembled into a surrounding concentric aluminum tubular housing The housing maintains all elements in proper alignment. The oil suction and discharge passages from the Gerotors are brought radially through the housing. They match the appropriate locations of the mating passages in the engine gearbox casing. The entire stack of port plates is retained in the housing with the retaining rings at the spline end. The outermost end of the housing has an integrally cast cover. The cover bolt holes are arranged to orient the pump assembly in the gearbox housing during installation.

Cold Oil Relief Valve. The cold oil relief valve protects the oil supply system from overpressure during cold starts (refer back to Figure 5-9). It is a conventional poppet-type valve with a cracking pressure of 120-180 psi. Valve tolerances are held sufficiently close to achieve the desired sacking pressure without adjustment shims or selective fitting of parts.

The valve includes a No. 10-32 threaded hole on the outside. This allows for the use of a bolt as a pulling handle during valve removal from the AGB.

Oil Cooler. The fuel-oil cooler is a tube and shell design (Figure 5-14). It cools the combined output of the scavenge discharge oil that is ported through gearbox-cored passages to the cooler. The cooler is mounted adjacent to the fuel-boost pump on the forward side of the gearbox. Oil and fuel porting enter on the same end via face porting to the gearbox. Fuel is used as the coolant. It is provided to the cooler via the boost pump, fuel falter, and hydromechanical control unit. A counterparallel flow, miltipass cooler design is used to minimize pressure drop while obtaining maximum cooler effectiveness. Fuel flows through the tubes, while the oil flows over the tubes resulting in the counterparallel flow arrangement.

Oil Cooler Bypass Valve. Design of the oil cooler bypass valve is identical to the cold oil relief valve with an exception (refer back to Figure 5-9). A lighter spring is utilized to obtain a lower cracking pressure of 22-28 psi. Housing modifications prevent inadvertent interchange with the cold oil relief valve.

Chip Detector. The chip detector in the common scavenge line is the engine diagnostic device most likely to provide first warning of impending part failure (Figure 5-15).

The chip detector magnetically attracts electrically conductive ferrous chips. The chips bridge the gap between the detector's electrodes and close a circuit in series with the aircraft cockpit indicator (warning light). The chip detecting gap has a magnetic field induced in tapered pose pieces at each end of a cylindrical permanent magnet. A single ferrous chip 0.090 inch in length or longer will be indicated if magnetically attracted to bridge the pole pieces. The local mangetic field is intense at the gap and tends to orient particles in the bridging direction. Smaller particles tend to form chains until the pole pieces are bridged

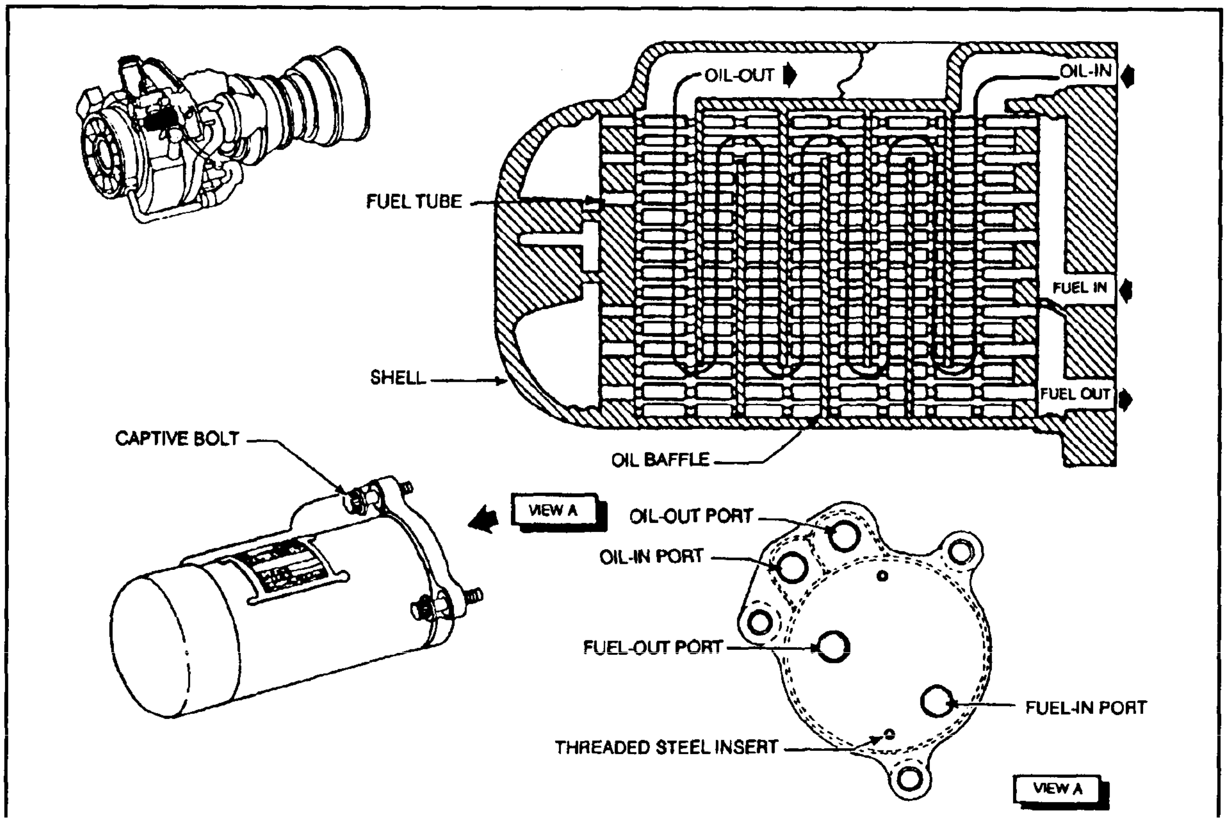


Figure 5-14. Oil Cooler

Nonconductive particles greater than 0.015 inch are trapped inside the screen for visual examination. Smaller particles will be found either in the lube tank or in the lube supply falter.

The detector housing pushes into the accessory gearbox It is retained by two captive bolts used in common with other accessories. Self-locking inserts in the gearbox ensure retention of these bolts if assembly torque is improperly low.

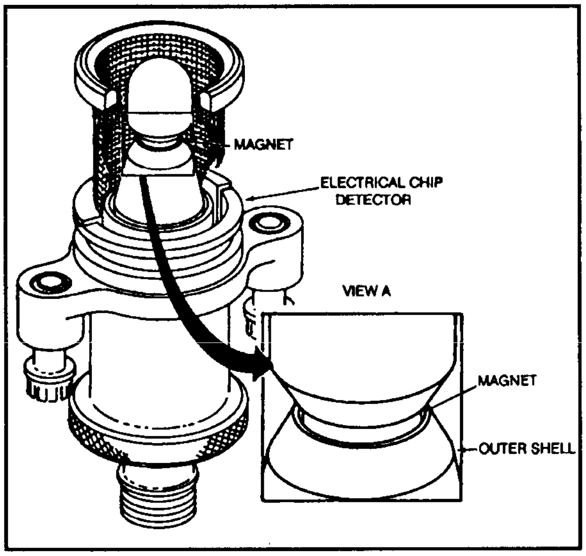


Figure 5-15. Electrical Chip Detector

Venting System

A-Sump. The A-sump centervent handles air-oil separation and overboard venting from these sources:

- A-sump seals and emergency air system.
- Scavenge pumped air from the lube tank.
- Accessory gearbox vent (no air sources).
- B-sump centervent flow which passes through the intershaft seal.

Path of this vent is into the bore of the power turbine shaft and torque-reference tube and out the aft end of the engine through the C-sump cover. The centrifugal air-oil separator vent holes in the power turbine shaft are located under the forward end of the high-speed shaft. Windage from PTO gear locknut wrenching slots assists in turning oil back into the sump. Air from the sump and intershaft seal flows inward radially through these holes in the power turbine shaft. The air must flow forward in the annulus between the power turbine shaft and the torque-reference tube. Movement of air is blocked by a standoff ring on the reference tube OD. The forward axial passage of the air centrifuges oil droplets outward to the bore of the power turbine shaft. They either flow back into the sump at the centervent or at small weep holes forward of the PT shaft spline. Dried air then exits through multiple rows of holes in the reference tube and out the aft C-sump cover. Some remaining oil in this air is spun into the C-Sump if it has condensed in transit. Any additional accumulated oil is then scavenged through the C-sump cover.

B-Sump. A centervent on the forward side of the No. 4 bearing accommodates air entering the sump at the labyrinth seals at each end Two rows of small holes are drilled in a radially thickened section of the forward seal runner. Use of many small holes increases the surface area of metal in contact with exiting oil droplets. These small holes also reduce effective window area for any droplets which may have a trajectory aimed directly at the holes. Ater the air is inside these holes, it follows a tortuous path through additional rows of holes in the turbine shaft and compressor rear shaft. The air then enters the annlus between the high- and low-speed shafts. In doing this, remaining oil is spun back into the sump.

About 70 percent of B-sump centervent flow moves forward through the bore of the compresor tiebolt and intershaft seal. It exits at the A-sump centervent. Oil weep holes are provided near the aft end of the compressor tiebolt. These weep holes keep oil out of the rotor by returning it to the sump. A rotor seal is provided hereto keep any weepage out of the seal air. This airflow keeps the compressor tiebolt relatively cool and uniformly clamped.

The remaining 30 percent of B-sump centervent air joins the inner balance piston seal leakage flow. It exits aft under the gas generator turbine wheels.

C-Sump. Centerventing the C-sump is a passage between the aft end of the PT shaft and a stationary standpipe built into the C-sump cover. Windage at the torque and speed-sensor teeth and in the annulus between the reference tube and the standpipe will return oil droplets to the sump. Weep holes are provided through the reference tube, shaft, and bearing spacer to allow oil from C-or A-sumps to enter the C-sump. C-sump cover scavenging through the C-sump housing removes remaining oil accumulation from the centerventing process during locked PT rotor operation and normal operation.

Oil Tank. After being routed through air-oil cooler pasages into the oil tank, air from the scavenge pumps flows down the radial drive shaft passage (Axis A) into the A-sump. Centerventing occurs after air enters the A-sump.

Accessory Gearbox. The accessory gearbox is vented through the Axis A pad via the mainframe oil tank and eventually through the A-sump. The AGB, tank, and A-sump essentially operate at the same pressure levels since they are interconnected.

LUBRICATION SYSTEM FOR T-62

The lubrication system consists of–

- Pump.
- Internal oil passages.
- Oil filter assembly.
- Falter bypass relief valve.
- Pressure switch (mounted externally).
- Oil jet ring,
- Sump.

The oil falter cavity, oil passages, and oil sump are built into the reduction drive housing. Two oil separator plates are installed on the accessory drive gear. Lubrication system capacity is 3 quarts and is a wet-sump system.

Oil is drawn out of the sump into the pump housing. The oil is carried between the pump gear teeth and pump housing wall. It is then forced through drilled passages to the oil filter housing.

Oil under pump pressure enters the bottom of the filter housing and passes through the filter element (from outside to inside). It then flows out the housing through a passage in the falter element cap. A relief valve in the filter element cap unseats at a differential pressure of 15 to 25 psi. This allows oil to flow from outside the filter element, through a passage in the falter element cap, to the falter outlet passage. If the filter element becomes clogged, the valve will open and allow oil to bypass the falter element.

From the filter, oil is forced into a passage to the system relief valve and to four oil jets. The oil jet ring, which encircles the high-speed input pinion, contains three of these jets. It sprays oil to the points where the high-speed input pinion meshes with the three planetary gears. One jet directs a spray between the end of the output shaft and the high-speed pinion to create a mist for lubrication of the rotor shaft bearings. The remaining gears and bearings are lubricated by air-oil mist created when oil strikes the planetary gears and high-speed pinion.

System pressure is maintained at 15 to 25 psi by a system relief valve. The valve regulates pressure by bypassing excessive pressure directly into the reduction drive housing. The bypassed oil strikes the inside surface of the air inlet housing, aiding in cooling the oil. Bypassed oil returns to the sump by gravity flow through an opening in the bottom of the planet carrier.

The normally open contacts of the low oil pressure switch close on increasing oil pressure at 5 to 7 psi. When the switch contacts close, the low oil pressure cirecuit is deenergized. At rated engine speed a drop in oil pressure below 5 to 7 psi will open the low oil pressure switch contacts. Through electrical circuitry, the drop in oil pressure will also close the main fuel solenoid valve and shut down the engine.

CHAPTER 6

IGNITION SYSTEMS

Turbine engine ignition systems fall into two general classifications. The induction type produces high-tension sparks by conventional induction coils. The capacitor type causes ignition by high-energy and very high temperature sparks produced by a condenser discharge. A third kind of ignition system not widely adopted uses aglow plug.

DESCRIPTION

Igniter-exciter components are contained in hermetically sealed boxes. With a malfunction, it is necessary to replace the entire exciter. Shielded cable is employed throughout the system to protect against abrasion and ignition system radio interference.

Ignition systems are not only used for engine starting but also for ignition standby protection. Ignition systems would be used to relight the engine if an in flight flameout occurred when operating under potentially unstable flight conditions. Turbine engines sometimes tend to flameout because of an overrich fuel-air ratio caused by a momentary fluctuation of air supply at the compressor inlet. A change in airflow at the compressor inlet or the entrance to the aircraft inlet duct may cause a condition fuel control cannot immediately compensate for. Flameout results. Flying in turbulent air, ingestion of a bird, or ingestion of ice broken loose at the engine inlet may cause such a situation. When one or both of the igniter plugs are operating, the engine will relight automatically after fuel control compensation takes place or the inlet condition corrects itself. The pilot may not be aware that flameout has occurred. When ignition is used as a precaution against flameout, the prescribed ignition-use time limitations must be observed. This prevents overheating the ignition system components and enhances the life span of the ignition system.

EARLY INDUCTION TYPE

Early turbine engine ignition systems evolved using the tried principles developed for the reciprocating engine. Some of the early systems employed a vibrator and transformer combination. This was similar to the booster coils used for starting reciprocating engines. Other units substituted a small electric motor driven cam. This provided the neccessary pulsating magnetic field to the primary coil of the transformer. Several variations appeared, all using the same basic principle. This principle was high-voltage induction using a transformer to reach the necessary voltage capable of causing an arc across the wide-gap jet igniter plug. An interesting variation of this transformer-type ignition system is the opposite-polarity system. In this circuit two electrodes extend into the combustion chamber. Each electrode alternately becomes highly positively and negatively charged, causing a very high potential difference to exist across the electrodes.

MODERN CAPACITOR TYPE

The high-energy, capacitor-type ignition system has been universally accepted for gas turbine engines. It provides both high voltage and exceptionally hot spark which covers a large area. Excellent chances of igniting the fuel-air mixture are assured at reasonably high altitudes.

The term “high energy” is used throughout this chapter to describe the capacitor-type ignition system. Strictly speaking the amount of energy produced is very small. The intense spark is obtained by expending a small amount of electric energy in a very small amount of time.

Energy is the capacity for doing work. It can be expressed as the product of the electrical power (watt) and time. Gas turbine ignition systems are rated in joules. The joule is also an expression of electric energy. It is equal to the amount of energy expended in one second by an electric current of one ampere through a resistance of one ohm. The relationship between these terms can be expressed by the formula—

$$w=\frac{1}{t}$$

where w= watts (power)
j = joules
t = time (second)

All other factors being equal, the spark temperature is determined by the power level reached. A high-temperature spark results from increasing the energy level (1) or shortening the duration (t) of the spark. Increasing the energy level results in a heavier, bulkier ignition unit. Energy delivered to the sparkplug is about 30 to 40 percent of total energy stored in the capacitor. Higher erosion rates on the igniter-plug electrodes occur because of heavy current flowing for a comparatively long time. Much of the spark is wasted since ignition takes place in a matter of microseconds (microsec). On the other hand, since heat is lost to the igniter-plug electrodes and the fuel-air mixture is never completely gaseous, the spark duration cannot be too short.

The relationship between watts and time is shown in the following table. The example is for a 4-joule ignition unit (4 joules appearing at the plug).

In an actual capacitor-discharge ignition system, most of the total energy available to the igniter plug is dissipated in 10 to 100 microsec (0.000010 to 0.000100 seconds). The system above would actually deliver 80,000 watts if the spark duration was 50 microsec.

TABLE. WATTS AND TIME RELATIONSHIP

TIME (SECOND)	POWER (WATTS)
1	4
0.01 (hundredths)	400
0.001 (thousandths)	4,000
0.0001 (ten thousandths)	40,000
0.00001 (hundred thousandths)	400,000
0.000001 (millionths)	4,000,000

$$w = \frac{1}{t}$$

$$= \frac{4}{0.000050}$$

$$= 80,000$$

To review, the spark temperature (a function of the watts value) is the most important characteristic of any ignition system. All three factors – watts, energy, and time – must be considered before any ignition system effectiveness can be determined

HIGH-ENERGY TYPE

Ignition systems for jet engines are divided into induction and capacitor discharge types. The capacitor discharge type can be further divided into two basic categories:

- High-voltage capacitor ignition system with DC or AC input.
- Low-voltage capacitor ignition system with DC or AC input.

High-Voltage Capacitor System - DC input (more than 5000 VDC to the plug)

This system is a typical turbojet engine system in use today. This system can include: two exciter units, two transformers, two intermediate ignition leads, and two high-tension leads. Depending on engine configuration a dual ignition is provided on the engine by two separately mounted exciters or by twin circuits throughout the exciter.

As operation begins, the power source delivers 28VDC (maximum) input to the system. Each triggering circuit is connected to a spark igniter. The operation described here takes place in each individual circuit. Except for the mechanical features of the armature, the operation is essentially the same in both Units.

As a safety factor, the ignition system is actually a dual system designed to fire two igniter plugs.

Before the electrical energy reaches the exciter unit, it passes through a falter. This filter prevents noise voltage from being induced into the aircraft electrical system. The low-voltage input power operates a DC motor, which 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 automatic 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. The collapse of the field induces a voltage in the secondary winding of the transformer. This voltage causes a puke of current to flow into the storage capacitor. The voltage flows 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 4 joules. (One joule per second equals 1 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 builds 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 in series 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. This is done together 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, which 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 pukes before discharge.

The employment of the high-frequency triggering transformer, with a low-reactance secondary winding, holds the duration of the discharge to a minimum. This concentration of maximum energy in minimum time achieves an optimum spark for ignition. An optimum spark is 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 and eliminating flashover at altitude due to pressure change. This also ensures shielding against leakage of high-frequency voltage interfering with the radio reception.

Two igniter plugs are mounted in the combustion section outer case. The spark igniters are generally located in two diametrically opposite combustion liners. The igniters receive the electrical output from the ignition exciter unit. The igniters discharge the electrical output from the ignition exciter unit. And they discharge the electric energy during engine starting to ignite the fuel-air mixture in the combustion liners.

Typical specifications for this system are as follows

Input voltage:	Normal: 24VDC Operating limits: 14 to 30 VDC
Spark rate:	4 to 8 per second at each plug, depending on input voltage
Designed to fire:	2 igniter plugs
Accumulated energy	3 joules
Duty cycle:	2 minutes ON, 3 minutes 0FF, 2 minutes ON, 23 minutes OFF

High-Voltage Capacitor System-AC Input

Power is supplied to the unit input connector from the 115-volt, 400-cycle source in the aircraft. Power is first led through a filter which blocks conducted noise voltage from feeding back into the airplane electrical system. From the filter, the circuit is completed through the primary of the power transformer to ground

In the secondary of the power transformer, an alternating voltage is generated at a level approximating 1700 volts. During the first half-cycle this follows a circuit through the doubler capacitor and rectifier A to ground, leaving the capacitor charged. During the second half-cycle when the polarity reverses, this circuit is blocked by rectifier A. The flow of this puke is through ground to the storage capacitor, rectifier B, resistor, doubler capacitor, and back to the power transformer.

With each pulse the storage capacitor assumes a greater charge. By virture of the action of the doubler capacitor, the charge approaches voltage approximately twice that generated in the power transformer. When this voltage reaches the predetermined level calibrated for the spark gap in the discharge tube X (the control gap), the gap breaks down. This allows a portion of the accumulated charge to flow through the primary of the high-tension transformer and the trigger capacitor in series with it. This surge of current induces a very high voltage in the secondary of the high-tension transformer. This surge is enough to ionize the gap in discharge tube Y. The storage capacitor immediately discharges the remainder of its accumulated energy through the spark igniter. This produces a capacitive spark of very high energy.

The bleeder resistors are provided to dissipate the residual charge on the trigger capacitor. This is accomplished between the completion of one discharge at the spark igniter and the succession of the next cycle.

Typical specifications for this system are as follows:

Input voltage:	Normal: 115-volts, 400-cycle AC Operating limits 90 to 1241 volts

Spark rate: Normal: 1.50 to 275 per sec
Operating limits: 0.75 to 5.00 per second

Designed to ignite: One spark igniter

Accumulated energy: 14 to 17 joules

Duty cycle: 2 minutes ON, 3 minutes OFF
2 minutes ON, 23 minutes OFF

Low-Voltage Capacitor System-DC Input (less than 1000 volts to the plug)

The basis of operation on which the low-voltage, high-energy ignition system is built is the self-ionizing feature of the igniter plug. In the high-voltage system a double spark is produced. The first part consists of a high-voltage component to ionize (make conductive) the gap between the igniter plug electrodes. The second high-energy, low-voltage portion follows. The low-voltage, high-energy spark is similar except that ionization is effected by the self-ionizing igniter plug.

The main ignition unit changes the amplitude and the frequency characteristics of aircraft power into pulsating DC. To do this, the components in the ignition unit are grouped in stages to falter, amplify, rectify, and store an electric charge.

The spark plugs used in the ignition system are the shunted-gap type, which are self-ionizing and designed for low-tension (relatively low voltage) applications.

Although the spark plug fires at relatively low voltage, a high-temperature spark is obtained from the speed the energy is discharged across the gap. The spark is of short duration (40 microsec), but momentarily expends a great amount of power. Tank capacitor discharge current from the main ignition unit surges to the spark-plug electrodes. This builds a potential between the center electrode and ground electrode. The semiconducting material shunts the electrodes. When the potential between electrodes reaches approximately 800 volts, it forces enough current through the semiconductor to ionize the air gap between the electrodes. The full-tank capacitor current arcs instantly across the ionized gap, emitting a high-energy spark.

COMBINATION OR DUAL DUTY

The operation of this system will not be discussed in detail. However, it is mentioned to make you aware of the system.

The ignition system includes one intermittent-duty exciter, one continuous-duty exciter, one intermediate voltage lead, and two high-tension leads. It is designed to tire two spark igniters during ground starts. This is accomplished by the 20-joule intermittent-duty exciter or one spark igniter during flight by the 4-joule continuous-duty exciter.

When intermittent operation is employed, DC power is supplied to the input of the intermittent-duty exciter from the 24-volt aircraft electrical system. It is first passed through a radio noise filter to prevent high-frequency feedback. When continuous operation is employed, power is supplied to the input of the continuous-duty exciter from the 115-volt, 400-cycle AC source in the aircraft.

ELECTRONIC

This modified capacity-type system provides ignition for turbojet and turboprop engines. It is required only for starting the engine. Once combustion begins the flame is continuous. Figure 6-1 shows the components of atypical electronic ignition system.

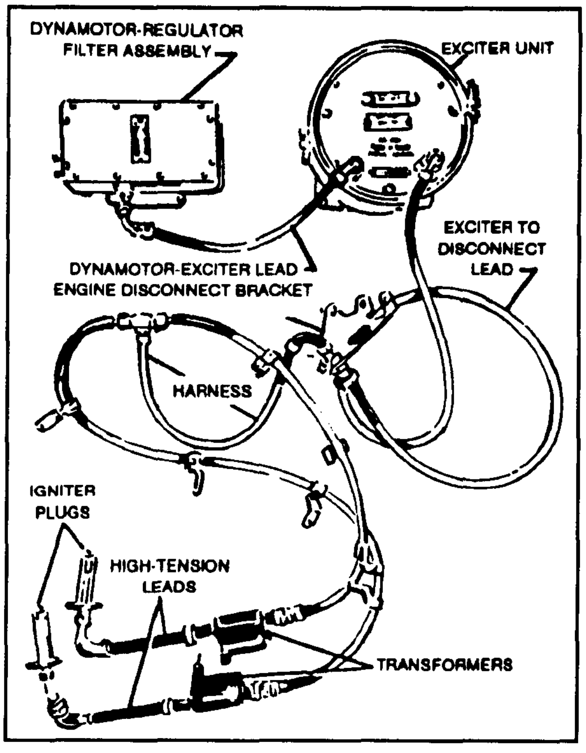


Figure 6-1. Typical Electronic Ignition Sys-

The system consists of a dynamotor/regulator/filter assembly, an exciter unit, two high-tension transformer units, two high-tension leads, and two igniter plugs. The necessary interconnecting cables, leads, control switches, and associated equipment for operation are used with these components.

The dynamotor is used to step up the direct current of the aircraft battery or the external power supply to the operating voltage of the exciter unit. This voltage is used to charge two storage capacitors which store the energy used for ignition.

In this system, the energy required to tire the igniter plug in the engine burner is not stored in an inductor coil Instead, the energy is stored in capacitors. Each discharge circuit incorporates two storage capacitors. Both are located 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 very high energy. The result is a spark of great heat intensity. It is capable not only of igniting abnormal fuel mixtures but also of burning away any foreign deposits on the plug electrodes.

The exciter is a dual unit, and it produces sparks at each of the two igniter plugs. A continuous series of sparks is produced until the engine starts. The battery current is then cut off. The plugs do not tire while the engine is operating.

TURBINE ENGINE IGNITERS

Turbine engine igniters come in many sizes and shapes depending on what their function is. The electrodes of the plugs used with high-energy ignition systems must accommodate a much higher energy current than the electrodes of conventional sparkplugs. The high-energy current causes more rapid igniter electrode erosion than in reciprocating engine sparkplugs. This is not a problem because of the relatively short time a turbine engine ignition system is in operation. This is one of the reasons for not operating the gas turbine ignition system any longer than necessary. Igniter plug gaps are large in comparison with those of conventional spark plugs. The gaps are large because the operating pressure at which the plug is fired is much lower than that of a reciprocating engine.

Most igniter plugs are of the annular-gap type. Constrained gaps are used in some engines. Normally, to provide an effective spark the annular-gap plug projects slightly into the combustion chamber liner. The spark of the constrained-gap plug does not closely follow the face of the plug. Instead, it tends to jump an arc which carries it beyond the face of the chamber liner. The constrained-gap plug need not project into the liner. The result is that the electrode operates at a cooler temperature than the annular-gap plug.

The turbojet ignition system is designed for severe altitude conditions common to military operation. It is rarely taxed to its full capability by transport use. Flameout is much less common than it was, and flight relight is not normally required of the ignition system. Ignition problems in general are minor compared to the constant attention required by the piston engine system. Airborne ignition analysis equipment is unnecessary. Spark igniter plug replacement is greatly minimized. Only two plugs per engine are used.

The trends taking place in the gas turbine ignition area are —

- Use of AC power inputs, which eliminates the vibrator, a major source of trouble.
- Use of solid-state rectifiers.
- Use of two discharge tubes, which permits the level of stored energy per spark to be more consistent throughout the life of the exciter.
- Sealed units.
- Longer time between overhauls.
- The advent of short-range jets, which increased the ratio of ignition-on time to engine operation and led to development of dual systems.

Two types of ignition systems in Army aircraft today are General Electric’s T-701 and Lycoming's T-55-L-712

T-701 GENERAL ELECTRIC

The ignition system is an AC-powered, capacitor-discharge, low-voltage system. It includes a dual exciter unit mounted on the right-hand side and two igniter plugs (Figure 6-2). The spark rate of each ignition circuit is two sparks per second minimum; energy at the igniter plugs is at least 0.25 joules per spark. The exciter is powered by one winding of the engine alternator and is connected to it by the yellow harness. The ignition system must be turned off after starting by shorting the alternator output. For normal starting the aircraft-ignition circuit is tied in with the aircraft-starting system to de-energize the ignition system at the starter or dropout speed

The igniter plug is a homogeneous semiconductor, surface-gap type spark plug using air cooling of the firing tip (Figure 6-3). It provides a projected electrical discharge for lightoff of the combustor. An engine set consists of igniters located at the 4 o’clock and 8 o’clock positions. They are mounted in the midframe using a

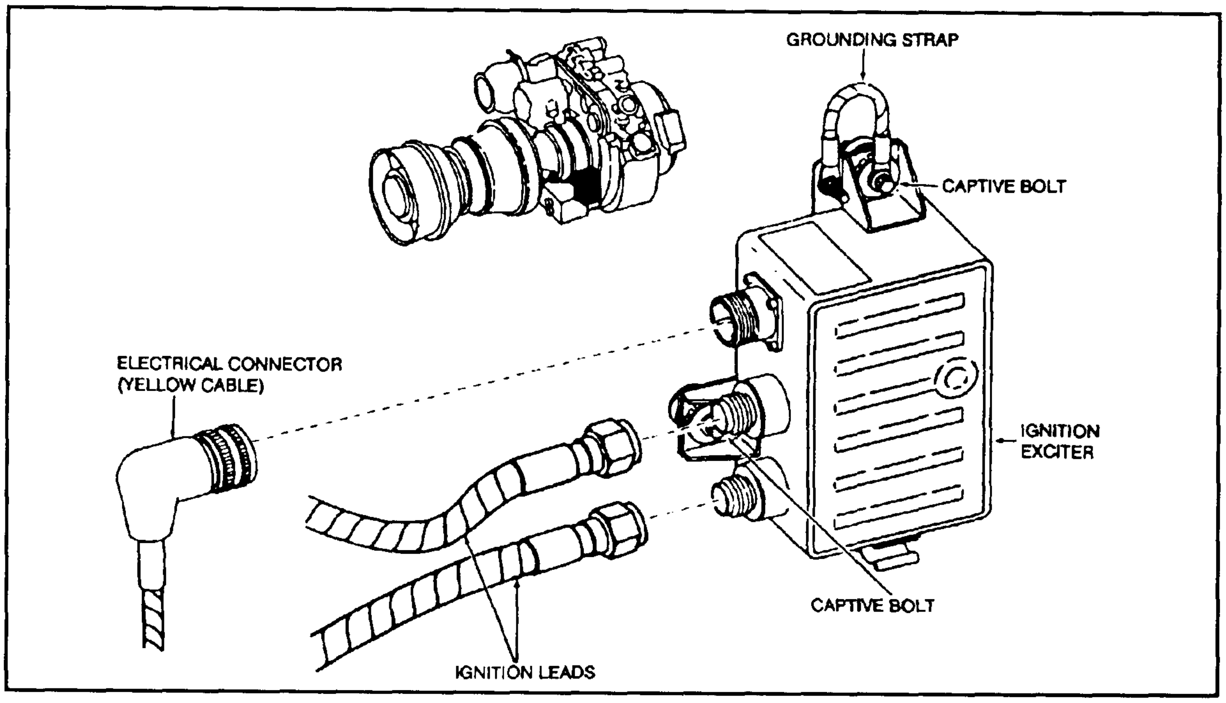


Figure 6-2. Ignition Exciter

screw-in boss and extend inward through the outer panel of the combustion liner.

The ignition system operates with a maximum output of 7000 volts. To create a spark across the electrode gap with this voltage, the gap surface is a semiconductor material, homogeneous button extending into the tip of the plug. It is, therefore, capable of coping with erosion over a long period of operating time. Consistent with this long life objective, the center electrode is pure tungsten and the outer electrode is tungsten alloy. These electrodes are nickel-plated to prevent oxidation, a problem further minimized by tip cooling. Compressor discharge air provides cooling air which enters through six holes around the tip body and exits through twelve holes at the tip end.

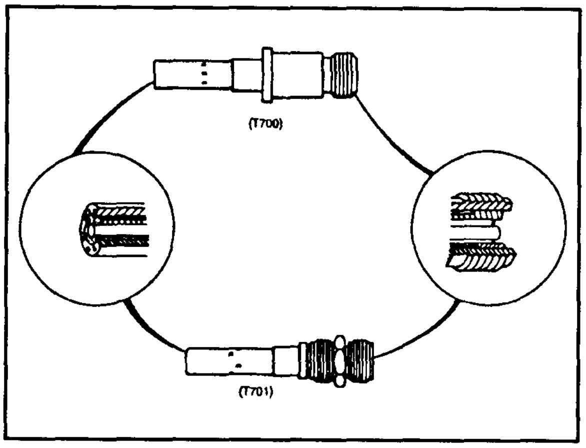


Figure 6-3. Igniter Plug

T-55-L-712 LYCOMING

The high potential ignition pulse is developed by the ignition exciter (Figure 6-4). A direct current at 28 volts is applied to the input of the exciter. Current flows throught the primary transformer winding the bias coil, and the vibrator points to ground This generates magnetic lines of force which permeate the transformer and bias coil cores, attract the vibrator reed upward, and interrupt the circuit. As current flow ceases, the lines of force collapse, and the reed falls back. This closes the circuit. This cycle repeats at a rate proportional to the input voltage. The resultant current flows in pulses, causing magnetic lines of force to build up and collapse with each pulsation. These lines induce voltage across the secondary. They are transformed to a higher potential by virtue of an increased number of windings comprising the secondary. The diodes rectify the pulsating current back into direct current to charge the capacitors. The charge on the capacitors continues to build up at a rate proportional to input voltage until a potential of 2500 AC volts exists. The calibrated spark gaps ionize at this voltage creating an electrical path for the tiring pulse. The capacitors discharge through this path into the lead coil assembly for distribution to the spark igniters.

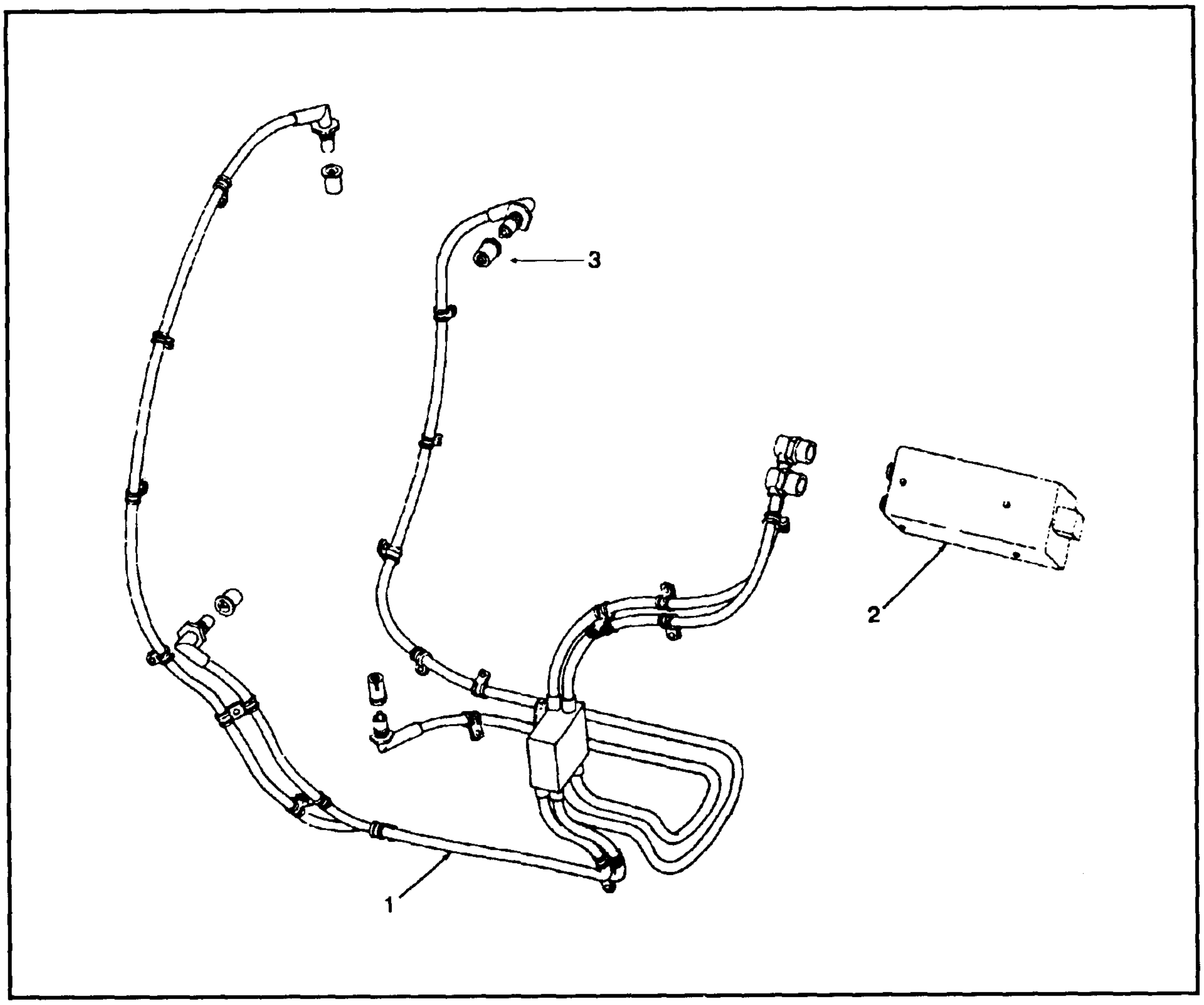


Figure 6-4. Harness, Ignition Exciter, and Spark Plugs

Radio frequency energy is generated within the exciter during normal operation. An inductive capacitive filter has been incorporated at the input. This will prevent energy from being fed back onto the 28-volt input line. Radio frequency interference on this line could damage the operation of other electrical accessories. The filter is turned to radio frequencies. It does not offer any appreciable opposition to the flow of 28-volt direct current.

The ignition lead and coil assembly constitutes the high potential ignition wiring. This assembly incorporates two coils fed with high voltage from the two outputs of the ignition exciter. The coil assemblies function as spark splitters distributing high voltage to four igniter plugs. Each coil assembly has one input and two outputs. The coil windings forma transformer having a 1:1 ratio. Any current flowing through either winding will induce a voltage across the other. Even a shortened igniter plug will not short out the high-voltage ignition signal. The entire wiring harness is shielded and grounded at airframe potential to suppress radiation of radio frequency interference.

CHAPTER 7

COOLING SYSTEM

The intense heat generated when fuel and air are burned mandates that some means of cooling be provided for all internal combustion engines. Reciprocating engines are cooled either by passing air over fins attached to the cylinders or by passing a liquid coolant through jackets surrounding the cylinders. Cooling is made easier because combustion occurs only during every fourth stroke of a four-stroke-cycle engine. In contrast, the burning process in a gas turbine engine is continuous, and nearly all of the cooling air must pass through the inside of the engine. If enough air were admitted to the engine to provide an ideal air-fuel ratio of 151, internal temperatures would increase to more than 40000°F. In practice, a large amount of air exceeding of the ideal ratio is admitted to the engine. This large surplus of air cools the hot sections of the engine to acceptable temperatures ranging from 1100° to 1500°F.

COOLING OF ENGINE OUTER CASE

Figure 7-1 illustrates the approximate engine outer-case (skin) temperatures encountered in a properly cooled dual-axial compressor turbojet engine. Because of the effect of cooling, the temperatures of the outside of the case are considerably less than those encountered inside the engine. The hottest spot occurs opposite the entrance to the first stage of the turbine. Although the gases have begun to cool a little at this point, the conductivity of the metal in the case carries the heat directly to the outside skin.

COOLING OF COMBUSTION CHAMBER AND GAS PRODUCER

The air passing through the engine the combustion-chamber burner cans or liners. The cans are constructed to induce a thin, fast-moving film of air over both the inner and outer surfaces of the can or liner. Can-annular-type burners are frequently provided with a center tube to lead cooling air into the center of the burner to promote high combustion efficiency and rapid dilution of the hot combustion gases while minimizing pressure losses. In all types of gas turbines, large amounts of relatively cool air

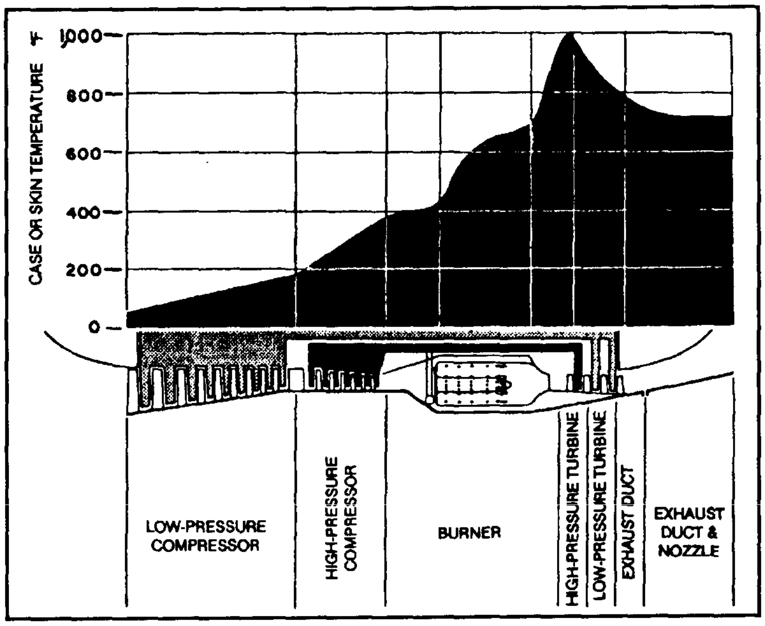
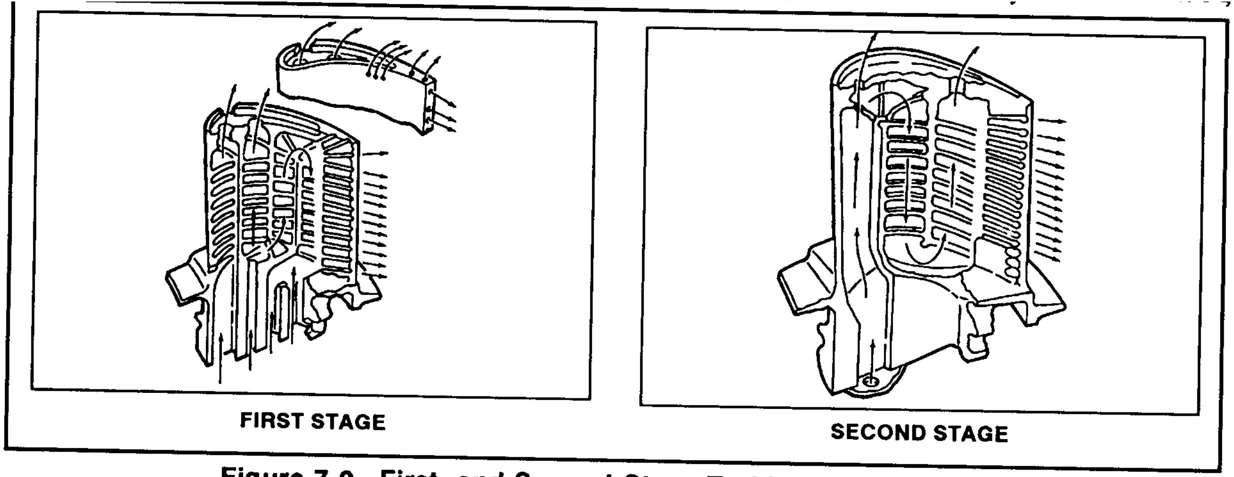


Figure 7-1. Typical Outer-Case Temperature for Dual-Axial Compressor Turbojet Engine

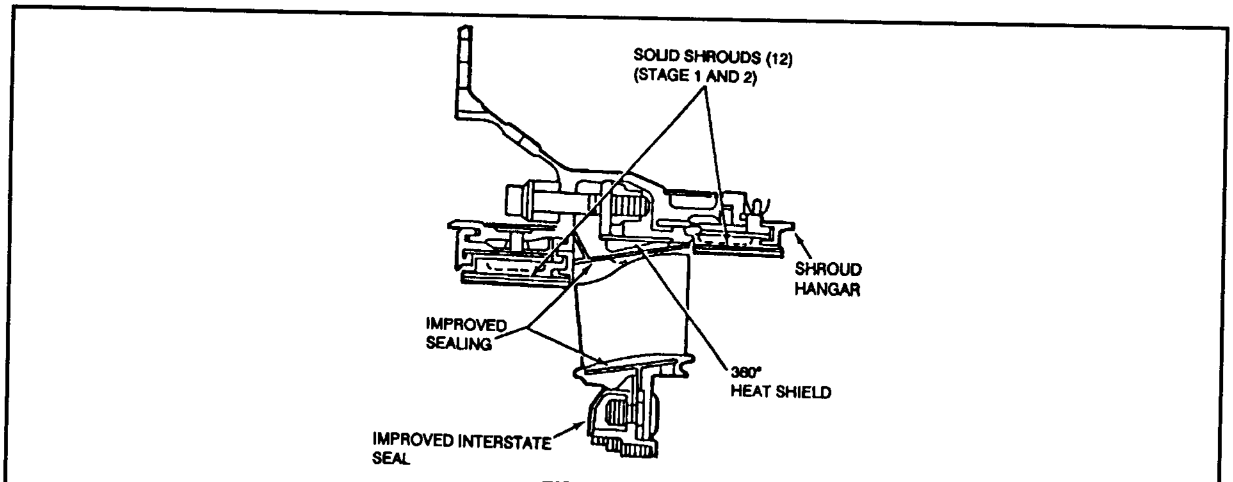
join and mix with the burned gases aft of the burners to cool the hot gases just before they enter the turbines.

All stage 1 and 2 airfoils in the GE T-701 engine are internally cooled by means of compressor discharge air (Figures 7-2, 7-3). The stage 1 nozzle leading edge is conection- and film-cooled with the air exiting through a shower-head series of holes in the leading edge. Aft of the leading edge, film-cooling air exits through convex and concave side gill holes and trailing edge slots. Cooling air for the stage 2 nozzle is bled from the centrifugal impeller exit and piped back through the midframe to enter the stage 2 nozzle. It cools by internal convection,

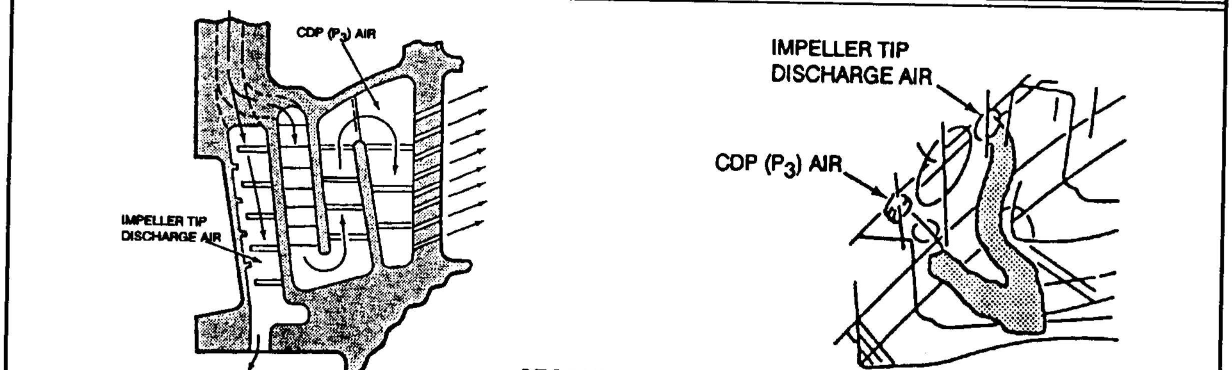

FIRST STAGE

SECOND STAGE

Figure 7-2. First- and Second-Stage Turbine Blade Cooling



FIRST STAGE



SECOND STAGE

Figure 7-3. Nozzle Cooling

exiting both by trailing edge holes and by inner band holes. There, it cools the interstage seal. The turbine blades are convection-cooled through radial holes in the dovetail. Air exits through tip holes. The stage 1 blades also employ trailing edge holes for cooling.

EXTERNAL COOLING

Cooling air inlets are frequently provided around the exterior of the engine to permit entrance of air to cool the turbine case, the bearings, and the turbine nozzle (Figure 7-4). In some instances internal air is bled from the engine compressor section and is vented to the bearings and other parts of the engine. Air vented into or from the engine is ejected into the exhaust stream. When an accessory case is mounted at the front of the engine, it is cooled by inlet air. When located on the side of the engine, the case is cooled by outside air flowing around it.

The engine exterior and the engine nacelle are cooled by passing air between the case and the shell of the nacelle. The engine compartment frequently is divided into two sections. The forward section is built around the engine air inlet duct; the aft section is built around the engine. A fume-proof seal is provided between the two sections. The advantage of such an arrangement is that fumes from possible leaks in the fuel and oil lines contained in the forward section cannot become ignited by contact with the hot sections of the engine. In flight ram air provides ample cooling of the two compartments. On the ground air circulation is provided by the effect of reduced pressure at the rear of the engine compartment produced by gases flowing from the exhaust nozzle.

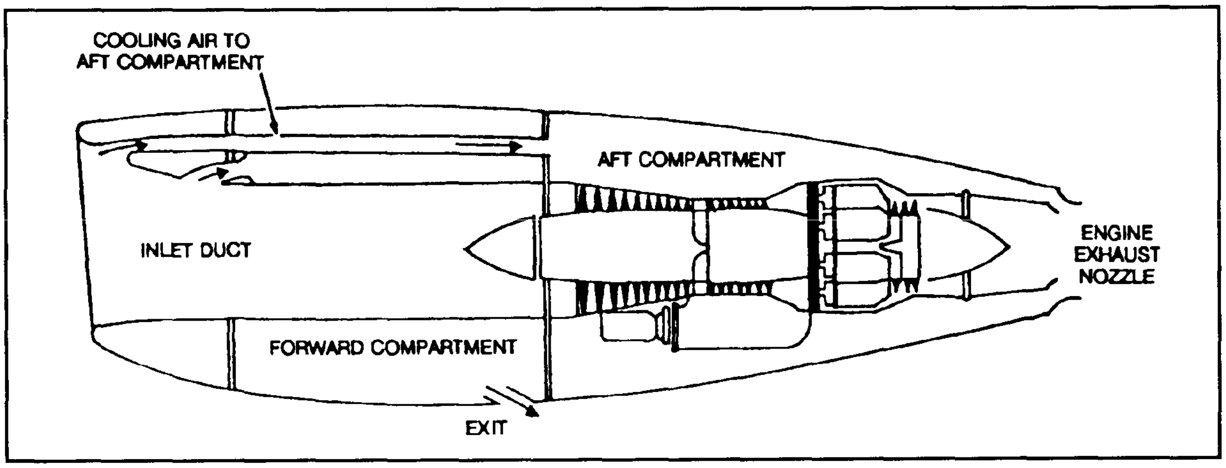


Figure 7-4. Typical Engine Nacelle Cooling Arrangement

CHAPTER 8

ACCESSORY SYSTEMS

Accessories for gas turbine engines can be divided into two categories those driven by bleed air taken from the compressor section of the engine; those driven mechanically by an accessory drive shaft and gearbox connected directly to the turbine shaft. The mechanical connection from the turbine shaft may be through an engine-mounted gearbox or through a power takeoff shaft to a remotely mounted gearbox.

BLEED-AIR-DRIVEN ACCESSORIES

Gas turbines are unique among engines. High--pressure air is available for driving aircraft accessories by air motors or air turbines. Compressor discharge air at high pressure and temperature is bled from the engine through ports provided. This air is ducted as a source of power. It operates the air-conditioning units, hydraulic pumps, thrust reverser actuators, and various mechanical actuators in the airplane. Air for cockpit or cabin pressurization is also provided by bleed air from the engine compressor. On multiengined aircraft equipped with pneumatic engine starters, one engine is usually started from an auxiliary power unit or a ground air source. Air from this operating engine is bled through a system of ducts in the aircraft, to power the starters of the other engines.

The Pratt and Whitney dual-axial compressor turbine engine is an example that uses bleed air to operate accessories. The JT3D turbofan engine is used on aircraft such as the Boeing 707 and B-52 bomber. This engine also uses a mechanical accessory gearbox. It usually has three separate bleed air systems: high pressure, low pressure, and overboard. The high- and low-pressure systems are used to drive aircraft, engine components, and accessories. The overboard is required to preclude compressor instability.

Compressor bleed air is also used to anti-ice the engine air inlet guide vanes and, frequently, parts of the air inlet duct. Low-pressure air has a pressure of approximately 50 psi and a temperature of more than 300°F. This low-pressure air is taken from bleed air parts compressor mid-section between the low- and high-pressure compressors. High-pressure bleed air has a pressure of about 160 psi and a temperature of more than 650°F when operating near sea level. This air is taken from the rear of the high-pressure compressor. The air available for driving accessories and for other purposes in the aircraft is usually about 3 or 4 percent of the primary engine airflow. Keep in mind the air under pressure that is extracted from the engine is not a bonus. Engine output and fuel consumption are sacrificed.

MECHANICALLY DRIVEN ACCESSORIES

The other method of driving accessories is a direct, mechanical drive operated by gearing from the compressor-turbine drive shaft. Accessory drives and accessory mounting pads are provided in an engine-mounted, accessory drive gearbox or in a remotely mounted gearbox. On some turbojet engines, accessory pads and mechanically powered drives are also provided in the engine nose section. For dual compressor, axial-flow engines, the main accessory drive gearbox usually receives its power from the high-pressure compressor drive shaft. Mechanically driven accessories include: tachometers, generators (alternators), hydraulic pumps, fuel pumps, oil pumps, fuel controls, starters, and (ii some instances) water pumps.

LYCOMING T-55 ENGINE

The power extraction system transmits power from the N1 and N2 systems to the accessory gearbox located at the 6 o’clock position on the inlet housing (Figures 8-1, 8-2). Most of these components receive their driving force from the N1 system. A minimum amount of power is extracted from the N2 system.

The starter gearbox, mounted at the 12 o’clock position, functions as a centrifuge for air-oil separation during engine operation. The N1 system provides the driving force. A single bevel gear is located at the front end of the compressor shaft; meshes with a planetary geartrain housed in the inlet housing This gear train transmits N1 power through two drive shafts: one to the starter gearbox, the other to the accessory gearbox to drive the idler system. A gear located on the output power shaft

Gearshaft assembly (1) and gearshaft (2) are located in the starter drive assembly. Bevel gearshafts (18 and 20) and bevel gear (19) are located in the accessory gear assembly. The fuel boost pump drive gear (6), main oil pump drive spur gear (7), fuel control drive spur gear (8), N1 driven bevel gear (9), overspeed governor control drive bevel spur gearshaft (10), spur gear cluster (11), spur gear (12), and N2 driven bevel gear (13) are located in the accessory gearbox assembly. The N2 driven bevel gearshaft (14) is part of the overspeed drive and tank outlet cover assembly. Overspeed drive bevel gear (15) and spur gear (16) are part of the output shaft support housing (not shown). The output shaft (17) is mounted and rotates through the output shaft support housing. Bevel gear (3) is part of the compressor rotor assembly (4).

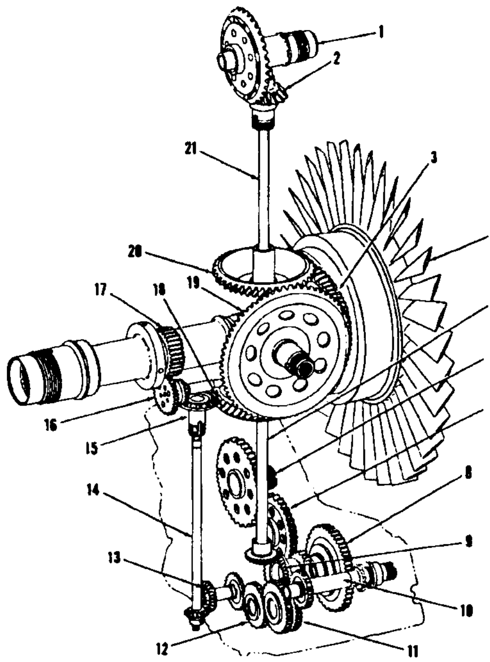


Figure 8-1. Power Extraction System and Gearbox

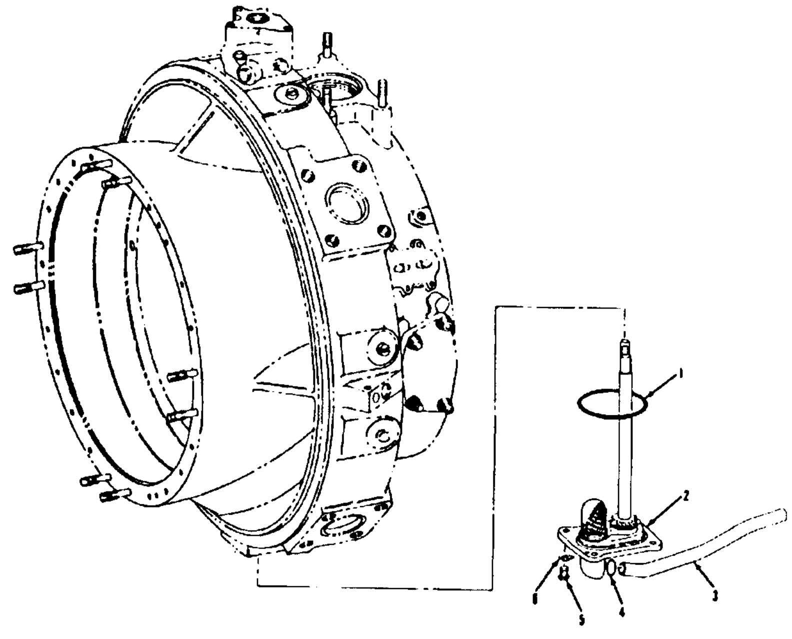


Figure 8-2. Overspeed Drive Cover Assembly

interconnects with the 90° angle gear in the output shaft support housing. The gears drive the N2 section of the accessory gear train.

The N2 driven overspeed governor in the fuel control is driven from a spur gear. This gear is attached to the N2 system drive shaft which rotates on a ball bearing with a pad, located at the 6 o'clock position on the inlet housing

Customer power extraction is provided through the vertical bevel pinion gear located within the accessory gear carrier. It is available for use by inserting a customer-supplied drive shaft in its internal splines.

The accessory drive gearbox supplies mounting pads for the engine-supporting accessories and provides the transmission capability to drive these components. Dimensional standardization permits interchanging components among engines and eliminates the need for adapters for test equipment.

GENERAL ELECTRIC T-701

The accessory module mounts on the cold section module at the 12 o'clock position of the main frame (Figures 8-3, 8-4). It includes the accessory drive gearbox (AGB) that is driven by a bevel-gear system from the compressor rotor via a radial drive shaft. Several accessories are contained in or mounted on the front and rear casings of the AGB. The rear face provides drive pads for the engine starter, hydromechanical unit, inlet separator blower, and a face-ported pad for the overspeed and drain valve. Pads for the alternator and fuel boost pump are on the front face. A cavity is provided for the lube and scavenge pump and chip detector. Pads are supplied for the oil cooler, fuel meter, and lube falter. Cored passages in the AGB housing convey fuel and oil between components.

Drive pad seals for the starter, hydromechanical unit, and fuel boost pump drain into a common cored passage in the AGB housing. It then drains to an external port on the right-hand side of the mainframe.

ACCESSORY DRIVES

Accessory Drive System

The accessory drive system provides drives for both the N1 driven accessory gearbox and the N2 driven overspeed governor and tachometer drive assembly. Provision is also made within the system for the drive of customer-furnished accessories through the power

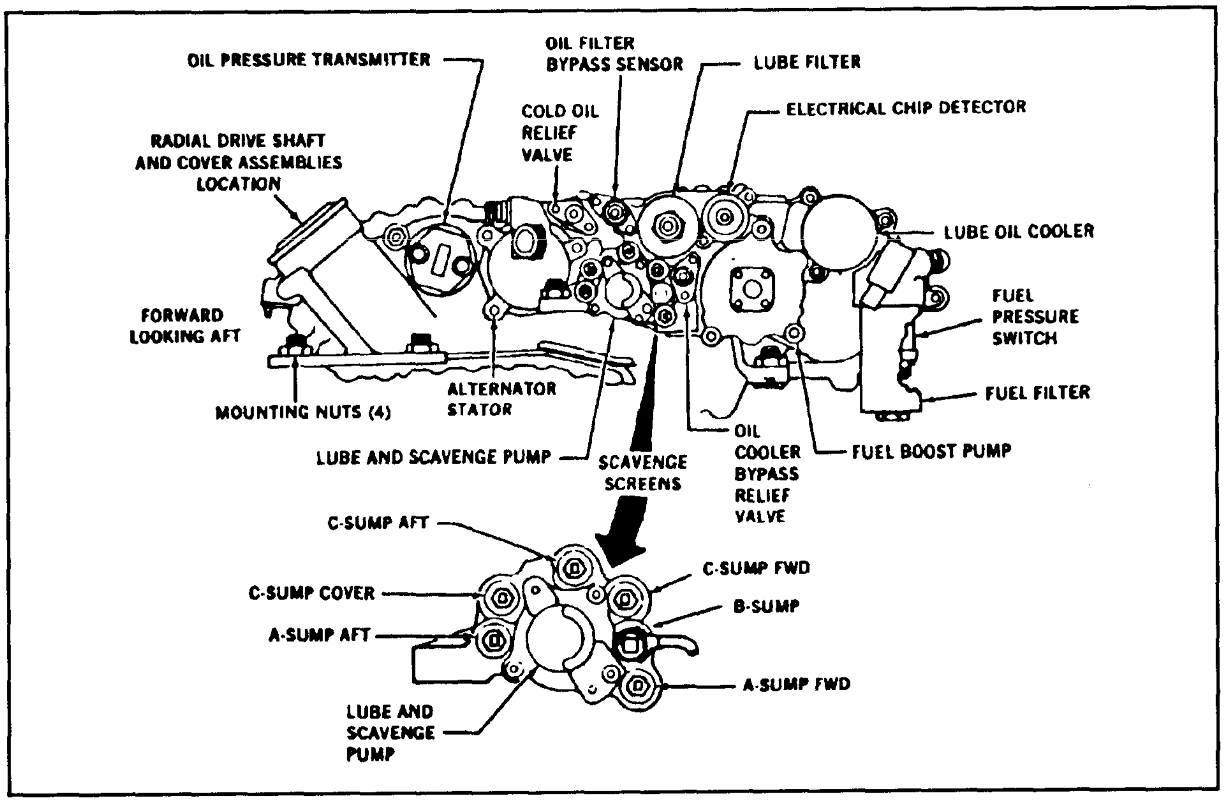


Figure 8-3. (T-701) Component Locations on Accessory Section Module

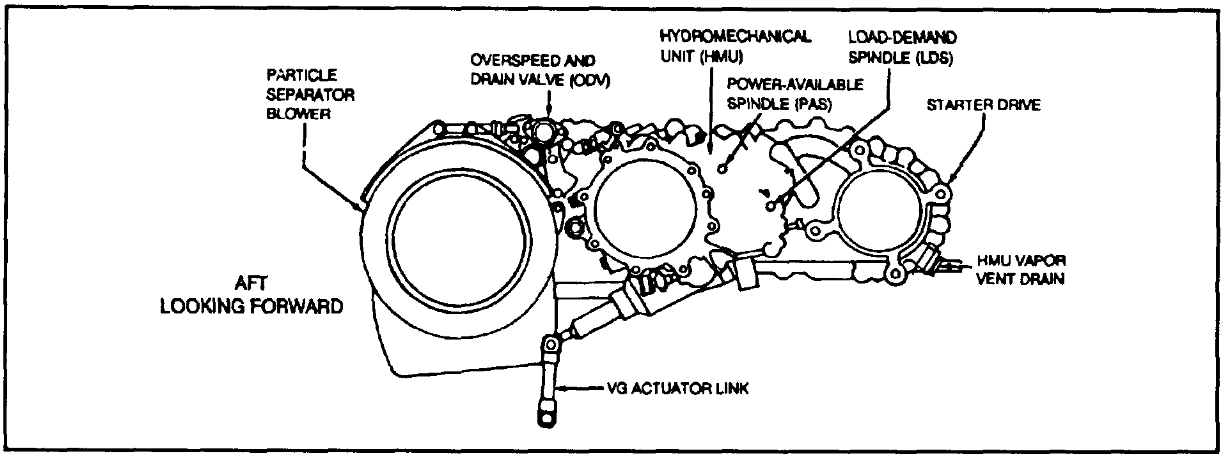


Figure 8-4. (T-701) Component Locations on Accessory Section Module

takeoff pad located at the 2 o'clock position on the engine inlet housing (Figure 8-5).

N_1 drive is provided from a pinion gear (9) mounted on the forward end of the compressor rotor shaft, driving two bevel gears (10 and 19) located within the accessory gear carrier.

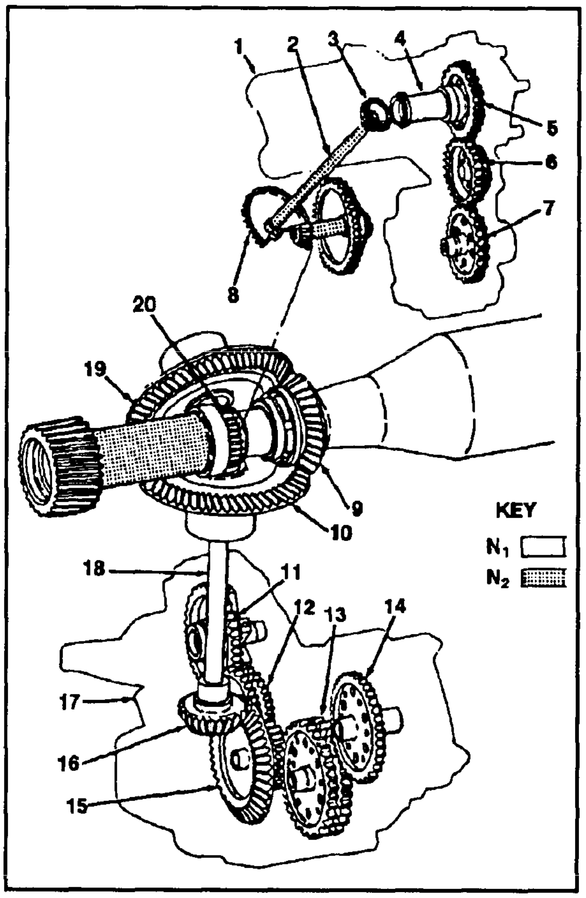


Figure 8-5. Accessory Drives (K-4 Gearing)

The bevel gear located at the 6 o'clock position within the carrier, being the accessory gearbox drive gear (10), is splined internally to accept the accessory gearbox shaft (18). This drive shaft connects the gear carrier to the accessory gearbox through the 90° pinion gear (16) which in turn is splined directly to the starter-generator drive gear (15). The starter-generator drive gear provides drive to all subordinate gears located with the accessory gearbox housing.

The power takeoff drive is provided through the second bevel gear (19) located within the accessory gear carrier and is used to drive airframe accessories.

The N_2-driven overspeed governor and tachometer drive gearbox (1) receives its drive from a spur gear (20) pressed to the power shaft aft of the sun gear. This gear engages the N_2 drive and driven gear package (8) located within the accessory gear carrier. This package, a series of three gears, provides an internal spline drive for the drive shaft (2) which passes up through the 10 o'clock inlet housing strut and into the gearbox (1).

The drive shaft then engages the internal splines of the upper drive gear (3) which provides drive to the tachometer gear (5). This gear meshes directly with an idler gear (6) which in turn transmits the drive to the combination torquemeter boost pump and overspeed governor drive gear (7).

Main Accessory Drive Gearbox

The accessory drive gearbox (Figure 8-6) is mounted at the 6 o'clock position of the engine inlet housing and is driven through bevel gears from the front end of the compressor rotor. Drive pads are provided on the rear of the gearbox for the fuel control, the starter-generator, and the gas producer (nI) tachometer generator. The gearbox front side has mounting for the rotary oil pump and also has an unused drive pad with connection line. Oil scavenge lines are connected at the right rear on the gearbox which serves as an oil collector sump, kept practically empty by the pump. A chip detector plug is located in the lower right side, and the oil filter is on the left side. A drain line from the inlet guide vane actuator is connected to the right side.

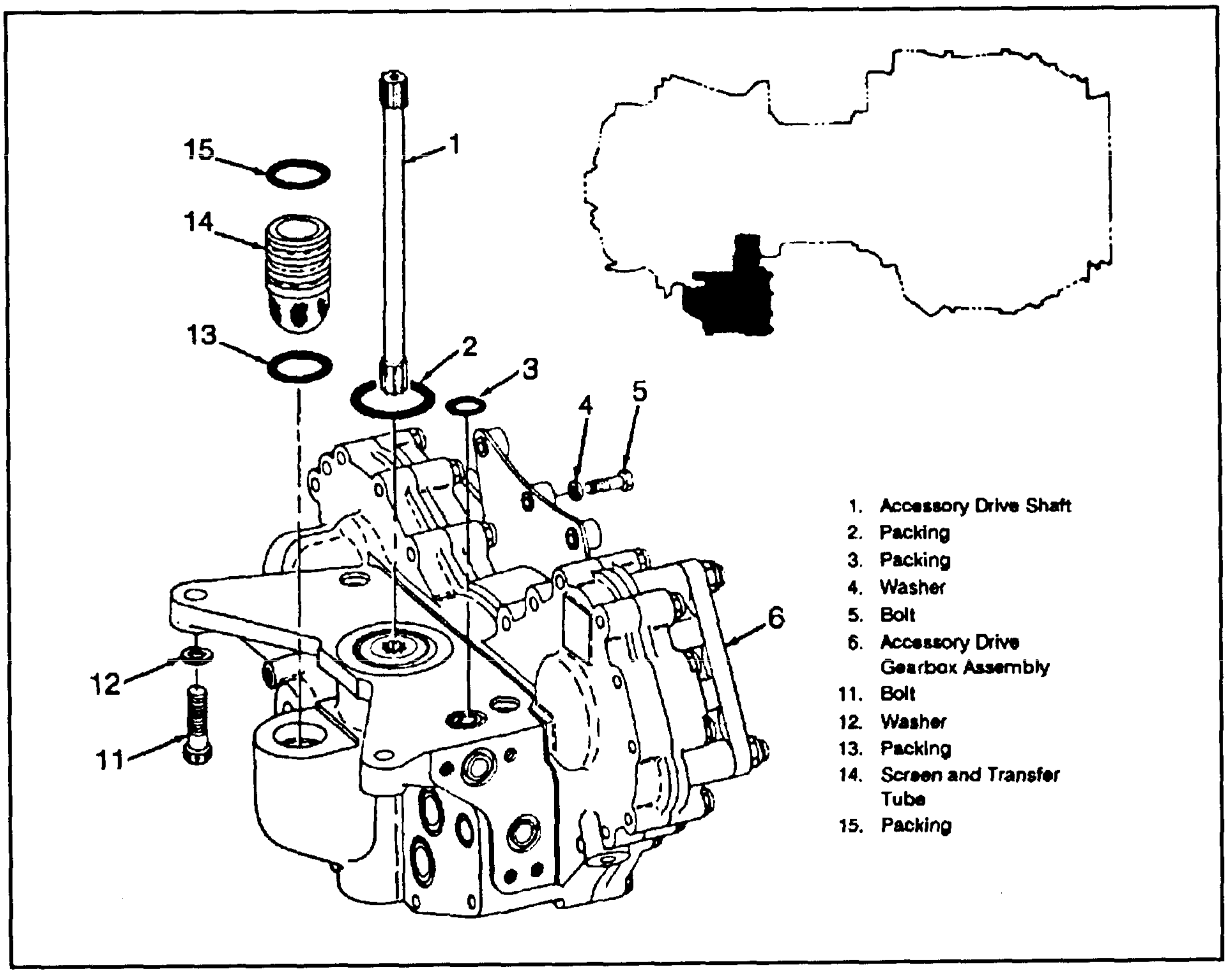


Figure 8-6. Main Accessory Drive Gearbox

Power and Accessory Gearbox

The main power and accsessory drive gear trains are enclosed in a single gear case. The gear case serves as the structural support of the engine. All engine components, including the engine-mounted accessories, are attached to the case. At 100 percent engine speed, reduction gearing reduces power turbine speed from 33,290 to 6016 RPM at the output drive pads. The power turbine gear train has a torquemeter to measure engine output torque. Accessories driven by the power turbine gear train are the power turbine tachometer-generator (N$_2$and the power turbine governor. The gas producer gear train drives the oil pump, fuel pump, gas producer fuel control, and tachometer-generator (N$_1$). The gearbox has a spare accessory mounting pad which is driven by the gas producer gear train. During starting the starter-generator cranks the engine through the gas producer gear train. After completion of the starting cycle, the starter-generator functions as a generator.

STARTERS

Gas turbine engines are started by rotating the compressor. In the case of dual axial-flow compressor engines, the high-pressure compressor is usually the only one rotated by the starter. First, compressor accelerates to provide sufficient air under pressure to support combustion in the burners. Second, after fuel is introduced and the engine is fired, starter continues to assist the engine above the self-sustaining speed. The torque must be in excess of that required to overcome rotor inertia and engine friction and air loads.

Basic types of starters developed for gas turbine engines are air turbine (pneumatic), electric motor, hydraulic, combustion, and cartridge pnuematic. Air turbine starters are the most commonly used. Smaller engines generally use electric starters. Hydraulic starters are frequently found in helicopters and some marine gas turbine installations. Combustion and cartridge-pneumatic starters are generally special application devices that may require a self-contained starting system. An impingement starting system is sometimes used An impingement starter consists of simple jets of compressed air piped to the inside of the compressor or turbine case. The jet air blast is directed onto the compressor or turbine rotor blades and causes them to rotate.

As the starter accelerates the compressor sufficiently to establish airflow through the engine, the ignition and then the fuel are turned on. The exact sequence of the starting procedure is important. There must be sufficient airflow through the engine to support combustion when the fuel-air mixture is ignited The fuel flow rate will not be sufficient to enable the engine to accelerate until after the self-sustaining or self-accelerating speed has been reached If assistance from the starter were cutoff below the self-sustaining speed, the engine would either fail to accelerate to idle speed or decelerate. Deceleration occurs because sufficient energy was not produced to sustain rotation or acceleration during the initial phase of the starting cycle. The starter must continue to assist the engine above the self-staining speed to avoid a delay in the starting cycle. This would result in a hot or hung (false) start, or a combination of both. In a hot start, the engine lights up, but the exhaust gas temperature exceeds that allowed for an engine start. In hung or false start the engine lights up normally but, instead of increasing to idle speed, the RPM remains at some lower value.

At the proper points in the sequence, the starter and the ignition cut off. The higher the RPM before the starter cuts out, the shorter the total time required for the engine to attain idle RPM. The engine and starter work together to furnish the torque necessary for engine acceleration.

The most important requirement of a starter is to produce sufficient torque to start the engine properly. Engines must be rotated and accelerated above a certain minimum rate if consistently good starts are to be achieved. The torque characteristics of an acceptable starter must be well above the required minimum.

Air Turbine

Air-turbine starters (which are also called pneumatic starters) are used more than any other for starting jet aircraft engines, particularly larger engines (Figure 8-7). A small geared air turbine is attached to the engine starter pad located at the accessory drive gearbox. Air-turbine starters must receive compressed air from an external power source. A compressor mounted on a ground unit or onboard the aircraft is one such source. A small turbine engine usually drives these units. On multiengine aircraft, air is often bled from the first engine started and used to operate the starters for the remaining engines. With an air-turbine starter, the air supply must be of sufficient volume and pressure to meet starter requirements. Otherwise, the starter torque may not produce consistently successful starts within an acceptable time limit. When bled air from another operating engine is used, the engine being used for a compressed air supply must be turning over fast enough to ensure adequate air pressure to the starter of the engine being started

Still another form of pneumatic starter is when the starter itself is part of the ground power unit. The end of a flexible shaft from the starter is placed in a connection box on the engine to turn the compressor. When the engine starts, the flexible shaft is removed This type starter might be used on small gas turbine engines. It might also be used on a gas turbine engine for a missile or where airborne weight must be held to the minimum.

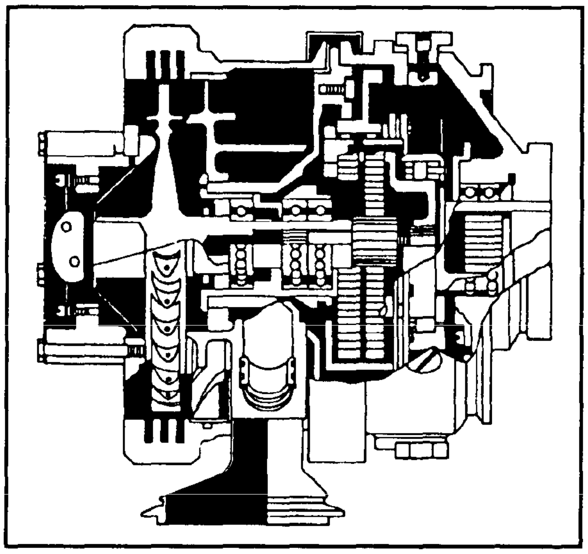


Figure 8-7. Air Turbine Starter

Combustion

A combustion starter is essentially a small turboshaft gas turbine engine (Figure 8-8). Its chief advantages are quick starts because of the high torque produced and portability. The complete starting system may be carried aboard the aircraft. This starter obtains its power from hot expanding gases. These gases are generated in the starter combustion chamber. They occur by burning a combustible mixture either fuel, air, or monopropellant. A monopropellant is a specially compounded solid or liquid slow-burning substance.

The quantity of fuel or monopropellant required by the starter is proportional to the length of time the starter is operating. Aircraft weight and size limitations require that the quantity of fuel or monoporpellant be held to a minimum in an airborne, combustion-starter system. The starter burning time must be held to a minimum. This is determined by the starter torque and the starter cutout speed. The starter cutout speed depends on the self-sustaining speed of the engine. The self-sustaining speed determines, to a large extent, the amount of fuel or monopropellant required. Ordinarily, sufficient fuel or monopropellant to provide a minimum of two starts will be carried aboard the aircraft. Some combustion starters operate as simple air turbines. When an outside air source from a ground unit or another engine which is already started is connected to the starter, the combustion starter functions as a pneumatic starter.

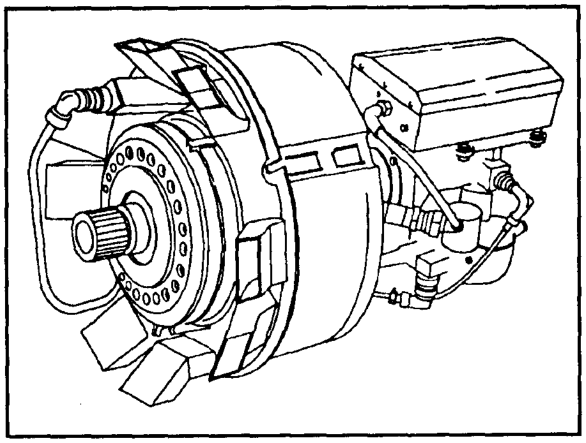


Figure 8-8. Fuel-Air Combustion Starter

Cartridge Pneumatic

A cartridge-pneumatic starter is a combustion starter that operates from monopropellant contained in a cartridge. Prior to starting, the monopropellant cartridge is inserted in the starter. Like a regular combustion starter, a cartridge starter fires electrically from a switch in the aircraft. Cartridge-pneumatic starters can be operated as pneumatic starters when provided with outside air.

Electric Starting

Direct cranking and starter generator are the two electric starting systems for gas turbine aircraft (Figure 8-9).

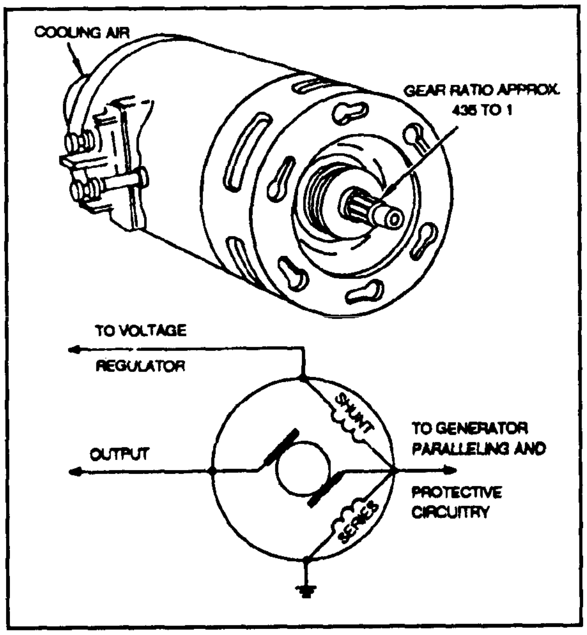


Figure 8-9. Typical Starter-Generator

Direct-cranking electric starting systems are similar to those used on reciprocating engines. Starter-generator starting systems are also similar to direct-cranking electrical systems. Electrically, the two systems may be identical. But the starter generator is permanently engaged with the engine shaft through the necessary drive gears. The direct-cranking starter must use some means of disengaging the starter from the shaft after the engine has started.

Direct-Cranking Gas Turbine Starters. On some gas turbine engines, no overload release clutch or gear reduction mechanism is used. This is because of the low-torque and high-speed requirement for starting. A reduced voltage mechanism is used, however, in the starting assembly during starting.

Starter-Generator Starting System. Many gas turbine aircraft are equipped with starter-generator systems. These starting systems use a combination starter-generator which operates as a starter motor to drive the engine during starting. After the engine reaches a self-sustaining speed, the starting system operates as a generator to supply the electrical system power.

The starter-generator unit is basically a shunt generator with an additional heavy series winding. This series winding is electrically connected to produce a strong field and a resulting high torque for starting. Start-generator units are desirable from an economical standpoint. One unit can perform the function of both starter and generator. Additionally, the total weight of starting system components is reduced, and fewer spare parts required

CHAPTER 9

INSTRUMENT SYSTEMS

Engine instruments are mounted on the instrument panel in the pilot's compartment. They are usually grouped together. They aid the pilot in monitoring the engine, rotor, or propeller RPM pressures temperatures and general engine performance. Refer to the engine's maintenance manual for maintenance, operational limitations, and color code markings. Instruments today read in vertical scales, digital readouts, and in some cases heads up display (HUD). The HUD system projects instrument images on the windshield in front of the pilots. In this way, pilots do not have to divert their eyes from the view in front of and around them. The vertical scale offers similar safety conditions. The pilots have the ability to quickly glance at the instrument for a reading. This chapter will discuss the most commonly used instruments and the newer vertical scale (VIDS).

VERTICAL INSTRUMENT DISPLAY SYSTEM (VIDS)

The VIDS (Figure 9-1) consists of a vertical strip central display unit (CDU), two vertical strip pilot display units (PDU), and two signal data converters (SDC). These readings are shown by ascending and descending columns of multicolored lights (red yellow, and green) measured against vertical scales. The scales operate as segments and light in normal progression. They remain on as the received signal level increases. They go off in normal progression as the received signal level decreases. When scales with red- and amber-coded segments below green-coded receive a signal level of zero (bottom scale), the segments light in normal progression and remain on. When the first segment above the red or amber range goes on, all red-or amber-coded segments go off. These segments remain off until the received signal level indicates a reading at or within the red or amber range. At that time all red- or amber-coded segments on the scale display goon or off in normal progression. For an increasing indication when a scale with side arrows lights, the corresponding side arrow also lights. As the segments go on, the corresponding side arrows also go on, one at a time. Only the side arrow associated with the highest percent indication of the corresponding scale will be on. For a decreasing indication, scales with side arrows will operate in the same manner. Only the side arrow associated with the highest percent indication of the corresponding scale will be on. The CDU and PDUs contain photocells that automatically adjust indicator lighting to ambient light. If either photocell fails, the lights on the vertical scales or the PDUs and the CDU go off. The DIM knob on the CDU has an override capabilty which allows the pilot to manually set the display light level.

TACHOMETER SYSTEM

The tachometer provides the pilot with a continuous indication of engine RPM. A variety or combination of systems may be used on gas turbine engines. Gas producer to gas generator tachometers, turbine and rotor tachometers, and N-I and N-II tachometer are some of the tachometer systems used (Figure 9-2).

Engine rotor RPM can be sensed by a mechanically driven tachometer generator, mechanically driven permanent magnet, or a pulse pickup which senses passing compressor, fan blades, or gear teeth. The output or signal from any of the sensors is directed to an appropriate indicator in the cockpit. The indicator is calibrated to read directly in percent RPM. Dual axial-flow compressor engines are usually provided with two tachometers: one indicates low-pressure compressor speed (N_1), and the other indicates high-pressure compressor speed (N_2). For the dual-axial and centrifugal compressors the second tachometer indicates power turbine speed (N_2).

For most axial-flow compressor engines, the tachometer monitors RPM during engine start and indicates overspeed condition should one occur. Use of the tachometer for setting thrust is not recommended on axial-flow compressor engines. The low-pressure compressor (N_1) tachometer on engine pressure ratio (EPR)-controlled dual-compressor engines may be used as an approximate reference to set engine thrust in transient and certain other flight conditions. When the N_1 tachometer sets engine thrust, the thrust setting should

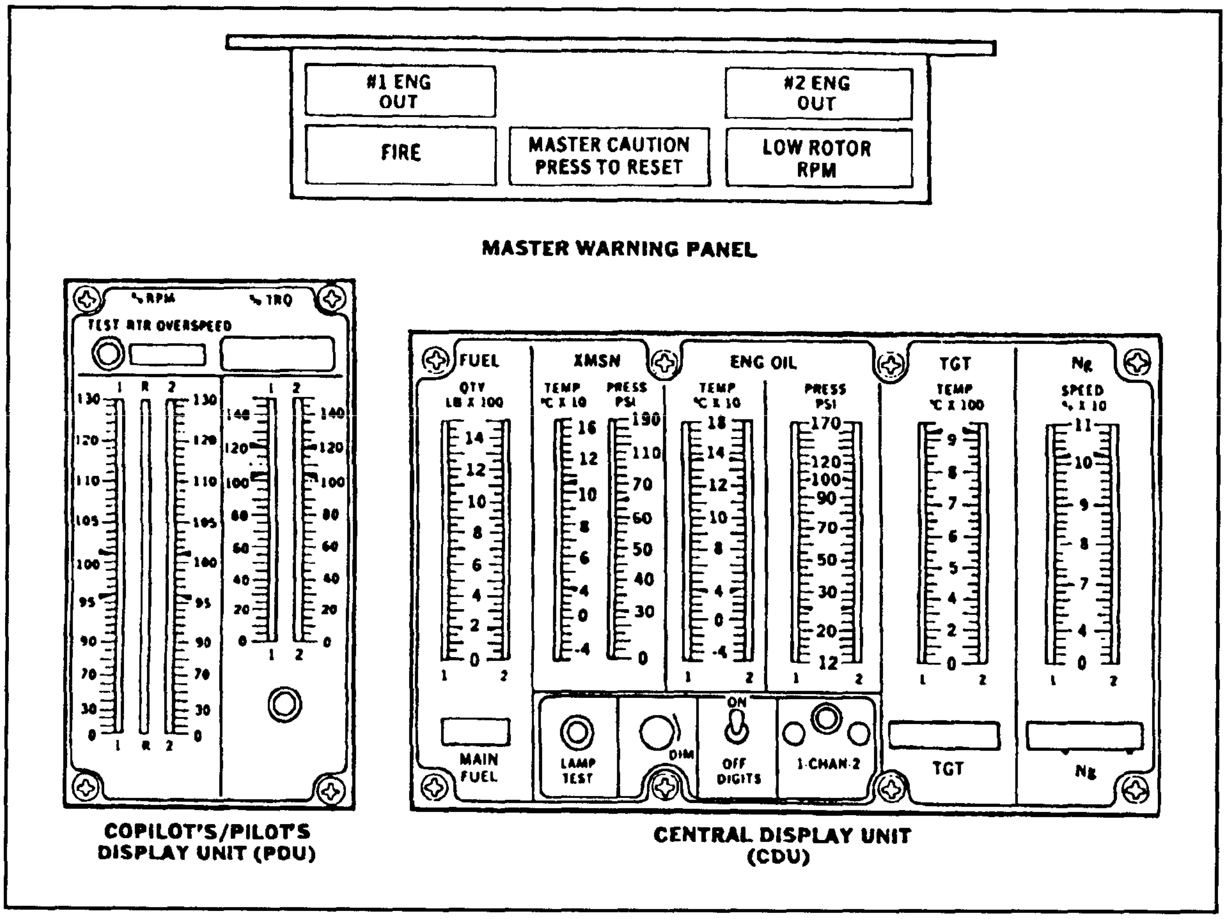


Figure 9-1. Vertical Instrument Display System (VIDS)

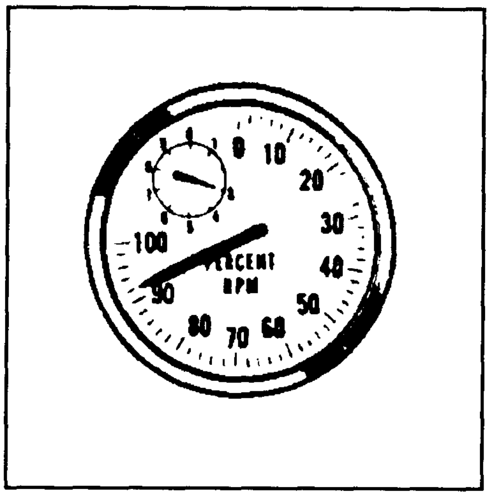


Figure 9-2. Tachometer

be more accurately adjusted by engine pressure ratio as soon as possible. On single-compressor, axial-flow engines, engine speed should not be used primarily to set or check engine thrust.

The General Electric T-700/701 system eliminates tach generators. Two N_p sensors are located in the exhaust frame. One sensor extends through the 1:30 o'clock strut and the other through the 10:30 o'clock strut. The power turbine shaft is equipped with two pairs of teeth which induce electrical pulses in the N_p sensors. These teeth permit measurement of the torsion or twist of the shaft, which is proportional to output torque. The sensors are identical and interchangeable but serve different functions.

The left-hand (10:30 o'clock) sensor provides an Np signal to the ECU. This signal is used in the N_p governing circuitry and for generation of a cockpit tachometer signal. The right-hand (1:30 o'clock) sensor feeds the ECU torque computation circuit and the N_p overspeed protection system. The sensors contain a permanent magnet and wire coil. They produce a pulse of current each time a shaft or reference tooth passes (Figure 9-3).

TORQUEMETER INDICATING SYSTEM

Only a small part of the propulsive force produced by a turboprop is caused by jet thrust. Neither turbine discharge pressure nor engine pressure ratio is used to indicate power produced by the engine. Instead a torquemeter measures the power level that the engine develops on the ground and in flight. Consult the engine maintenance manual for a description of torquemeter system functions. In most systems, however, torquemeter oil pressure is used to actuate a torque indicating instrument in the aircraft. The torquemeter instrument portrays torquemeter oil pressure (which is proportional to engine power) in pounds per square inch. Some torquemeter instruments are calibrated to read pound-feet of torque. Some may read shaft horsepower directly (Figure 9-4).

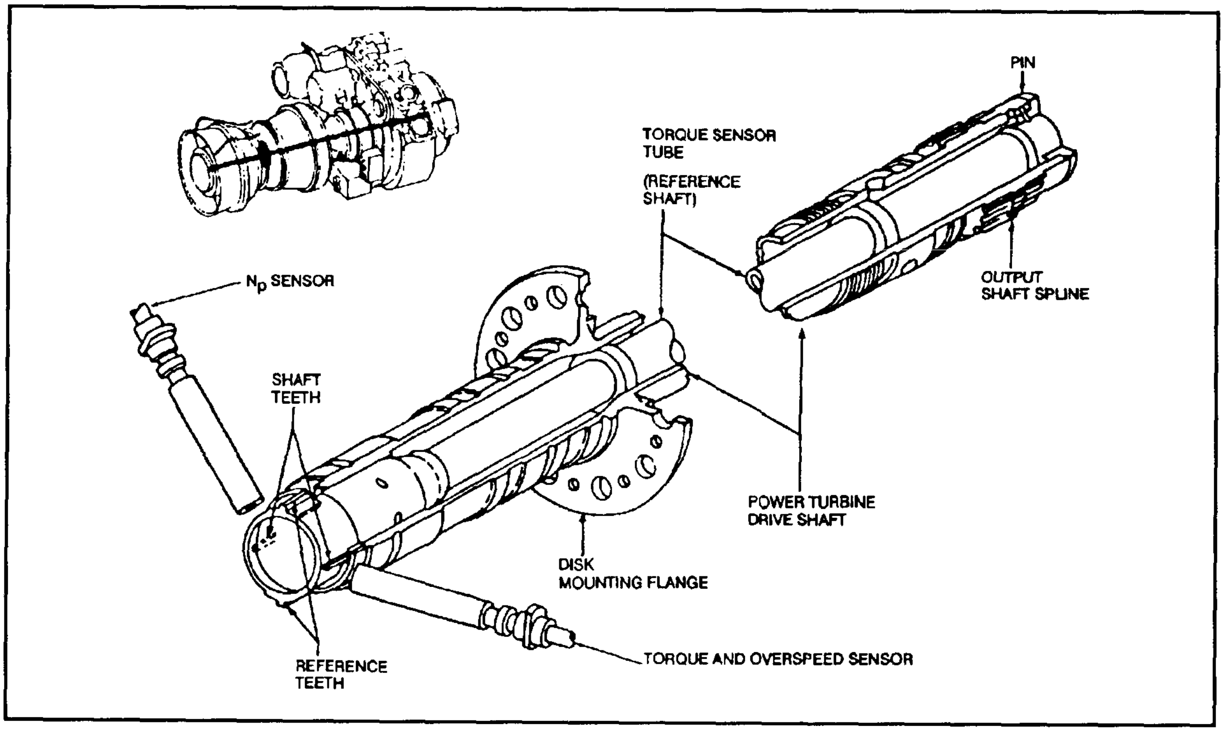


Figure 9-3. Power Turbine Sensors

One torquemeter indicating system sometimes called a torque pressure indicating system, contains a pressure-indicator-type instrument. It provides continuous reading of engine output shaft torque supplied by an electrical transmitter mounted on the engine inlet section. The transmitter is connected by hoses to a specialized oil pressure tap on the engine inlet housing and to a vent connection on the accessory drive gearbox The 28-volt AC system operates the electrical circuit.

The Lycoming (T-55-L-712) torquemeter, a refined torque measuring system, comprises five components and interconnecting wiring. Two of these, the power

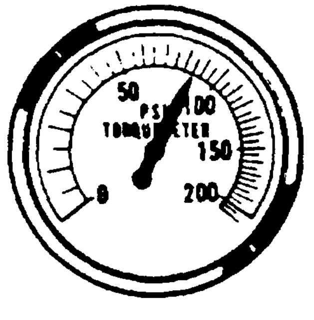


Figure 9-4. Torquemeter

supply and indicator, are airframe-supplied components. They may be replaced anytime without recalibration. The remaining three (power output shaft, head assembly, and junction box) are only replaced as a precalibrated set.

When torque is imposed on the engine power output shaft, tension and compression stresses change the magnetic reluctance of the shaft. This system measures the change of magnetic reluctance because of the torsionally induced forces (Figure 9-5).

The output shaft has welded to it a ferromagnetic sleeve which serves as a transformer core in the head assembly. A nonrotating transformer, the head assembly contains the primary coils which receive alternating current required to power the transformer from the power supply. It also contains six sets of secondary coils oriented at 90°to each and 45°to the shaft axis. They pick up induced current and register the differential in current on the dial face of the indicator. In operation, the head assembly surrounds the ferromagnetic sleeve on the shaft which acts as the transformer core.

The junction box acts as the system conditioner and includes key calibration controls. The potentiometers standardize the signal level for indicator display and balance out effects of magnetic nonhomogeneities. The box also rectifies the secondary voltages from the head assembly.

The cockpit-mounted indicator reads the engine-applied torque in percent. A network located within the indicator computes the algebraic difference between the two secondary-induced voltages coming from the junction box.

The power supply is an airframe-mounted unit which converts the airframe 28VDC signal to a constant 70VAC 2K Hz signal for system operation.

The General Electric T-700/701 torque-sensing system is a reference shaft that is pinned to the front end of the drive shaft and extends to the aft end. It is free to rotate relative to the drive shaft. The relative rotation is due to output torque. The resultant phase angle between the drive shaft teeth and reference teeth is electrically sensed by a pickup sensing the two teeth on the drive shaft plus two reference teeth. The electrical signal is conditioned in the electrical control unit, which provides a DC voltage proportional to torque (Figure 9-5). An intermediate power (1690 SHP), the output torque is 410 pound-feet, and the twist of the shaft is 7.4°.

EXHAUST GAS TEMPERATURE INDICATING SYSTEM

Turbine engines may be instrumented for exhaust gas temperature indication at locations before, between, or behind the turbine stages. Exhaust gas temperature is an engine operating limit and is used to monitor the mechanical integrity of the turbines. It also checks engine operating conditions. Actually, the temperature at the turbine inlet is the important consideration. This is the most critical of all engine variables. However, it is impractical to measure turbine inlet temperature in most engines. Consequently, thermocouples are inserted at the turbine discharge. This provides a relative indication of temperature at the inlet. The temperature at this point is much lower than that at the inlet. It enables the pilot to maintain surveillance over engine internal operation conditions.

Several thermocouples are usually used. They are spaced at intervals around the perimeter of the engine exhaust duct near the turbine exit. The exhaust gas temperature indicator in the aircraft shows the average temperature measured by the individual thermocouples. The readings of several thermocouples are usually obtained individually during ground engine maintenance by a selective switch. The spread between the lowest and the highest thermocouple reading is useful in maintenance. It serves to indicate the presence of hot or cold spots in the engine exhaust pattern which may indicate a problem inside the engine. The importance of exhaust gas temperature cannot be overemphasized. Two systems that are in use on Army helicopters follow.

Thermoelectrical Systems (T-55-L-11E/T-55-L-712)

The chromel-alumel, thermoelectric (MGT) measuring system is independent of all other engine electrical wiring (Figure 9-6). The engine components are five dual-probe segments; each probe is connected externally so each segment can be operationally checked independently and replaced individually. The 10 thermocouple probes protrude into the gas stream at the power turbine entrance (station 45). The probes react to variations in temperature by developing a proportional electromotive force across the chromel-alumel junction.

This potential difference results in meter deflections of the cockpit indicator. The cockpit indicator is calibrated to read temperature in degrees centigrade.

In addition, this system incorporates two buss-bars located on the aft fire shield. This allows for connection of the five MGT segments to the single MGT harness.

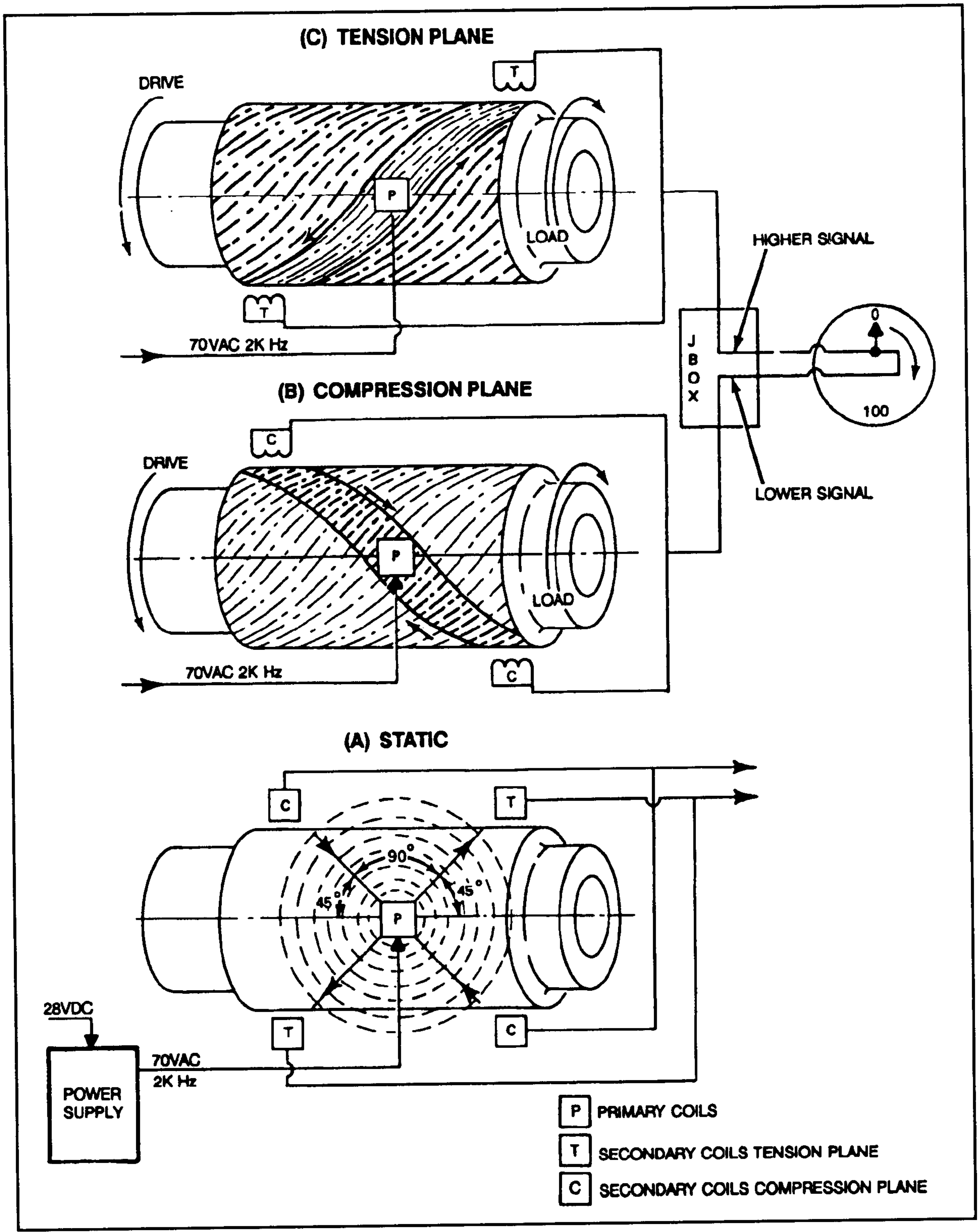


Figure 9-5. Torquemeter System Operation

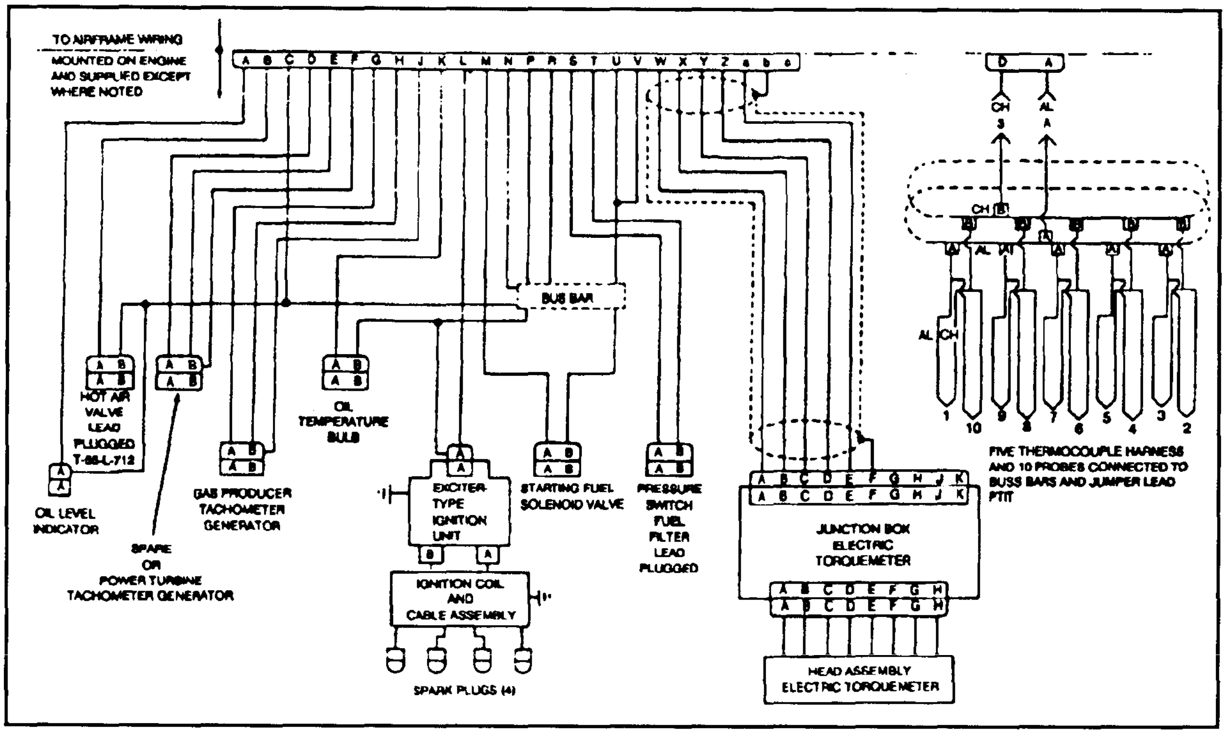


Figure 9-6. Electrical System Schematic (T-55-L-11E/T-55-L-712)

T-701 General Electric Thermocouple

The thermocouple harness is a one-piece assembly. It consists of seven single-immersion, equally spaced thermocouples for measuring power turbine inlet gas temperature (Figure 9-7). The thermoelements are made from special tolerance, oxidation-resistant, chromel-alumel wire. Each thermocouple junction is sealed within a Hastalloy X sheath. The thermoelement for the junction of each probe is continuous without joints or splices from the junction to the harness output connector junction box where all outputs are parallel. The harness output connector is hermetically sealed, has two alumel contacts, and has two chromel contacts. The average output of the seven probes provides the temperature signal to the ECU via the yellow cable. From the ECU, the signal is relayed to the cockpit TGT indicator and to the history recorder.

EXHAUST GAS TEMPERATURE INDICATORS

The indicator (Figure 9-8) in a typical exhaust gas temperature indicating system operates on electrical potential from an engine thermocouple harness. The probes are mounted in the aft section of the engine exhaust diffuser, The thermocouple converts heat into electricity. The exhaust gas temperature indicator (thermocouple-thermometer indicator) is actually a sensitive millivoltmeter calibrated in degrees centigrade. Its D'Arsonval movement is activated by an electrical force generated by its relative thermocouple. The indicator circuit is entirely independent of any other electrical power source. It includes a coil resistor which provides instrument calibration.

FUEL-FLOW-RATE INDICATING SYSTEM

The fuel-flow-rate indicating system measures the rate of fuel flow consumed by the engine. A typical system consists of an indicator (dual indicator if a two engine system), a fuel-flow meter, and a fuel transmitter, which is an integral part of the fuel-flow meter located on the engine. The fuel-flow-rate indicator, driven by a differential autosyn, registers the rate of fuel flow to the engine in hundreds of pounds per hour. A four-digit subtracting counter on the indicator can be set to read the total pounds of fuel remaining in the aircraft. The fuel-flow-meter transmitter is installed on a mount on the engine. The flow meter consists of a metering chamber and a differential autosyn. As fuel travels from the main tank or valve manifold to the engine fuel control, it passes through the metering chamber, moving a pivoted vane. The pivot shaft of the vane is coupled to the rotor shaft of the differential autosyn. When fuel flows through the metering chambers, the differential autosyn rotates. This

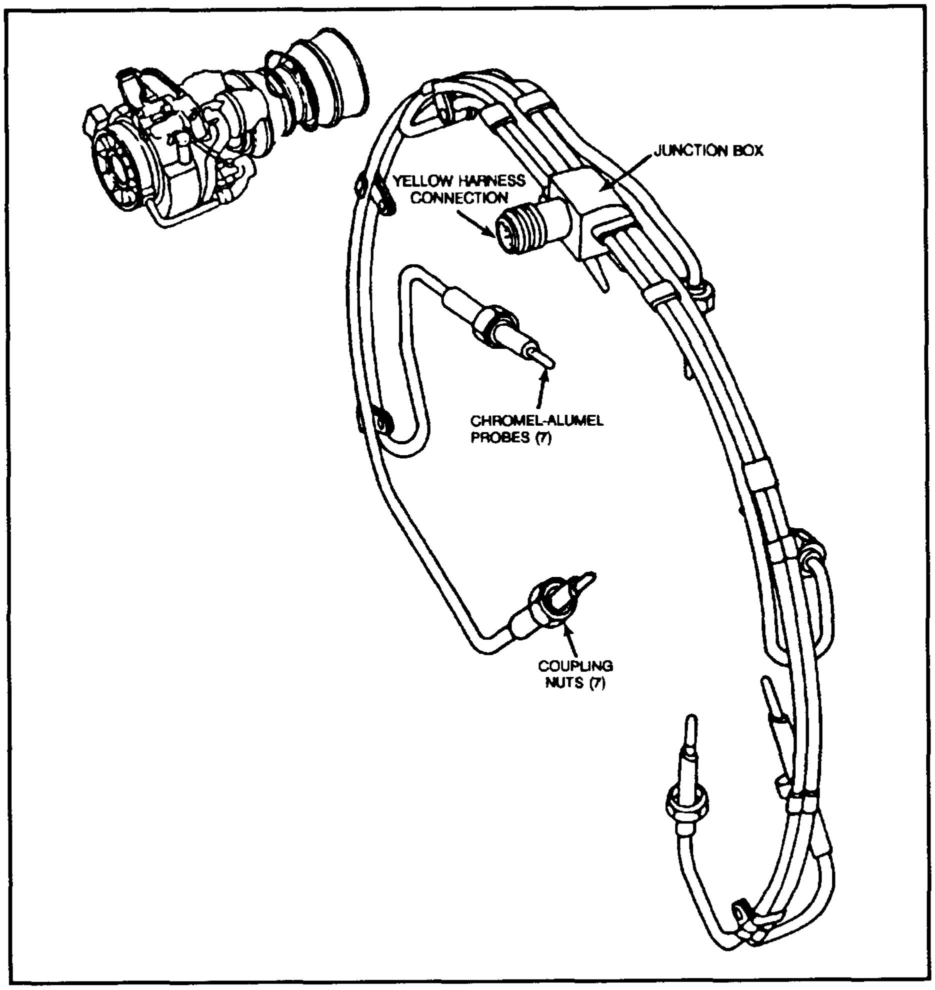


Figure 9-7. Thermocouple Assembly

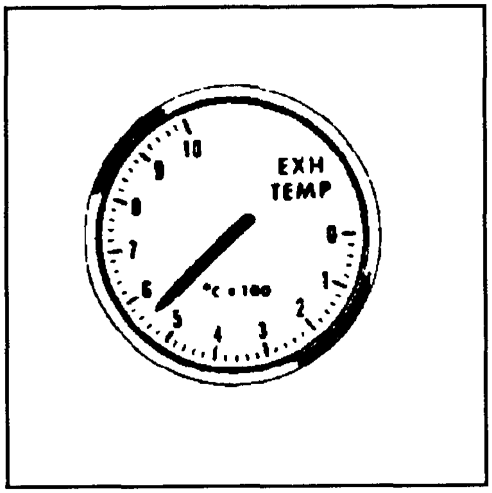


Figure 9-8. Exhaust Gas Temperature Indicator

autosyn rotation, in turn, causes the indictor autosyn to rotate. This results in an indication of engine fuel consumption.

FUEL FLOW INDICATOR

The fuel flow indicator shows fuel flow in pounds (or kilograms) per hour to the fuel nozzles (Figure 9-9). Fuel flow is monitored for in-flight fuel consumption, checking engine performance, and in-flight cruise control. The relationship of abnormal fuel flow to other instrument readings provides one of the best indicators for probable cause of engine malfunction.

FUEL PRESSURE INDICATING SYSTEM

A typical fuel pressure indicating system provides continuous reading of fuel pressure (psi) in the main fuel supply line from boost pumps in the tanks by an electrical transmitter. The transmitter is connected to a tap on the valve manifold. All fuel supply lines join the top electrical

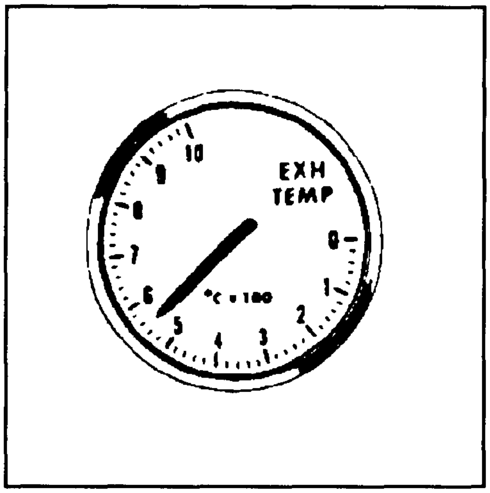


Figure 9-9. Fuel Flow Indicator

transmitter to deliver fuel to the engine through the fuel control inlet hose. Electricity is supplied to the transmitter by the 28-volt AC system.

FUEL INLET PRESSURE INDICATOR

Fuel system characteristics frequently make it advisable to monitor the fuel pump inlet pressure (Figure 9-10). In case of fuel flow stoppage in flight, the source of difficulty should be located quickly. This determines whether trouble developed in the engine or in the aircraft fuel system. Prompt corrective action may then be taken. In addition, the fuel pump inlet pressure indicates possible cavitation at the fuel pump inlet in flight. It will also show whether or not the fuel system is operating properly during engine ground checks.

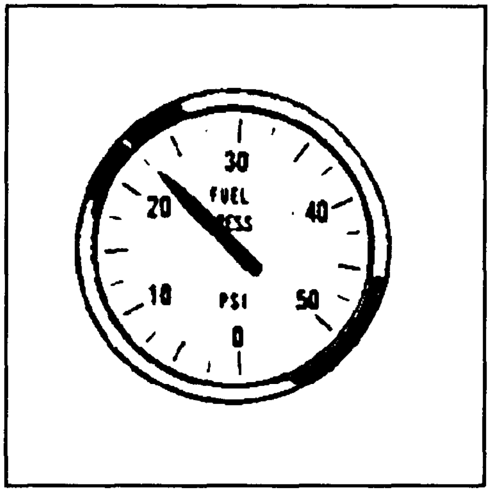


Figure 9-10. Fuel Inlet Pressure Indicator

ENGINE OIL PRESSURE INDICATING SYSTEM

A typical engine oil pressure indicating system provides continuous reading of engine oil pump pressure in psi to the indicator. This is provided by an electrical transmitter mounted on the engine inlet section. The transmitter is connected to the 28-volt AC electrical system and by a hose to a pressure tap on the engine oil falter housing.

OIL PRESSURE INDICATOR

To guard against engine failure resulting from inadequate lubrication and cooling of engine parts, oil supply to critical areas must be monitored (Figure 9-11). The oil pressure indicator shows the pressure relayed by the oil pressure transmitter. On most installations, the oil pressure transmitter takes breather pressure into consideration, relaying the true pressure drop across the oil jets in the oil system.

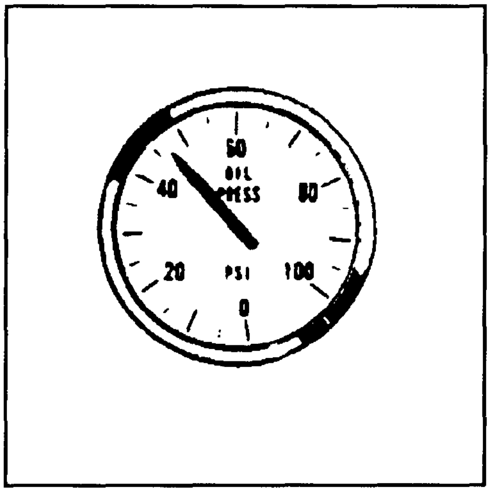


Figure 9-11. Oil Pressure Indicator

ENGINE OIL TEMPERATURE INDICATING SYSTEM

In a typical engine oil temperature indicating system, the indicator is electrically connected to the 28-volt DC system. A electrical resistance-type thermobulb installed in the engine oil pump housing measures the temperature of oil entering that unit. The temperature reading is transmitted to the indicator in degrees centigrade. Two dissembler metals heat to electricity.

OIL-IN TEMPERATURE INDICATOR

The ability of the engine oil to lubricate and cool is a function of the oil temperature and the amount of oil supplied to the critical areas. An oil inlet temperature indicator is frequently provided to show the oil temperature as it enters the engine-bearing compartments. Oil inlet temperature also indicates proper operation of the engine oil cooler (Figure 9-12).

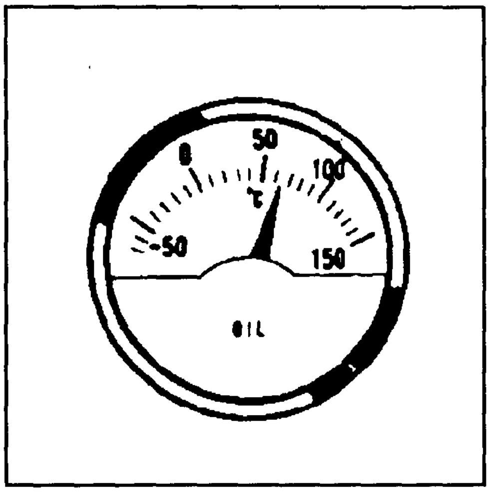


Figure 9-12. Oil-In Temperature Indicator

AIR TEMPERATURE INDICATOR

The air temperature indications (Figure 9-13) currently used in aircraft are free air temperature (FAT), outside air temperature (OAT), ram air temperature (RAT), total air temperature (TAT), and static air temperature (SAT). Regardless of which temperature is instrumented in a specific aircraft model, the flight manual shows how to use it, along with applicable charts or tables, to set the EPR values which provide rated thrust levels. The EPR setting varies with the thrust level desired and with the true TAT existing at the front of the engine (T_{t2}). Some aircraft have instrumentation which indicates T_{t2} values that may be used without correction to determine EPR settings.

ENGINE THRUST INDICATION

The way a pilot sets and monitors the thrust produced by the engine has been mentioned before (Figure 9-14). Thrust indication is discussed in detail below.

On some engines, engine RPM and exhaust gas temperature (EGT) are used to indicate and set thrust. On such engines, the pilot receives the full rated thrust of the engine for takeoff at 100 percent RPM and a specified EGT. The specified EGT at 100 percent RPM is established on a thrust-measuring ground test standby varying the exhaust nozzle area of the engine to achieve the desired EGT.

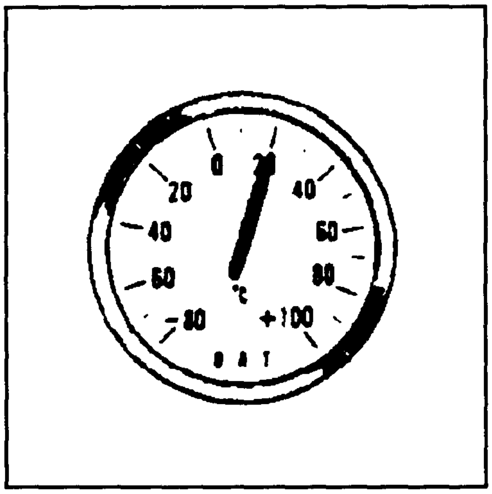


Figure 9-13. Air Temperature Indicator

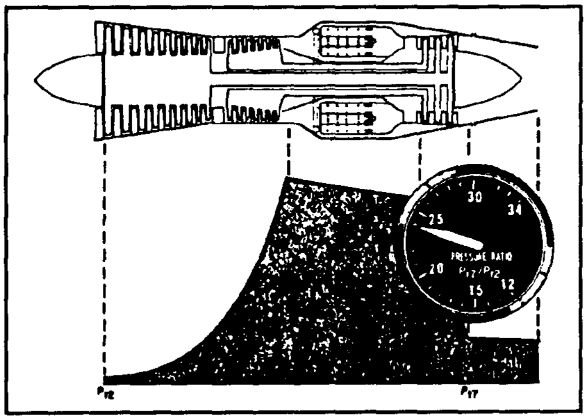


Figure 9-14. Engine Pressure Ratio Indicator

On centrifugal compressor engines, notably the military J48, thrust is indicated by RPM alone. Full rated thrust for takeoff is obtained when the tachometer reads 200 percent. The J48 has a fixed nozzle area which is established at manufacture. While there is an EGT limit for takeoff and for the other engine ratings, a J48 will normally operate at EGT below the applicable limit for the thrust rating used by the pilot. If the EGT reaches the allowable limit, the engine deteriorates or malfunctions.

Most afterburning and non-afterburning turbojets and turbofans with single or dual axial-flow compressors use engine ratio to measure engine thrust. EPR indicators compare total turbine discharge pressure to total air pressure entering the compressor. EPR then indicates the ratio of these pressures. Engines instrumented for EPR have a fixed exhaust nozzle area. Some military afterburning engines have two fixed areas. One is used for non-afterburning operation. A variable nozzle area is used for some afterburning engines, but it varies only while in afterburning. On both afterburning and non-afterburning engines, RPM and EGT may vary when the aircraft throttle is adjusted to obtain desired engine thrust.

Some military afterburning models have exhaust nozzles which are scheduled to vary the exhaust area when the engine is running. Consequently, these engines cannot be operated to EPR settings. They must be controlled by throttle position with various engine parameters checked to assure correct thrust output.

For engines with a fixed nozzle area, actual exhaust gas temperatures obtained during operation are usually below prescribed limits. It is permissible for an engine to operate at the temperature limit for any given thrust rating. However, an engine that does may have a problem which causes it to run abnormally hot.

With the exception noted in the use of the tachometer, engine RPM is considered a very inadequate parameter for setting and checking engine thrust on single and dual axial-flow compressor turbojet and turbofan engines having fixed exhaust nozzle areas. When RPM is used as the controlling variable on such engines, complications arise. The most important are –

- RPM does not provide an accurate means of determining if the complete engine is functioning properly. High- pressure RPM on dual axial-flow compressor engines and the RPM of the whole compressor on single axial-flow compressor engines is governed by fuel control. For example, RPM alone will not enable an engine operator to detect a damaged or dirty compressor. RPM carefully used in conjunction with other engine variables such as fuel flow, exhaust gas temperature, and engine pressure ratio allow for detection.
- RPM for any given thrust condition will vary slightly among individual engines, depending upon the engine trim speed. Engines are trimmed by a fuel control adjustment to produce full rated thrust at a fixed-throttle position on a standard day. The RPM variation must be taken into account when RPM is used to measure thrust being developed by the engine. This causes a complication which cannot be tolerated when precise thrust settings are necessary during flight.
- On dual axial-flow compressor engines, RPM variation of one percent causes approximately four percent variation in thrust at the higher thrust settings for the low-pressure compressor rotor (N_1) and five percent variation for the high-pressure compressor rotor (N_2). One percent variation in turbine discharge pressure or engine pressure ratio results in only one and one-half percent variation in thrust. The five percent variation in thrust for one percent variation in RPM also holds true for single axial-flow compressor engines.
- RPM does not vary in direct proportion to thrust produced by the engine over the entire thrust range.

For these reasons, either turbine discharge pressure or engine pressure ratio must be used as the engine variable to indicate thrust on axial-flow compressor engines with fixed area exhaust nozzles. The use of either is simpler undermost conditions and is more accurate.

MEASURING POWER AND THRUST FOR TURBOPROPS

For engines other than those with fully variable exhaust nozzles, turbine discharge pressure, engine pressure, or engine pressure ratio can be used with good results to indicate or set engine thrust. They vary proportionally to the thrust the engine is developing. Most turbojet and turbofan aircraft today are instrumented for engine pressure ratio. This is the parameter generally used to set or measure engine thrust during takeoff, climb, and cruise. For very accurate thrust measurement, such as during ground trimming of an engine, turbine discharge pressure is often used to measure thrust. In such cases, it is common practice to temporarily connect a turbine discharge pressure indicator to the engine.

ENGINE PRESSURE RATIO INDICATING SYSTEM

In a typical engine pressure ratio indicating system, the indicator is a dual-synchro instrument. The system shows a constant reading of engine performance. This is done by computing the ratio between the gas generator discharge pressure and the inlet pressure of the engine. These ratios are then transmitted to an indicator (both indicators if a two-engine aircraft). Sample pressures are taken from engine gas producer or gas generator ports and from the pilot pressure system. The system includes a transducer. The transducer includes a mounting bracket and a transmitter unit. The transmitter unit contains a multicell, diaphram-actuated computer; gear train; two-phase motor; and transmitting synchros. The indicators are graduated from 1.0 to 2.5 EPR units with 0.1 EPR markings and a vernier dial graduated in 0.01 EPR markings. An adjustable pointer on the face of the indicator is set to the maximum EPR for the ambient temperature to indicate possible engine overspeed. The maximum EPR for given temperatures is listed on the instrument panel. The AC Power system supplies electrical power through the EPR circuit breaker.

TURBINE DISCHARGE PRESSURE INDICATOR

This instrument indicates the internal engine pressure upstream of the jet nozzle, immediately aft of the last stage of the turbine (P_{t5} to P_{t7}). It indicates pressure available across the nozzle to generate thrust. Turbine discharge pressure must be used in conjunction with T_{12} and P_{12}.

ENGINE PRESSURE RATIO INDICATOR

This instrument (Figure 9-15) indicates the engine pressure ratio as a measure of thrust developed by the engine. This is the ratio of the turbine discharge total pressure to the equivalent of the compressor inlet total pressure (P_{t5}/P_{t2} or P_{t7}/P_{t2}). Values for P_{t2} must be corrected for inlet duct loss on the engine pressure ratio curves or charts by the aircraft manufacturer. Therefore, both for static (takeoff) and flight use, the actual value for P_{t2} will vary among different aircraft types and models because of installation effects. However, the relation of P_{t2} at the engine face to P_{am} plus P_r is equivalent to total pressure at or near the compressor inlet when airborne. It is not advisable to instrument the compressor inlet when airborne. It is not advisable to instrument the compressor inlet directly for P_{t2}. The P_{t2} sensor for the pressure ratio indicator may be placed at some other location on the aircraft, preferably as near the engine air inlet as possible. After appropriate corrections are made to the in-flight charts in the flight of operation manual, any rated thrust or percent of rated thrust may be set with the aircraft throttle (as a function of the TAT or T_{t2}).

Pressure ratio between the pressure at the engine air inlet and the discharge pressure at the jet nozzle indicates thrust developed by the engine. Turbine discharge pressure alone is not an accurate indication of engine output. Compressor inlet pressure (P_{t2}) must be taken into account on curves or charts when only turbine discharge pressure is instrumented.

For static engine operation, this is usually accomplished by showing barometric pressure (corrected for inlet duct loss) rather than P_{t2} values on the curves or charts. In flight, curves or tables usually show airspeed and altitude. This eliminates the need for actually

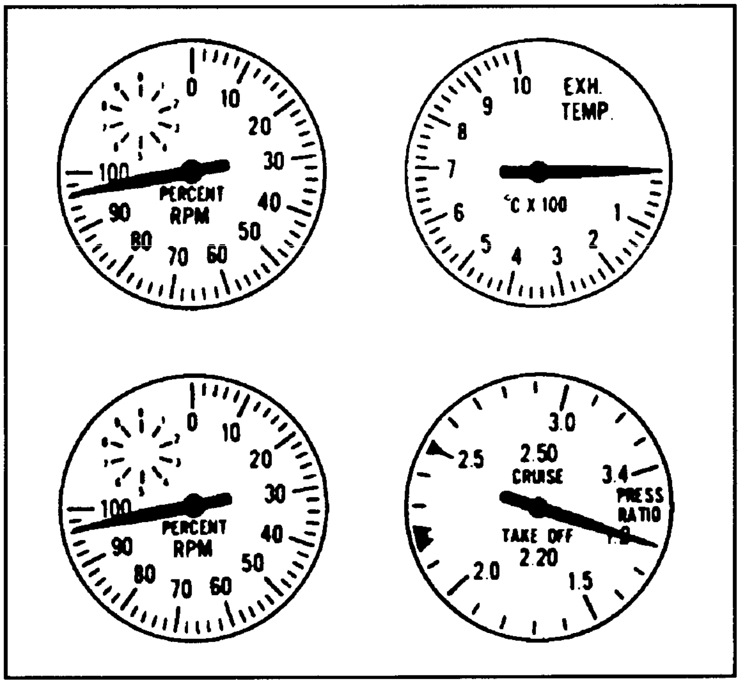


Figure 9-15. Engine Thrust Indicator

delineating P_{t2} values in the operating data. Engine pressure ratio indicators have the P_{t2} value introduced into the system. This factor is automatically taken into account on the observed instrument reading. Except for an indicator to measure engine thrust, the above represents the minimum adequate instrumentation for control of the engine. Some installations may have additional imtruments.

GLOSSARY

ABBREVIATIONS AND ACRONYMS

ADU	auxiliary drive unit
abs	absolute
AC	alternating current
AGB	accessory gearbox
API	American Petroleum Institute
atm	atmosphere
BDC	bottom dead center
BHP	brake horsepower
BTU	British thermal unit
c	Celsius
cal	calibrated
CDU	central display unit
cyl	cylinder
db	decibel
DC	direct current
ECM	electrochemical machining
ECU	electrical control unit
EDM	electric discharge machining
EGT	exhaust gas temperature
EPR	engine pressure ratio
ESHP	equivalent shaft horsepower
F	Fahrenheit
FAT	free air temperature
FOD	foreign object damage
ft-lb	foot-pound
fps	foot per second
GE	General Electric
hd	head
Hg	mercury
HP	horsepower
HMU	hydromechanical unit
hr	hour
HUD	heads up display
Hz	Hertz
in	inch
lb	pound
LDS	load-demand spindle
LH	left-hand
man	manifold
MGT	measured gas temperature
microsec	microsecond
min	minute
MPH	miles per hour
N	north
NATO	North Atlantic Treaty Organization

OAT	outside air temperature
OD	outside diameter
ODV	overspeed and drain valve
OEI	one engine inoperative
PAS	power-available spindle
PDU	pilot display unit
PRT	power recovery turbine
PRV	pressure regulating valve
psi	pounds per square inch
psig	pounds per square inch gage
PT	power turbine
PTO	power takeoff
RAT	ram air temperature
res	resistance
RH	right-hand
RPM	revolutions per minute
s	south
SAT	static air temperature
SDC	signal data converter
SHP	shaft horsepower
TAT	total air temperature
TC	top center
TCP	tricresyl phosphate
TDC	top dead center
TEL	tetraethyl lead
temp	temperature
TGT	turbine gas temperature
TRQ	torque
VG	variable geometry
VIDS	vertical instrument display system
VS	versus
wt	weight

DEFINITIONS

Acceleration lag – in the turbine engine, delay between the time instant power is requested and when power is available. The time it takes the engine to accelerate and give the required power increase.

Aerodynamic drag – force which thrust must overcome to move an aircraft forward. Design can lesson aerodynamic drag through streamlining. Drag increases with increased speed.

Airbleed actuator – device that operates the interstage bleed system, to improve compressor acceleration characteristics by unloading small amounts of compressed air.

Air density – total mass of air per given volume, the weight of a given volume of air. Air is denser at lower altitude, at lower temperature, and lower humidity.

Airfoil profile – outline of an airfoil section.

Airfoil section – cross section of an airfoil parallel to a specific reference plane.

Air-fuel ratio – Ideal mixture of 15 parts of air to 1 part of fuel by weight; the mixture to be burned in the combustion chamber.

Air inlet – large, smooth aluminum or magnesium duct at mouth of engine which conducts air into the compressor with minimum turbulence and restriction.

Aluminum alloy – any of a variety of alloys formed by combining commercially pure aluminum with other metals or materials such as copper, silicon, manganese, magnesium, and zinc. These alloying agents maybe added singly or in combination to produce a metal with desired characteristics or strength, heat resistance, corrosion resistance, and the like. Both wrought- and cast-aluminum alloys are widely used in the manufacture of rotor blades and aircraft propellers.

Ambient – condition of atmosphere existing around the engine, such as ambient pressure or temperature.

Annular combustion chamber– two-part combustion chamber made up of an annular liner and a housing assembly. The compressed air goes into a ring-shaped space formed by the annular liner around the turbine shaft rather than into individual combustion chambers. The space between the outer liner wall and the housing assembly allows the flow of cooling air. Used with axial-flow and dual compressors.

Annular reverse-flow engine – type of gas turbine engine most commonly used in Army aircraft. Airflow direction is reversed in the combustion area.

Anti-icing system – device that supplies hot air under pressure to prevent icing of the inlet housing areas and inlet guide vanes. Hot scavenged oil is also circulated through internal passages in the walls and struts.

Army Spectrometric Oil Analysis Program (ASOAP) – periodic oil analysis for microscopic metal particles. This takes place at an oil analysis laboratory.

Atmospheric pressure – barometric pressure exerted by the atmosphere as a result of gravitational attraction above the point in question.

Atomizer – nozzle that creates minute particles and accurately shaped spray of fuel suitable for rapid mixing and combustion.

Axial-flow compressor — one in which the air is compressed parallel to the axis of the engine. It is made up of a series of alternating rotor and stator vane stages.

Bending – combination of tension and compression. The inside curve is under compression; the outside is under tension.

Bleed system – device that unloads small amounts of air to relieve pressure.

Boss – raised rim around a hole; e.g., axle hole in a wheel. Circular projection on a casting, usually serving as the seat for a bolt head or nut.

Brayton cycle – constant pressure cycle, with four basic operations which it accomplishes simultaneously and continuously for an uninterrupted flow of power. The turbine engine operates on this cycle.

Camber – the curvature of an airfoil’s surfaces from the chord line. It maybe positive, negative, or zero.

Can-annular combustion chamber – one with characteristics of both the annular types. It has an outer shell and a number of individual cylindrical liners.

Can combustion chamber – one made up of individual combustion chambers in which the air from the compressor enters each individual chamber through the adapter.

Center of pressure – aerodynamic center of an airfoil; the point where all forces act.

Centrifugal axial-flow compressor– combination of the centrifugal-flow and the axial-flow compressor. It usually consists of a five- or seven-stage axial-flow compressor and one centrifugal-flow compressor. Also called the dual compressor.

Centrifugal-flow compressor – one with an impeller (rotor), stator, and compressor manifold. The rotor revolves at high speed drawing air into the blades. Centrifugal lforce accelerates the air, and it moves through the stator and through the manifold.

Centrifugal twisting movement – force that tends to streamline rotating blades with the plane of rotation.

Choked nozzle – a nozzle whose flow rate has reached the speed of sound.

Chord line – imaginary line drawn between the leading and trailing edges of an airfoil.

Combustion – process of burning the fuel-air mixture in a gas turbine engine.

Combustion chamber – part of a turbine engine in which the propulsive power is developed by combustion of the injected fuel and the expansive force of the resulting gases.

Combustion chamber liner – engine part usually constructed of welded high-nickel steel, subjected to flame of extremely high temperature. It is behind the compressor and receives the compressed air which is mixed with fuel and ignited. The combustor is where the combustion takes place.

Compressibility effects – the phenomenon encountered at extremely high speeds (near the speed of sound) when air ceases to flow smoothly over the wings (or blade) and piles up against the leading edge, causing extreme buffeting and other effects.

Compressor – that section of an engine that produces an increase in air pressure. It is made up of rotating and stationary vane assemblies. It is the gas producer, or it maybe thought of as an air pump.

Compressor rotor – impeller, may be thought of as an air pump. It accelerates the air rearward into the first stage vane assemblies.

Compressor stall – separation of the airflow from the suction surface of the freed or rotating blades of a compressor. Any degree of stall reduces airflow.

Concave – pressure side of an airfoil.

Conduction – transfer of heat through material by communication of kinetic energy from particle to particle rather than by a flow of heated material.

Convergent area – place where the cross-sectional area of a duct becomes smaller.

Convergent exhaust duct – duct used on fixed-wing aircraft; formed by tapering toward the rear of the duct.

Convex – suction side of an airfoil.

Crossover tube – duct carrying flame to the individual cylindrical liners of the can-annular combustion chamber.

Diffuser – aft structural member of an engine. It receives high velocity air from the centrifugal impeller and decreases velocity and increases air pressure. In the combustor, a diffuser forms a divergent flow path for the exhaust gases.

Diffusion – process by which gases intermingle as the result of their spontaneous movement caused by thermal agitation.

Directional references – specific definitions of terms referring to gas turbine engines to identify front and rear, right and left, bottom and top.

Divergent area – place where air flows from a smaller into a larger area.

Divergent exhaust duct – used on helicopter. Device to diffuse the exhaust gases rearward and to eliminate thrust.

Drag parasite – drag caused by any member or structure which does not contribute to lift, such as engine cowlings.

Drag profile – friction resistance produced by a member moving through the air; in simple terms, the “stickness” of air against the surface of an airfoil.

Dry-cleaning solvent – cleaning compound that maybe used for all metal parts.

Dry-sump engine – one in which the oil is stored separate from the engine.

Dual compressor – see centrifugal-flow, axial-flow compressor.

Duplex nozzle – dual-orifice channel through which highly atomized and accurately shaped sprays of fuel go into the combustion chamber.

Dynamic load – load on an aircraft due to a dynamic force.

Effective angle of attack – that part of a given angle of attack that lies between the chord of an airfoil and a line representing the resultant velocity of the disturber airflow.

End play – longitudinal back-and-forth play of a shaft.

Engine airflow path – route of the airflow through the engine.

Engine oil pressure indicating system – device that gives continuous readings of engine oil pump pressure in psi.

Engine oil temperature indicating system – device electrically connected to the 28 VDC system which transmits temperature readings to the indicator in degrees centigrade.

Engine speed notation – the capital letter N, which represents the rotational speed of the engine. When a number is placed after the N (as in “N_1”), it indicates a specific system on the engine.

Engine stations – specific locations on the engine designating temperature or pressure-measuring locations. For example, T_3 means the third temperature pickup on the engine.

Engine surge – result of compressor stall. The complete engine in stall.

Exhaust – hot gases discharged from the engine through the exhaust diffuser section.

Exhaust diffuser – section composed of an inner and outer housing, separated by hollow struts across the exhaust passage. It forms a divergent flow path for the exhaust gases.

Exhaust gas temperature indicator – sensitive millivoltmeter calibrated in degree centigrade, activated by an electrical force generated by its thermocouple.

Feedback – relay through the controls of aerodynamic forces exerted on the control surfaces and felt by the pilot.

Fir tree mount – manner of attaching the blades to the disk in the turbine rotor assembly. The root of the blade where it is attached to the disk is shaped like a fir tree.

Foreign object – any object such as a tool, piece of equipment, engine part (nut, bolt, lockwire) that could in any way damage the engine.

Foreign object damage – commonly called FOD, harm or destruction to the turbine engine caused by foreign objects sucked into the inlet area of the engine with the required air.

Forged – shaped by hammering. Only the malleable metals are worked successfully. The application of heat increases plasticity.

Free-power turbine engine – the turbine engine used by the Army. Sixty percent of the energy produced by combustion is extracted by the gas producer turbine to drive the gas producer rotor. The rest of the energy is converted to shaft horsepower to drive the output shaft of the engine.

Frictional loss – resistance to the relative motion of air flowing along a duct.

Frontal area – front part of a gas turbine engine, smaller than that of a reciprocating engine, therefore producing less drag.

Front of engine – end from which power is extracted. An exception is the T73 engine on the CH-54, in which the power is extracted at the end where the exhaust gas is expelled.

Fuel-air ratio – see air-fuel ratio.

Fuel atomizer – see atomizer.

Fuel controls – devices to control fuel flow. They are usually hydromechanical and include speed governors, servo systems, valves, metering systems, and sensing pickups.

Fuel divider – device that meters fuel to the engine nozzles according to a predetermined schedule of secondary flow versus primary flow.

Fuel nozzle – device to inject fuel into the combustion chamber in a highly atomized and accurately shaped spray.

Fuel pressure indicating system– device that gives continuous readings in psi of fuel pressure in the main fuel supply line.

Gas producer – the compressor in a free-power turbine engine.

Gas turbine engine – aircraft power plant that is adaptable for both airplanes and helicopters.

Gerotor pump – modified gear-type pump with two moving parts, an inner toothed element and an outer toothed element. The inner one has one less tooth than the outer.

Glow plug – device that consists of a heating element in a short conventional-looking spark plug.

Ground angle – angle between the wing chord and the horizontal plane when the airplane is at rest on the ground.

Heat exchanger – fuel-oil cooler, to help cool the oil. The exchanger is a cylindrical oil chamber surrounded by a jacket through which the fuel passes. Heat from the oil is transferred to the fuel by conduction.

Hot start – overtemperature during starting.

Hung start – failure to reach normal idling RPM during starting.

Igniter plugs – spark plugs which function only during starting and cut out of the circuit as soon as combustion is self-supporting.

Imbalance – uneven distribution of weight resulting in rotating parts being out of balance. Measured in inch-grams or inch-ounces.

Impeller rotor – rotor in a compressor that revolves at high speed, drawing air into the blades.

Induced angle of attack – that part of any given angle of attack in excess of the effective angle of attack.

Induced drag – the part of the total dragon an airplane induced by the airflow about the lifting surfaces.

Inlet guide vanes – devices positioned by the inlet guide vane actuator pilot valve. They are located in front of the first compressor rotor, and they control the angle of incidence of the inlet air, thus ensuring a compressor surge margin.

Inlet housing assembly– forward structural support of the engine.

Jam acceleration – rapid movement of the power lever, calling for maximum rate of rotor-speed increase.

Jetcal analyzer – device used to check the exhaust gas temperature during periodic maintenance inspections or when abnormally high or low temperatures are noted.

Jet propulsion – propulsion of a body by means of a jet or stream of gas, obtaining all or most if its thrust by reaction to the ejection of the combustion products (gas).

Jet silencer – a device used to reduce and change the lower-frequency sound waves emitting from the engine's exhaust nozzle, and thus reducing the noise factor.

Joule – unit of energy or work used in rating gas turbine ignition systems. A joule is equal to the amount of energy expended in one second by an electric current of one ampere through a resistance of one ohm.

Labyrinth seal – device for preventing leakage of gas on the gas generator shaft in a turbine. A labyrinth consists of a series of projections on the rotating element running in close contact with grooves on the stationary element.

Maintenance allocation chart – chart in a -20 TM that assigns maintenance tasks to the lowest level capable of doing them, based on experience, skills, tools, and time available.

Mean aerodynamic chord – chord of an assumed rectangular airfoil representing the mean chord of an actual airfoil.

Metal fatigue – weakening of metal due to microscopic changes in molecular structures caused by vibration or exposure.

Micron – one millionth of a meter.

N_1 system – gas producer.

N_2 system – power turbine and shaft.

Nacelle – an enclosed shelter (cowling) on an aircraft for a power plant.

Nozzle – channel through which gas is conveyed to the rotor vanes of a turbine. Its purpose is to convert pressure into velocity.

Orifice – opening having a closed perimeter through which a fluid may discharge. It may be open to the atmosphere, or it may be partially or completely submerged in the discharged fluid.

Otto cycle – a constant volume cycle, with four distinct operations performed intermittently. Reciprocating engines operate on this cycle.

Outside air temperature – commonly abbreviated as OAT, the temperature of the air outside the engine.

Overspeed – RPM in excess of design; 100 percent RPM.

Overspeed governor, N2 – gearbox mounted on engine inlet housing and driven from the power shaft.

Overspeed governor, fuel control – part of the torquemeter system, an individual pumping unit which, with the tachometer drive assembly, sets the torquemeter oil pressure.

Overtemperature – temperature in excess of maximum allowable design temperature at the turbine exit.

PD 680 – cleaning solvent for exterior of engine and its attached components.

Planform – form or shape of an object, as of an airfoil, as seen in plan view or from above.

Power – the rate of doing work; work per unit of time.

Power-to-weight ratio – relationship between power and weight. Turbine engines produce more power for weight than reciprocating engines.

Power turbine (N_2) – turbine that is free and independent of the gas producer system. It develops rotational shaft power.

Pressure oil system – method of supplying oil under pressure to engine parts.

Pressure pumps – devices to put oil into the system.

Pressurizing and drain dump valve– device to prevent flow of fuel to the nozzle until enough pressure is built up in the fuel control. One also drains the fuel manifold at engine shutdown and traps fuel in the upper portion of the system to keep the fuel control primed for faster starts.

Primary air – air that mixes with fuel in the combustion chamber to form a combustible mixture. The ratio is 15 parts of air to 1 part of fuel.

Radial inflow turbine – type of turbine made by some manufacturers, not used in any Army aircraft today, even though it is rugged and simple, relatively inexpensive, and easy to manufacture. Similar in design and construction to the centrifugal-flow compressor.

Ram – the amount of pressure buildup above ambient pressure at the engine's compressor inlet due to the forward motion of the engine through the air (initial momentum of the air).

Ram air pressure – free stream air pressure, provided by the forward motion of the engine,

Ram ratio – the ratio of ram pressure to ambient pressure.

Ram recovery – the ability of an engine's air inlet duct to take advantage of ram pressure.

Rear of engine – end of engine from which exhaust gas is expelled.

Reverse flow – change in direction of airflow in the combustion chamber of a gas turbine engine.

Rotational direction – direction of movement of the rotating part, determined by viewing the engine from the rear.

Rotational speed – speed at which a propeller, rotor, or some other rotating part rotates; measured in revolutions per minute.

Scavenge oil system – method of returning oil from the engine to the oil tank for cooling and reuse.

Scavenger pumps – those that drain oil from the sumps at various parts of the engine, return it through the oil cooler, and back to the oil tank.

Scoring – multiple scratches, usually parallel and resulting from the same cause.

Secondary air – large surplus of air that cools the hot sections of a gas turbine engine to lower temperatures.

Shaft horsepower (SHP) – energy used to drive the compressor and accessories in a turbine engine.

Shot peening – process used to work-harden metals.

Shroud – device used with turbine rotor to prevent blade tip losses and excessive vibrations. The shrouded blades can be thinner than unprotected ones.

Simplex nozzles – single-orifice channels through which highly atomized and accurately shaped sprays of fuel go into the combustion chamber.

Solvent immersion – cleaning method in which parts are immersed in solvent to remove carbon, gum, grease, and other surface contaminants.

Span – dimension of an airfoil from tip to tip or from root to tip.

Spar – any principal structural member in an airfoil running from tip to tip or root to tip.

Specific heat – the ratio of the thermal capacity of a substance to the thermal capacity of water.

Speed governor – device to relieve the pilot from resetting the power lever when outside air temperature and pressure change. Consists of flyweights balanced by a spring.

Splines – teeth in a gear.

Stable operation – condition where no appreciable fluctuation, intentional or unintentional, is occurring to any of the engine's variables such as RPM, temperature, or pressure.

Standard day conditions – 59ºF, sea level barometric pressure (29.92 inches of mercury).

Static-balanced surface – surface that is in balance about its hinge axis.

Stator – part of assembly that remains stationary with respect to a rotating part. Stator vanes are a stationary set of airfoils in a compressor.

Stress – resultant condition of strain or pressure.

Tachometer generator – device that supplies power at a frequency proportional to the driven speed which drives the synchronous motors in the indicator.

TBO – time between overhauls. This is established by the Army and the engine manufacturer.

Test cell – building, usually concrete, that contains both a control room and an engine room, used for testing engines. The test cell is at the manufacturer's; a mobile engine-test unit is used in the field.

Thermodynamic cycle – succession of processes which involve changes in temperature, pressure, and density in which the substance acts as a means of transformation of energy. See Otto and Brayton cycles.

Thrust – a reaction force in pounds.

Thrust, gross – the thrust developed by the engine, not taking into consideration any presence of initial-air-mass momentum.

Thrust, net – the effective thrust developed by the engine during flight, taking into consideration the initial momentum of the air mass prior to entering the influence of the engine.

Thrust, reverser – a device used to partially reverse the flow of the engine's nozzle discharge gases and thus create a thrust force in the rearward direction.

Thrust, specific fuel consumption – the fuel that the engine must burn per hour to generate 1 pound of thrust.

Thrust, static – same as gross thrust without any initial airmass momentum present due to the engine's static condition.

Torque – a force, multiplied by its lever arm, acting at right angles to an axis.

Torquemeter – hydromechanical torque-measuring device located in the reduction-gear section of the inlet housing. The measurement is read as torque oil pressure in psi.

Torquemeter indicating system – pressure indicator for continuous readings of engine output-shaft torque.

Transient conditions – conditions which may occur briefly while accelerating or decelerating or while passing through a specific range of engine operation.

Turbine nozzle – stationary nozzle which discharges a jet of gas against the blades on the periphery of a turbine wheel.

Turbine rotor – rotating portion of a turbine engine. It is made of specially alloyed steel because of severe centrifugal loads, the result of high rotational speeds.

Turbine section – part of the turbine engine that extracts the kinetic energy of the expanding gases and transforms it into shaft horsepower.

Turbojet – engine most commonly used in high-speed, high-altitude aircraft.

Vapor blasting – abrasive method used to clean combustor parts. Not to be used on ceramic, magnesium, painted, or aluminum surfaces.

Vapor decreasing – cleaning method used on unpainted metal parts or aluminum-painted steel parts.

Vaporizing tubes – devices used instead of fuel nozzles in a T53-L-11 engine.

Variable inlet guide vanes – devices located in front of the first compressor rotor to guide the angle of incidence of the inlet air to the first compressor rotor.

Vermatherm element – device which senses outlet fuel temperature and closes the core valve and opens the bypass valve.

Vibration meter – device for measuring vibrations.

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