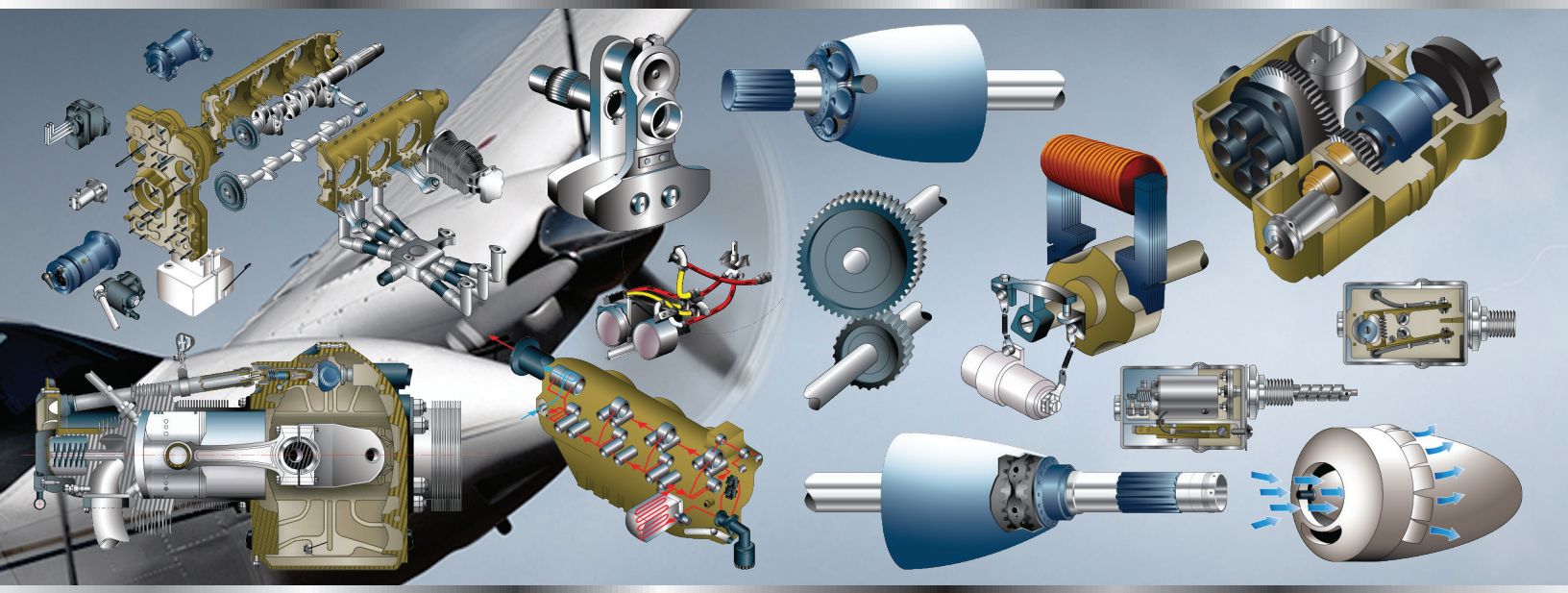
Module 16

PISTON ENGINE

Aviation Maintenance Technician Certification Series



-Fundamentals
-Engine Performance
-Engine Construction
-Engine Fuel Systems
-Starting and Ignition Systems
-Induction, Exhaust and Cooling Systems
-Supercharging/Turbocharging
-Lubricants and Fuels
-Lubrication Systems
-Engine Indication Systems
-Powerplant Installation
-Engine Monitoring and Ground Operation
-Engine Storage and Preservation

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

MODULE 16

Piston Engine

Aviation Maintenance Technician Certification Series

COMPLIANT WITH EASA
EASA PART 66/147

COMPLIANT WITH FEDERAL AVIATION ADMINISTRATION
FAA PART 66/147
POWERPLANT

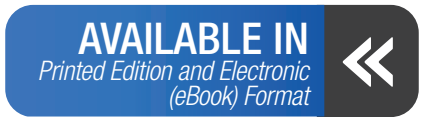


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AVIATION MAINTENANCE TECHNICIAN CERTIFICATION SERIES

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

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	A or B1 Aeroplane with:		A or B1 Helicopter with:		B2	B3
Subject Module	Turbine Engine(s)	Piston Engine(s)	Turbine Engine(s)	Piston Engine(s)	Avionics	Piston-engine non-pressurized aeroplanes 2000 kg MTOM and below
1	X	X	X	X	X	X
2	X	X	X	X	X	X
3	X	X	X	X	X	X
4	X	X	X	X	X	X
5	X	X	X	X	X	X
6	X	X	X	X	X	X
7A	X	X	X	X	X	
7B						X
8	X	X	X	X	X	X
9A	X	X	X	X	X	
9B						X
10	X	X	X	X	X	X
11A	X					
11B		X				
11C						X
12			X	X		
13					X	
14					X	
15	X		X			
16		X		X		X
17A	X	X				
17B						X

FORWARD

PART-66 and the Acceptable Means of Compliance (AMC) and Guidance Material (GM) of the European Aviation Safety Agency (EASA) Regulation (EC) No. 1321/2014, Appendix 1 to the Implementing Rules establishes the Basic Knowledge Requirements for those seeking an aircraft maintenance license. The information in this Module (16) of the Aviation Maintenance Technical Certification Series published by the Aircraft Technical Book Company meets or exceeds the breadth and depth of knowledge subject matter referenced in Appendix 1 of the Implementing Rules. However, the order of the material presented is at the discretion of the editor in an effort to convey the required knowledge in the most sequential and comprehensible manner. Knowledge levels required for Category A, B1, B2, B3, and C aircraft maintenance licenses remain unchanged from those listed in Appendix 1 Basic Knowledge Requirements. Tables from Appendix 1 Basic Knowledge Requirements are reproduced at the beginning of each module in the series and again at the beginning of each Sub-Module.

Piston engines, in their many forms, have been the mainstay of aviation since the first days of powered flight. Today, from simple 2 stroke sport aircraft engines to 300+ horsepower turbocharged, fuel injected, Lycoming and Continental powerplants, piston engines offer an economical and reliable option for many small to mid-sized aircraft. This module provides a detailed look at the construction, component systems, inspection, maintenance, operation, and performance of the major types of aircraft piston engines. Each component of each system is covered in detail including its variations, function, and limitations. Thus when combined with the practical portions of a B1.2 or A&P program this module will provide you with a level of knowledge to begin your career maintaining and operating these venerable and state of the art machines.

Module 16 Syllabus as outlined in PART-66, Appendix 1.

	LEVELS		
CERTIFICATION CATEGORY →	A	B1	B3
Sub-Module 01 - Fundamentals			
Mechanical, thermal and volumetric efficiencies; Operating principles — 2 stroke, 4 stroke, Otto and Diesel; Piston displacement and compression ratio; Engine configuration and firing order.	1	2	2
Sub-Module 02 - Engine Performance			
Power calculation and measurement; Factors affecting engine power; Mixtures/leaning, pre-ignition.	1	2	2
Sub-Module 03 - Engine Construction			
Crank case, crank shaft, cam shafts, sumps; Accessory gearbox; Cylinder and piston assemblies; Connecting rods, inlet and exhaust manifolds; Valve mechanisms; Propeller reduction gearboxes. Airframe symmetry: methods of alignment and symmetry checks.	1	2	2
Sub-Module 04 - Engine Fuel Systems			
Sub-Module 04.1.1 - Carburetors			
Types, construction and principles of operation; Icing and heating.	1	2	2
Sub-Module 04.1.2 - Fuel Injection Systems			
Types, construction and principles of operation.	1	2	2

CERTIFICATION CATEGORY →	LEVELS A	B1	B3
Sub-Module 04.1.3 - Electronic Engine Control Operation of engine control and fuel metering systems including electronic engine control (FADEC); Systems lay-out and components.	1	2	2
Sub-Module 05 - Starting and Ignition Systems Starting systems, pre-heat systems; Magneto types, construction and principles of operation; Ignition harnesses, spark plugs; Low and high tension systems.	1	2	2
Sub-Module 06 - Induction, Exhaust and Cooling Systems Construction and operation of: induction systems including alternate air systems; Exhaust systems, engine cooling systems — air and liquid.	1	2	2
Sub-Module 07 - Supercharging/Turbocharging Principles and purpose of supercharging and its effects on engine parameters; Construction and operation of supercharging/turbocharging systems; System terminology; Control systems; System protection.	1	2	2
Sub-Module 08 - Lubricants and Fuels Properties and specifications; Fuel additives; Safety precautions.	1	2	2
Sub-Module 09 - Lubrication Systems System operation/lay-out and components.	1	2	2
Sub-Module 10 - Engine Indication Systems Engine speed; Cylinder head temperature; Coolant temperature; Oil pressure and temperature; Exhaust Gas Temperature; Fuel pressure and flow; Manifold pressure.	1	2	2
Sub-Module 11 - Powerplant Installation Configuration of firewalls, cowlings, acoustic panels, engine mounts, anti-vibration mounts, hoses, pipes, feeders, connectors, wiring looms, control cables and rods, lifting points and drains.	1	2	2

CERTIFICATION CATEGORY →	LEVELS A	B1	B3
Sub-Module 12 - Engine Monitoring and Ground Operation Procedures for starting and ground run-up; Interpretation of engine power output and parameters; Inspection of engine and components: criteria, tolerances, and data specified by engine manufacturer.	1	3	2
Sub-Module 13 - Engine Storage and Preservation Preservation and depreservation for the engine and accessories/systems.	-	2	1
Sub-Module 14 - Light Sport Aircraft Engines			

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PART-66 SYLLABUS	LEVELS		
CERTIFICATION CATEGORY →	A	B1	B3

Sub-Module 01
Piston Engine - Fundamentals

16.1 Fundamentals Mechanical, thermal and columetric efficiencies; Operating principles- 2 stroke, 4 stroke, Otto, and Diesel; Piston displacement and compression ratio; Engine configuration and firing order.	1	2	2

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

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

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

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

PISTON ENGINE-FUNDAMENTALS
OPERATING PRINCIPLES

FUNDAMENTAL RECIPROCATING ENGINE OPERATING PRINCIPLES

The relationships between pressure, volume, and temperature of gases are the basic principles of engine operation. An internal combustion engine is a device for converting heat energy into mechanical energy. Gasoline is vaporized and mixed with air, forced or drawn into a cylinder, compressed by a piston, and then ignited by an electric spark. The conversion of the resultant heat energy into mechanical energy and then into work is accomplished in the cylinder. ***Figure 1.1*** illustrates the various engine components necessary to accomplish this conversion and also presents the principal terms used to indicate engine operation.

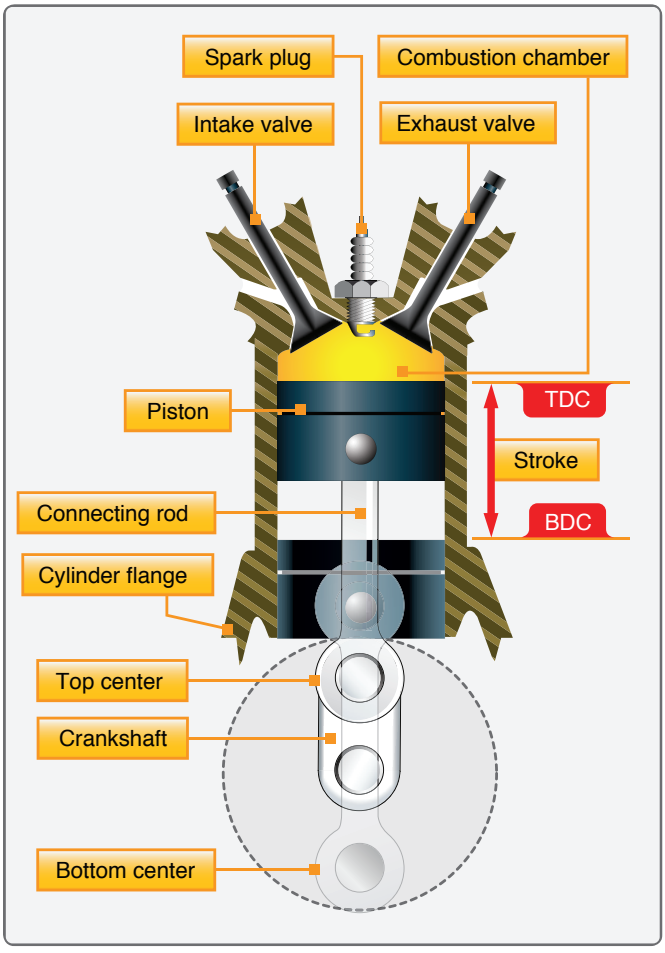


Figure 1-1. Piston engine design and components.

On a typical four-stroke aircraft engine, the operating cycle of an internal combustion reciprocating engine includes the series of events required to induct, compress, ignite, and burn, causing expansion of the fuel/air charge in the cylinder and to scavenge or exhaust the byproducts of the combustion process. When the compressed mixture is ignited, the resultant gases of combustion expand very rapidly and force the piston to move away from the cylinder head. This downward motion of the piston, acting on the crankshaft through the connecting rod, is converted to a circular or rotary motion by the crankshaft. A valve in the top or head of the cylinder opens to allow the burned gases to escape, and the momentum of the crankshaft and the propeller forces the piston back up in the cylinder where it is ready for the next event in the cycle. Another valve in the cylinder head then opens to let in a fresh charge of the fuel/air mixture. The valve allowing for the escape of the burning exhaust gases is called the exhaust valve, and the valve that lets in the fresh charge of the fuel/air mixture is called the intake valve. These valves are opened and closed mechanically at the proper times by the valve-operating mechanism.

The bore of a cylinder is its inside diameter. The stroke is the distance the piston moves from one end of the cylinder to the other, specifically from top dead center (TDC) to bottom dead center (BDC), or vice versa. [***Figure 1-1***]

OPERATING CYCLES

There are several engine operating cycles in use:

1. Four-stroke
2. Two-stroke
3. Rotary
4. Diesel

FOUR-STROKE CYCLE

The vast majority of certified aircraft reciprocating engines operate on the four-stroke cycle, sometimes called the Otto cycle after its originator, a German physicist. The four-stroke cycle engine has many advantages for use in aircraft. One advantage is that it lends itself readily to high performance through supercharging.

In this type of engine, four strokes are required to complete the required series of events or operating cycle of each cylinder. Refer to ***Figure 1-2***. Two complete revolutions of the crankshaft (720°) are required for the four strokes; thus, each cylinder in an engine of this type fires once in every two revolutions of the crankshaft. In the following

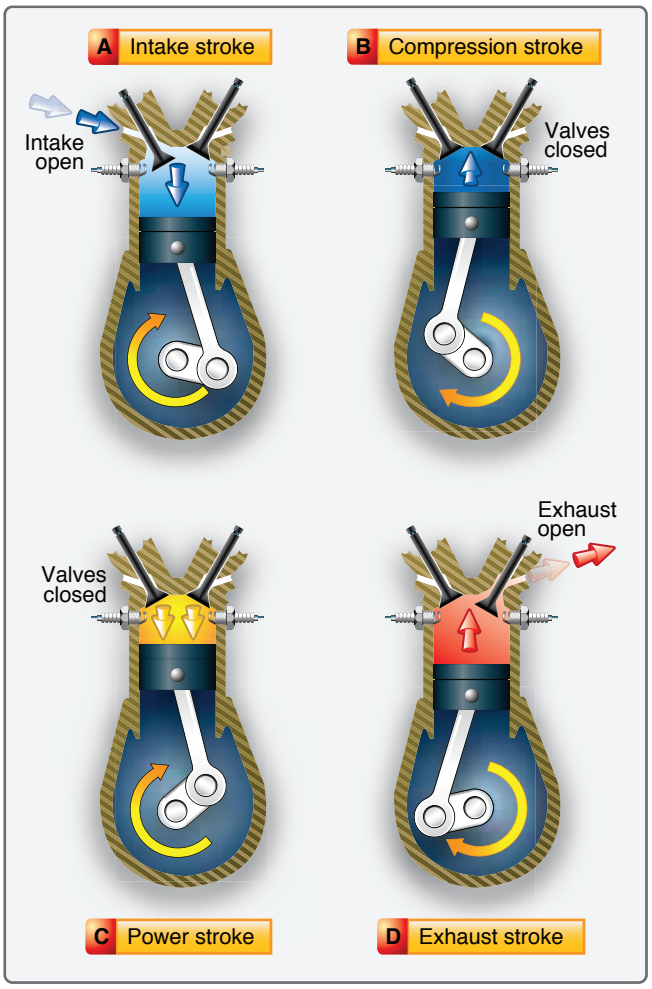


Figure 1-2. Four-stroke cycle.

discussion of the four-stroke cycle engine operation, note that the timing of the ignition and the valve events vary considerably in different engines. Many factors influence the timing of a specific engine, and it is most important that the engine manufacturer's recommendations in this respect be followed in maintenance and overhaul. The timing of the valve and ignition events is always specified in degrees of crankshaft travel. It should be remembered that a certain amount of crankshaft travel is required to open a valve fully; therefore, the specified timing represents the start of opening rather than the full-open position of the valve. An example valve timing chart can be seen in ***Figure 1-3***.

INTAKE STROKE

During the intake stroke, the piston is pulled downward in the cylinder by the rotation of the crankshaft. This reduces the pressure in the cylinder and causes air under atmospheric pressure to flow through the fuel metering device, which meters the correct amount of fuel in proportion to the air ingested by the cylinders. The fuel/air mixture passes through the intake pipes and intake valves into the cylinders. The quantity or weight of the fuel/air charge depends upon the degree of throttle opening.

The intake valve is opened considerably before the piston reaches TDC on the exhaust stroke, in order to induce a greater quantity of the fuel/air charge into the cylinder and thus increase the horsepower (see ***Figure 1-3***). The distance the valve may be opened before TDC, however, is limited by several factors, such as the possibility that hot exhaust gases remaining in the cylinder from the previous cycle may flash back into the intake pipe and induction system.

In all high-power aircraft engines, both the intake and the exhaust valves are off their valve seats at TDC at the start of the intake stroke. As mentioned above, the intake valve opens before TDC on the exhaust stroke (valve lead), and the closing of the exhaust valve is delayed considerably after the piston has passed TDC and has started the intake stroke (valve lag). This timing is called valve overlap and is designed to aid in cooling the cylinder internally by circulating the cool incoming fuel/air mixture, to increase the amount of the fuel/air mixture induced into the cylinder, and to aid in scavenging the byproducts of combustion from the cylinder.

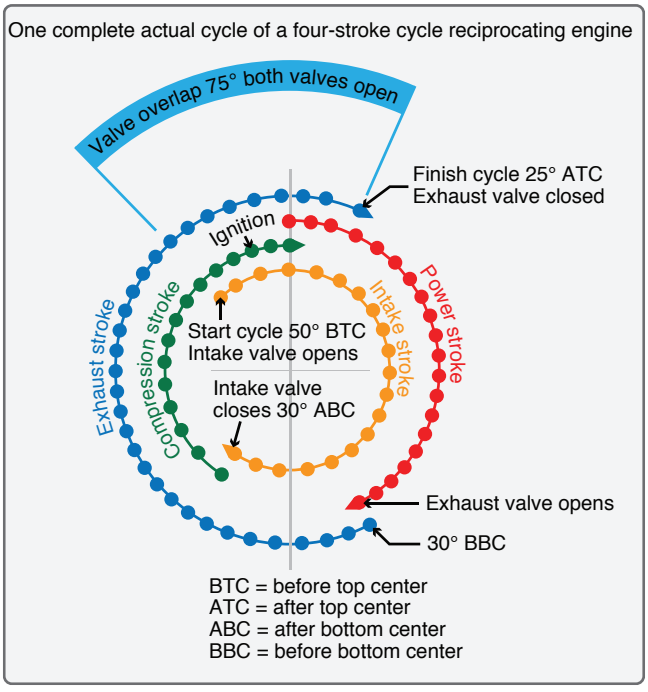


Figure 1-3. Four-stroke valve timing.

The intake valve is timed to close about 50° to 75° past BDC on the compression stroke as the piston is moving up the cylinder, depending upon the specific engine, to allow the momentum of the incoming gases to charge the cylinder more completely. Because of the comparatively large volume of the cylinder above the piston when the piston is near BDC, the slight upward travel of the piston during this time does not have a great effect on the incoming flow of gases. This late timing can be carried too far because the gases may be forced back through the intake valve and defeat the purpose of the late closing.

COMPRESSION STROKE

After the intake valve is closed, the continued upward travel of the piston compresses the fuel/air mixture to obtain the desired burning and expansion characteristics. The charge is fired by means of an electric spark as the piston approaches TDC. The time of ignition typically varies from 20° to 35° before TDC, depending upon the requirements of the specific engine to ensure complete combustion of the charge by the time the piston is slightly past the TDC position.

Many factors affect ignition timing, and the engine manufacturer has expended considerable testing to determine the best setting. All engines incorporate devices for adjusting the ignition timing, and it is most important that the ignition system be timed according to the engine manufacturer's recommendations.

POWER STROKE

As the piston moves through the TDC position at the end of the compression stroke and starts down on the power stroke, it is pushed downward by the rapid expansion of the burning gases within the cylinder head with a force that can be greater than 15 tons (30,000 psi) at maximum power output of the engine. The temperature of these burning gases may be between 3,000°F and 4,000°F (1,650°C and 2,200°C). As the piston is forced downward during the power stroke by the pressure of the burning gases exerted upon it, the downward movement of the connecting rod is changed to rotary movement by the crankshaft. Then, the rotary movement is transmitted to the propeller shaft, or propeller gear reduction system, to drive the propeller. As the burning gases are expanded, the temperature drops to within safe limits before the exhaust gases flow out through the exhaust port.

The timing of the exhaust valve opening is determined by, among other considerations, the desirability of using as much of the expansive force as possible and of scavenging the cylinder as completely and rapidly as possible. The valve is opened considerably before BDC on the power stroke (on some engines at 50° and 75° before BDC) while there is still some pressure in the cylinder. This timing is used so that the pressure can force the gases out of the exhaust port as soon as possible. This process frees the cylinder of waste heat after the desired expansion has been obtained and avoids overheating the cylinder and the piston. Thorough scavenging is very important, because any exhaust products remaining in the cylinder dilute the incoming fuel/air charge at the start of the next cycle.

EXHAUST STROKE

As the piston travels through BDC at the completion of the power stroke and starts upward on the exhaust stroke, it begins to push the burned exhaust gases out the exhaust port. The speed of the exhaust gases leaving the cylinder creates a low pressure in the cylinder. This low or reduced pressure speeds the flow of the fresh fuel/air charge into the cylinder as the intake valve begins to open. The intake valve opening is timed to occur at 8° to 55° before TDC on the exhaust stroke on various engines.

TWO-STROKE CYCLE

The two-stroke-cycle engine has re-emerged being used in ultra-light, light sport, and many experimental aircraft. As the name implies, two-stroke cycle engines require only one upstroke and one down stroke of the piston to complete the required series of events in the cylinder. Thus, the engine completes the operating cycle in one revolution of the crankshaft. The intake and exhaust functions are accomplished during the same stroke. These engines can be either air or water cooled and generally require a gear reduction housing between the engine and propeller.

In comparison to a conventional four-stroke power plant, two-stroke engines have some unique operational features. Oil is mixed with the fuel to lubricate the connecting rods and bearings associated with the crankshaft, wrist pin and bearing, and rings and cylinder wall. This oil is consumed during the ignition and power stroke of the engine. Also, two-stroke engines often run at relatively high rpms.

The cylinders of two-stroke engines contain a series of ports that are crucial to the operation of the engine. These ports are blocked and unblocked by the piston as it travels up and down the cylinder. The locations and dimensions of these ports are engineered to provide the desired performance of the two-stroke engine.

The piston rings of a two-stroke engine are different from those of a four-stroke power plant. The rings are pinned within the ring groove to prevent their rotation during operation. If the piston rings were free to revolve in their grooves, the ends of the rings would become snagged in the cylinder ports resulting in ring, and ultimately, engine failure. Also, two-stroke engines do not use oil and scraper rings as the lubricant is mixed with the fuel/air charge and consumed during the combustion process.

The intake flow of the fuel/air/oil mixture begins as the piston travels to TDC. Unlike a four-stroke engine, the crankcase has sealed chambers for each cylinder. The movement of the piston from BDC to TDC generates a low pressure in the crankcase chamber. This action draws the fuel/air/oil charge into the crankcase chamber. As the piston travels from TDC to BDC, the fuel/air/oil charge contained in the crankcase becomes compressed. When the piston unblocks the transfer ports located along the cylinder wall, the fuel/air/oil charge travels from the crankcase chamber into the cylinder. After reaching BDC and moving toward TDC, the ports along the cylinder wall are blocked by the piston. This allows the upward moving piston to compress the fuel/air/oil charge before the ignition event. As with the four-stroke engine, the combustible mixture is ignited before the piston reaches TDC.

After ignition, the pressure generated by the expanding gases increases as the piston reaches TDC and travels down the cylinder wall until the exhaust port is unblocked. Exhaust gases escape through the exhaust port. As the piston continues its downward movement, the transfer ports are opened to allow the fuel/air/oil charge in the crankcase chamber to flow into the cylinder for the next cycle.

One advantage offered by the two-stroke engine is its relative light weight when compared to the four-stoke engine. The time-between-overhaul (TBO) is generally shorter on a two-stroke engine than a four-stroke engine. Overall, the overhaul of the two-stroke is somewhat simpler due to the lack of intake and exhaust valves and a number of other components included in the four-cycle engine.

ROTARY CYCLE

The rotary cycle has a three-sided rotor that turns inside an elliptical housing, completing three of the four cycles for each revolution. These engines can be single rotor or multi-rotor and can be air-cooled or water-cooled. They are used mostly with experimental and light aircraft. Vibration characteristics are also very low with this type of engine.

Where a piston power plant uses the cylinder to complete all the events associated with the operation of the engine, the housing of a rotary engine, also know as a Wankel, has separate compartments that serve specific functions. Using ports that are covered and uncovered by the triangular rotor, the intake occurs in a separate segment of the housing. As the rotor revolves within the housing, it uncovers the intake port and fills the housing with the fuel/air charge as the rotor/housing area increases in volume. After the rotor seals off the intake port, the rotor/housing area decreases. This compresses the fuel/air charge. The ignition occurs when the rotor/housing area is at a minimum. This is the combustion region of the housing. Ignition is delivered from two spark plugs. The timing of the two sparks is staggered to generate a more complete combustion process.

The expanding gases from the combustion event cause the rotor to turn as the volume in the rotor/housing area increases. This is similar to the downward movement of a piston during the power stroke of a reciprocating engine. As the rotor continues to rotate during the power phase, the exhaust port becomes unblocked, allowing the exhaust gases to escape. The cycle begins anew as the rotor revolves within the housing for the next intake event. Because the rotor has three surfaces, all three sides experience the intake, compression, power, and exhaust phases in a continuous sequence. Refer to ***Figure 1-4***. The rotor uses apex and face seals that serve functions similar to those of piston rings on a reciprocating power plant. The rotor, or rotors, are connected to an output shaft that somewhat resembles the crankshaft of a piston engine. The output shaft passes through the center of the rotor(s) and revolves as the rotor(s) turn within the housing. The output shaft

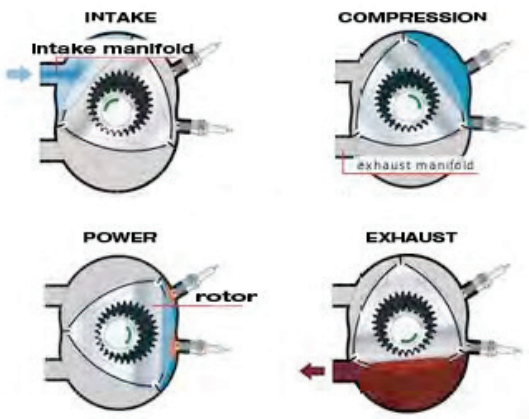


Figure 1-4. Rotary engine phases of operation.



Figure 1-5. Rotary engine rotors, housing, and output shaft.

is connected to a propeller gear reduction housing that spins the propeller. Refer to ***Figure 1-5***.

DIESEL CYCLE

The diesel cycle depends on high compression pressures to provide for the ignition of the fuel/air charge in the cylinder. After air is drawn in the cylinder, it is compressed by a piston and, at maximum pressure, fuel is sprayed in the cylinder. At this point, the high pressure and temperature in the cylinder causes the fuel to burn increasing the internal pressure of the cylinder. This drives the piston down, turning or driving the crankshaft. Water and air-cooled engines that can operate on JET A fuel (kerosene) use a version of the diesel cycle. There are many types of diesel cycles, in use including two-stroke and four-stroke diesels.

ENGINE CONFIGURATION

Aircraft engines can be classified by several methods. They can be classed by operating cycles, cylinder arrangement, or the method of thrust production. All are heat engines that convert fuel into heat energy that is converted to mechanical energy to produce thrust. Most of the current aircraft engines are of the internal combustion type because the combustion process takes place inside the engine. Aircraft engines come in many different types, such as gas turbine based, reciprocating piston, rotary, two or four cycle, spark ignition, diesel, and air or water cooled. Reciprocating and gas turbine engines also have subdivisions based on the type of cylinder arrangement (piston) and speed range (gas turbine).

Many types of reciprocating engines have been designed. However, manufacturers have developed some designs that are used more commonly than others and are, therefore, recognized as conventional. Reciprocating engines may be classified according to the cylinder arrangement (inline, V-type, radial, and opposed) or according to the method of cooling (liquid cooled or air cooled). Actually, all piston engines are cooled by transferring excess heat to the surrounding air. In air-cooled engines, this heat transfer is direct from the cylinders to the air. Therefore, it is necessary to provide thin metal fins on the cylinders of an air-cooled engine in order to have increased surface area for sufficient heat transfer. Most reciprocating aircraft engines are air cooled although a few high powered engines use an efficient liquid-cooling system. In liquid-cooled engines, the heat is transferred from the cylinders to the coolant, which is then sent through tubing and cooled within a radiator placed in the airstream. The coolant radiator must be large enough to cool the liquid effectively and efficiently. The main problem with liquid cooling is the added weight of coolant, heat exchanger (radiator), water pump, and associated tubing to connect the components. Liquid cooled engines do allow high power to be obtained from the engine safely. Certain engines designed for use in light aircraft may be cooled by liquid or a combination of air and liquid.

INLINE ENGINES

An inline engine generally has an even number of cylinders, although some three-cylinder engines have been constructed. This engine may be either liquid cooled or air cooled and has only one crankshaft, which is located either above or below the cylinders. If the engine is designed to operate with the cylinders below the crankshaft, it is called an inverted inline engine.

The inline engine has a small frontal area and is better adapted to streamlining. When mounted with the cylinders in an inverted position, it offers the added advantages of a shorter landing gear and greater pilot visibility. With increase in engine size, the air cooled, inline type offers additional problems to provide proper cooling; therefore, this type of engine is confined to low- and medium-horsepower engines used in older light aircraft.

OPPOSED OR O-TYPE ENGINES

The opposed-type engine has two banks of cylinders directly opposite each other with a crankshaft in the center as shown in ***Figure 1-6***. The pistons of both cylinder banks are connected to the single crankshaft. Although the engine can be either liquid cooled or air cooled, the air-cooled version is used predominantly in aviation. It is generally mounted with the cylinders in a horizontal position. The opposed-type engine has a low weight-to-horsepower ratio, and its narrow silhouette makes it ideal for horizontal installation on the aircraft wings (twin engine applications). Another advantage is its low vibration characteristics.



Figure 1-6. Four-cylinder opposed engine.

Opposed engines are normally designated with the letter "O" and a dash followed by the piston displacement. For example, an O-360 is an opposed engine with 360 cubic inches of displacement. If the is no prefix before the "O", the engine will likely be mounted with the crankshaft in a horizontal position. If the letter "V" precedes the letter "O", (e.g., VO-360), the engine is mounted with the crankshaft in the vertical position. This is common with early generation reciprocated powered helicopters. When an opposed engine includes the prefix "I", such as IO-360, the engine is fuel injected. The prefix "T" or "TS" indicates the engine has a turbo-supercharging system. The prefix "G" designates a geared engine. A prefix of "L" is used to show that the engine has left-hand rotation as view from the rear of the engine looking forward.

V-TYPE ENGINES

In V-type engines, the cylinders are arranged in two in-line banks generally set 60° apart. Most of the V-type engines have 12 cylinders, which are either liquid cooled or air cooled. The engines are designated by a V followed by a dash and the piston displacement in cubic inches. For example, V-1710. This type of engine was used mostly during the second World War and its use is largely limited to older aircraft.

RADIAL ENGINES

The radial engine consists of a row, or rows, of cylinders arranged radially about a central crankcase as illustrated in ***Figure 1-7***. This type of engine has proven to be very rugged and dependable. The number of cylinders which make up a row may be three, five, seven, or nine.



Figure 1-7. Single-row radial engine.

Some radial engines have two rows of seven or nine cylinders arranged radially about the crankcase, one in front of the other in a staggered arrangement. These are called double-row radials. See ***Figure 1-8***. One type of radial engine has four rows of cylinders with seven cylinders in each row for a total of 28 cylinders. Radial engines are still used in some older cargo planes, war birds, and crop spray planes. Although many of these engines still exist, their use is limited. The single-



Figure 1-8. Double-row radial engine.

row, nine-cylinder radial engine is of relatively simple construction, having a one-piece nose and a two-section main crankcase. The larger twin-row engines are of slightly more complex construction than the single row engines. For example, the crankcase of the Wright R-3350 engine is composed of the crankcase front section, four crankcase main sections (front main, front center, rear center, and rear main), rear cam and tappet housing, supercharger front housing, supercharger rear housing, and supercharger rear housing cover. Pratt and Whitney engines of comparable size incorporate the same basic sections, although the construction and the nomenclature differ considerably.

PISTON DISPLACEMENT

When other factors remain equal, the greater the piston displacement, the greater the maximum horsepower an engine is capable of developing. When a piston moves from BDC to TDC, it displaces a specific volume. The volume displaced by the piston is known as piston displacement and is expressed in cubic inches for most American-made engines and cubic centimeters or liters for others.

The piston displacement of one cylinder may be obtained by multiplying the area of the cross-section of the cylinder by the total distance the piston moves in the cylinder in one stroke. For multi-cylinder engines, this product is multiplied by the number of cylinders to get the total piston displacement of the engine.

Since the volume (V) of a geometric cylinder equals the area (A) of the base multiplied by the height (h), it is expressed mathematically as:

$$V = A \times h$$

The area of the base is the area of the cross-section of the cylinder.

AREA OF A CIRCLE

To find the area of a circle, it is necessary to use a number called pi (π). This number represents the ratio of the circumference to the diameter of any circle. Pi cannot be stated exactly because it is a never-ending decimal. It is 3.1416 expressed to four decimal places, which is accurate enough for most computations.

The area of a circle, as in a rectangle or triangle, must be expressed in square units. The distance that is one-half the diameter of a circle is known as the radius. The area of any circle is found by squaring the radius (r) and multiplying by π. The formula to calculate the area of a circle is:

$$A = \pi r^2$$

The radius (r) of a circle is equal to 1/2 the diameter:

$$r = d \div 2$$

Example

Compute the piston displacement of a 4-cylinder engine having a cylinder with a 5.125 inch diameter and a 4.375 inch stroke. Formulas required are:

$r = d \div 2$
$A = \pi r^2$
$V = A \times h$
Total Volume = V x n (number of cylinders)

Substitute values into these formulas and complete the calculation.

$r = d \div 2 = 5.125$ inches (in) $\div 2 = 2.5625$ inches
$A = \pi r^2 = 3.1416\ (2.5625\ in)^2$
$A = 3.1416 \times 6.5664$ square inches (in^2) = 20.6290 in^2
$V = A \times h = 20.6290\ in^2 \times 4.375$ in = 90.2519 cubic inches (in^3)

Total Volume = V x n = 90.2519 in^3 x 4
Total Volume = 361.0075 in^3

Rounded off to the nearest whole number, total piston displacement equals 361 cubic inches.

Another method of calculating the piston displacement uses the diameter of the piston instead of the radius in the formula for the area of the base.

Area = 1/4(π) (d^2)

Substituting:

A = 1/4 x 3.1416 x (5.125 $in)^2$
A = 0.7854 x 26.2656 in^2
A = 20.6290 in^2

From this point on, the calculations are identical to the preceding example.

The process for calculating displacement using the metric system is identical. Converting the bore and stroke from the previous example to centimeters yields a bore of 13.02 cm and a stroke of 11.11 cm. Plugging these values into the previous example:

A = 1/4 x 3.1416 x (13.02 $cm)^2$
A = 0.7854 x 169.52 cm^2
A = 133.14 cm^2
V = A x h = 133.14 cm^2 x 11.11 cm = 1479.19 cm^3
Total Volume = 1479.19 cm^3 x 4 = 5916.76 cm^3
Divide by 1,000 to convert to liters = 5.92 Liters

COMPRESSION RATIO

All internal combustion engines must compress the fuel/air mixture to receive a reasonable amount of work from each power stroke. The fuel/air charge in the cylinder can be compared to a coil spring in that the more it is compressed, the more work it is potentially capable of doing.

The compression ratio of an engine is a comparison of the volume of space in a cylinder when the piston is at the bottom of the stroke to the volume of space when the piston is at the top of the stroke. Refer to ***Figure 1-9***. This comparison is expressed as a ratio, hence the term compression ratio. Compression ratio is a controlling factor in the maximum horsepower developed by an engine, but it is limited by present day fuel grades and the high engine speeds and manifold pressures required for takeoff. For example, if there are 140 cubic inches of space in the cylinder when the piston is at the bottom and there are 20 cubic inches of space when the piston is at the top of the stroke, the compression ratio would be 140 to 20. If this ratio is expressed in fraction form, it would be 140/20 or 7 to 1, usually represented as 7:1.

The limitations placed on compression ratios, manifold pressure, and the manifold pressure's effect on compression pressures has a major effect on engine operation. Manifold pressure is the average absolute pressure of the air or fuel/air charge in the intake manifold and is measured in units of inches of mercury ("Hg). Manifold pressure is dependent on engine speed and throttle setting and the degree supercharging, when applicable. The operation of the supercharger increases the weight of the fuel/air charge entering the cylinder. When a true supercharger is used with the aircraft engine, the manifold pressure may be considerably higher than the pressure of the ambient atmosphere. The advantage of this condition is that a greater amount of charge is forced into a given cylinder volume and a greater output of horsepower results.

Compression ratio and manifold pressure determine the pressure in the cylinder in that portion of the operating cycle when both valves are closed. The pressure of the charge before compression is determined by manifold pressure, while the pressure at the height of compression (just prior to ignition) is determined by manifold pressure times the compression ratio. For example, if an engine were operating at a manifold pressure of 30"Hg with a compression ratio of 7:1, the pressure at the instant before ignition would be approximately 210"Hg. However, at a manifold

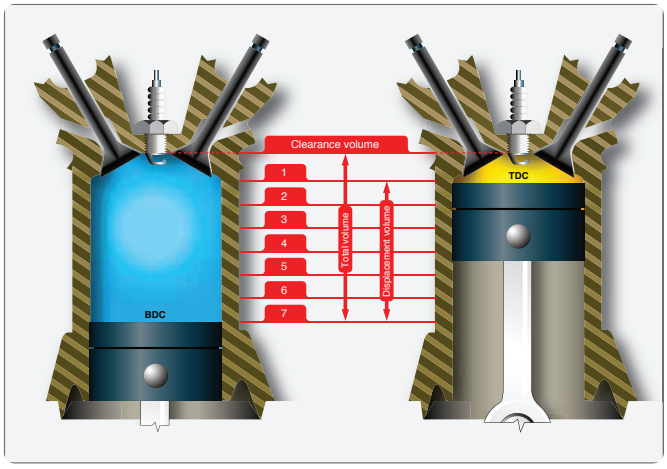


Figure 1-9. Compression ratio.

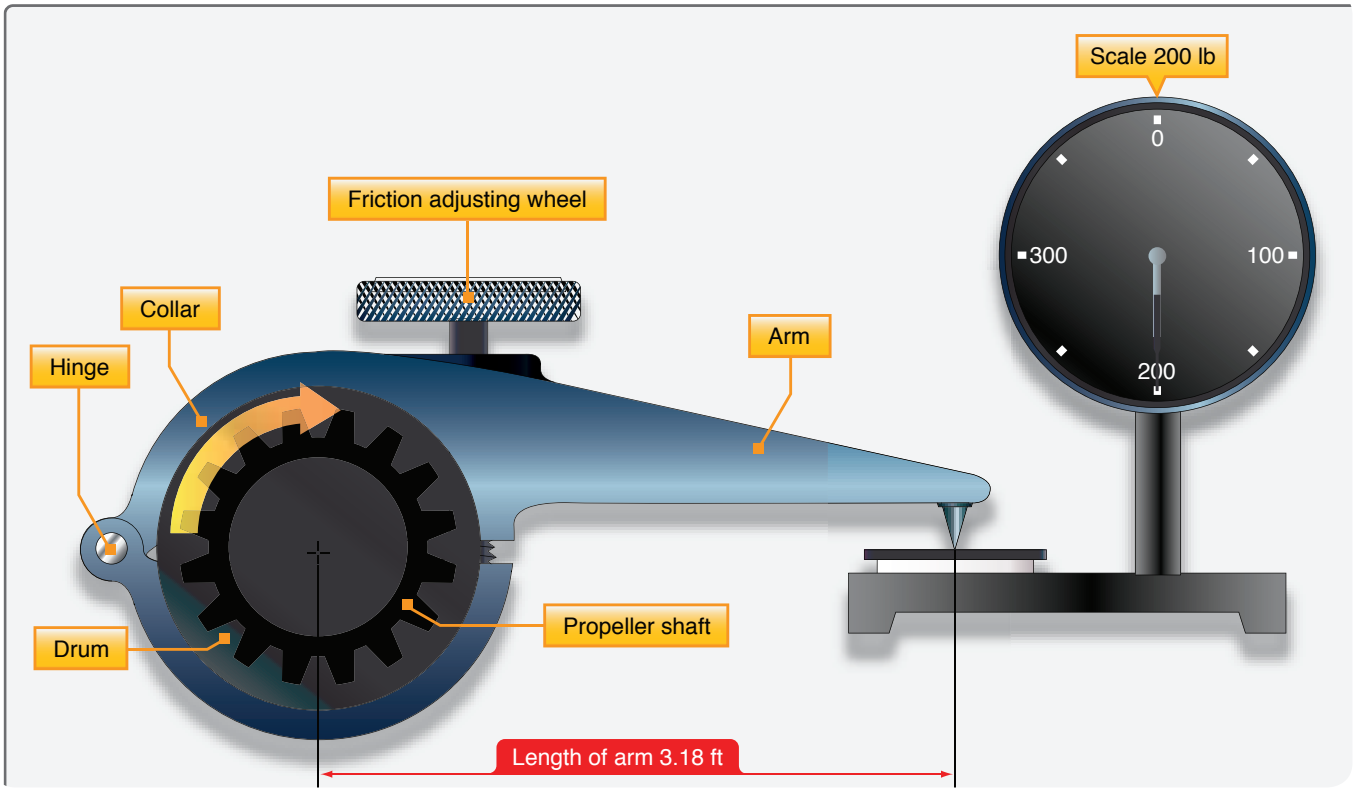


Figure 1-10. Prony brake.

pressure of 60"Hg, the pressure would be 420"Hg.

Without going into great detail, it has been shown that the compression event magnifies the effect of varying the manifold pressure, and the magnitude of both affects the pressure of the fuel/air charge just before the instant of ignition. If the pressure at this time becomes too high, preignition or detonation occur and produce overheating. Preignition is when the fuel/air charge starts to burn before the spark plug fires. Detonation occurs when the fuel/air charge is ignited by the spark plug, but instead of burning at a controlled rate, it explodes causing cylinder temperatures and pressures to spike very quickly. If this condition exists for very long, the engine can be damaged or destroyed.

EFFICIENCIES

MECHANICAL EFFICIENCY

Mechanical efficiency is the ratio that shows how much of the power developed by the expanding gases in the cylinder is actually delivered to the output shaft. It is a comparison between the brake horsepower (bhp) and the indicated horsepower (ihp). It can be expressed by the formula:

Mechanical efficiency = bhp ÷ ihp

Brake horsepower is the useful power delivered to the propeller shaft. Refer to ***Figure 1-10*** for an illustration of how engine torque is measured via a Prony brake. From this measurement, horsepower output of the power plant may be calculated. Indicated horsepower is the total hp developed in the cylinders. The formula for calculating indicated horsepower is:

ihp = PLANK ÷ 33,00

where:

P = indicated mean effective combustion pressure in psi, (see ***Figure 1-11***)
L = the length of the stroke in feet or fraction of a foot,
A = area of the piston head in square inches,
N = number of power strokes per minute (rpm ÷ 2 for four-stroke engines), and
K = the number of cylinders.

The difference between bhp and ihp is friction horsepower (fhp), the power lost in overcoming friction. The factor that has the greatest effect on mechanical efficiency is the friction within the engine itself. The

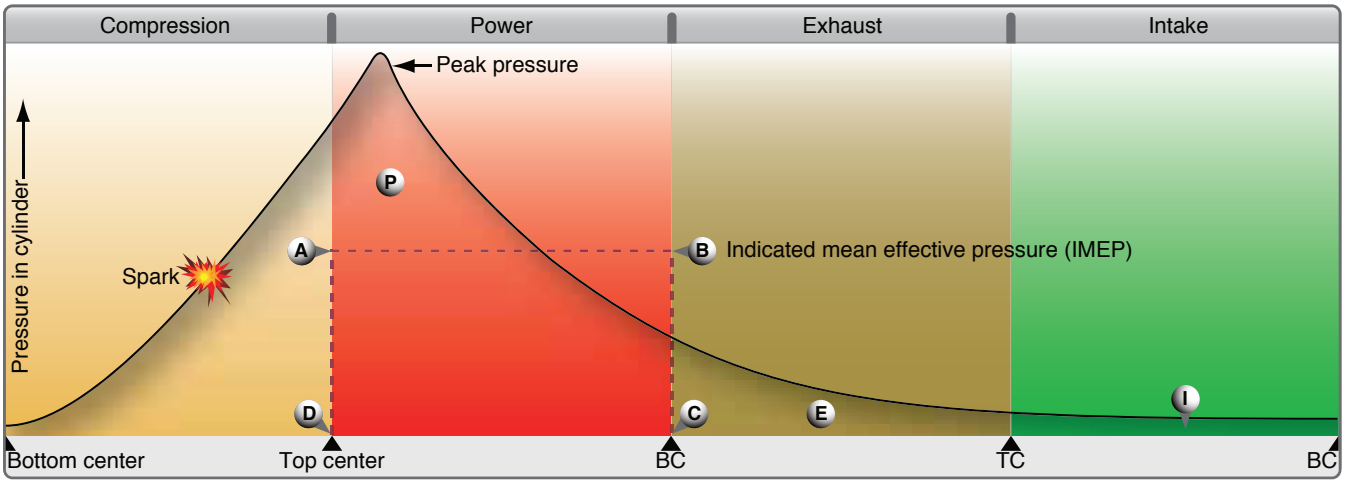


Figure 1-11. Cylinder pressures and mean effective pressure.

friction between moving parts in an engine remains practically constant throughout an engine's speed range. Therefore, the mechanical efficiency of an engine is highest when the engine is running at the rpm at which maximum bhp is developed. Mechanical efficiency of the average aircraft reciprocating engine approaches 90 percent.

THERMAL EFFICIENCY

Any study of conventional aircraft engines and power production involves consideration of heat as the source of power. The heat produced by the burning of gasoline in the cylinders causes a rapid expansion of the gases in the cylinder, and this, in turn, moves the pistons and creates mechanical energy. It has long been known that mechanical work can be converted into heat and that a given amount of heat contains the energy equivalent of a certain amount of mechanical work. Heat and work are theoretically interchangeable and bear a fixed relation to each other. Heat can therefore be measured in work units (for example, ft-lb) as well as in heat units. The British thermal unit (BTU) of heat is the quantity of heat required to raise the temperature of 1 pound of water by 1°F. It is equivalent to 778 ft-lb of mechanical work. A pound of petroleum fuel, when burned with enough air to consume it completely, gives up about 20,000 BTU, the equivalent of 15,560,000 ft-lb of mechanical work. These quantities express the heat energy of the fuel in heat and work units, respectively.

The ratio of useful work done by an engine to the heat energy of the fuel it uses, expressed in work or heat units, is called the thermal efficiency of the engine. If two similar engines use equal amounts of fuel, the engine that converts into work the greater part of the energy in the fuel (higher thermal efficiency) delivers the greater amount of power. Furthermore, the engine that has the higher thermal efficiency has less waste heat to dispose of through the valves, cylinders, pistons, and cooling system of the engine. A high thermal efficiency also means low specific fuel consumption and, therefore, less fuel for a flight of a given distance at a given power. Thus, the practical importance of a high thermal efficiency is threefold, and it constitutes one of the most desirable features in the performance of an aircraft engine.

Of the total heat produced, 25 to 30 percent is utilized for power output, 15 to 20 percent is lost in cooling (heat radiated from cylinder head fins), 5 to 10 percent is lost in overcoming friction of moving parts, and 40 to 45 percent is lost through the exhaust. Anything that increases the heat content going into mechanical work on the piston, that reduces the friction and pumping losses, or that reduces the quantity of unburned fuel or the heat lost to the engine parts, increases the thermal efficiency.

The portion of the total heat of combustion that is turned into mechanical work depends to a great extent upon the compression ratio. The compression ratio is the ratio of the piston displacement plus combustion chamber space to the combustion chamber space, as mentioned earlier. Other things being equal, the higher the compression ratio, the larger the proportion of the heat energy of combustion turned into useful work at the crankshaft. On the other hand, increasing the compression ratio increases the cylinder head temperature. This is a limiting factor because the extremely high temperature created by high compression ratios causes the material

in the cylinder to deteriorate rapidly and the fuel to detonate instead of burning at a controlled rate.

The thermal efficiency of an engine may be based on either brake horsepower (bhp) or indicated horsepower (ihp) and is represented by the formula:

Indicated Thermal Efficiency = ihp x 33,000 ÷ (weight of fuel burned/min.) x heat value x 778

The formula for brake thermal efficiency is the same as shown above, except the value for bhp is inserted instead of the value for ihp.

Example

An engine delivers 85 bhp for a period of 1 hour and during that time consumes 50 pounds of fuel. Assuming the fuel has a heat content of 18,800 BTU per pound, find the thermal efficiency of the engine:

85 bhp x 33,000 ÷ 0.833 x 18,800 BTU x 778 = 2,805,000 ÷ 12,183,791

Brake thermal efficiency = 0.23 or 23 percent

Reciprocating engines are only about 34 percent thermally efficient, that is, they transform only about 34 percent of the total heat potential of the burning fuel into mechanical energy. The remainder of the heat is lost through the exhaust gases, the cooling system, and the friction within the engine. Thermal distribution in a reciprocating engine is illustrated in ***Figure 1-12***.

VOLUMETRIC EFFICIENCY

Volumetric efficiency is a ratio expressed in terms of percentages. It is a comparison of the volume of fuel/air charge (corrected for temperature and pressure) inducted into the cylinders to the total piston displacement of the engine. Various factors cause departure from a 100 percent volumetric efficiency. The pistons of a naturally aspirated engine displace the same volume each time they travel from top dead center to bottom dead center of the cylinders. The amount of charge that fills this volume on the intake stroke depends on the existing pressure and temperature of the surrounding atmosphere. Therefore, to find the volumetric efficiency of an engine, standards for atmospheric pressure and temperature had to be established. In the United States, the standard atmosphere used in the U.S. was established in 1958 and provides the necessary pressure and temperature values to calculate volumetric efficiency.

The standard sea level temperature is 59°F, or 15°C. At this temperature, the pressure of one atmosphere is 14.69 lb/in2, and this pressure supports a column of mercury (Hg) 29.92 inches high, or 29.92"Hg. These standard sea level conditions determine a standard density, and if the engine draws in a volume of charge of this density exactly equal to its piston displacement, it is said to be operating at 100 percent volumetric efficiency. An engine drawing in less volume than this has a volumetric efficiency lower than 100 percent. An engine equipped with true supercharging (boost above 30.00"Hg) may have a volumetric efficiency greater than 100 percent. The equation for volumetric efficiency is:

Volumetric Efficiency = Volume of Charge (corrected for temperature and pressure) ÷ Piston Displacement

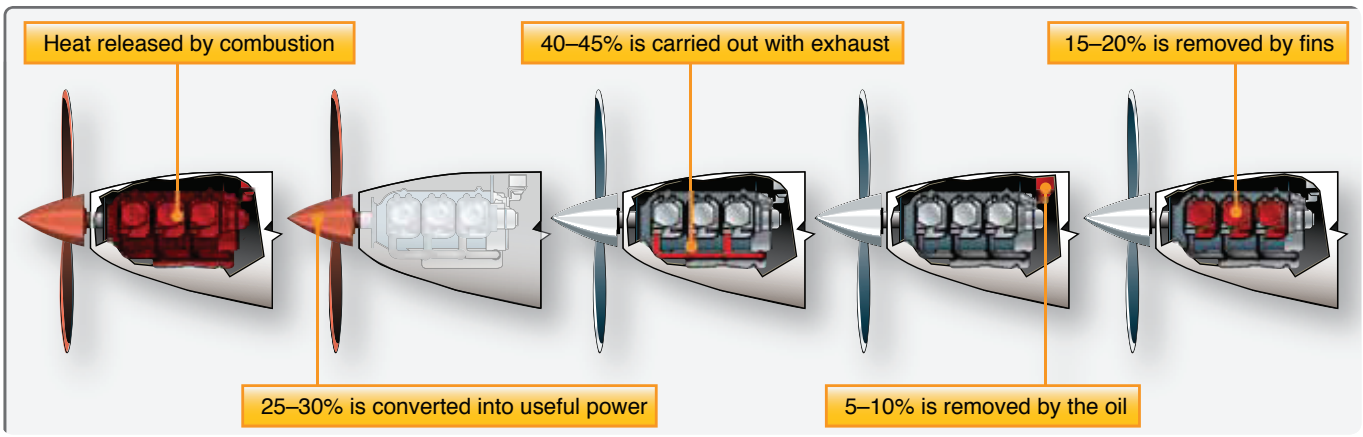


Figure 1-12. Thermal distribution of an aircraft engine.

Many factors decrease volumetric efficiency, including:

- Partial-throttle operation
- Long intake pipes of small diameter
- Sharp bends in the induction system
- Carburetor air temperature too high
- Cylinder-head temperature too high
- Incomplete scavenging
- Improper valve timing

FIRING ORDER

The firing order of an engine is the sequence in which the power event occurs in the different cylinders. The firing order is designed to provide for balance and to eliminate vibration to the greatest extent possible. In radial engines, the firing order must follow a special pattern since the firing impulses must follow the motion of the crank throw during its rotation.

In inline engines, the firing orders may vary somewhat, yet most sequences are arranged so that the firing of cylinders is evenly distributed along the crankshaft. Six-cylinder inline engines generally have a firing order of 1-5-3-6-2-4. Cylinder firing order in opposed engines can usually be listed in pairs of cylinders, as each pair fires across the center main bearing. The firing order of a Lycoming six-cylinder opposed engines is typically 1-4-5-2-3-6. Continental six-cylinder engines normally use a firing order of 1-6-3-2-5-4. The firing order of one model four-cylinder opposed engine is 1-4-2-3, but on another model it is 1-3-2-4.

Regarding cylinder firing order, engine manufacturers do not use the same cylinder numbering system. As an example, Lycomings have their number one cylinder on the right side of the engine closest to the propeller. By contrast, Continental engines have their number one cylinder in the right rear location. Technicians need to be aware of the cylinder numbering system used by different manufacturers.

SINGLE-ROW RADIAL ENGINES

On a single-row radial engine, all the odd-numbered cylinders fire in numerical succession; then, the even numbered cylinders fire in numerical succession. On a five-cylinder radial engine, for example, the firing order is 1-3-5-2-4, and on a seven-cylinder radial engine it is 1-3-5- 7-2-4-6. The firing order of a nine-cylinder radial engine is 1-3-5-7-9-2-4-6-8.

DOUBLE-ROW RADIAL ENGINES

On a double-row radial engine, the firing order is somewhat complicated. The firing order is arranged with the firing impulse occurring in a cylinder in one row and then in a cylinder in the other row; therefore, two cylinders in the same row never fire in succession.

An easy method for computing the firing order of a 14-cylinder, double-row radial engine is to start with any number from 1 to 14, and add 9 or subtract 5 (these are called the firing order numbers), whichever gives an answer between 1 and 14, inclusive. For example, starting with 8, 9 cannot be added since the answer would then be more than 14; therefore, subtract 5 from 8 to get 3, add 9 to 3 to get 12, subtract 5 from 12 to get 7, subtract 5 from 7 to get 2, and so on. The resulting firing order is: 1, 10, 5, 14, 9, 4, 13, 8, 3, 12, 7, 2, 11, and 6.

The firing order numbers of an 18-cylinder, double-row radial engine are 11 and 7; that is, begin with any number from 1 to 18 and add 11 or subtract 7. For example, beginning with 1, add 11 to get 12; 11 cannot be added to 12 because the total would be more than 18, so subtract 7 to get 5, add 11 to 5 to get 16, subtract 7 from 16 to get 9, subtract 7 from 9 to get 2, add 11 to 2 to get 13, and continue this process for 18 cylinders. Using this mathematical technique yields a firing order of: 1, 12, 5, 16, 9, 2, 13, 6, 17, 10, 3, 14, 7, 18, 11, 4, 15, and 8.

Question: 1-1
The four types of engine operating cycles are:
_____,
_____,
_____,
_____.

Question: 1-2
The internal combustion engine functions by converting _____ energy into _____ energy.

Question: 1-3
In a 4 stroke internal combustion engine, in which strokes are both valves closed?

Question: 1-4
In a 4 stroke combustion engine, ignition typically occurs during the _____ stroke, when the piston is located _____ degrees _____ top dead center.

Question: 1-5
On a 2 stroke engine, why are the rings prevented from rotating on the piston?

Question: 1-6
In which two phases on a rotary engine does the housing area increase in volume?

Question: 1-7
What primary function of a 4 stroke gasoline engine does not exist in a diesel engine?

Question: 1-8
What is the total displacement of a 6 cylinder engine in which the cylinder is 5 inches in diameter and the stroke is 4 inches?

ANSWERS

Answer: 1-1
*4 stroke,
*2 stroke,
*Rotary,
*Diesel.
page 1.2

Answer: 1-2
Heat; Mechanical.
page 1.2

Answer: 1-3
Compression stroke and power stroke.
page 1.3

Answer: 1-4
Compression; 20-35°; Before.
page 1.4

Answer: 1-5
The ring's ends could entangle in the intake or exhaust ports.
page 1.5

Answer: 1-6
Intake; Power.
Page 1.5

Answer: 1-7
Spark ignition.
page 1.6

Answer: 1-8
471 cubic inches.
page 1.8

Question: 1-9

With a compression ratio of 7:1 and a manifold pressure of 25"Hg, what is the cylinder pressure just prior to ignition?

Question: 1-10

What is meant by "mechanical efficiency"? What is the formula to determine it.

ANSWERS

Answer: 1-9
175" Hg.
page 1.9

Answer: 1-10
Power delivered to the propeller divided by power developed in the cylinders.
page 1.10



PART-66 SYLLABUS	LEVELS		
CERTIFICATION CATEGORY →	A	B1	B3
	1	2	2

Sub-Module 02
Piston Engine - Engine Performance

16.2 - Engine Performance

Power calculations and measurements; Factors affecting engine power; Mixtures/leaning, pre-ignition.

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

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

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

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

ENGINE PERFORMANCE

RECIPROCATING ENGINE POWER

All aircraft engines are rated according to their ability to do work and produce power. This section presents an explanation of work and power and how they are calculated. Previously discussed were the various efficiencies that govern the power output of a reciprocating engine.

WORK

A physicist defines work as force times distance. Work done by a force acting on a body is equal to the magnitude of the force multiplied by the distance through which the force acts.

Work (W) = Force (F) x Distance (D)

Work is measured by several standards. The most common unit in the U.S. is called foot-pound (ft-lb). If a one-pound mass is raised one foot, one ft-lb of work has been performed. The greater the mass is and/or the greater the distance is, the greater the work performed.

In the metric system, work is frequently expressed in joules. Using the same formula for work, work = force times distance or W = F x d, where the Le Système international d'unités or (SI) defines:

- The unit for force in Newtons (N).
- The unit for distance in meters (m).
- The unit for work in joules (J).

HORSEPOWER

The common unit of mechanical power is the horsepower (hp). Late in the 18th century, James Watt, the inventor of the steam engine, found that an English workhorse could work at the rate of 550 ft-lb per second, or 33,000 ft-lb per minute, for a reasonable length of time. From his observations came the unit of horsepower, which is the standard unit of mechanical power in the English system of measurement. To calculate the hp rating of an engine, divide the power developed in ft-lb per minute by 33,000, or the power in ft-lb per second by 550.

One hp = ft-lb per min ÷ 33,000

or

One hp = ft-lb per sec ÷ 550

As stated above, work is the product of force and distance, and power is work per unit of time. Consequently, if a 33,000-lb weight is lifted through a vertical distance of 1 foot in 1 minute, the power expended is 33,000 ft-lb per minute, or exactly 1 hp.

Work is performed not only when a force is applied for lifting; force may be applied in any direction. If a 100-lb weight is dragged along the ground, a force is still being applied to perform work, although the direction of the resulting motion is approximately horizontal. The amount of this force would depend upon the roughness of the ground. If the weight were attached to a spring scale graduated in pounds, then dragged by pulling on the scale handle, the amount of force required could be measured. Assume that the force required is 90 lb, and the 100-lb weight is dragged 660 feet in 2 minutes. The amount of work performed in the 2 minutes is 59,400 ft-lb or 29,700 ft-lb per minute. Since 1 hp is 33,000 ft-lb per minute, the hp expended in this case is 29,700 divided by 33,000, or 0.9 hp. In units of Watts, one horsepower equals 746 Watts.

FACTORS AFFECTING ENGINE POWER

With the exception of rocket engines, the typical aircraft engine is an “air breather” in that it intakes air from the atmosphere, adds fuels, ignites the fuel/air charge, and extracts power from the heat and expanding gases generated by the combustion process. Consequently, anything that adversely impacts the quality of the atmosphere has an effect on the power output of the power plant. Simply stated, the quality of the power input consumed by the engine affects the magnitude of the power output from the power plant.

NATURE’S VARIABLES TO ENGINE PERFORMANCE

AMBIENT PRESSURE

The ambient pressure of the atmosphere varies from day-to-day. Where slight changes in barometric pressure may have little, to no, impact on the performance of an aircraft, significant increases in altitude generate notable

reduction in engine performance. As an example. a naturally-aspirated piston-powered aircraft takes off from an airport that has a field elevation near sea level. The plane continues to climb during the course of the flight. The rate of climb will be excellent as the plane lifts from the surface and gains altitude. As the aircraft passes through 5,000 feet (1,500m), 8,500 feet (2,600m), 10,000 feet (3,000m), 15,000 feet (4,600m), and so on, the rate of climb will drop to a low value, if the plane is even capable of reaching such altitudes. If the engine is not equipped with some form of supercharging, it is likely that it will encounter great difficulty ascending to 15,000 feet (4,600m). The airplane has a "service ceiling" which dictates the highest altitude the aircraft is capable of achieving. Often aircraft will be incapable of achieving its service ceiling for a variety of reasons.

In the previous example, the main issue associated with the reduction of the aircraft's ability to continue to climb in an aggressive fashion is the reduction of barometric pressure provided by Nature as the aircraft ascends. In other words, the air becomes rarified, or thinner, as we gain altitude. This means that the atmosphere contains less molecules of oxygen per unit volume. So when the cylinder experiences an intake stroke, less oxygen is ingested by the cylinder at high altitude than when the engine is operating near sea level. The net result is a reduction of horsepower developed by the power plant.

For example, in a zero wind condition a single engine aircraft TAKE-OFF DISTANCE chart reveals a ground run of 735 feet (224m) at sea level and 1,385 feet (422m) to clear a fifty-foot obstacle. The same aircraft requires a ground run of 910 feet (277m) at 2,500 feet (762m) altitude and 1,660 feet (505m) to clear a fifty-foot (15m) obstacle. At 5,000 feet (1,524m) altitude, the ground run is 1,115 feet (340m) and 1,985 feet (605m) are required to clear a fifty-foot (15m) obstacle. And at 7,500 feet (2,286m) altitude, the take-off ground run is 1,360 feet (415m) with 2,440 feet (744m) needed to clear the fifty-foot (15m) obstacle. (From: Cessna Model 150 Owner's Manual, 1967, page 5-3.)

TEMPERATURE

Temperature plays an important role in the performance of an aircraft. Most flight manuals contain a section on aircraft performance. Generally included in this section are performance charts revealing how much runway is needed for takeoffs, climbs, and landings. A key variable involved in determining aircraft performance for any given day is temperature.

As an example, a single-engine aircraft indicates that the pilot should increase distances shown on the TAKE-OFF DISTANCE chart by 10% for each 35˚F above standard temperature for the listed altitudes. Likewise the rate of climb performance chart shows a reduction in the rate of climb with increases in altitude. The rate of climb for the aircraft is further reduced by 15 feet (4.6m) per minute for each 10˚F above the standard temperature for the altitude listed. (From: Cessna Model 150 Owner's Manual, 1967, page 5-3.)

Both aircraft performance and power plant output are affected by temperature. In terms of aircraft performance, the lift generated by the wings is proportional to the density of the air. On hot, humid days, the takeoff roll is notably longer than on cold, dry days. The same parallel is true concerning the output of the power plant.

The issue concerning aircraft and engine performance and ambient temperature is associated with Charles' Law. This law states that when pressure remains constant, the volume occupied by a gas is proportional to its absolute temperature. This relationship is presented in the following formula: $V_1 \div V_2 = T_1 \div T_2$. To demonstrate the association between changes in temperature and the volume occupied by a gas, calculate the following problem. A volume of gas occupies 500 cubic inches at 0˚C. For a given pressure, how much increase in volume will this gas have at 50˚C? To figure this problem first solve for V_2. Plugging in the appropriate values, 500 cubic inches $\div$ V_2 = 273˚ Kelvin $\div$ 323˚ Kelvin. Because the formula is in absolute temperature, 273˚ are added to the Centigrade values. Solving this formula produces a value of approximately 591.58 cubic inches. The second step is to subtract 500 cubic inches from 591.58. Remember the problem asked for how much increase in volume is generated by the increase in temperature from 0°C to 50˚C. To determine this, V_1 is subtracted from V_2.

Where Charles' Law offers a means for calculating the relationship between the volume of a gas and absolute temperature, a practical explanation is in order. As the temperature of a gas increases, the atoms move further apart from one another. Charles' Law demonstrates this phenomenon. This basically means that, for any given pressure, the number of oxygen molecules (O_2)

per volume becomes less as the temperature of the air increases. Now consider the piston engine. Piston engines are, in reality, positive displacement pumps. The volume ingested by the engine is constant based on the number of cycles over a given period. In other words, a piston engine displaces the same volume of air at 2,000 rpm whether it is operating on the ground or at 8,500 feet (2,600 m). Do not confuse volume and mass. Volume refers to a certain area while mass is in reference to weight or number of particles. When air expands due to an increase in temperature, the number of oxygen molecules entering the combustion chambers goes down for any given rpm. This reduces the power input entering the combustion chambers and, as a consequence, reduces the power output of the engine. Therefore, as temperature goes up, engine performance goes down.

To further complicate the issue, the mixture consumed by the engine enriches as the temperature increases. This too works to reduce engine performance. Additional information concerning changes to mixtures based on temperature is presented in a subsequent chapter.

HUMIDITY

Another meteorological variable that affects the quality of the air is humidity. When the temperature and humidity are high, humans become uncomfortable. This is because the perspiration produced by the body does not readily evaporate into the atmosphere. The reason perspiration is unable to freely evaporate is because the atmosphere already contains a high level of water vapor, or is highly saturated. When the air is dry it is able to accept more water vapor. But when the air is thoroughly saturated, it is unable to absorb much more additional water vapor. This characteristic may be compared to a towel. When a towel is dry, it is able to absorb a considerable amount of moisture. When a towel is saturated, it is unable to absorb additional water.

When the humidity level is high, the performance of the power plant and airfoils are adversely affected. In the case of the former, there is less oxygen per unit volume of air because of the space in the atmosphere occupied by the water vapor. As a result, each intake stroke pulls in less oxygen and alters the combustion of the fuel/air charge. As far as the wings are concerned, when trying to takeoff when the humidity is high, lift is adversely affected because the air is not as heavy, again due to the atmosphere. Consequently, it has less capacity to support the weight of the aircraft. To compensate for humidity, an additional measure of airspeed is needed. This serves to add to the length of runway required for takeoff.

MECHANICAL ISSUES AFFECTING ENGINE PERFORMANCE

IGNITION PROBLEMS

The previous examples discussed how Nature impacts the output of a reciprocating power plant. Those are not the only variables that affect power plant performance. A myriad of power plant issues may also adversely alter performance.

One element that has an adverse affect on engine performance is poor ignition. The ignition system of a typical reciprocating aircraft power plant is supplied using two magnetos. These devices are free of the aircraft's electrical system save for the booster devices (e.g., Bendix Shower of Sparks) used during the starting of the engine. As such, the magneto generates its own electrical power used for the creation of the spark during the ignition event. The spark plugs need thousands of volts to generate a hot spark that bridges the electrodes. Any defect that reduces the magnitude of the spark may result in a reduction of engine power.

INTERNAL MAGNETO TIMING

Defects that may reduce the intensity of the spark during the ignition event include internal timing of the magneto. As the magnet rotors revolves within the magneto housing, lines of flux travel through the pole shoes and iron cores that transmit the flux lines to the primary windings of the coil. To attain a hot spark, the contact breakers, also known as points, must remain closed for a certain amount of magnet shaft rotation and must open at a certain magnet shaft position to produce a hot spark. This is commonly referred to as e-gap timing. When the e-gap timing is incorrect, the spark quality is reduced and the combustion process is adversely affected.

MAGNETO-TO-ENGINE TIMING

Where incorrect e-gap timing reduces the intensity of the spark delivered to the spark plugs, when the spark occurs during the compression stroke also impacts the performance of the engine.

If the engine timing is too late, a condition referred to as retarded timing, the portion of the potential of the fuel/air charge is lost to an increase in waste out the exhaust

pipe. A retarded spark results in a fuel/air charge that continues to burn after the piston reaches and passes top dead center compression (TDCC). Consequently, the heat energy created by the combustion process is not fully transferred to the piston. An additional measure of heat escapes through the exhaust system. The exhaust gas temperature (EGT) increases as a result. The greater the degree of ignition retardation, the greater the loss of engine power experienced by the power plant.

By contrast, when the ignition timing occurs sooner than specified, the engine timing is advanced. In extreme cases of advancement, engine failure may result. When the spark occurs too soon as the piston travels up the compression stroke, the piston absorbs more heat than intended. This may result in detonation of the fuel/air charge. Advanced timing reduces EGT and causes a loss of engine power.

OTHER IGNITION PROBLEMS

Beyond the issues concerning magneto-to-engine timing and magneto internal timing, other ignition problems will affect engine performance. One problem frequently occurring to aircraft ignition systems is the fouling of spark plugs. Spark plug fouling may be the result of a variety of issues. A common form of spark fouling is lead fouling. Most often lead fouling occurs with the lower spark plugs. Once the ceramic nose area of the spark plug fills with lead deposits, the plug will not generate a spark across its electrodes. Rather, the high-tension voltage delivered to the spark plug will travel along the lead deposit instead of the spark plug gap. Such conditions are detected during the ignition system check conducted by the pilot prior to takeoff. As the fouled spark plug does not provide a spark to the fuel/air charge, engine roughness will be present when the operator selects the magneto associated with the fouled spark plug.

Other ignition system problems that affects engine performance includes faults in the secondary system. Starting with the ignition coil, problems with the carbon brush, distributor rotor, and ignition harness generally produce ignition system roughness as the affected cylinders misfire.

FUEL METERING ISSUES

A critical component for generating the designed performance from an aircraft power plant is the fuel metering system. Whether carbureted or fuel injected, the fuel metering device mixes fuel and air at the level determined by the throttle position commanded by the operator. If the proportion of fuel and air is incorrect, the power output of the engine will be affected. Beyond the proper ratio of fuel and air, the fuel must be thoroughly atomized in order to fully mix with the air before combustion.

A host of problems with fuel metering devices may cause a loss of engine performance. In float carburetors, defects with the needle valve and seat will affect fuel level in the float bowl. Likewise a leaky float will cause the fuel/air mixture to become enriched. Problems with the discharge nozzle and/or venturi will generate issues with the fuel metering process. And defects with the acceleration system will cause notable performance issues.

With continuous flow fuel injection system, dirty fuel injection nozzles often produce engine roughness. Incorrect levels of unmetered fuel pressure will cause the Continental Fuel Injection System to deliver imprecise fuel/air mixtures to the cylinders. Adjustment of the Continental Fuel Injection System contains numerous steps and improper adjustments will affect engine performance. Bendix Fuel Injection systems may develop faults within the regulator that will alter the fuel metering process.

Unlike the relatively simple float carburetor, pressure carburetors have numerous complex components that may cause fuel metering problems. The regulator, fuel control unit, mixture control, acceleration system, and discharge network are areas that may develop problems within the pressure carburetor. Beyond possible faults with the system, pressure carburetors have somewhat complex adjustments that may present problems in terms of operation.

Problems with the fuel/air mixture delivered to the engine may exist in the delivery system. A common fault found on the reciprocating aircraft engine is the induction leak. The gasket and seals used on the typical piston engine are prone to leak over time. Such leaks alter the fuel/air mixture consumed by the engine and will result in a loss of engine power. Technicians need to closely inspect the induction system to spot and correct induction leaks.

Another issue with the induction system that will result in poor engine performance is the ingestion of heat intake air. When the carburetor heat control fails to reach the FULL COLD position, the air entering the induction system will be heated. The net outcome of consuming heated induction air will be an enrichment of the fuel/air mixture and a reduction in engine performance. This is evident during the PRE-TAKEOFF CHECKLIST when the pilot actuates the carburetor heat control. The engine loses rpm during this check as a result of the heated air.

Technicians should consider improper control rigging as a source of engine power loss. Beyond the rigging of the carburetor heat control as previously discussed, lack of full throttle travel will result in loss of engine power. Likewise, if the engine is equipped with a controllable pitch propeller and it lacks full travel in the high rpm or low pitch position, the engine will fail to generate full takeoff rpm.

EXHAUST SYSTEM

Similar to the leaks that occur in the induction system, reciprocating aircraft power plants will frequently develop leaks in the exhaust system. In particular the gaskets used at the exhaust ports are prone to leaks after they have been in service for a period of time.

Exhaust system leaks may impact the flow of exhaust departing the exhaust port and may adversely affect the flow of fuel and air into the combustion chamber. Exhaust leaks associated with the carburetor heat system will cause a large loss of engine rpm during the application of carburetor heat as the engine ingests exhaust fumes during the intake process. Exhaust leaks also present the possibility of allowing carbon monoxide to enter the interior of the aircraft when the cabin heater and/or defroster is turned on. Carbon monoxide (CO) poisoning may generate severe health issues for the crew and passengers aboard the aircraft. Death may result from exposure to carbon monoxide. Maintenance technicians must closely inspect and repair the exhaust system to prevent such exposure. Many airplanes are equipped with CO detectors to help identify CO entry into the cabin.

COMPRESSION

Reciprocating aircraft power plants depend on cylinder compression to properly extract the heat energy present in the fuel/air charge. If cylinder compression is diminished, engine power is reduced. There are several reasons why cylinders loose compression.

As the engine accrues hours of service, the piston rings and cylinder wall surfaces develop areas of leaks. The rate of wear should be small enough throughout the specified time-between-overhaul (TBO) to allow the engine to produce rated power. However, the wear rate may be excessive for a variety of reasons rendering the engine no longer capable of delivering rated power.

The intake and exhaust valves may become leaky before the TBO life of the engine has been reached. Such leaks may be detrimental to the operation of the power plant as valve failure may cause the engine to quit during flight.

Leaky valves may be discovered during the compression test procedure. When using the differential compression test, an audible leak of air escaping past the intake valve will be heard coming from the intake system. Likewise, air leaking past the exhaust valve will be detected coming from the associated exhaust pipe. A borescopic inspection is useful is locating leaky valves. Heated exhaust gases passing through the leak will burn the carbon off the valve and provide a discoloration to the valve at the location of the leak.

Improperly adjusted valve clearances will adversely affect power production. As many aircraft power plants use zero-lash lifters, a leaky lifter will be unable to hold the proper valve lash, reducing the height and duration of the valve opening. The “bled-down” or “dry lifter” clearance may be measured to determine whether the zero-lash lifter is using the proper length push rod. Push rods are available in different lengths to ensure the engine has the proper bled-down clearance.

MIXTURES

The basic requirement of a reciprocating fuel metering system is the same, regardless of the type of system used or the model engine on which the equipment is installed. It must meter fuel proportionately to air to establish the proper fuel/air mixture ratio for the engine at all speeds and altitudes at which the engine may be operated. In the fuel/air mixture curves shown in ***Figure 2-1***, note that the basic best power and best economy fuel/air mixture requirements for reciprocating engines are approximately the same. The fuel metering

system must atomize and distribute the fuel from the carburetor into the mass airflow. This must be accomplished so that the fuel/air charges going to all cylinders hold equal amounts of fuel. Each one of the engine's cylinders should receive the same quantity of fuel/air mixture and at the same fuel/air ratio.

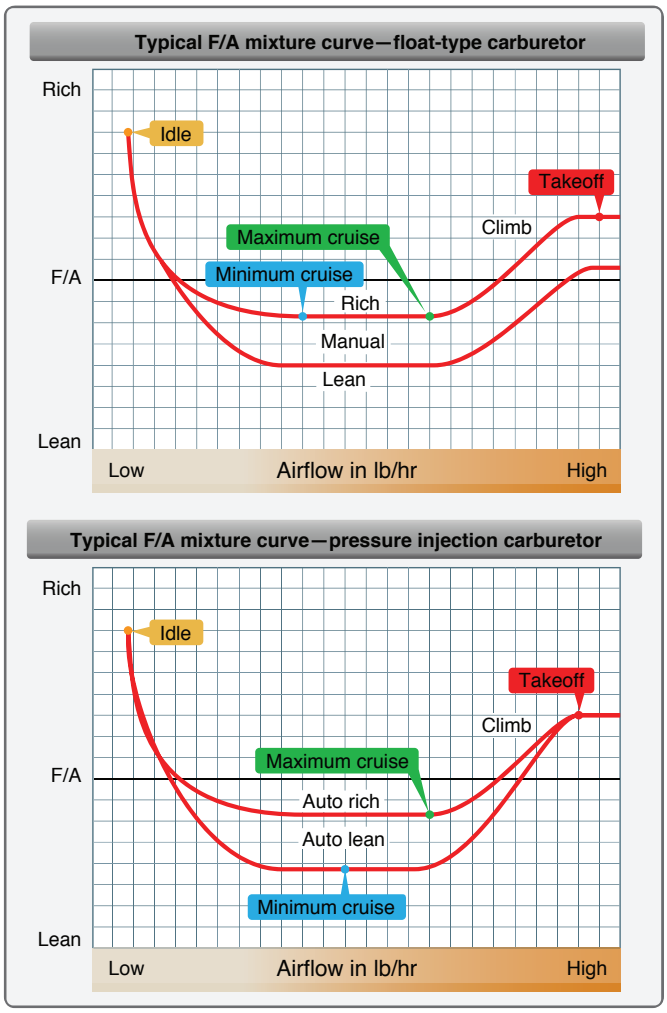


Figure 2-1. Fuel/air mixture curves.

Due to the drop in atmospheric pressure as altitude is increased, the density of the air also decreases. A naturally-aspirated engine has a fixed amount or volume of air that it can draw in during the intake stroke, therefore less air, by weight, is drawn into the engine as altitude increases. Less air tends to make carburetors run richer at altitude than at ground level, because of the decreased density of the airflow through the carburetor throat for a given volume of air. Thus, it is necessary that a mixture control be provided to lean the mixture and compensate for this natural enrichment. Some aircraft use carburetors in which the mixture control is operated manually. Other aircraft employ carburetors that automatically lean the carburetor mixture at altitude to maintain the proper fuel/air mixture.

FUEL/AIR MIXTURES

Gasoline and other liquid fuels do not burn at all unless they are mixed with air. If the mixture is to burn properly within the engine cylinder, the ratio of air to fuel must be kept within a certain range. It would be more accurate to state that the fuel is burned with the oxygen in the air. Seventy-eight percent of air by volume is nitrogen, which is inert and does not participate in the combustion process, and 21 percent is oxygen. Heat is generated by burning the mixture of gasoline and oxygen. Nitrogen and gaseous byproducts of combustion absorb this heat energy and turn it into power by expansion. The mixture proportion of fuel and air by weight is of extreme importance to engine performance. The characteristics of a given mixture can be measured in terms of flame speed and combustion temperature.

The composition of the fuel/air mixture is described by the mixture ratio. For example, a mixture with a ratio of 12 to 1 (12:1) is made up of 12 pounds of air and 1 pound of fuel. In aviation the fuel/air ratio is expressed in weight because the volume of air varies greatly with temperature and pressure. Changes in aircraft altitude affect both pressure and temperature. The mixture ratio can also be expressed as a decimal. Thus, a fuel/air ratio of 12:1 and a fuel/air ratio of 0.083 describe the same mixture ratio. To convert ratio mixture values into decimal forms, divide 1 by the number of parts of air. For example, if the mixture is 12:1, divide 1 by 12. This produces a value of 0.0833. To convert a decimal mixture value into a ratio, divide 1 by the decimal value. Using 0.0833 as an example, 1 divided by 0.0833 equals 12.

Mixtures of air and gasoline as rich as 8:1 and as lean as 16:1 will burn in an engine cylinder, but beyond these mixtures, either lean or rich may cause the engine to quit running. The engine develops maximum power with a mixture of approximately 12 parts of air and 1 part of gasoline by weight.

From a chemist's point of view, the perfect mixture for combustion of fuel and air would be 0.067 pounds of fuel to 1 pound of air (mixture ratio of 15:1). Scientists

call this chemically correct combination a stoichiometric mixture (pronounced stoy-key-o-metric). With this mixture (given sufficient time and turbulence), all the fuel and all the oxygen in the air are completely used in the combustion process. The stoichiometric mixture produces the highest combustion temperatures because the proportion of heat released to a mass of charge (fuel and air) is the greatest. If more fuel is added to the same quantity of air charge than the amount giving a chemically perfect mixture, changes of power and temperature occur. The combustion gas temperature is lowered as the mixture is enriched, and the power increases until the fuel/air ratio is approximately 0.0725. For mixtures from 0.0725 fuel/air ratio to 0.080 fuel/air ratio, the power remains essentially constant even though the combustion temperature continues downward. Mixtures from 0.0725 fuel/air ratio to 0.080 fuel/air ratio are called best power mixtures, since their use results in the greatest power for a given airflow or manifold pressure. In this fuel/air ratio range, there is no increase in the total heat released, but the weight of nitrogen and combustion products is augmented by the vapor formed with the excess fuel. Thus, the working mass of the charge is increased. In addition, the extra fuel in the charge (over the stoichiometric mixture) speeds up the combustion process, which provides a favorable time factor in converting fuel energy into power.

If the fuel/air ratio is enriched above 0.080, there is loss of power and a reduction in temperature. The cooling effects of excess fuel overtake the favorable factor of increased mass. This reduced temperature and slower rate of burning lead to an increasing loss of combustion efficiency. If, with constant airflow, the mixture is leaned below 0.067, fuel/air ratio power and temperature decrease together. This time, the loss of power is not a liability but an asset. The purpose in leaning is to save fuel. Air is free and available in limitless quantities. The object is to obtain the required power with the least fuel flow. A measure of the economical use of fuel is called specific fuel consumption (SFC), which is the fuel weight in pounds per hour per horsepower.

SFC = Pounds of Fuel/Hour ÷ Horsepower

By using this ratio, the engine's use of fuel at various power settings can be compared. When leaning below 0.067 fuel/air ratio with constant airflow, even though the power diminishes, the cost in fuel to support each horsepower hour (SFC) also is lowered. While the mixture charge is becoming weaker, this loss of strength occurs at a rate lower than that of the reduction of fuel flow. This favorable tendency continues until a mixture strength known as best economy is reached. With this fuel/air ratio, the required hp is developed with the least fuel flow or, to put it another way, the greatest power produced by a given fuel flow. The best economy fuel/air ratio varies somewhat with rpm and other conditions, but for cruise powers on most reciprocating engines, it is sufficiently accurate to define this range of operation as being from 0.060 to 0.065 fuel/air ratios on aircraft where manual leaning is practiced.

Below the best economical mixture strength, power and temperature continue to fall with constant airflow while the SFC increases. As the fuel/air ratio is reduced further, combustion becomes so cool and slow that power for a given manifold pressure gets so low as to be uneconomical. The cooling effect of rich or lean mixtures results from the excess fuel or air over that needed for combustion. Internal cylinder cooling is obtained from unused fuel when fuel/air ratios above 0.067 are used. The same function is performed by excess air when fuel/air ratios below 0.067 are used.

Varying the mixture strength of the charge produces changes in the engine operating condition affecting power, temperature, and spark-timing requirements. The best power fuel/air ratio is desirable when the greatest power from a given airflow is required. The best economy mixture results from obtaining the given power output with the least fuel flow. The fuel/air ratio that gives most efficient operation varies with engine speed and power output.

In the graph showing this variation in fuel/air ratio, note that the mixture is rich at both idling and high-power operations and is lean in the cruising range. See ***Figure 2-2***. At idling speed, some air or exhaust gas is drawn into the cylinder through the exhaust port during valve overlap. The mixture that enters the cylinder through the intake port must be rich enough to compensate for this gas or additional air. At cruising power, lean mixtures save fuel and increase the range of the airplane. An engine running near full power requires a rich mixture to prevent overheating and detonation. Since the engine is operated at full power for only short periods, the high fuel consumption is not

a serious matter. If an engine is operating on a mixture that is too lean, and adjustments are made to increase the amount of fuel, the power output of the engine increases rapidly at first, then gradually until maximum power is reached. With a further increase in the amount of fuel, the power output drops gradually at first, then more rapidly as the mixture is further enriched.

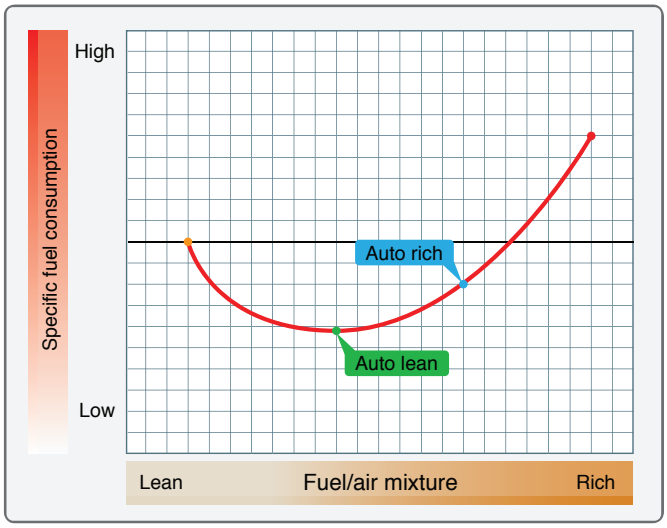


Figure 2-2. Specific fuel consumption.

There are specific instructions concerning mixture ratios for each type of engine under various operating conditions. Failure to follow these instructions results in poor performance and often in damage to the engine. Excessively rich mixtures result in loss of power and waste of fuel. With the engine operating near its maximum output, very lean mixtures cause a loss of power and, under certain conditions, serious overheating. When the engine is operated on a lean mixture, the cylinder head temperature gauge should be watched closely. If the mixture is excessively lean, the engine may backfire through the induction system or stop completely. Backfire results from slow burning of the lean mixture. If the charge is still burning when the intake valve opens, it ignites the fresh mixture and the flame travels back through the combustible mixture in the induction system.

DETONATION

Two combustion anomalies that significantly affect power output are detonation and pre-ignition. If allowed to continue over a protracted period, internal damage to the power plant may take place. Detonation occurs when the cylinder experiences an uncontrolled burning of the fuel/air charge upon ignition. Generally speaking, detonation occurs when the fuel/air charge encounters a temperature and pressure that exceeds the safe limit of the fuel. As an example, using a low octane fuel in an engine that requires high octane gasoline will result in detonation.

PRE-IGNITION

The fuel/air charge experiences pre-ignition when it ignites before the normal ignition event occurs. Several faults may produce pre-ignition. If water enters the distributor of the magneto, the spark intended to reach a particular spark plug may jump to another plug. If the high tension portion of the magneto experiences a condition known as carbon tracking, the spark may follow the carbon track and reach the incorrect spark plug. Evidence of carbon tracking is provided by visible thin lines inside the distributor cap. They are similar in appearance to pencil lines. Pre-ignition also takes place when something in the cylinder becomes incandescent. For example, a valve develops a leak whereby exhaust gases flow past the leak. This will cause the valve to overheat. When the edge of the valve becomes incandescent, the fuel/air charge will ignite during the compression stroke before the sparking of the spark plug.

Question: 2-1
What is the formula for work in metric terms?

Question: 2-2
As altitude increases, a reciprocating engine's power output_____.
As outside air temperature increases, a reciprocating engines power output _____.

Question: 2-3
Why does an increases in outside air temperature or atmospheric humidity decrease power output?

Question: 2-4
What concept explains why a certain volume of air may have changing mass based on temperature?

Question: 2-5
Incorrect e-gap timing reduces the _____ of the spark.
a. intensity
b. duration
c. temperature

Question: 2-6
If spark timing occurs too soon before the piston reaches top dead center, exhaust gas temperature will:
a. increase
b. decrease
c. not be effected

Question: 2-7
How will a leaky float in a carburetor effect exhaust gas temperature?

Question: 2-8
Why does the application of carburetor heat reduce RPM?

ANSWERS

Answer: 2-1
Work = Force x distance:
Joules = Newtons x Meters.
page 2.2

Answer: 2-2
Decreases; Decreases.
page 2.3

Answer: 2-3
Warm air is less dense than cold air.
Humid air is less dense than dry air.
page 2.3

Answer: 2-4
Charles' Law.
page 2.4

Answer: 2-5
a – intensity.
page 2.5

Answer: 2-6
b – decrease.
page 2.5

Answer: 2-7
Too much fuel will enter the mixture and therefore EGT will be reduced.
page 2.5

Answer: 2-8
Warmer air entering the mixture is less dense, mixture becomes rich, power output decreases.
page 2.6

Question: 2-9

What common test is good indicator of leaky valves?

Question: 2-10

What is the optimum mixture ratio in which burning fuel will produce the maximum amount of power?

ANSWERS

Answer: 2-9
Differential compression test.
page 2.6

Answer: 2-10
12 parts of air: 1 part of gasoline.
page 2.7



PART-66 SYLLABUS	LEVELS		
CERTIFICATION CATEGORY →	A	B1	B3
	1	2	2

Sub-Module 03
Piston Engine - Engine Construction

16.3 - Engine Construction

Crankcase, crankshaft, cam shafts, sumps; accessory gearbox; cylinder and piston assemblies; connecting rods, inlet and exhaust manifolds; valve mechanisms; propeller reduction gearboxes

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

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

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

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

PISTON ENGINE-ENGINE CONSTRUCTION

The basic major components of a reciprocating engine are the crankcase, cylinders, pistons, connecting rods, valves, valve-operating mechanism, and crankshaft. In the head of each cylinder are the valves and spark plugs. One of the valves is in a passage leading from the induction system; the other is in a passage leading to the exhaust system. Inside each cylinder is a movable piston connected to a crankshaft by a connecting rod. ***Figure 3-1*** illustrates the basic parts of a reciprocating engine.

CRANKCASE SECTIONS

The foundation of an engine is the crankcase. It contains the bearings and bearing supports in which the crankshaft revolves. Besides supporting itself, the crankcase must provide a tight enclosure for the lubricating oil and must support various external and internal mechanisms of the engine. It also provides support for attachment of the cylinder assemblies, and the power plant to the aircraft. It must be sufficiently rigid and strong to prevent misalignment of the crankshaft and its bearings. Cast or forged aluminum alloy is generally used for crankcase construction because it is light and strong. The crankcase is subjected to many variations of mechanical loads and other forces. Since the cylinders are fastened to the crankcase, the tremendous forces placed on the cylinder tend to pull the cylinder off the crankcase. The unbalanced centrifugal and inertia forces of the crankshaft acting through the main bearings subject the crankcase to bending moments which change continuously in direction and magnitude. The crankcase must have sufficient stiffness to withstand these bending moments without major deflections. See the crankcase half presented in ***Figure 3-2***.

If the engine is equipped with a propeller reduction gear, the front or drive end is subjected to additional forces. In addition to the thrust forces developed by the propeller under high power output, there are severe centrifugal and gyroscopic forces applied to the crankcase due to sudden changes in the direction of flight, such as those

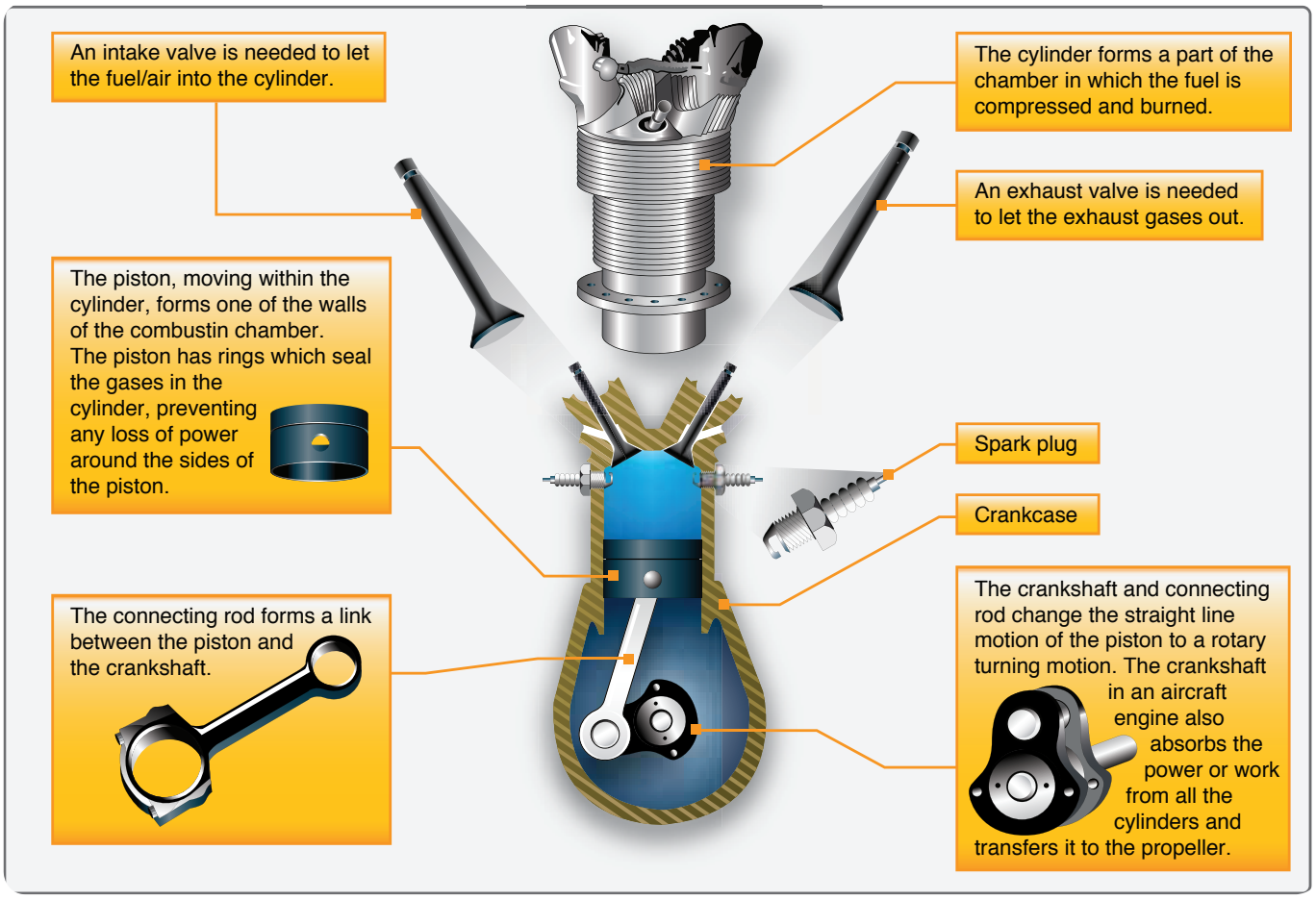


Figure 3-1. Basic parts of a piston engine.

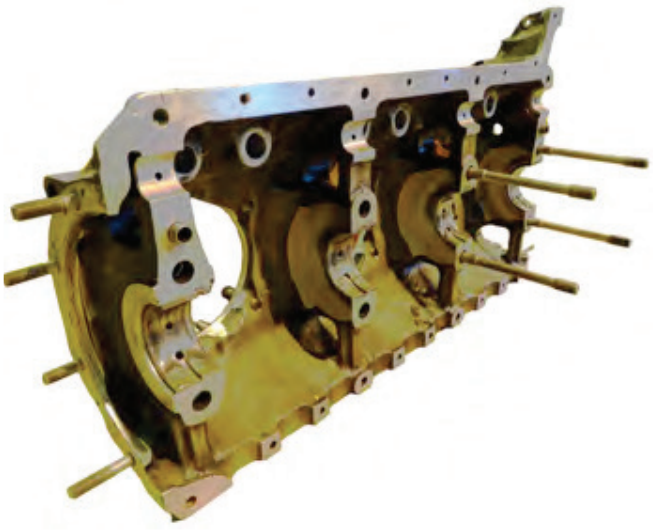


Figure 3-2. Interior of crankcase half. Note: crankshaft webs and bearings, camshaft bearings through studs, and lifter body wells.

occurring during maneuvers of the airplane. Gyroscopic forces are particularly severe when a heavy propeller is installed. To absorb centrifugal loads, a large centrifugal bearing is used in the nose section.

The shape of the nose or front of the crankcase section varies considerably. In general, it is either tapered or round. Depending upon the type of reciprocating engine, the nose or front area of the crankcase varies somewhat. If the propeller is driven directly by the crankshaft, less area is needed for this component of the engine. The crankcases used on engines having opposed or inline cylinder arrangements vary in form for the different types of engines, but in general they are approximately cylindrical. One or more sides are surfaced to serve as a base to which the cylinders are attached by means of cap screws, bolts, or studs. These accurately machined surfaces are frequently referred to as cylinder pads. If the propeller is driven by reduction gearing (gears that slow down the speed of the propeller less than the engine rpm), more area is required to house the reduction gears. A tapered nose section is used quite frequently on direct-drive, low-powered engines, because extra space is not required to house the propeller reduction gears. Crankcase nose sections are usually cast of either aluminum alloy or magnesium. The crankcase nose section on engines that develop from 1,000 to 2,500 hp is usually larger to house reduction gears and sometimes ribbed to get as much strength as possible.

The governor is used to control propeller speed and blade angle. The mounting of the propeller governor varies. On some engines, it is located on the rear section, although this complicates the installation, especially if the propeller is operated or controlled by oil pressure, because of the distance between the governor and propeller. Where hydraulically operated propellers are used, it is good practice to mount the governor on the nose section as close to the propeller as possible to reduce the length of the oil passages. The governor is then driven either from gear teeth on the periphery of the bell gear or by some other suitable means. This basic arrangement is also used for turboprops.

On some of the larger radial engines, a small chamber is located on the bottom of the nose section to collect the oil. This is called the nose section oil sump. Since the nose section transmits many varied forces to the main crankcase or power section, it must be secured properly to transmit the loads efficiently.

The machined surfaces on which the cylinders are mounted are called cylinder pads or cylinder mounting pads. They are provided with a suitable means of retaining or fastening the cylinders to the crankcase. The general practice in securing the cylinder flange to the pad is to mount studs in threaded holes in the crankcase. Often on opposed engines, through studs are also used in conjunction with the cylinder studs. Through studs normally secure a couple of flange holes on one cylinder, pass through the crankcase, and secures two flange holes on a cylinder on the opposite side of the crankcase. The inner portion of the cylinder pads are sometimes chamfered or tapered to permit the installation of a large rubber O-ring around the cylinder skirt, which effectively seals the joint between the cylinder and the crankcase pads against oil leakage.

Because oil is thrown about the crankcase, especially on inverted inline and radial-type engines, the cylinder skirts extend a considerable distance into the crankcase sections to reduce the flow of oil into the inverted cylinders. The piston and ring assemblies must be arranged so that they throw out the oil splashed directly into them.

Mounting lugs are spaced about the periphery of the rear of the crankcase or the diffuser section of a radial engine. These are used to attach the engine assembly to

the engine mount or framework provided for attaching the power plant to the fuselage of single-engine aircraft or to the wing nacelle structure of multi-engine aircraft. The mounting lugs may be either integral with the crankcase or diffuser section or detachable, as in the case of flexible or dynamic engine mounts.

The mounting arrangement supports the entire power plant including the propeller, and therefore is designed to provide ample strength for rapid maneuvers or other loadings. Because of the elongation and contraction of the cylinders, the intake pipes which carry the mixture from the diffuser chamber through the intake valve ports are arranged to provide a slip joint which must be leak proof. The atmospheric pressure on the outside of the induction system of an un-supercharged engine is higher than on the inside, especially when the engine is operating at idling speed. If the engine is equipped with a supercharger and operated at full throttle, the pressure is considerably higher on the inside than on the outside of the induction system. If the slip joint connection has a slight leakage, the engine may idle fast due to a slight leaning of the mixture. If the leak is quite large, it may not idle at all. At open throttle, a small leak probably would not be noticeable in the operation of the engine, but the slight leaning of the fuel/air mixture might cause detonation or damage to the valves and valve seats. On some radial engines, the intake pipe has considerable length and on some inline engines, the intake pipe is at right angles to the cylinders. In these cases, flexibility of the intake pipe or its arrangement eliminates the need for a slip joint. In any case, the engine induction system must be arranged so that it does not leak air and change the desired fuel/air ratio.

CRANKSHAFTS

The crankshaft is carried in a position parallel to the longitudinal axis of the crankcase and is generally supported by a main bearing between each throw. The crankshaft main bearings must be supported rigidly in the crankcase. This usually is accomplished by means of transverse webs in the crankcase, one for each main bearing. The webs form an integral part of the structure and, in addition to supporting the main bearings, add to the strength of the entire case. The crankcase is divided into two sections along a longitudinal plane. This division may be in the plane of the crankshaft so that one-half of the main bearing (and sometimes camshaft bearings) are carried in one section of the case and the other half in the opposite section. Refer to ***Figure 3-3***. Another method is to divide the case in such a manner that the main bearings are secured to only one section of the case on which the cylinders are attached, thereby providing means of removing a section of the crankcase for inspection without disturbing the bearing adjustment.

The crankshaft is the backbone of the reciprocating engine. It is subjected to most of the forces developed by the engine. Its main purpose is to transform the reciprocating motion of the piston and connecting rod into rotary motion for rotation of the propeller or helicopter transmission. The crankshaft, as the name implies, is a shaft composed of one or more cranks located at specified points along its length. The cranks, or throws, are formed by forging offsets into a shaft before it is machined. Since crankshafts must be very strong, they generally are forged from a very strong alloy, such as chromium-nickel-molybdenum steel.

A crankshaft may be of single-piece or multi-piece construction. ***Figure 3-4*** shows two representative types of solid crankshafts used in aircraft engines. The four-throw construction may be used either on four-cylinder horizontal opposed or four-cylinder inline engines. The six-throw shaft is used on six-cylinder inline engines, 12- cylinder V-type engines, and six-cylinder opposed engines. Crankshafts of radial engines may be the single-throw, two-throw, or four-throw type, depending on whether the engine is the single-row, twin-row, or four-row type. A single-throw radial engine crankshaft is shown in ***Figure 3-5***. No matter how many throws it may have, each crankshaft has three main parts—a journal, crankpin, and crank cheek. Counterweights and dampers, although not a true part of a crankshaft, are usually attached to it to reduce engine vibration.

The journal is supported by, and rotates in, a main bearing. It serves as the center of rotation of the crankshaft. It is surface-hardened to reduce wear. The crankpin is the section to which the connecting rod is attached. It is off-center from the main journals and is often called the throw. Two crank cheeks and a crankpin make a throw. When a force is applied to the crankpin in any direction other than parallel or perpendicular to and through the center line of the crankshaft, it causes the crankshaft to rotate. The outer surface is hardened by nitriding to increase its resistance to wear and to provide

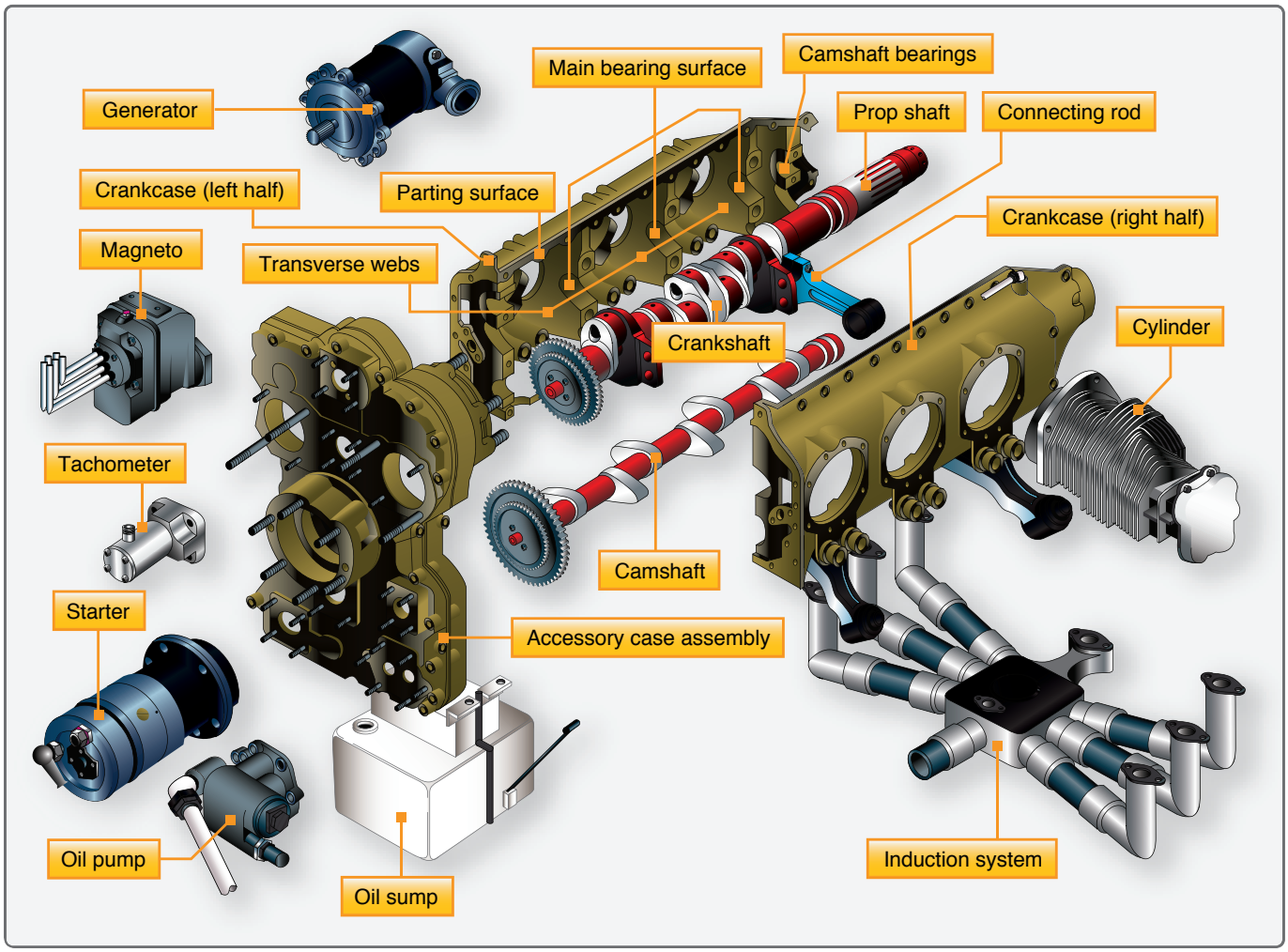


Figure 3-3. Exploded view of an aircraft engine.

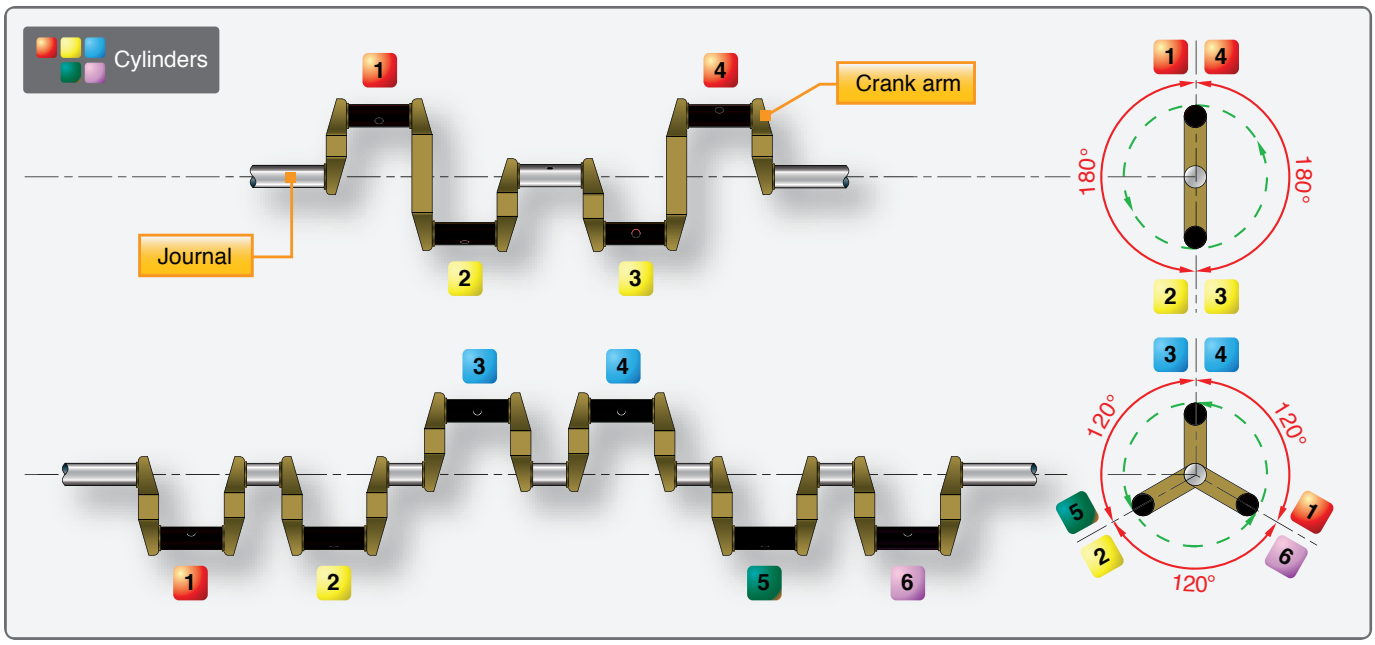


Figure 3-4. Four and six cylinder solid crankshafts.

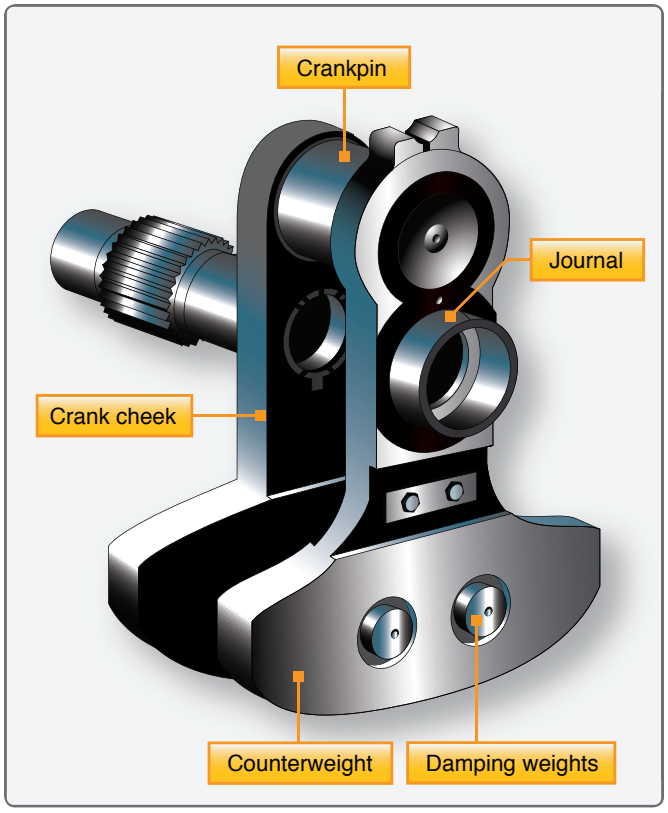


Figure 3-5. Single-throw radial engine crankshaft.

the required bearing surface. The crankpin is usually hollow. This reduces the total weight of the crankshaft and provides a passage for the transfer of lubricating oil. On early engines, the hollow crankpin also served as a chamber for collecting sludge, carbon deposits, and other foreign material. Centrifugal force threw these substances to the outside of the chamber and kept them from reaching the connecting-rod bearing surface. Due to the use of ashless dispersant oils, newer engines no longer use sludge chambers. On some engines, a passage is drilled in the crank cheek to allow oil from the hollow crankshaft to be sprayed on the cylinder walls. The crank cheek connects the crankpin to the main journal. In some designs, the cheek extends beyond the journal and carries a counterweight to balance the crankshaft. The crank cheek must be of sturdy construction to obtain the required rigidity between the crankpin and the journal.

In all cases, the type of crankshaft and the number of crankpins must correspond with the cylinder arrangement of the engine. The position of the cranks on the crankshaft in relation to the other cranks of the same shaft is expressed in degrees.

The simplest crankshaft is the single-throw or 360° type. This type is used in a single-row radial engine. It can be constructed in one or two pieces. Two main bearings (one on each end) are provided when this type of crankshaft is used. The double-throw or 180° crankshaft is used on double-row radial engines. In the radial-type engine, one throw is provided for each row of cylinders.

CYLINDERS

The portion of the engine in which the power is developed is called the cylinder. Shown in **Figure 3.6**, the cylinder provides a combustion chamber where the burning and expansion of gases take place, and it houses the piston and the connecting rod. There are four major factors that need to be considered in the design and construction of the cylinder assembly. It must:

1. Be strong enough to withstand the internal pressures developed during engine operation.
2. Be constructed of a lightweight metal to keep down engine weight.
3. Have good heat-conducting properties for efficient cooling.
4. Be comparatively easy and inexpensive to manufacture, inspect, and maintain.



Figure 3-6. Cylinder.

The cylinder head of an air-cooled engine is generally made of aluminum alloy because aluminum alloy is a good conductor of heat and its light weight reduces the overall engine weight. Cylinder heads are forged or die-cast for greater strength. The inner shape of a cylinder head is generally semispherical. The semispherical shape is generally stronger than other designs and aids in a more rapid and thorough scavenging of the exhaust gases. The cylinder used in the air-cooled engine is the overhead valve type. As illustrated in ***Figure 3-7***, each cylinder is an assembly of two major parts: cylinder head and cylinder barrel. At assembly, the cylinder head is expanded by heating and then screwed down on the cylinder barrel, which has been chilled. When the head cools and contracts and the barrel warms up and expands, a gas-tight joint results. The majority of the cylinders used are constructed in this manner using an aluminum head and a steel barrel. See ***Figure 3-8*** for an illustration of a cylinder head.

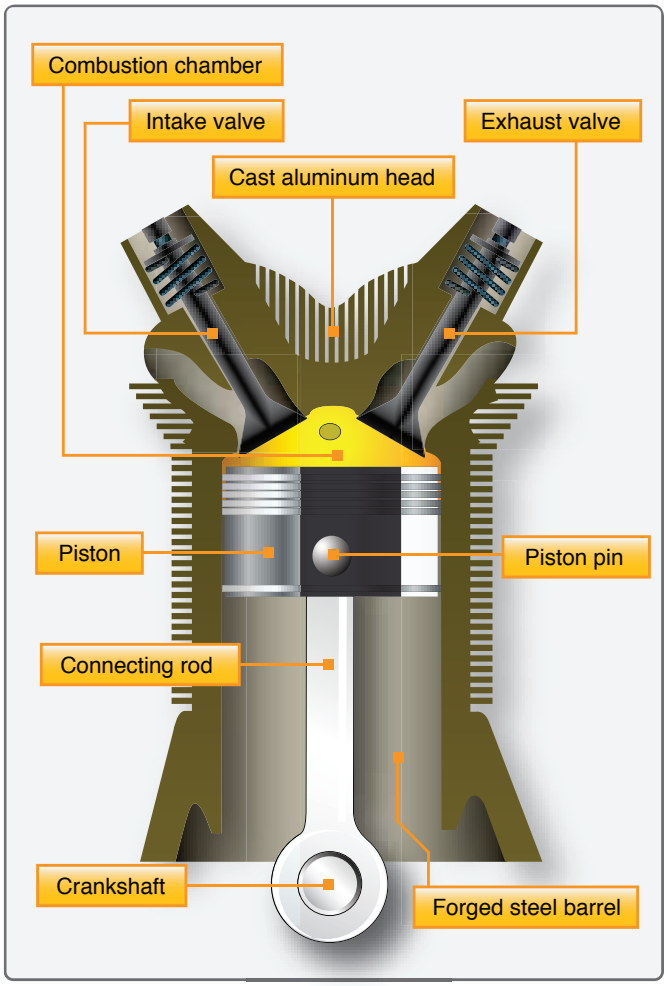


Figure 3-7. Cutaway view of cylinder, piston, and rod assembly.



Figure 3-8. Cylinder head. Note: the threads used to affix the cylinder head to the cylinder barrel, valve seats and valve guides, and spark plug threads.

CYLINDER HEADS

The purpose of the cylinder head is to provide a place for combustion of the fuel/air mixture and to give the cylinder more heat conductivity for adequate cooling. The fuel/air mixture is ignited by the spark in the combustion chamber and commences burning as the piston travels toward top dead center (top of its travel) on the compression stroke. The ignited charge is rapidly expanding at this time, and pressure is increasing so that, as the piston travels through the top dead center position, it is driven downward on the power stroke. The intake and exhaust valve ports are located in the cylinder head along with the spark plugs and the intake and exhaust valve actuating mechanisms.

After the cylinder head is cast, the spark plug bushings, valve guides, rocker arm bushings, and valve seats are installed in the cylinder head. Spark plug openings may be fitted with bronze or steel bushings that are shrunk and pressed or screwed into the openings. Stainless steel Heli-Coil spark plug inserts are used in many engines currently manufactured. Bronze or steel valve guides are usually shrunk and pressed or screwed into drilled openings in the cylinder head to provide guides for the valve stems. These are generally located at an angle to the center line of the cylinder. The valve seats are circular rings of hardened metal that protect the relatively soft metal of the cylinder head from the hammering action of the valves (as they open and close) and from the exhaust gases.

The cylinder heads of air-cooled engines are subjected to extreme temperatures; it is therefore necessary to provide adequate cooling fin area and to use metals that conduct heat rapidly. Cylinder heads of air-cooled engines are usually cast or forged. Aluminum alloy is used in the construction for a number of reasons. It is well adapted for casting or for the machining of deep, closely spaced fins, and it is more resistant than most metals to the corrosive attack of tetraethyl lead in gasoline. The greatest improvement in air-cooling has resulted from reducing the thickness of the fins and increasing their depth. In this way, the fin area has been increased in modern engines. Cooling fins taper from 0.090" (2.29mm) at the base to 0.060" (1.52mm) at the tip end. Because of the difference in temperature in the various sections of the cylinder head, it is necessary to provide more cooling-fin area on some sections than on others. The exhaust valve region is the hottest part of the internal surface; therefore, more fin area is provided around the outside of the cylinder head in this section.

VALVES

The fuel/air mixture enters the cylinders through the intake valve ports, and burned gases are expelled through the exhaust valve ports. The head of each valve opens and closes these cylinder ports. The valves used in aircraft engines are the conventional poppet type. The valves are also typed by their shape and are called either mushroom or tulip because of their resemblance to the shape of these plants. ***Figure 3-9*** illustrates various shapes and types of these valves.

VALVE CONSTRUCTION

The valves in the cylinders of an aircraft engine are subjected to high temperatures, corrosion, and operating stresses; thus, the metal alloy in the valves must be able to resist all these factors. Because intake valves operate at lower temperatures than exhaust valves, they can be made of chromic-nickel steel. Exhaust valves are usually made of nichrome, silchrome, or cobalt-chromium steel because these materials are much more heat resistant.

The valve head has a ground face that forms a seal against the ground valve seat in the cylinder head when the valve is closed. The face of the valve is usually ground to an angle of either 30° or 45°. In some engines, the intake-valve face is ground to an angle of 30°, and the exhaust-valve face is ground to a 45° angle. Some installations have the valves and valve

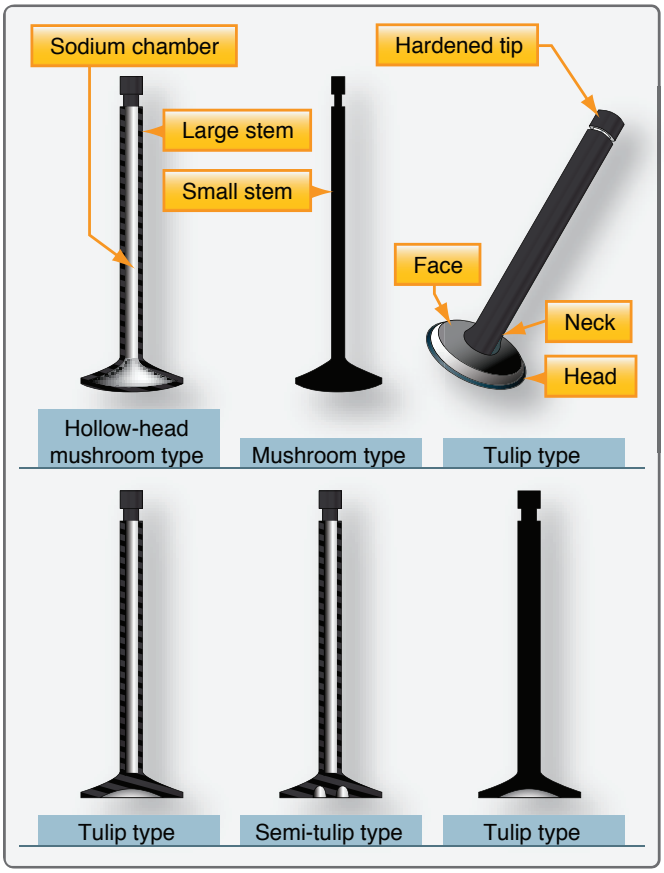


Figure 3-9. Type of valves .

seats ground 1/2 degree different to enhance the seal formed between the face of the valve and the valve seat. Valve faces are often made more durable by the application of a material called stellite. About 1/16 inch of this alloy is welded to the valve face and ground to the correct angle. Stellite is resistant to high-temperature corrosion and also withstands the shock and wear associated with valve operation. Some engine manufacturers use a nichrome facing on the valves. This serves the same purpose as the stellite material.

The valve stem acts as a pilot for the valve head and rides in the valve guide installed in the cylinder head for this purpose. Refer to ***Figure 3-10***. The valve stem is surface hardened to resist wear. The neck is the part that forms the junction between the head and the stem. The tip of the valve is hardened to withstand the hammering of the valve rocker arm as it opens the valve. A machined groove on the stem near the tip receives the split-ring stem keys. These stem keys form a lock ring to hold the valve spring retaining washer in place, as seen in ***Figure 3-11***.



Figure 3-10. View of cylinder head showing valve seats, valve guides, and spark plug holes.



Figure 3-11. Valve installation showing valve tip, valve springs, valve spring cap, and valve stem keepers.

Some intake and exhaust valve stems are hollow and partially filled with metallic sodium. This material is used because it is an excellent heat conductor. The sodium melts at approximately 208°F and the reciprocating motion of the valve circulates the liquid sodium, allowing it to carry away heat from the valve head to the valve stem where it is dissipated through the valve guide to the cylinder head and the cooling fins. Thus, the operating temperature of the valve may be reduced as much as 300°F to 400°F. Under no circumstances should a sodium-filled valve be cut open or subjected to treatment that may cause it to rupture. Exposure of the sodium in these valves to the outside air results in fire or explosion with possible personal injury.

The most commonly used intake valves have solid stems, and the head is either flat or tulip shaped. Intake valves for low-power engines are usually flat headed. In some engines, the intake valve may be the tulip type and have a smaller stem than the exhaust valve or it may be similar to the exhaust valve but have a solid stem and head. Although these valves are similar, they are not interchangeable since the faces of the valves are constructed of different material. The intake valve usually has a flat milled on the tip to identify it. Also, the head of the intake valve typically has a larger diameter than the exhaust valve.

VALVE OPERATING MECHANISM

For a reciprocating engine to operate properly, each valve must open at the correct time, stay open for the required length of time, and close at the proper time. Intake valves are opened just before the piston reaches top dead center on the exhaust stroke, and exhaust valves remain open after top dead center as the cylinder begins its intake stroke. At a particular instant, therefore, both valves are open at the same time (end of the exhaust stroke and beginning of the intake stroke). This valve overlap permits better volumetric efficiency and lowers the cylinder operating temperature. This timing of the valves is controlled by the valve-operating mechanism and is referred to as the valve timing.

The valve lift (distance that the valve is lifted off its seat) and the valve duration (length of time the valve is held open) are both determined by the shape of the cam lobes. Typical cam lobes are illustrated in ***Figure 3-12***. The portion of the lobe that gently starts



Figure 3-12. Cam lobe.

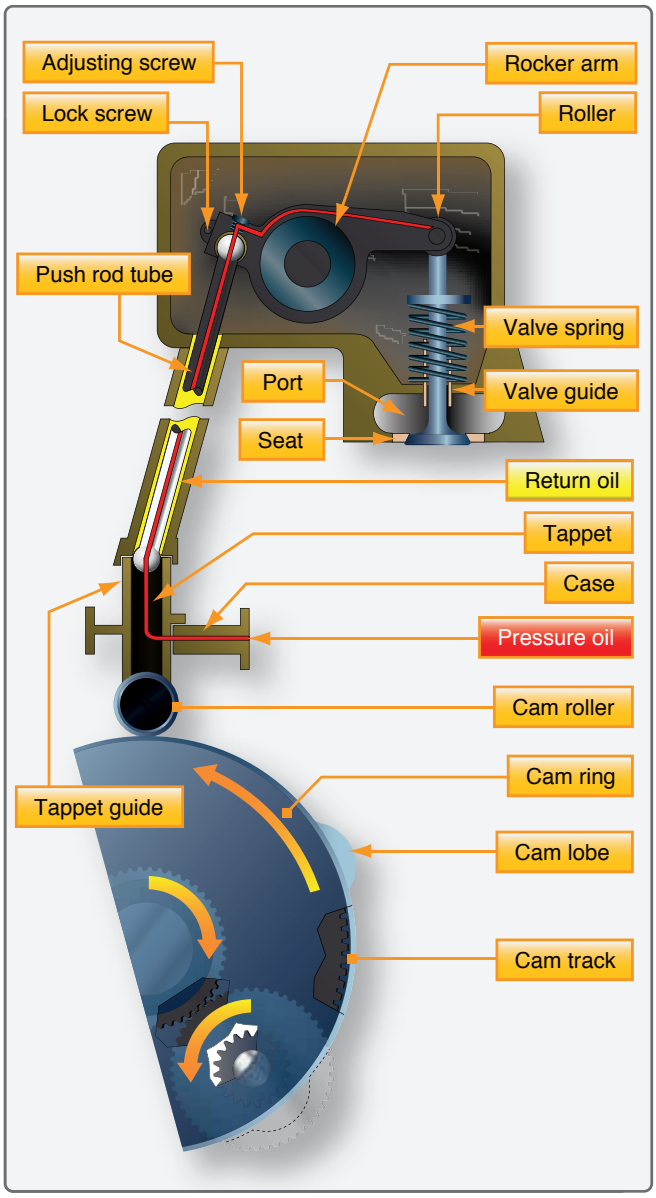


Figure 3-13. Radial engine cam plate and valve train assembly.

the valve operating mechanism moving is called a ramp, or step. The ramp is machined on each side of the cam lobe to permit the rocker arm to be eased into contact with the valve tip and thus reduce the shock load that would otherwise occur. The valve operating mechanism consists of a cam ring or camshaft equipped with lobes that work against a cam roller or a cam follower as revealed in ***Figures 3-13 and 3-14***. The cam follower pushes a push rod and ball socket, actuating a rocker arm, which in turn opens the valve. Springs, which slip over the stem of the valves and are held in place by the valve-spring retaining washer and stem key, close each valve and push the valve mechanism in the opposite direction. See ***Figure 3-15***.

CAM RINGS

The valve mechanism of a radial engine is operated by one or two cam rings, depending upon the number of rows of cylinders. In a single-row radial engine, one ring with a double cam track is used. One track operates the intake valves, the other operates the exhaust valves. The cam ring is a circular piece of steel with a series of cams or lobes on the outer surface. The surface of these lobes and the space between them (on which the cam rollers ride) is known as the cam track. As the cam ring revolves, the lobes cause the cam roller to raise the tappet in the tappet guide, thereby transmitting the force through the push rod and rocker arm to open the valve. In a single-row radial engine, the cam ring is usually located between the propeller reduction gearing and the front end of the power section. In a twin-row radial engine, a second cam for the operation of the valves in the rear row is installed between the rear end of the power section and the supercharger section.

The cam ring is mounted concentrically with the crankshaft and is driven by the crankshaft at a reduced rate of speed through the cam intermediate drive gear assembly. The cam ring has two parallel sets of lobes spaced around the outer periphery, one set (cam track) for the intake valves and the other for the exhaust valves. On a nine-cylinder radial engine, the cam rings used may have four or five lobes on both the intake and the exhaust tracks. The timing of the valve events is determined by the spacing of these lobes and the speed and direction at which the cam rings are driven in relation to the speed and direction of the crankshaft. The method of driving the cam varies on different makes of engines. The cam ring can be designed with teeth on either the inside or outside periphery. If the reduction gear meshes with the teeth on the outside of the ring, the cam turns in the direction of rotation of the crankshaft. If the ring is driven from the inside, the cam turns in the opposite direction from the crankshaft. See ***Figure 3-13***.

A four-lobe cam may be used on either a seven-cylinder or nine-cylinder engine. Refer to ***Figure 3-16*** for additional information. On the seven cylinder, it rotates in the same direction as the crankshaft, and on the nine cylinder, opposite the crankshaft rotation. On the nine-cylinder engine, the spacing between cylinders is 40° and the firing order is 1-3-5-7-9-2-4-6-8. This means that there is a space of 80° between firing impulses.

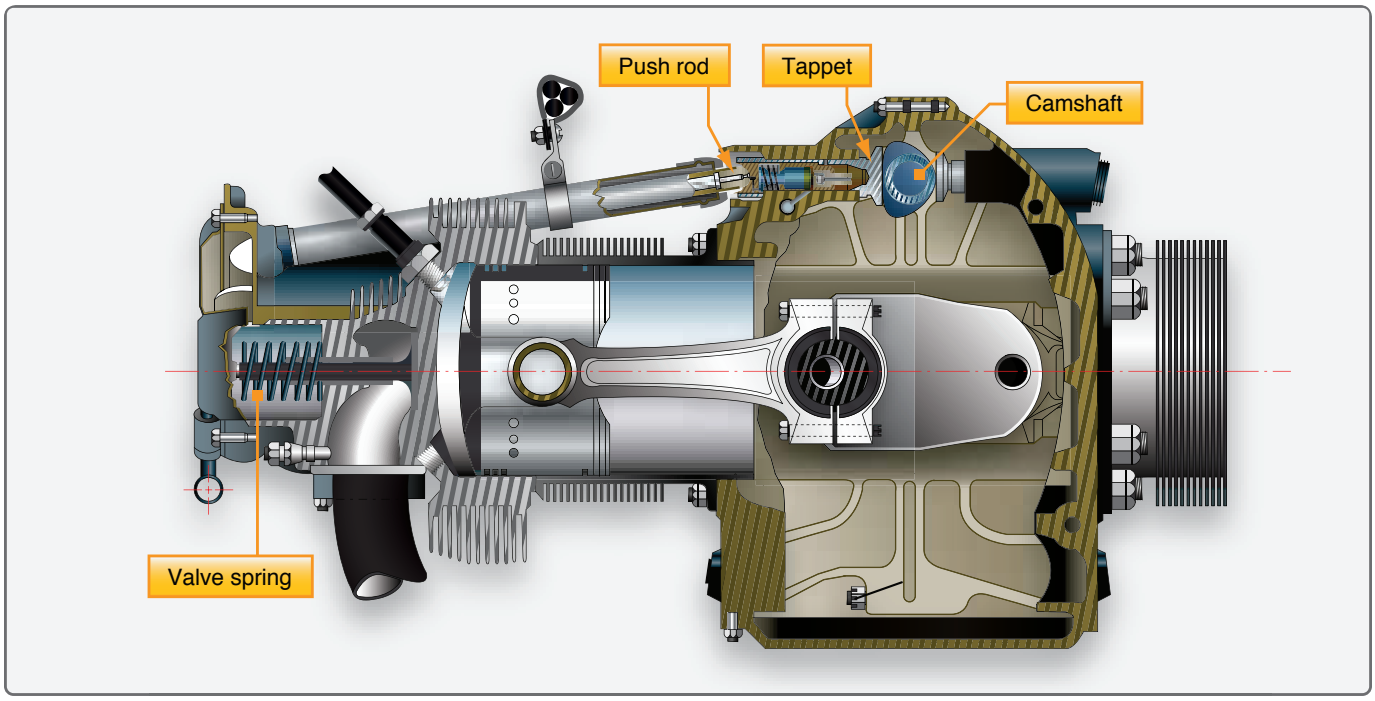


Figure 3-14. Cutaway view of engine showing camshaft, tappet, push rod, and valve assembly.



Figure 3-15. Inner and outer valve springs, valve spring cap, and valve stem keepers .

The spacing on the four lobes of the cam ring is 90°, which is greater than the spacing between impulses. Therefore, to obtain proper relation of valve operations and firing order, it is necessary to drive the cam opposite the crankshaft rotation. Using the four-lobe cam on the seven-cylinder engine, the spacing between the firing of the cylinders is greater than the spacing of the cam lobes. Therefore, it is necessary for the cam to rotate in the same direction as the crankshaft.

5 Cylinders		7 Cylinders		9 Cylinders		Direction of Rotation
Number of Lobes	Speed	Number of Lobes	Speed	Number of Lobes	Speed	
3	1/6	4	1/8	5	1/10	with crankshaft
2	1/4	3	1/6	4	1/8	opposite crankshaft

Figure 3.16: Radial Engine Cam Plate Data

CAMSHAFT

The valve mechanism of an opposed engine is operated by a camshaft. The camshaft is driven by a gear that meshes with another gear attached to the crankshaft as shown in ***Figure 3-17***. The camshaft always rotates at one-half the crankshaft speed. As the camshaft revolves, the lobes cause the tappet assembly to rise in the tappet guide, transmitting the force through the push rod and rocker arm to open the valve as illustrated in ***Figures 3-14, 3-18 and 3-19***.

TAPPET ASSEMBLY

The tappet assembly consists of:

1. A cylindrical tappet, which slides in and out in a tappet guide installed in one of the crankcase sections around the cam ring;
2. A tappet roller or face, which follows the contour of the cam ring and lobes;
3. A tappet ball socket or push rod socket; and
4. A tappet spring.

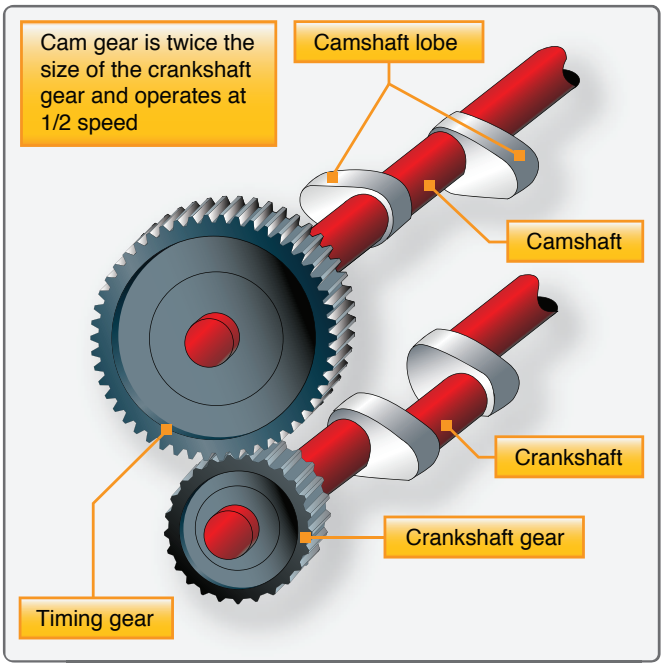


Figure 3-17. Camshaft and crankshaft.



Figure 3-18. Cam lobe, tappet, and push rod.

The function of the tappet assembly is to convert the rotational movement of the cam lobe into reciprocating motion and to transmit this motion to the push rod, rocker arm, and then to the valve tip, opening the valve at the proper time. The purpose of the tappet spring is to take up the clearance between the rocker arm and the valve tip to reduce the shock load when the valve is opened. A hole is drilled through the tappet to allow engine oil to flow to the hollow push rods to lubricate the rocker assemblies.

SOLID LIFTERS/TAPPETS

Solid lifters or cam followers generally require the valve clearance to be adjusted manually by adjusting a screw and lock nut. Valve clearance is needed to assure that the valve has enough clearance in the valve train to close completely. This adjustment or inspection was a continuous maintenance item until hydraulic lifters were developed and employed. A number of aircraft engines in service today continue to use solid lifters. This is especially the case with radial engines.

HYDRAULIC VALVE TAPPETS/ LIFTERS

Some aircraft engines incorporate hydraulic tappets that automatically keep the valve clearance at zero when the engine is running, eliminating the necessity for any valve clearance adjustment mechanism. A typical hydraulic tappet (zero-lash valve lifter) is shown in ***Figure 3-19***.

When the engine valve, intake or exhaust, is closed, the face of the tappet body (cam follower) is on the base circle or back of the cam. See ***Figure 3-19***. The light plunger spring lifts the hydraulic plunger so that its outer end contacts the push rod socket, exerting a light pressure against it, thus eliminating any clearance in the valve linkage. As the plunger moves outward, the ball check valve moves off its seat. Oil from the supply chamber, which is directly connected with the engine lubrication system, flows in and fills the pressure chamber. As the camshaft rotates, the cam pushes the tappet body and the hydraulic lifter cylinder outward. This action forces the ball check valve onto its seat; thus, the body of oil trapped in the pressure chamber acts as a cushion. During the interval when the intake or exhaust valve is off its seat, a predetermined leakage occurs between plunger and cylinder bore, which compensates for any expansion or contraction in the valve train. Immediately after the valve closes, the amount of oil required to fill the pressure chamber flows in from the supply chamber, preparing for another cycle of operation.

Hydraulic valve lifters are normally adjusted at the time of overhaul. They are assembled dry (no lubrication), clearances checked, and adjustments are usually made by using push rods of different lengths. A minimum and maximum valve clearance is established. Any measurement between these extremes is acceptable, but approximately half way between the extremes is desired. Hydraulic valve lifters require less maintenance, are better lubricated, and operate more quietly than the screw adjustment type.

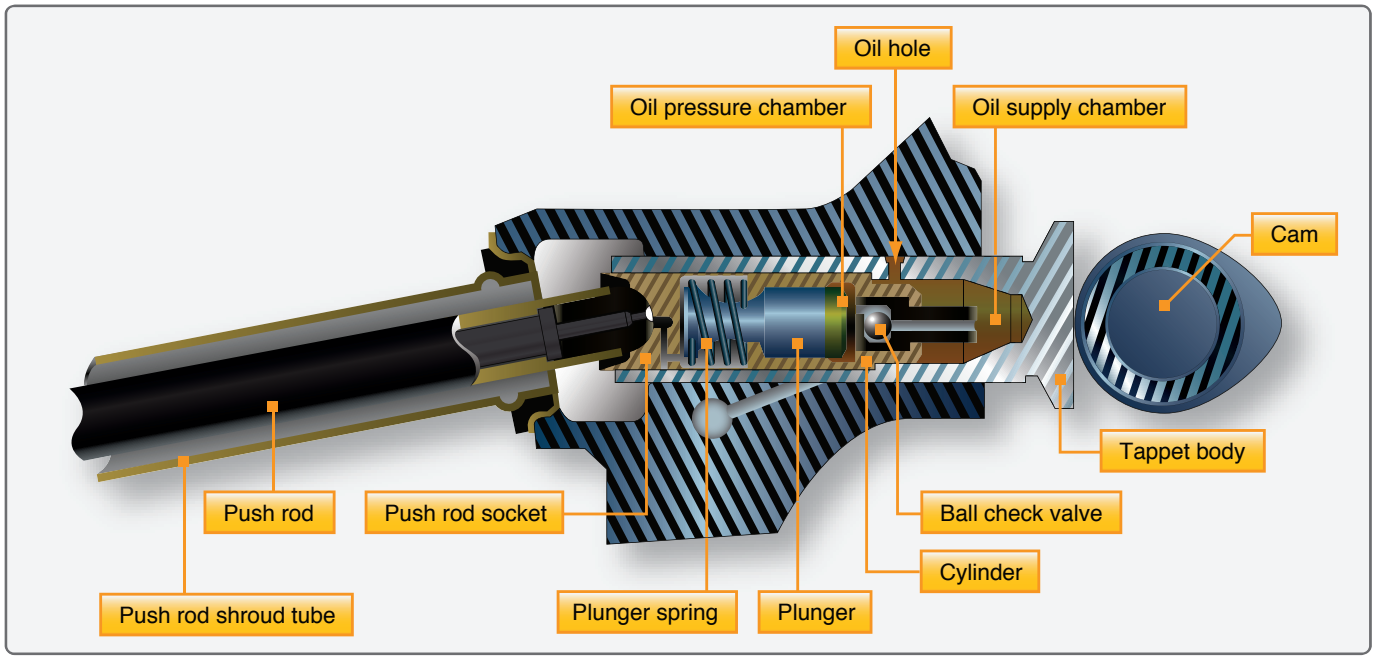


Figure 3-19. Illustration of zero-lash hydraulic lifter .

PUSH ROD

The push rod, tubular in form, transmits the lifting force from the valve tappet to the rocker arm. A hardened-steel ball is pressed over or into each end of the tube. One ball end fits into the socket of the rocker arm. See ***Figure 3-21***. In some instances, the balls are on the tappet and rocker arm, and the sockets are on the push rod. The tubular form is employed because of its lightness and strength. It further permits the engine lubricating oil under pressure to pass through the hollow rod and the drilled ball ends to lubricate the ball ends, rocker-arm bearing, and valve-stem guide. The push rod is enclosed in a tubular housing that extends from the crankcase to the cylinder head, referred to as push rod tubes.

ROCKER ARMS

The rocker arms transmit the lifting force from the cams to the valves. Refer to ***Figures 3-20 and 3-21***. Rocker arm assemblies are supported by a plain, roller, or ball bearing, or a combination of these, which serves as a pivot. Generally, one end of the arm rides against the push rod and the other bears on the valve stem. One end of the rocker arm is sometimes slotted to accommodate a steel roller. The opposite end is constructed with either a threaded split clamp and locking bolt or a tapped hole. The arm may have an adjusting screw, for adjusting the clearance between the rocker arm and the valve stem tip. The screw can be adjusted to the specified clearance to make certain that the valve closes fully.



Figure 3-20. Rocker arms.



Figure 3-21. Rocker arm. Push rod socket on the left, rocker pin bushing in the center, and valve stem tappet on right.

VALVE SPRINGS

Each valve is closed by two or three helical springs. If a single spring were used, it would vibrate or surge at certain speeds. To eliminate this difficulty, two or more springs (one inside the other) are installed on each valve. Each spring vibrates at a different engine speed and

rapid damping out of all spring-surge vibrations during engine operation results. Two or more springs also reduce danger of weakness and possible failure by breakage due to heat and metal fatigue. The springs are held in place by split locks installed in the recess of the valve spring upper retainer or washer, and engage a groove machined into the valve stem. The functions of the valve springs are to close the valve and to hold the valve securely on the valve seat. Refer to ***Figure 3-15*** for a photo of valve springs, valve spring cap, and valve stem keepers.

CYLINDER BARRELS

The cylinder barrel in which the piston operates must be made of a high-strength material, usually steel. It must be as light as possible, yet have the proper characteristics for operating under high temperatures and pressures. It must be made of a good bearing material and have high tensile strength. The cylinder barrel is made of a steel alloy forging with the inner surface hardened to resist wear of the piston and the piston rings that bear against it. This hardening is usually done by exposing the steel to ammonia or cyanide gas while the steel is very hot. The steel soaks up nitrogen from the gas, which forms iron nitrides on the exposed surface. As a result of this process, the metal is said to be nitrided. This nitriding only penetrates into the barrel surface a few thousands of an inch. As the cylinder barrels wear due to use, they can be repaired by chroming. This is a process that plates chromium on the surface of the cylinder barrel and brings it back to new standard dimensions. Chromium-plated cylinders should use cast iron rings. Honing the cylinder walls is a process that brings it to the correct dimensions and provides crosshatch pattern for seating the piston rings during engine break-in. Some engine cylinder barrels are choked at the top, or they are smaller in diameter to allow for heat expansion and wear.

In recent years additional cylinder wall coatings have become available. Cermicrome and nickel and carbide coatings have minimized cylinder wear. Such coatings further resist corrosion when compared to steel barrels.

In some instances, the barrel has threads on the outside surface at one end so that it can be screwed into the cylinder head. The cooling fins are machined as an integral part of the barrel and have limits on repair and service.

PISTONS

The piston of a reciprocating engine is a cylindrical member that moves back and forth within a steel cylinder. See ***Figure 3-22***. The piston acts as a moving wall within the combustion chamber. As the piston moves down in the cylinder, it draws in the fuel/air mixture. As it moves upward, it compresses the charge, ignition occurs, and the expanding gases force the piston downward. This force is transmitted to the crankshaft through the connecting rod. On the return upward stroke, the piston forces the exhaust gases from the cylinder and the cycle repeats.

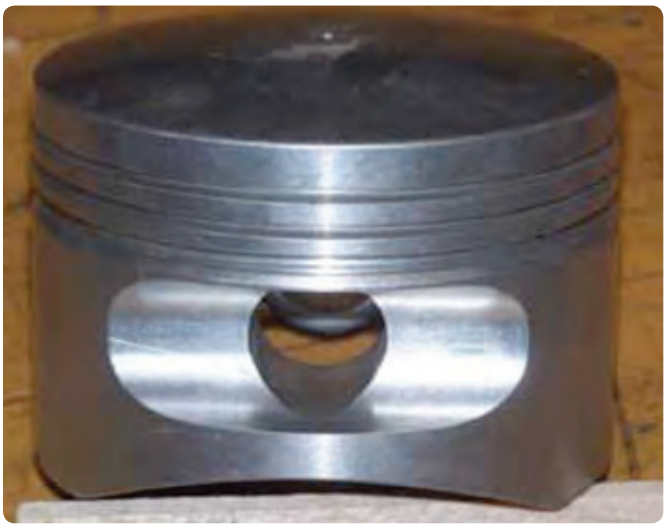


Figure 3-22. Piston.

PISTON CONSTRUCTION

The majority of aircraft engine pistons are machined from aluminum alloy forgings. Grooves are machined in the outside surface of the piston to receive the piston rings, and cooling fins are provided on the inside of the piston on some models for greater heat transfer to the engine oil. Pistons may be either the trunk type or the slipper type as shown in ***Figure 3-23***. Slipper-type pistons are not used in modern, high-powered engines because they do not provide adequate strength or wear resistance. The top of the piston, or head, may be flat, convex, or concave. Recesses may be machined in the piston head to prevent interference with the valves.

Modern engines use cam ground pistons that have a larger diameter perpendicular to the piston pin. This larger diameter keeps the piston straight in the cylinder as the engine warms up from initial start up. As the piston heats up during warm up, the part of the piston in line with the pin has more mass and expands more making the piston completely round. At low temperatures, the

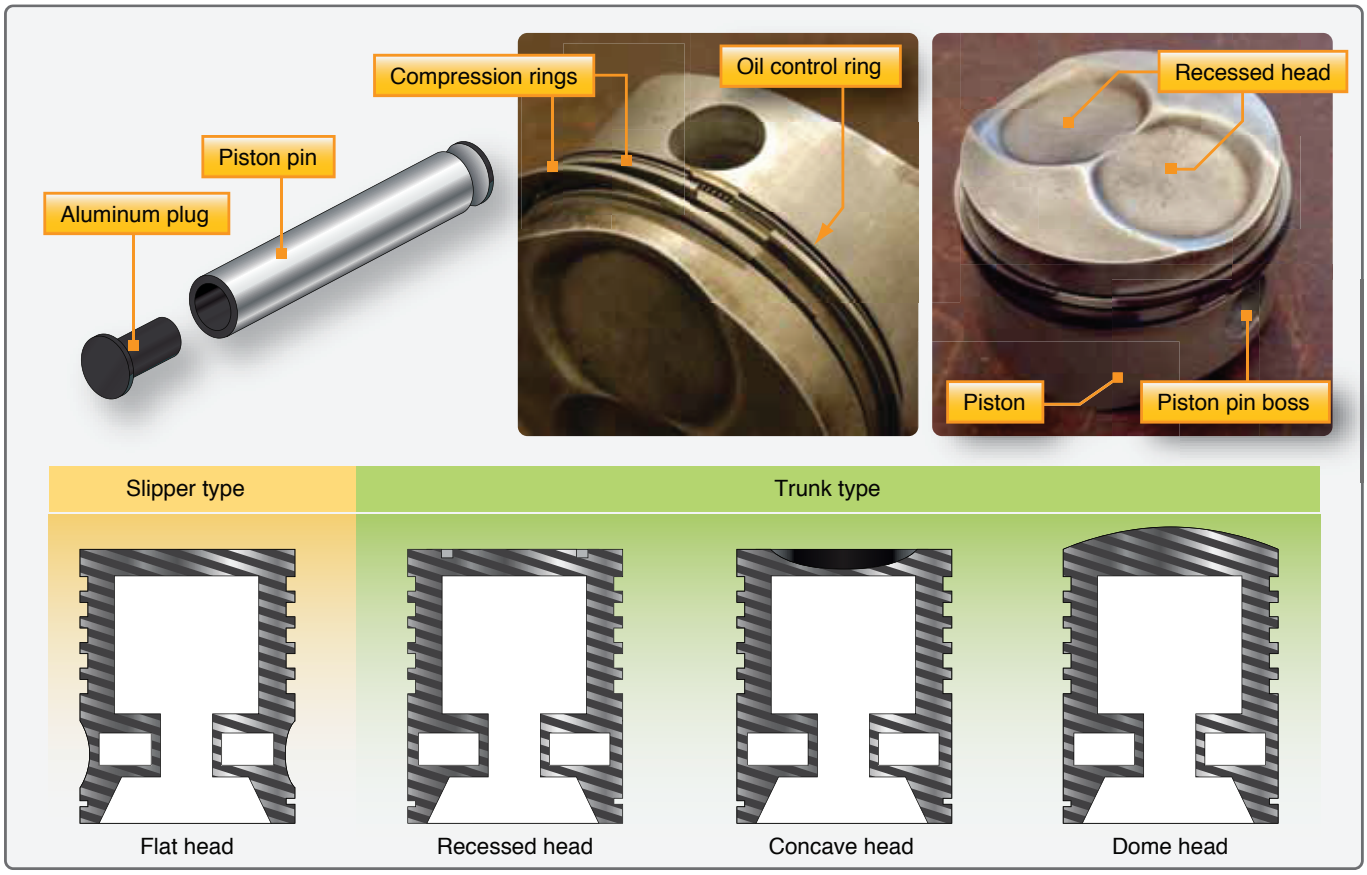


Figure 3-23. Types of pistons.

piston is oval shaped and, when it warms to operating temperature, it becomes round. This process reduces the tendency of the piston to cock or slap in the cylinder during warm up. When the engine reaches its normal operating temperature, the piston assumes the correct dimensions in the cylinder.

As many as six grooves may be machined around the piston to accommodate the compression rings and oil rings. ***Figure 3-22*** reveals a piston with three piston ring grooves. The compression rings are installed in the uppermost grooves and the oil control rings are installed immediately above the piston pin. The piston is usually drilled at the oil control ring grooves to allow surplus oil scraped from the cylinder walls by the oil control rings to pass back into the crankcase. An oil scraper ring is installed at the base of some pistons to prevent excessive oil consumption. The portions of the piston walls that lie between ring grooves are called the ring lands. In addition to acting as a guide for the piston head, the piston skirt incorporates the piston-pin bosses. The piston-pin bosses are of heavy construction to enable the heavy load on the piston head to be transferred to the piston pin.

PISTON PIN

The piston pin joins the piston to the connecting rod as illustrated in **Figure 3.7**. It is machined in the form of a tube from a nickel steel alloy forging, casehardened and ground. The piston pin is sometimes called a wristpin because of the similarity between the relative motions of the piston and the connecting or articulated rod and that of the human arm. The piston pin used in modern aircraft engines is the full-floating type, so called because the pin is free to rotate in both the piston and in the connecting rod piston-pin bearing. The piston pin must be held in place to prevent the pin ends from scoring the cylinder walls. A plug of relatively soft aluminum in the pin end provides a good bearing surface against the cylinder wall. A piston pin with its aluminum plug is illustrated in ***Figure 3-23***.

PISTON RINGS

The piston rings prevent leakage of gas pressure from the combustion chamber and reduce to a minimum the seepage of oil into the combustion chamber. Refer to ***Figure 3-23***. The rings fit into the piston grooves but spring out to press against the cylinder walls; when properly lubricated, the rings form an effective gas seal.

PISTON RING CONSTRUCTION

Most piston rings are made of high-grade cast iron. After the rings are made, they are ground to the cross-section desired. Then they are split so that they can be slipped over the outside of the piston and into the ring grooves that are machined in the piston wall. Since their purpose is to seal the clearance between the piston and the cylinder wall, they must fit the cylinder wall snugly enough to provide a gas-tight fit. They must exert equal pressure at all points on the cylinder wall, and must make a gas-tight fit against the sides of the ring grooves.

Gray cast iron is most often used in making piston rings. In some engines, chrome-plated mild steel piston rings are used in the top compression ring groove because these rings can better withstand the high temperatures present at this point. Chrome rings must be used with steel cylinder walls. Never use chrome rings on chrome cylinders. Technicians must correctly select, fit, and install piston rings to ensure proper engine operation.

COMPRESSION RING

The purpose of the compression rings is to prevent or minimize the escape of combustion gases past the piston during engine operation. They are placed in the ring grooves immediately below the piston head. The number of compression rings used on each piston is determined by the type of engine and its design, although most aircraft engines use two compression rings plus one or more oil control rings.

The cross-section of the ring is either rectangular or wedge shaped with a tapered face. The tapered face presents a narrow bearing edge to the cylinder wall, which helps to reduce friction and provide better sealing.

OIL CONTROL RINGS

Oil control rings are placed in the grooves immediately below the compression rings and above the piston pin bores. There may be one or more oil control rings per piston; two rings may be installed in the same groove, or they may be installed in separate grooves. Oil

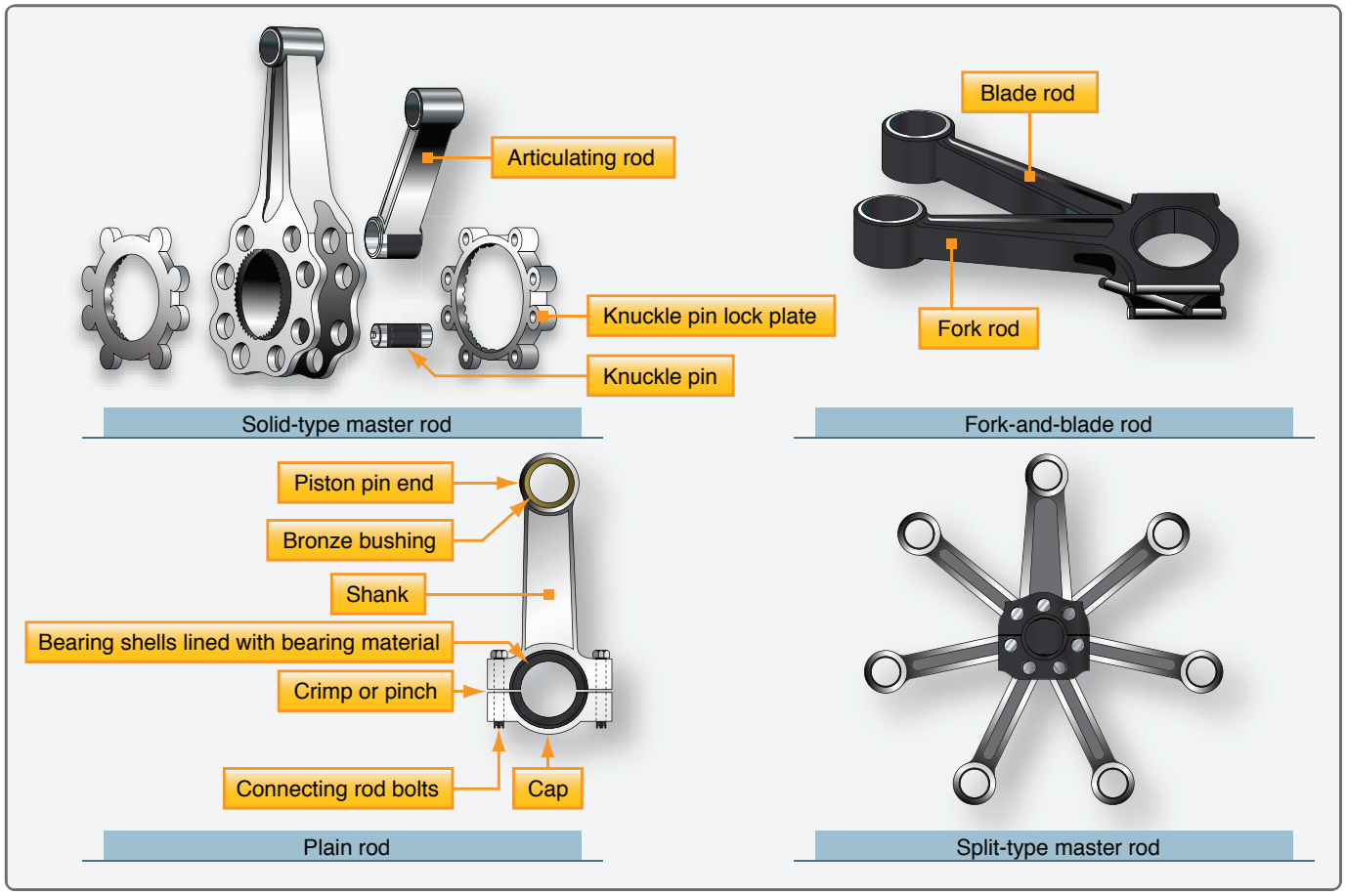


Figure 3-24. Types of connecting rod.

control rings regulate the thickness of the oil film on the cylinder wall. If too much oil enters the combustion chamber, it burns and leaves a thick coating of carbon on the combustion chamber walls, the piston head, the spark plugs, and the valve heads. This carbon can cause the valves and piston rings to stick if it enters the ring grooves or valve guides. In addition, the carbon can cause spark plug misfiring as well as detonation, preignition, or excessive oil consumption. To allow the surplus oil to return to the crankcase, holes are drilled in the bottom of the oil control piston ring grooves or in the lands next to these grooves.

OIL SCRAPER RING

The oil scraper ring usually has a beveled face and is installed in the groove at the bottom of the piston skirt. The ring is installed with the scraping edge away from the piston head or in the reverse position, depending upon cylinder position and the engine series. In the reverse position, the scraper ring retains the surplus oil above the ring on the upward piston stroke, and this oil is returned to the crankcase by the oil control rings on the downward stroke.

CONNECTING RODS

The connecting rod is the link that transmits forces between the piston and the crankshaft as shown in ***Figure 3-24***. Connecting rods must be strong enough to remain rigid under load and yet be light enough to reduce the inertia forces that are produced when the rod and piston stop, change direction, and start again at the end of each stroke.

There are four types of connecting-rod assemblies:

1. Plain
2. Fork and blade
3. Master and articulated
4. Split-type

PLAIN-TYPE CONNECTING RODS

Plain-type connecting rods are used in inline and opposed engines (***Figure 3-25***). The end of the rod attached to the crankpin is fitted with a cap and a two-piece bearing. The bearing cap is held on the end of the rod by bolts or studs. To maintain proper fit and balance, connecting rods should always be replaced in the same cylinder and in the same relative position.



Figure 3-25. Plain-type connecting rod and cap assembly.

FORK-AND-BLADE ROD ASSEMBLY

The fork-and-blade rod assembly is used primarily in V-type engines. The forked rod is split at the crankpin end to allow space for the blade rod to fit between the prongs. A single two-piece bearing is used on the crankshaft end of the rod. This type of connecting rod is not used much on modern engines.

MASTER-AND-ARTICULATED AND SPLIT-TYPE ROD ASSEMBLIES

The master-and-articulated rod assembly is commonly used in radial engines. In a radial engine, the piston in one cylinder in each row is connected to the crankshaft by a master rod. All other pistons in the row are connected to the master rod by articulated rods. In an 18-cylinder engine, which has two rows of cylinders, there are two master rods and 16 articulated rods. The articulated rods are constructed of forged steel alloy in either the I- or H-shape, denoting the cross-sectional shape. Bronze bushings are pressed into the bores in each end of the articulated rod to provide knuckle-pin and piston-pin bearings. The master rod serves as the connecting link between the piston pins and the crankpin. The crankpin end, or the big end, contains the crankpin or master rod bearing. Flanges around the big end provide for the attachment of the articulated rods. The articulated rods are attached to the master rod by knuckle pins, which are pressed into holes in the master rod flanges during assembly. A plain bearing, usually called a piston-pin bushing, is installed in the piston end of the master rod to receive the piston pin.

When a crankshaft of the split-spline or split-clamp type is employed, a one-piece master rod is used. The master and articulated rods are assembled and then installed on the crankpin; the crankshaft sections are then joined together. In engines that use the one-piece type of crankshaft, the big end of the master rod is split, as is the master rod bearing. See

Figure 3-26. The main part of the master rod is installed on the crankpin; then the bearing cap is set in place and bolted to the master rod. The centers of the knuckle pins do not coincide with the center of the crankpin. Thus, while the crankpin center describes a true circle for each revolution of the crankshaft, the centers of the knuckle pins describe an elliptical path. [***Figure 3-27***] The elliptical paths are symmetrical about a center line through the master rod cylinder. It can be seen that the major diameters of the ellipses are not the same. Thus, the link rods have varying degrees of angularity relative to the center of the crank throw.



Figure 3-26. Split-type master rod.

Because of the varying angularity of the link rods and the elliptical motion of the knuckle pins, all pistons do not move an equal amount in each cylinder for a given number of degrees of crank throw movement. This variation in piston position between cylinders can have considerable effect on engine operation. To minimize the effect of these factors on valve and ignition timing, the knuckle pin holes in the master rod flange are not equidistant from the center of the crankpin, thereby offsetting to an extent the effect of the link rod angularity.

KNUCKLE PINS

The knuckle pins are of solid construction except for the oil passages drilled in the pins, which lubricate the knuckle pin bushings. These pins may be installed

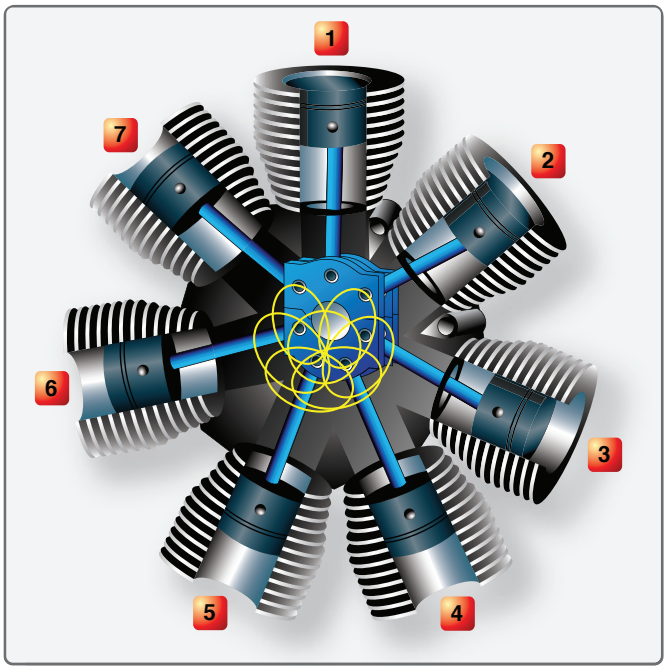


Figure 3-27. Articulating rod elliptical paths.

by pressing into holes in the master rod flanges so that they are prevented from turning in the master rod. Knuckle pins may also be installed with a loose fit so that they can turn in the master rod flange holes, and also turn in the articulating rod bushings. These are called full-floating knuckle pins. In either type of installation, a lock plate on each side retains the knuckle pin and prevents a lateral movement.

PROPELLER REDUCTION GEARING

The increased brake horsepower delivered by a high horsepower engine results partly from increased crankshaft rpm. It is therefore necessary to provide reduction gears to limit the propeller rotation speed to a value at which efficient operation is obtained. Whenever the speed of the blade tips approaches the speed of sound, the efficiency of the propeller decreases rapidly. Reduction gearing for engines allows the engine to operate at a higher rpm, developing more power while slowing down the propeller rpm. This prevents the propeller efficiency from decreasing. Since reduction gearing must withstand extremely high stresses, the gears are machined from steel forgings. Many types of reduction gearing systems are in use. The three types most commonly used are spur planetary, bevel planetary, and spur and pinion as illustrated in ***Figure 3-28***.

The spur planetary reduction gearing consists of a large driving gear or sun gear splined (and sometimes shrunk)

to the crankshaft, a large stationary gear, called a bell gear, and a set of small spur planetary pinion gears mounted on a carrier ring. The ring is fastened to the propeller shaft and the planetary gears mesh with both the sun gear and the stationary bell or ring gear. The stationary gear is bolted or splined to the front section housing. When the engine is operating, the sun gear rotates. Because the planetary gears are meshed with

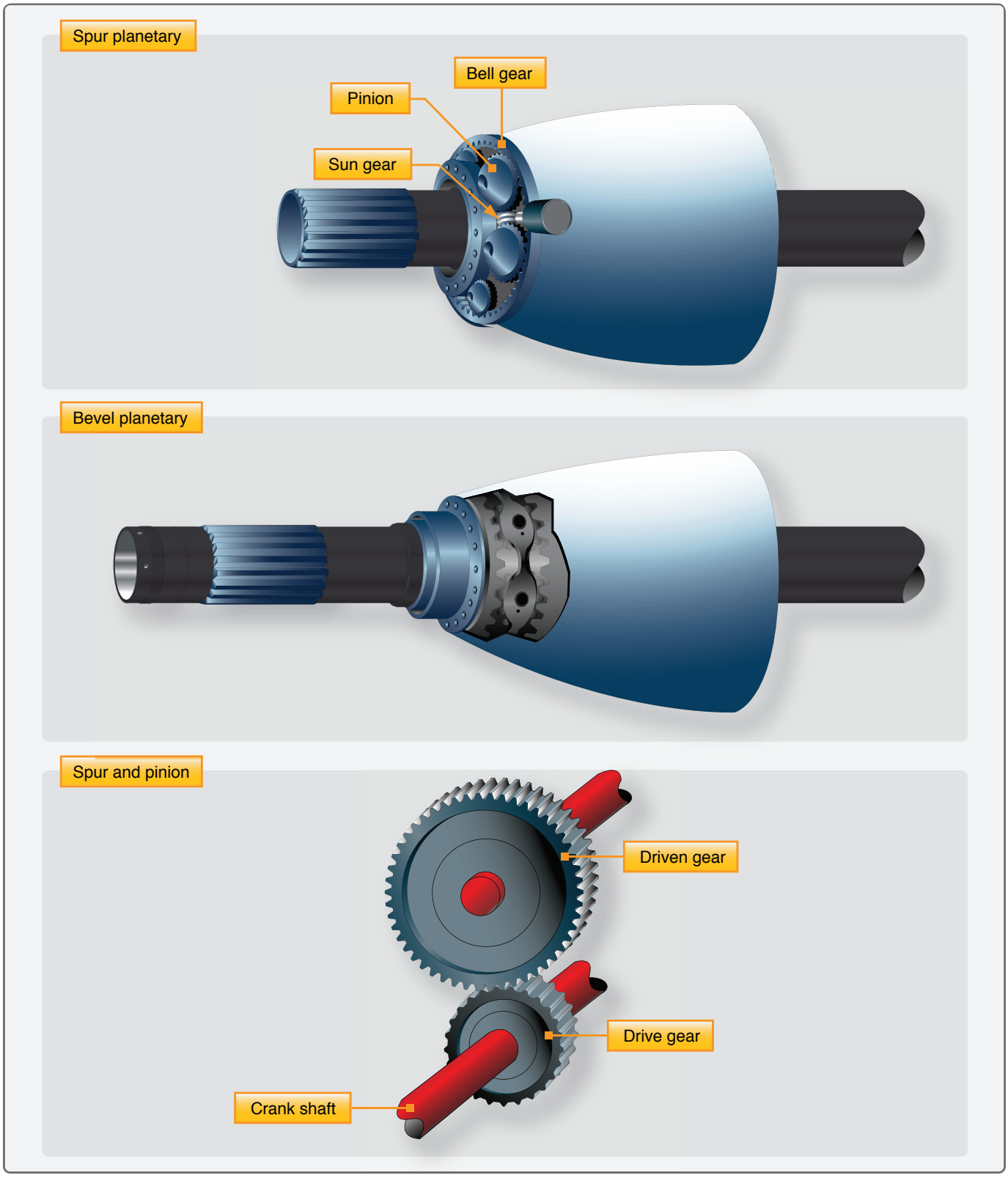


Figure 3-28. Propeller gear reduction systems.

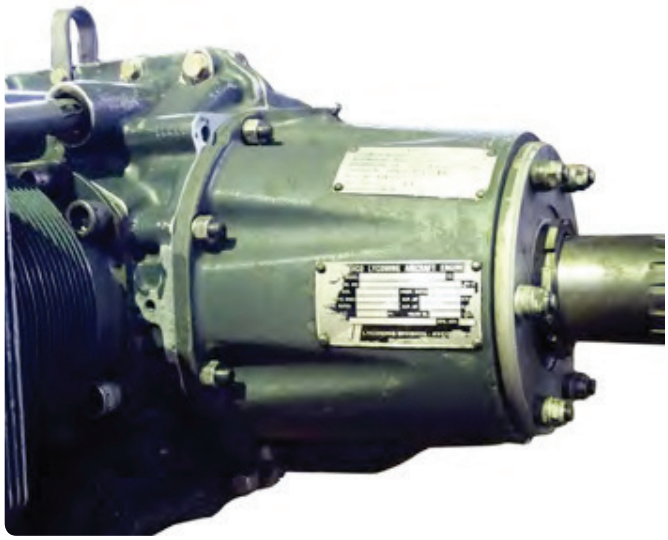


Figure 3-29. Planetary gear reduction system.

this ring, they also must rotate. Since they also mesh with the stationary gear, they walk or roll around it as they rotate, and the ring in which they are mounted rotates the propeller shaft in the same direction as the crankshaft but at a reduced speed. ***Figure 3-29*** shows a planetary propeller gear reduction system.

In some engines, the bell gear is mounted on the propeller shaft, and the planetary pinion gear cage is held stationary. The sun gear is splined to the crankshaft and acts as a driving gear. In such an arrangement, the propeller travels at a reduced speed but in opposite direction to the crankshaft.

In the bevel planetary reduction gearing system, the driving gear is machined with beveled external teeth and is attached to the crankshaft. A set of mating bevel pinion gears is mounted in a cage attached to the end of the propeller shaft. The pinion gears are driven by the drive gear and walk around the stationary gear, which is bolted or splined to the front section housing. The thrust of the bevel pinion gears is absorbed by a thrust ball bearing of special design. The drive and the fixed gears are generally supported by heavy-duty ball bearings. This type of planetary reduction assembly is more compact than the other one described and, therefore, can be used where a smaller propeller gear step-down is desired. In the case of gas turbine turboprop engines, more than one stage of reduction gearing is used due to the high output speeds of the engine. Several types of lower powered engines can use the spur and pinion reduction gear arrangement.

The spur and pinion type of propeller gear reduction system is relatively simple when compared to planetary gear reduction system. The spur and pinion gears are directly meshed, thereby connecting the crankshaft to the propeller shaft. Refer to ***Figure 3-30*** for an example of a spur type propeller gear reduction system.



Figure 3-30. Spur-type propeller gear reduction system.

PROPELLER SHAFTS

Propeller shafts may be of three major types: tapered, splined, or flanged. Tapered shafts are identified by taper numbers. Splined and flanged shafts are identified by SAE (Society of Automotive Engineers) numbers. The propeller shaft of most low power output engines is forged as part of the crankshaft. It is tapered and a milled slot is provided so that the propeller hub can be keyed to the shaft. The keyway and key index of the propeller are in relation to the No. 1 cylinder top dead center. The end of the shaft is threaded to receive the propeller retaining nut. Tapered propeller shafts are common on older and smaller engines. See ***Figure 3-31***.

The propeller shaft of high-output radial engines is generally splined. It is threaded on one end for a propeller hub nut. The thrust bearing, which absorbs propeller thrust, is located around the shaft and transmits the thrust to the nose section housing. The shaft is threaded for attaching the thrust-bearing retaining nut. On the portion protruding from the housing (between the two sets of threads), splines are located to receive the splined propeller hub. The shaft is generally machined from a steel-alloy forging throughout its length. The propeller shaft may

be connected by reduction gearing to the engine crankshaft, but in smaller engines the propeller shaft is simply an extension of the engine crankshaft. To turn the propeller shaft, the engine crankshaft must revolve. Refer to ***Figure 3-32*** for an illustration of a splined propeller shaft.

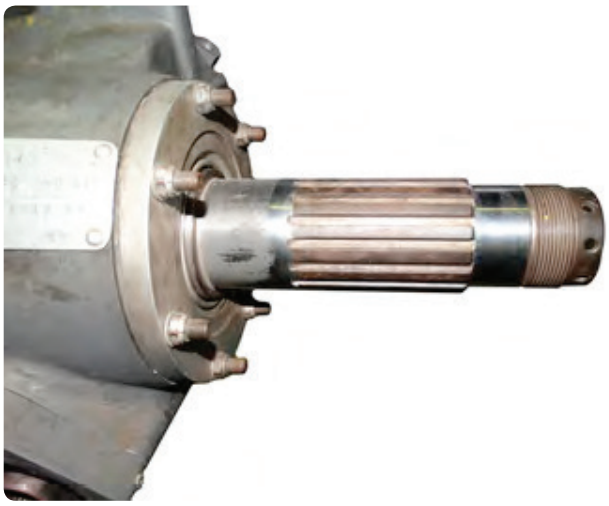


Figure 3-32. Splined propeller shaft .

Flanged propeller shafts are used on most modern reciprocating and turboprop engines. One end of the shaft is flanged with drilled holes to accept the propeller mounting bolts or studs. The installation may be a short shaft with internal threading to accept the distributor valve to be used with a controllable propeller. The flanged propeller shaft is a very common installation on most propeller driven aircraft. An example of a flanged propeller shaft is presented in ***Figure 3-33***.



Figure 3-33. Flanged propeller shaft.

ACCESSORY SECTION

The accessory (rear) section usually is of cast construction and the material may be either aluminum alloy, which is used most widely, or magnesium, which has been used to some extent. On some engines, it is cast in one piece and provided with means for mounting the accessories, such as magnetos, carburetors, fuel, oil, vacuum pumps, starter, generator, tachometer drive, etc., in the various locations required to facilitate accessibility. Other adaptations consist of an aluminum alloy casting and a separate cast magnesium cover plate on which the accessory mounts are arranged. Accessory drive shafts are mounted in suitable drive arrangements that are carried out to the accessory mounting pads. In this manner, the various gear ratios can be arranged to give the proper drive speed to magnetos, pumps, and other accessories to obtain correct timing or functioning.

ACCESSORY GEAR TRAINS

Gear trains, containing both spur- and bevel-type gears, are used in the different types of engines for driving engine components and accessories. Spur-type gears are generally used to drive the heavier loaded accessories or those requiring the least play or backlash in the gear train. Bevel gears permit angular location of short stub shafts leading to the various accessory mounting pads. On opposed, reciprocating engines, the accessory gear trains are usually simple arrangements. Many of these engines use simple gear trains to drive the engine's accessories at the proper speeds.

SUMPS

Reciprocating aircraft engines have sumps that are used as part of the oil system. The sumps are located at the low point of the engine and are used to collect oil circulating through the engine after the oil has completed its tasks. Depending on where the lubricating oil for the engine is stored will determine whether the engine is a wet sump or a dry sump.

Wet sump engines use the sump as the storage tank for the oil. Oil departs the oil sump, passes through the engine, and returns to the oil sump beneath the engine. Because the oil remains in the engine, with the exception that it may travel to a remote oil cooler, the engine is classified as a wet sump design. See ***Figure 3-s34***.

By contrast, dry sump engines store their oil in a remote tank. Generally speaking, dry sump engines have oil



Figure 3-34. Wet sump engine .

quantities that are comparatively large. For example, an airplane equipped with a 9-cylinder radial engine may have an oil capacity of 8 gallons. A 14-cylinder radial engine typically has an oil tank with a 30 gallon capacity. In such instances, it would not be practical to keep those quantities of oil within the engine. Consequently, the oil sump is used to collect the oil that has passed through the engine and return the oil to the oil tank. A scavenge oil pump is used to transfer the oil from the dry sump to the oil tank. Normally, the oil returning to the oil tank from the sump passes through an oil cooler. An example of a dry sump is presented in ***Figure 3-35***.

INDUCTION SYSTEMS

The induction system of a typical reciprocating aircraft power plant begins with the inlet air filter, or opening for carburetor heat or alternate air entrance, and ends at the intake port. Induction air passes through the air box, if used, into the fuel-metering system and induction



Figure 3-35. Dry sump on a radial engine located between the two lowest cylinders.



Figure 3-36. Updraft induction manifold.

pipes before reaching the intake ports of the cylinders. The fuel/air charge next passes the intake valve before entering the combustion chamber.

Induction systems can consist of several different arrangements. Two that are commonly used on opposed engines are the updraft and downdraft induction systems. An updraft induction system places the induction pipes below the cylinders. The fuel/air charge in the induction pipes has to flow in an upward direction to deliver the combustible mixture to the intake valve of the cylinders. Refer to ***Figure 3-36***.

Downdraft induction manifolds are situated above the cylinders. The fuel/air destined for the intake ports flows downward to reach the intake valve as shown in ***Figure 3-37***.

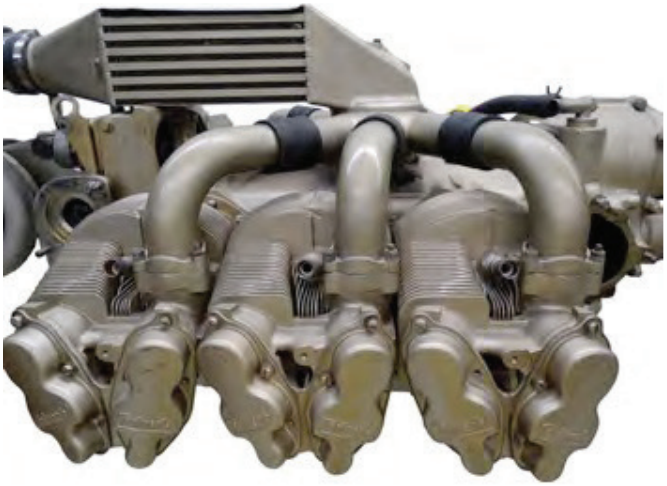


Figure 3-37. Downdraft induction manifold.

On radial engines, the intake pipes depart the diffuser housing and run parallel to the cylinders. The intake pipes terminate at the intake ports. For an illustration of the induction pipes of a radial engine see ***Figure 3-38***.



Figure 3-38. Radial engine induction tubes.

RECIPROCATING ENGINE EXHAUST SYSTEMS

The reciprocating engine exhaust system is fundamentally a scavenging system that collects and disposes of the high temperature, noxious gases being discharged by the engine. Its main function is to dispose of the gases with complete safety to the airframe and the occupants of the aircraft. The exhaust system can perform many useful functions, but its first duty is to provide protection against the potentially destructive action of the exhaust gases. Modern exhaust systems, though comparatively light, adequately resist high temperatures, corrosion, and vibration to provide long, trouble-free operation with minimum maintenance. There are two general types of exhaust systems in use on reciprocating aircraft engines: the short stack (open) system and the collector system. The short stack system is generally used on non-supercharged engines and low-powered engines where noise level is not too objectionable. On the other end of the spectrum, short stack exhaust systems are sometimes found on World War II airplanes like the P-51 Mustang.

The collector system is used on most large non-supercharged engines and on all turbo-supercharged engines and installations on which it would improve nacelle streamlining or provide easier maintenance in the nacelle area. On turbo-supercharged engines, the exhaust gases must be collected to drive the turbine of the supercharger. Such systems have individual exhaust headers that empty into a common collector ring with only one outlet. From this outlet, the hot exhaust gas is routed via a tailpipe to the turbo-supercharger that drives the turbine. Although the collector system raises the back pressure of the exhaust system, the gain in horsepower from turbo-supercharging more than offsets the loss in horsepower that results from increased back pressure. The short stack system is relatively simple, and its removal and installation consists essentially of removing and installing the hold-down nuts and clamps. Short stack systems have limited use on most modern aircraft.

The exhaust system in ***Figure 3-39*** consists of a down-stack from each cylinder, an a pair of exhaust collector tubes, or manifold, on each side of the engine, and an exhaust ejector assembly protruding aft and down from each side of the firewall. The down-stacks are connected to the cylinders with high temperature locknuts, or plain nuts with flat and lock washers, and secured to the exhaust collector tube by ring clamps. On most single engine aircraft, an exhaust shroud is installed around certain exhaust system components to provide heat for inlet air, the cabin heater, and the windshield defrosting system.



Figure 3-39. Exhaust pipes.

RADIAL ENGINE EXHAUST COLLECTOR RING SYSTEM

Figure 3-40 shows the exhaust collector ring installed on a fourteen-cylinder radial engine. The collector ring is a welded corrosion-resistant steel assembly manufactured in seven sections, with each section collecting the exhaust from two cylinders. The sections are graduated in size. The exhaust tailpipe is joined to the collector ring by a telescoping expansion joint, which allows enough slack for the removal of segments of the collector ring without removing the tailpipe. The exhaust tailpipe is a welded, corrosion-resistant steel assembly consisting of the exhaust tailpipe and, on some aircraft, a muff-type heat exchanger.

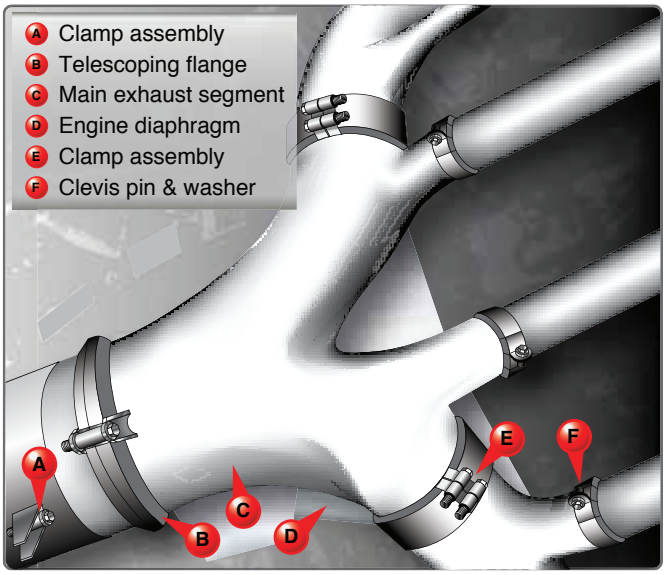


Figure 3-40. Exhaust collector of radial engines.

Question: 3-1
What are the 3 principle forces from various components which a crankcase must resist?

Question: 3-2
What are the three main components of every crankshaft?

Question: 3-3
What is the primary purposes of counterweights and dampeners on crank shafts?

Question: 3-4
What are the four principle benefits of aluminum for use in the construction of cylinders?

Question: 3-5
Which section of a cylinder contains the greatest amount and size of cooling fins?

Question: 3-6
In what way does filling an exhaust valve with Sodium help to keep it cool?

Question: 3-7
At what point in the typical 4 stroke cycle are both the intake and exhaust valve open at the same time?

Question: 3-8
When connected by gears, for the camshaft to rotate at one half the speed of the crankshaft, the gear connected to the camshaft must be_____ the size.

ANSWERS

Answer: 3-1
Gyroscopic forces of the propeller.
Tension forces of the cylinders.
Centrifugal forces from crankshaft.
page 3.2

Answer: 3-2
Journal; Crankpin; Crank cheek.
page 3.4

Answer: 3-3
Reduce engine vibration.
page 3.4

Answer: 3-4
Light weight; Good conductor of heat; Easily cast; Corrosion resistant.
page 3.5

Answer: 3-5
The area around the exhaust valve.
page 3.6

Answer: 3-6
Sodium melts and flows up and down stem thus transferring heat.
page 3.7

Answer: 3-7
As the exhaust stroke ends and the intake stroke begins.
page 3.8

Answer: 3-8
Twice the size.
page 3.10

Question: 3-9
What is the primary advantage of hydraulic valve lifters over solid lifters?

Question: 3-10
Of the five basic components directing valve movement, list the order in which each component is engaged?

Question: 3-11
When is the process of chrome plating cylinders applicable?

Question: 3-12
Of the two types of piston rings, which type is positioned closer to the piston head?

Question: 3-13
Which ring type manages proper lubrication on the cylinder wall?

Question: 3-14
What are the 4 types of connecting rod assemblies?

Question: 3-15
With which type of reduction gear does the propeller spin in the opposite direction as the crankshaft?

Question: 3-16
A splined propeller shaft is typically found on a:
a. low power engine
b. mid powered engine
c. high powered engine

ANSWERS

Answer: 3-9
Valve clearance is always at zero; eliminates the need for adjustments.
page 3.11

Answer: 3-10
Camshaft drive the tappets, which moves the pushrod, which moves the rocker arms, which pushes the valve.
page 3.11

Answer: 3-11
After the cylinder has worn to restore it to proper dimensions.
page 3.12

Answer: 3-12
Compression rings are closer to the head; Oil control rings are positioned lower.
page 3.13

Answer: 3-13
Oil control rings.
page 3.14

Answer: 3-14
Plain; Fork & Blade; Master & Articulated; Split Type.
page 3.14

Answer: 3-15
Spur planetary type.
page 3.17

Answer: 3-16
c – high powered engine.
page 3.18

Question: 3-17
What type of sump system is typically employed on engines which require large quantities of oil?

Question: 3-18
What is the primary purpose of the exhaust system on non-supercharged reciprocating engines?

ANSWERS

Answer: 3-17
Dry sump with a remote oil tank.
page 3.19

Answer: 3-18
Safely dispose of exhaust gasses without danger to the crew or damage to the airframe.
page 3.20



PISTON ENGINE

ENGINE FUEL SYSTEMS

SUB-MODULE 04

PART-66 SYLLABUS	LEVELS		
CERTIFICATION CATEGORY →	A	B1	B3
Sub-Module 04 **Piston Engine - Engine Fuel Systems**			
16.4.1 - Carburetors Types, construction and principles of operation; icing and heating	1	2	2
16.4.2 - Fuel Injection Systems Types, construction and principles of operation	1	2	2
16.4.1 - Electronic Engine Control Operation of engine control and fuel metering systems including electronic engine control (FADEC); Systems layout and components	1	2	2

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

Objectives:

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

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

Objectives:

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

ENGINE FUEL SYSTEMS

CARBURETORS

The basic requirement of a reciprocating fuel metering system is the same, regardless of the type of system used or the model engine on which the equipment is installed. It must meter fuel proportionately to air to establish the proper fuel/air mixture ratio for the engine at all speeds and altitudes at which the engine may be operated. In the fuel/air mixture curves shown in **Figure 2.1**, note that the basic best power and best economy fuel/air mixture requirements for reciprocating engines are approximately the same. The fuel metering system must atomize and distribute the fuel from the carburetor into the mass airflow. This must be accomplished so that the fuel/air charges going to all cylinders holds equal amounts of fuel. Each one of the engine's cylinders should receive the same quantity of fuel/air mixture and at the same fuel/air ratio.

The information provided in this section is for instructional purposes. It is not to be used as a substitute for the technical data presented in the manuals published by the various carburetor manufacturers.

CHARACTERISTICS OF THE FLOAT CARBURETOR

The float carburetor has served the fuel metering needs of aeronautical engines for decades. It still reigns as the primary means of fuel metering on small, general aviation aircraft and amateur-built machines.

The carburetor is, for the most part, very reliable. Its main weakness is in the area of carburetor ice. A second point in which the float carburetor falls short in comparison to other forms of fuel metering deals with flight attitude. A float carburetor must remain upright or under a positive force of gravity (plus Gs) to properly function. Another short coming of the float carburetor involves fuel distribution. Because the intake valves of the cylinders are typically located either a little nearer or further from the carburetor's discharge nozzle, a minute disparity of fuel delivery occurs between the cylinders. Despite these negative characteristics, the float carburetor has proven its worth in the field of aeronautics. Image the total number of people who learned to fly using an engine equipped with a float carburetor. Beyond flight training, how many total flight hours have been amassed using float carburetors?

DESIGN OF A FLOAT CARBURETOR

The float carburetor is an amalgamation of various systems and subsystems. Some systems are independent of the others while other systems are dependent on one another. Typically, a float carburetor is composed of the following systems: (a) fuel inlet and filtration, (b) fuel level, (c) main discharge, (d) idle circuit, (e) air bleeds (f) power enrichment, (g) mixture control, and (h) acceleration. A discussion of each system and associated theories of operations and construction details are provided.

FUEL INLET AND FILTERING

Generally, a fuel filter or screen is installed at the inlet of the fuel metering device. This screen is normally serviced during the inspection of the power plant. It is also removed and inspected during troubleshooting operations.

NEEDLE VALVE, VALVE SEAT, AND FLOAT MECHANISM

As the carburetor consumes fuel from its float bowl, some means of replenishing the fuel is necessary for continued operation. This is accomplished through the use of a needle valve, valve seat, and float mechanism.

Fuel that passes through the inlet of a carburetor normally encounters a filter or screen before reaching the needle valve and valve seat. ***(Figure 4-1)*** When the needle valve is opened, fuel travels past the valve seat and enters the float bowl. Fuel then departs the bowl and exits the carburetor through one of the discharge systems. Fuel discharge avenues include the idle circuit, main discharge nozzle, and the acceleration system, if equipped. Fuel may also be removed from the float bowl via drain plugs and/or drain valves.

The material used for needle valves and seats have evolved over the years. Initially, the needle valves and seats were made from metal. The metal-to-metal valve worked well but was subjected to wear. When the wear



Figure 4-1. Carburetor fuel inlet screen.

became significant, the valves would leak with the result of having gasoline overflow from the carburetor. The mixture also became enriched due to the high fuel level within the float bowl.

Today, needle valves will likely have a soft tip to eliminate the metal-to-metal contact of the early generation needle valves and seats. A common material used as the valve tip is viton. Other needle valves are entirely constructed using a plastic-like material. As with the viton-tipped valves, the plastic units have better wear characteristics than the metal-to-metal needle valves and seats.

Along with the introduction of the soft tip valve came a new problem. The needle valves would sometimes stick in the valve seat. A conically-shaped soft valve tip inserted into the hole of the valve seat is similar to sticking a cork in a bottle. When the needle valve becomes stuck in the valve seat, fuel flow into the carburetor's float bowl ceases, thereby causing the engine to stop. To prevent this from occurring, one manufacturer developed a retraction clip.

The retraction clip engages the knob at the end of the needle valve and the float assembly. Downward movement of the float assembly as fuel is consumed from the float bowl pulls on the needle valve to unseat it in the event that it sticks in its seat. This measure is a safety precaution as fuel flow to the carburetor's bowl ceases when the needle valve sticks in the seat. Refer to ***Figure 4-2*** for an illustration of the retraction clip and associated needle valve.

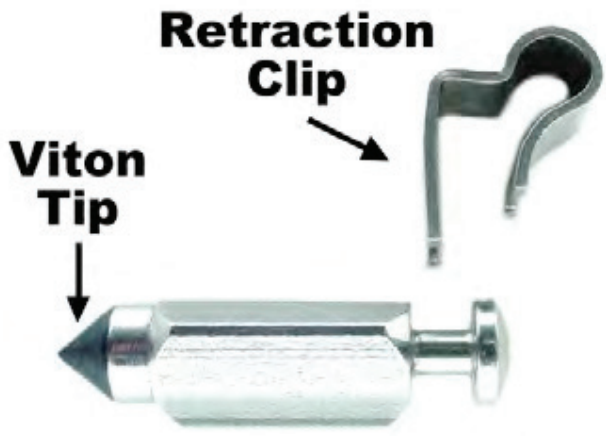


Figure 4-2. Needle valve and retraction clip.

The purpose of the float is to maintain the proper fuel level within the bowl. It accomplishes this by opening and closing the needle valve. As fuel is admitted into the float bowl, the float rises. The upward movement of the float acts on the needle valve. When the fuel level reaches its designed level, the float presses the needle valve into the seat to stop additional fuel from entering the carburetor, thereby controlling the fuel level.

The construction of the float varies from metallic to composite units. Due to service difficulties that have developed with floats, they have been redesigned over the years. Material used to form the composite float has also changed over time. See ***Figures 4-3 and 4-4*** for examples of metallic and composite floats.

Failures of the float typically involve the loss of buoyancy. In such instances, the float is unable to cutoff the entry of



Figure 4-3. Metal float.



Figure 4-4. Composite float.

fuel into the float bowl and a flooded condition occurs. This results in a reduction of engine performance. In severe cases, the loss of engine power may prevent the aircraft from sustaining altitude.

The float must be properly adjusted to establish proper fuel flows during engine operation. A fuel level that is too high or too low in the float chamber will result in richer and leaner mixtures, respectively. Technicians must closely follow manufacturer's instructions when adjusting or checking the float adjustment of a carburetor.

MAIN DISCHARGE SYSTEM

There are a number of discharge points that deliver fuel from the carburetor to the engine. They are: (a) main discharge, (b) idle discharge, and (c) accelerator discharge. The carburetor is designed to shift from the idle discharge to the main discharge and vice versa as power settings are changed by the operator. In addition, the acceleration system is designed to simultaneously discharge fuel from its nozzle while the engine is digesting fuel from either the idle or main discharge circuits. Despite the number of discharge points, the engine receives fuel primarily from the main discharge system. At low power settings the idle discharge is used to deliver fuel flow to the engine.

The motive force needed to push fuel through the various jets and passageways of the carburetor is generated by the pressure differential between the float bowl and the discharge nozzle. The power to deliver fuel from the acceleration system is provided by the opening of the throttle. The pressure in the float bowl is nearly equal to atmospheric pressure. Conversely, the pressure at the exit points of the idle system and main discharge nozzle are relatively low pressure due to the action of pressure in the induction manifold and air flowing through the venturi. The absolute pressure in the venturi is determined by three main factors: (a) the basic shape and dimensions of the venturi, (b) the starting ambient pressure, and (c) the quantity of air flowing through the unit. The quantity of air passing through the venturi is determined by the rpm of the engine and the position of the throttle plate.

In terms of the main discharge system, the venturi for a particular carburetor is designed to limit the maximum air flow to the engine at full throttle. Because the venturi is in series and upstream of the induction manifold system, air flowing into the engine must first pass through the venturi. This arrangement means that the air consumed by the power plant is first measured by the venturi.

Before delving into an explanation of metering forces, study the series of illustrations depicted below. In the first example the pressures at A and B are equal. Because there is no pressure differential the fluid levels are also equal. ***(Figure 4-5)***

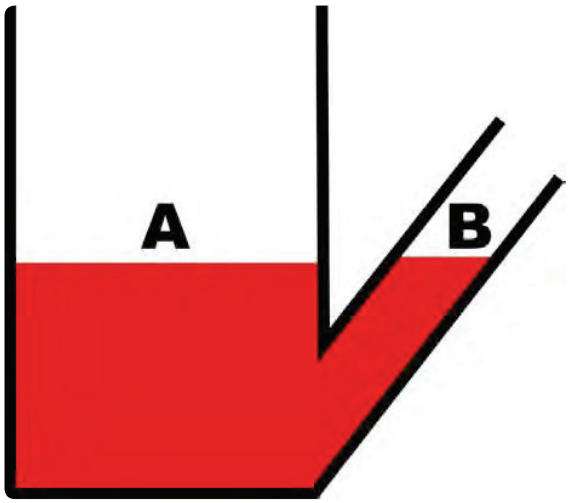


Figure 4-5. Fuel levels at "A" and "B" are equal when pressures at "A" and "B" are equal.

The same result occurs when a float carburetor does not have air flowing through it. The fuel level in the float bowl equals the level of the fuel at rest in the discharge nozzle. The level of the fuel in the bowl is checked using a special plumbing fitting with a transparent piece of tubing (Refer to ***Figure 4-6***). After screwing the viewing tool into the drain of the bowl, the level of the fuel within the bowl may be determined by opening the fuel valve and observing the height of the meniscus in the transparent tube. Another check of the float and valve mechanism is to operate the auxiliary pump, if equipped, while monitoring the meniscus in the transparent tube.

In the next illustration the pressure at B has been reduced by the action of air flowing through the venturi. The net result is the establishment of a pressure differential between A and B. The magnitude of the pressure differential may be determined by measuring the height of the fluid at point B above the level of the fluid at point A (e.g., 1 inch of water pressure).

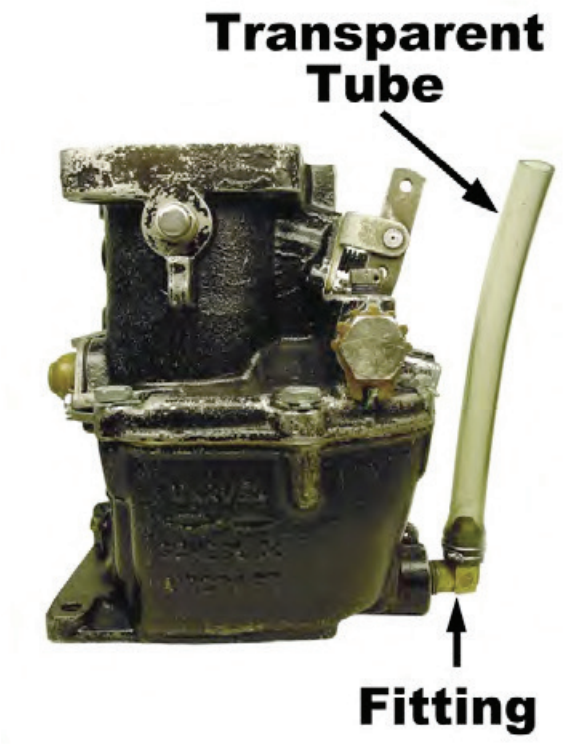


Figure 4-6. Transparent tube and fitting screwed into float bowl drain.

In the case of the float carburetor, the area labeled region "A" is the float chamber. Its pressure is near ambient. Region "B" represents the end of the main discharge nozzle. Because the end of the discharge nozzle is situated in the venturi, low pressures are generated as the air flows through the unit. As in illustrated in ***Figure 4-7***, it is the pressure differential generated by the carburetor that causes the fuel to rise to the end of the discharge nozzle. This is a basic concept for generating flow through the carburetor.

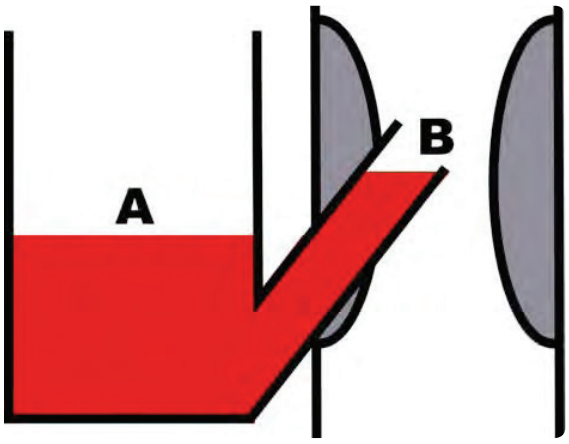


Figure 4-7. Fuel levels at "A" and "B" are unequal when pressures "A" and "B" are unequal.

In the following illustration ***(Figure 4-8)*** notice the addition of an orifice. This restrictor serves as a metering device. The flow through an orifice is determined by the size of the orifice, the pressure differential exerted across the orifice, and the viscosity of the fluid. Because the viscosity of gasoline is fairly constant throughout the operational range of the power plant, the focus of this discussion is placed on the size of the orifice and the pressure differential acting across it.

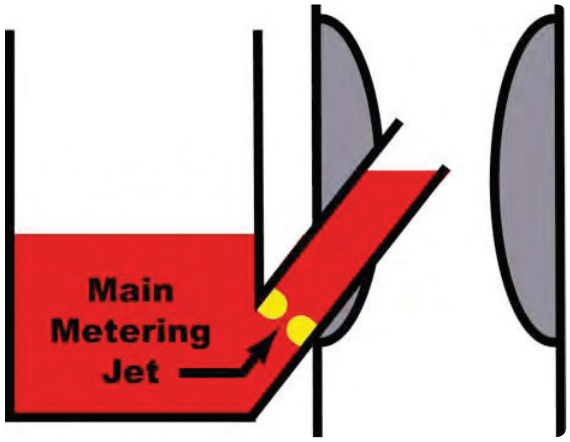


Figure 4-8. Main metering jet situated between float bowl and venturi controls fuel flow based on pressure differential.

In the realm of fuel metering engineering, the designers carefully devise the carburetor to ensure the proper flow delivery to the engine. Areas of major importance include the amount of pressure differential between the bowl chamber and the venturi and the size of the main metering jet. If the pressure differential is the same, more fuel will flow through a larger orifice than a smaller orifice. Similarly, more fuel flows through a particular size orifice if the pressure differential acting across it is increased. Consequently, manufacturers of aircraft carburetors must carefully determine the amount of pressure differential generated by the unit, the necessary fuel and air flows, and the size of the metering orifice.

MIXTURE CONTROLS

Aircraft fuel metering systems encounter a problem in maintaining a constant fuel/air ratio as the aircraft ascends and descends. Vehicles that operate on the surface do not have this problem or have this problem only when driving through mountainous terrain.

The problem associated with the change in mixture is attributed to the change in the weight of the air as altitude increases and decreases. As altitude increases, the weight of the air decreases.

The carburetor functions by creating a pressure differential between the float bowl chamber and the discharge nozzle. In regard to the main discharge system, the pressure differential is based on the flow of air through the venturi. As air passes through the venturi, the pressure changes as per Bernoulli's Principle. The pressure drop is determined by the amount of flow and less dependent on the absolute pressure of the incoming air. Consequently, if the pressure drop through the venturi for a particular quantity of flow is 5 inches of water, it does not matter whether the initial pressure is at 29.92"HG or 26.00"HG, a pressure drop is a pressure drop. Therefore, if the pressure drop is constant, the fuel metering force remains the same and the fuel flow remains constant. But because the air has less weight, the same quantity of fuel flow generates an enriched mixture.

To compensate for this problem, aircraft carburetors are normally equipped with a mixture control system. There are two major styles of mixture controls: (a) manual and (b) automatic. The latter is often called an automatic mixture control or AMC. Some systems include both a manual mixture control and an AMC. The primary purpose of the mixture control is to tailor the fuel flow to the engine so that the fuel/air ratio remains suitable for the engine at various altitudes. Without this ability, the enrichening of the fuel/air mixture adversely affects the power output of the engine. A secondary use of the manual mixture control is to kill the engine. This is accomplished by placing the mixture control in idle cutoff (ICO). In ICO the flow passage from the bowl to the discharge nozzle is blocked. Shutting down the engine using ICO enhances safety as the probability of having a combustible fuel/air charge in the cylinders after the engine comes to a complete stop is less than it would be if the engine was killed using the ignition switch. This is particularly critical when the magnetos are equipped with impulse couplings due to the hot spark generated while rotating the engine in direction of rotation regardless of the speed of rotation.

Two means for manually manipulating the fuel/air mixture are used on float carburetors: (a) mechanical blockers and (b) back-suction. Each provides a means whereby the operator may lean the mixture from its full-rich mode.

MECHANICAL BLOCKER TYPE MIXTURE CONTROLS

Manual mixture controls that mechanically block the fuel passage leading to the discharge nozzle, both main and idle discharge nozzles, are able to completely close the fuel passageway. This allows the mixture control valve to become the dominant orifice when its opening is smaller than the size of the main metering jet. In ICO the valve completely blocks the passageway leading to the main metering jet and idle circuit. ***(Figure 4-9)***

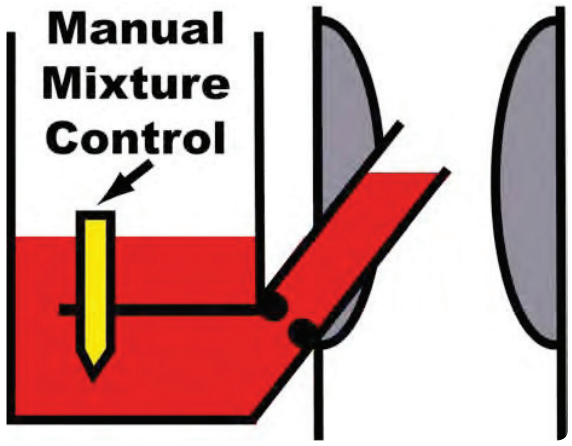


Figure 4-9. Mechanical blocker type manual mixture control.

Manual mixture controls that physically block the fuel passage leading to the discharge nozzles typically incorporate two stops: (a) full rich and (b) idle cutoff. Technicians should ensure that the mixture control reaches each stop. Failure to fully reach each stop will adversely affect the operation of the carburetor and power plant.

BACK SUCTION MIXTURE CONTROLS

Back suction mixture controls, used predominately on the Bendix-Stromberg NAS-3 series carburetors, operate by controlling the pressure differential between the float bowl chamber and the discharge nozzle. A passageway leading from the float bowl (B) to a port slightly downstream of the venturi (C) is used to lessen the pressure in the bowl. Refer to ***Figure 4-10***. By decreasing the pressure in the bowl, the pressure differential between the bowl and the discharge nozzle is reduced. When the pressure

differential between the float bowl chamber and discharge nozzle decreases for other variables being equal, fuel flow to the engine is reduced.

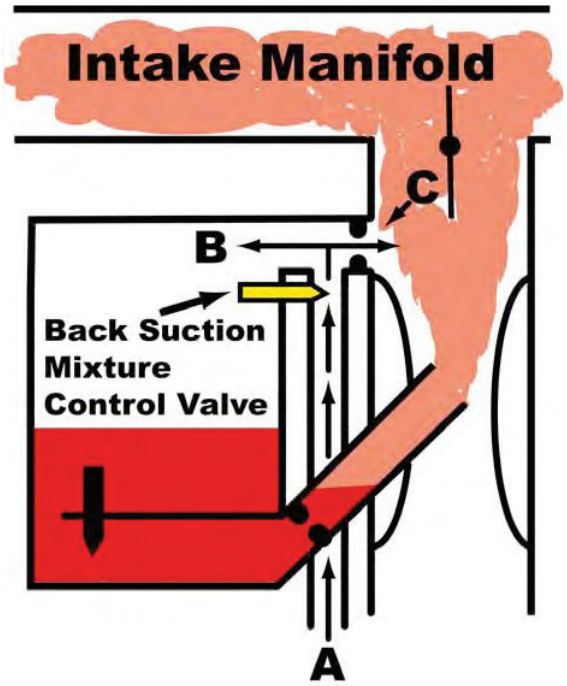


Figure 4-10. Back suction mixture control works by manipulating bowl chamber pressure.

To elaborate on the operation of this mixture control system, bowl chamber pressure enters at port A as shown in ***Figure 4-10***. When the mixture control valve is fully opened, air entering port A is allowed to fill the float bowl chamber faster than it escapes from port C. This provides maximum bowl chamber pressure. Air from the bowl is pulled from port B to port C (which is slightly downstream of the venturi). The pressure at port C is lower than the pressure of the air entering at port A. When the mixture control valve moves toward full lean, air entering port A is unable to freely fill the bowl chamber. The bulk of the air that does enter the bowl chamber is pulled from the bowl area into the throttle bore region through port C. This reduces the pressure in the bowl chamber and lowers the pressure differential between bowl chamber and discharge nozzle. The end result is a reduction of fuel flow.

The back suction mixture control does not have an idle cutoff position as other types of mixture controls that block the flow path of the fuel. This is because the suction port (C) has greater pressure than the tip of the discharge nozzle situated in the venturi.

This technique for manipulating pressure differentials is used by Bendix for controlling the mixture of its small pressure carburetors. It is also used by the AMCs of their large and small pressure carburetors and continuous flow fuel injection systems.

AUTOMATIC MIXTURE CONTROLS (AMCS)

AMCs, in float carburetors, operate by sampling the absolute pressure in the float bowl chamber. AMCs are basically aneroid barometers that expand and contract with increases and decreases in altitude. Such movement of the AMC aneroid serves to reposition its metering valve. As the valve attached to the AMC changes its position, the opening of the passageway leading to the main metering jet changes in terms of size. ***(Figure 4-11)***

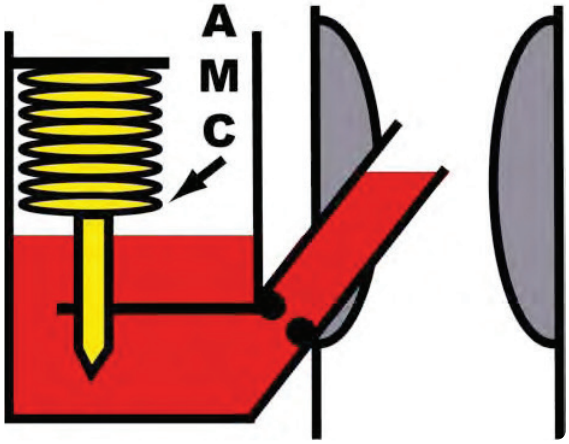


Figure 4-11. Aneroid bellow AMC (fuel blocker type).

AMCs are designed to ***fail safe***. If the aneroid develops a leak, the springy design of the bellows assembly causes the unit to revert to its full rich mixture. In this way, the risk of operating with a lean mixture at low altitudes is averted. ***Figure 4-12*** is a cutaway photograph of an automatic mixture control used with popular carburetors. Note the accordion-shaped bellows assembly. It expands and contracts in reaction to changes in the bowl chamber pressure.

MAIN AIR BLEED

In the preceding pages, a simple carburetor has been built. The systems thus far have included a fuel inlet; needle valve, valve seat, and float mechanism; a means for producing differential pressure between the bowl chamber and the tip of the discharge nozzle via airflow through a venturi; a main metering jet; and



Figure 4-12. Automatic mixture control assembly.

a mixture control valve. Where the aforementioned carburetor would meter fuel to the engine, the unit would not thoroughly atomize the fuel as it departs the fuel nozzle. Remember that all reciprocating power plant fuel metering systems must accomplish two basic functions: (a) meter and (b) atomize. To atomize the metered fuel, air is blended with the fuel before it exits the discharge nozzle. ***(Figure 4-13)***

To illustrate the blending of air with a liquid, construct a simple air bleed system as shown in ***Figure 4-14***. This

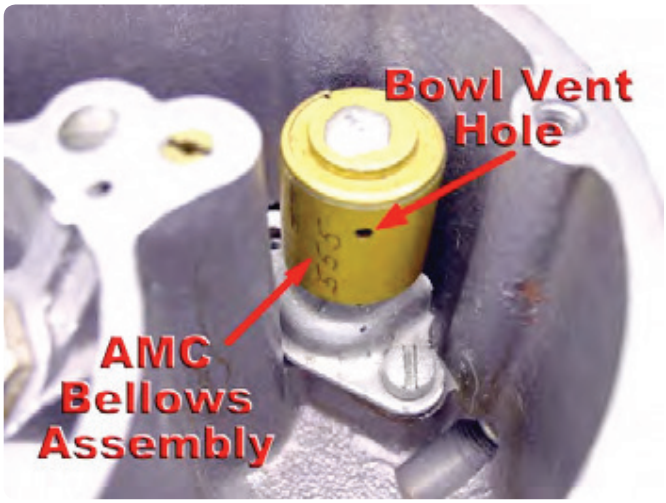


Figure 4-13. AMC in float bowl of Marvel-Schebler/Precision MA-6 carburetor.

device consists of a piece of tubing with a tee-fitting. To the straight leg of the tee-fitting is connected a segment of tubing. The total vertical run of tubing is now a modified straw. Attach a short segment of tubing to the remaining port of the tee-fitting. Affix a 90° elbow to open end of the short piece protruding from the tee-fitting. Add a segment of tubing to the remaining port of the elbow so that it runs vertical and parallel to the modified straw. Submerge the unit in a container of water so that the tee-fitting is beneath the meniscus. Take a drink of water by applying suction to the straw portion of the device. Note that the liquid is broken down into a water/air mixture. While taking a drink, momentarily plug the air bleed inlet with your finger and notice the reaction.

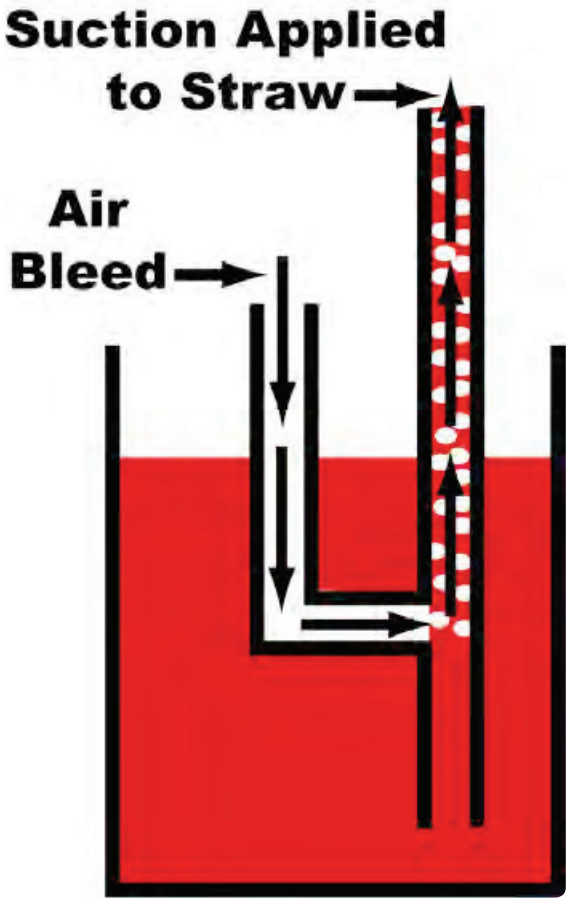


Figure 4-14. A simple air bleed.

The introduction of air to the metered fuel is undertaken by the air bleed system. Carburetors typically have two air bleed systems: (a) idle air bleed and (b) main air bleed. The idle air bleed works in conjunction with the idle circuit during low power operations and the main air bleed operates when the carburetor is discharging fuel through the main discharge nozzle. Idle air bleeds are presented under the section covering the idle system.

Air bleeds not only initiate the atomization process by uniting fuel and air, they carefully meter the amount of air mixed with the metered fuel. In this sense they help to establish the fuel/air ratio. Certain model carburetors manipulate the main air bleed system to achieve power enriched mixtures.

As fuel and air are united during the air bleed process, a number of changes occur. First, the fuel breaks down and mixes with air. The introduction of air basically means that more fuel is in contact with air. As the air bubbles its way through the fuel, the contact area of the micro-bubbles increases the total area where fuel and air interact. The final result is that a more homogeneous, combustible mixture emerges from the discharge nozzle. Upon departing the discharge nozzle, this mixture more readily blends with the induction-bound air.

The mixing of fuel and air is vital to the combustion process. In the final analysis, the conversion of the fuel into a combustible mixture is central to the power output generated by the engine. Just because a certain quantity of fuel enters the cylinders, this does not automatically guarantee that the conversion from the potential energy of the fuel into horsepower is going to take place. Instead, the fuel and air must be properly combined before the conversion of potential energy into horsepower is possible.

The blending of fuel and air is often assisted through the use of heat. One technique is to run the induction system through the engine's oil pan. The routing of the fuel/air charge through the oil pan adds heat to the mixture. By contrast, other engine manufacturers do not pass the induction manifold through the oil pan. In any event, the fuel/air charge encounters a considerable level of heat as it enters the intake port of the cylinders. The level of heat present at the intake port is determined by the cylinder head temperature.

Another change that occurs as fuel and air are combined during the air bleed process is the alteration to the viscosity of the mixture. Liquid fuel is considerably more viscous than a mixture of fuel and air. The latter offers less resistance to flow than the former. Consequently, the amount of force needed to move the fuel/air charge up the discharge nozzle is reduced.

And finally, the weight of the fuel/air blend is less than liquid fuel. This too lessens the amount of force required to raise the fluid up the discharge nozzle. For example, the same force needed to raise mercury one inch will lift water 13.6 inches. This means that if the fuel is required to ascend a height of one inch before reaching the tip of the discharge nozzle, less pressure differential is needed to raise a fuel/air mixture than raw liquid fuel.

Air used for the air bleed is often taken from the bowl vent system. In such cases, air is constantly entering and exiting the float bowl area. Refer to ***Figure 4-15*** that depicts the main air bleed.

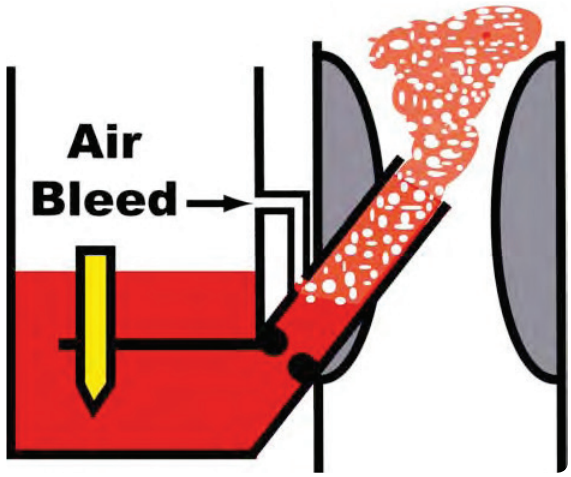


Figure 4-15. Main discharge system air bleed.

IDLE CIRCUIT

Due to the lack of pressure differential between the bowl chamber and the main discharge nozzle during low power settings, the carburetor employs a separate idle circuit. The design of the idle system not only furnishes a path of fuel delivery for low power settings, it further provides a means whereby the carburetor is able to seamlessly transition from its idle delivery circuit to the main discharge circuit and vice versa. The transition from the idle circuit to the main discharge circuit is controlled by the position of the throttle plate.

As with the main discharge circuit, an air bleed system is included in the idle system. Unlike the main air bleed system, the idle air bleed system on many carburetors use multiple air supplies. The activation and deactivation of the second and, if equipped, the third and fourth idle air bleeds are dependent on the position of the throttle.

Note in ***Figure 4-16*** that the throttle plate is nearly closed. As a result, the air consumed by the engine is limited by how much flows past the opening made between the perimeter of the throttle plate and the bore of the throttle body. As shown in the illustration, the size of the venturi is much larger in comparison to the amount of air ingested by the engine, that virtually no pressure drop is created. Furthermore, no significant pressure differential between bowl chamber pressure and main discharge nozzle pressure is generated. As a consequence, fuel does not rise to the tip of the main discharge nozzle.

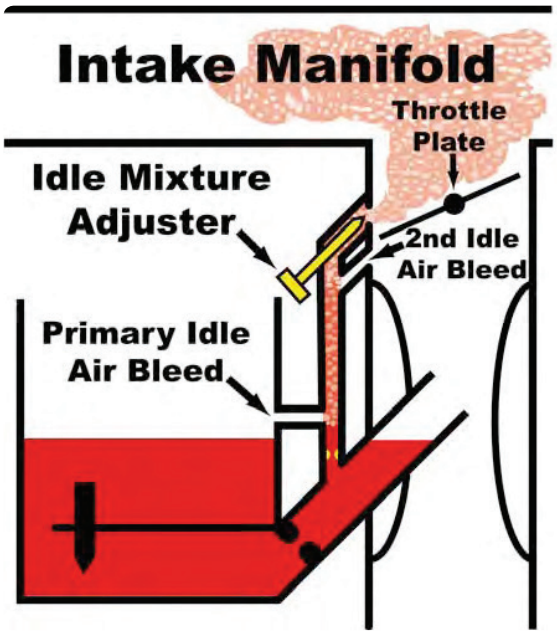


Figure 4-16. Typical idle circuit at low power.

The pressure differential during idle is between the manifold pressure and the bowl chamber pressure. Because the primary idle discharge port is situated downstream of the throttle plate, it is, technically speaking, in the induction manifold region. During idle and low power operations, the pressure in the manifold is quite low, usually between 11"HG to 15"HG depending on the engine and its condition. By contrast, the pressure in the bowl chamber is around 30"HG. Bowl chamber pressure is dependent on the ambient pressure applied to the metering unit. Exerting a pressure differential of 15"HG to 19"HG causes the fuel to rise up the idle circuit and discharge into the low pressure region of the manifold.

Another element that factors into the quantity of pressure exerted at the idle discharge nozzle(s) is the velocity of the flowing air mass. Because the opening between the bore of the throttle body and the perimeter of the throttle plate is small, the incoming air has a certain velocity. As per Bernoulli's Principle, the pressure of this rapidly flowing air is reduced, thereby serving to augment the pressure differential between the bowl chamber and the idle discharge nozzle(s).

Tracing the flow of fuel and air through the carburetor during idle, fuel is taken from the bowl. It then passes through the mixture control valve(s) and main metering jet. After passing the main metering jet, fuel is diverted upwards toward the idle discharge nozzles. Before reaching the idle discharge nozzle(s), idle fuel is first metered. An idle jet situated at the bottom of the idle passageway, as shown in yellow in ***Figure 4-16***, limits the flow of fuel delivered by the idle circuit. Note that because the idle jet is much smaller than the main metering jet that it is doing the metering. This is because the main metering jet is too large to offer any resistance to flow during low power operations. Fuel is then united with the primary idle air bleed. Fuel and air travel to the discharge nozzle(s). Note that the uppermost discharge port contains an adjustment screw. This mechanism is used to tailor the fuel-to-air ratio of the engine during idle operations. Information regarding the adjustment of this device is contained in the aircraft service manual.

In ***Figure 4-16***, the throttle valve is positioned so that only one discharge port is downstream of the throttle plate. The second hole labeled, “2nd Idle Air Bleed” is located beneath the throttle plate. The pressure differential across the throttle plate is high. On the upstream side the pressure is nearly ambient. On the downstream side there is manifold pressure, which is extremely low during idle operations. Because of this pressure differential, the second idle hole acts as a second air bleed during low idle power settings. High pressure air from the underside of the throttle plate enters the second hole and mixes with the fuel/air mixture traveling to the upper hole. This action is due to the fact that fluids travel from areas of high pressure to those of low pressure.

As the throttle valve is further opened, the second hole becomes exposed to the induction manifold pressure. Where manifold pressure increases as the throttle is opened, the pressure differential between the bowl

chamber and the first and second holes is still great enough to draw fuel and air from the idle circuit. Consequently, fuel discharges from both ports.

Many carburetors are equipped with a third idle hole and some have a fourth idle port. The operation of the third and fourth idle ports is similar to that of the second hole. When the edge of the throttle plate is above an idle port, it serves the role of a supplemental idle air bleed. When the throttle plate is opened so that the third hole is exposed to the manifold pressure, it discharges fuel. The same is true of the fourth idle port, if the carburetor is so equipped. This action of the idle ports is predicated on whether or not the main discharge system is delivering fuel to the engine. The main purpose for placing a series of idle ports down the throttle bore is to provide a means whereby the carburetor is able to transition from its idle circuit to its main discharge circuit and vice versa.

Note in ***Figure 4-17*** that the fuel level in the main discharge nozzle is near the tip of the nozzle. The elevation of the fuel up the discharge nozzle is in response to the pressure differential created by the increase of air flow through the venturi. Because the throttle was opened from low idle ***(Figure 4-16)*** to high idle ***(Figure 4-17)***, more air is consumed by the engine. As the venturi is located upstream of the induction manifold and in series with the manifold, the air consumed by the engine flows through the venturi. If the throttle is opened a little further, an additional measure of air will flow through the venturi. At some point, the pressure drop in venturi, in response to air flow, will be strong enough to cause fuel to flow from the main discharge nozzle. At that point, the manifold pressure will be high enough to discontinue flow through the idle circuit. In other words, the pressure differential between the bowl chamber and the discharge nozzles of the idle circuit will be too low to cause fuel to flow from the idle system. When this occurs, the carburetor has transitioned from its idle circuit to its main discharge circuit.

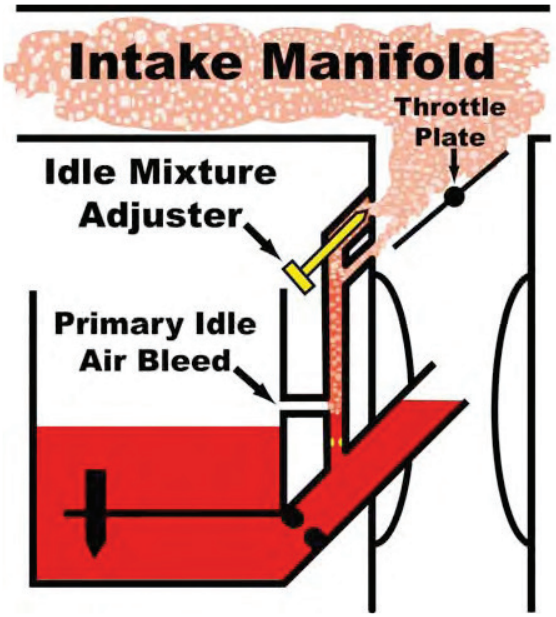


Figure 4-17. Idle discharge through multiple ports during high idle operation.

THROTTLE SYSTEM

The throttle system of a carburetor is used for various operations. Its most basic function is to regulate air flow into the induction manifold. As such, it is used by the operator to control power input to the engine.

The throttle plate itself, also known as the butterfly valve, conforms to the shape of the throttle bore. In most carburetors the butterfly valve is circular. Throttle plates may also be rectangular in design. The edge of the throttle plate is often beveled as shown in ***Figure 4-18***. This is necessary as the throttle valve generally does not have enough rotation to form a perpendicular angle with the throttle bore. Instead, when it is fully seated against the walls of the throttle bore, a slight angle is formed. When correctly installed, the bevel of the throttle plate runs parallel with the throttle bore when the throttle is fully closed in the idle position.

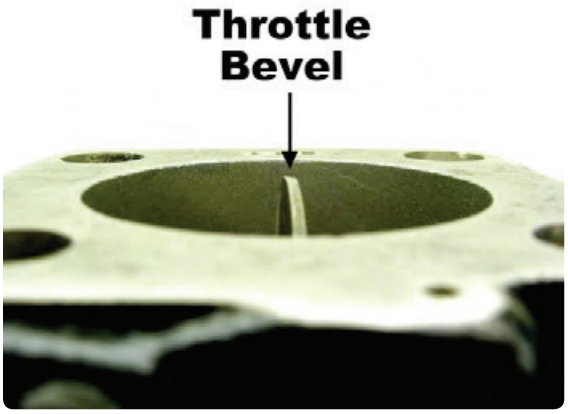


Figure 4-18. Side view of throttle valve. Note beveled edge.

The butterfly valve is attached to the throttle shaft by screws that are safety peened. Safety peening is accomplished by flaring out the portion of the throttle plate screws that protrude beyond the throttle shaft.

Special tools are used for peening the throttle plate screws. Without the use of special tools, peening the screws may result in damage to the carburetor.

The throttle shaft is connected to the throttle control manipulated by the operator. The throttle link between the control knob and throttle shaft has to accommodate for relative motion between the engine and the airframe. Because the engine mounts typically use rubber members, the engine is able to move in relation to the airframe during operation. Because of this relative motion, it is common for the final anchor point of the conduit of the throttle cable to be attached to the engine case in some fashion.

Another issue concerning the attachment of the throttle control to the throttle shaft involves geometry. The throttle lever is used to interconnect the control mechanism to the throttle shaft. Because the throttle shaft rotates about its axis, the end of the lever moves in an arc. Consequently, the connection between the throttle control and the throttle lever must include some means of pivoting. This is necessary because the point of connection moves in an arc while the control mechanism moves in a linear direction.

Several approaches are taken to provide for movement at the connection point between the throttle lever and the control mechanism. One technique is to use a special bolt that has a hole drilled through its shank where the threads meet the grip. ***(Figure 4-19)*** The control cable passes through this hole. It is secured by carefully tightening the nut so that the washer pinches the cable in the hole. The nut is only tightened enough to secure the cable. The bolt should be free to pivot in the throttle lever.



Figure 4-19. Control cable bolt. Note hole in grip near threads.

Spherical rod ends are often used to attach the control cable to the throttle lever. These rod ends have bearings that are free to rotate within their frames. They are commonly used to move flight control surfaces. The technician must ensure that there is adequate thread engagement of the frames of the rod ends. This is accomplished by trying to pass a small piece of wire through the witness hole. If the test wire passes through the witness hole into the threaded portion of the rod end, there is insufficient thread engagement between the rod end and control cable. Note the witness hole in ***Figure 4-20***. When possible, install rod ends so that the witness holes are visible and accessible.

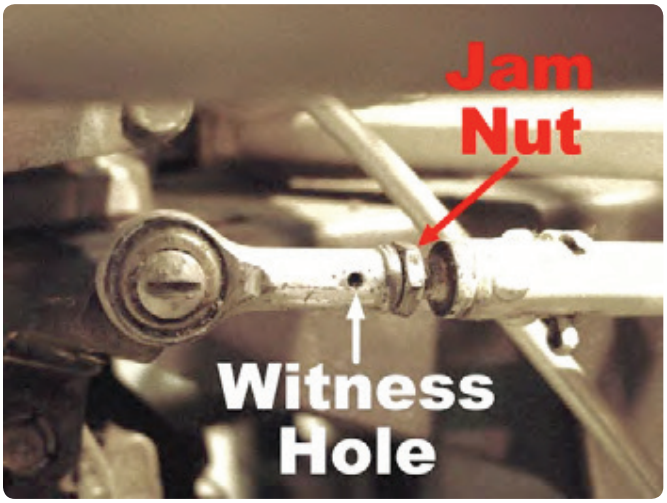


Figure 4-20. Typical control rod end using bearing. Note jam nut and witness hole.

During the inspection of the control mechanism, ensure not only that enough thread engagement is present, but make certain that the jam nut is properly tightened. Also check to make certain that the rod end is free to rotate and lever has full travel without binding in both directions. ***[Figure 4-21]***

Clevis ends are sometimes used to connect the control cable to the control lever. The clevis resembles a fork in that it straddles the control lever. As with the other control mechanisms, the clevis must be free to pivot about its connection point. Like the rod end, check for proper thread engagement using the witness hole, check the jam nut for proper torque, and make certain that the lever moves throughout its entire range without binding.

Another hardware unit employed to connect control cables to control levers is a ball and socket end. Like the spherical rod end, the ball and socket unit provides universal movement between the control cable and the control lever. It also has a witness hole and must be

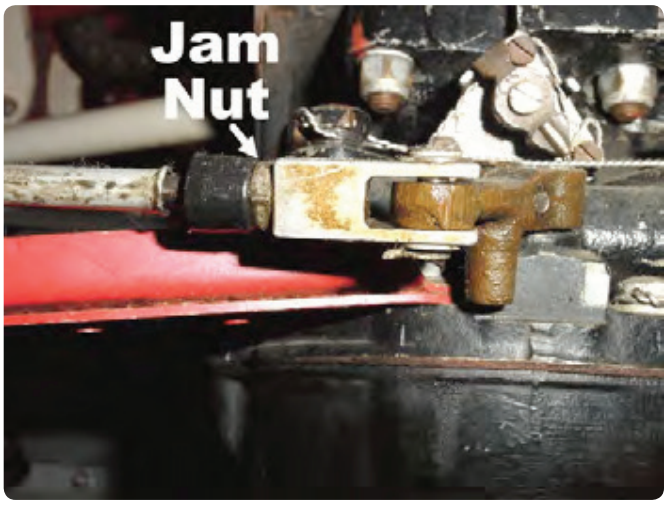


Figure 4-21. Control using a clevis fork.

check for proper thread engagement and security of its jam nut. As with all control systems, full travel without binding must be checked. ***[Figure 4-22]***

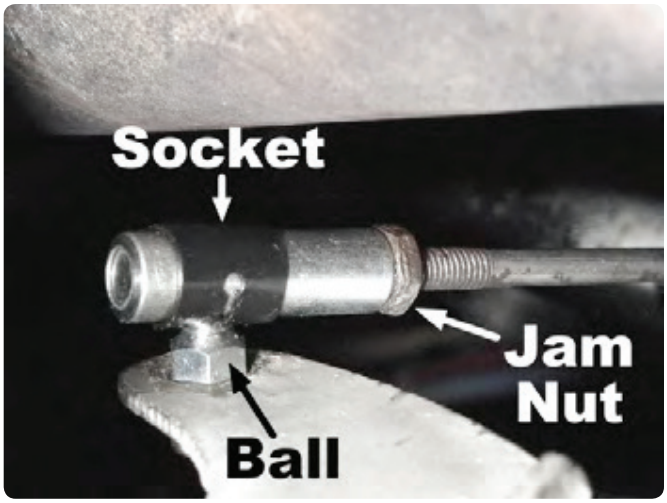


Figure 4-22. Control system using ball and socket connector .

ACCELERATION SYSTEM INTERCONNECT

Another feature associated with the throttle shaft is its connection to the accelerating pump. Because of the intake and discharge operations associated with the movement of the throttle, the accelerator pump is connected to the throttle shaft. In this way, moving the throttle toward its idle position produces an intaking action of fuel from the bowl into the accelerator system. Opening the throttle causes fuel to be discharged from the accelerator nozzle.

Because the intake and discharge actions of the accelerator must precisely correspond to the movement of the throttle, the design of the throttle shaft and accelerator interconnect provides some means of synchronizing the movement of the accelerator with the throttle. One means of accomplishing the keying between the throttle and the accelerator pump is to machine a flat on the shaft. The interconnect hardware that is affixed to the throttle shaft is keyed to this flat. When the acceleration mechanism is connected to the interconnect hardware, correct movement of the accelerator is provided. ***[Figure 4-23]***

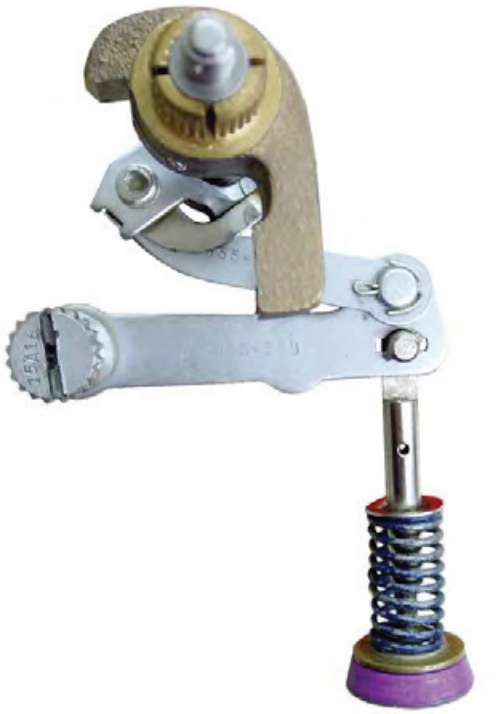


Figure 4-23. Throttle shaft, accelerator linkage, and accelerator plunger.

POWER ENRICHMENT INTERCONNECT

On the Precision MA-4-5 and HA-6 series carburetors, the throttle shaft is used to control the application of power enrichment. These carburetors achieve power enrichment by reducing the level of air bleed air reaching the main discharge nozzle.

To reduce the quantity of air bleed air directed toward the main discharge nozzle, the Precision MA-4-5 and HA-6 series carburetors use an air metering pin and an air metering jet. The air metering pin is spring-loaded to its opened position. When fully opened, the

carburetor delivers an economical mixture. In other words, the fuel spraying from the main discharge nozzle has the maximum amount of air bleed action. When moving the throttle into its high power range, the air metering pin is repositioned so that it blocks a portion of the air metering jet. In such cases, the flow of air bleed air through the jet is obstructed. By reducing the flow of air through the air bleed system, the mixture becomes enriched. Refer to the explanation concerning this type of power enrichment under the heading, "Air Bleed Restrictor."

This type of power enrichment system requires that the application of power enrichment be timed to the position of the throttle shaft. To ensure proper system timing, the position of the air metering jet in relation to the air metering pin is carefully adjusted during the overhaul process. The keying mechanism that synchronizes the linkage with the throttle shaft of the MA-4-5 series is revealed in ***Figures 4-24 and 4-25*** at the parts labeled, "Throttle Shaft Flat" and "Keying Flat."



Figure 4-24. Throttle shaft flat for keying operation of the acceleration and power enrichment systems and safetying same.

This portion of the interconnect is seated in a flat surface machined into the throttle shaft. The link is secured in this position. When properly situated, the operation of the accelerator plunger and the application of power enrichment are determined by the movement and position of the throttle shaft. The procedure for ascertaining the correct adjustment of the power enrichment system of these carburetors is detailed in the overhaul manual. ***[Figure 4-26]***

Some carburetors employ external links to interconnect the action of the acceleration and power enrichment

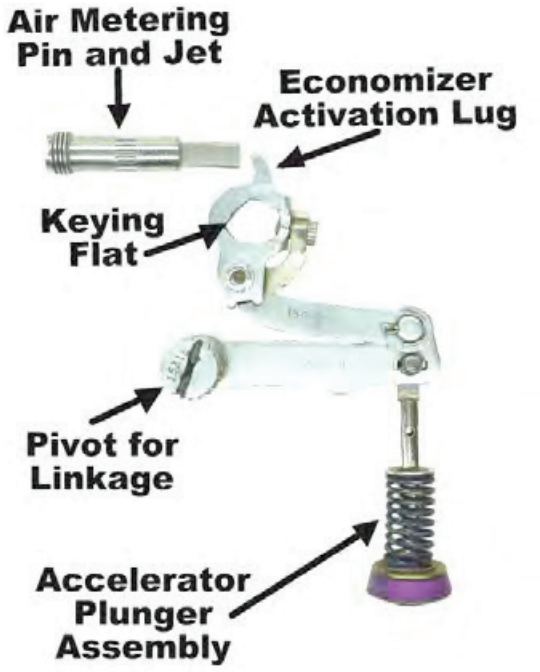


Figure 4-25. Metering pin and jet assembly. Throttle shaft interconnect with power enrichment lug, pivot for the accelerator linkage, and accelerator plunger assembly.

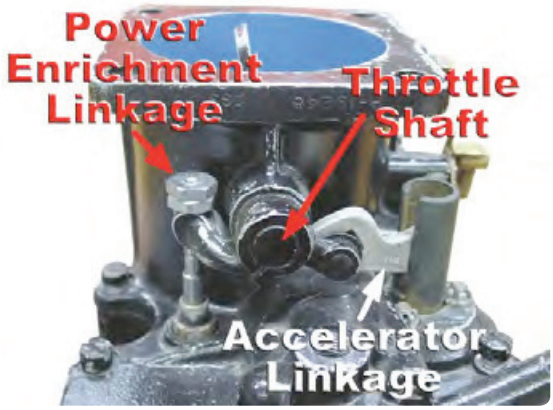


Figure 4-26. Accelerator and power enrichment interconnects of a stromberg model. Note that these links are on the exterior of the carburetor.

systems. Examples of such carburetors include large Stromberg carburetors and Precision HA-6 series carburetors.

The accelerator and power enrichment interconnect of the Precision HA-6 carburetor was modified from its original design mechanism. The improved design uses a lug rather than the links, pins, and fitting. Compare ***Figure 4-27 to 4-28*** to note the differences in construction between the first and second generation interconnect links for the Precision HA-6 carburetor.

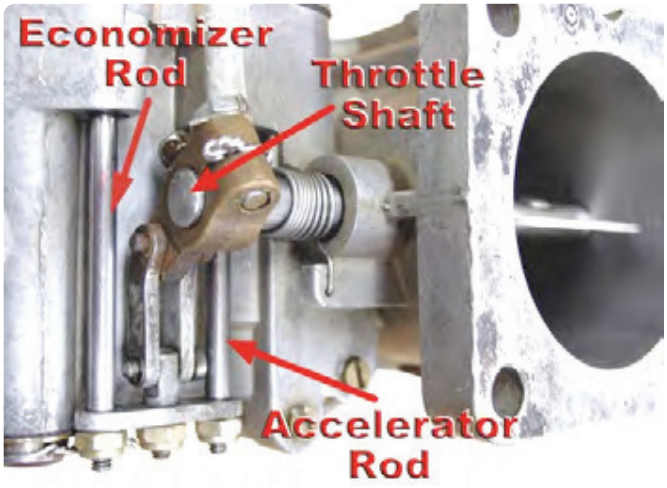


Figure 4-27. Old style interconnect link for precision HA-6 acceleration and Power enrichment systems.



Figure 4-28. Second generation interconnect mechanism for acceleration and power enrichment systems for HA-6.

SAFETY SPRING

Carburetors used on aircraft power plants often include a safety spring. This device is used to move the throttle to full open when it loses its connection to the throttle control. On surface vehicles (e.g., cars, motorcycles, etc.), the throttle shaft spring takes the throttle to idle rather than full open. Such action is appropriate for surface vehicles but unacceptable for aircraft. In the case of aeronautical vehicles, safety refers to keeping the craft in the air until the pilot decides to descend. See ***Figure 4-29*** for an illustration of a safety spring.

The reason there is a need for the safety spring is evident. If, for some reason, the throttle control becomes disconnected at the throttle lever, the pilot (and passengers) would be at the mercy of the throttle plate.

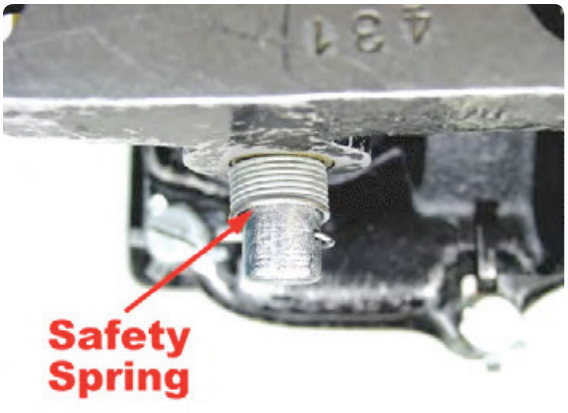


Figure 4-29. Throttle shaft safety spring. This mechanism takes the throttle to its full open position.

If the throttle valve moved toward closed, the aircraft will descend. This could lead to forced landings at the discretion of the capricious throttle valve rather than at the option of the pilot.

To avoid such a scenario, the safety spring is used to fully open the throttle. Where on the surface this seems like an unwise move, in reality the pilot prefers full power over idle power in such cases. In general it may be stated, "The pilot prefers to have too much power over too little power when desiring to maintain or gain altitude." Despite the full opened throttle, the pilot may descend by placing the mixture control in its idle cutoff position. When power is needed, the pilot may return the mixture control to the rich position while the engine continues to windmill. In this way, the power of the engine may be controlled to the limitation that the engine is either running at full power or is wind milling.

An alternative way to descend when operating under full power is to turn the ignition switch to its "OFF" position. This method is not preferred over the mixture control technique as damage to the exhaust system is likely to occur when returning the ignition switch to its "ON" or "BOTH" position. Damage to the exhaust system takes place because the fuel/air charge entering the combustion chambers is not burned when the ignition system is turned OFF. During the exhaust stroke, the unburned fuel/air charge is expelled into the exhaust system. The reactivation of the ignition system will, in all likelihood, ignite the fuel/air charge in the exhaust system. The pressure and temperature generated in such cases are too much for the exhaust system. Bear in mind that the exhaust system is engineered to carry

exhaust from the combustion chambers. Such gases have expended a great portion of their energy before reaching the exhaust system. When ignition occurs within the exhaust system, the exhaust gaskets, the exhaust stacks, mufflers, internal baffles, and tail pipe(s) absorb much of the energy released during combustion.

Despite the obvious benefit provided by the safety spring, not all carburetors are equipped with this device. Some aircraft manufacturers conclude that their throttle controls are not prone to failure when proper inspections and appropriate maintenance operations are employed.

A change to the throttle shaft of Precision carburetors has been made to prevent the separation of the throttle lever from the throttle shaft. This is accomplished by the addition of a stud that protrudes from the lever-end of the throttle shaft. Security of the installation of the lever is provided by the addition of a large-area washer, castellated nut, and cotter key. Compare the old and new styles of throttle shafts in the accompanying figure. ***(Figure 4-30)*** The old style throttle shaft may remain in service, provided that the throttle levers are properly torqued and safetied.



Figure 4-30. New and old style precision throttle shafts.

POWER ENRICHMENT

Most reciprocating aircraft engines are air cooled. Air is a suitable coolant as it readily absorbs heat and is available without the weight and bulkiness of liquid coolants and associated hardware. Furthermore, using air as the primary coolant is safer than liquid cooled designs as the latter may suffer a leak or other defect that may result in engine overheating and failure.

Despite the positive attributes of using air as the primary coolant, there are some inherent drawbacks. One is the lack of maintenance directed at ensuring the integrity of the engine baffles and related seals. Technicians and aircraft owners often underestimate the criticality of the baffles and seals. To many they simply appear as pieces of sheet metal wrapped around the cylinders and attached to the engine. Consequently, the baffles are frequently neglected and fall into a state of disrepair. After years of deterioration the baffles and seals no longer direct air in the proper fashion. When the network of engine baffling is unable to guide the air in the proper quantity through the various passageways, overheating occurs. By comparison, liquid cooling systems do not tolerate the same level of neglect. When they spring a leak or experience a component failure, corrective measures must be taken.

Another impediment to cooling aircraft engines primarily by air is related to operational characteristics. Because reciprocating aircraft engines are of the internal combustion design, they process a power input by igniting the fuel/air charge and converting the heat released during combustion into horsepower. There is a direct correlation between the amount of heat absorbed by the power plant and the horsepower generated by same. There is also a direct correlation between the flow of air through the engine compartment and the airspeed of the aircraft. The faster the airspeed, the greater the volume of cooling air flow. Because of these relationships a problem emerges.

Aircraft power plants develop maximum power, or high power, during takeoff and climb operations. This means that a great deal of heat energy is released from the fuel and absorbed by the power plant. Ironically, the slow airspeeds and nose high attitudes of the aircraft during high power operations translate into minimum air flow through the engine compartment. As a consequence, the engine is generating maximum heat while receiving minimum cooling.

Because of the scenario listed in the preceding paragraph, reciprocating aircraft engines receive an extra measure of cooling from the fuel metering system. The predominant approach is to cool combustion temperatures via a technique known as power enrichment. Another method for cooling combustion chamber temperatures is to employ an anti-detonant

injection or water injection system. Both power enrichment and anti-detonant injection use the heat absorbing outcome of evaporation to cool the combustion chambers. Anti-detonant injection is mostly used on higher horsepower engines in conjunction with large pressure carburetors and direct fuel injection.

The power enrichment system is often referred to as an economizer. There seems to be an apparent contrast between the terms "power enrichment" and "economizer." How can enrichment equal economy? The term economizer basically refers to lower power settings. In other words, if the carburetor did not have a system of power enrichment, it would have to provide an enriched fuel flow for all power settings so that detonation and other problems would not occur during high power operations. Because the power enrichment system allows the carburetor to deliver a normal mixture at lower power settings and administer an enriched mixture only during high power settings, economical flows are provided at less than high power settings. Hence the term "economizer."

Float carburetors achieve power enrichment by using one of the following approaches: (a) adding fuel, (b) restricting air bleed air, or (c) manipulating the fuel metering force. Before discussing each of these techniques for power enrichment, a general discussion of power enrichment is warranted.

Regardless of the technique employed by the carburetor to achieve power enrichment, one commonality is found among all the systems. As its name implies, power enrichment involves the enrichment of the fuel/air mixture at high power settings. Now there are three ways to enrich the fuel/air mixture. One is to add more fuel while the quantity of air remains the same. Another is to keep the flow of fuel the same and reduce the amount of air. And the final method for enrichening the fuel/air mixture is to change both fuel and air flows, but do so in a fashion whereby the proportion of fuel becomes greater than the proportion of air.

The addition of fuel during power enrichment operations is not to add to the total level of potential energy of the fuel/air charge. Rather, the addition of fuel is to absorb heat during the combustion process. The enriched mixture enters the combustion chamber. But because the enrichment fuel is not properly combined with air in a stochiometric proportion, the fuel does not fully burn. Instead, the unburned fuel absorbs heat from the combustion process. This results in combustion chamber temperatures that is reduced to a safe level. Be mindful that some means of cooling is needed during high power operations because of the relatively high level of heat generated during high power settings and the low level of cooling air flow during takeoff and climb operations.

DIRECT FUEL ADDER

Power enrichment systems that directly augment fuel flow to the engine have supplemental fuel passageways that lead to the main discharge nozzle. The opening and closing of these passageways are determined by the position of valves. Because the valves are interconnected to the throttle linkage, the application of power enrichment and the return to normal mixtures are controlled by the position of the throttle.

In this way, the operator automatically activates and deactivates power enrichment based on throttle demand. The automatic approach to applying power enrichment is preferred to having the operator manually activate and deactivate the power enrichment system. Obviously, if the pilot forgot to turn the power enrichment system on and off, the mixture of the engine would be improper. On a more serious note, the safety of the flight could be jeopardized if power enrichment remained deactivated during high power settings.

Operation of this system is simplicity itself. When the power enrichment valve opens, an extra measure of fuel is added to the discharge flow exiting the discharge nozzle. Refer to **Figures 4.31** and **4.32**.

AIR BLEED RESTRICTOR

Directly adding fuel to the discharge flow exiting the discharge nozzle is but one method for providing power enrichment. An alternate approach is to reduce the level of air bleed. Precision MA-4-5 and HA-6 carburetors employ an air bleed restrictor type of power enrichment system.

The air bleed restriction technique works primarily by decreasing the amount of air blended with the discharge-bound fuel. This approach does more than change the weight of the fuel versus the weight of the air. Other elements are at work.

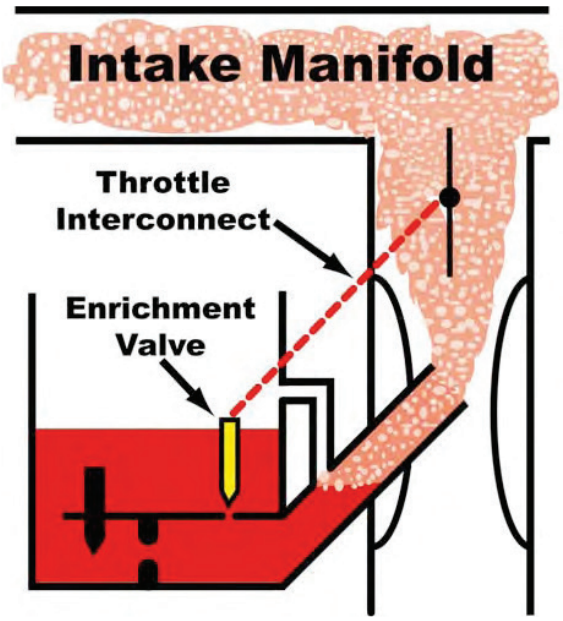


Figure 4-31. Direct fuel adder power enrichment system.

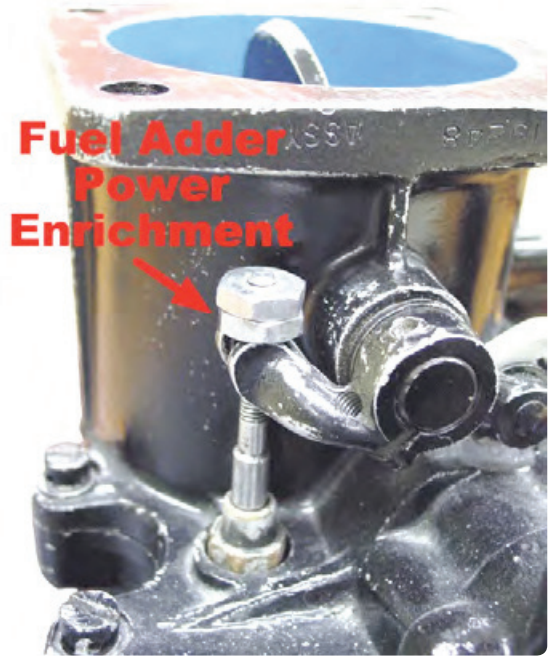


Figure 4-32. Direct fuel adder type power enrichment system on stromberg float carburetor. Note throttle interconnect system lifting power enrichment valve.

One outcome of reducing the level of air bleed is that less air departs the bowl chamber. Because the source of the main air bleed originates from the bowl chamber, less air is removed from the bowl vent when the main air bleed flow is reduced. This, in turn, works to increase bowl chamber vent pressure. When bowl chamber pressure increases, the pressure differential between the bowl chamber and discharge nozzle increases. For other conditions the same, an increase in the pressure differential produces an increase in fuel flow. Such action serves to augment fuel flow.

Another alteration to the fuel metering process stemming from a reduction of flow from the main air bleed system deals with atomization. When the level of air bleed is reduced, the fuel does not have the same level of atomization. Rather than departing the discharge nozzle in a fine spray that readily evaporates with engine-bound air, the fuel exits the discharge nozzle as a coarse spray. The result is that the fuel does not atomize as thoroughly as before. In the end, some of the fuel entering the combustion chamber is unprepared to burn as it has not properly bonded with oxygen atoms. During the combustion process, the fuel that does not ignite evaporates, thereby absorbing some of the heat in the combustion chamber. In this way, combustion temperatures are kept at safe levels. ***(Figure 4-33)***

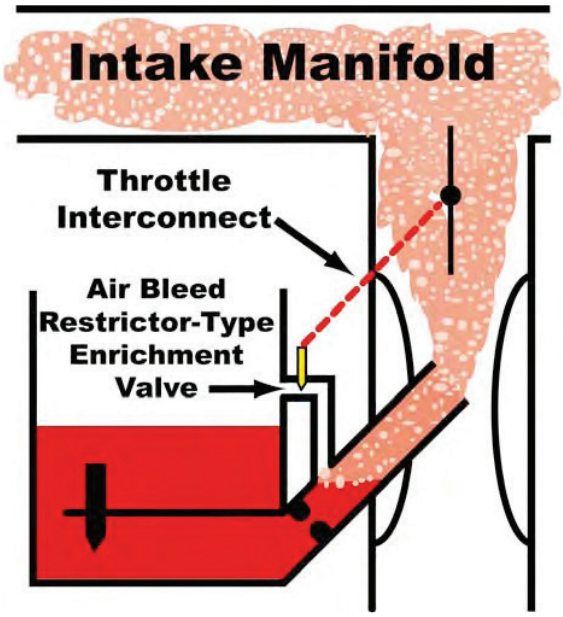


Figure 4-33. Air bleed restrictor type power enrichment system.

Precision MA-4-5 and HA-6 series carburetors have power enrichment systems that employ this technique. The enrichment valve is moved to reduce main air bleed flow during high power operations. The mechanism does not fully seat. Instead it partially restricts the flow of air directed at the air bleed ports of the main discharge nozzle. See ***Figure 4-34*** for an illustration of a typical main discharge nozzle.



Figure 4-34. Marbel-Schebler/precision discharge nozzle assembly.

MANIPULATING FUEL METERING FORCES

Where the previous two forms of power enrichment involved either the process of adding fuel or removing air, another technique for achieving power enrichment involves the manipulation of the fuel metering forces. These systems are normally designed without the need for additional valves and throttle interconnection systems. They manipulate fuel metering forces by pneumatic means.

In a float carburetor, the forces that generate fuel flow include the bowl chamber pressure and the discharge nozzle pressure. The mixture may be enriched by changing one or both of the metering forces in the desired direction. For example, for the same venturi pressure, an increase in the bowl chamber pressure increases the pressure differential. Such action augments fuel flow through the main metering jet and discharge nozzle. Remember that the amount of flow through an orifice is dependent on the size of the orifice and the pressure differential exerted across same. Conversely, when the bowl chamber pressure is reduced for the same venturi force, fuel flow through the main metering jet and discharge nozzle is reduced.

The Precision MA3 and MA4-SPA carburetors achieve power enrichment by altering the bowl chamber pressure based on throttle position. One of the main advantages of this system is that there are no moving parts. In addition, there are no adjustment procedures for the power enrichment system.

In ***Figure 4-35***, note that the air entering the bowl chamber area is taken from the inlet of the carburetor at "A". This air is connected to two ports: (a) one leading to the bowl chamber indicated by the letter "B" and (b) another to a hole in the throttle bore indicated by the letter "C". Because the throttle is near idle in **Figure 4.35**, the pressure beneath the throttle valve, or at "C", is near ambient. Consequently, the bowl chamber pressure is high because both "A" and "C" will keep the bowl filled. Such pressure is useful for idle operations.

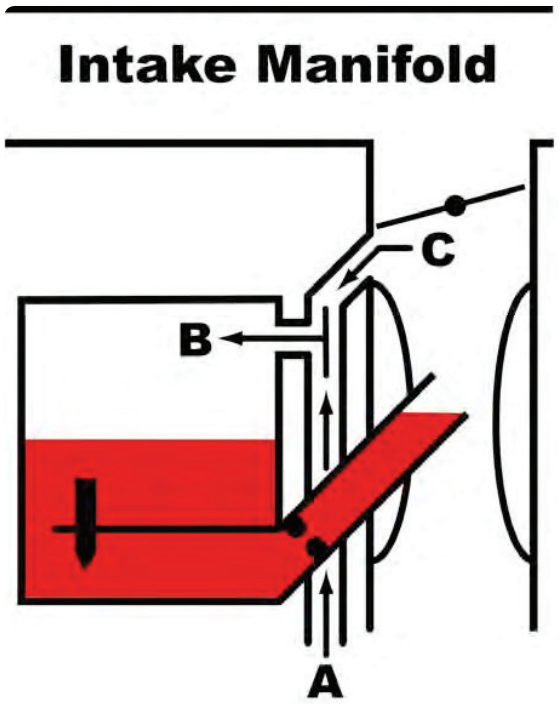


Figure 4-35. Marvel-Schebler/Precision MA3- and MA4-SPA power enrichment system at low power settings.

In ***Figure 4-36***, observe that the throttle is opened far enough to generate flow from the main discharge system. For the purposes of this discussion consider the throttle to be at cruise power. Because the throttle bore port is above the throttle plate, the area marked "C" has lower pressure than the opening at "A". As a result, some of the air entering "A" flows to the low pressure region at "C" rather than the float bowl "B". Because of this flow, the bowl chamber pressure goes down. The pressure at "C" is nearly equal to manifold pressure which is lower than ambient pressure. This reduction in bowl chamber pressure provides a normal, cruise power mixture.

Figure 4-37 shows the Precision MA3- and MA4-SPA power enrichment system at high power. The throttle does not have to be fully opened to trigger power enrichment. Bear in mind that power settings that may be employed for climbs and other high-power operations require power enrichment.

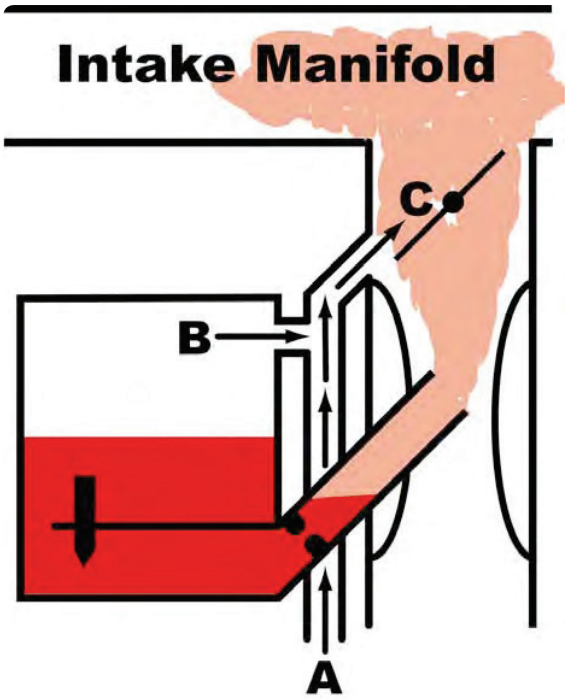


Figure 4-36. Marvel-Schebler/Precision MA3- and MA4-SPA power enrichment system at cruise power.

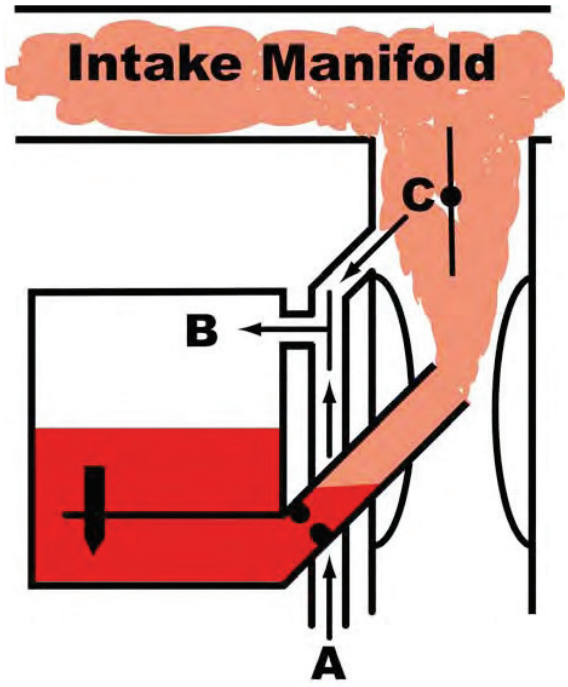


Figure 4-37. Marvel-Schebler/Precision MA3- and MA4-SPA power enrichment system at high power.

In this example, the pressure at "C" is once again high. As in **Figure 4.36**, the pressure at "C" reflects manifold pressure. At high power settings, manifold pressure is high (near ambient). Because the pressure at "C" is higher than it was during cruise power settings, the pressure in the bowl chamber, or area "B", is once again high. By increasing the bowl chamber pressure, the pressure differential across the main metering jet is increased and, as a consequence, fuel flow through the jet is augmented. This action provides the necessary power enrichment.

ACCELERATION

During operation, reciprocating power plants establish their rpm by bringing into balance the power input ingested by the engine and converting the power input into power output as efficiently as possible for the existing conditions. One element that greatly impacts the rpm of a reciprocating power plant is the load placed on the crankshaft. For other conditions the same, an increase in the load on the crankshaft reduces engine rpm and vice versa when the resistance encountered by the engine is reduced.

In the simplest terms, acceleration occurs when the rpm of the power plant is increased. Starting from a stable rpm, increasing the speed of a reciprocating power plant may be achieved in one of two ways. First, the power input of the engine may be increased. Second, the load absorbed by the crankshaft may be reduced. Both ploys for acceleration are discussed. Changes to the ignition system, fuel metering system, or other appliance that affects the efficiency of the power plant have an impact on the balance between power input, power output, and crankshaft load.

Another way to view engine acceleration is to consider the rpm of the engine to be a balance between power input, power output, and crankshaft load. When the engine accelerates, or decelerates, the balance is disturbed until it is re-established.

To increase the power input to the engine, both fuel and air must be increased. It would not be correct to merely inject more fuel into the combustion chambers without providing the corresponding portion of air. Remember that the raw potential energy level of the fuel by itself does not dictate the actual potential energy of the power input delivered to the cylinders. Instead, the potential energy of the fuel charge is determined by the blending of the fuel and air.

Normally the operator increases the power input by moving the throttle toward its full-opened position.

As the butterfly valve opens, more air travels through the venturi. This new volume of air enters the induction system before reaching the intake ports of the cylinders and the combustion chambers. The increase of air flow through the venturi increases the amount of venturi suction experienced by the discharge nozzle. This, in turn, causes an increase in the pressure differential acting on the metering jet. As the pressure differential increases, fuel flow increases. In the end, the cylinders receive a greater volume of fuel and air. The engine converts this increased power input into more power output.

On a reciprocating aircraft power plant, the increase in engine rpm produces an increase in propeller rpm. As propeller rpm increases, the resistance encountered by the engine, or the load placed on the crankshaft, increases in proportion to rpm. RPM and crankshaft load increase simultaneously until a new balance is established between power input, power output, and engine load.

Engine acceleration may also be accomplished by reducing crankshaft load. On a reciprocating aircraft power plant equipped with a fixed-pitch propeller, the load on the crankshaft may be reduced by lowering the nose of the aircraft during flight. The changes that occur to the aerodynamic loads of the propeller lessen the resistance placed on the crankshaft. As a result, the engine gains rpm until a new balance between power input, power output, and crankshaft load is established. On engines equipped with controllable-pitch propellers, a reduction of propeller pitch angle results in an increase of rpm for other conditions being the same.

ACCELERATION SYSTEMS

A common issue with advancing the throttle of a reciprocating power plant is the initial establishment of fuel flow to correspond with the new air flow. As the operator moves the throttle toward full open, the flow of air into the manifold is nearly instantaneous. Fuel flow, however, is delayed for a brief period until the new metering forces are established and have time to work on the fuel in the float bowl. Stated another way, there is a lag time between the opening of the throttle and the establishment of the new fuel flow. This is because gasoline has greater viscosity than air and, as a consequence, does not flow as readily as air. Also, due to Newton's First Law of Motion, when fuel flow occurs at a particular rate, an additional force is required to augment the rate of flow. The time required to change the rate of flow generates the lag time previously discussed.

To compensate for the lag time associated with the acceleration of the reciprocating power plant, carburetors are equipped with acceleration systems. These vary in terms of sophistication. The simplest is the accelerating well. More complex systems involve acceleration pumps.

The accelerating well system contains no moving parts. Rather the system works by having a measure of gasoline kept in reserve by the outlet of the main discharge nozzle. This fuel has already passed the main metering jet and is available for immediate discharged when the throttle is advanced. Because the fuel is near the outlet of the main discharge nozzle, it is in position to depart the nozzle without delay during acceleration.

The accelerating well system is generally limited to use on smaller engines. Larger engines require a system that sprays fuel into the induction system as the throttle is moved toward open. The accelerating pump has a number of moving parts. The typical system uses an inlet check valve, a piston plunger, an acceleration cylinder, an outlet check valve, and a discharge nozzle. The check valves control the flow of fuel so that gasoline enters the acceleration cylinder during the intake stroke and discharges during acceleration. There are numerous passageways to direct fuel during the intake and discharge operations. A discharge nozzle is typically situated to discharge fuel into the main stream of induction-bound air. In this way the fuel is able to intermingle with the air to form a combustible mixture. ***(Figure 4-38)***

In general terms, the typical accelerating pump system is a single-action, piston-type pump. It is designed to intake fuel during movement of the throttle toward idle and discharge fuel when opening the throttle. In most carburetors, the acceleration cylinder is part of the float bowl casting and the piston is connected to the throttle shaft. A few carburetors hold the piston stationary and move the acceleration cylinder. Regardless of the basic design, the acceleration pump system generates its discharge by relative movement between the piston and the cylinder. As the piston or cylinder moves in a direction in which fuel exits the system, the flow passes through the outlet check valve, various passageways, and discharge nozzle.

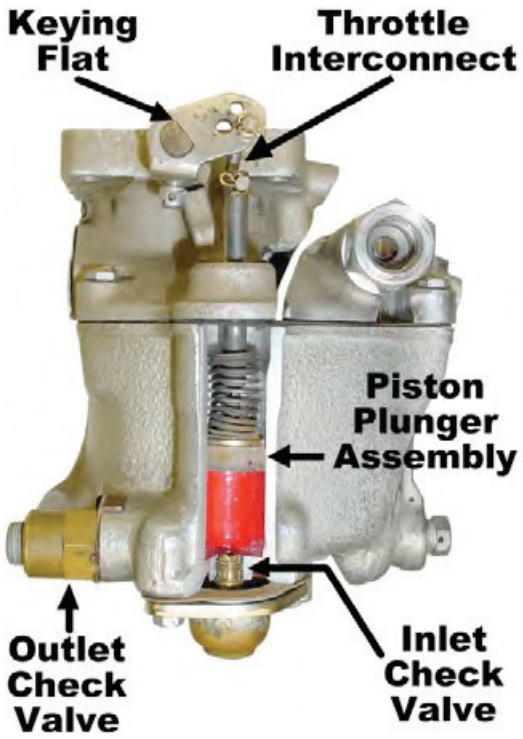


Figure 4-38. Acceleration pump system.

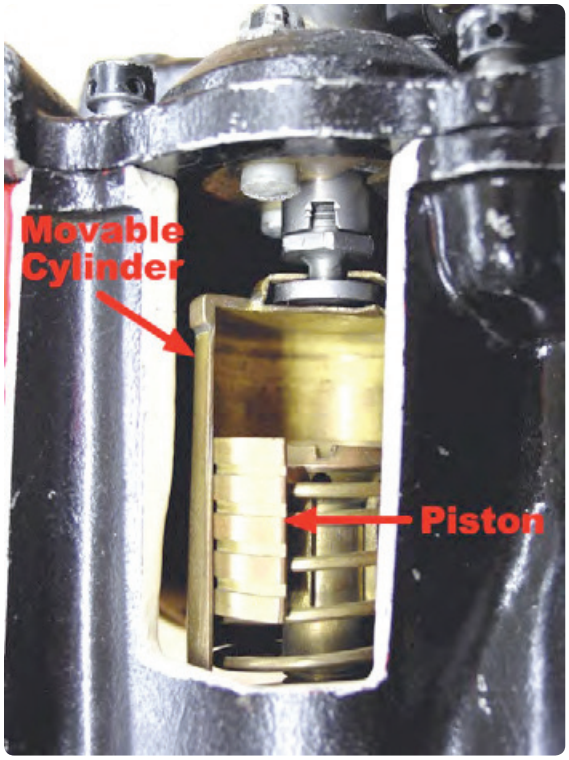


Figure 4-39. Stromberg carburetor showing movable cylinder type acceleration system.

Figure 4-39 shows the workings of the Stromberg acceleration system. The cutaway shows the movable cylinder and spring-loaded piston. The latter opens during the discharge of the fuel.

OPERATION OF A FLOAT CARBURETOR

Float carburetors have been in existence for over a century. Over that period numerous modifications to the unit have taken place. The basic construction, material selection, and other elements have improved since their inception in the industry.

One feature enjoyed by the carburetor is its reliability. It is safe to say that when subjected to a proper maintenance program and when contaminates are kept out of the system, the float carburetor will flawlessly operate for its prescribed Time Between Overhaul (TBO) period. The reason float carburetors possess such a high level of reliability is attributed to their principle of operation.

Float carburetors use a minimum number of forces to generate fuel flow. Gravity, or a positive upright force of gravity during maneuvers, maintains the fuel in the float bowl. The other force employed by the carburetor is differential pressure. In the final analysis, float carburetors are designed to generate the proper pressure differential for their various modes of operation. The idle circuit establishes a pressure differential between the float bowl chamber and its discharge nozzle(s) near the butterfly valve. The main discharge system creates a pressure differential between the float bowl chamber and its discharge nozzle situated in the venturi. In each case, the pressure in the bowl is relatively higher than the pressure at the tip of the discharge nozzle(s).

One additional issue in determining fuel flow is the metering jet. The pressure differential between the float bowl chamber and the discharge nozzle may be considered potential energy. Under normal operations, the flow, or kinetic energy, cannot be higher than that established by the potential energy. It may not be wise to use the pressure differential as the entire metering determination factor. Rather, a metering jet is placed in series between the bowl chamber and the discharge nozzle. In this way, the metering may be precisely controlled. Consider the following example. What if the kitchen faucet in your home was not able to meter the flow of water? Instead, the full, potential energy generated by the municipal water tower flowed from the faucet. In other words, the faucet merely served as an on-off valve and when the valve was opened, maximum flow discharged from the tap. Would such a system be

desirable? Probably not. Aside from serving the function of an on-off valve, the typical faucet also meters the flow of water. When the operator wishes to have a trickle of flow, the tap is barely opened. When higher flow volumes are needed, the valve is opened to a larger aperture. In the end, the flow through the faucet, or carburetor discharge, is determined by the size of the orifice and the pressure differential exerted across the orifice.

IDLE OPERATION

During idle, the pressure differential is established by the manifold pressure and the bowl chamber pressure. As long as the bowl pressure and manifold pressure are correct, the flow through the idle system should be correct. The only things that may alter the flow are some disturbance in either pressure or a modification to the size of the orifice. It is unlikely that changes to the pneumatic pressures will occur. The idle jet may experience a reduction in size in the event that a foreign object plugs, or partially plugs, the orifice. However, the draining of fuel before each flight from the various fuel sumps and the draining of fuel from the float bowl along with any sediment takes place during the inspection of the power plant.

The following operation is not limited to a particular carburetor. Instead, the operation of the idle circuit is typical to most aircraft carburetors.

Fuel destined to reach the float bowl travels through the aircraft fuel system, enters the carburetor through a filtering screen, and flows through the needle valve and seat assembly when the float allows the valve to remain open. As the level of fuel in the float bowl reaches its designed level, the float rises and pushes the needle valve into the seat shutting off additional fuel flow into the float bowl. As fuel is consumed from the carburetor, the float mechanism drops allowing the needle valve to unseat. When this occurs, fuel flow into the float bowl continues until the proper fuel level is established. ***[Figure 4-40]***

Fuel contained in the float bowl travels through a series of passageways, valves, and jets before being discharged into the induction manifold. On a typical carburetor, fuel will travel from the float bowl through a passageway that contains the manual mixture control valve. If equipped, the fuel will also flow through the automatic mixture control or AMC. From the mixture control(s), fuel

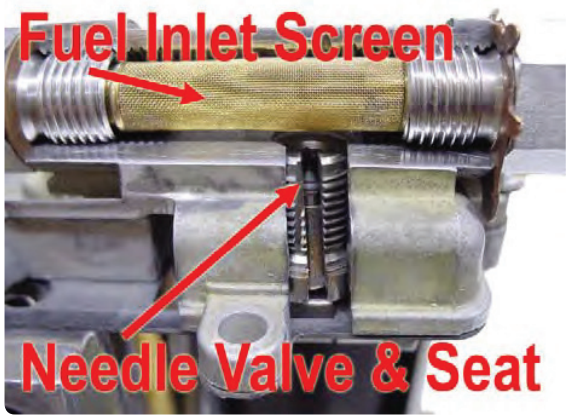


Figure 4-40. Carburetor fuel inlet.

reaches the main metering jet. As the main metering jet is too large to perform metering during idle operations, the jet serves as a passageway for idle fuel. ***(Figure 4-41)*** Next, fuel is metered by the idle jet. After being metered, idle fuel destined for the idle discharge nozzle is mixed with idle air bleed air. The idle circuit uses two air bleeds. The primary idle air bleed flows whenever the idle circuit is delivering fuel to the engine. The secondary idle air bleed network is turned off and on by the position of the throttle plate in relation to the idle ports. Refer to ***Figures 4-16 and 4-17*** and the previous discussion concerning this topic under the section entitled Idle Circuits.



Figure 4-41. Typical idle tube assembly. Fuel first flow through metering jet. Primary idle air bleed is added to the metered fuel.

The delivery of fuel from the idle circuit involves multiple discharge nozzles. The primary idle nozzle is located downstream of the throttle plate, regardless of throttle position. The remaining idle discharge nozzles are situated in the throttle bore so that they are upstream of the throttle plate at lower power settings and downstream of the throttle plate at higher idle power settings. These ports serve as secondary idle air bleeds

when they are upstream of the throttle plate and idle discharge nozzles as they are exposed to the induction manifold as the throttle is opened. When the throttle is sufficiently opened to provide cruise power settings and above, the main discharge system delivers fuel to the engine and the idle circuit basically ceases fuel delivery to the engine or the level of idle fuel delivery becomes insignificant when compared to the main delivery system. The reverse happens as the throttle setting is reduced from a high power operation. As the throttle plate closes, the idle circuit is reemployed. In this way, the idle system is activated and deactivated based on throttle setting. The transition to and from the idle system is seamless. ***[Figures 4-42 to 4-44]***

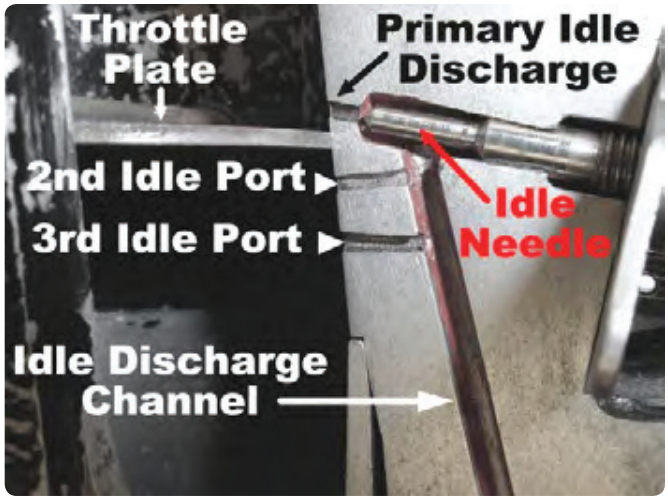


Figure 4-42. Idle delivery ports shown at idle. Note primary idle discharge is above throttle plate while second and third idle ports are upstream of throttle plate.

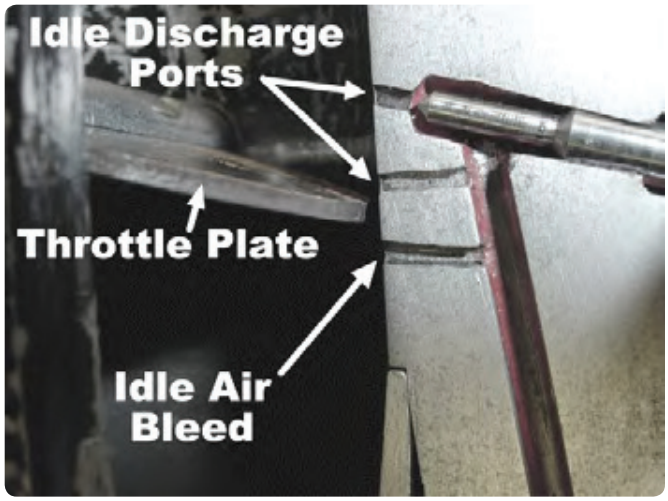


Figure 4-43. In this illustration, the top two idle ports are delivering idle fuel while the lower port is serving as an idle air bleed.

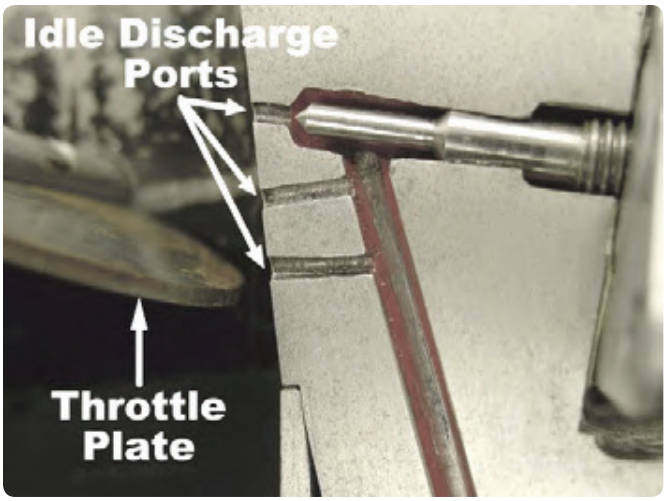


Figure 4-44. All three idle ports are delivering idle fuel flow to the engine in this throttle position.

The main idle discharge nozzle includes an adjustment needle. This device is used to set the idle mixture of the engine. Turning the adjuster clockwise leans the idle mixture while counter-clockwise rotation enriches same. ***(Figure 4-45)***



Figure 4-45. Typical main discharge nozzle assembly. Note the main metering jet, air bleed holes.

MAIN CIRCUIT

The preceding section covered the operation of a typical aircraft float carburetor during idle and low power settings. In actual practice, such operations are generally limited to start up, taxiing, descents, and flight training maneuvers. For most operations, fuel delivery of an aircraft float carburetor takes place through the main discharge system.

Where it is difficult to precisely determine the exact throttle position in which the main discharge fuel begins its delivery to the engine, the approximate position is

around ¼ of the throttle movement from idle. Main fuel discharge operates from that position all the way to full open. The main air bleed system operates in conjunction with the main discharge system.

Fuel for the main discharge system is taken from the float bowl. Entry of fuel into the float bowl was previously discussed in the section entitled Idle Operation. As with the idle system, fuel from the float bowl flows past the mixture control and through the main metering jet. If the carburetor has an automatic and manual mixture control, the flow is through both units. Fuel then travels up the discharge nozzle and exits through the tip of the discharge nozzle into the primary venturi as previously shown in ***Figure 4-15***.

In conjunction with the main fuel flow, the main air bleed system is incorporated. As with the idle circuit, fuel is first metered before the addition of air bleed air.

Air for the air bleed originates from the float bowl in most carburetors. As a consequence, air, just like fuel, is constantly entering and exiting the carburetor. The proportion of air bleed flow mixed with metered fuel is critical to the fuel/air mixture delivered to the engine.

Depending on the style of power enrichment system employed by the carburetor, the flow of air bleed air may be reduced during high power operation. Refer to the previous section on Power Enrichment for additional details.

PRESSURE CARBURETION

Because of the limitations and shortcomings of float carburetors, the next generation of fuel metering involves the process whereby fuel is sprayed from the carburetor into the induction system. These fuel metering devices are known as pressure carburetors or pressure injection carburetors.

Spraying fuel into the induction-bound air provides some major advantages over drawing the fuel from the discharge nozzle using low pressure action. In particular, pressure carburetors are less prone to icing. The positive pressure that sprays the fuel from the discharge nozzle helps to reduce the formation of ice. One reason is that the pressure applied to the fuel elevates its boiling point. By contrast, subjecting fuel to a low pressure reduces the boiling point of the liquid.

In addition to enhanced icing characteristics, the pressure carburetor provides greater flexibility in terms of flight attitude. Where the float carburetor basically requires that the aircraft remains upright or maintains a positive force of gravity in the normal direction, pressure carburetors meter fuel regardless of the attitude. The reason is that pressure carburetors do not have a float bowl, float mechanism, or fuel levels. Although some pressure carburetors do include floats and valve assemblies, these items are used for vapor ejection rather than fuel metering.

The discussion of pressure carburetors entails a general description of the units, followed by the operation of small and large pressure carburetors.

GENERAL DESCRIPTION

Pressure carburetors are composed of several major subassemblies: (a) air throttle body, (b) regulator, (c) fuel control unit, and (d) discharge nozzle. Other elements of pressure carburetors include: (a) vapor ejection, (b) acceleration, (c) power enrichment, (d) power derichment on units that have water or anti-detonant injection (ADI), (e) priming systems, (f) adjustment mechanisms, and (f) mixture controls. The latter typically includes both manual and automatic mixture controls. ***[Figure 4-46]***

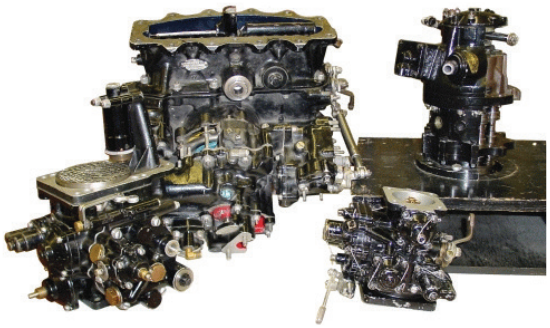


Figure 4-46. Pressure carburetors.

To condense the explanation of the operation of the pressure carburetor, a general purpose description of the components is provided. Specific issues pertinent to the small and large pressure carburetors are addressed in the appropriate sections.

AIR THROTTLE BODY

The air throttle body houses the major subassemblies. Basically, all the other elements of pressure carburetors are mounted directly onto the throttle body.

Aside from serving as the main body of the unit, the throttle body houses the throttle valve. As with other fuel metering systems, the operator has direct control over the position of the throttle valve.

The flow of air to the engine first passes through the throttle body. Air entering the assembly has two main flow paths: (a) directly through the body and past the throttle valve into the induction manifold and (b) through a series of passages that lead to and from the regulator unit. Air that flows through the regulator ultimately exits the unit through openings in the venturi and travels into the induction manifold. However, before reaching the manifold, the regulator applies a force generated by the pressure differential between impact and venturi suction to the poppet valve. The opening of the poppet valve plays a major role in the fuel metering process. This action is parallel to the workings of a float carburetor that determines fuel flow based on the pressure differential between the float chamber and the venturi suction.

Other mechanisms attached to the throttle body are the adjustments for idle speed and mixture. They are used for performing field adjustments to the carburetor. Some pressure carburetors also have an adjustment for setting power enrichment in the field. Fuel connections to the air throttle body include: (a) the inlet from the fuel pump, (b) the outlet to the discharge nozzle, (c) vapor ejection lines, and (d) fuel pressure gauge connection. Some models are connected to the water injection regulator.

REGULATOR

The regulator of a pressure carburetor is at the heart of the metering operation. Regulators are divided into a series of chambers. Each chamber plays an important role in the metering process. Chamber identification is as follows:

Chamber A: senses impact pressure.
Chamber B: houses venturi pressure.
Chamber C: contains fuel that has been metered and regulated.
Chamber D: holds unmetered, but regulated fuel pressure.
Chamber E: is where inlet fuel pressure from the pump enters the unit. This pressure is unmetered and unregulated.

The regulator is engineered to generate and utilize two main forces: (a) air metering and (b) fuel metering. The air metering force is similar to the pressure differential used by float carburetors for metering. For all practical purposes, the impact pressure in Chamber A is similar to bowl chamber pressure and the pressure in Chamber B, venturi, is the same as the venturi suction developed by the float carburetor. The main difference between the pneumatic forces in a float carburetor versus those in a pressure carburetor is that rather than applying the force directly to the fuel, the pressure carburetor transmits its pneumatic force to the poppet valve. The amount of force generated by the difference between Chamber A and Chamber B is termed air metering force.

The pressure in Chamber E is fuel pump output pressure. Fuel entering Chamber E is filtered. Fuel in Chamber E must pass through the poppet valve to enter Chamber D. By passing through the poppet valve, fuel in Chamber D is regulated, but unmetered fuel pressure. Fuel departing Chamber D is directed to the fuel control unit where it is metered. The metering process of a pressure carburetor may be as simple as having fuel travel through a metering jet or as complex as having a variety of jets and an idle valve. In any event, metered fuel is sent to the discharge nozzle and to Chamber C in the regulator. A diaphragm in the regulator is used to separate the pressures in Chambers D and C. The pressure differential between Chambers D and C establishes the fuel metering force. As with the air metering force, the fuel metering force is applied to the poppet valve.

The small pressure carburetor has a little different arrangement in its regulator. Chamber C pressure is not placed in opposition to Chamber D pressure. Rather, Chamber C fuel is directed to the fuel control mechanism. Chamber D pressure acts upon a diaphragm that separates Chambers B and D. The small pressure carburetor regulator includes a strong spring in Chamber A that works to open the poppet valve. The strength of this spring is such that it is able to oppose the hydraulic action of Chamber D fuel pressure.

The regulator of a pressure carburetor is designed to seek and maintain a balance between the air metering force and the fuel metering force. Whenever the balance between the forces is disturbed, the poppet valve either opens or closes until a new equilibrium is attained. The major variable responsible for generating

an imbalance between the air metering force and the fuel metering force is venturi suction. In this regard, the regulator works like a float carburetor where the venturi suction generates the bulk of the pressure differential between the near-ambient bowl chamber pressure and the tip of the discharge nozzle.

Because the amount of air passing through the pressure carburetor during idle and other low power settings is minimal, the air metering force in the regulator is low. To overcome this lack of air metering force, a special spring is used to hold the poppet valve off its seat. The need for this spring is similar to the reason why a separate idle circuit is needed for a float carburetor. At low power settings, the amount of poppet valve opening provided by the spring is brought into balance by the regulator. To better understand the operation of the regulator of a pressure carburetor, the following explanation and scenarios are provided.

Beginning at idle, the amount of air passing through the air throttle body is unable to establish much in the way of an air metering force. The spring keeps the poppet valve off its seat to allow for the flow of gasoline. Fuel passing through the poppet valve enters Chamber D. This fuel flows to the fuel control unit where it is metered and sent to the discharge nozzle. On large pressure carburetors, a portion of the metered fuel is sent to Chamber C of the regulator. An equilibrium within the regulator is established when a balance between the air metering force, including spring tension, and the fuel metering force is reached. ***[Figure 4-47]***

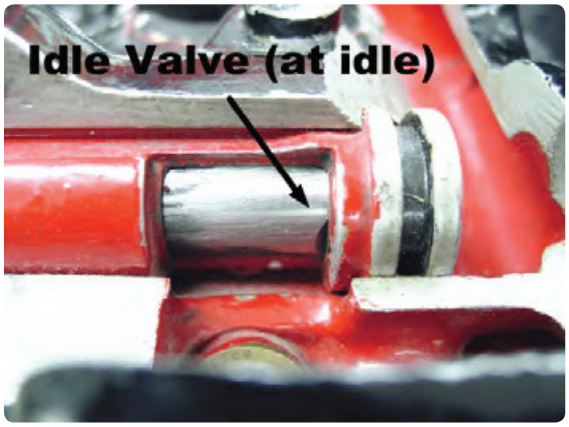


Figure 4-47. Idle valve of a larger pressure carburetor shown in the idle, or restrictive, position. This valve is metering idle fuel in this position.

As the throttle is opened, an additional measure of air enters and passes through the air throttle body. The increased air flow enlarges the pressure differential between Chambers A and B. This force is transmitted through the poppet valve stem to the poppet valve. The poppet valve moves to a larger opening. As the poppet valve opens, the pressure in Chamber D increases in response to the additional fuel flow through the poppet valve. The increase in Chamber D pressure continues until the new fuel metering force equals the new air metering force. In this example, because the poppet valve opened to augment the pressure in Chamber D, more fuel pressure is applied to the fuel control and its various valves. By increasing the pressure applied to the orifice, the pressure differential across the orifice is increased. This causes an increase in the flow of fuel through the metering orifice. Also, there may be a corresponding increase in the size of the metering orifice (e.g., idle valve opening) that accompany increases in throttle opening. As a consequence, more fuel is sent to the discharge nozzle. This increase in fuel flow corresponds to the new air flow that was generated by opening the throttle valve. Reducing the opening of the throttle produces the opposite reaction. ***(Figure 4-48)***

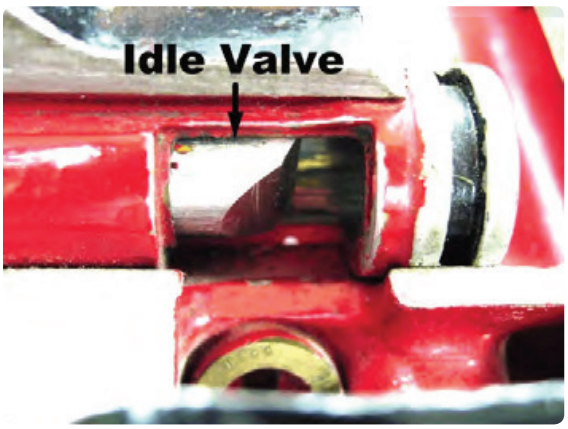


Figure 4-48. Idle valve of a large pressure carburetor shown beyond the idle range. No fuel metering is performed by the valve in this position.

To look at the workings of the regulator in another light, bear in mind the following operational foundation: the regulator strives to achieve and maintain equilibrium between the air metering and fuel metering forces. Because the air metering force changes in response to throttle movement and air flow through the air throttle body, this force is primarily responsible for generating imbalances within the regulator. By contrast, the level

of fuel metering force is determined by the pressure differential between the fuel in Chamber D and venturi suction in the small pressure carburetor and between Chambers D and C in the large pressure carburetor. When the position of the poppet valve changes in response to a change in the air metering force, the volume of fuel entering Chamber D changes and the pressure within Chamber D changes. This action continues until the fuel metering force is brought into balance with the new air metering force. When a new equilibrium is reached, the poppet valve holds its position until the forces within the regulator experience another imbalance. In the final analysis, increases and decreases in the air metering force are met by corresponding increases and decreases in the fuel metering force and the opening of the poppet valve.

FUEL CONTROL UNIT

Fuel entering the fuel control unit is regulated, but unmetered, Chamber D fuel. The fuel that departs the fuel controller is regulated and metered. This fuel is known as Chamber C fuel.

In large pressure carburetors, as fuel travels from Chamber D into the fuel controller, it first encounters the idle valve. As with the float carburetor, the main metering jet is too large to meter fuel at low power settings. The size of the idle jet is determined by the position of the throttle. At idle, the size of the idle valve opening is at its minimum. Advancing the throttle not only increases the opening of the air throttle valve, it enlarges the size of the idle fuel valve aperture. By gradually opening the idle valve in this fashion, a smooth transition from the idle circuit to the main discharge network is achieved. This action also corresponds to increases that occur in the air metering force in the regulator and the additional flow of air ingested by the engine.

At some predetermined throttle setting, the idle valve is fully opened. When this occurs, the size of the idle valve is so large that metering is achieved by the main metering jet, or jets, as determined by the design of the mechanism.

Specifics describing the workings of the fuel control are provided in the appropriate sections. There are a number of distinctions between certain models small pressure carburetors. And, the workings of the fuel control for a large pressure carburetor is considerably different than that of a small pressure carburetor.

DISCHARGE NOZZLE

After the fuel has been regulated and metered, it is discharged into the air stream flowing into the induction system. Because the fuel departs the pressure carburetor under the force provided by the fuel pump(s), there is no need to place the discharge nozzle in the venturi. Nor is there any reason for positioning the discharge nozzle upstream of the throttle plate. The discharge nozzles of pressure carburetors are normally located downstream of the venturi and throttle plate(s).

By locating the discharge nozzle downstream of the venturi and throttle valve, certain benefits in the area of carburetor icing are accrued. First, as the fuel is sprayed under pressure rather than drawn from the discharge nozzle, there is less chance of generating evaporation ice. Because the fuel does not evaporate until it is well into the induction manifold, the opportunity to form evaporation ice is greatly reduced. In contrast to float carburetors that apply low pressure to the discharge fuel, spraying discharge fuel under pressure increases the boiling point of the gasoline. This further reduces the likelihood of developing evaporation ice.

Another benefit of placing the discharge nozzle downstream of the venturi and throttle valve concerns throttle ice. Again, because the fuel is sprayed under pressure downstream of the throttle valve, the cooling action generated by a float carburetor while it is operating via the idle circuit is minimized. There is no evaporation action occurring near the throttle valve. Also, there is no evaporation action taking place upstream of the throttle plate. This is due to the placement of the discharge nozzle downstream of the throttle plate. There are, however, temperature changes generated as the air flowing through the venturi and throttle valve experiences changes in pressure. In contrast to a float carburetor where evaporation is also taking place, such temperature changes are minimal.

On the PS series carburetor, the discharge nozzle does more than spray fuel into the induction system. It adds air bleed air to the fuel during the discharge process. Remember that fuel metering devices used on reciprocating engines must meter and atomize the fuel. Fuel sprayed from the discharge nozzle is

further blended with the cylinder-bound air as it passes through the induction system.

SMALL PRESSURE CARBURETORS

Small pressure carburetors have been in existence for decades. They are basically scaled-down, and simplified, versions of the large pressure carburetor. During the era when most general aviation aircraft used float carburetors, the small pressure carburetor added a new dimension to flying. General aviation aircraft equipped with small pressure carburetors are able to fly at any attitude. In addition, the favorable icing characteristic provides a measure of safety when compared to a float carburetor.

Today, small pressure carburetors have been largely replaced by continuous flow fuel injection systems. Because pressure carburetors discharge fuel from a single nozzle, some intake valves may be closer to the discharge nozzle than other intake valves. This is especially true of six-cylinder power plants. Despite the advantages offered by fuel injection, many older aircraft originally certificated with a small pressure carburetor continue to use this type of fuel metering system. Small pressure carburetors are also widely used on older aerobatic aircraft. Over the years, the small pressure carburetor has proven that it is a reliable form of fuel metering.

THROTTLE BODY

The throttle body of a small pressure carburetor is available in different sizes. Engine displacement generally dictates the size of the throttle body needed for a particular installation. Two common size throttle bodies are used for the Bendix Stromberg small pressure carburetors: (a) PS-5 and (b) PS-7. The former is used for smaller engines and the latter for larger displacement units. PS-7 pressure carburetors are also used on geared engines because of the requisite airflows at high rpm.

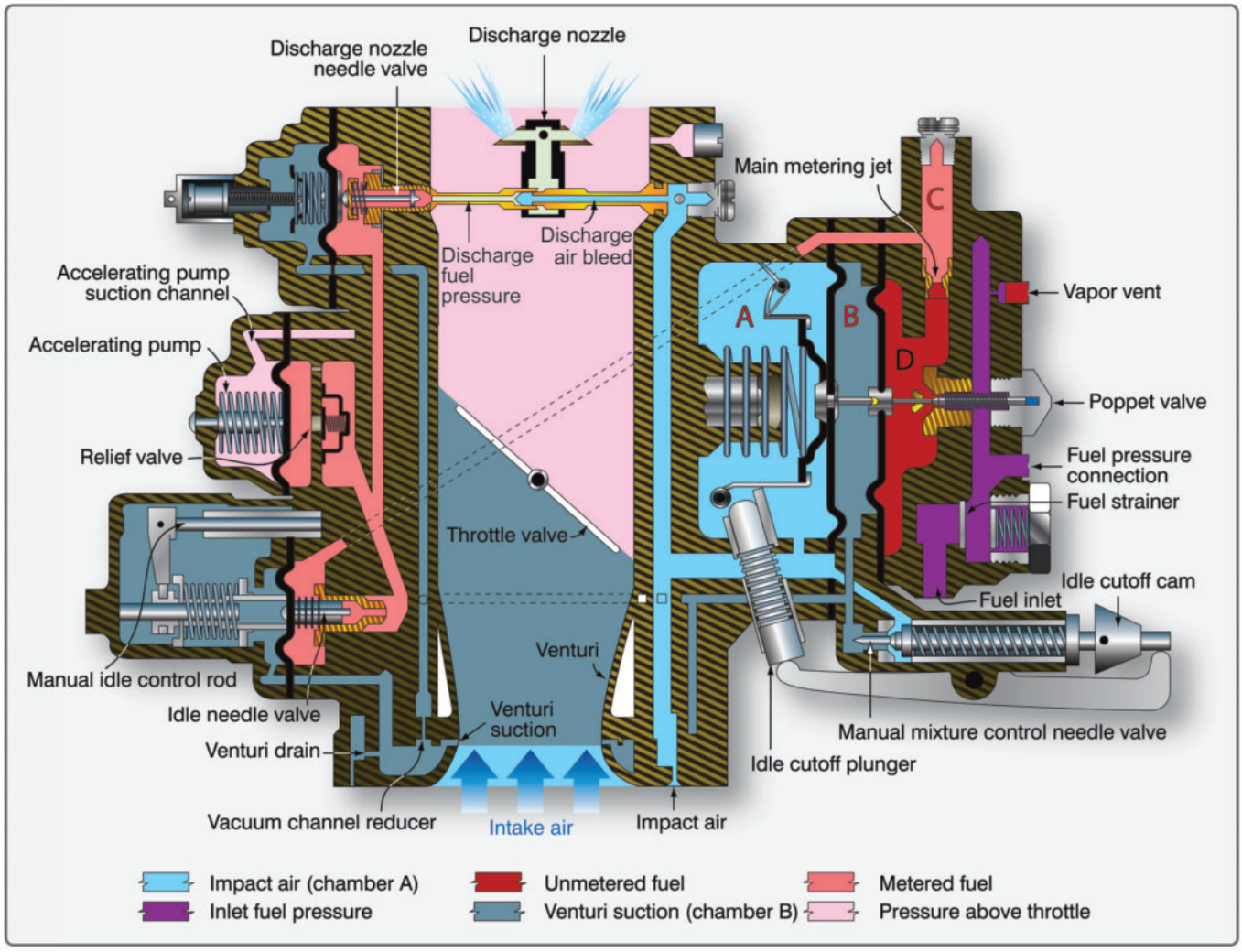


Figure 4.49: Bendix-Stromberg PS-5C Schematic

In the realm of pressure carburetors manufactured by the Bendix corporation, "PS" indicates a "Pressure" carburetor using a "Single" barrel, or venturi. The letter "D" in the model's prefix denotes downdraft design (e.g., PSD-5C). When the letter "H" is used in place of the letter "D," the unit is a horizontal draft (e.g., PSH-5C). Units equipped with electric primers are designated by the letter "E" in the prefix portion of the model number (e.g., PSE-7BD). ***[Figure 4-49]***

The throttle body houses the regulator unit, idle valve assembly, air flow power enrichment mechanism (when used), acceleration system, discharge nozzle, and automatic mixture control (AMC), when installed. There is a fuel line connected to the inlet and a vapor return line from the regulator to a fuel tank. A fitting is provided to connect a fuel pressure gauge to the unit.

The venturi and throttle valve are installed in the throttle body. The venturi not only establishes a pressure drop and limits maximum air flow to the engine, on the small pressure carburetor the venturi has a series of ports and passageways used to lead air to Chamber A, pull air from Chamber B and the idle valve housing, and direct air to the air bleed mechanism. ***[Figure 4-50]***

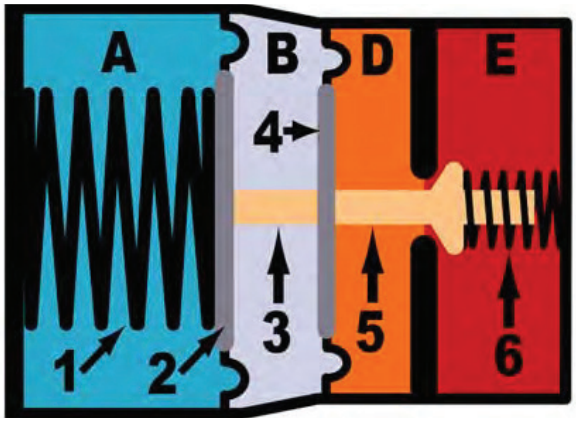


Figure 4-50. PS series regulator showing Chambers A, B, D, and E. Also shown are: (1) Chamber A spring, (2) pneumatic diaphragm, (3) Chamber B poppet valve stem, (4) fuel diaphragm, (5) voppet valve, and (6) poppet valve closing spring in Chamber E. The relatively closed position of the poppet indicates low power operation.

The throttle control and mixture levers are attached to the throttle body. The mixture control also has a mechanism to depress the spring located in Chamber A during cutoff operations. When the spring in Chamber A is compressed, the poppet valve closes as the forces in the regulator become dramatically imbalanced by the loss of this powerful spring. A small spring in Chamber E ensures that the poppet valve seats during cutoff (see **Figure 4.51**).



Figure 4-51. Poppet valve of a Bendix PS carburetor with Chamber E spring.

There are provisions for adjusting idle speed and mixture. A somewhat tedious adjustment of the manual-style power enrichment system is required after setting the idle mixture.

Mounting the small pressure carburetor to the induction system is similar to mounting other types of fuel metering units. Four fasteners are used for this process. A gasket is installed between the mounting flange and induction manifold. The air box is installed on the inlet side of the unit. It too uses four fasteners and a gasket.

REGULATOR

The basic operation of the regulator of a pressure carburetor was introduced in an earlier section of this chapter. Small pressure carburetors have a slightly different configuration as far as the regulator is concerned. Specifically, they lack Chamber C. Instead a powerful spring is installed in Chamber A. This spring opposes the hydraulic action generated by the unmetered fuel pressure in Chamber D.

To better understand the operation of the regulator of a PS series carburetor, the discussion first examines the individual forces taking part in the positioning of the poppet valve followed by an explanation detailing the operation of the regulator. By combining the basic operation of the regulator with the role played by each force, the reader should be able to determine how the regulator responds to individual pressure changes within the regulator.

FORCES ACTING WITHIN THE PS SERIES REGULATOR

Various forces are employed by the regulator of a PS series carburetor to position the poppet valve. There are four chambers involved in this process: (a) Chamber A, (b) Chamber B, (c) Chamber D, and

(d) Chamber E. Chamber C is not included in the regulator of the PS series regulator.

CHAMBERS A AND B

Before examining how the regulator develops imbalances and recovers from same, the physical attributes of the regulator need to be addressed chamber-by-chamber. Chamber A contains unregulated impact pressure. A portion of the air entering the throttle body is directed into Chamber A. This pressure, like the bowl chamber pressure of a float carburetor, represents ambient air or upper deck pressure, in the case of turbocharged installations. A stout spring is installed in Chamber A. This mechanism holds the popper valve open during low power settings when there is not enough air metering force to move the poppet valve off its seat.

Chamber B houses regulated venturi suction. Air flowing into Chamber B originates from Chamber A. It reaches Chamber B by first traveling through the manual mixture control valve. The manual mixture control blocks the transfer of air from Chamber A into Chamber B when it is in the FULL RICH position. The valve opens as the mixture control moves from its FULL RICH position toward CUTOFF. The size of the opening formed by the position of the needle in relation to the mixture control jet determines how much air flows from Chamber A into Chamber B.

The regulation of Chamber B pressure is not solely determined by the position of the mixture needle. A vacuum channel reducer (VCR) is installed between Chamber B and the venturi to control how much air is pulled from Chamber B into the venturi. Because the venturi generates a low pressure, air in Chamber B flows from the chamber into the venturi. After exiting the opening in the constriction of the venturi, Chamber B air joins the induction-bound air and enters the combustion chambers.

CHAMBER D

Fuel in Chamber D is regulated, but unmetered. By flowing through the poppet valve, this fuel has been regulated. It has not been through the idle valve and metering jets at this point, therefore the fuel is unmetered.

One issue that must be emphasized at this time is that the force generated by Chamber D works to close the poppet valve. When the force produced by Chamber D increases, the effort attempting to close the poppet valve is augmented.

Establishing and maintaining the correct pressure in Chamber D is keystone to the metering process. This fact should not be minimized as the flow through the metering jets contained in the fuel control unit is dependent on the fuel pressure applied to the jets.

CHAMBER E

Fuel in Chamber E comes from the fuel pump. The system will more than likely have an engine-driven fuel pump and an auxiliary pump. Either pump should be capable of supplying the requisite pressure and flow to the carburetor to sustain engine operation. Before entering Chamber E, the fuel is filtered. On fuel metering system, it is customary to place a filtering screen at the inlet of the metering unit as most do not tolerate foreign objects.

A small spring is installed in Chamber E. It applies a closing force to the poppet valve. The spring provides a seating moment to the poppet valve during cutoff. This action ensures a positive engine cutoff when shutting down the engine.

The fuel in Chamber E supplies the motive force necessary to push fuel through the carburetor. It is the highest pressure applied to the carburetor. The inlet fuel pressure must be within its operational range to establish the proper position of the poppet valve. If the fuel pressure is too high or too low, the operation of the regulator may be altered. In order to establish and maintain the delicate balance between the air metering force and the fuel metering force, the fuel entering the carburetor must be within its specified range. Check the engine's data sheet for minimum and maximum fuel pressures. The fuel pressure gauge should reflect these limits as well as the normal operating fuel pressure range.

BASIC OPERATION OF THE PS SERIES REGULATOR

The general operation of the regulator of the large pressure carburetor was previously presented. The discussion, however, included Chamber C as one of the forces comprising the fuel metering force. Because the PS series carburetor does not include Chamber C in its regulator, the specifics concerning the operation of this unit is provided.

To begin understanding the operation of the regulator of a PS series carburetor, some of the physical attributes of the unit are required. Using a PS5 as an example, the pneumatic diaphragm measures 2.5" (63.5mm) in diameter and the diaphragm forming the partition between Chambers B and D has a diameter of 1.5" (38.1mm). The differences in diameter is a critical design factor in that changes to Chamber B pressure results in the desired imbalance of the air metering and fuel metering forces. As previously mentioned, a powerful spring is installed in Chamber A. The tension of this spring is applied to the pneumatic diaphragm. It works to open the poppet valve and keep it open at low power settings when the flow through the venturi is insufficient in terms of generating a viable air metering force. ***[Figure 4-52]***

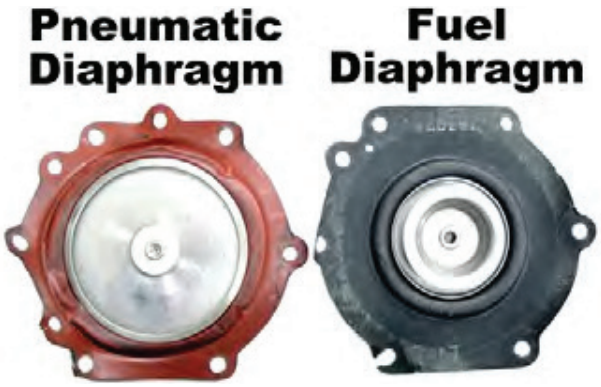


Figure 4-52. Pneumatic and fuel diaphragms of a Bendix PS5 pressure carburetor. Compare the diameters of the metal disks.

There is a passageway between Chambers A and B. Impact air from Chamber A flows through the manual mixture control and into Chamber B when the mixture control is away from its FULL RICH position. In the FULL RICH position, the passageway between Chambers A and B is closed. During FULL RICH operations, Chamber B is exposed to an unregulated venturi suction.

From Chamber B, the flow continues through the vacuum channel reducer (VCR) until it exits through the openings in the venturi. See ***Figure 4-53***. Regulation occurs by manipulating the size of the orifice formed by the manual mixture control. Because the VCR has a fixed size, the pressure in Chamber B may be increased by augmenting the flow through the mixture control. When the mixture control needle is clear of its jet, more air flows from Chamber A into Chamber B.



Figure 4-53. Vacuum channel reducer (VCR) to regulate venturi suction in Chamber B.

Consequently, the pressure in Chamber B goes up while the pressure in Chamber A stays relatively constant. The reason why Chamber A does not lose pressure in this exchange is that a large passageway ensures plenty of flow into Chamber A. The result of increasing the pressure in Chamber B while maintaining the same pressure in Chamber A is that the pressure differential acting on the pneumatic diaphragm between Chambers A and B goes down. For other conditions the same, anything that diminishes the pressure differential that acts on the pneumatic diaphragm reduces the air metering force. This further translates into a smaller poppet valve opening and a reduction in fuel flow.

On a side note, the operation of this mixture control system is, for the most part, a derivative of the back-suction mixture control used on NAS-3 float carburetors (refer to the section on Back Suction Mixture Controls). The major difference is that in the float carburetor, bowl chamber pressure is manipulated while in the PS carburetor, the pressure in the venturi chamber is altered. The similarity between the two systems is that fuel metering is controlled by manipulating the pressure differential of the pneumatic forces.

The force exerted by the pneumatic diaphragm is transmitted to the poppet valve stem, through the fuel diaphragm, and to the poppet valve. One feature of the design of the poppet valve stem is that it keeps the volume of Chamber B constant.

Because venturi suction is the lowest pressure in the regulator, and because the pressure on each side of Chamber B is relatively higher than venturi suction, the portion of the poppet valve stem that travels through

Chamber B prevents the chamber from imploding. This is important as the entire chamber floats within its linear range of motion inside the regulator. The pressure in Chamber D is applied to the fuel diaphragm. It directly opposes the air metering force applied by the pneumatic diaphragm. The tip of the poppet valve protrudes into Chamber D. It contacts the fuel diaphragm.

The following example serves to illustrate how the regulator becomes imbalanced when the air flow through the venturi is increased. Also included is how the regulator reestablishes the balance between air and fuel metering forces.

Beginning from a state of equilibrium, the opening of the throttle is increased which produces a reduction in pressure of 20 inches of water in Chamber B in this example. Because Chamber B is sandwiched between Chambers A and D, this reduction in venturi chamber pressure produces an imbalance between the air metering force and the fuel metering force. The reason for this imbalance is because the pneumatic diaphragm is 1" larger in diameter than the fuel diaphragm. Consequently, each diaphragm has a different surface area with the pneumatic diaphragm being the largest. To illustrate the production of the imbalance, mathematics are applied to this scenario. The air metering and fuel metering forces are calculated separately and the net force determined.

The first step in calculating the change in the air metering force is to compute the surface area of the pneumatic diaphragm. Using the formula pi times radius squared (π r2), the diameter of the air diaphragm is divided by 2 to determine its radius. Dividing 2.5 inches by 2 produces a radius of 1.25 inches. Squaring the radius yields a value of 1.5625 inches. Multiply 1.5625 inches by π provides a surface area of approximately 4.9 square inches.

To compute the change in the air metering force when the venturi chamber pressure goes down by 20 inches of water, the formula ***Force = Area X Pressure*** is used. It may be helpful to convert inches of water into its equivalent psi value. For psi, this conversion is made by multiplying inches of water by 0.036. In this case, 20 inches of water multiplied by 0.036 equals 0.72 psi. The final step required to calculate the change in the air metering force is to multiply 4.9 square inches by 0.72 psi. The product of these numbers is 3.528. After canceling units of square inches in the numerator and denominator, the total change in the air metering force is 3.528 pounds. Because the pressure differential between Chambers A and B increased, this additional 3.528 pounds of force is applied to the poppet valve stem and works to further open the poppet valve.

The change in the fuel metering force is calculated in the same fashion. First compute the surface area of the diaphragm. The 1.5 inch diaphragm has a surface area of 1.77 square inches. Note that this diaphragm has considerably less area than the pneumatic diaphragm which has 4.9 square inches of surface area. The decrease in Chamber B pressure by 20 inches of water is converted into psi by multiplying by 0.036. As before, the conversion yields 0.72 psi. Multiplying the surface area of the fuel diaphragm by this pressure, the change in the fuel metering force equals 1.27 pounds. Because the total pressure in Chamber B went down, the pressure differential acting on the fuel diaphragm increased. This means that the fuel metering force increased by 1.27 pounds.

Because the air metering force and the fuel metering force are in direct opposition to one another, the system that generates the strongest force moves the poppet valve. When the air metering force becomes greater than the fuel metering force, the poppet opens an additional amount. When the fuel metering force becomes stronger than the air metering force, the poppet moves in the direction of close. The opening and closing action of the poppet continues until the forces are brought back into balance.

The calculations thus far reveal that by causing the pressure within Chamber B to go down by 20 inches of water, the net change in the air metering force to open the poppet is greater than the net change in the fuel metering force to close the poppet. In this example, the air metering force increased by approximately 3.5 pounds while the fuel metering force went up by 1.27 pounds. Because the air metering force became comparatively stronger, the poppet valve moves to a larger opening. The result of this movement is that the pressure in Chamber D goes up as more fuel passes through the larger opening at the poppet valve. The increase in Chamber D pressure continues until the new pressure generates enough fuel metering force to bring the regulator back into balance.

In this scenario, an increase of 1.98 psi is needed to bring the two forces into balance. This is calculated by determining how much pressure needs to be applied to the particular diaphragm to equal the force generated by the other diaphragm. In this example: 3.5 pounds equals 1.77 square inches multiplied by X psi. Solving for X, 1.98 psi are needed to generate 3.5 pounds of fuel metering force.

The increase of Chamber D pressure by 1.98 psi translates into more fuel flow. When the additional fuel pressure is applied to the metering jets, more flow passes through the orifices and discharges into the induction-bound air.

When the pressure in Chamber B increases, or goes up by reducing the level of venturi suction, the air metering force decreases. The reaction of the regulator occurs in a similar fashion, only in the opposite direction as Chamber D pressure goes down to reduce the fuel metering force until it matches the air metering force.

In the final analysis, changes to Chamber B are responsible for creating pressure imbalances within the regulator. The design of the regulator is that as an imbalance occurs, the mechanism reestablishes a new equilibrium through the use of two different diameter diaphragms and varying the pressure in Chamber D to correspond to changes in Chamber B pressure.

AUTOMATIC MIXTURE CONTROL

Bendix PS carburetors have the opetion of being fitted with an automatic mixture control (AMC). The suffix "D" is used to designate the inclusion of an AMC (e.g., PS-7BD). Unlike the mechanical blocker-type AMCs used with float carburetors, the AMC of a PS series carburetor works by controlling the pressure differential exerted across the pneumatic diaphragm. The AMC of a PS carburetor is connected in parallel with the manual mixture control. Because of this association with the manual mixture control, the pilot is unable to enrich the mixture beyond the level established by the AMC. However, the operator may further lean the mixture all the way to CUTOFF.

The physical action of the PS series AMC is basically identical to that of an AMC installed on a float carburetor. The bellows is designed to expand and contract according to the ambient pressure or turbo-supercharged pressure entering the carburetor. Expansion occurs when the inlet pressure is reduced and contraction takes place when the inlet pressure increases. Like the AMC installed in float carburetors, the PS AMC is designed to fail-safe in the event of a leak.

One feature of the AMC unit used with PS series carburetors is the reverse tapered needle design. This arrangement provides for a greater opening between chambers A and B as the bellows expands. This means that as the aircraft ascends and the bellows expands, the flow of air from the impact chamber into the venturi suction chamber increases. This produces a decrease in the pressure differential between chambers A and B, a corresponding decrease in the air metering force, and a reduction in fuel flow as previously discussed. The end result is that the fuel flow to the engine is based on the quality of the air entering the carburetor in terms of pressure and temperature. ***[Figure 4-54]***

FUEL CONTROLLER

On the PS carburetor, fuel from Chamber D departs the regulator as regulated, but unmetered fuel pressure. The fuel flows through the main meter jet before reaching the idle valve and discharge nozzle. The fuel is also eligible to enter the acceleration system after it departs the idle valve. ***[Figure 4-55]***

Small pressure carburetors have relatively simple fuel control networks. Aside from the operation of the idle system as discussed in the next two sections, the small pressure carburetor meters fuel using a single jet. On units that have air flow power enrichment systems, a quantity of fuel bypasses the main jet and joins the fuel bound for the discharge nozzle during power enriched operations.

Small pressure carburetors that use manual power enrichment systems control enriched flows by selecting the proper size main jet. To maintain normal mixtures at less than high power settings, a special shaped idle valve is used to limit fuel flows from idle until the throttle reaches the specified position requiring power enrichment.

The main jet is the first metering component to receive Chamber D, or regulated, fuel. As with the float carburetor, the main jet is too large to meter fuel at low power settings. To control metering at low power settings, an idle valve is incorporated into the operation

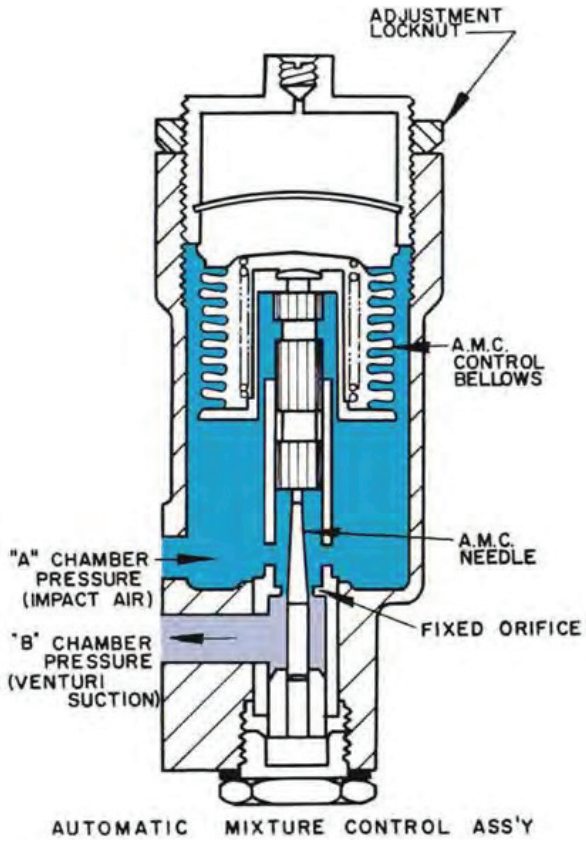


Figure 4-54. Automatic mixture control assembly (AMC) of PS series carburetor. Note the reverse-tapered needle and fixed orifice design.



Figure 4-55. PS-5C main metering jet.

of the system. The size of the opening formed by the idle valve varies in accordance with the position of the throttle. Two styles of idle valves exist: (a) manual power enrichment units and (b) airflow power enrichment systems. An explanation of each is provided.

MANUAL POWER ENRICHMENT SYSTEM

PS carburetors have two distinct forms of power enrichment. The mechanical unit activates power enrichment by throttle position. Such pressure carburetors are identified by the letter "C" added to the model designation (e.g., PS5-C). At and above certain throttle settings, the position of the idle valve allows enriched flows to reach the engine. Airflow power enrichment carburetors use predetermined levels of venturi suction and Chamber D pressure to open the enrichment valve. A pressure carburetor designated with the letter "B" (e.g., PS7-BD) has an airflow power enrichment system.

The manual power enrichment system achieves enriched mixtures by selecting a main metering jet that is suitable for the desired flows. Such systems limit fuel flow at other-than-enriched mixtures by mechanically blocking a portion of the flow using the idle valve assembly.

The idle valve assembly of the manual power enrichment design is composed of a valve seat, two-step idle needle, spring, and associated linkage that interconnects the needle valve to the throttle. This system must be adjusted in the field after performing idle mixture adjustments to the carburetor.The following illustration ***(Figure 4-56)*** is provided to further demonstrate the operation of the manual power enrichment idle valve.

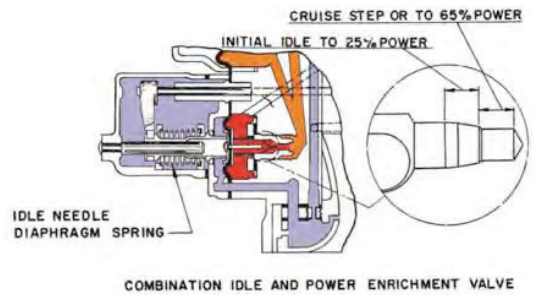


Figure 4-56. Drawing of PS-5C idle valve and associated mechanism.

Three modes of operation are achieved by the position of the idle needle: (a) idle, (b) cruise, and (c) high power. During idle, the large-diameter segment of the needle valve is held in the orifice. This limits the flow of fuel through the valve seat for idle operations. The tapered shape of this portion of the needle valve also provides fuel flows up to 25% power.

Throughout this range of operation, the special link that interconnects the idle valve to the throttle mechanically acts to keep the idle needle valve in the low power setting mode. Because the orifice produced by the needle valve and seat is much smaller than the main metering jet orifice, fuel metering takes place at the idle valve assembly. ***[Figure 4-57]***



Figure 4.57: Small Pressure Carburetor with Throttle Link Pushing Idle Link Rod to the Right. This is for Low Idle Power Settings.

While operating at cruise power settings, the straight or cylindrical section of the needle valve is inserted into the orifice. The idle needle is positioned by metered fuel pressure, unregulated venturi suction, and a spring. The throttle interconnect is not in contact with the idle needle during cruise power settings. Cruise operations run from 25% power to approximately 65% power. The effective orifice size generated when the straight portion of the idle needle is in the jet is smaller than the main metering jet orifice. In this respect, metering occurs at the idle valve assembly. Or stated another way, the idle valve assembly serves as the dominant orifice from idle to approximately 65% power. ***[Figure 4-58]***

Power enrichment operations begin when the throttle interconnect linkage pushes the idle needle away from its metering orifice. After the needle is removed from the orifice, the main metering jet becomes the dominant metering orifice. This is because the opening of the valve is larger than the orifice of the main metering jet. Enriched mixtures extend from 65% power to full power. ***[Figure 4-59]***

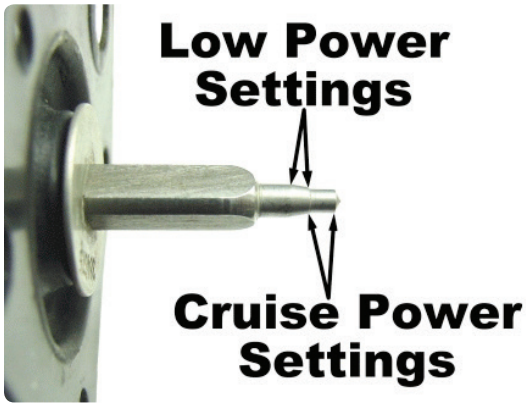


Figure 4-58. PS-5C idle needle valve. Note different ranges of operation.

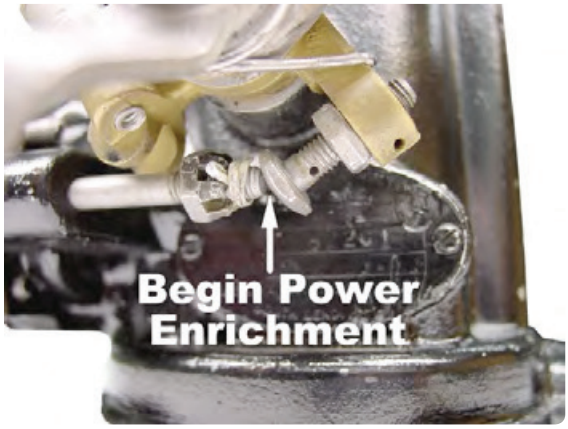


Figure 4-59. Manual power enrichment begins when bolt head on throttle linkage pushes idle rod to the left.

Because the idle needle is positioned according to the throttle setting, a somewhat tedious adjustment must be performed to synchronize the application of power enrichment with the position of the throttle. Involved in the process is the manipulation of the adjuster shown in ***Figure 4-60***. As might be expected, access to the associated hardware is rather limited when the carburetor is installed on the engine. This procedure should be implemented after performing adjustments to the idle mixture. Special adjustment blocks are used for this operation. Refer to the specification table provided by the manufacturer for the proper power enrichment setting.

Advance the throttle until the full throttle stop on the throttle shaft wedges the adjustment block against the throttle stop on the air throttle body. Remove the safety wire, loosen the jam nut on the power enrichment adjustment bolt, and adjust its position so that the head of the bolt contacts the end of the idle control rod.



Figure 4-60. Adjusting the manual power enrichment system. Insert the proper gauge block between the full opened throttle stop at "A", loosen the jam nut and adjust bolt "B" so that it contacts the tip of the idle link rod at "C".

Tighten the jam nut, recheck the setting, and safety the adjustment. The result of this adjustment is that the head of the power enrichment bolt begins to push the idle needle away from its seat at this particular throttle position. Opening the throttle a little more continues to push the straight segment of the idle needle away from the valve seat. At some predetermined throttle position, the needle valve is completely out of the valve seat. The throttle interconnect linkage is spring-loaded to the throttle shaft to allow for further movement of the throttle beyond the point of initial contact between the adjustment bolt and the end of the idle valve rod.

One issue associated with this adjustment is that every time the idle mixture is changed, the power enrichment setting is disturbed. For example, leaning the idle mixture delays the application of power enrichment until a higher throttle setting is attained. To further compound the problem, performing this adjustment while the carburetor is mounted on the power plant is generally more difficult than making this adjustment on the bench. But field adjustments are required because the idle mixture setting cannot be finalized until the carburetor is operated on the engine.

AIRFLOW POWER ENRICHMENT SYSTEM

Bendix developed a power enrichment system that does not require the aforementioned adjustment process. The alternate design works by sensing venturi suction and Chamber D pressure rather than throttle position. The premise of this design is based on the relationship between power setting and venturi suction. At high power settings, the level of venturi suction becomes significant.

Idle valves installed in PS series carburetors that use airflow power enrichment systems are simpler in design than those used with manual power enrichment systems. Because these valves only control fuel flow from idle to approximately 25% power, they have a single taper or, as in the case of the PS-7 carburetors, is a sleeve-type valve. This single-step design is all that is needed because the main metering jet controls fuel flow during cruise operations. A separate flow path that bypasses the main metering jet supplements fuel flow for power enriched mixture similar to the direct fuel adder style of power enrichment found on certain model float carburetors. To summarize the metering process, the idle valve controls fuel from idle to approximately 25%, the main metering jet controls metering from 25% to high cruise, and the main metering jet, in combination with the airflow power enrichment mechanism, manage enriched, high-power fuel flows.

Forces involved in the operation of the airflow power enrichment system are: (a) venturi suction, (b) spring tension, and (c) Chamber D fuel pressure. A diaphragm forms two compartments with venturi suction and spring tension on one side and Chamber D fuel pressure on the other. Chamber C fuel is located on the downstream side of the valve and is isolated from the other pressures when the valve is closed.

In terms of operation, when venturi suction is low, the power enrichment valve is spring-loaded against its seat. Such action prevents the addition of power enrichment fuel to the main discharge flow. As the airflow through the venturi generates a significant quantity of venturi suction, Chamber D pressure opens the valve. The reduction of pneumatic pressure on the spring-side of the diaphragm at high power settings allows Chamber D fuel pressure to overcome the strength of the closing spring. ***[Figure 4-61]***

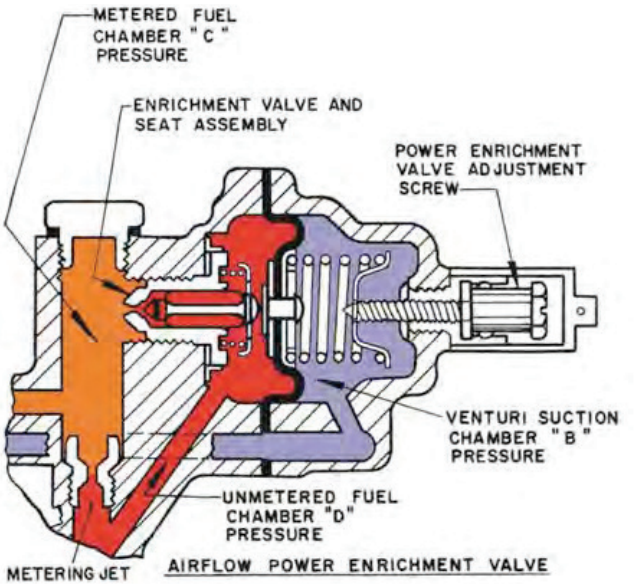


Figure 4-61. PS Series airflow power enrichment system.

Gasoline that flows through the opened power enrichment valve joins discharge-bound fuel. It should be noted that unlike the manual system previously described, power enrichment fuel does not pass through the main metering jet. Instead, power enrichment fuel flows through an alternate passageway before joining engine-bound fuel.

ACCELERATION SYSTEM

Acceleration of PS series carburetors is somewhat unique when compared to the operation of acceleration systems typically used with standard float carburetors. The system does not use a plunger that is synchronized to the throttle shaft. Rather, a diaphragm and spring are used to deliver acceleration fuel. Operation of the mechanism is determined by changes in manifold pressure.

The acceleration mechanism of the PS series carburetor is connected in parallel with the discharge fuel, downstream of the idle valve. Fuel bound for the acceleration system departs the idle valve and enters the acceleration chamber. During the filling phase of the operation, discharge fuel from the idle valve acts on the diaphragm located in the acceleration chamber. The force exerted by the fuel compresses the spring on the backside of the diaphragm. Because the spring side of the diaphragm is connected to manifold pressure and because manifold pressure is low during low power settings, the force of the discharge fuel is great enough to completely fill the acceleration chamber. During this process, a balance between the fuel acting on one side of the diaphragm and the combination of manifold and spring pressure on the opposite side of the diaphragm is reached. When the throttle is suddenly opened, the manifold pressure experiences an increase in pressure. The change of manifold pressure creates an imbalance in the accelerator system. This allows the spring to push fuel from the chamber until a new balance is attained.

Many of the PS acceleration systems include a check valve and orifice assembly. This device is installed on the fuel side of the acceleration chamber. It is needed to slow the fill rate of the acceleration chamber during rapid throttle closings. When the throttle is rapidly moved to idle from high rpm, the induction manifold experiences a sudden, large drop of pressure. Without the check valve and orifice, the flow of fuel to the discharge nozzle is diverted to quickly fill the acceleration chamber. This produces a sudden leanness of the mixture and may cause the power plant to momentarily die. Such action is undesirable as operators and passengers are typically not fond of engine stoppage. ***[Figure 4-62]***

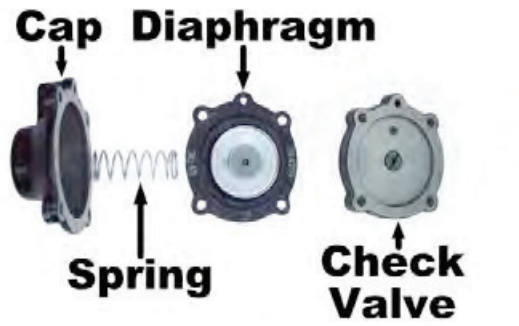


Figure 4-62. Parts of the pneumatically-operated acceleration system of a PS series pressure carburetor.

The check valve and orifice combination is used to limit the rate of fuel flow into the acceleration chamber by requiring the fuel to enter the cavity through the orifice. During fuel discharge, acceleration fuel exits both the check valve and the orifice. The discharge is initially unrestricted. However, the check valve is designed to seat when its threshold discharge pressure is not attained or exceeded. When the check valve closes during the discharge of acceleration fuel, the rate of flow from the system is reduced as the fuel has to exit solely through the orifice. This produces a prolonged discharge of acceleration fuel. ***[Figure 4-63]***

Fuel discharged from the acceleration system rejoins fuel bound for the discharge nozzle. This addition of

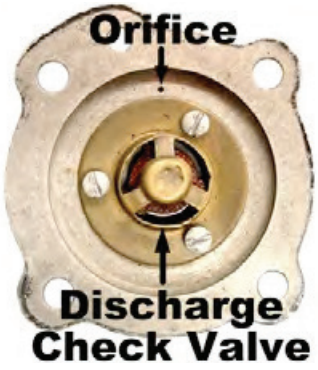


Figure 4-63. PS accelerator discharge check valve and orifice assembly.

fuel acts on the discharge nozzle's diaphragm and creates an imbalance of forces on the discharge nozzle mechanism. The result is a momentary enlargement of the opening of the discharge valve that results in an increase in fuel flow. After the acceleration is complete, fuel metering returns to normal.

DISCHARGE SYSTEM

The discharge system of a PS series carburetor delivers metered fuel to the engine's induction system. It is composed of three main components: (a) the discharge needle valve assembly, (b) the air bleed system, and (c) the discharge nozzle.

The discharge needle valve assembly involves three forces: (a) spring tension, (b) venturi suction, and (c) metered fuel pressure. A diaphragm divides the assembly with venturi suction and spring tension on one side and metered fuel on the other. Because the venturi suction is regulated, changes to Chamber B pressure, such as operation of the manual and/or automatic mixture controls, affect the level of venturi suction applied to the diaphragm.

Fuel entering the discharge assembly acts on the diaphragm. This causes the valve to open until a balance between the force generated by the metered fuel comes into balance with the force produced by the spring and venturi suction. As fuel flow increases in response to higher power settings, the valve opens further to accommodate the new fuel flow rate. Although the spring provides a greater resistance as the valve opens, the increase level of venturi suction aids in the opening process. ***[Figure 4-64]***

Fuel passing through the discharge valve is directed to the discharge nozzle. Air bleed air is also sent to the

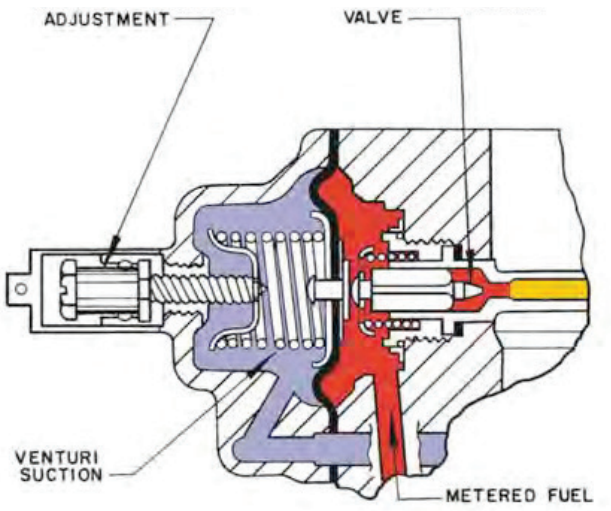


Figure 4-64. Schematic of PS series discharge valve.

discharge nozzle. Air supply for the air bleed originates from the impact pressure system. At the discharge nozzle, air and fuel are combined just prior to departing the nozzle. Upon exiting the nozzle, the emulsified fuel/air mixture is united with cylinder-bound air. ***[Figure 4-65]***



Figure 4-65. PS-5 discharge nozzle assembly.

The reader is reminded that the discharge nozzle of a PS series carburetor is located downstream of the venturi and throttle valve as seen in ***Figure 4-66***. This arrangement lessens the likelihood of ice formation on the venturi or throttle plate.

LARGE PRESSURE CARBURETORS

Large pressure carburetors are basically oversized versions of the small pressure carburetors. They are equipped with more features than the small pressure carburetor. In terms of genealogy, the large pressure carburetor has been in existence for a greater period than the small pressure carburetor. They were not called "large" pressure carburetors until the "small" pressure carburetors were created. ***[Figure 4-67]***

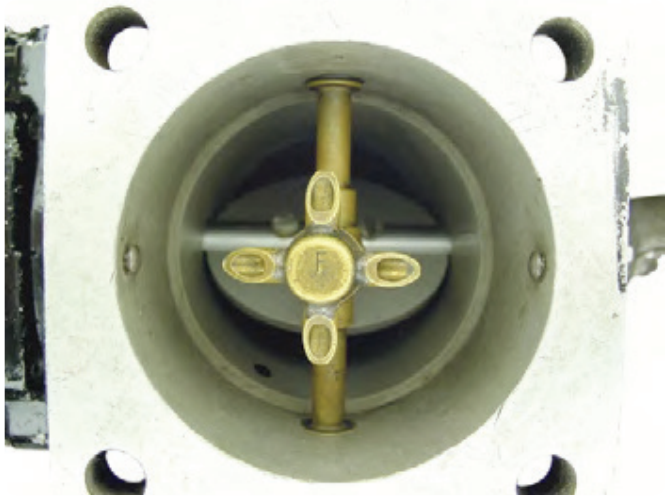


Figure 4-66. PS series discharge nozzle located downstream of the venturi and throttle plate.

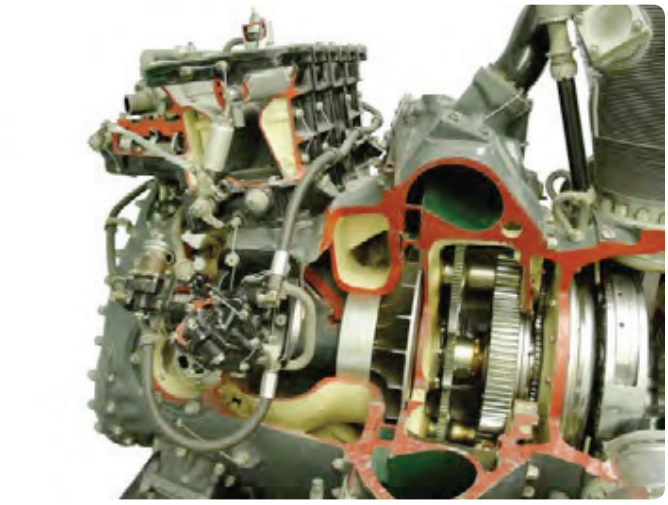


Figure 4-67. Large pressure carburetor, water injection, supercharger, and induction system cutaway view.

The emergence of the large pressure carburetor was something of a necessity. Attempting to operate a multi-row radial engine or large vee design using a float carburetor is not practical. Imagine the size of the float chamber, needle valve and seat, and pontoon needed to process fuel for an engine with a fuel consumption of 70 gallons per hour or more. How about the discharge nozzle(s) needed to deliver such fuel flows? Chances are that such engines would require multiple carburetors. Multiple carburetors must be synchronized in terms of throttle valve position and fuel flows. Such synchronization requires extremely precise maintenance operations.

Pressure carburetors have proven to be suitable substitutes for float carburetors when the size of the engine became large. Spraying pressurized fuel into the induction system provides numerous advantages over using venturi suction to draw fuel from the float chamber. As previously mentioned, and aside from the issues discussed in the preceding paragraph, spraying pressurized fuel into the induction system reduces the possibility of forming ice during the metering process. Also, the pressure carburetor is generally indifferent to flight attitude. The amount of flow required by the power plant is easily tailored for the particular engine by making adjustments to the regulator and/or fuel control unit. Consequently, with the exception of the size of the venturi and its many jets, the basic large pressure carburetor fits many different engines.

In this section, attributes of the large pressure carburetor are presented. The depth of the discussion is confined to general operation and noting differences between large and small pressure carburetors.

THROTTLE BODY

Large pressure carburetors manufactured by Bendix have a variety of throttle bodies. They often are PD, PT, or PR designs. The letter "P" indicates that the unit is a pressure carburetor. The second letter, D, T, or R, is used to describe the venturi network. D indicates a double venturi, T signifies a triple venturi, and R is used to designate that the venturi is rectangular.

The throttle body serves as the main structure for the carburetor. A number of components are attached to the main throttle body. These include the: (a) AMC bellows, (b) regulator assembly, (c) fuel control unit, (d) acceleration pump, (e) primer system, and (f) discharge nozzle. The throttle body also includes the various connection ports leading to and from the carburetor. Included are the: (a) main fuel inlet, (b) discharge outlet, (c) primer lines, (d) vapor ejection lines, (e) fuel pressure gauge tap, and, when installed, (f) lines leading to and from the water injection regulator. Mounted on the throttle body are the idle stop and full throttle stop. The idle speed and idle mixture adjustments are part of the linkage associated with these stops.

The venturi(s) is(are) mounted in the throttle body. As with other fuel metering devices, the size of the venturi is selected to limit air flow to the engine during full

power operation. Conventional throttle valves are used to control the flow of air into the engine.

One of the more complicated features of the throttle body is the internal maze of passageways. Numerous passages are drilled throughout the throttle body. Although initially complex to manufacture, the internal passageways greatly simplify the unit by keeping to a minimum the number of external lines needed to connect the various systems.

A number of discharge systems are available for use with large pressure carburetors. Two styles are most often employed: (a) discharge rake and (b) single-point nozzle. The discharge rake has a number of discharge holes running nearly the entire span of the opening to the induction manifold. The single-point discharge nozzle typically sprays fuel into the entrance of the engine's supercharger impeller.

REGULATOR

The regulator of a large pressure is relatively complex when compared to the regulator of a small pressure carburetor. The arrangement of the regulator, in combination with the additional systems and subsystems, account for the added dimension of complexity.

Fuel entering the regulator is ported into Chamber E. Under normal operations, this fuel is fed directly from the engine-driven fuel pump. The auxiliary pump may also be used to send fuel into Chamber E. The auxiliary pump may be used alone when the engine is not running or in combination with the engine-driven pump when the engine is operating.

Chamber E fuel may be used to prime the engine. A solenoid-type primer directs fuel from Chamber E into the primer discharge nozzles located in the throttle bore on some models. Normally, the auxiliary pump supplies fuel flow for priming operations. Engines are often started using the solenoid primer with the mixture control in idle cutoff (ICO). After the engine is started using fuel from the solenoid primer, the mixture control in placed into auto rich or auto lean after a brief period running off the solenoid primer. ***[Figure 4-68]***

Chamber E contains a float mechanism. Where the operation is basically similar to its counterpart in a float carburetor, this device is for discharging vapors that

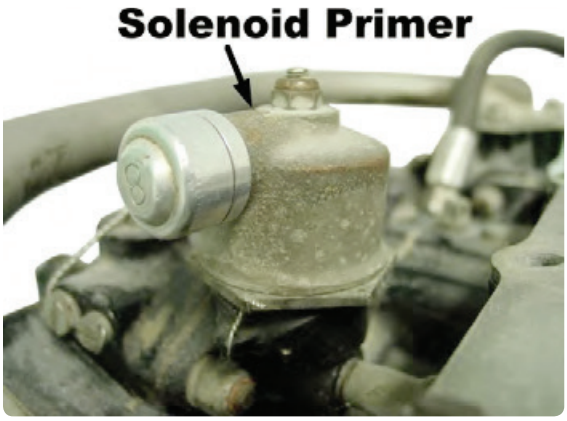


Figure 4.68: Solenoid Primer

accumulate in the regulator. Another float assembly is located in Chamber D. When predetermined quantities of vapors collect in their respective chambers, the floats drop. When this occurs, the ejection valve operated by the float mechanism opens. The vapors, along with some fuel, escape from the cavity where the float is installed. Once the vapors have been removed, the float rises and seats the valve, thereby closing the outlet. Keeping vapors out of the system helps to ensure accurate metering. ***[Figure 4-69]***

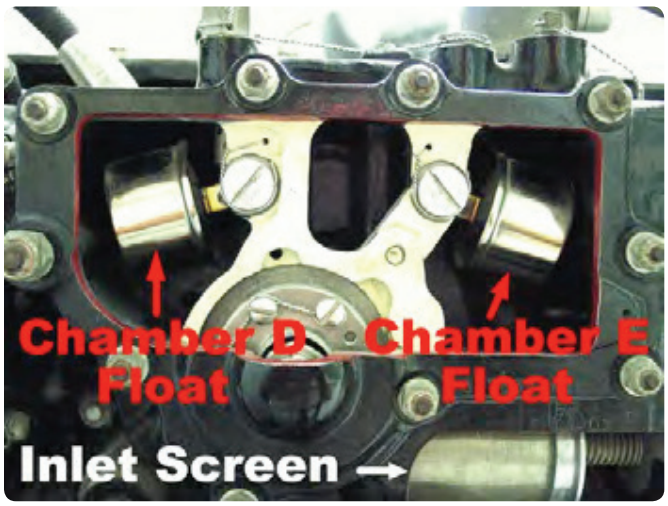


Figure 4-69. Large pressure carburetor vapor ejection floats and inlet screen.

Chamber E fuel is filtered before reaching the poppet valve. This filter is removed, inspected, cleaned, and reinstalled during the routine inspections. A pressure tap for the fuel pressure gauge senses fuel pressure downstream of the filter. Knowing where the pressure gauge is connected is beneficial during troubleshooting operations.

Fuel that flows from Chamber E into Chamber D is regulated by the action of the poppet valve. Chamber D fuel pressure is applied to the fuel diaphragm used to separate Chambers D and C. It is also sent to: (a) the fuel control unit, (b) accelerator pump, and (c) balance diaphragms. A discussion describing the flow through each path is presented in the appropriate sections.

Fuel departs the fuel control unit after being metered and is sent back to the regulator as Chamber C fuel. This fuel is regulated and metered. Chamber C fuel originates from the regulator fill valve. This fuel circulates through Chamber C and reunites with fuel bound for the discharge nozzle. An orifice is placed in the return line. The purpose of the regulator fill valve and orifice is to ensure a positive idle cutoff. When the operator places the mixture control in idle cutoff, the regulator fill valve closes. Because the orifices restrict how quickly fuel flows from Chamber C, the engine dies without the ability to draw fuel from Chamber C through the discharge nozzle into the low pressure region of the induction system. ***(Figure 4-70)***

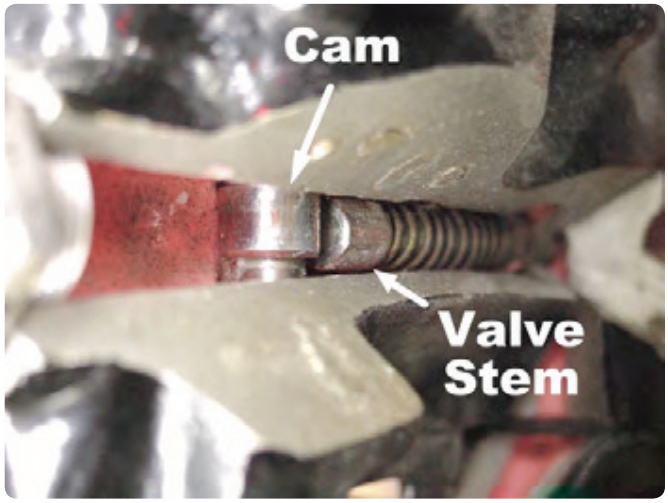


Figure 4-70. Regulator fill valve showing activation cam and valve stem. This device closes and opens by movement of the manual mixture control to and from idle cutoff.

On the pneumatic side of the regulator, air enters and exits through the throttle body. The path through the pneumatic chambers begins at the impact tubes. A series of small ports is located along the inlet side of the carburetor. Some of the air entering the carburetor is diverted from entering the induction manifold and is directed to Chamber A. Before reaching the Chamber A, this air travels from the impact tubes to the automatic mixture control mechanism. ***[Figure 4-71]***

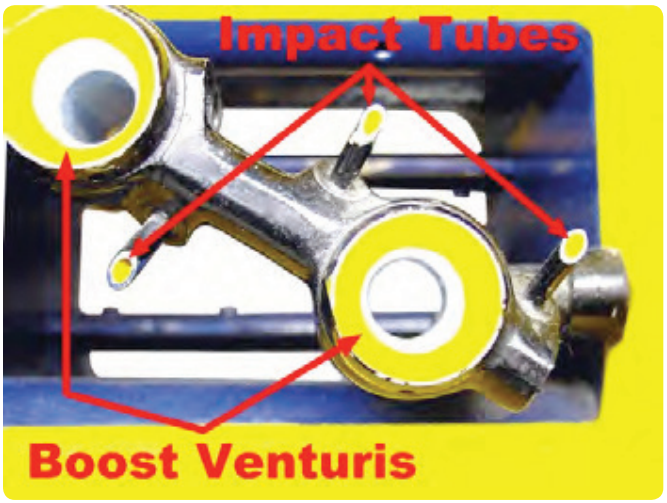


Figure 4-71. Air inlet of large pressure carburetor showing impact pick up tubes and boost venturis.

The length of the AMC valve is determined by the ambient pressure and temperature sensed by the bellows assembly. Air that passes through the AMC is sent to Chamber A. A bleed between Chambers A and B allows for the constant flow of air from Chamber A into Chamber B. As the rate of flow through the AMC increases and decreases, the pressure differential acting on the pneumatic diaphragm increases and decreases. The force generated by this pressure differential is transmitted through the poppet valve stem to the poppet valve. When the pressure differential across the air diaphragm increases and decreases, the size of the poppet valve opening and, in the end, fuel delivery to the engine, increases and decreases. Because the pressure in Chamber A is controlled in this fashion, it is regulated impact pressure. As no valves or restrictors are placed between suction chamber and the venturi, Chamber B is unregulated venturi suction.

The AMC is designed to fail-safe. Similar to the AMC mechanisms used with float carburetors, small pressure carburetors, and Bendix fuel injection systems, if the bellows assembly develops a leak, the AMC is designed to contract. This maximizes the opening formed by the valve and provides maximum impact chamber pressure. The operator still has the option of using the manual mixture control when the AMC fails. ***[Figure 4-72]***

Air leaves Chamber A through the bleed between Chambers A and B and exits through the opening in the venturi. This air is reunited with the cylinder-bound air. ***[Figure 4-73]***



Figure 4-72. Large pressure carburetor automatic mixture control (AMC).



Figure 4-73. Air Exit Point from Chamber A through Chamber B.

Chambers B and C are separated by a partition. This prevents the pressure in Chamber C from acting directly on Chamber B. However, where the poppet valve stem passes through Chamber B into Chamber C, a pressure differential between the two chambers acts on the seal diaphragm. To negate this effect, fuel from Chamber D is sent to the balance diaphragms in Chambers A and E.

The acceleration system uses the balance diaphragm system to open the poppet valve for acceleration fuel. During acceleration, fuel contained in the accelerator pump is discharged from the acceleration cylinder. The discharged fuel travels to the balance diaphragm in Chamber A and to Chamber D. But two orifices leading to Chamber D restrict the flow into the regulated fuel chamber. Because of this action, fuel pressure increases in the balance diaphragm compartment in Chamber A. This force is directed to further unseat the poppet valve, thereby generating a series of events that provides acceleration fuel. As the fuel bleeds through the orifices, the pressure in the balance diaphragm in Chamber A returns to normal. This system of acceleration works by creating a temporary imbalance between the forces acting on the poppet valve. ***[Figure 4-74]***



Figure 4-74. Accelerator piston for large pressure carburetor.

The general operation of the regulator is based on balancing a series of forces. The two main players are: (a) air metering force and (b) fuel metering force. The air metering force is primarily generated by the pressure differential between the impact and venturi suction chambers. This differential is applied to the surface area of the pneumatic diaphragm. Supplementing this force is spring tension. As with other fuel metering devices that employ a venturi for determining fuel flow, the amount of air flowing though the unit during low power settings is too small to establish an adequate metering force. Consequently, a supplemental means of metering is needed for low power settings.

Fuel metering force is established by the pressure differential between Chambers C and D. The difference between the chambers is exerted across the fuel diaphragm. Force derived from the fuel diaphragm is applied to the poppet valve stem. Chamber D pressure is greater than Chamber C pressure. Because of this relationship and the configuration of the regulator, the fuel metering force opposes the air metering force. It strives to close the poppet valve.

During operation, the opening action of the air metering force is brought into balance with the closing action of the fuel metering force. The outcome of this activity is that the poppet valve is properly positioned to deliver the correct fuel flow to the fuel control unit and to the engine. To better understand the general operation of the regulator, the following example is provided.

Starting from idle, as the throttle is advanced, more air travels through the throttle body. This increase in air flow produces an increase in impact pressure and venturi suction. Remember, when venturi suction increases, the absolute pressure in Chamber B goes down. The net result is an increase in the air metering force. The poppet valve opens an additional measure as a result of the imbalance generated by the increase in air flow through the unit.

As the poppet valve opens, more fuel from Chamber E passes through the poppet into Chamber D. This produces an increase in the regulated fuel pressure. This increase in Chamber D pressure travels to the fuel control unit where it encounters an enlarged idle valve. Because the idle valve is connected to the throttle, the size of the orifice formed by the position of the valve increases as the throttle is opened from idle. At some predetermined throttle position, the idle valve is fully opened. Refer to ***Figures 4.47 and 4.48***. Fuel passing through the series of orifices in the fuel control unit emerges as metered fuel. A quantity of this fuel is sent to Chamber C where it opposes Chamber D pressure. In a short period of time, the increase in the fuel metering force balances with the increase in the air metering force. When this occurs, the poppet remains stationary until another imbalance occurs between the air metering and fuel metering forces.

FUEL CONTROL UNIT

The fuel control unit of a large pressure carburetor is perhaps the most complicated fuel control of all the reciprocating engine metering devices. The following components compose a typical fuel control unit of a large pressure carburetor: (a) idle valve, (b) power enrichment jet, (c) automatic rich jet, (d) automatic lean jet, (e) power enrichment valve, (f) regulator fill valve, (g) manual mixture control, and, when water injection is included, (h) a derichment valve and jet. Before delving into the basic operation, one issue must be addressed. In order for this mechanism to properly function, the correct fuel pressure must be applied to the regulator. Be certain to check the fuel pressure before making adjustments or implementing other maintenance or troubleshooting measures.

Regulated fuel from Chamber D flowing into the fuel control unit first encounters the idle valve. Unlike the small pressure carburetor where fuel flowed through the metering jet before reaching the idle valve, the position of the idle valve dictates how much fuel reaches the metering jets. The idle valve is connected to the throttle by a direct link. The latter has a provision for adjusting idle mixture.

At low power settings, the idle valve restricts flow into the fuel control unit. See ***Figures 4.47 and 4.48***. Fuel entering the controller has several flow paths that lead to the discharge port. Anytime the engine is running, fuel is allowed to flow through the automatic lean jet. In this sense, this device acts as the primary metering jet. The other jets serve to supplement the flow to the discharge port. The manual mixture control is shaped like a clover leaf. Because of its distinctive shape, this valve is often called the clover leaf. ***[Figure 4-75]***

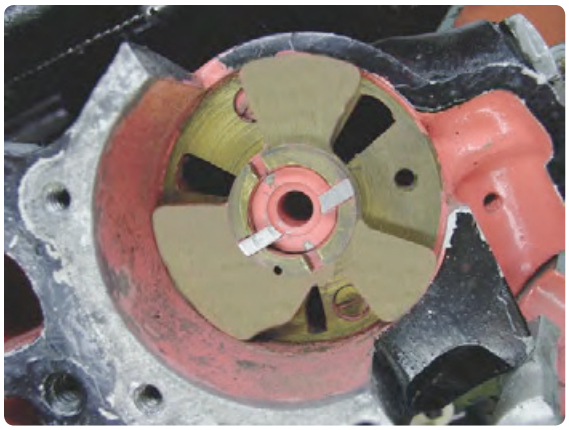


Figure 4-75. "Clover leaf" manual mixture control of large pressure carburetor. Note how petals block and unblock passageways.

The different petals, or valve surfaces, are used to block, or unblock, the output from the jets as determined by the position of the mixture control. The mixture lever moved by the operator has discernible detents. There is one for automatic rich, one for automatic lean, and one for cutoff. ***[Figure 4-76]***

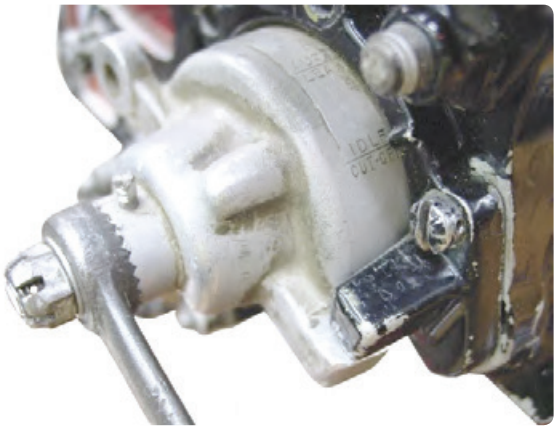


Figure 4-76. Large pressure carburetor manual mixture control shown in IDLE CUT-OFF position. This mechanism positions the "clover leaf."

When the mixture is in automatic lean, only the passage from the automatic lean jet is unblocked by the clover leaf. The system is able to add power enrichment fuel, or derich the power enrichment flow during water injection operations, at high power settings. When the mixture control is placed in automatic rich, an additional passageway is unblocked by the clover leaf. The automatic rich jet, which is smaller than the automatic lean jet, adds a measure of fuel flow to the discharge port. ***[Figure 4-77]***

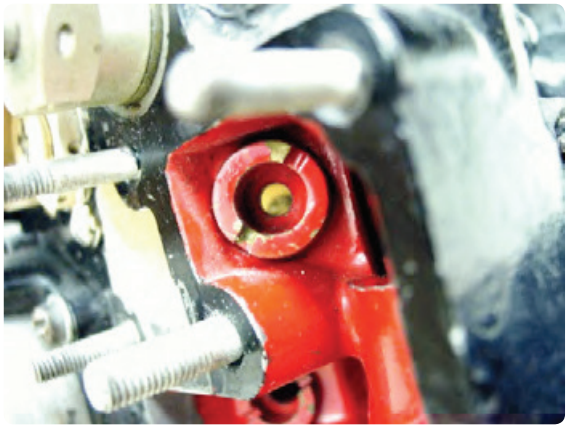


Figure 4-77. Large pressure carburetor fuel control metering jets.

For power enriched flows, a diaphragm operated valve provides a supplemental quantity of fuel flow. This valve opens when Chamber D pressure reaches or exceeds a certain pressure threshold. The pressure applied to the diaphragm overcomes spring tension and opens a poppet-type valve. Fuel passing through the valve is first metered by the power enrichment jet. When equipped with water injection, an additional flow of fuel into this system comes from the derichment jet. When the derichment system is activated by pressure from the water injection system, fuel flow from the derichment jet into the power enrichment valve is discontinued. After passing through the power enrichment valve, enrichment fuel joins the other fuel bound for the discharge port. ***(Figure 4-78)***

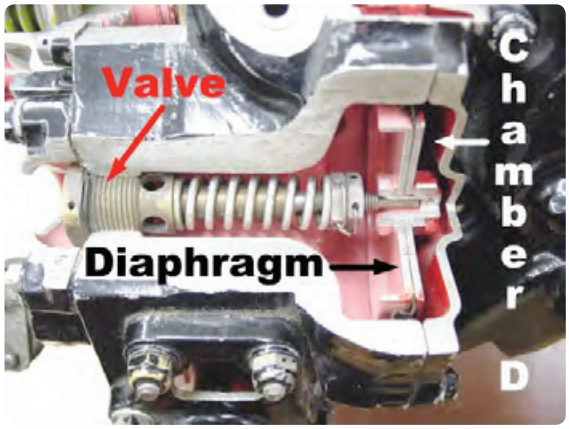


Figure 4-78. Power enrichment valve.

DISCHARGE SYSTEM

Fuel leaving the fuel control unit is regulated and metered. As previously discussed, a small portion of this fuel travels to Chamber C and the remainder is directed to the discharge nozzle(s).There are various discharge nozzles used with large pressure carburetors.

The two most prominent styles are: (a) the discharge rake and (b) the single nozzle. Discharge rakes are bolted directly to the throttle body. They have a manifold that extends laterally across the unit. Along the length of this manifold is a series of holes. Fuel entering the discharge rake exits one of the holes and mixes with induction-bound air. ***[Figure 4-79]***

The single-point nozzle is typically installed in the throat of the impeller. Fuel sprayed from this unit mixes with air entering the impeller. A fuel/air mixture emerges from the diffuser, or outlet, of the impeller mechanism. The fuel/air charge leaving the impeller mechanism is well

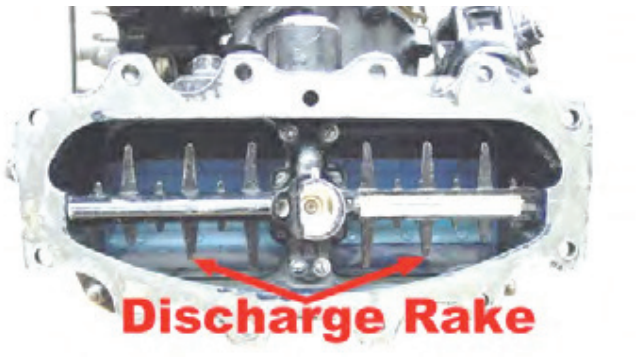


Figure 4-79. Large pressure carburetor discharge rake.

mixed as a result of the nozzle spray pattern, ambient heat absorbed by the fuel/air charge, and mixing action of the rapidly spinning impeller. ***(Figure 4-80)***



Figure 4-80. Large pressure carburetor single-point discharge nozzle.

FUEL INJECTION SYSTEMS

TYPES OF FUEL INJECTION

Fuel injection in aviation reaches back to the days of the Wright Brothers. The very early Wright engines used a simple fuel metering system that did not include a throttle valve. Fuel from an elevated tank dripped into the air inlet. Where this technique allowed the Wright engines to develop full power, it also presented numerous limitations. The Wright Brothers developed an early form of what is now known as continuous flow fuel injection. This form of fuel injection is considerably different than direct fuel injection. The latter sprays fuel into the combustion chamber at precisely the correct crankshaft position. Direct fuel injection systems require high-pressure pumps, high-pressure nozzles, and exact system timing. By comparison, continuous flow fuel injection delivers fuel continuously to the intake port of the cylinders. The fuel absorbs the heat from the cylinder head as it waits its turn to enter the combustion chamber via the intake valve. The Wright Brothers developed a continuous flow fuel injection system sometime during 1904 to 1908.

Although the Wrights did not entitle their system continuous flow fuel injection, their inline, upright four-cylinder engine of 1906, or perhaps it was a later model, clearly reveals the continuous flow design. It is likely that the drip-type fuel system used on the 1903 engine was inadequate for aircraft that were capable of protracted flights. Certainly the drip system experienced changes in the metering process when the rpm of the engine changed. In other words, as the engine gained or loss rpm, the constant drip caused the mixture to become either lean or rich, depending on the change of rpm. This may have been a problem with the early model Wright Flyers as they were prone to undulating during flight. As the craft flew, it had a tendency to pitch up and down. The operator was constantly chasing after the aircraft's attitude. But as the aircraft pitched up and down, the aerodynamics of the propellers changed. This resulted in a change of engine rpm, which altered the mixture of the drip-type fuel metering system. In addition, intentional climbs and descents caused changes in the rpm. Metering may also have been affected by fuel consumption. As the fuel quantity in the tank was consumed, a change in the pressure exerted by the fuel in the tank changed. Such action may have resulted in changes to the fuel metering.

In any event, the drip-type fuel metering system offered too many inconsistencies in terms of fuel metering.

To amend the aforementioned problems regarding fuel metering, the Wrights decided to deliver fuel to the engine in proportion to rpm. Rather than simply drip fuel into the induction manifold, the Wrights added a fuel pump and nozzle to their system. The fuel nozzle was placed in the air inlet. A cloverleaf shaped valve, like those used to control the flow of air to gas burners, was used to adjust the quantity of air entering the engine. This system did not include a throttle. It, like the 1903 engine, ran full open. A compression release that held the exhaust valves off their seats was used for descents. As the engine rotated, the fuel pump sprayed a fixed volume of fuel into the air inlet based on rpm. As rpm changed, so did the quantity of fuel delivered to the engine. In this way, fuel flow was based on engine rpm rather than some measure of drip.

Over the years direct fuel injection was developed and mechanical continuous flow units also emerged. The future will likely provide the industry with electronic fuel injection. ***[Figure 4-81]***

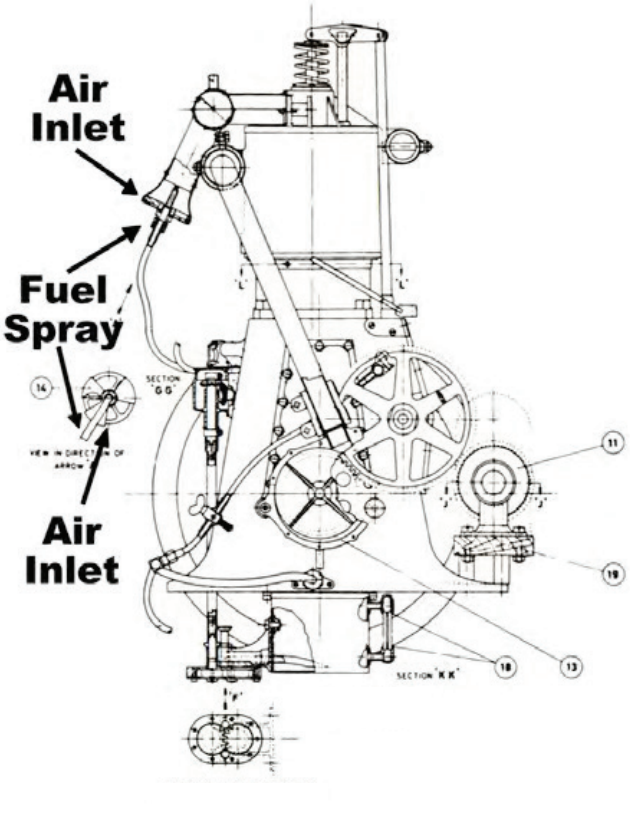


Figure -81. Early form of continuous flow fuel injection.

DIRECT FUEL INJECTION

Fuel injection systems used on reciprocating power plants normally take one of two forms: (a) continuous flow fuel Injection or (b) direct fuel injection. Continuous flow units have fuel continuously discharging from their discharge nozzle(s) the entire time the engine is operating. By contrast, direct injection systems spray fuel into the combustion chamber during the intake stroke. The fuel discharge from the direct injection system must be precisely timed to the engine.

Because the direct injection system closely parallels the operation of the large pressure carburetor, the focus of this section concentrates on the differences. Specifically, the operation of the injector pump and nozzles are addressed.

INJECTOR PUMP

The direct fuel injection system places the discharge tip of the injector nozzle into the combustion chamber. Because of the pressures generated in the combustion chamber, the system operates using high pressure. To develop the pressure necessary for the operation of the system, a piston pump is used. A separate piston assembly is dedicated to each cylinder. An adjustment for each piston assembly provides a means whereby the mixture for each cylinder may be accurately tailored.

The Wright R-3350 is a twin-row, 18 cylinder radial power plant. It uses a direct fuel injection unit manufactured by Bendix. To meet the needs of the power plant, two nine-piston injector pumps are used. The pumps use a standard wobble plate drive mechanism to generate the reciprocating motion of the pistons. ***[Figure 4-82]***

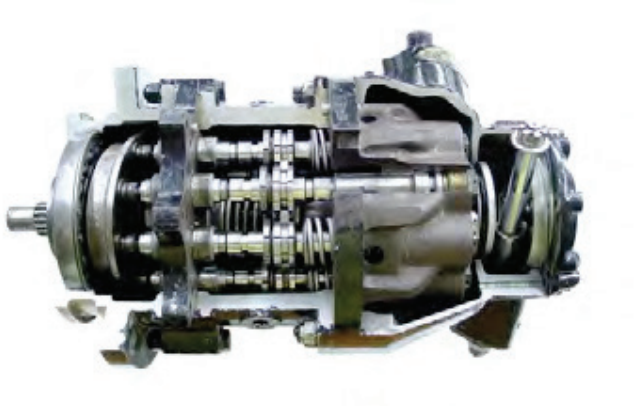


Figure 4-82. Bendix direct injection high-pressure pump. Note the wobble plate on the left side of the unit and the separate piston assemblies in the center of the pump.

Because the discharge of fuel from the nozzles must occur at a precise engine position, the operation of the pump must be critically timed to the crankshaft. This is accomplished through the incorporation of a ***master spline*** on the drive shaft of the pump. The master spline prevents the inadvertent improper installation of the high-pressure fuel pump. ***[Figure 4-83]***



Figure 4-83. Master spline on drive shaft of direct injection high-pressure fuel pump.

The pumps are mounted directly behind and beneath the fuel controller. The latter is basically a large pressure carburetor that directs its discharge fuel to the injector pumps rather than a discharge rake or impeller nozzle. The output from the controller is sent to the injector pumps where the fuel undergoes an intake and discharge stroke by the plunger assemblies. The discharge from each plunger assembly is directed to its assigned cylinder.

A quick examination of the intricate workings of the injector pump illustrates the complexity of the unit. The intense amount of precision machining alone dictates high production costs. Because of the expense and complexity of operation, few engines use direct fuel injection.

INJECTOR NOZZLE

Fuel injector nozzles used with the direct injection system are stoutly constructed to withstand the environment of the combustion chambers. Unlike the open nozzle design used with continuous flow fuel injection units, the direct fuel injection nozzle contains a valve that opens and closes in response to fuel flow pulses. As with the injector pump, the extensive machining necessary to manufacture this fuel injection nozzle greatly adds to the cost of production.

Connecting the output of the high-pressure pumps to the injector nozzles is accomplished through the use of banjo bolts and fittings. The banjo bolt is a threaded fastener drilled to allow fluid flow. Using banjo bolts and fittings simplifies line alignment issues that frequently arise when making hydraulic connections with pipe threaded fittings. The technician is able to properly align the fittings before tightening the banjo bolts. ***[Figure 4-84]***



Figure 4-84. Banjo bolt.

The direct fuel injection nozzle contains a spring-loaded valve that requires a minimum fuel pressure of approximately 500 psi to open. The piston pump provides the hydraulic force necessary to open the valve. Fuel discharging through the nozzle enters the cylinder during the intake stroke. It exits the nozzle in the form of a fine spray. It quickly and thoroughly vaporizes in the hot cylinder and mixes with air. ***[Figure 4-85]***



Figure 4-85. Direct fuel injection nozzle. Note banjo bolt and fitting.

BENDIX CONTINUOUS FLOW FUEL INJECTION

Bendix continuous flow fuel injection systems are designated by the model prefix ***RS***, which stands for Reciprocating power plant Servo control. The early versions were identified as RS units. The second generation of Bendix continuous flow fuel injectors is indicated by the designation ***RSA***. As the earlier RS systems have been largely replaced by the RSA units, the focus of this segment will be placed on the RSA system.

BENDIX RSA FUEL INJECTION

Bendix refined their continuous flow fuel injection system as previously indicated. The RSA system that emerged has been in service for decades. After several changes and modifications, the current unit is a reliable and relatively simple metering device. ***[Figure 4-86]***

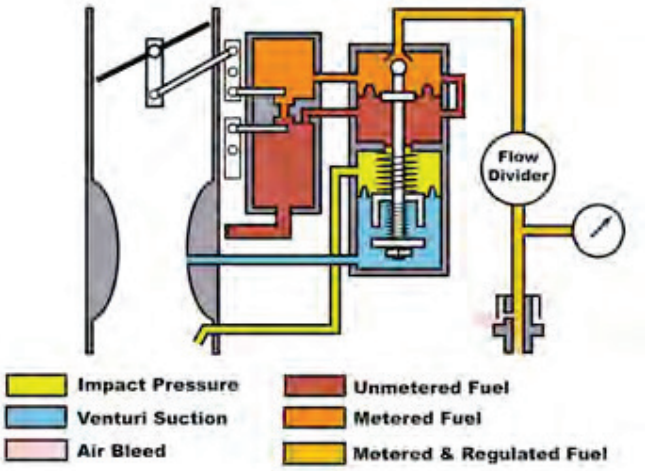


Figure 4-86. Schematic of RSA continous flow fuel injection system.

The RSA continuous flow fuel injection system is composed of various systems and components. A discussion of the physical attributes of the components along with an explanation of the operation is included in this section. The discourse initially concentrates on controllers that do not include the automatic mixture control (AMC). Supplementary data regarding the construction and operation of the AMC system is provided near the end of this section.

DESIGN AND OPERATION OF THE RSA FUEL INJECTION SYSTEM

Before delving into the particulars of this system, a simple schematic is provided. ***(Figure 4-87)*** Not included in this depiction is the associated fuel system provided by the aircraft and engine manufacturers (e.g., fuel tank, auxiliary fuel pump, fuel strainers, engine-driven fuel pump, etc.).

THROTTLE BODY

The throttle body of the RSA injector is similar to the throttle body of other pressure injection controllers. It houses the regulator and fuel control unit. A number of internal passageways are used to interconnect the regulator to the fuel control unit and the pneumatic channels associated with impact pressure and venturi suction.

Aside from the regulator and fuel control unit, the throttle body contains the venturi and throttle valve. Other items associated with the throttle body include the throttle stops and the link that interconnects the butterfly valve with the fuel control unit. The throttle and mixture control levers are also attached to the throttle body assembly.

FUEL CONTROL UNIT

The fuel control unit of the Bendix RSA system is not overly complex. Fuel enters the unit through a screen. Filtered fuel then encounters the manual mixture control. The screen should be removed, inspected, cleaned, and reinstalled during the inspection process of the power plant. Technicians should also remove and inspect the screen during troubleshooting operations directed at the metering device. After passing through the mixture control valve orifice, unmetered fuel has two flow options: (a) to the unmetered fuel chamber in the regulator or (b) to the metering jet and idle valve assembly. The idle valve assembly proportions the size of the metering orifice to correspond with the throttle position. ***[Figure 4-88]***

Unmetered fuel pressure directed to the regulator is the strongest pressure applied to the regulator. It is used to move the ball valve toward the closed position.

Fuel passing through the metering jet and idle valve assembly is ported to the metered fuel chamber in the regulator. This force is placed in direct opposition to the unmetered fuel pressure and works to open the ball valve. Metered fuel must exit the regulator through the ball valve before reaching the cylinders. ***[Figure 4-89]***

REGULATOR

The regulator of the Bendix RSA system is similar to regulators used with the pressure carburetors. There are, however, two significant differences between

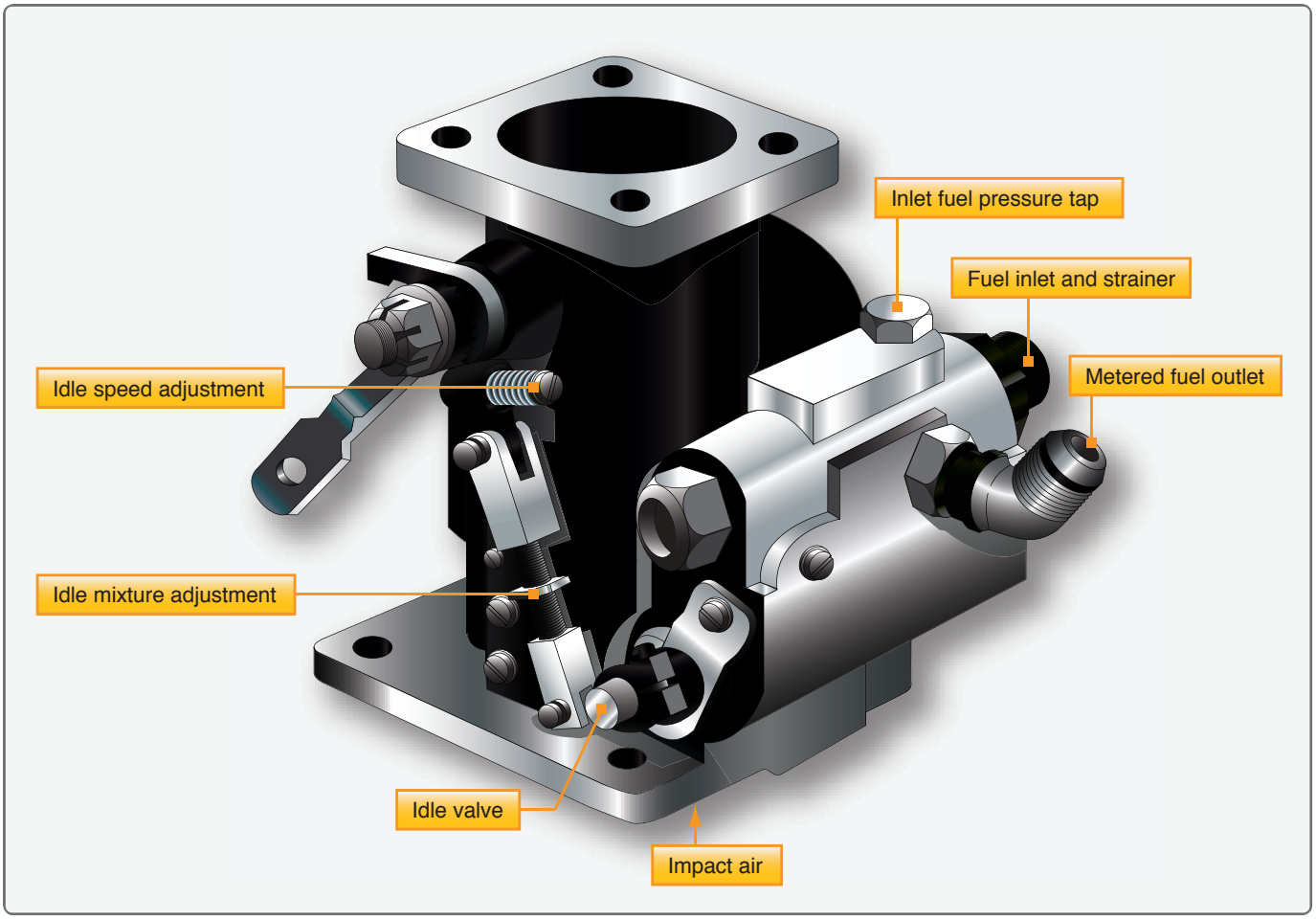


Figure 48-7. RSA Fuel injection unit.

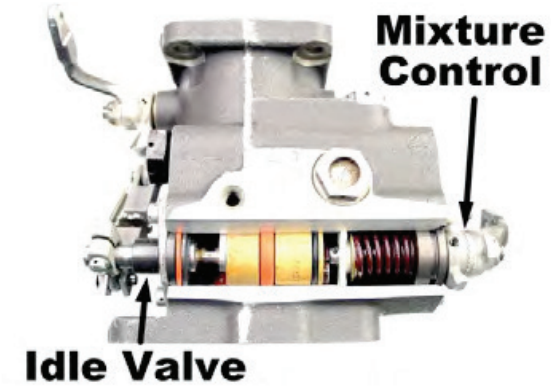


Figure 4-88. RSA fuel control unit.

the operation of this unit and the regulator used with the pressure carburetor. First, pressure carburetors regulate the fuel before the metering process. The RSA inverts the process by metering the fuel before it is regulated. Second, the locations of the chambers are different in respect to order. ***[Figure 4-90]***

Before discussing the operation of the RSA regulator, an introduction to the pressures contained in each chamber and physical attributes of the regulator are provided.

THEORY OF OPERATION

Impact pressure is taken from the incoming air entering the throttle body. This pressure is unregulated and is the highest pneumatic force within the regulator in terms of absolute pressure. The constant effort spring is contained within the impact pressure chamber. The impact pressure chamber is adjacent to the venturi suction chamber and unmetered fuel pressure chamber. It is isolated from unmetered fuel pressure by a partition and inner body seal and separated from the venturi suction chamber by the pneumatic diaphragm.

Venturi suction is transmitted from the openings in the narrowest constriction of the venturi to the venturi suction chamber. This force is unregulated unless the unit is equipped with an AMC. The constant head

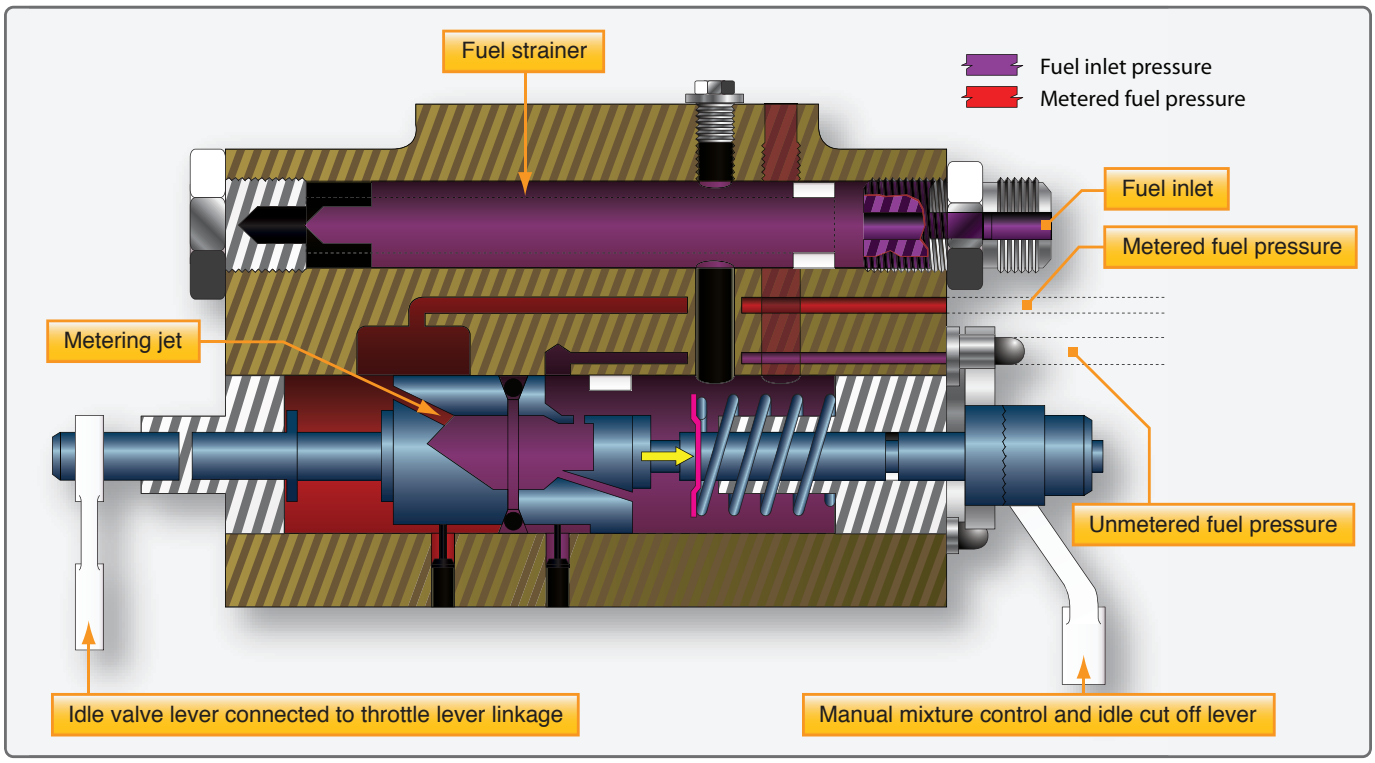


Figure 4-89. RSA fuel control unit flow.

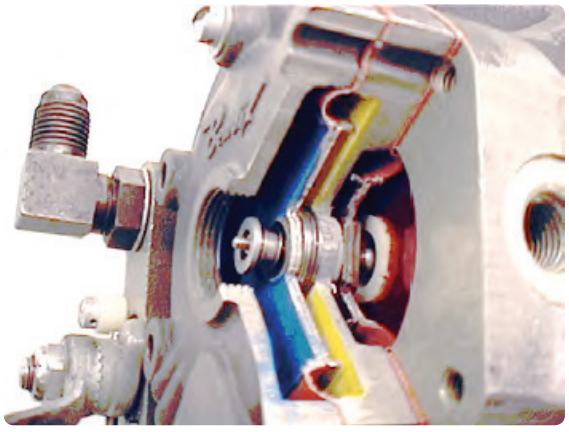


Figure 4-90. RSA regulator. Note the difference in size between the pneumatic (blue) diaphragm and the fuel (red) diaphragm.

spring is installed in the venturi suction chamber. The venturi suction pressure chamber is situated the greatest distance from the ball valve.

On a typical RSA unit, the pneumatic diaphragm measures 2 inches in diameter. As with the PS series small pressure carburetor, the pneumatic diaphragm is larger than the fuel diaphragm which has a 1.25-inch in diameter. This design attribute provides a measure of mechanical advantage to the pneumatic diaphragm.

A partition separates the pneumatic portion of the regulator from the hydraulic side. To allow for passage of the ball valve stem from the pneumatic side to the fuel side, a seal is installed between the impact pressure chamber and the unmetered fuel pressure chamber.

The pneumatic diaphragm is not rigidly affixed to the ball valve stem. The air diaphragm floats on the ball valve stem and is provided with a small amount of linear travel that helps the unit transition from idle to higher power settings.

Unmetered fuel pressure enters the regulator from the mixture control valve. Unmetered fuel is the greatest pressure applied to the regulator. It supplies the motive force that pushes the fuel through the unit. The unmetered fuel pressure is the only force working in the regulator to close the ball valve. An equilibrium between the unmetered fuel pressure and the remainder of the forces is established during operation. As with the pressure carburetor, when an imbalance occurs, the regulator responds by repositioning the ball valve until a new balance is attained. For the most part, unmetered pressure is fairly consistent throughout the operational range of the power plant. A small bleed connects the two fuel chambers.

Metered fuel pressure opposes unmetered pressure as it works to open the ball valve. During low power operations, the two have about the same magnitude of pressure. At higher power settings, the level of metered fuel pressure acting within the chamber is reduced. The ball valve is included in the metered fuel pressure chamber. Fuel exiting the metered chamber travels to the flow divider and injector nozzles.

The regulator of a RSA continuous flow fuel injection system works in a fashion that parallels the operation of a regulator in a pressure carburetor. In particular, the regulator is arranged to seek, establish, and maintain an equilibrium between the air metering and fuel metering forces.

The explanation of the operation of the regulator begins by examining the theory of operation and a sample regulator under two different power settings. Values selected for these examples were selected to illustrate the basic operation of the regulator. Following the introductory demonstration, examples involving actual numbers recorded from an operable unit are presented and discussed. The data provided herein were generated from measurements taken from a Bendix RSA-5AD1 injector.

The regulator is composed of four separate chambers: (a) impact pressure, (b) venturi suction, (c) unmetered fuel pressure, and (d) metered fuel pressure. The two air chambers are placed on opposite sides of the pneumatic diaphragm. They work together to form the air metering force. The two fuel pressures are exerted on opposing sides of the fuel diaphragm. The fuel chambers are arranged so that the metered fuel pressure chamber joins the air metering force in opposing the unmetered fuel pressure. The latter is the only force within the regulator working to close the ball valve. It is the highest pressure within the regulator. All the other forces direct their efforts toward opening the ball valve. ***[Figure 4-91]***

As with other fuel metering units that incorporate a conventional venturi, a supplemental system is necessary to provide idle fuel. The RSA injector uses a pair of springs in the air chambers: (a) constant effort and (b) constant head. These springs are engineered to keep the ball valve open for idle operations and assist the unit in its transition from low power operations to higher power settings. They too work to oppose the unmetered fuel pressure.

The two primary forces within the regulator are: (a) air metering force and (b) fuel metering force. To

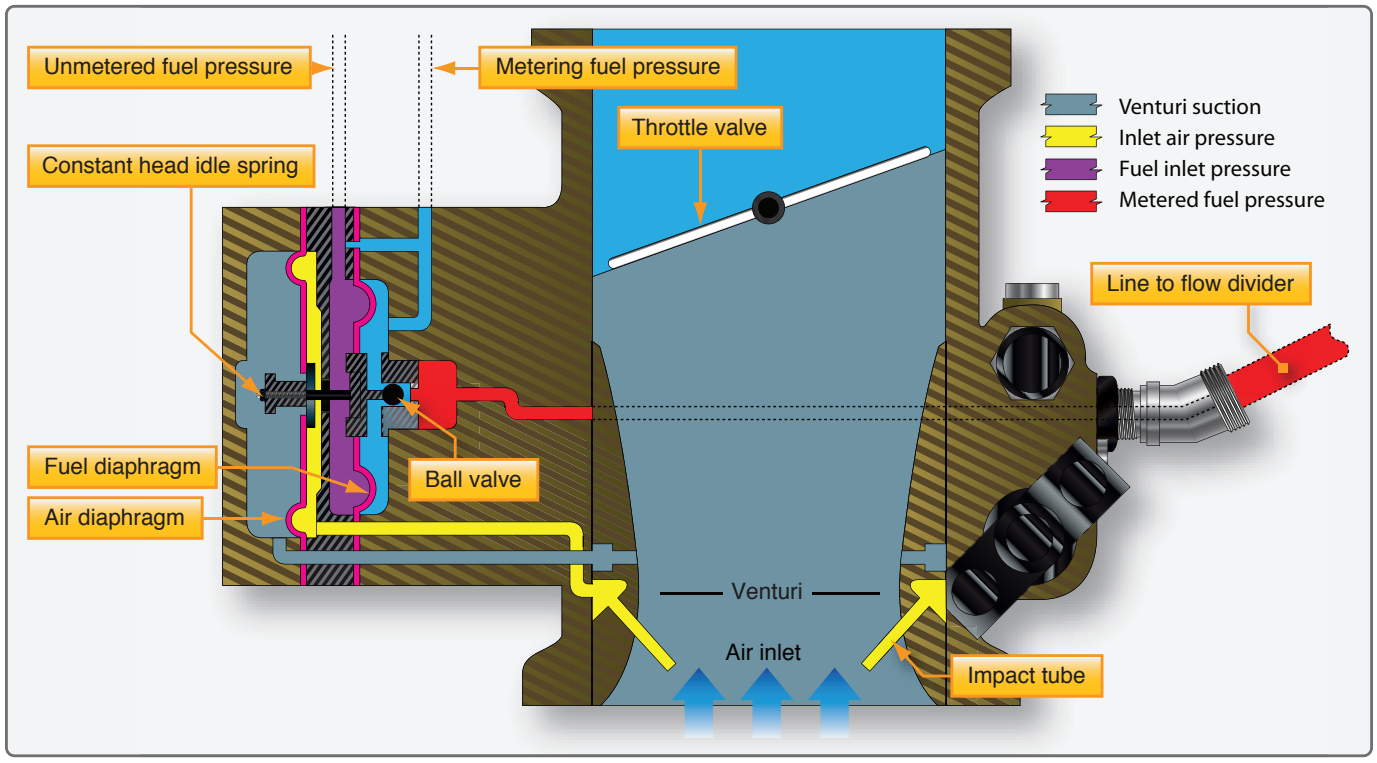


Figure 4-91. RSA regulator schematic.

calculate the air metering force, measure the pressure differential between the impact and venturi suction and multiply the pressure differential by the surface area of the diaphragm. The same process is used to figure the fuel metering force. When the engine is operating with the throttle at or near idle, there is little pressure differential acting across the pneumatic diaphragm. Because the regulator is designed to establish and maintain an equilibrium between the air metering force and the fuel metering force, the magnitude of the fuel metering force at low power settings corresponds to the level of the air metering force. At low power settings, the air metering force is low. In such instances, there is little pressure differential acting on the air diaphragm. To maintain equilibrium between the air metering and fuel metering forces, unmetered and metered fuel pressures are nearly the same.

As air flow through the unit increases, the amount of suction generated by the venturi increases. This serves to increase the pressure differential acting on the air diaphragm. The corresponding increase in the air metering force produces an imbalance within the regulator. As a result, the ball valve opening increases. The enlarged ball valve opening provides a path whereby an additional measure of metered fuel escapes from its chamber. Although the throttle valve inside the fuel control unit is enlarged by the movement of the throttle toward open, the net result is that the ball valve continues to open until the new pressure within the metered chamber drops sufficiently to bring the regulator into equilibrium. In the end, the pressure within the metered fuel chamber is less than it was before the throttle was opened. This is the technique used to increase fuel metering force. As might be expected, the pressure of the fuel traveling to the discharge nozzle(s) increases as a result of the enlargement of the opening of the ball valve.

To rephrase the previous paragraph illustrating regulator action, to increase either the air metering or fuel metering force, the pressure differential acting on the corresponding diaphragm must be increased. Because the regulator establishes and maintains a balance between the two forces, when the air metering force increases, the fuel metering force increases. In terms of pneumatic forces, venturi suction has the greatest range of change. It varies according to air flow through the unit. Little change in impact pressure occurs throughout the range of operation. On the fuel side of the regulator, the chief variable is metered fuel pressure. Metered fuel pressure is subject to change based on the position of the mixture control, throttle valve setting, and size of the ball valve opening. The unmetered fuel pressure remains relatively constant.

OPERATION

The forthcoming examples are designed to illustrate the operation of the regulator within the RSA servo controller. To simplify the explanation, the force exerted by the constant effort and head springs are omitted. Instead, the examples serve to deepen understanding regarding the general hydro-pneumatic-mechanical relationships within the regulator.

Examine the illustration entitled, "RSA Regulator at Low Power" shown in ***Figure 4-92***. Note that the pneumatic diaphragm is larger than the fuel diaphragm. In this example, the two-inch air diaphragm is experiencing an impact pressure that is 1.0 inch of water above ambient and the venturi suction is 1.0 inch of water below ambient. The net pressure differential is 2.0 inches of water. To calculate air metering force, figure the surface area of the pneumatic diaphragm using the formula: AREA = πr^2. The two-inch diameter diaphragm has a surface area of π square inches. It will be advantageous to convert inches of water into pounds per square inch. This simplifies the comparison between the air and fuel metering forces. To convert the 2.0 inches of water into psi, multiply by 0.036. This conversion yields 0.072 psi. The final step in the calculation of the air metering force is to multiply the pressure times the area (F = A X P): Air Metering Force = 0.072 psi times π square inches. In this case, the air metering force equals 0.226 pounds. It is emphasized that in this example the force generated by the action of the constant head and effort springs are not included.

Calculating the corresponding fuel metering force is performed in a similar fashion. The 1.25 inch fuel diaphragm has 1.23 square inches of surface area [$(1.25/2)^2$ times π equals 1.23 square inches]. If the unmetered pressure is 20 psi, how much metered fuel pressure is needed to bring the fuel metering force into balance with the 0.226 pounds of air metering force? To solve this problem use the following steps. First set the fuel metering force equal to the target air

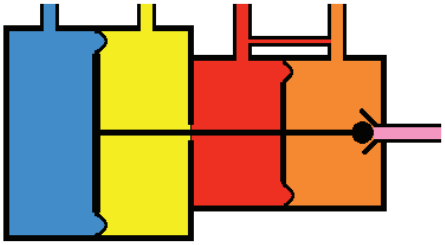


Figure 4-92. RSA regulator at low power
PIC impact chamber (yellow) = + 1" H_2O
PVSC venturi suction chamber (blue) = - 1" H_2O
PUFC unmetered fuel chamber (red) = 20 psi
PMFC metered fuel chamber (orange) = 19.82 psi

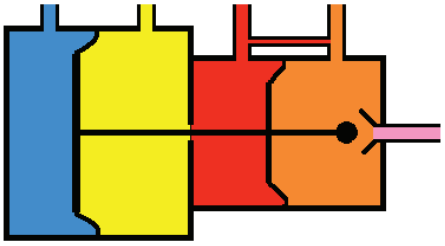


Figure 4-93. RSA regulator at high power
PIC impact chamber (yellow) = 0" H_2O
PVSC venturi suction chamber (blue) = - 20" H_2O
PUFC unmetered fuel chamber (red) = 20 psi
PMFC metered fuel chamber (orange) = 18.16 psi

metering force: 0.226 pounds equals 1.23 square inches times X psi. Solving for X, the pressure acting on the fuel diaphragm must equal 0.184 pound per square inch. The final step is to subtract this value from the level of unmetered fuel pressure. Because the unmetered fuel pressure is 20 psi, the pressure in the metered chamber must be 19.816 psi to produce a pressure differential of 0.184 psi. It is the pressure differential acting on the diaphragm that generates the force rather than the pressure of any single chamber.

For the pressure in the metered chamber to be nearly equal to the unmetered pressure, the ball valve must be restrictive. In other words, the opening of the ball valve will be small resulting in a small quantity of fuel being delivered to the flow divider and injector nozzles.

In the second example, presented in ***Figure 4-93***, the impact pressure is at ambient and the venturi suction is 20 inches of water below ambient. The pressure differential is 20 inches of water which converts into 0.72 psi (20 inches of water times 0.036). The air metering force in this example is: 0.72 psi times π square inches = 2.26 pounds. The corresponding fuel pressure differential needed to bring the regulator into balance when the air metering force becomes 2.26 pounds is solved using the following formula: 2.26 pounds = 1.23 square inches times X psi. In this case, X equals 1.84 psi. To determine the level of metered fuel pressure, subtract 1.84 psi from 20 psi. Throughout these examples, unmetered fuel pressure continues to be 20 psi. To generate 1.84 psi pressure differential across the fuel diaphragm, the metered chamber pressure must be 18.16 psi.

Comparing the changes that occurred over these examples, in the first one, impact and venturi suction were nearly the same. Likewise, unmetered and metered fuel pressures were nearly equal. In the second example, the 20 inches of venturi suction required the metered chamber pressure to be 1.84 psi less than the unmetered pressure. Overall, the relationship between changes in venturi suction and metered chamber pressure is evident: the greater the venturi suction, the less the metered chamber pressure. The reduction of pressure in the metered fuel chamber is the result of the enlargement of the ball valve opening. This allows more fuel to flow through the ball valve, thereby reducing the pressure in the metered fuel chamber. Do not confuse metered fuel chamber pressure with metered fuel pressure delivered to the nozzles. The fuel pressure traveling to the nozzle(s) increases as the air metering force and fuel metering force increase. This pressure, however, is considerably less than the pressure in the metered fuel chamber in the regulator. In this sense, metered chamber pressure represents the potential of the available fuel flow to the engine.

SYSTEM PRESSURES

To further the understanding of the operation of the RSA continuous flow fuel injection system, a series of graphs revealing various pressures throughout the system is provided. The data contained herein were taken from a RSA-5AD1 operated on a six-cylinder power plant. Included are data on: (a) the impact pressure, (b) venturi suction pressure, (c) pressure differential acting on the pneumatic diaphragm, (d) unmetered fuel chamber pressure, (e) metered fuel chamber pressure, (f) pressure differential acting on the fuel diaphragm, and (g) inlet and outlet pressures of the flow divider. An explanation of each graph follows.

Note the shape of the curve showing impact pressure. ***(Figure 4-94)*** At idle rpm, the impact pressure is slightly above ambient. Impact pressure increases from idle until 1,800 rpm. From 1,800 rpm until 2,200 rpm, the level of impact pressure steadily drops. Observe that by 2,200 rpm, the impact pressure is slightly below ambient. The explanation for this outcome is that because the pneumatic diaphragm floats on the ball valve stem and because the level of venturi suction becomes formidable at this rpm range, the powerful venturi suction pulls a considerable volume of air through the mechanism that allows the diaphragm to float on the ball valve stem. As this connection is not air tight, venturi suction draws air from the impact chamber. Also consider the range of impact pressure. With ambient pressure at the 0, the entire range of impact pressure ran from a high of 1.25 inches above ambient to .25 inches below ambient for a total span of 1.5 inches. In compariсon with venturi suction, the impact pressure remains relatively constant.

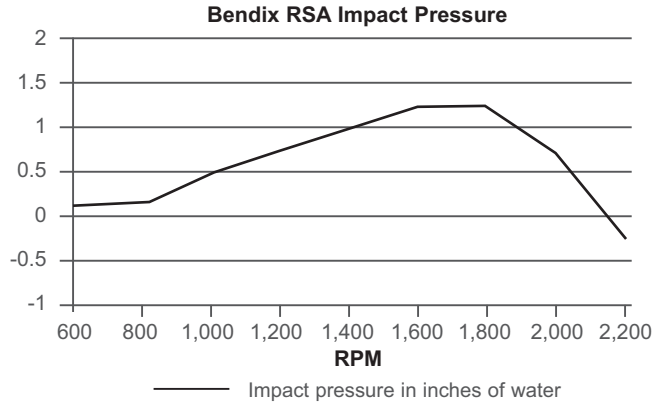


Figure 4-94. RSA impact pressure graph.

The next graph ***(Figure 4-95)*** shows venturi suction from idle to 2,200 rpm. When the suction is positive, the total pressure in the chamber is below ambient and when the suction is negative, the pressure is above ambient. Observe that the suction remains around zero from idle until 1,400 rpm. From that point note that the venturi suction becomes increasingly strong as rpm goes up.

The net pressure differential generated by the impact pressure and venturi suction is shown on the assigned graph. ***(Figure 4-96)*** Data presented on this graph reveal that little pressure differential is developed at the lower rpms. Around 1,600 rpm, a distinct increase in the pneumatic pressure differential begins to form. Where the impact

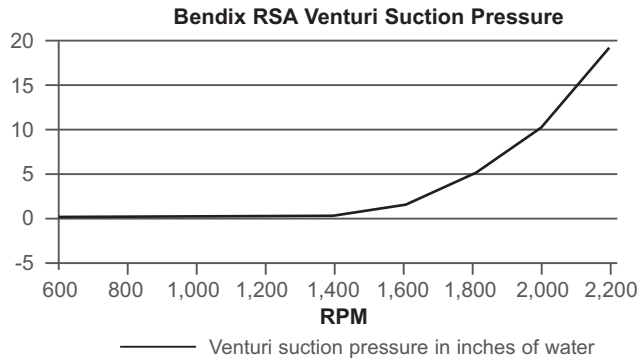


Figure 4-95. RSA venturi suction graph.

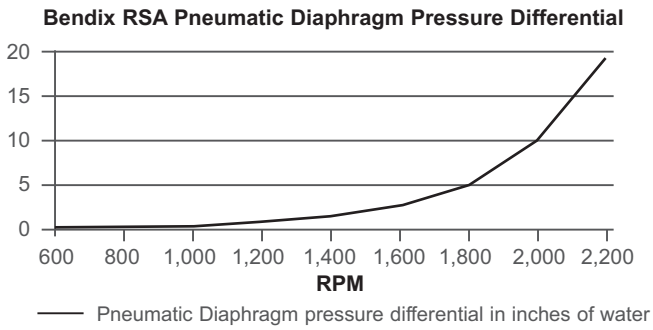


Figure 4-96. RSA pneumatic diaphragm pressure differential graph.

and venturi graphs wavered up and down, the pressure differential graph shows a continued increase in pressure. By multiplying the pressure differential by the surface area of the pneumatic diaphragm, the quantity of air metering force may be calculated. This figure does not include the force exerted by the constant effort and head springs. As previously indicated, these springs are used to hold the ball valve open at low power settings. They are also used to help the unit transition from low power operations to higher power settings.

Unmetered fuel pressure is plotted on the next graph. ***(Figure 4-97)*** It remains constant from idle to 1,400 rpm. Above 1,400 rpm, there is a gradual diminishment of unmetered pressure.

The response of metered fuel chamber pressure is shown on the next graph. ***(Figure 4-98)*** Like the unmetered fuel chamber pressure, the pressure in the metered fuel chamber remains fairly constant from idle until 1,400 rpm. During this range, the air metering force is quite low as impact and venturi chambers pressures are relatively the

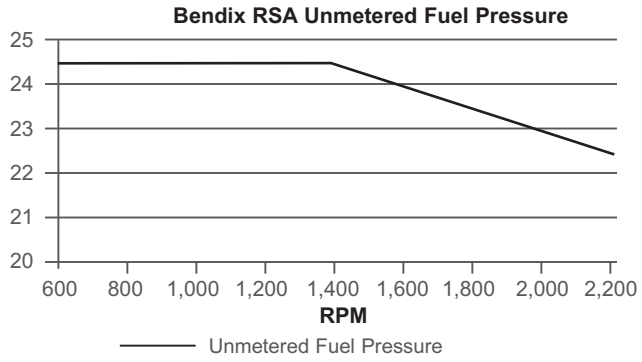


Figure 4-97. RSA unmetered fuel pressure graph.

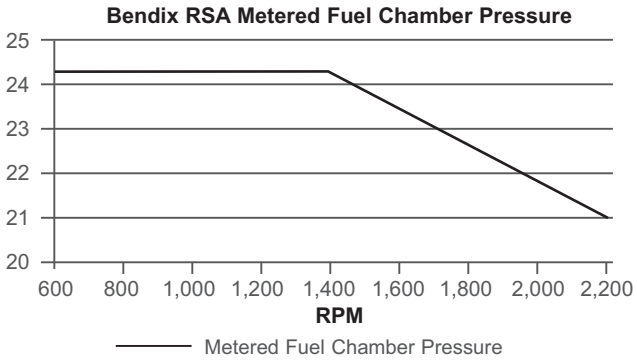


Figure 4-98. RSA metered fuel chamber pressure.

same. Above 1,400 rpm, there is a discernible drop in metered fuel chamber pressure. It must be remembered that the idle valve, or throttle control valve, in the fuel control unit enlarges as the operator increases the throttle setting. Therefore, the combination of the added influx of fuel into the chamber in combination with the drop in chamber pressure resulting from an enlargement of the ball valve opening indicates that fuel flow exiting the regulator is becoming significant.

The graph in ***Figure 4-99*** reveals the pressure differential sensed by the fuel diaphragm at varying rpms. This graph was generated by subtracting metered fuel chamber pressure values from unmetered fuel pressure readings. The shape of the graph demonstrates that the fuel metering force rapidly increases above 1,600 rpm. Compare this graph to the one depicting the pneumatic pressure differential ***(Figure 4-96)*** acting on the air diaphragm. Note the similarities between the two graphs.

The final graph ***(Figure 4-100)*** shows the inlet and outlet pressures of the flow divider. The inlet to the flow divider is the outlet from the metered fuel chamber

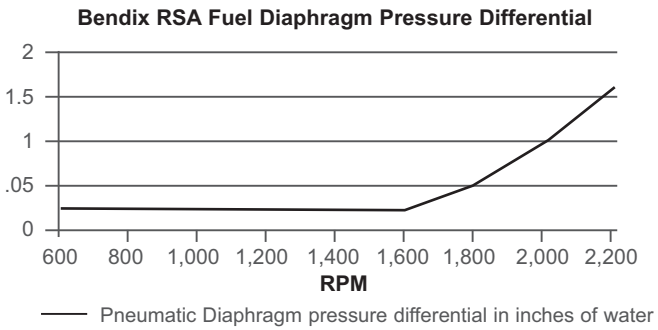


Figure 4-99. RSA fuel diaphragm pressure differential.

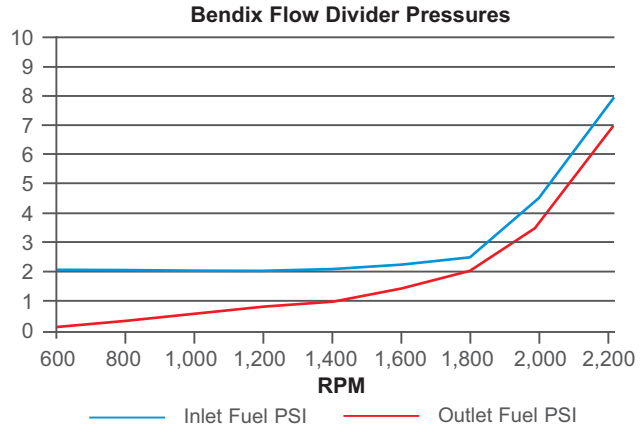


Figure 4-100. RSA flow divider inlet and outlet pressure graph.

of the regulator. The outlet from the flow divider is sent to the injector nozzle(s). This pressure is also used by the standard fuel flow meter located on the instrument panel. From idle until 1,600 rpm, the flow divider was only partially opened. This is evident by the increased level of pressure drop taking place as a function of the valve. At approximately 1,600 rpm, and above, the flow divider is fully opened. Observe that a pressure drop of approximately 1 psi is constant from 1,600 rpm to 2,200 rpm.

FLOW DIVIDER

Fuel exiting the servo unit is directed to the flow divider. This device divides the flow of fuel so that each cylinder receives its portion of the fuel flow.

Another feature of the flow divider involves its spring-loaded sleeve valve. This valve closes when the minimum fuel pressure threshold needed to open the flow divider is not met. The closing of the valve provides a positive cutoff action. ***[Figure 4-101]***



Figure 4-101. RSA flow divider.

The flow divider receives inlet fuel from the ball valve of the servo unit. Inlet fuel pressure is applied to the underside of a spring-loaded diaphragm and to the upstream side of the fuel valve. When the fuel pressure reaches or exceeds a prescribed level, the diaphragm moves upward. A large spring on the air side of the diaphragm opposes this movement. The chamber containing the spring is vented. Because the physical volume of the chamber that houses the spring varies as the valve moves, the vent allows the diaphragm to move up and down in an unimpeded fashion. Without the vent, the pressure within the chamber would increase as the valve opened and would decrease as it closed. Such action would adversely affect the balance of forces applied to the diaphragm. Fuel stains in the area of the vent indicates a leak past the diaphragm. ***[Figure 4-102]***

As the diaphragm travels upward, the sleeve valve begins to open. The exit ports for the fuel nozzles are arranged in a circular fashion around the body of the flow divider. As the valve opens, fuel is equally distributed to all the cylinders.

One other connection associated with the flow divider is the fuel flow meter. This gauge is located on the instrument panel and is used by the operator to monitor fuel flow and adjust mixtures during flight. Technicians use the instrument for troubleshooting the system.

Figure 4-100 reveals the pressures entering and exiting the flow divider. The graph showing the outlet fuel psi reveals the increase in fuel flow with rpm.

FUEL LINES

Fuel lines are used to interconnect the various system components. Both rigid and flexible lines are employed by the system.

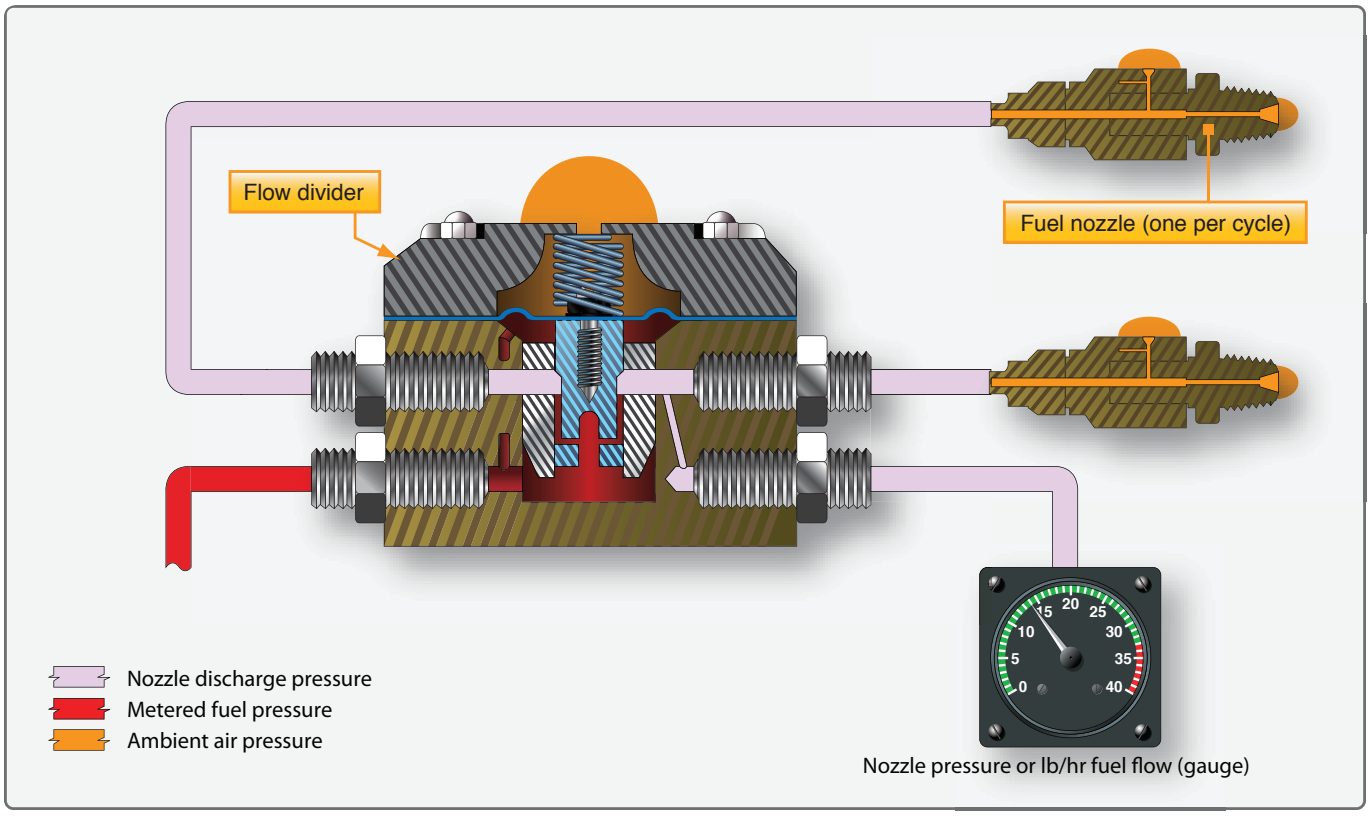


Figure 4-102. RSA flow divider schematic.

In terms of general maintenance, fuel lines should be free of defects, such as twists, kinks, dents, nicks, scratches, chafes, etc. Also, the routing of the lines and their anchoring is important.

Fuel lines running from the flow divider to the injector nozzles are special units. The lines use brass B-nuts that are prone to cracking when over tightened. Those maintaining the system must be careful when replacing injector lines. Although they may appear similar to other lines (e.g., lines used with solenoid priming systems), the inside diameter of the injector line is critical to the proper operation of the unit. If, for example, a primer line with a smaller inside diameter than an injector line is installed, the injector nozzle connected to this line will receive less fuel flow. As a result, the cylinder associated with this fault will run leaner. The problem will be most pronounced at high power settings. This may lead to cylinder failure.

NOZZLES

Fuel nozzles used with the RSA fuel injection system may be individual per cylinder or may be single point. The latter are frequently used to spray fuel into the impeller of a supercharged power plant. With the exception of high flow rate nozzles, (e.g., LW-14540), nozzles used for individual cylinders are engineered to flow within 2% of a master calibration nozzle. This means that standard nozzles may be switched from one engine to the next.

There are two generations of nozzles currently in service. The older style is assembled as a single piece unit. ***(Figure 4-103)*** The new style has a removable orifice. ***(Figure 4-104)*** The manufacturer refers to the removable fuel orifice as the restrictor. Where it is permissible to remove a one-piece nozzle from a cylinder and install a two-piece unit or vice-versa, do not interchange restrictors from one nozzle body to another. The restrictors and nozzle bodies are matched at the factory and must remain as a unit.

During operation, the nozzles are subjected to three pressures: (a) fuel inlet from the flow divider, (b) air bleed source, and (c) manifold pressure. In order for the nozzle to properly function, the hierarchy of pressures applied to the nozzle is that inlet fuel pressure must be the highest, followed by the air bleed source, and manifold pressure. Any disturbance in this hierarchy of pressure will cause fuel to incorrectly flow and air to be improperly mixed with fuel.

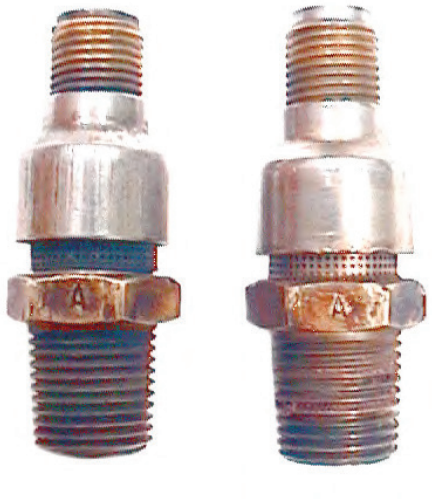


Figure 4-103. RSA nozzles, with the old style, one-piece unit on the left and the new style, two-piece model on the right. The removable metering jet protruding from the top of the two-piece nozzle.

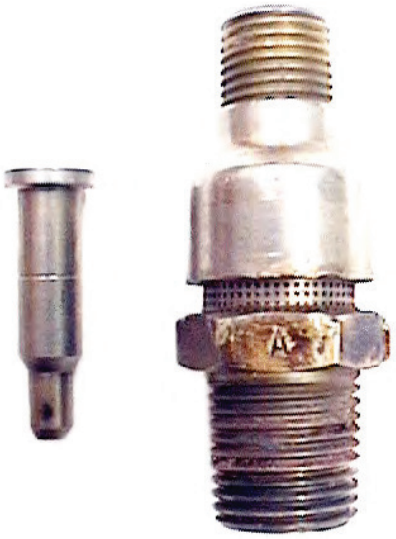


Figure 4-10. RSA two-piece injector nozzle with restrictor, or metering jet, removed (Note the letter "A" on the wrenching flat that identifies the location of the air bleed port.

The air bleed of a continuous flow injector nozzle plays an important role in the mixture delivered to the combustion chambers. The amount of air bleed varies with the level of manifold pressure. At low power settings, the manifold pressure is low. By contrast, the ambient nacelle pressure, or in the case of turbocharged installations upper deck pressure, is relatively high. This pressure differential acting on the air bleed orifice causes the flow of air bleed air. The air bleed air and fuel are mixed within the body of the nozzle immediately before it is discharged into the intake port of induction system. The fuel/air charge departing the nozzle is more thoroughly atomized by the heat of the cylinder head at the intake port.

When installing a Bendix injector nozzle in an other-than-vertical position (e.g., angled or horizontal), the technician must ensure that the air bleed port in the body of the nozzle faces up. This is accomplished by making sure that the letter "A" stamp on one of the wrenching flats points down. The air bleed port is 180º from the letter "A." When the injector nozzles are installed in a vertical position, this issue is not a factor.

RSA AUTOMATIC MIXTURE CONTROL

Bendix RSA fuel injectors may be equipped with an automatic mixture control (AMC). This device serves the same purpose as other AMCs. It adjusts the mixture delivered by the metering unit in proportion with the conditions of the ambient atmosphere or upper deck pressure on turbocharged engines. Because the fuel controller is equipped with a manual mixture control, the operator has the ability to further lean the mixture. However, the mixture may not be enriched beyond the level established by the AMC.

The AMC of the RSA unit works like the AMC of a PS series small pressure carburetor. Impact air is connected in parallel with the AMC bellows assembly. The bellows assembly expands and contracts in response to the pressure and temperature of the ambient air or upper deck pressure. As the bellows expands and contracts, the restriction formed by the reversed-tapered needle in its orifice controls how much impact air travels to the venturi suction chamber. ***[Figure 4-105]***

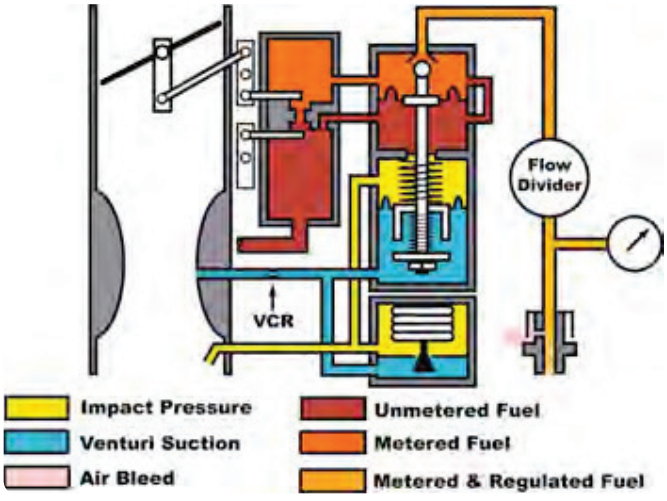


Figure 4-105. RSA schematic of unit with anAMC.

Venturi suction of an AMC equipped RSA continuous flow fuel injection system is regulated. The combination of the air transferred from the impact source via the AMC and the action of the vacuum channel reducer (VCR) works to control the level of absolute pressure within the venturi suction chamber. This controls the pressure differential exerted across the pneumatic diaphragm. In the end, the action of the AMC and VCR manipulates the air metering force generated by the regulator. Because the regulator is designed to seek and maintain equilibrium between the air and fuel metering forces, the level of fuel metering force is in balance with the level of air metering force.

In terms of general operation, as the aircraft ascends, or when upper deck pressure drops, the bellows assembly expands in response to a reduction of ambient pressure. When the bellows assembly expands, the opening formed by the reverse-tapered needle in its orifice becomes enlarged. This allows more air to flow from impact into the venturi suction chamber. Because the VCR limits how fast the air is pulled from the venturi suction chamber, increasing the volume of flow into the venturi suction chamber results in an increase of the absolute pressure within the chamber. For other conditions the same, increasing the absolute pressure in the venturi suction chamber decreases the pressure differential acting on the pneumatic diaphragm and reduces the level of air metering force. This serves to lean the mixture.

The bellows assembly is designed to fail-safe. The construction features of the bellows act like a spring. In the event that the unit develops a leak, the bellows will fail-safe by contracting so that the reverse-tapered needle valve become restrictive. This action provides a full rich mixture. In such instances, the operator has the option of using the manual mixture control to adjust the mixture.

CONTINENTAL FUEL INJECTION

Thus far all of the fuel metering devices presented determine fuel flow by measuring the flow of air through the air throttle body. In particular, the metering units have all used a venturi to establish a metering force. The continuous flow fuel injection system developed by Continental is unique in that it does not contain a venturi. Instead, fuel flow is determined by: (a) engine rpm, (b) throttle position, and (c) mixture control valve position. The operation of the Continental continuous flow fuel injection system is remarkably similar to the early fuel injection developed by the Wright Brother. ***(Figure 4-106)***

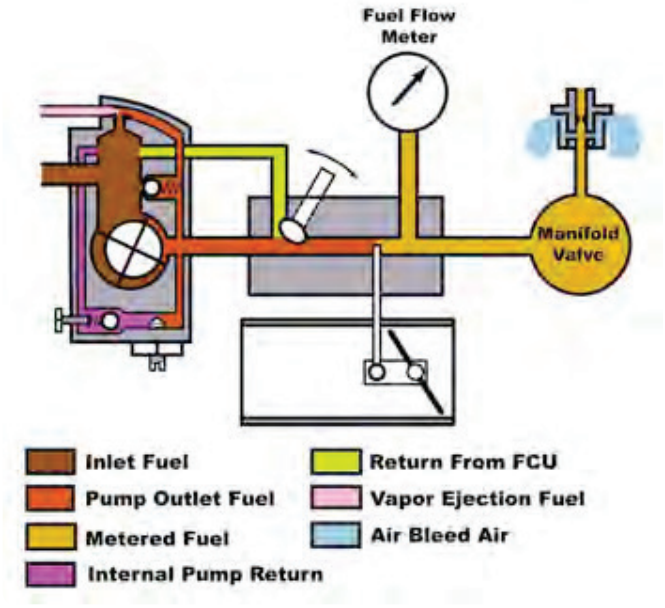


Figure 4-106. Schematic of the continental fuel injection system.

The Continental continuous flow fuel injection uses four major components. These include: (a) the engine-driven fuel pump, (b) fuel/air controller, (c) manifold valve, and (d) injector nozzles. A description of each along with an explanation of the system operation is provided.

ENGINE-DRIVEN FUEL PUMP

The engine-driven fuel pump used with the Continental system contains the only continuously moving part, the vane pump. This pump assembly is basically a modified standard vane pump used for a variety of fuel metering devices.

The typical Continental fuel injection pump has two fuel inlets and two fuel outlets. The main inlet connection comes from the aircraft fuel system. It supplies fuel to the pump assembly. The other inlet serves as a return line from the mixture control valve within the fuel control unit. Pumps that house the mixture control valve do not have an external return line from the fuel control unit. The two outlets involve the main outlet that supplies fuel to the metering unit and the other outlet is a vapor return to a fuel tank. When the system is installed on a turbocharged power plant, upper deck is connected to the aneroid valve used to control high unmetered fuel pressure. ***[Figure 4-107]***

Fuel entering the engine-driven pump is directed to the swirl well. The swirl well is a cylindrically-shaped chamber that feeds fuel to the inlet port of the vane pump. Fuel enters the swirl well at a tangential angle. This causes the liquid to revolve around the interior of the swirl well. The result of this swirling action is that vapors gather in the center portion of the swirl well. This is due to the centrifugal force of the liquid fuel. ***[Figure 4-108]***

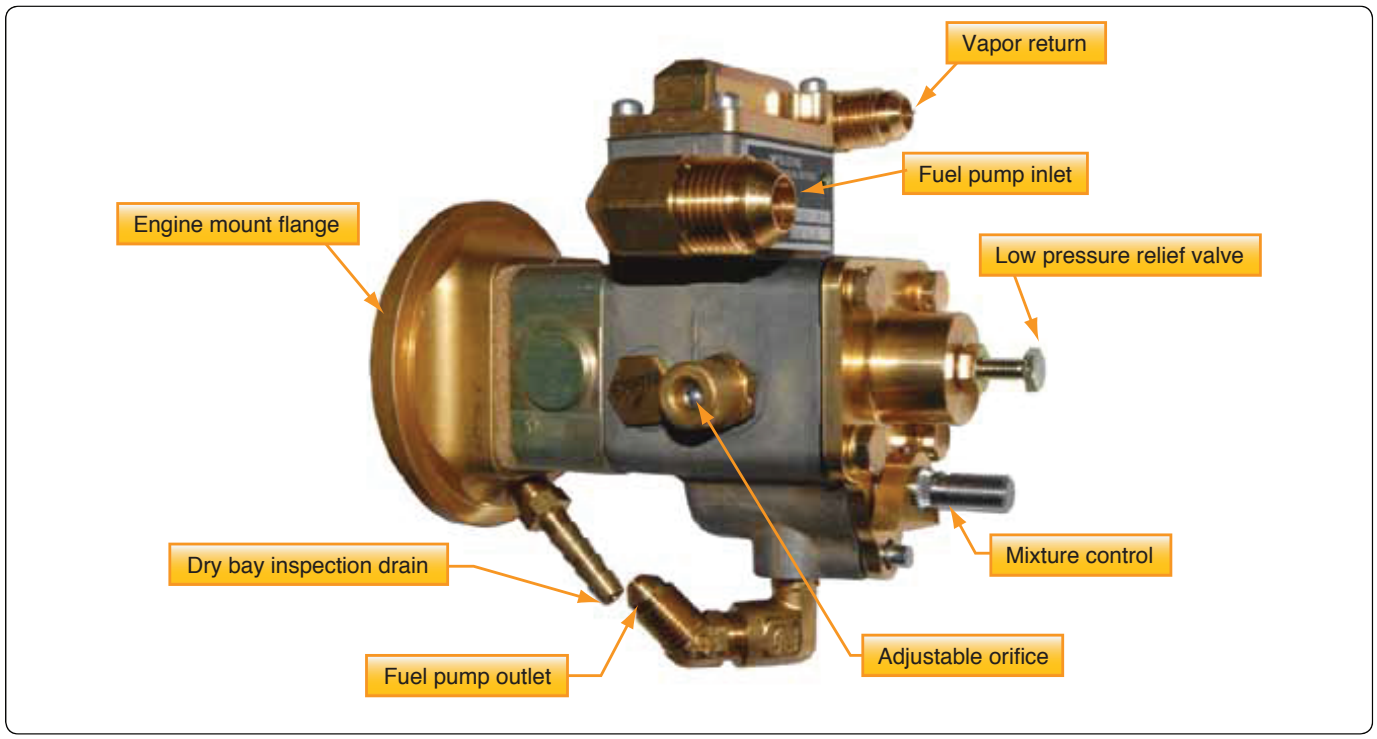


Figure 4-107. Continental fuel injection pump.

Vapors are removed from the swirl well by the vapor ejection system. This mechanism is a jet pump situated atop of the swirl well. It is energized by fuel from the outlet of the vane pump. The reason fuel from the outlet of the vane pump may be used to power the vapor ejector is that the vane pump produces more fuel flow than the power plant requires. In this case, a small portion of the surplus fuel flows over the swirl well, through a jet where it picks up vapors, and back to a receiving fuel tank.

A bypass check valve is installed in the pump. This device provides a path of flow from the swirl well to the exit port of the pump. The bypass check valve opens whenever the inlet pressure to the engine-driven fuel pump exceeds the outlet pressure of the vane pump. In other words, the bypass check valve opens when the pressure from the auxiliary pump is greater than the output from the engine-driven vane pump. The bypass check valve is used for: (a) priming the engine, (b) removing vapor lock, and (c) sustaining engine operation via the boost pump in the event that the engine-driven pump fails.

The vane pump is a common unit that has been in service for decades. It works in the traditional fashion whereby the pump cavity is divided into four segments. As the pump rotates, the size of each segment increases and decreases, depending whether it is intaking or discharging fuel.

The drive of the pump is designed with a shear shaft. This feature disconnects the pump from the drive network when the torque required to turn the pump exceeds its designed limitation. It is used when the vane pump fails. If the pump shaft did not shear during seizure of the pump, forcing the pump to turn would only contaminate the system with metal fragments. This, in turn, might clog the passageways and prevent the flow of fuel through the system. By shearing the drive, the system is less likely to experience clogged passageways, thereby allowing the engine to continue operation using the auxiliary pump. In addition, shearing the pump shaft reduces the likelihood of an engine accessory drive failure.

A seal drain is installed in the mounting pad cavity. It ports oil and fuel overboard when a leak develops in the accessory drive seal or fuel pump shaft seal. Evidence of oil at the discharge port of the seal drain indicates that the oil seal is leaking. Likewise, the presence of fuel reveals a leaking pump shaft seal. Technicians should periodically inspect the outlet of the seal drain. If a leak goes undetected, other problems may develop. For example,

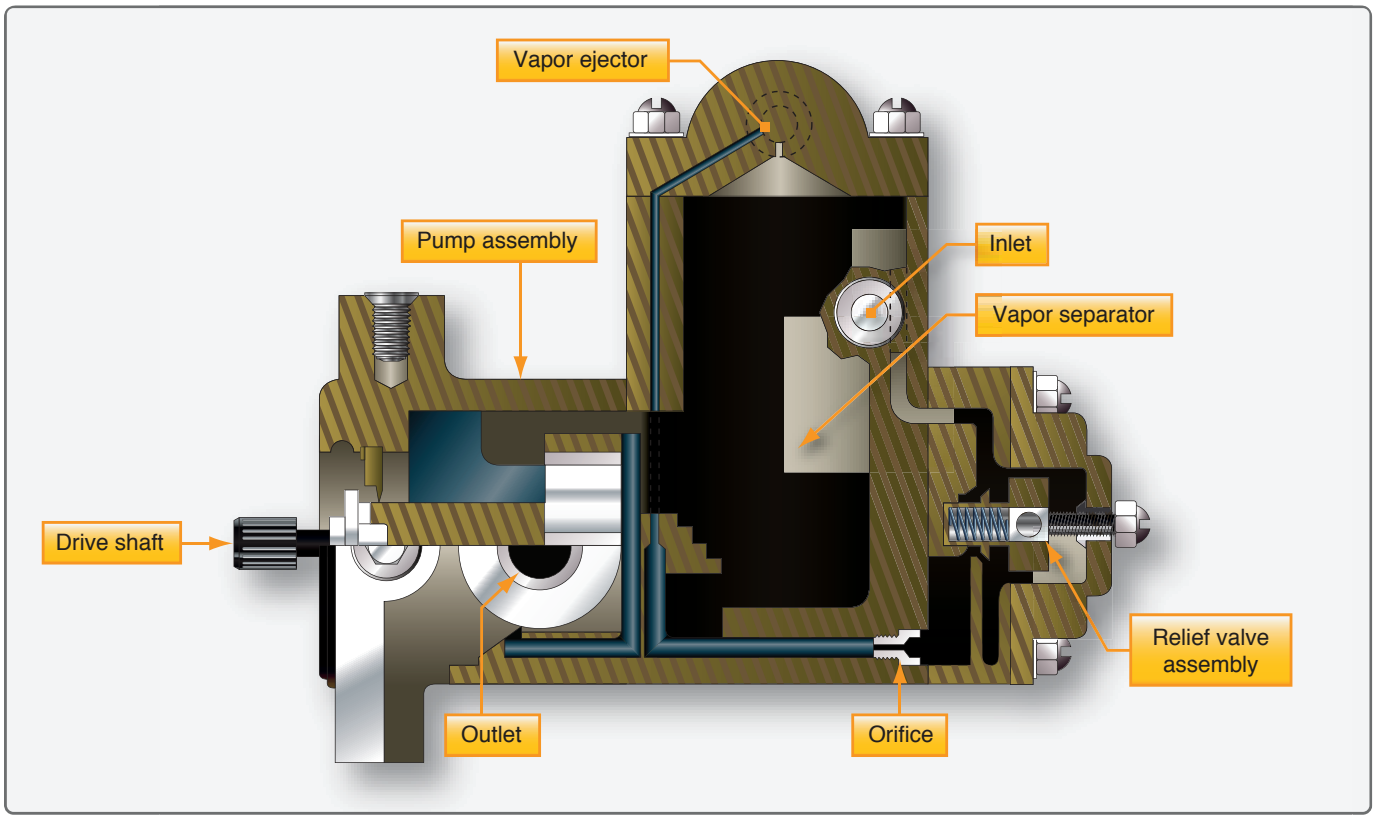


Figure 4-108. Continental engine-driven fuel pump schematic.

if the pump shaft seal of the engine-driven fuel pump develops a leak, gasoline could enter into the crankcase through the accessory drive. This will dilute engine oil.

As previously mentioned, the engine-driven pump produces more flow than the engine requires at any given rpm. This design attribute is typical among engine-driven fuel pumps. They provide the proper input to the fuel-metering device. The latter performs the metering function. If the engine-driven fuel pump only delivered the exact amount of fuel required by the engine, it would be metering the fuel.

Within the Continental pump, two mechanisms are used to regulate unmetered fuel pressure. They are: (a) the high unmetered fuel pressure orifice and (b) the relief diaphragm valve. The latter controls unmetered fuel pressure during low and medium rpm operations. Where most fuel metering systems require that the discharge from the pump remain within a narrow psi range, the Continental pump has a wide spectrum of fuel pressure. The pressure varies directly with engine rpm. As rpm increases, unmetered fuel pressure increases. This relationship between rpm and unmetered fuel pressure is so precise, that for any given rpm and mixture control setting, the fuel pressure will be at its assign value. In fact, if a graph is generated to depict the magnitude of unmetered fuel pressure for any given rpm, the technician could adjust engine rpm using the value of unmetered fuel pressure as a tachometer.

Before entering a discussion about the unmetered fuel pressure of a Continental system, the basic concept of pumps and pressure must be examined. Technically, pumps produce a volume of flow. Pressure is generated as the volume of flow encounters resistance. Consequently, pressure may be controlled by manipulating the volume of flow, or by varying the resistance to flow, or by changing both.

The unmetered fuel pressure of the Continental system begins with the output of the vane pump. Because the volume generated by the vane pump exceeds that required by the engine and because the vane pump is a positive-displacement design, the surplus fuel must flow somewhere. As previously mentioned, a portion of the surplus fuel is used to operate the vapor ejection system. The remainder is circulated within the pump. This is accomplished by placing two orifices in series between the outlet of the vane pump and internal return passage to the swirl well.

The first orifice that handles the pump output is the high unmetered fuel pressure orifice. It is a fixed orifice except when the pump is equipped with an altitude compensator or turbocharger. An aneroid is used to vary the size of the orifice when the system includes the altitude compensator or turbocharger. Early naturally-aspirated pumps used an unadjustable orifice. Later units have a high unmetered fuel pressure adjustment. This orifice limits the quantity of internal return fuel at high rpm power settings.

The aneroid used with the naturally aspirated pump serves as an altitude compensation device. It manipulates high unmetered fuel pressure to control mixture at altitude. As the aircraft ascends, the aneroid expands. This enlarges the size of the high unmetered orifice. This allows more fuel to return to the swirl well. The net change in unmetered pressure is that less unmetered pressure is applied to the fuel control unit. As a consequence, less fuel is discharged from the nozzles. In this sense, the aneroid assembly performs the function of an automatic mixture control.

A fuel pressure regulator is installed on some Continental systems. It controls unmetered fuel pressure. During initial system adjustment, the regulator must be deactivated. After completing the initial adjustment, the operation of the regulator must be verified and, when necessary, corrected.

The high unmetered fuel pressure orifice is too large to limit internal return fuel at idle and lower power settings. To provide the appropriate restriction to internal return fuel at other than high power settings, a spring-loaded, diaphragm relief valve is used. This device has the ability to completely seat. At low power settings, the diaphragm relief valve is nearly seated. Consequently, the volume of internal return fuel flow is minimal. As engine rpm increases to its midrange, the diaphragm relief valve moves to enlarge its opening. The opening of the diaphragm relief valve continues to enlarge in proportion with increases in rpm until the high unmetered fuel pressure orifice, which is located upstream of the diaphragm relief valve, begins to limit internal return fuel flow.

A vent is provided to allow for freedom of movement of the diaphragm relief valve. The presence of fuel stain near the vent indicates a leaky diaphragm assembly.

Provisions for adjusting the low and high unmetered fuel pressure are provided. They are used to adjust the operation of the system. The adjustment process is relatively extensive when compared to other fuel metering systems. Refer to the depiction of the fuel pump provided in ***Figures 4-106, 4-107, and 4-108*** for a better understanding of the operation of this component.

FUEL/AIR CONTROLLER

The fuel/air controller is composed of two components: (a) the fuel control unit and (b) the air throttle body assembly. A brief description of each is provided along with operational fundamentals. ***[Figure 4-109]***

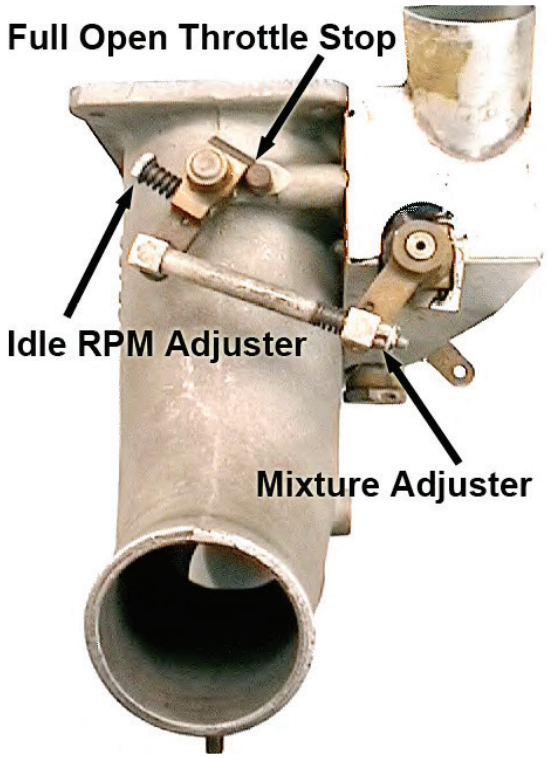


Figure 4-109. Continental fuel/air controller. Also shown are the mixture control adjustment link and full open and idle throttle stops.

The air throttle body assembly houses the throttle valve and shaft. The throttle shaft is mounted on oilite bearings. These bearings are bronze bushings impregnated with oil and have a very good service life. After spraying the assembly with cleaning solvents, a drop of oil should be added to the bushings to help restore their oil level.

Throttle stops are located on the air throttle body assembly. The idle rpm stop is a traditional spring-loaded bolt. The full throttle stop shares the same stop pin as the idle rpm stop. Technicians should verify full travel during the inspection of the power plant and when conducting troubleshooting operations.

A connection for the manifold pressure gauge is included in a number of the throttle body assemblies. This port communicates with the manifold pressure gauge via lines and fittings.

The fuel control unit is bolted to the air throttle body. An interconnect link between the air throttle valve and the fuel throttle valve is included. It is used to move both valves in synchronization. On the typical Continental fuel injection system, the interconnect link also serves as the mixture adjustment. This adjustment should not be confused with the role of the mixture control valve. The length of the interconnect link is field adjusted to set the idle mixture. The mixture control valve is used by the pilot to adjust the mixture during cruise flight and other operations. ***[Figure 4-110]***

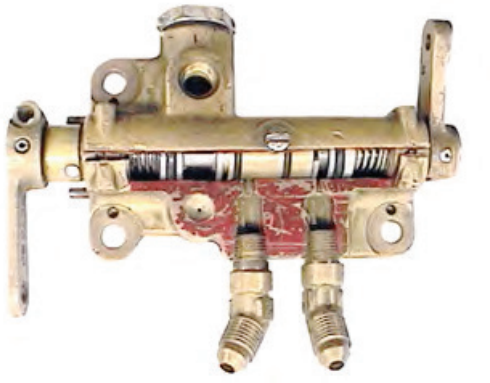


Figure 4-110. Continental fuel metering unit.

The fuel control unit typically houses the mixture control valve and the throttle control valve. Some Continental fuel injection systems have their mixture control valves located within the engine-driven fuel pump assembly. Regardless of the location of the mixture control valve, the operation of the system is the same. ***[Figure 4-111]***

Gasoline entering the fuel control unit first encounters a filtering screen. Placing a screen downstream of a pump is a common practice in aviation. The screen should be removed and inspected during the inspection process and when troubleshooting the system. The gasket on the screen assembly should be replaced during the installation process.

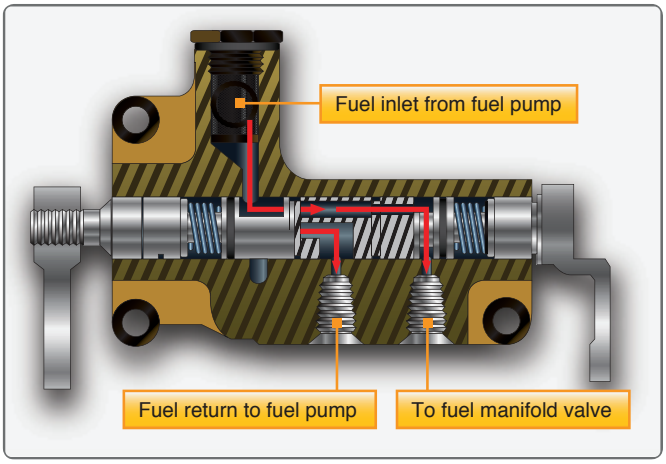


Figure 4-111. Continental fuel metering unit schematic.

After the filtering process, the fuel travels to the mixture control valve. This valve has three ports: (a) inlet, (b) outlet to the throttle valve, and (c) return to the swirl well. The valve is designed to control the flow through its two outlets in proportion to its position. The valve may direct all of the fuel to the throttle valve, all of the fuel to the return port so the fuel returns to the swirl well in the engine-driven pump, or it may divvy the fuel so that a portion travels to the throttle valve and the remainder returns to the engine-driven fuel pump. Controlling the flow in this manner is necessary as the positive-displacement design of the vane pump requires that the flow of fuel go somewhere.

Fuel exiting the fuel control en route to the combustion chambers passes through the throttle control valve. The size of this valve is dependent on the position of the throttle. An interconnect between the air throttle valve and the fuel throttle valve ensures that the size of the orifice formed by the position of the fuel throttle valve maintains the proper fuel/air ratio.

The metering action taking place within the fuel control is not solely dependent on the size of the fuel throttle valve. Because the unmetered fuel pressure changes with engine rpm, the flow through the orifice involves the size of the orifice and the pressure applied to same.

Fuel that passes through the throttle control valve becomes metered fuel. It is directed to the manifold valve where it is distributed to the individual nozzles. The fuel flow meter is connected between the downstream side of the throttle valve and the upstream side, or inlet, of the manifold valve.

Before discussing the manifold valve a brief explanation depicting unmetered fuel pressure is in order. Because there is no venturi to generate a force for metering the fuel, the Continental system relies on unmetered fuel pressure to establish flow to the nozzles.

UNMETERED FUEL PRESSURE

The unmetered fuel pressure of the Continental continuous flow fuel injection system is relatively unique in comparison to other fuel systems in that it has a wide range of operating output. There are four operations that affect Continental unmetered fuel pressure: (a) engine rpm, (b) mixture control valve position, (c) throttle movement during constant speed operations, and (d) rapid throttle movements during non-constant speed operations.

One point regarding unmetered fuel pressure must be established. Unmetered fuel pressure is located between the outlet of the engine-driven fuel pump and the inlet to the fuel control unit. Its name reveals its location as “unmetered” implies before the metering unit and “fuel pressure” demarcates the location to be somewhere after the fuel pump.

The relationship between engine rpm and the level of unmetered fuel pressure is: the faster the speed of the positive-displacement fuel pump, the greater its output. By increasing the volume of flow from the pump, unmetered fuel pressure goes up.

Unmetered fuel pressure is also controlled by the position of the mixture control valve. Because the mixture control valve is able to return fuel to the swirl well of the engine-driven fuel pump, the level of unmetered fuel pressure goes down as the bypass return line is opened. Stated another way, unmetered fuel pressure goes down as the mixture control valve moves from its FULL RICH position to CUTOFF. Analyzing the resistance to flow, as the operator moves the mixture control from FULL RICH toward CUTOFF, the fuel output from the pump has two flow paths. One is to continue to flow through the fuel control unit and exit through the nozzles and the other is to return to the swirl well. In terms of total resistance to flow, the combination of two flow paths results in a reduction of resistance to flow. This causes the unmetered fuel pressure to go down. In terms of controlling mixture, by reducing the level of unmetered fuel pressure applied to the throttle valve, less flow passes through the metering orifice.

Engines that have Continental fuel injection normally have constant speed propeller systems. The combination of the Continental system and constant speed propeller places a design requirement on the system. During constant speed operations, the rpm of the engine-driven fuel pump remains the same. Consequently, the volume of flow from the outlet of the pump remains the same. When the operator opens the throttle during constant speed operation, the unmetered fuel pressure goes down. The reason the unmetered pressure goes down in such cases is due to the relationship between flow and resistance to flow. Because the volume of flow is the same during constant speed operations, the opening of the throttle lessens the resistance to flow. This is due the enlargement of the metering orifice associated with the opening of the throttle. In the final analysis, by opening the throttle during constant speed operations, the same volume of fuel flow encounters less restriction, thereby decreasing unmetered fuel pressure.

One issue that must be highlighted is that unmetered fuel pressure normally runs two to four times greater than metered fuel pressure. For example, at idle an engine may operate with an unmetered fuel pressure of 9 psi. The metered pressure for this engine at idle may be 2.5 psi. By keeping unmetered pressure much higher than metered pressure, the operator is able to open the throttle during constant speed operations without running the risk of causing a lean mixture. In this sense, the relatively high level of unmetered fuel pressure serves as a reserve of fuel pressure needed for various operations.

Although the unmetered fuel pressure decreased during the aforementioned scenario, the flow of fuel to the engine increased. The enlarged throttle valve opening results in an increase in fuel flow to the nozzles. This is needed because the propeller pitch increases as the throttle is opened under constant-speed operations. In other words, a higher power input, both fuel and air, is needed to keep the propeller spinning at the same rpm when it has a higher pitch angle.

The remaining element that affects unmetered fuel pressure is rapid throttle movement. When the operator quickly opens the throttle, the unmetered fuel pressure momentarily drops. As the engine gains rpm, the unmetered pressure increases in response to the increase in rpm. The temporary drop in unmetered fuel pressure is due to the acceleration characteristics of a piston power plant. Because the engine does not accelerate in an instantaneous fashion, the moment the throttle is opened, the throttle valve opening is enlarged by the mechanical interconnect between the air throttle valve and the fuel control unit. As the rpm at that precise moment has not increased, the volume of flow from the pump remains the same while encountering less restriction to flow because of the enlarged orifice. This causes the unmetered fuel pressure to drop until the engine increases rpm. This reaction to rapid throttle openings serves as the acceleration system. The reserve of unmetered fuel pressure represents the potential supply of fuel needed for acceleration.

During rapid throttle closings, the unmetered fuel pressure momentarily increases until the rpms decrease. This is because at the moment that the throttle valve is closed, the rpm of the pump and its associated volume of flow are high. By closing the throttle valve, the high volume of flow encounters high restriction to flow. The net result is a momentary increase in unmetered fuel pressure. The unmetered pressure comes down with rpm due to the reduced volume of flow from the pump as the engine decelerates.

MANIFOLD VALVE

The manifold valve of a Continental continuous flow fuel injection system serves the same functions as a flow divider of a RSA system. It provides a positive cutoff and evenly distributes the fuel to each cylinder. ***[Figure 4-112]***

A vent is provided atop of the diaphragm to allow or freedom of movement. This vent must not be pointed in direction of flight as the build up of ram pressure may affect operation.

A conically-shaped screen is used to filter inlet fuel. This is the final filter used by the system. It is intended to keep particles from reaching the manifold valve mechanism and fuel injection nozzles.

The manifold valve includes a port for connecting the fuel flow meter. In comparison to the RSA flow divider, the pressure at this location is upstream of the action of the manifold valve rather than downstream of the action of the flow divider.

Unlike the flow divider used by the RSA system, manifold valves are available in different flow rates. The two valves currently available include: (a) M and (b) P.

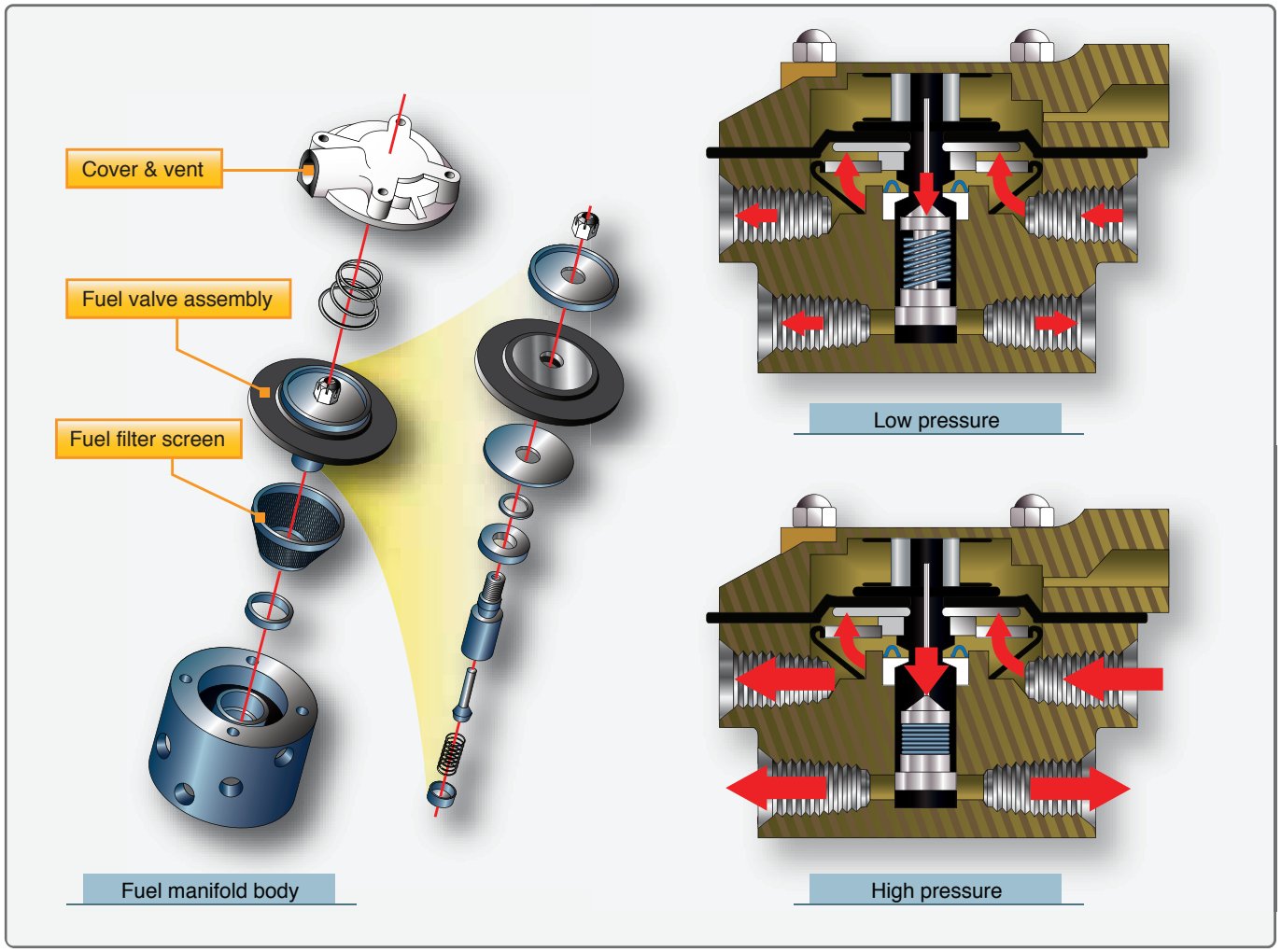


Figure 4-112. Continental manifold valve.

The M valve contains a weaker spring. It is rated for 2.0 psi. The P valve is rated for 4.0 psi. To help remember which valve has more spring tension, consider the P valve to have plus spring tension and the M valve to have ***minus*** spring tension. In terms of flow, the M valve has ***more*** flow and the P valve has ***partial*** fuel flow. ***[Figure 4-113]***

The availability of different manifold valves is helpful in establishing the optimum operation of the system. Before the power plant leaves the factory, technicians determine which manifold valve is best suited for the engine. In addition, the optimum nozzle set is selected at this time.

Some Continental manifold valves are heated for high altitude operation. Warm oil from the engine is sent through the body of the manifold valve to keep the unit heated. After the oil exits the manifold valve, it returns to the crankcase. ***[Figure 4-114]***

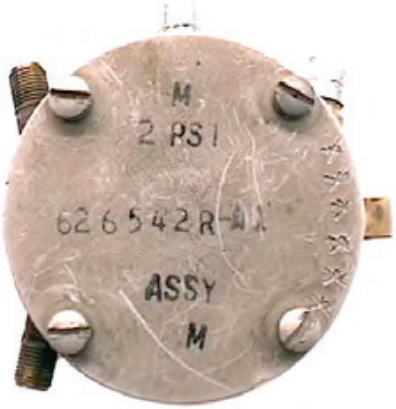


Figure 4-113. Continental "M" manifold valve. Note the 2 PSI rating of this valve.

FUEL NOZZLES

The fuel injection nozzles of a Continental system are similar to the nozzles used with the RSA continuous flow fuel injection system. The major differences are in the air bleed and the availability of a wide variety of flow rates.

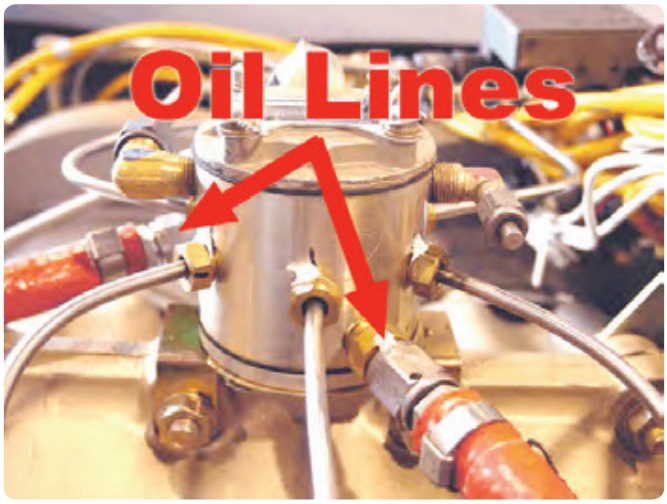


Figure 4-114. Heated manifold valve.

Three pressures are applied to the Continental nozzles: (a) inlet fuel, (b) air bleed, and (c) manifold absolute pressure. To assure proper operation, fuel pressure must be the highest pressure applied to the nozzle. Air bleed is next in terms of high pressure. And manifold pressure must be the lowest pressure applied to the nozzle. If the hierarchy of pressure varies from this arrangement, the operation of the nozzle will be adversely affected.

Four air bleed ports supply air for the air bleed system. Because the air bleed ports are situated near the top of the nozzle and due to the internal configuration, there is no special provision regarding which way the air bleed must point when installing the nozzle in an angled or horizontal position.

Flow rates of the nozzles are indicated by a letter. Beginning with letter A, the flow rates of the nozzles increase as the assigned letter progresses from A. In other words, a set of B nozzles flows more fuel than a set of A nozzles. The variety of available flow rates provides flexibility in establishing the optimum performance of the system. As previously indicated, technicians at the factory operate the engine to determine the best combination of manifold valve and nozzle set.

One issue that warrants attention is nozzle size. Do not use a variety of nozzle sizes in an engine. All of the cylinders should have the same size injector nozzle. If for some reason a cylinder is running either richer or leaner than the other cylinders, do not attempt to correct the problem by switching the nozzle size of the faulty cylinder. Instead, identify the fault (e.g., induction leak, clogged manifold drain, etc.) and correct the problem.

ELECTRONIC ENGINE CONTROL

A Full Authority Digital Engine (or Electric) Control, Known as FADEC, is a solid-state digital electronic ignition and electronic sequential port fuel injection system with only one moving part that consists of the opening and closing of the fuel injector. FADEC continuously monitors and controls ignition, timing, and fuel mixture/delivery/injection, and spark ignition as an integrated control system. FADEC monitors engine operating conditions (crankshaft speed, top dead center position, the induction manifold pressure, and the induction air temperature) and then automatically adjusts the fuel-to-air ratio mixture and ignition timing accordingly for any given power setting to attain optimum engine performance. As a result, engines equipped with FADEC require neither magnetos nor manual mixture control.

This microprocessor-based system controls ignition timing for engine starting and varies timing with respect to engine speed and manifold pressure. ***[Figure 4-115]***

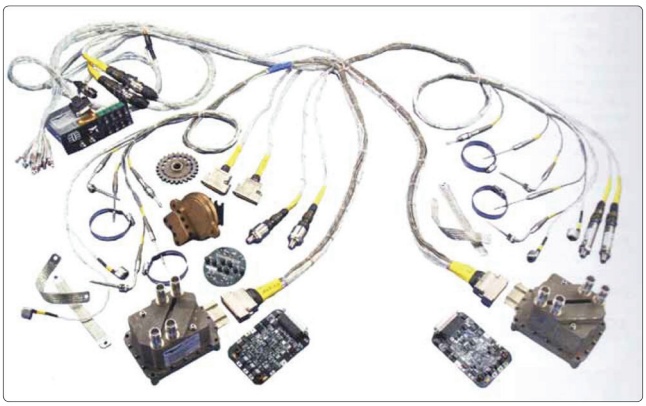


Figure 4-115:.Power link system.

PowerLink provides control in both specified operating conditions and fault conditions. The system is designed to prevent adverse changes in power or thrust. In the event of loss of primary aircraft-supplied power, the engine controls continue to operate using a secondary power source (SPS). As a control device, the system performs self-diagnostics to determine overall system status and conveys this information to the pilot by various indicators on the health status annunciator (HSA) panel. PowerLink is able to withstand storage temperature extremes and operate at the same capacity as a non-FADEC-equipped engine in extreme heat, cold, and high humidity environments.

LOW-VOLTAGE HARNESS

The low-voltage harness connects all essential components of the FADEC System. This harness acts as a signal transfer bus interconnecting the electronic control units (ECUs) with aircraft power sources, the ignition switch, speed sensor assembly (SSA), temperature and pressure sensors. The fuel injector coils and all sensors, except the SSA and fuel pressure and manifold pressure sensors, are hardwired to the low-voltage harness. This harness transmits sensor inputs to the ECUs through a 50-pin connector. The harness connects to the engine-mounted pressure sensors via cannon plug connectors. The 25-jpin connectors connect the harness to the speed sensor signal conditioning unit. The low-voltage harness attaches to the cabin harness by a firewall-mounted data port through the same cabin harness/bulkhead connector assembly. The bulkhead connectors also supply the aircraft electrical power required to run the system.

The ECU is at the heart of the system, providing both ignition and fuel injection control to operate the engine with the maximum efficiency realizable. Each ECU contains two microprocessors, referred to as a computer, that control two cylinders. Each computer controls its own assigned cylinder and is capable of providing redundant control for the other computer's cylinder.

The computer constantly monitors the engine speed and timing pulses developed from the camshaft gear as they are detected by the SSA. Knowing the exact engine speed and the timing sequence of the engine, the computers monitor the manifold air pressure and manifold air temperature to calculate air density and determine the mass air flow into the cylinder during the intake stroke. The computers calculate the percentage of engine power based on engine revolutions per minute (rpm) and manifold air pressure.

From this information, the computer can then determine the fuel required for the combustion cycle for either best power or best economy mode of operation. The computer precisely times the injection event, and the duration of the injector should be on time for the correct fuel-to-air ratio. Then, the computer sets the spark ignition event and ignition timing, again based on percentage of power calculation. Exhaust gas temperature is measured after the burn to verify that the fuel-to-air ratio calculations were correct for that combustion event. This process is repeated by each computer for its own assigned cylinder on every combustion/power cycle.

The computers can also vary the amount of fuel to control the fuel-to-air ratio for each individual cylinder to control both cylinder head temperature (CHT) and exhaust gas temperature (EGT).

ELECTRONIC CONTROL UNIT (ECU)

An ECU is assigned to a pair of engine cylinders. (***Figure 4-116)*** The ECUs control the fuel mixture and spark timing for their respective engine cylinders; ECU 1 controls opposing cylinders 1 and 2, ECU 2 controls cylinders 3 and 4, and ECU 3 controls cylinders 5 and 6. Each ECU is divided into upper and lower portions. The lower portion contains an electronic circuit board, while the upper portion houses the ignition coils. Each electronic control board contains two independent microprocessor controllers that serve as control channels. During engine operation, one control channel is assigned to operate a single engine cylinder. Therefore, one ECU can control two engine cylinders, one control channel per cylinder. The control channels are independent, and there are no shared electronic components within one ECU. They also operate on independent and separate power supplies. However, if one control channel fails, the other control channel in the pair within the same ECU is capable of operating both its assigned cylinder and the other opposing engine cylinder as backup control for fuel injection and ignition timing. Each control channel on the ECU monitors the current operating conditions and operates its cylinder to attain engine operation within specified parameters. The following transmit inputs to the control channels across the low-voltage harness:

1. Speed sensor that monitors engine speed and crank position
2. Fuel pressure sensors
3. Manifold pressure sensors
4. Manifold air temperature (MAT) sensors
5. CHT sensors
6. EGT sensors

All critical sensors are dually redundant with one sensor from each type of pair connected to control channels in different ECUs. Synthetic software default values are also used in the unlikely event that both sensors of a redundant pair fail. The control channel continuously monitors changes in engine speed, manifold pressure, manifold temperature, and fuel pressure based on sensor input relative to operating conditions to determine how much fuel to inject into the intake port of the cylinder.



Figure 4-116. Electronic control unit.

POWERLINK IGNITION SYSTEM

The ignition system consists of the high-voltage coils atop the ECU, the high-voltage harness, and spark plugs. Since there are two spark plugs per cylinder on all engines, a six-cylinder engine has 12 leads and 12 spark plugs. One end of each lead on the high-voltage harness attaches to a spark plug, and the other end of the lead wire attaches to the spark plug towers on each ECU. The spark tower pair is connected to opposite ends of one of the ECU's coil packs. Two coil packs are located in the upper portion of the ECU. Each coil pack generates a high-voltage pulse for two spark plug towers. One tower fires a positive polarity pulse and the other of the same coil fires a negative polarity pulse. Each ECU controls the ignition spark for two engine cylinders. The control channel within each ECU commands one of the two coil packs to control the ignition spark for the engine cylinders ***(Figure 4-117)***. The high-voltage harness carries energy from the ECU spark towers to the spark plugs on the engine.

For both spark plugs in a given cylinder to fire on the compression stroke, both control channels must fire their coil packs. Each coil pack has a spark plug from each of the two cylinders controlled by that ECU unit.

The ignition spark is timed to the engine's crankshaft position. The timing is variable throughout the engine's operating range and is dependent upon the engine load conditions. The spark energy is also varied with respect to the engine load.

NOTE: Engine ignition timing is established by the ECUs and cannot be manually adjusted.

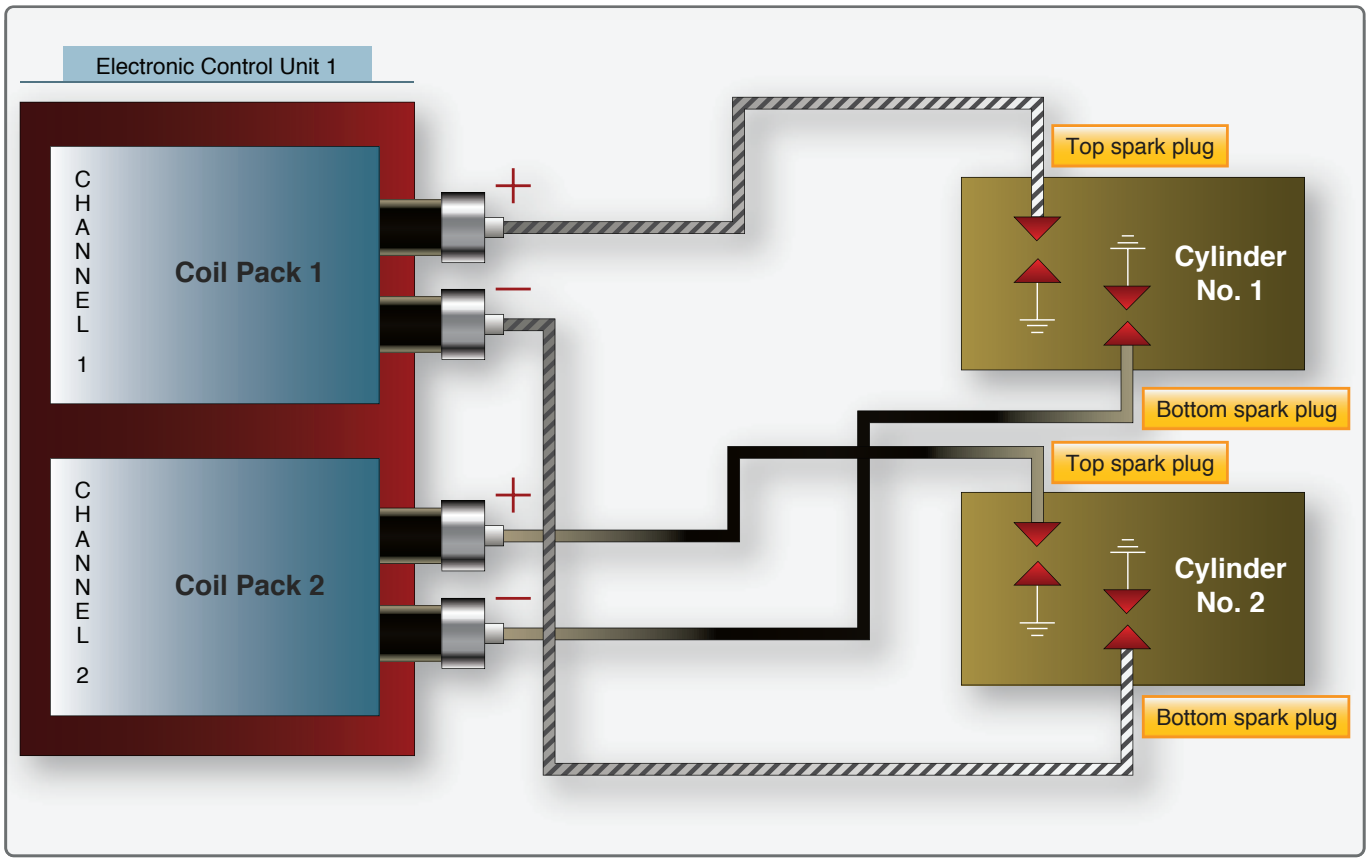


Figure 4-117. Ignition control schematic.

Question: 4-1
Name 3 aspects which are problematic for carburetors:

_____
_____
_____

Question: 4-2
If the fuel level in a float bowl is too low, what will be the effect of the fuel/mixture entering the cylinders?

Question: 4-3
What three factors determine the flow of fluids within a carburetor?

Question: 4-4
What are the two basic functions of every aircraft fuel metering system?

Question: 4-5
What is the primary way to cool down the temperature of combustion?

Question: 4-6
What are the two methods of providing power enrichment?

Question: 4-7
When is an acceleration system used and what is its primary function?

Question: 4-8
What two factors determine the pressure differential in a float carburetor during idle operations?

ANSWERS

Answer: 4-1
*Prone to icing.
*Must remain upright.
*Small variances of fuel per cylinder.
page 4.2

Answer: 4-2
The mixture will become lean.
page 4.4

Answer: 4-3
*The size of orifice.
*The pressure differential on each side of an orifice.
*The viscosity of the fluid.
page 4.5

Answer: 4-4
Meter the fuel; Atomize the fuel.
page 4.8

Answer: 4-5
Enrich the mixture.
page 4.17

Answer: 4-6
*Adding fuel to the discharge flow.
*Restricting the level of air bleed.
page 4.19

Answer: 4-7
When the operator advances the throttle; Injects a burst of fuel to match the immediate input of air flow.
page 4.22

Answer: 4-8
Manifold pressure and bowl chamber pressure.
page 4.24

Question: 4-9
In a float carburetor's main circuit, where does air flow for air bleed originate?

Question: 4-10
What are the 4 major components of a pressure carburetor
_____
_____
_____
_____

Question: 4-11
The two major benefits of a pressure carburetor system over a float carburetor include:

Question: 4-12
In a large pressure carburetor, how is acceleration fuel provided into the mixture?

Question: 4-13
What is the principle difference between continuous and direct fuel injection systems?

Question: 4-14
A principle and frequently repeated aspect of maintenance to an RSA fuel control unit is to:

Question: 4-15
Within an RSA fuel injection system, the greatest air pressure is from _____ and the greatest fuel pressure is from _____.

Question: 4-16
An RSA servo controller contains a _____ diaphragm which is larger in surface area than the _____ diaphragm.

ANSWERS

Answer: 4-9
Normally from the float bowl.
page 4.26

Answer: 4-10
*Air throttle body.
*Regulator.
*Fuel control unit.
*Discharge nozzle.
page 4.27

Answer: 4-11
*Operates at any aircraft attitude.
*Less likely to encounter icing.
page 4.30

Answer: 4-12
A pressurized diaphragm opens a poppet valve injecting fuel into Chamber D and fuel comtrol unit.
page 4.45

Answer: 4-13
Continuous systems inject fuel into the intake manifold or intake ports. Direct systems spray fuel directly into the cylinder's combustion chamber.
page 4.49

Answer: 4-14
Inspect and clean the filter screen.
page 4.53

Answer: 4-15
Incoming impact air; Unmetered fuel.
page 4.54

Answer: 4-16
Pneumatic; Fuel.
page 4.57

Question: 4-17
In a Bendix RSA system, as rpm increases, unmetered fuel pressure _____ and metered fuel pressure _____

Question: 4-18
What would be the result if a technician replaced fuel injection lines to the nozzles using primer lines on an RSA fuel injection system?

Question: 4-19
The Continental fuel injection systems primarily differs from the RSA system in that the Continental system measures _____ while the RSA system measures the flow of _____

Question: 4-20
The fuel control component of a FADEC system contains just one moving part, with the function of_____.

ANSWERS

Answer: 4-17
Remains the same or slightly decreases; Decreases.
page 4.59

Answer: 4-18
Mixtures within the cylinders would vary out of specifications with one lean cylinder subject to failure.
page 4.62

Answer: 4-19
Engine rpm; Air.
page 4.65

Answer: 4-20
Opening or closing the fuel injector.
page 4.71



PART-66 SYLLABUS	LEVELS		
CERTIFICATION CATEGORY →	A	B1	B3

Sub-Module 05
Piston Engine - Starting and Ignition Systems

16.5 - Starting and Ignition Starting systems, pre-heat systems; Magneto types, construction and principles of operation; Ignition harnesses, spark plugs; Low and high tension systems.	1	2	2

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

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

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

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

STARTING AND IGNITION SYSTEMS

RECIPROCATING ENGINE STARTING SYSTEMS

Most aircraft engines, reciprocating or turbine, require help during the starting process. Hence, this device is termed the starter. A starter is an electromechanical mechanism capable of developing large amounts of mechanical energy that can be applied to an engine, causing it to rotate. Reciprocating engines need only to be turned through at a relatively slow speed until the engine starts and turns on its own. Once the reciprocating engine has fired and started, the starter is disengaged and has no further function until the next start. In the case of a turbine engine, the starter must turn the engine up to a speed that provides enough airflow through the engine for fuel to be ignited. Then, the starter must continue to help the engine accelerate to a self-sustaining speed. Turbine engine starters have a critical role in starting of the engine.

In the early stages of aircraft development, relatively low powered reciprocating engines were started by pulling the propeller through a part of a revolution by hand. This is known as "hand cranking" or "propping" the engine. Difficulty was often experienced in cold weather starting when lubricating oil temperatures were near the congealing point. In addition, the magneto systems delivered a weak starting spark at the very low cranking speeds. This was often compensated for by providing a hot spark using such ignition system devices as the booster coil, induction vibrator, or impulse coupling. Also, fuel atomization is relatively at a minimum when the ambient temperature is very low.

Some small, low-powered aircraft that use hand cranking of the propeller, or propping, for starting are still being operated. Individuals involved in hand cranking operations should first be properly trained in this technique to avoid injuries. Throughout the development of the aircraft reciprocating engine from the earliest use of starting systems to the present, a number of different starter systems have been used. Most reciprocating engine starters are the direct cranking electric type. A few older model aircraft are still equipped with inertia starters. Thus, only a brief description of these starting systems is included in this section.

INERTIA STARTERS

There are three general types of inertia starters: hand, electric, and combination hand and electric. The operation of all types of inertia starters depends on the kinetic energy stored in a rapidly rotating flywheel for cranking ability. Kinetic energy is energy possessed by a body by virtue of its state of motion, which may be movement along a line or spinning action.

In the inertia starter, energy is stored slowly during an energizing process by a manual hand crank or electrically with a small motor. The flywheel and movable gears of a combination hand electric inertia starter are shown in ***Figure 5-1***.

The electrical circuit for an electric inertia starter is shown in ***Figure 5-2***. During the energizing of the starter, all movable parts within it, including the flywheel, are set in motion. After the starter has been fully energized, it is engaged to the crankshaft of the engine by a cable pulled manually or by a meshing solenoid that is energized electrically.

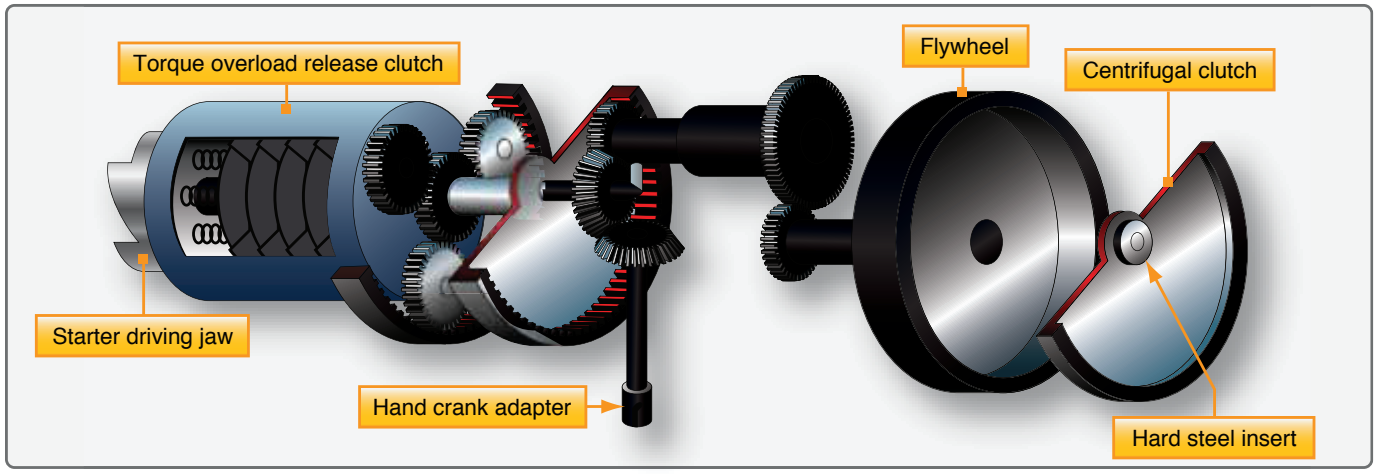


Figure 5-1. Combination hand and electric inertia starter.

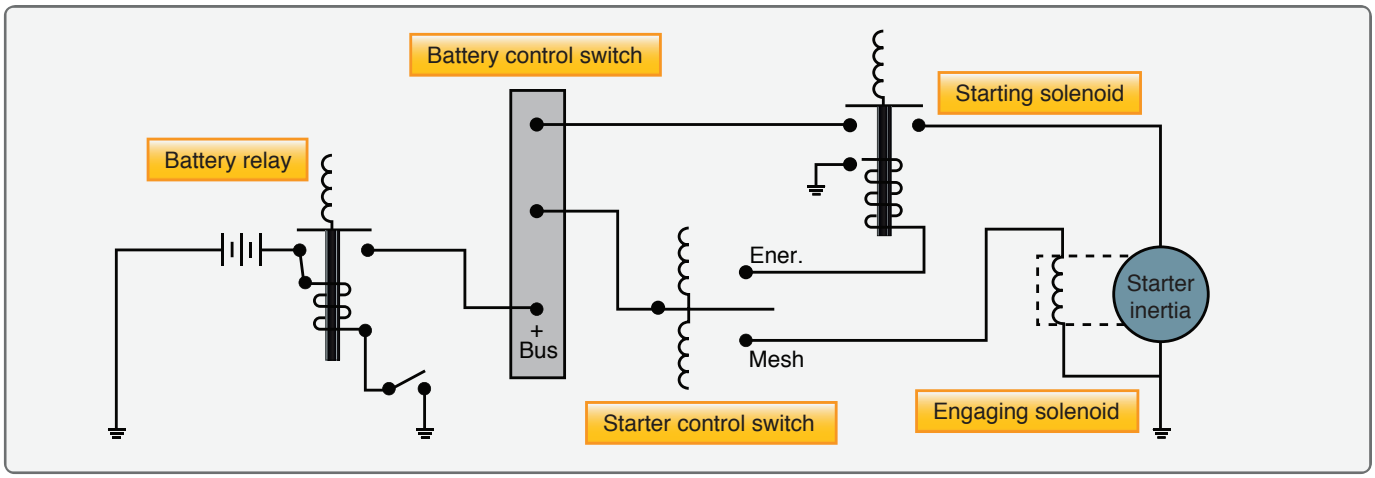


Figure 5-2. Electric inertia starter schematic.

When the starter is engaged, or meshed, flywheel energy is transferred to the engine through sets of reduction gears and a torque overload release clutch. ***[Figure 5-3]***

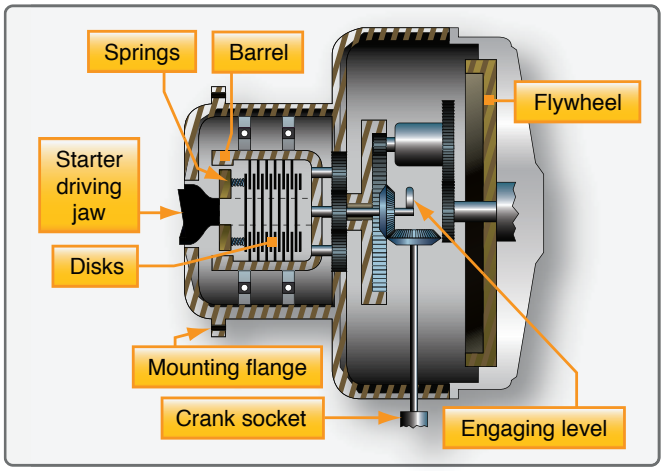


Figure 5-3. Inertia starter.

DIRECT CRANKING ELECTRIC STARTER

The most widely used starting system on all types of reciprocating engines utilizes the direct cranking electric starter. This type of starter provides instant and continual cranking when energized. The direct cranking electric starter consists basically of an electric motor, reduction gears, and an automatic engaging and disengaging mechanism that is operated through an adjustable torque overload release clutch. A typical circuit for a direct cranking electric starter is shown in ***Figure 5-4***. The engine is cranked directly when the starter solenoid is closed. As shown in ***Figure 5-4***, the main cables leading from the starter to the battery are heavy duty to carry the high current flow, which may be in a range from as high as 350 amperes to 100 amperes (amps), depending on the starting torque required. The use of solenoids and heavy wiring with a remote control switch reduces overall cable weight and total circuit voltage drop. The typical starter motor is a 12- or 24-volt,

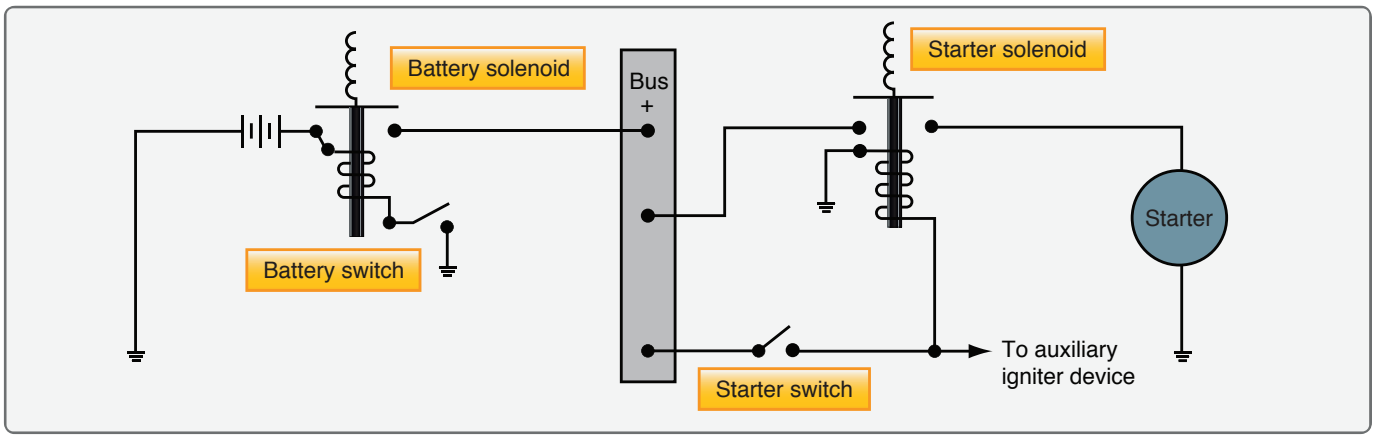


Figure 5-4. Typical starter circuit.

series-wound motor that develops high starting torque. On many units, the torque of the motor is transmitted through reduction gears to the overload release clutch. Typically, this action actuates a helically splined shaft moving the starter jaw outward to engage the engine cranking jaw before the starter jaw begins to rotate. Some starters use direct drive without the benefits of gearing. After the engine reaches a predetermined speed, the starter automatically disengages. The schematic in ***Figure 5-5*** provides a pictorial arrangement of an entire starting system for a light twin-engine aircraft.

DIRECT CRANKING ELECTRIC STARTING SYSTEM FOR LARGE RECIPROCATING ENGINES

In a typical high horsepower reciprocating engine starting system, the direct cranking electric starter consists of two basic components: a motor assembly and a gear section. The gear section is bolted to the drive end of the motor to form a complete unit. The motor assembly consists of the armature and motor pinion assembly, the end bell assembly, and the motor housing assembly. The motor housing also acts as the magnetic yoke for the field structure.

The starter motor is a nonreversible, series interpole motor. Its speed varies directly with the applied voltage and inversely with the load. The starter gear section consists of an external housing with an integral mounting flange, planetary gear reduction, a sun and integral gear assembly, a torque-limiting clutch, and a jaw and cone assembly as seen in ***Figure 5-6***. When the starter circuit is closed, the torque developed in the starter motor is transmitted to the starter jaw through the reduction

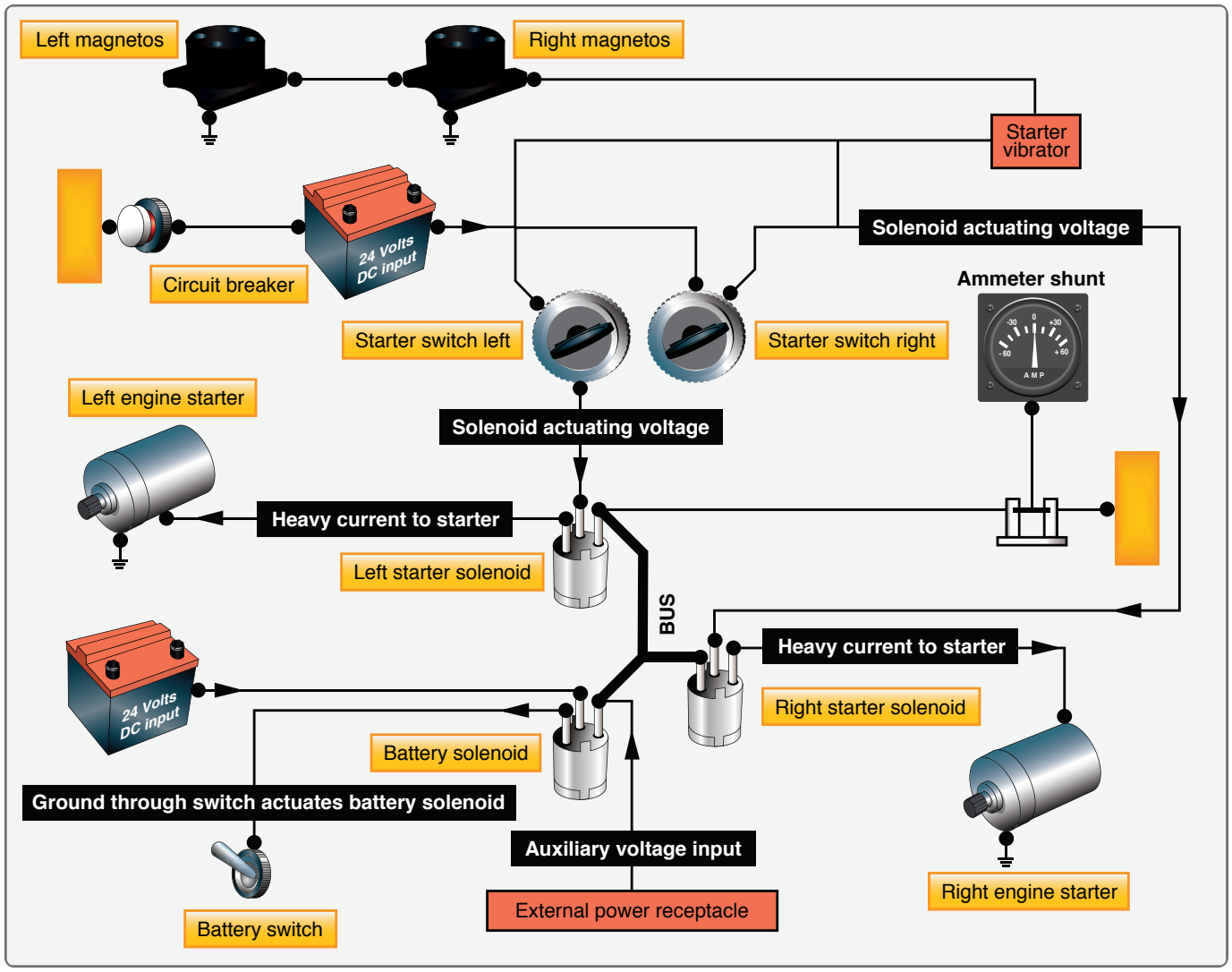


Figure 5-5. Starter system components.

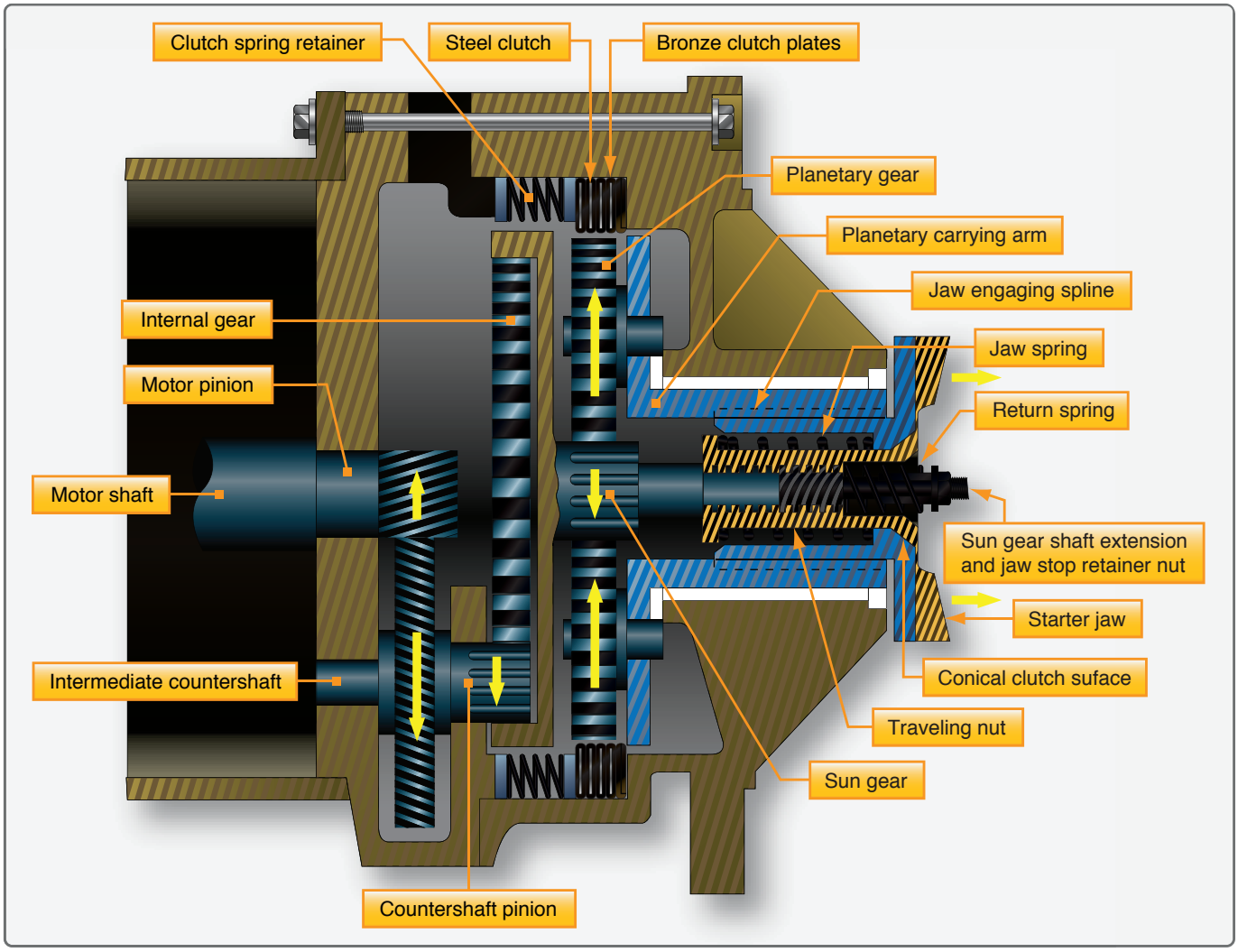


Figure 5-6. Starter clutch and gear assembly.

gear train and clutch. The starter gear train converts the high-speed low torque of the motor to the low speed high torque required to crank the engine. In the gear section, the motor pinion engages the gear on the intermediate countershaft. The pinion of the countershaft engages the internal gear. The internal gear is an integral part of the sun gear assembly and is rigidly attached to the sun gear shaft. The sun gear drives three planet gears that are part of the planetary gear assembly. The individual planet gear shafts are supported by the planetary carrying arm, a barrel-like part shown in ***Figure 5-6***. The carrying arm transmits torque from the planet gears to the starter jaw as follows:

1. The cylindrical portion of the carrying arm is splined longitudinally around the inner surface.

2. Mating splines are cut on the exterior surface of the cylindrical part of the starter jaw.

3. The jaw slides fore and aft inside the carrying arm to engage and disengage with the engine.

The three planet gears also engage the surrounding internal teeth on the six steel clutch plates. These plates are interleaved with externally splined bronze clutch plates that engage the sides of the housing, preventing them from turning. The proper pressure is maintained upon the clutch pack by a clutch spring retainer assembly. A cylindrical traveling nut inside the starter jaw extends and retracts the jaw. Spiral jaw-engaging splines around the inner wall of the nut mate with similar splines cut on an extension of the sun gear shaft.

Being splined in this fashion, rotation of the shaft forces the nut out and the nut carries the jaw with it. A jaw spring around the traveling nut carries the jaw with the nut and tends to keep a conical clutch surface around the inner wall of the jaw head seated against a similar surface

around the underside of the nut head. A return spring is installed on the sun gear shaft extension between a shoulder, formed by the splines around the inner wall of the traveling nut, and a jaw stop retaining nut on the end of the shaft. Because the conical clutch surfaces of the traveling nut and the starter jaw are engaged by jaw spring pressure, the two parts tend to rotate at the same speed. However, the sun gear shaft extension turns six times faster than the jaw. The spiral splines on it are cut left hand, and the sun gear shaft extension, turning to the right in relation to the jaw, forces the traveling nut and the jaw out from the starter its full travel (about 5/16 inches) in approximately 12° of rotation of the jaw.

The jaw moves out until it is stopped either by engagement with the engine or by the jaw stop retaining nut. The travel nut continues to move slightly beyond the limit of jaw travel, just enough to relieve some of the spring pressure on the conical clutch surfaces. As long as the starter continues to rotate, there is just enough pressure on the conical clutch surfaces to provide torque on the spiral splines that balance most of the pressure of the jaw spring. If the engine fails to start, the starter jaw does not retract since the starter mechanism provides no retracting force. However, when the engine fires and the engine jaw overruns the starter jaw, the sloping ramps of the jaw teeth force the starter jaw into the starter against the jaw spring pressure. This disengages the conical clutch surfaces entirely, and the jaw spring pressure forces the traveling nut to slide in along the spiral splines until the conical clutch surfaces are again in contact.

When the starter and engine are both running, there is an engaging force keeping the jaws in contact that continue until the starter is de-energized. However, the rapidly moving engine jaw teeth, striking the slowly moving starter jaw teeth, hold the starter jaw disengaged. As soon as the starter comes to rest, the engaging force is removed and the small return spring throws the starter jaw into its fully retracted position where it remains until the next start. When the starter jaw first engages the engine jaw, the motor armature has had time to reach considerable speed because of its high starting torque. The sudden engagement of the moving starter jaw with the stationary engine jaw would develop forces sufficiently high enough to severely damage the engine or the starter were it not for the plates in the clutch pack that slip when the engine torque exceeds the clutch-slipping torque.

In normal direct cranking action, the internal steel gear clutch plates are held stationary by the friction of the bronze plates with which they are interleaved. When the torque imposed by the engine exceeds the clutch setting, however, the internal gear clutch plates rotate against the clutch friction, allowing the planet gears to rotate while the planetary carrying arm and the jaw remain stationary. When the engine reaches the speed that the starter is trying to achieve, the torque drops off to a value less than the clutch setting, the internal gear clutch plates are again held stationary, and the jaw rotates at the speed that the motor is attempting to drive it. The starter control switches are shown schematically in ***Figure 5-7***. The engine selector switch must be positioned and the starter switch and the safety switch—wired in series—must be closed before the starter can be energized. Current is supplied to the starter control circuit through a circuit breaker labeled "Starter, Primer, and Induction Vibrator." ***(Figure 5-7)*** When the engine selector switch is in position for the engine start, closing the starter energizes the starter relay located in the engine nacelle area. Energizing the starter relay completes the power circuit to the starter motor. The current necessary for this heavy load is taken directly from the master bus through the starter bus cable.

All starting systems have operating time limits because of the high energy used during cranking or rotation of the engine. These limits are referred to as starter limits and must be observed, or overheating and damage of the starter occurs. After energizing the starter for 1 minute, it should be allowed to cool for at least 1 minute. After a second or subsequent cranking period of 1 minute, it should cool for 5 minutes.

DIRECT CRANKING ELECTRIC STARTING SYSTEM FOR SMALL AIRCRAFT

Most small, reciprocating engine aircraft employ a direct cranking electric starting system. Some of these systems are automatically engaged starting systems, while others are manually engaged. Manually engaged starting systems used on many older, small aircraft employ a manually operated overrunning clutch drive pinion to transmit power from an electric starter motor to a crankshaft starter drive gear as seen in ***Figure 5-8***. A knob or handle on the instrument panel is connected by a flexible control to a lever on the starter. This lever shifts the starter drive pinion into the engaged position

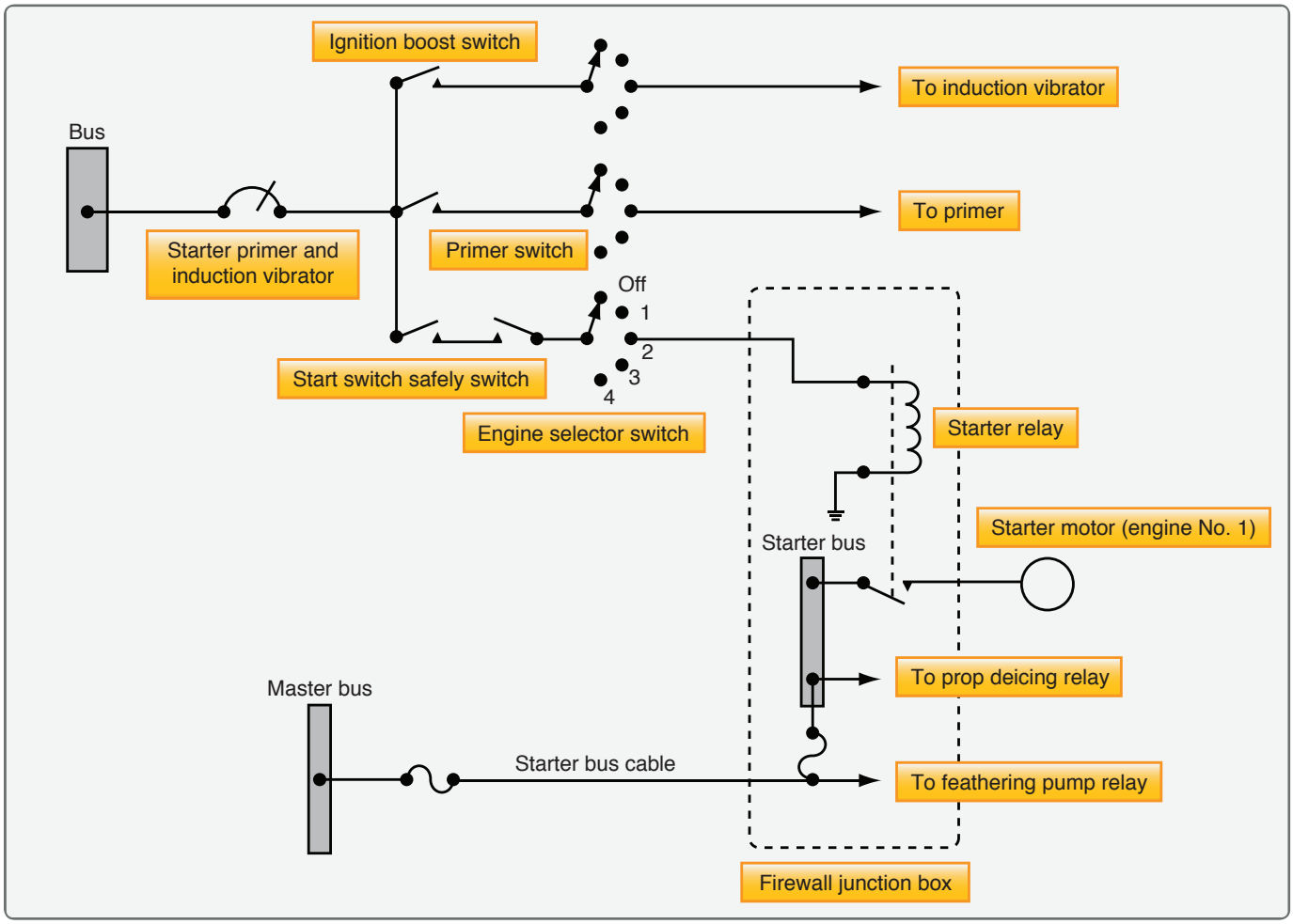


Figure 5-7. Starter control circuit.

and closes the starter switch contacts when the starter knob or handle is pulled.

The starter lever is attached to a return spring that returns the lever and the flexible control to the off position. When the engine starts, the overrunning action of the clutch protects the starter drive pinion until the shift lever can be released to disengage the pinion. For the typical unit, there is a specified length of travel for the starter gear pinion. It is important that the starter lever move the starter pinion gear this proper distance before the adjustable lever stud contacts the starter switch as two functions are accomplished when the starter handle is activated. First, the gear must be fully engaged. Second, the electrical circuit is completed. If the electrical circuit energizes the starter before the gear is properly engaged, a grinding action will take place and the cranking of the engine will not occur.

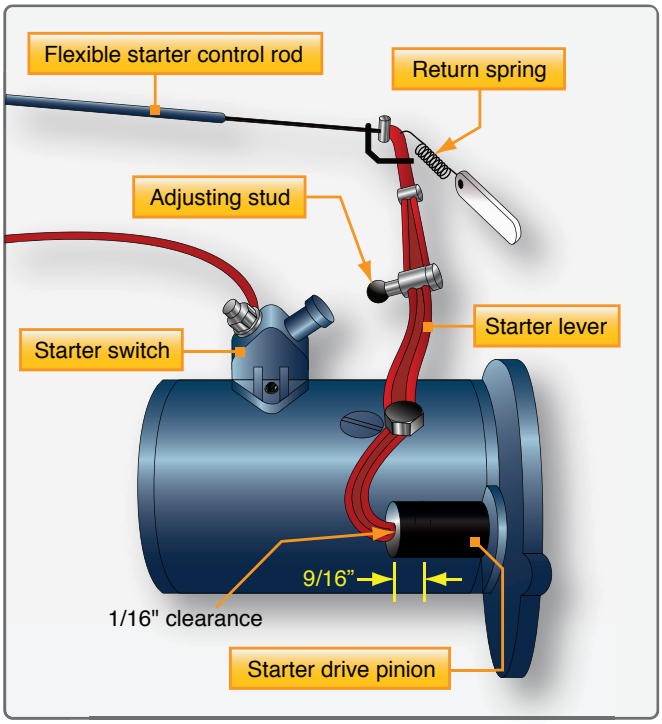


Figure 5-8. Manual starter system.

The automatic, or remote solenoid engaged, starting systems employ an electric starter mounted on an engine

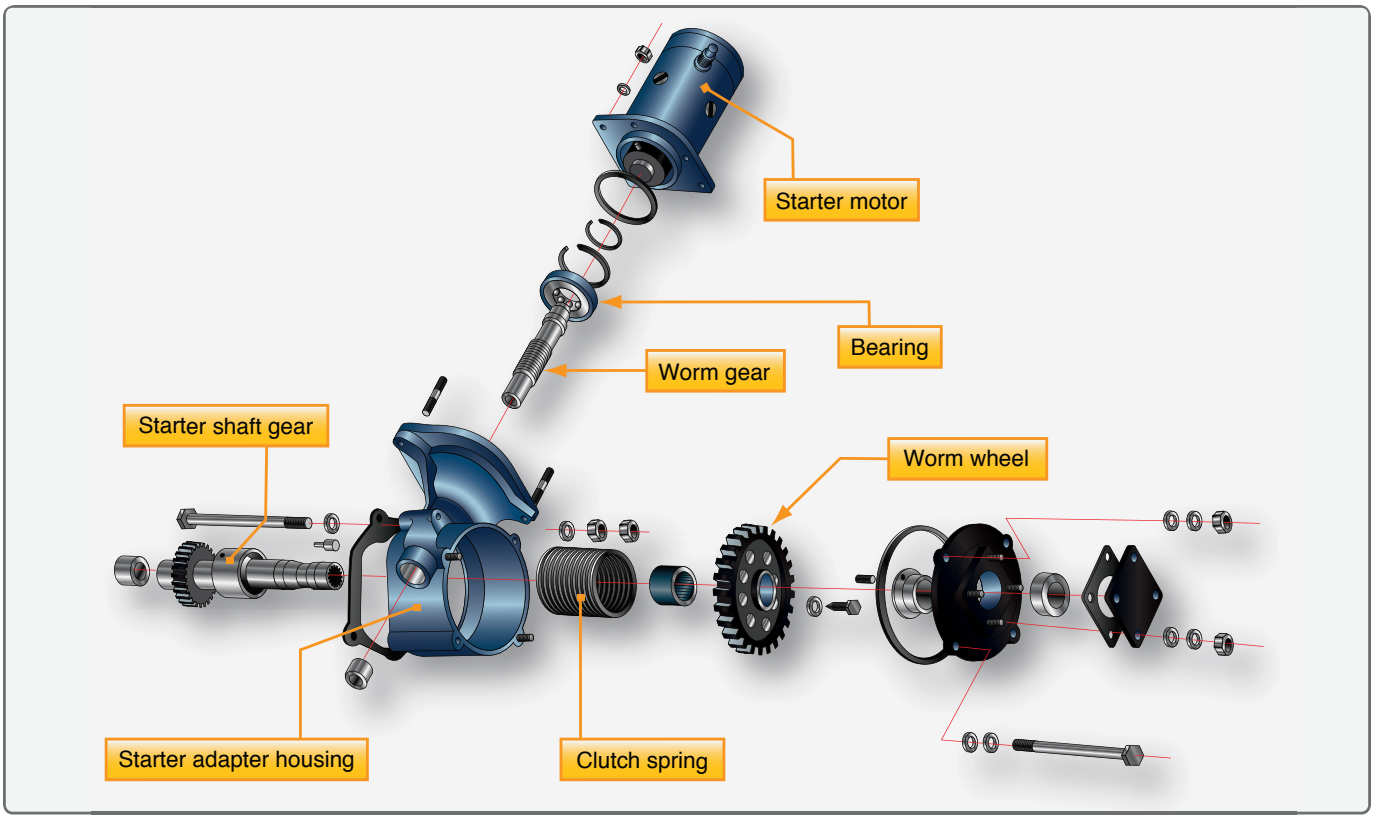


Figure 5-9. 90˚ starter drive assembly.

adapter. A starter solenoid is activated by either a push button or turning the ignition key on the instrument panel. When the solenoid is activated, its contacts close and electrical energy energizes the starter motor. Initial rotation of the starter motor engages the starter through an overrunning clutch in the starter adapter, which incorporates worm reduction gears.

Some engines incorporate an automatic starting system that employs an electric starter motor mounted on a right angle drive adapter. As the starter motor is electrically energized, the adapter worm shaft and gear engage the starter shaft gear by means of a spring and clutch assembly. The shaft gear, in turn, rotates the crankshaft. When the engine begins to turn on its own power, the clutch spring disengages from the shaft gear. The starter adapter uses a worm drive gear shaft and worm gear to transfer torque from the starter motor to the clutch assembly. See ***Figure 5-9***. As the worm gear rotates the worm wheel and clutch spring, the clutch spring is tightened around the drum of the starter shaft gear. As the shaft gear turns, torque is transmitted directly to the crankshaft gear.

Other engines use a starter that drives a ring gear mounted to the propeller hub as illustrated in ***Figure 5-10***. It uses an electric motor and a drive gear that engages as the motor is energized and spins the gear, which moves out and engages the ring gear on the propeller hub cranking the engine for start.

As the engine starts, the starter drive gear is spun back by the engine turning, which disengages the drive gear. Refer to ***Figure 5-11***. The starter motors on small aircraft also have operational limits with cool down times that should be observed.

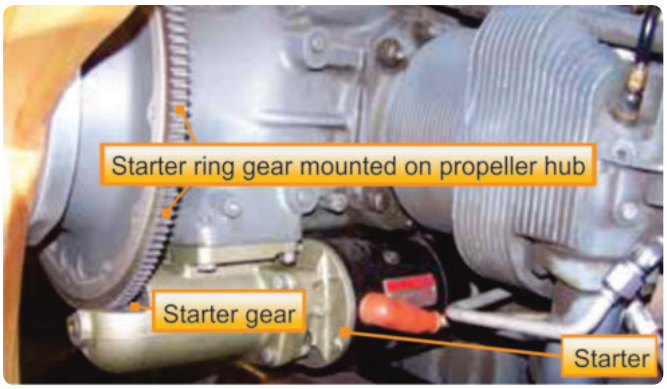


Figure 5-10. Starter and ring gear system.

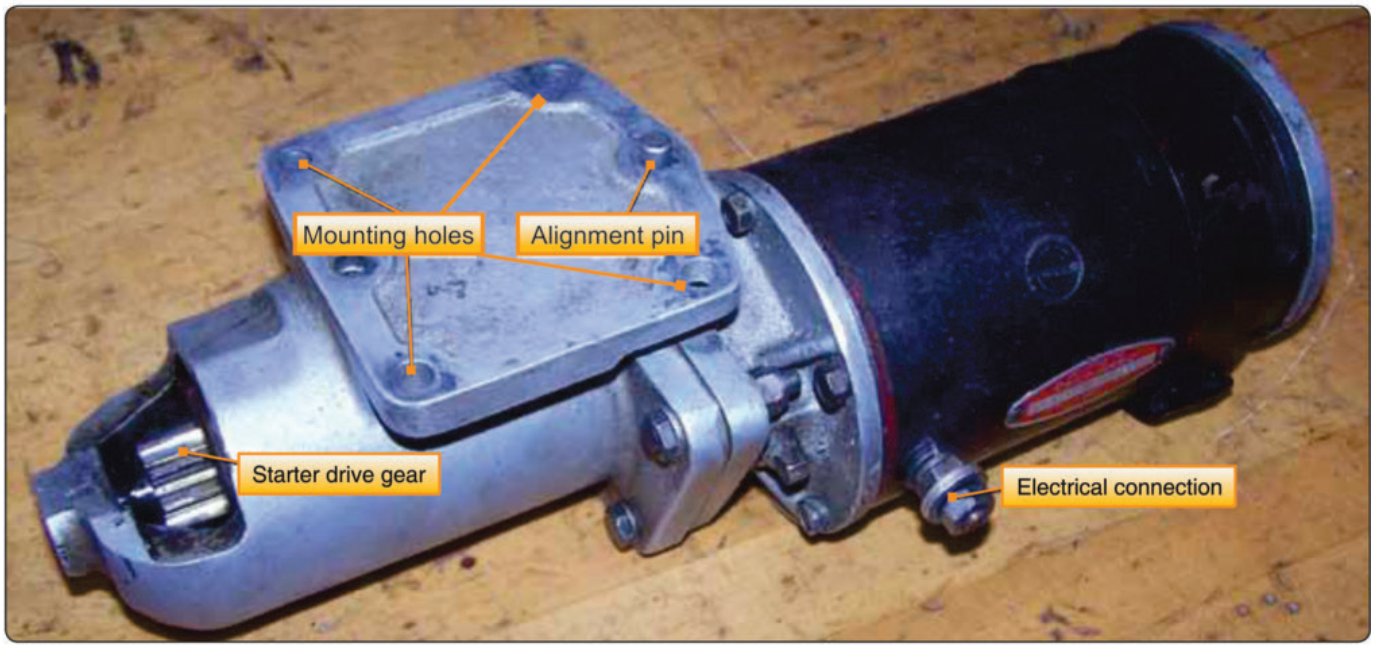


Figure 5-11. Common starter assembly.

RECIPROCATING ENGINE STARTING SYSTEM MAINTENANCE PRACTICES

Most starting system maintenance practices include replacing the starter motor brushes and brush springs, cleaning dirty commutators, and turning down burned or out-of-round starter commutators. As a rule, starter brushes should be replaced when worn down to approximately one-half the original length. Brush spring tension should be sufficient to give brushes a good firm contact with the commutator. Brush leads should be unbroken and lead terminal screws tight.

A glazed or dirty starter commutator can be cleaned by holding a strip of double-0 sandpaper or a brush seating stone against the commutator as it is turned. The sandpaper or stone should be moved back and forth across the commutator to avoid wearing a groove. Emery paper or carborundum should never be used for this purpose because of their possible shorting action.

Roughness, out-of-roundness, or high-mica conditions are reasons for turning down the commutator. In the case of a high-mica condition, the mica should be undercut after the turning operation is accomplished.

The drive gear should be checked for wear along with the ring gear. The electrical connections should be checked for looseness and corrosion. Also, check the security of the mounting of the housing of the starter.

PREHEAT SYSTEMS

Aircraft engines, when compared to automotive engine, are more difficult to start when the ambient temperature is extremely cold. One reason is that aircraft engines are primed for start. The fuel discharged for priming purposes is reluctant to atomize in cold climates. Magneto ignition systems require a starting aid for starting. One such device, the impulse coupling, may experience difficulties engaging their stop pin if cold oil impedes the freedom of motion of the flyweight arms.

Aside from the actual starting of the engine, aircraft engines started during extreme cold climates may experience a considerable delay in establishing engine oil pressure. Many aircraft oils are relatively viscous, which becomes a problem when the temperatures are cold. Some measure of internal damage may take place while the engine runs without oil pressure.

To alleviate problems associated with cold weather starts, aircraft engines may be preheated. The preheating allows the engine to attain a normal start with immediate oil pressure following start. It also expedites the pre-takeoff warm-up period.

Preheating may be accomplished in a variety of ways. First, the aircraft may be placed in a heated hangar for a suitable period, such as over night, to keep the engine, and, in this example, the entire aircraft warm. This

technique is likely to further assist the cranking ability of the aircraft battery when compared to a battery that has been cold-soaked. Another technique for preheating involves remote heat sources. Electric or gas-powered heat sources using blower motors are frequently used to preheat aircraft that have been parked in cold climates. Hot air is pumped into the engine compartment for a period of time, depending on the ambient temperature. Often, blankets are placed over the cowling to retain heat during the preheating process. This technique does not directly benefit the cranking ability of the battery unless the battery is installed in the engine compartment.

Electrically-powered heaters offer another technique for engine preheating. Such devices will typically involve a heating pad affixed to the oil tank that is plugged into an electrical source. After a few hours of operation, the oil is reasonably warm. More elaborate electrical heaters include heating elements that are installed into the cylinder head temperature (CHT) probe well in the cylinders that are not connected to the CHT indication system. Adding heat to the cylinder heads enhances the ability of the cylinder to fire during the cranking operation. Crankcase heaters are also available for a more complete preheat. Misuse of these preheaters may result in engine failure.

Aircraft owners often incorrectly deem that the best thing they can do for the aircraft engine over the winter period is to plug in the heating pads and probe and let them run throughout the winter season. Such action will result in internal engine corrosion. The atmosphere within the engine compartment becomes warm and circulates within the confines of the crankcase. As the vapors circulate, they experience heating and cooling. The net result is the formation of condensation within the interior of the engine. Rather than leave the heating system in operation on a continuous basis, the prescribed technique is to activate the heating elements a few hours before cranking the engine.

RECIPROCATING AIRCRAFT ENGINE IGNITION SYSTEMS

The basic requirements for reciprocating engine ignition systems are similar, regardless of the type of engine. All ignition systems must deliver a high-tension spark across the electrodes of each spark plug in each cylinder of the engine in the correct firing order. At a predetermined number of degrees ahead of the top dead center position of the piston, as measured by crankshaft travel in degrees of rotation, the spark occurs in the cylinder. The potential output voltage of the system must be adequate to arc the gap in the spark plug electrodes under all operating conditions. The spark plug is threaded into the cylinder head with the electrodes exposed to the combustion area of the engine's cylinder.

Ignition systems can be divided into two classifications: magneto-ignition systems or electronic Full Authority Digital Engine Control (FADEC) systems for reciprocating engines (See Module 4.3). Ignition systems can also be subclassified as either single or dual magneto-ignition systems. The single magneto-ignition system, usually consisting of one magneto and the necessary wiring, is used with another single magneto on the same engine. Dual magnetos generally use one rotating magnet that feeds two complete magnetos in one magneto housing. An example of each type is shown in ***Figure 5-12***.

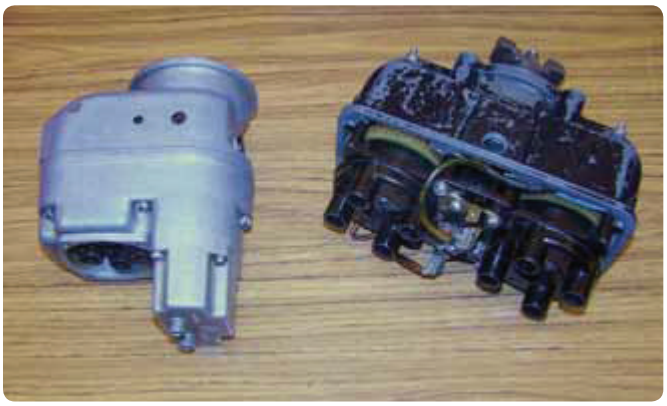


Figure 5-12. Single (left) and dual (right) magnetos.

Aircraft magneto-ignition systems can be classified as either high-tension or low-tension. The low-tension magneto system, covered in a later section of this module, generates a low-voltage that is distributed to a transformer coil near each spark plug. This system eliminates some problems inherent in the high-tension system that contained the high-voltage until it passed through the spark plug. The materials that were used for earlier generation ignition leads could not withstand the high-voltage and were prone to leak to ground before the spark would get to the cylinder. As new materials evolved and shielding was developed, the problems with high-tension magnetos were overcome. The high-tension magneto system is still the most widely used aircraft ignition system.

Some very old antique aircraft used a battery-ignition system. In this system, the source of energy is a battery or generator, rather than a magneto. This system was similar to that used in most automobiles at the time. ***Figure 5-13*** shows a simplified schematic of a battery-ignition system.

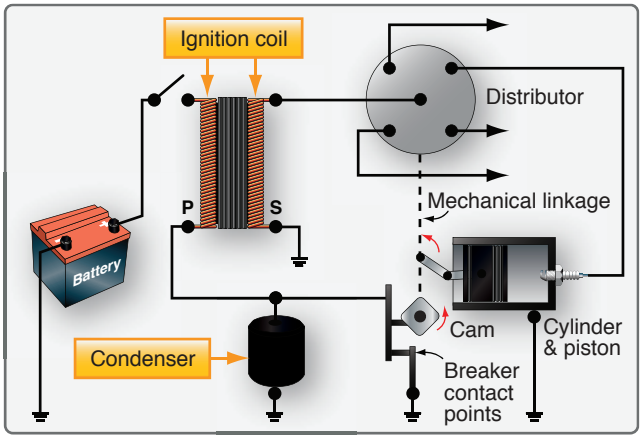


Figure 5-13. Battery-type ignition schematic.

MAGNETO-IGNITION SYSTEM OPERATING PRINCIPLES

The magneto, a special type of engine-driven alternate current (AC) generator, uses a permanent magnet as a source of energy. By the use of a permanent magnet (basic magnetic field), coil of wire (concentrated lengths of conductor), and relative movement of the magnetic field, current is generated in the wire. At first, the magneto generates electrical power by the engine rotating the permanent magnet and inducing a current to flow in the coil windings. As current flows through the coil windings, it generates its own magnetic field that surrounds the coil windings. At the correct time, this current flow is stopped and the magnetic field collapses across a second set of windings in the coil and a high-voltage is generated. This is the voltage used to arc across the spark plug gap. In general, the magneto produces the basic things needed to generate electrical power to develop the high voltage that forces a spark to jump across the spark plug gap in each cylinder. Magneto operation is timed to the engine so that a spark occurs only when the piston is on the proper stroke at a specified number of crankshaft degrees before the top dead center piston position.

HIGH-TENSION MAGNETO SYSTEM THEORY OF OPERATION

The high-tension magneto system can be divided, for purposes of discussion, into three distinct circuits: magnetic, primary electrical, and secondary electrical circuits.

THE MAGNETIC CIRCUIT

The magnetic circuit consists of a permanent multi-pole rotating magnet, a soft iron core, and pole shoes. ***Figure 5-14*** show the flow of flux for a four-pole magnet rotor. Many current magneto models use a two-pole magnet rotor. The response of the flux is the same only the degrees of rotation between the various flux positions is double. Also, two-pole rotors are typically equipped with cams that have two lobes as a two-pole rotor produces two sparks per revolution rather than four sparks as in the case of a four-pole magnet rotor.

The magnet is geared to the aircraft engine and rotates in the gap between two pole shoes to furnish the magnetic lines of force (flux) necessary to produce an electrical voltage. The poles of the magnet are arranged in alternate polarity so that the flux can pass out of the north pole through the coil core and back to the south pole of the magnet. When the magnet is in the position shown in ***Figure 5-14*** example A, the number of magnetic lines of force through the coil core is maximum because two magnetically opposite poles are perfectly aligned with the pole shoes.

This position of the rotating magnet is called the full register position and produces a maximum number of magnetic lines of force, flux flow clockwise through the magnetic circuit and from left to right through the coil core. When the magnet is moved away from the full register position, the amount of flux passing through the coil core begins to decrease. This occurs because the magnet's poles are moving away from the pole shoes, allowing some lines of flux to take a shorter path through the ends of the pole shoes.

As the magnet moves farther from the full register position, more lines of flux are short circuited through the pole shoe ends. Finally, at the neutral position 45° from the full register position, all flux lines are short circuited, and no flux flows through the coil core. ***(Figure 5-14 example B)*** As the magnet moves from full register to the neutral position, the

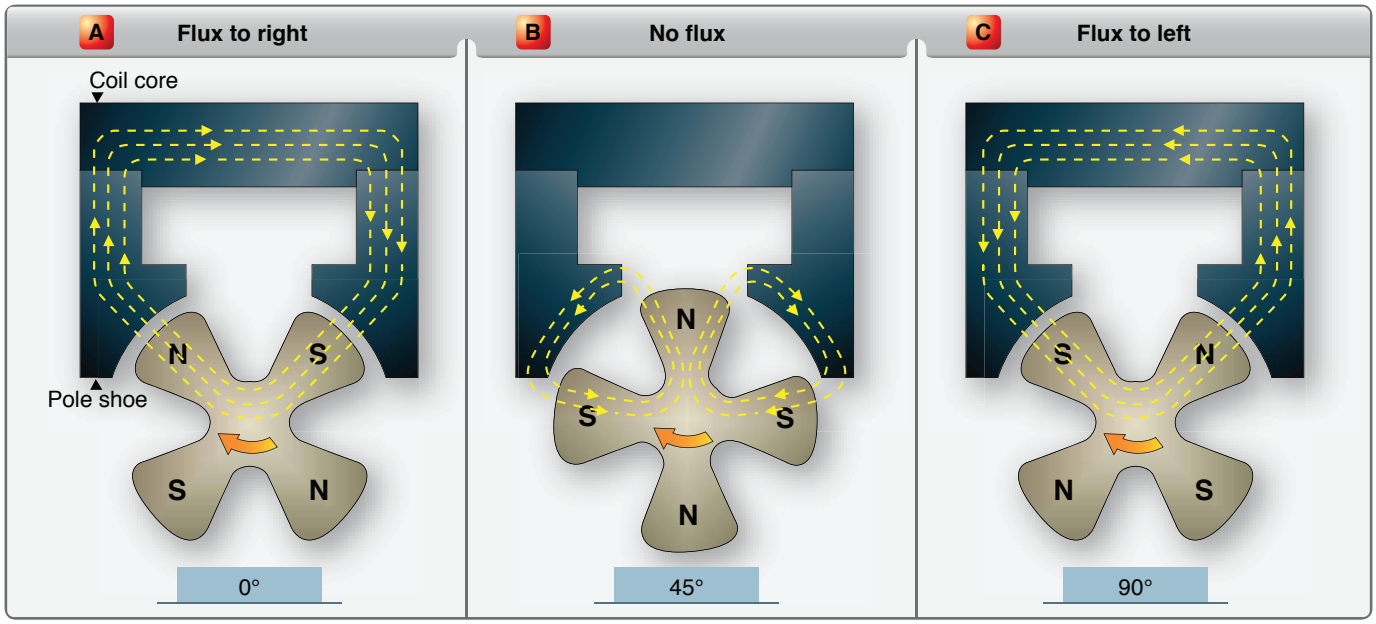


Figure 5-14. Flux flow of four-pole magnet rotor.

number of flux lines through the coil core decreases in the same manner as the gradual collapse of flux in the magnetic field of an ordinary electromagnet.

The neutral position of the magnet is where one of the poles of the magnet is centered between the pole shoes of the magnetic circuit. As the magnet is moved clockwise from this position, the lines of flux that had been short circuited through the pole shoe ends begin to flow through the coil core again. But this time, the flux lines flow through the coil core in the opposite direction. ***(Figure 5-14 example C)*** The flux flow reverses as the magnet moves out of the neutral position because the north pole of the rotating permanent magnet is opposite the right pole shoe instead of the left. ***[Figure 5.14 example A]***

When the magnet is again moved a total of 90˚, another full register position is reached with a maximum flux flow in the opposite direction. The 90˚ of magnet travel is shown in ***Figure 5-15***, where a curve shows how the flux density in the coil core, without a primary coil around the core, changes as the magnet is rotated.

Figure 5-15 shows that as the magnet moves from the full register position 0˚, flux flow decreases and reaches a zero value as it moves into the neutral position 45˚. While the magnet moves through the neutral position, flux flow reverses and begins to increase as indicated by the curve below the horizontal line. At the

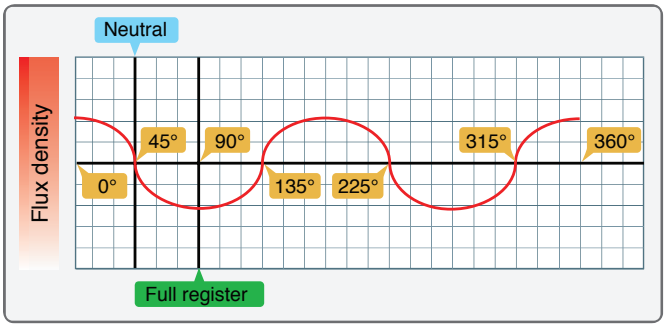


Figure 5-15. Graph of flux flow.

90˚ position, another position of maximum flux is reached. Thus, for one revolution 360˚ of the four pole magnet, there are four positions of maximum flux, four positions of zero flux, and four flux reversals.

This discussion of the magnetic circuit demonstrates how the coil core is affected by the rotating magnet. It is subjected to an increasing and decreasing magnetic field and a change in polarity each 90˚ of magnet travel.

When a coil of wire as part of the magneto's primary electrical circuit is wound around the coil core, it is also affected by the varying magnetic field.

THE PRIMARY ELECTRICAL CIRCUIT

The primary electrical circuit consists of a set of breaker contact points, a condenser, and an insulated coil. ***(Figure 5-16)*** The coil is made up of a few turns of heavy copper wire, one end is grounded to the coil core and the

other end to the ungrounded side of the breaker points. ***(Figure 5-16)*** The primary circuit is complete only when the ungrounded breaker point contacts the grounded breaker point. The third unit in the circuit, the condenser (capacitor), is wired in parallel with the breaker points. The condenser minimizes arcing at the points when the circuit is opened and hastens the collapse of the magnetic field about the primary coil.

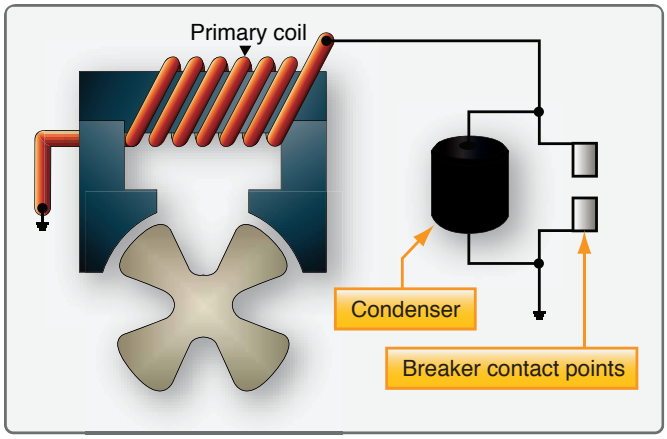


Figure 5-16. Magneto primary circuit.

The primary breaker closes at approximately full register position. When the breaker points are closed, the primary electrical circuit is completed and the rotating magnet induces current flow in the primary circuit. This current flow generates its own magnetic field, which is in such a direction that it opposes any change in the magnetic flux of the permanent magnet's circuit.

While the induced current is flowing in the primary circuit, it opposes any decrease in the magnetic flux in the core. This is in accordance with Lenz's Law that states: "An induced current always flows in such a direction that its magnetism opposes the motion or the change that induced it." Thus, the current flowing in the primary circuit holds the flux in the core at a high value in one direction until the rotating magnet has time to rotate through the neutral position to a point a few degrees beyond neutral. This position is called the E-gap position (E stands for efficiency).

With the magnetic rotor in E-gap position and the primary coil holding the magnetic field of the magnetic circuit in the opposite polarity, a very high rate of flux change can be obtained by opening the primary breaker points. Opening the breaker points stops the flow of current in the primary circuit and allows the magnetic rotor to quickly reverse the field through the coil core. This sudden flux collapse and reversal produces a high rate of flux change in the core, that cuts across the secondary coil of the magneto (wound over and insulated from the primary coil), inducing the pulse of high-voltage electricity in the secondary needed to fire a spark plug. As the rotor continues to rotate to approximately full register position, the primary breaker points close again and the cycle is repeated to fire the next spark plug in firing order.

The sequence of events can now be reviewed in greater detail to explain how the state of extreme magnetic stress occurs.

With the breaker points, cam, and condenser connected in the circuit as shown in ***Figure 5-17***, the action that takes place as the magnetic rotor turns is depicted by the graph curve in ***Figure 5-18***. At the top (A) of ***Figure 5-18***, the original static flux curve of the magnets is shown. Shown below the static flux curve is the sequence of opening and closing the magneto breaker points. Note that opening and closing the breaker points is timed by the breaker cam, which is affixed to the magnet rotor shaft. The points close when a maximum amount of flux is passing through the coil core and open at a position after neutral. Since there are four lobes on the cam, the breaker points close and open in the same relation to each of the four neutral positions of the rotor magnet. Also, the point opening and point closing intervals are approximately equal.

Starting at the maximum flux position marked 0° at the top of ***Figure 5-18***, the sequence of events in the following paragraphs occurs. As the magnet rotor is turned toward the neutral position, the amount of flux through the core starts to decrease. ***(Figure 5-18 example D)*** This change in flux linkages induces a current in the primary winding. ***(Figure 5-18 example C)*** This induced current creates a magnetic field of its own that opposes the change of flux linkages inducing the current. Without current flowing in the primary coil, the flux in the coil core decreases to zero as the magnet rotor turns to neutral and starts to increase in the opposite direction (dotted static flux curve in ***Figure 5-18 example D***). But, the electromagnetic action of the primary current prevents the flux from changing and temporarily holds the field instead of allowing it to change (resultant flux line in ***Figure 5-18 example D***). As

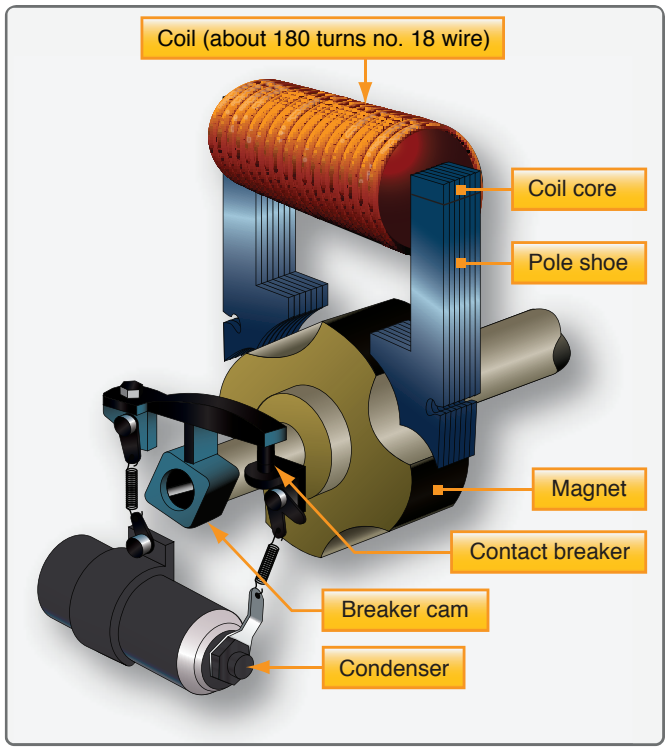


Figure 5-17. Magneto primary circuit components.

a result of the holding process, there is a very high stress in the magnetic circuit by the time the magnet rotor has reached the position where the breaker points are about to open. The breaker points, when opened, function with the condenser to interrupt the flow of current in the primary coil, causing an extremely rapid change in flux linkages. The high-voltage in the secondary winding discharges across the gap in the spark plug to ignite the fuel/air mixture in the engine cylinder. Each spark actually consists of one peak discharge, after which a series of small oscillations takes place.

They continue to occur until the voltage becomes too low to maintain the discharge. Current flows in the secondary winding during the time that it takes for the spark to completely discharge. The energy or stress in the magnetic circuit is completely dissipated by the time the contacts close for the production of the next spark. Breaker assemblies, used in high-tension magneto-ignition systems, automatically open and close the

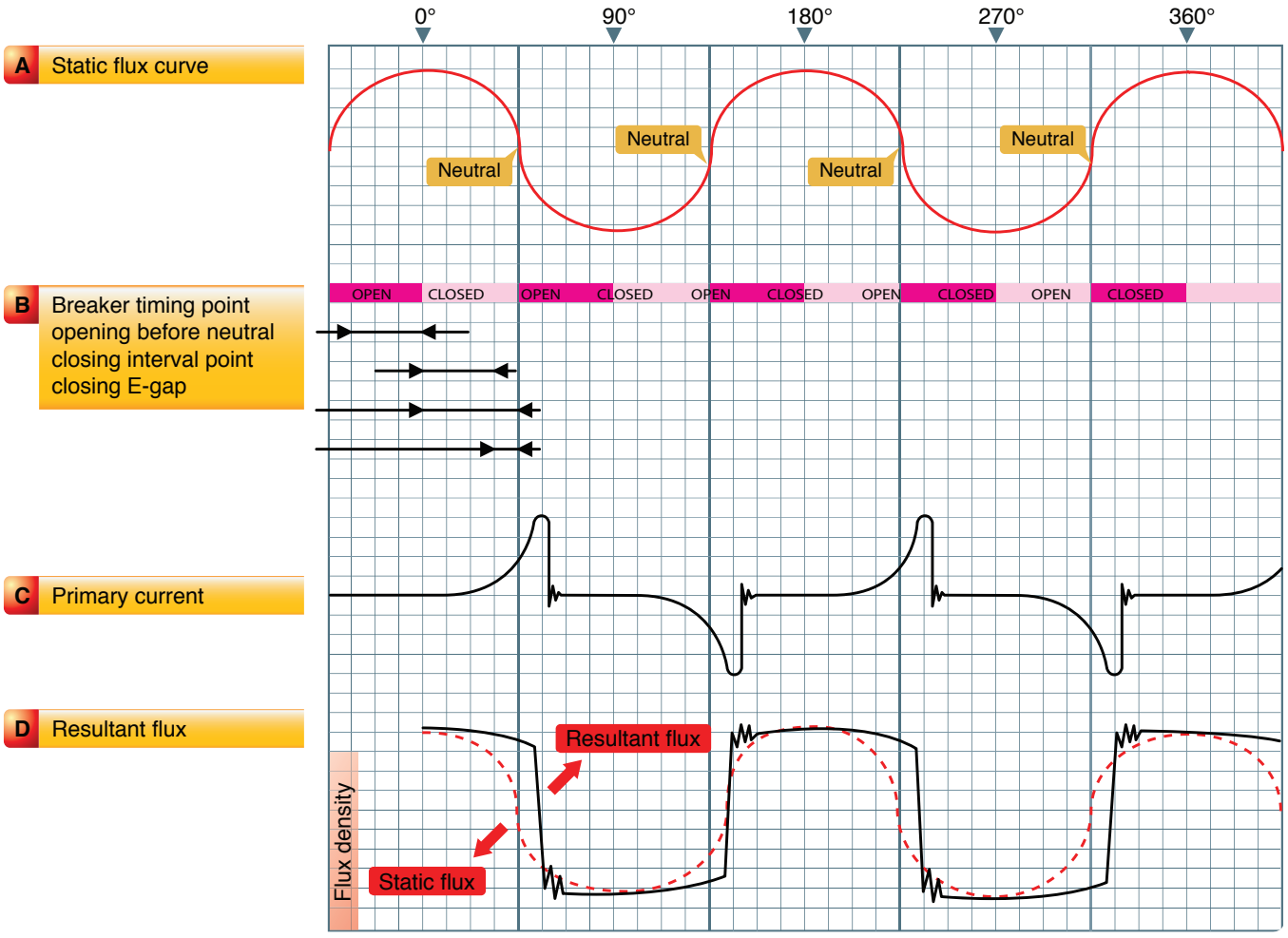


Figure 5-18. Flux fields illustrated.

primary circuit at the proper time in relation to piston position in the cylinder to which an ignition spark is being furnished. The interruption of the primary current flow is accomplished through a pair of breaker contact points made of an alloy that resists pitting and burning. Most breaker points used in aircraft ignition systems are of the pivotless type in which one of the breaker points is movable and the other stationary. ***(Figure 5-19)*** The movable breaker point attached to the leaf spring is insulated from the magneto housing and is connected to the primary coil. The stationary breaker point is grounded to the magneto housing to complete the primary circuit when the points are closed and can be adjusted so that the points can open at the proper time. Another part of the breaker assembly is the cam follower, which is spring-loaded against the cam by the metal leaf spring. The cam follower is a Micarta block or similar material that rides the cam and moves upward to force the movable breaker contact away from the stationary breaker contact each time a lobe of the cam passes beneath the follower. A felt oiler pad is located on the underside of the metal spring leaf to lubricate and prevent corrosion of the cam.

The breaker-actuating cam may be directly driven by the magneto rotor shaft or through a gear train from the rotor shaft. Most large radial engines use a compensated cam that is designed to operate with a specific engine and has one lobe for each cylinder to be fired by the magneto. The cam lobes are machine ground at unequal intervals to compensate for the elliptical path of the articulated connecting rods. This path causes the pistons top dead center position to vary from cylinder to cylinder with regard to crankshaft rotation. A compensated 14-lobe cam, together with a two-, four-, and eight-lobe uncompensated cam, is shown in ***Figure 5-20***.

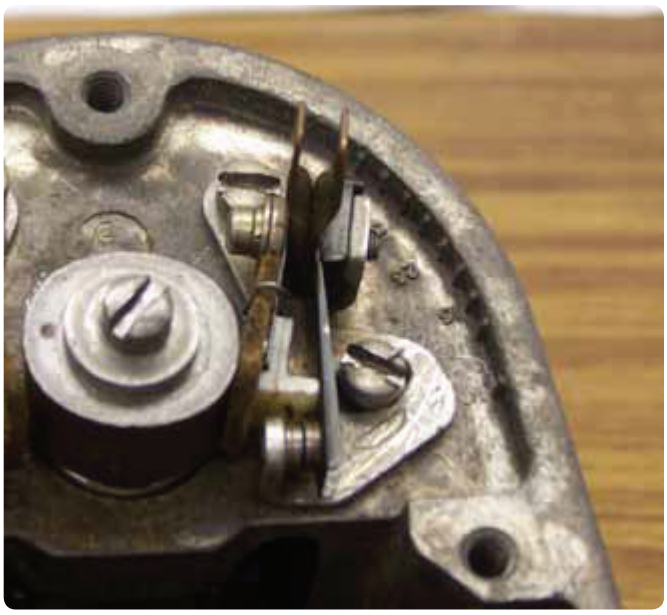


Figure 5-19. Pivotless points.

The unequal spacing of the compensated cam lobes, although it provides the same relative piston position for ignition to occur, causes a slight variation of the E-gap position of the rotating magnet and thus a slight variation in the high voltage impulses generated by the magneto. Since the spacing between each lobe is tailored to a particular cylinder of a particular engine, compensated cams are marked to show the series of the engine, the location of the master rods, the lobe used for magneto timing, the direction of cam rotation, and the E-gap specification in degrees past neutral of magnet rotorshaft rotation. In addition to these markings, a step is cut across the face of the cam, that, when aligned with scribed marks on the magneto housing, places the rotating magnet in the E-gap position for the timing cylinder. Since the breaker points should begin to open when the rotating magnet moves into the E-gap position, alignment of the step

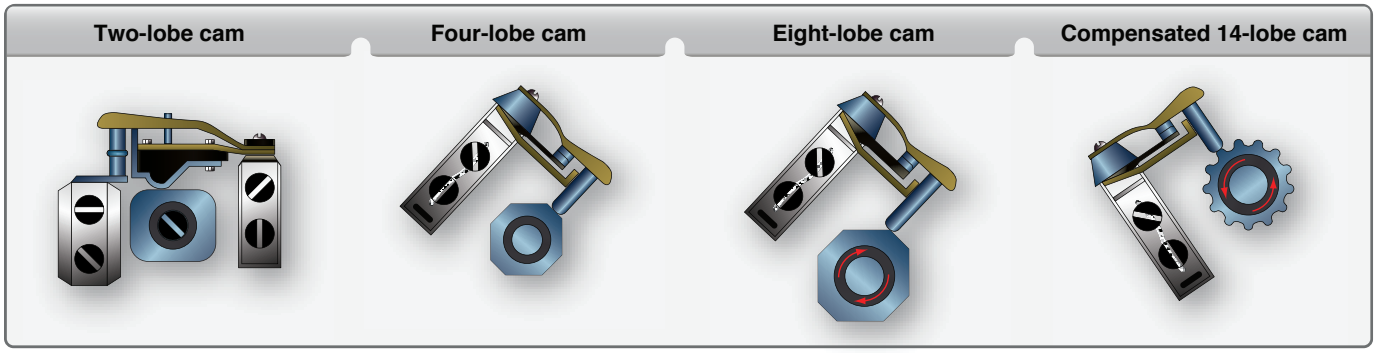


Figure 5-20. Various cam lobe examples.

on the cam with marks in the housing provides a quick and easy method of establishing the exact E-gap position to check and adjust the breaker points.

SECONDARY ELECTRICAL CIRCUIT

The secondary circuit contains the secondary windings of the coil, distributor rotor, distributor cap, ignition lead, and spark plug. The secondary coil is made up of a winding containing approximately 13,000 turns of fine, insulated wire; one end of which is electrically grounded to the primary coil or to the coil core and the other end connected to the distributor rotor. The primary and secondary coils are encased in a non-conducting material. The whole assembly is then fastened to the pole shoes with screws and clamps.

When the primary circuit is closed, the current flow through the primary coil produces magnetic lines of force that cut across the secondary windings, inducing an electromotive force. When the primary circuit current flow is stopped, the magnetic field surrounding the primary windings collapses, causing the secondary windings to be cut by the lines of force. The strength of the voltage induced in the secondary windings, when all other factors are constant, is determined by the number of turns of wire. Since most high-tension magnetos have many thousands of turns of wire in the secondary coil windings, a very high voltage, often as high as 20,000 volts, is generated in the secondary circuit. The high-voltage induced in the secondary coil is directed to the distributor, which consists of two parts: revolving and stationary. The revolving part is called a distributor rotor, or rotor finger, and the stationary part is called a distributor block. The rotating part, which may take the shape of a disk, drum, or finger, is made of a non-conducting material with an embedded conductor. The stationary part consists of a block also made of non-conducting material that contains terminals and terminal receptacles into which the ignition lead wiring that connects the distributor to the spark plug is attached. This high-voltage is used to jump the air gap of electrodes of the spark plug in the cylinder to ignite the fuel/air mixture.

As the magnet moves into the E-gap position for the No. 1 cylinder and the breaker points just separate or open, the distributor rotor aligns itself with the No. 1 electrode in the distributor block. The secondary voltage induced as the breaker points open enters the rotor where it arcs a small air gap to the No. 1 electrode in the block.

Since the distributor rotates at one-half crankshaft speed on all four-stroke cycle engines, the distributor block has as many electrodes as there are engine cylinders, or as many electrodes as cylinders served by the magneto. The electrodes are located circumferentially around the distributor block so that, as the rotor turns, a circuit is completed to a different cylinder and spark plug each time there is alignment between the rotor finger and an electrode in the distributor block. The electrodes of the distributor block are numbered consecutively in the direction of distributor rotor travel. ***[Figure 5-21]***

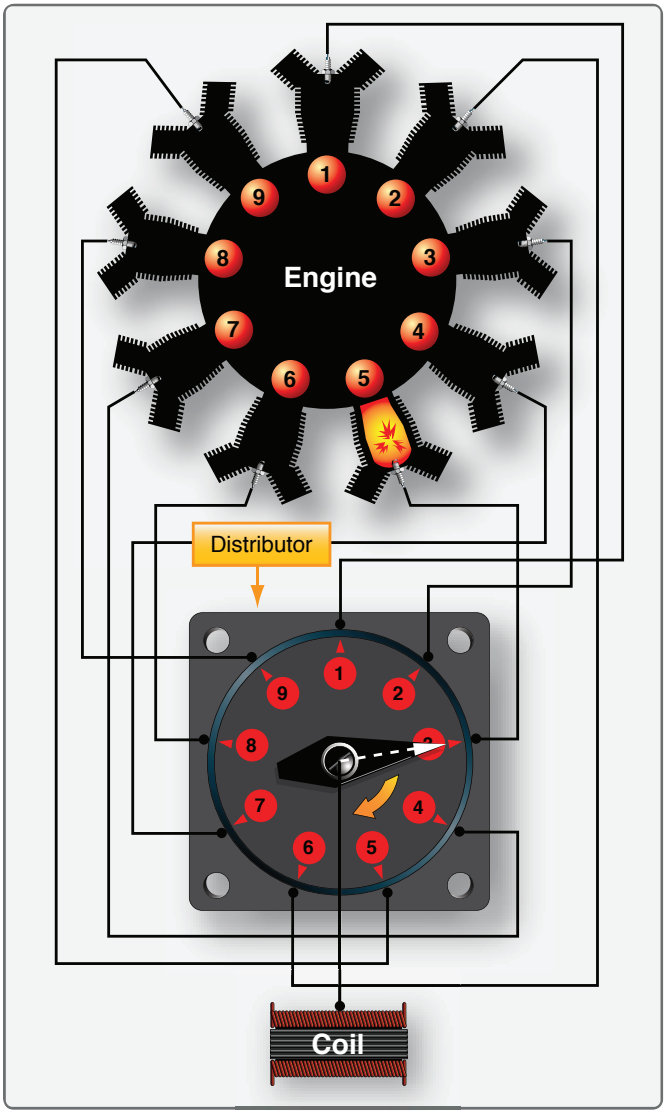


Figure 5-21. Relationship between distributor and cylinder firing order.

The distributor numbers represent the magneto sparking order rather than the engine cylinder numbers. The distributor electrode marked "1" is connected to the spark plug in the No. 1 cylinder; distributor electrode marked "2" to the second cylinder to be fired in the engine's firing order; distributor electrode marked "3" to the third cylinder to be fired in the firing order, and so forth.

MAGNETO AND DISTRIBUTOR VENTING

Since magneto and distributor assemblies are subjected to sudden changes in temperature, the problems of condensation and moisture are considered in the design of these units. Moisture in any form is a good conductor of electricity. If absorbed by the non-conducting material in the magneto, such as distributor blocks, distributor fingers, and coil cases, it can create a stray electrical conducting path. The high-voltage current that normally arcs across the air gaps of the distributor can flash across a wet insulating surface to ground, or the high-voltage current can be misdirected to some spark plug other than the one that should be fired. This condition is called flashover and usually results in cylinder misfiring. This can cause a serious engine condition called pre-ignition, which can damage the engine. For this reason, coils, condensers, distributors, and distributor rotors are waxed so that moisture on such units stand in separate beads and do not form a complete circuit for flashover.

Flashover can lead to carbon tracking, which appears as a fine pencil-like line on the unit across which flashover occurs. The carbon trail results from the electric spark burning dirt particles that contain hydrocarbon materials. The water in the hydrocarbon material is evaporated during flashover, leaving carbon to form a conducting path for current. When moisture is no longer present, the spark continues to follow the carbon track to the ground. This prevents the spark from getting to the proper spark plug, so the cylinder does not fire.

Magnetos cannot be hermetically sealed to prevent moisture from entering a unit, because the magneto is subject to pressure and temperature changes in altitude. Thus, adequate drains and proper ventilation reduce the tendency of flashover and carbon tracking. Good magneto circulation also ensures that corrosive gases produced by normal arcing across the distributor air gap, such as ozone, are carried away. In some installations, pressurization of the internal components of the magnetos and other various parts of the ignition system is essential to maintain a higher absolute pressure inside the magneto and to eliminate flashover due to high altitude flight. This type of magneto is used with turbocharged engines that operate at higher altitudes. Flashover becomes more likely at high altitudes because of the lower air pressure, which makes it easier for the electricity to jump air gaps. By pressurizing the interior of the magneto, the normal air pressure is maintained and the electricity or the spark is held within the proper areas of the magneto even though the ambient pressure external of the magneto is very low.

Even in a pressurized magneto, the air is allowed to flow through and out of the magneto housing. By providing more air and allowing small amounts of air to bleed out for ventilation, the magneto remains pressurized. Regardless of the method of venting employed, the vent bleeds or valves must be kept free of obstructions. Further, the air circulating through the components of the ignition system must be free of oil since even minute amounts of oil on ignition parts result in flashover and carbon tracking. Evidence of oil at the outlet of a magneto vent may indicate that the drive seal of the magnet shaft is leaking. Such conditions merit additional investigation and corrective measures.

IGNITION HARNESSES

The ignition lead directs the electrical energy from the magneto to the spark plug. The ignition harness contains an insulated wire for each spark plug that the magneto serves in the engine. ***(Figure 5-22)*** One end of each wire is connected to the magneto distributor block and the other end is connected to the proper spark plug. The ignition harness leads serve a dual purpose. It provides the conductor path for the high-tension voltage to the spark plug. It also serves as a shield for stray magnetic fields that surround the wires as they momentarily carry high-voltage current. By conducting these magnetic lines of force to the ground, the ignition harness cuts down electrical interference with the aircraft radio and other electrically sensitive equipment.

A magneto is a high frequency radiation emanating (radio wave) device during its operation. The wave oscillations produced in the magneto are uncontrolled and cover a wide range of frequencies and must be shielded. If the magneto and ignition leads were not shielded, they



Figure 5-22. Sample of ignition harness components.

would form antennas and pick up the random frequencies from the ignition system. The lead shielding is a medal mesh braid that surrounds the entire length of the lead. The lead shielding prevents the radiation of the energy into the surrounding area.

Capacitance is the ability to store an electrostatic charge between two conducting plates separated by a dielectric. Lead insulation is called a dielectric, meaning it can store electrical energy as an electrostatic charge. An example of electrostatic energy storage in a dielectric is the static electricity stored in a plastic hair comb. When shielding is placed around the ignition lead, capacitance increases by bringing the two plates closer together. Electrically, the ignition lead acts as a capacitor and has the ability to absorb and store electrical energy. The magneto must produce enough energy to charge the capacitance caused by the ignition lead and have enough energy left over to fire the plug.

Ignition lead capacitance increases the electrical energy required to provide a spark across the plug gap. More magneto primary current is needed to fire the plug with the shielded lead. This capacitance energy is discharged as fire across the plug gap after each firing of the plug. By reversing the polarity during servicing by rotating the plugs to new locations, the plug wear is equalized across the electrodes. The very center of the ignition lead is the high-voltage carrier surrounded by a silicone insulator material that is surrounded by a metal mesh, or shielding, covered with a thin silicone rubber coating that prevents damage by engine heat, vibration, chemical and moisture exposure, or weather.

A sectional view of the end of a typical ignition lead is shown in ***Figure 5-23***. Ignition leads must be routed and clamped correctly to avoid hot spots on the exhaust and vibration points as the leads are routed from the magneto to the individual cylinders. Ignition leads are normally of the all-weather type and are hard connected at the magneto distributor and affixed to the spark plug by threads. The shielded ignition lead spark plug terminal is available in all-weather 3/4 inch diameter and 5/8 inch diameter barrel ignition lead nut. ***(Figure 5-24)*** The 5/8" – 24 spark plug takes a 3/4" wrench on the lead nut and the 3/4" – 20 spark plug takes a 7/8" wrench on the lead nut. The 3/4 inch all-weather design utilizes a terminal seal that results in greater terminal well insulation and sealing. This is recommended because the lead end of the spark plug is completely sealed from moisture. The spark plug end of most ignition harnesses include a center component that has a wrenching flat. Technicians should hold the center of the lead from rotating when installing and removing leads from the spark plugs. Rotational damage to the end of the spark plug lead may lead to failure and may injure the shielding.

An older radial engine type of ignition harness is a manifold formed to fit around the crankcase of the engine with flexible extensions terminating at each spark plug. A typical high-tension ignition harness is shown

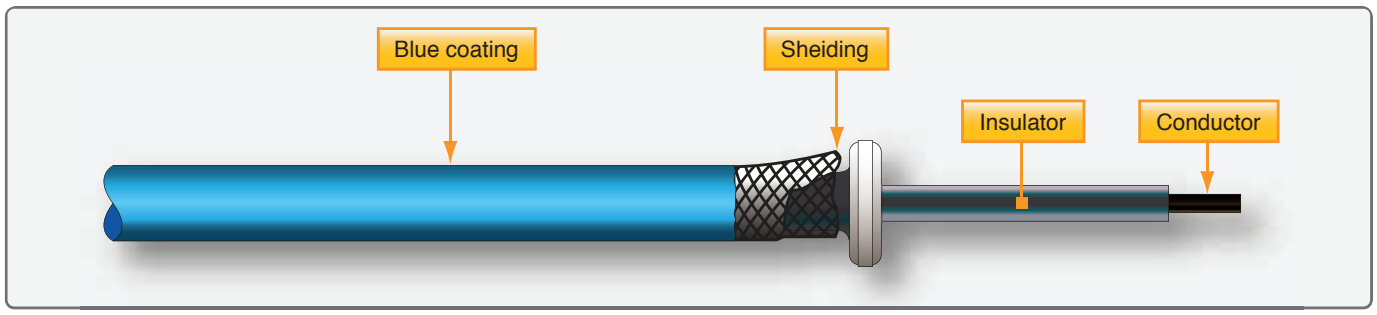


Figure 5-23. Ignition lead end.

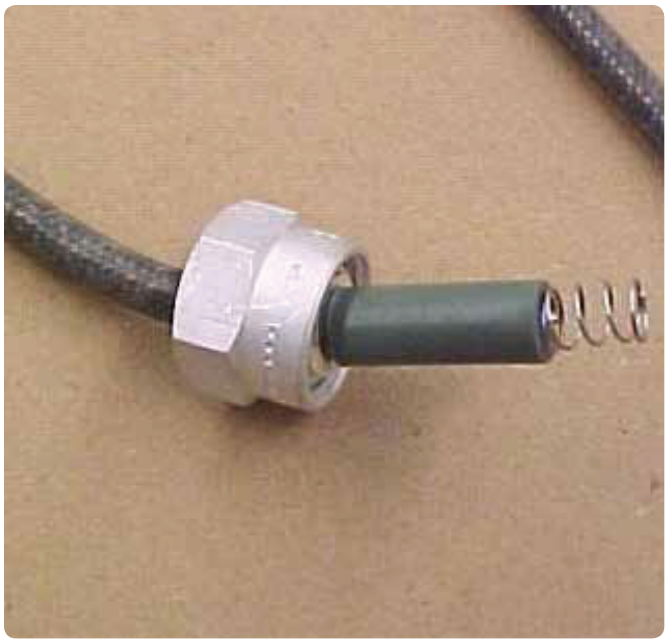


Figure 5-24. 5/8" by 24 thread-per-inch spark plug lead end.

in ***Figure 5-25***. Many older single-row radial engine aircraft ignition systems employ a dual-magneto system, in which the right magneto supplies the electric spark for the front spark plugs in each cylinder, and the left magneto fires the rear spark plugs.

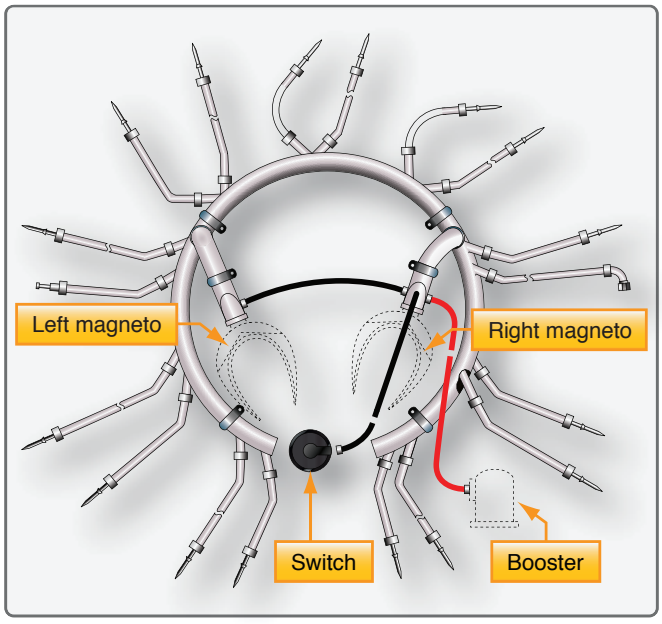


Figure 5-25. Radial engine ignition harness.

IGNITION SWITCHES

All units in an aircraft ignition system are controlled by an ignition switch. The type of switch used varies with the number of engines on the aircraft and the type of magnetos used. All switches, however, turn the system off and on in much the same manner. With the exception of the battery-coil ignition system shown in ***Figure 5-13***, the ignition switch is different in at least one respect from all other types of switches: when the ignition switch is in the off position, a circuit is completed through the switch to ground. In other electrical switches, the off position normally breaks or opens the circuit.

The ignition switch has one terminal connected to the primary electrical circuit between the coil and the breaker contact points. The other terminal of the switch is connected to the aircraft ground structure. As shown in ***Figure 5-26***, two ways to complete the primary circuit are:

1. Through the closed breaker points to ground and
2. Through the closed ignition switch to ground.

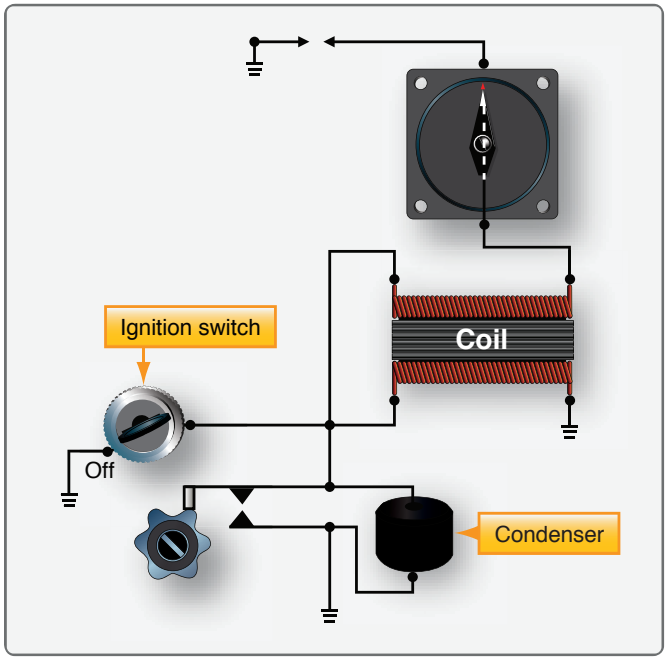


Figure 5-26. Magneto switch in the OFF position completes ground to primary coil.

Figure 5-26 shows that the primary current is not interrupted when the breaker contacts open since there is still a path to ground through the closed, or off, ignition switch. Since primary current is not stopped when the contact points open, there can be no sudden collapse of the primary coil flux field and no high-voltage induced in the secondary coil to fire the spark plug.

As the magnet rotates past the efficiency gap (E-gap) position, a gradual breakdown of the primary flux field occurs. But that breakdown occurs so slowly that the

induced voltage is too low to fire the spark plug. Thus, when the ignition switch is in the off position with the switch closed, the contact points are as completely short-circuited as if they were removed from the circuit, and the magneto is inoperative.

When the ignition switch is placed in the on position switch open, the interruption of primary current and the rapid collapse of the primary coil flux field is once again controlled or triggered by the opening of the breaker contact points. ***(Figure 5-27)*** When the ignition switch is in the on position, the switch has absolutely no effect on the primary circuit.

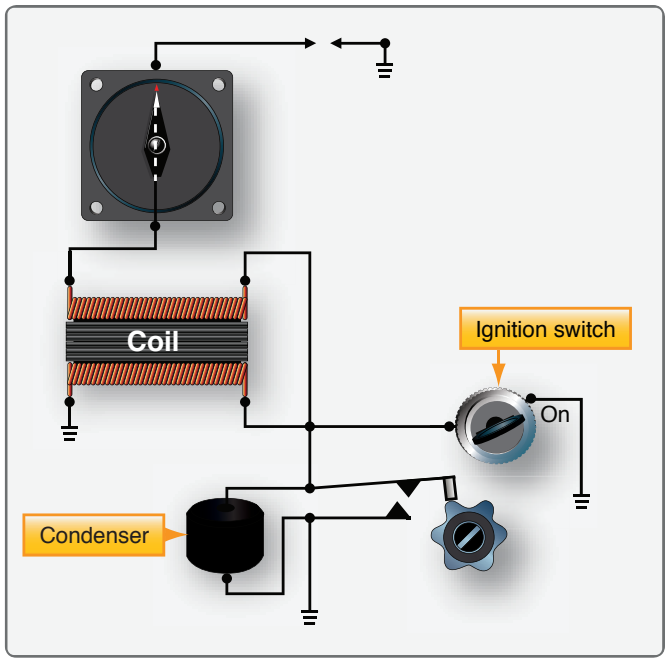


Figure 5-27. Magneto switch in the ON position opening the path to ground when the contact breakers separate.

The ignition/starter switch, or magneto switch, controls the magnetos on or off and can also connect the starter solenoid for turning the starter. When a starting vibrator, a box that emits pulsating direct current (DC), is used on the engine, the ignition/starter switch is used to control the vibrator and retard points. This system is explained in detail later in this module. Some ignition starter switches have a push to prime feature during the starting cycle. This system allows additional fuel to spray into the intake port of the cylinder during the starting cycle.

SINGLE AND DUAL HIGH-TENSION SYSTEM MAGNETOS

High-tension system magnetos used on aircraft engines are either single or dual type magnetos. The single magneto design incorporates the distributor in the housing with the magneto breaker assembly, rotating magnet, and coil. ***[Figure 5-28]***

The dual magneto incorporates two magnetos contained in a single housing. One rotating magnet and a cam are common to two sets of breaker points and coils. Two separate distributor units are mounted in the magneto. ***[Figure 5-29]***

MAGNETO MOUNTING SYSTEMS

Flange-mounted magnetos are attached to the engine by a flange around the driven end of the rotating shaft of the magneto. ***[Figure 5-30]*** Elongated slots in the mounting flange permit adjustment through a limited range to aid in timing the magneto to the engine. Some magnetos mount by the flange and use clamps on each side to secure the magneto to the engine. This design also allows for timing adjustments. Base mounted magnetos are primarily used on very old or antique aircraft engines.

LOW-TENSION MAGNETO SYSTEM

High-tension ignition systems have undergone many refinements and improvements in design. This includes new electronic systems that control more than just providing ignition to the cylinders. High-tension voltage presents certain problems with carrying the high voltage from the magneto internally and externally to the spark plugs. In early years, it was difficult to provide insulators that could contain the high-voltage, especially at high altitudes where the ambient air pressures were reduced. Another requirement of high-tension systems was that all weather and radio-equipped aircraft have ignition wires enclosed in shielding to prevent radio noise due to high voltages. Many aircraft were supercharged and operated at increased high altitudes. The low pressure at these altitudes would allow the high-voltage to leak out even more. To meet these problems, low-tension ignition systems were developed.

Electronically, the low-tension system is different from the high-tension system. In the low-tension system, low voltage is generated in the magneto and flows to the primary winding of a transformer coil located near the spark plug. There, the voltage is increased to high by

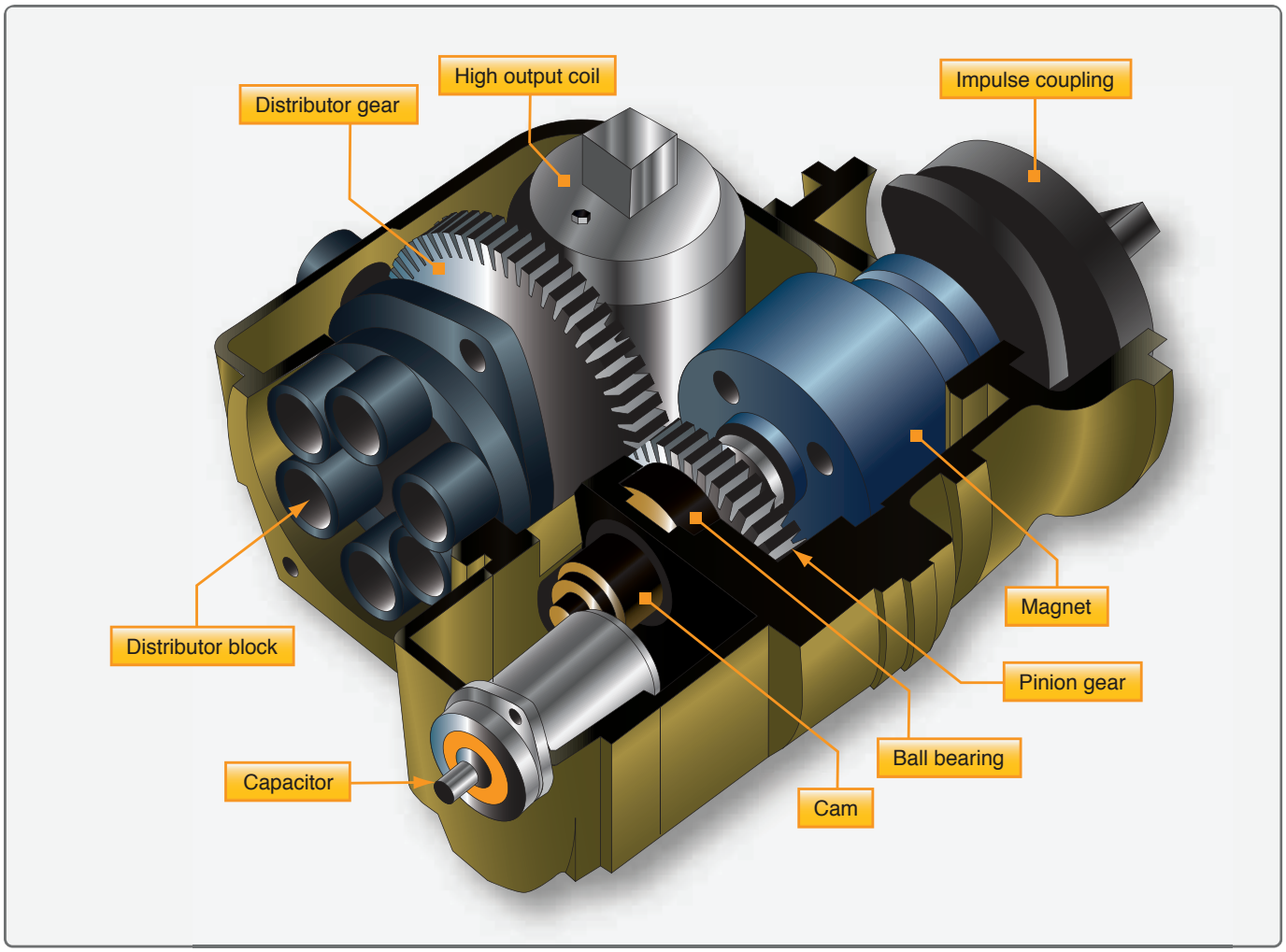


Figure 5-28. Typical high-tension single magneto.



Figure 5-29. Dual magneto.

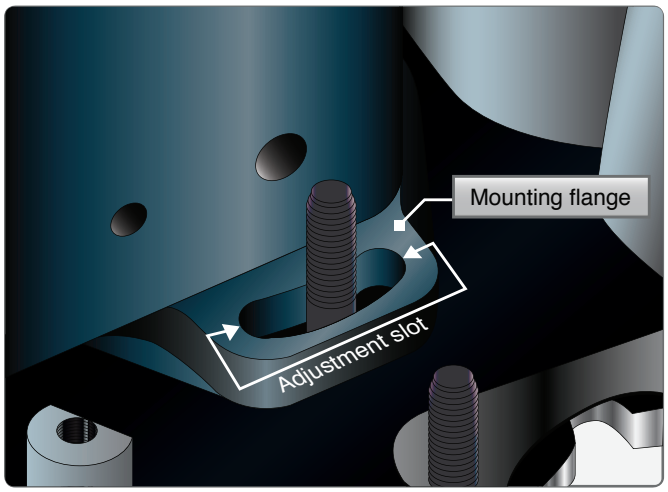


Figure 5-30. Slotted magneto mounting flange.

transformer action and conducted to the spark plug by very short high-tension leads. ***[Figure 5-31]***

The low-tension system virtually eliminates flashover in both the distributor and the harness because the air gaps within the distributor have been eliminated by the use of a brush-type distributor, and high-voltage is present only in short leads between the transformer and spark plug.

Although a certain amount of electrical leakage is characteristic of all ignition systems, it is more pronounced on radio-shielded installations because the metal conduit is at ground potential and close to the ignition wires throughout their entire length. In low-tension systems, however, this leakage is reduced considerably because the current throughout most of the system is transmitted at a low-voltage potential. Although the leads between the transformer coils and the spark plugs of a low-tension ignition system are short, they are high-tension high-voltage conductors, and are subject to the same failures that occur in high-tension systems. Low-tension ignition systems have limited use in modern aircraft because of the excellent materials and shielding available to construct high-tension ignition leads and the added cost of a coil for each spark plug with the low-tension system.

LIMITED AUTHORITY SPARK ADVANCE REGULATOR (LASAR)

In recent years an aircraft ignition system emerged that closely rivals automotive ignition systems. The LASAR provides a hotter spark than conventional magnetos and delivers a spark to every spark plug during start. Engine timing with the LASAR system varies with the power setting selected by the pilot.

Because the LASAR system delivers a very hot spark, the spark plugs remain cleaner. Carbon and lead deposits are reduced over hours of operation. Engine timing of a LASAR system is dependent on engine rpm and manifold pressure. The result is that the controller selects and delivers the best engine timing based on rpm and manifold pressure. Engine timing generally ranges from 0° before top dead center compression (BTDCC) to 42° BTDCC. Crankshaft position sensors and a direct connection with manifold pressure are inputs to the system controller.

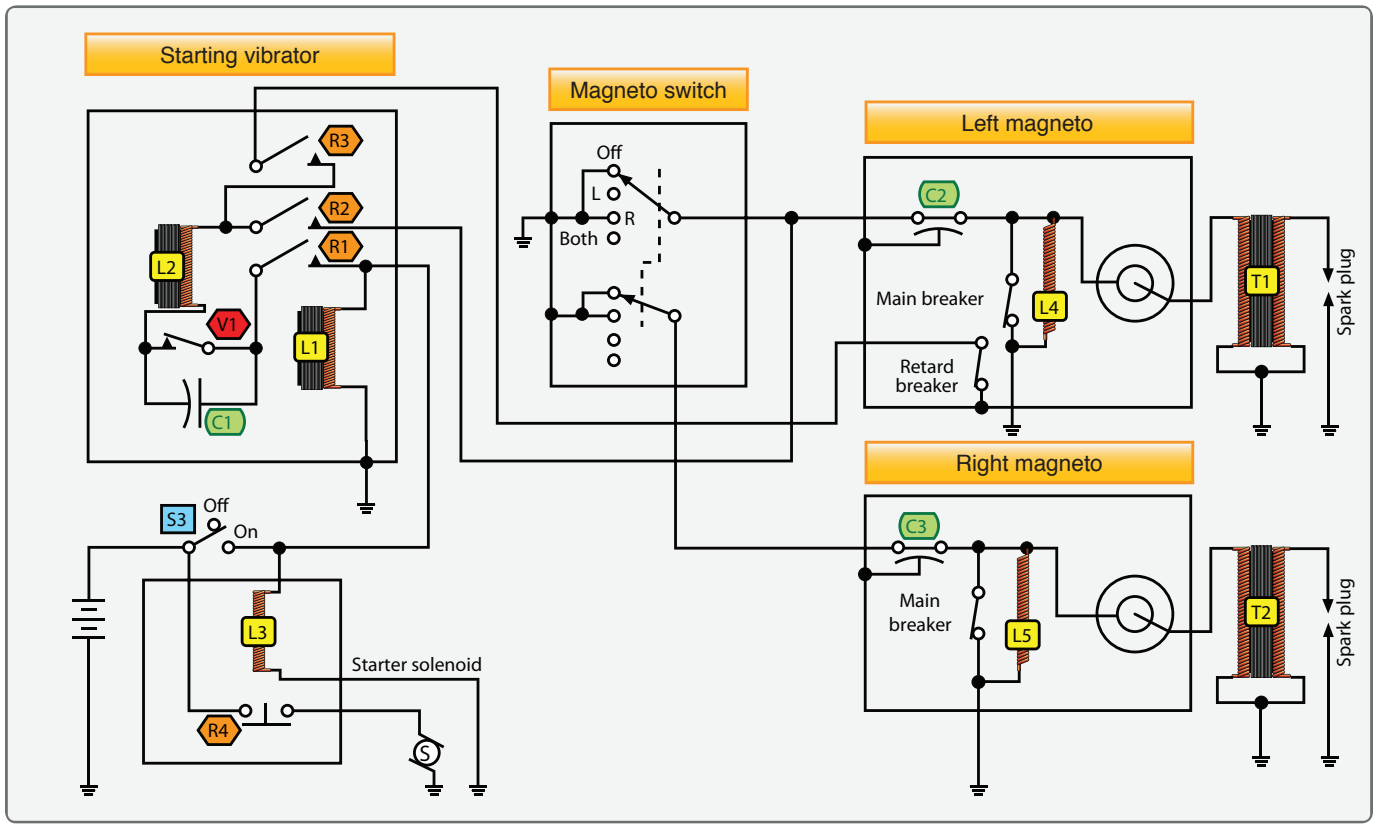


Figure 5-31. Low-tension ignition schematic.

Unlike traditional magneto systems, the LASAR ignition system is connected to the electrical system. An annuciator light is used to signal a failed system. The LASAR system uses conventional magneto operation as a backup in the event of a failure. In essence, aircraft equipped with the LASAR system have four ignition systems. The traditional magneto system has one fixed timing position.

Because the LASAR ignition system requires voltage to operate, the system will be unable to start with a dead battery. To overcome this deficiency, the left magneto may be equipped with an impulse coupling to get the engine running in the event of a dead battery, failed controller, or both.

STARTING AIDS

Traditional magneto-type ignitions systems will generally generate a weak spark while cranking the engine. This is because the output from the magneto is dependent on the speed of rotation of the magnet rotor. To elevate the quality of the spark during engine starts, special devices are employed. A couple of starting aids are the booster coil and the impulse coupling. The former requires electrical power to generate a hot spark during cranking operations while the latter is completely mechanical. A couple of variants of the booster coil, known as the Shower of Sparks system and Slick Start, are commonly used with light aircraft ignition systems. Unlike the booster coil, these units use the secondary coil within the magneto to generate a high-tension output during cranking operations.

BOOSTER COIL

The booster coil assembly, used mainly with older radial engine ignition systems, consists of two coils wound on a soft iron core, a set of contact points, and a condenser. ***(Figure 5-32)*** The booster coil is separate from the magneto and can generate a series of sparks on its own. During the start cycle, these sparks are routed to the trailing finger on the distributor rotor and then to the appropriate cylinder ignition lead. The primary winding has one end grounded at the internal grounding strip and its other end connected to the moving contact point. The stationary contact is fitted with a terminal to which battery voltage is applied when the magneto switch is placed in the start position, or automatically applied when the starter is engaged. The secondary winding, which contains several times as many turns as the primary coil, has one end grounded at the internal grounding strip and the other terminated at a high-tension terminal. The high-tension terminal is connected to an electrode in the distributor by an ignition cable.

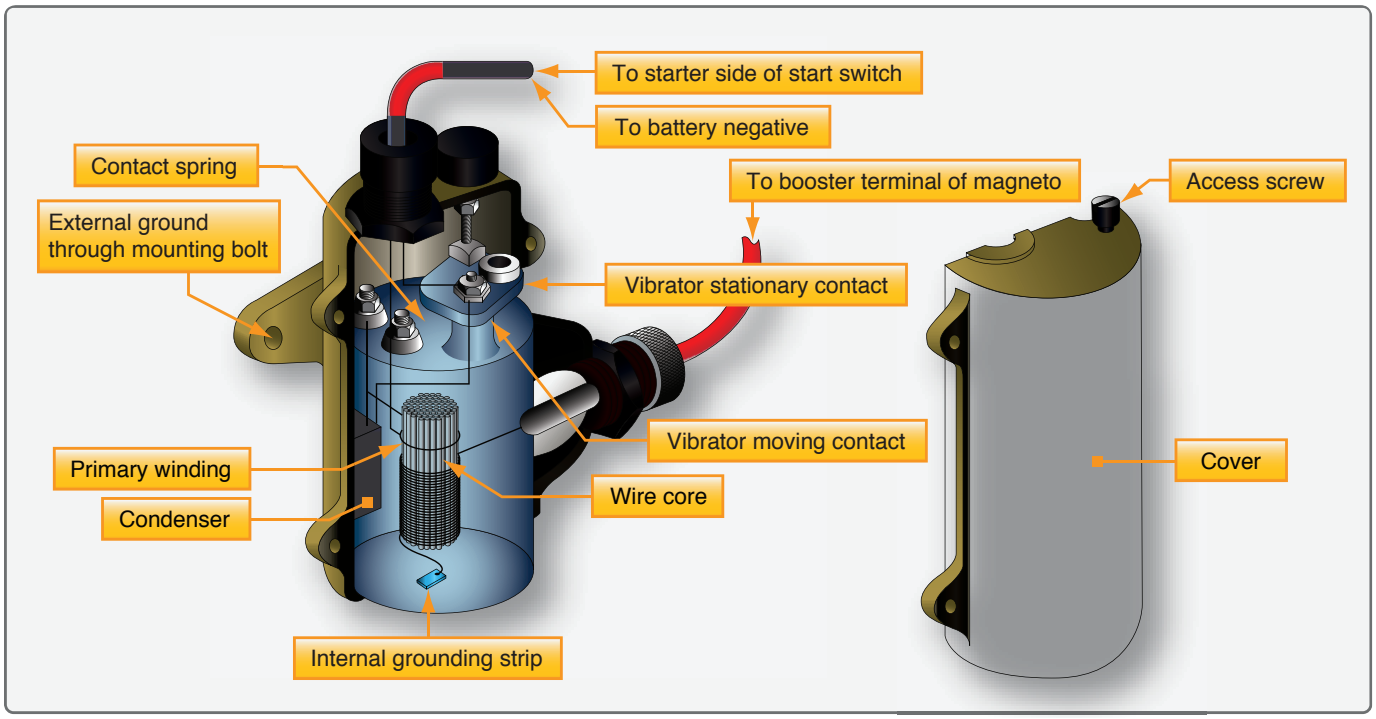


Figure 5-32. Booster coil.

Since the regular distributor terminal is grounded through the primary or secondary coil of a high-tension magneto, the high-voltage furnished by the booster coil must be distributed by a separate circuit in the distributor rotor. This is accomplished by using two electrodes in one distributor rotor. The main electrode, or finger, carries the magneto output voltage and the auxiliary electrode, or trailing finger, distributes only the output of the booster coil. The auxiliary electrode is always located so that it trails the main electrode, thus retarding the spark during the starting period.

Figure 5-33 illustrates, in schematic form, the booster coil components shown in ***Figure 5-32***. In operation, battery voltage is applied to the positive (+) terminal of the booster coil through the start switch. This causes current to flow through the closed contact points to the primary coil and ground. Current flow through the primary coil sets up a magnetic field about the coil that magnetizes the coil core. As the core is magnetized, it attracts the movable contact point, which is normally held against the stationary contact point by a spring.

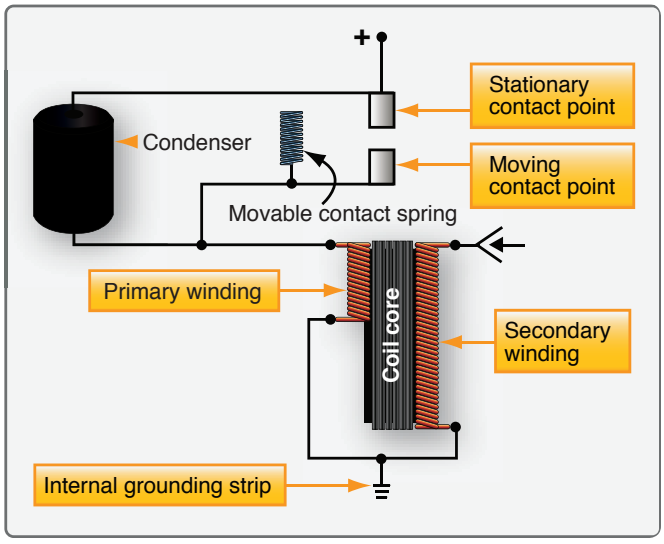


Figure 5-33. Booster coil schematic.

As the movable contact point is pulled toward the iron core, the primary circuit is broken, collapsing the magnetic field that extended about the coil core. Since the coil core acts as an electromagnet only when current flows in the primary coil, it loses its magnetism as soon as the primary coil circuit is broken. This permits the action of the spring to close the contact points and again complete the primary coil circuit. This re-magnetizes the coil core, and again attracts the movable contact point, which again opens the primary coil circuit. This action causes the movable contact point to vibrate rapidly, as long as the start switch is held in the closed, or on, position. The result of this action is a continuously expanding and collapsing magnetic field that links the secondary coil of the booster coil. With several times as many turns in the secondary as in the primary, the induced voltage that results from lines of force linking the secondary is high enough to furnish ignition for the engine.

The condenser, which is connected across the contact points, has an important function in this circuit. ***(Figure 5-33)*** As current flow in the primary coil is interrupted by the opening of the contact points, the high self-induced voltage that accompanies each collapse of the primary magnetic field surges into the condenser. Without a condenser, an arc would jump across the points with each collapse of the magnetic field. This would burn and pit the contact points and greatly reduce the voltage output of the booster coil. The booster coil generates a pulsating DC in the primary winding that induces a high-voltage spark in the secondary windings of the booster coil.

HIGH-TENSION RETARD BREAKER VIBRATOR

To provide for more spark power during the starting cycle, the Shower of Sparks and Slick Start systems were developed. They provide multiple sparks at the spark plug electrodes during starting. The starting vibrator, or shower of sparks, consists essentially of an electrically operated vibrator, a condenser, and a relay. ***(Figure 5-34)*** These units are mounted on a base plate and enclosed in a case.

The starting vibrator, unlike the booster coil, does not produce the high ignition voltage within itself. The function of this starting vibrator is to change the DC of the battery into a pulsating DC and deliver it to the primary coil of the magneto. Closing the ignition switch energizes the starter solenoid and causes the engine to rotate. At the same time, current also flows through the vibrator coil and its contact points. Current flow in the vibrator coil sets up a magnetic field that attracts and opens the vibrator points. When the vibrator points open, current flow in the coil stops, and the magnetic field that attracted the movable vibrator contact point disappears. This allows the vibrator points to close and

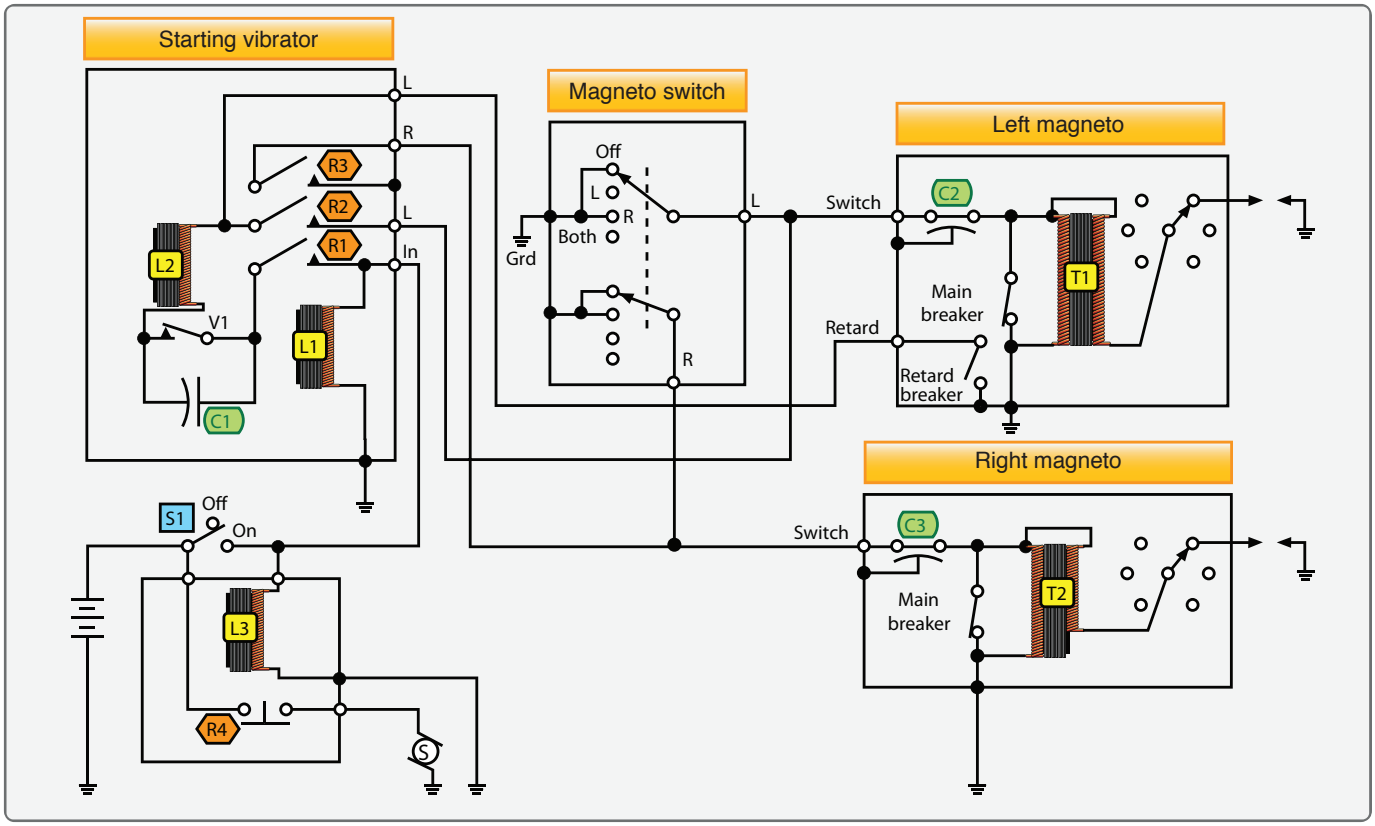


Figure 5-34. Shower of sparks schematic.

again permits battery current to flow in the vibrator coil. This completes a cycle of operation. The cycle, however, occurs many times per second, so rapidly that the vibrator points produce an audible buzz.

Each time the vibrator points close, current flows to the magneto as a pulsating DC. Since this current is being interrupted many times per second, the resulting magnetic field is building and collapsing across the primary and secondary coils of the magneto many times per second. The rapid successions of separate voltages induced in the secondary coil produces a shower of sparks across the selected spark plug air gap.

The retard breaker magneto and starting vibrator system is used as part of the high-tension starting system on many types of aircraft. Designed for four-, six-, and eight-cylinder ignition systems, the retard breaker magneto eliminates the need for the impulse coupling in light aircraft. This system uses an additional breaker to obtain retarded sparks for starting. The starting vibrator is also adaptable to many helicopter ignition systems. A schematic diagram of an ignition system using the retard breaker magneto and starting vibrator concept is shown in ***Figure 5-34***.

With the magneto switch in the both position and the starter switch S1 in the on position, starter solenoid L3 and coil L1 are energized, closing relay contacts R4, R1, R2, and R3. R3 connects the right magneto to ground, keeping it inoperative during starting operation to prevent an inadvertent engine kick back. Electrical current flows from the battery through R1, vibrator points V1, coil L2, through both the main breaker points, through R2, and the retard breaker points of the left magneto to ground.

The energized coil L2 opens vibrator points V1, interrupting the current flow through L2. The magnetic field about L2 collapses, and vibrator points V1 close again. Once more, current flows through L2, and again V1 vibrator points open. This process is repeated continuously, and the interrupted battery current flows to ground through the main and retard breaker points of the left magneto.

Since relay R4 is closed, the starter is energized and the engine crankshaft is rotated. When the engine reaches its normal advance firing position, the main breaker points of the left magneto begin to open. The interrupted surges of current from the vibrator can still

find a path to ground through the retard breaker points, which do not open until the retarded firing position of the engine is reached. At this point in crankshaft travel, the retard points open. Since the main breaker points are still open, the magneto primary coil is no longer shorted, and current produces a magnetic field around T1.

Each time the vibrator points V1 open, current flow through V1 is interrupted. The collapsing field about T1 cuts through the magneto coil secondary and induces a high-voltage surge of energy used to fire the spark plug. Since the V1 points are opening and closing rapidly and continuously, a shower of sparks is furnished to the spark plugs when both the main and retard breaker points are open.

After the engine begins to accelerate, the manual starter switch is released, causing L1 and L3 to become de-energized. This action causes both the vibrator and retard breaker circuits to become inoperative. It also opens relay contact R3, which removes the ground from the right magneto. Both magnetos now fire at the normal advanced running degrees of crankshaft rotation before top dead center piston position.

LOW-TENSION RETARD BREAKER VIBRATOR

This system, which is in limited use, is designed for light aircraft reciprocating engines. A typical system consists of a retard breaker magneto, a single breaker magneto, a starting vibrator, transformer coils, and a starter and ignition switch. ***[Figure 5-35]***

To operate the system, place the starter switch S3 in the on position. This energizes starter solenoid L3 and coil L1, closing relay contacts R1, R2, R3, and R4. With the magneto switch in the L position, current flows through R1, the vibrator points, L2, R2, and through the main breaker points to ground. Current also flows through R3 and the retard breaker points to ground. Current through L2 builds up a magnetic field that opens the vibrator points. Then, the current stops flowing through L2, re-closing the points. These surges of current flow through both the retard and main breaker points to ground.

Since the starter switch is closed, the engine crankshaft is turning. When it has turned to the normal advance or running ignition position, the main breaker

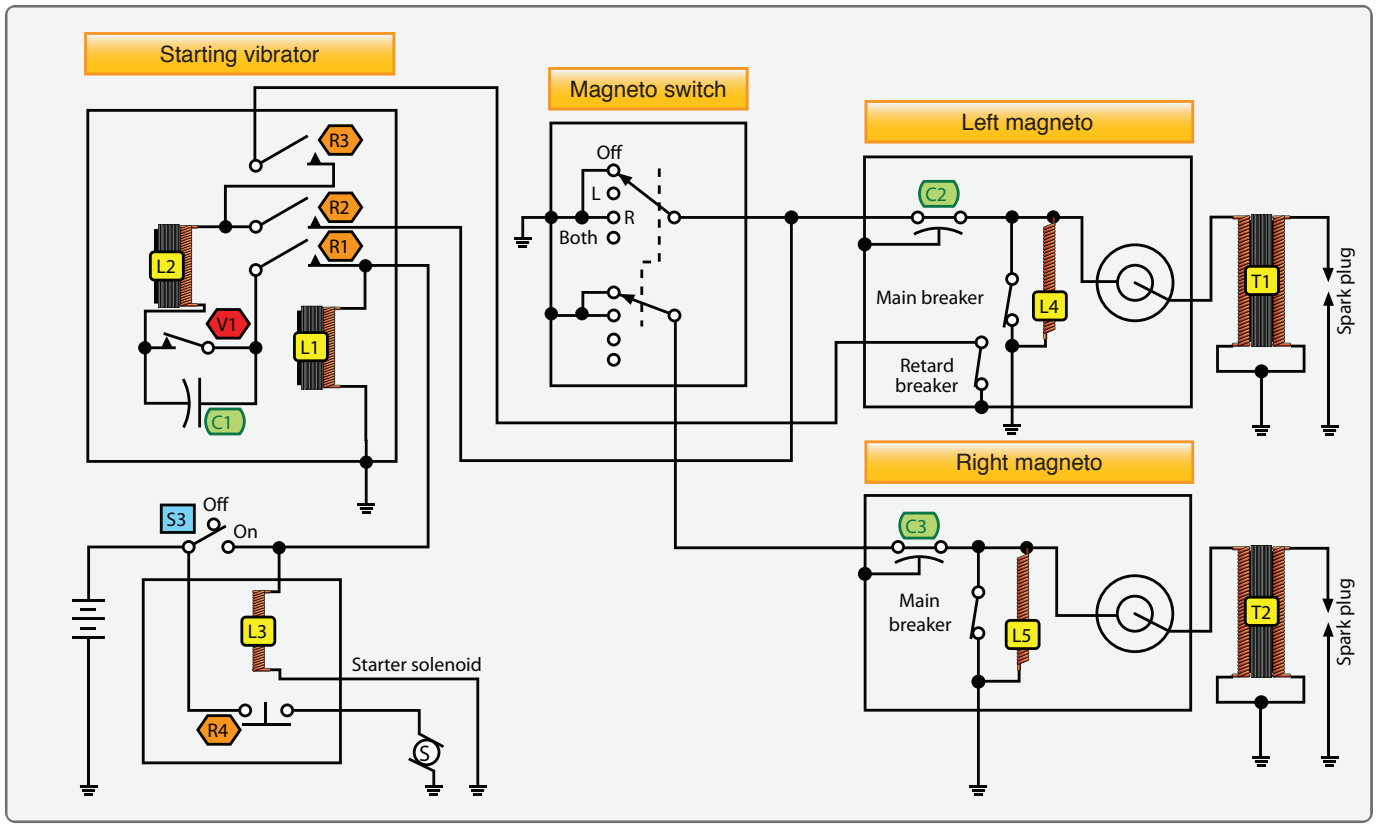


Figure 5-35. Shower of sparks for low tension ignition systems.

points of the magneto open. However, current still flows to ground through the closed retard breaker points. As the engine continues to turn, the retard ignition position is reached, and the retard breaker points open. Since the main breaker points are still open, current must flow to ground through coil L4, producing a magnetic field around the coil L4.

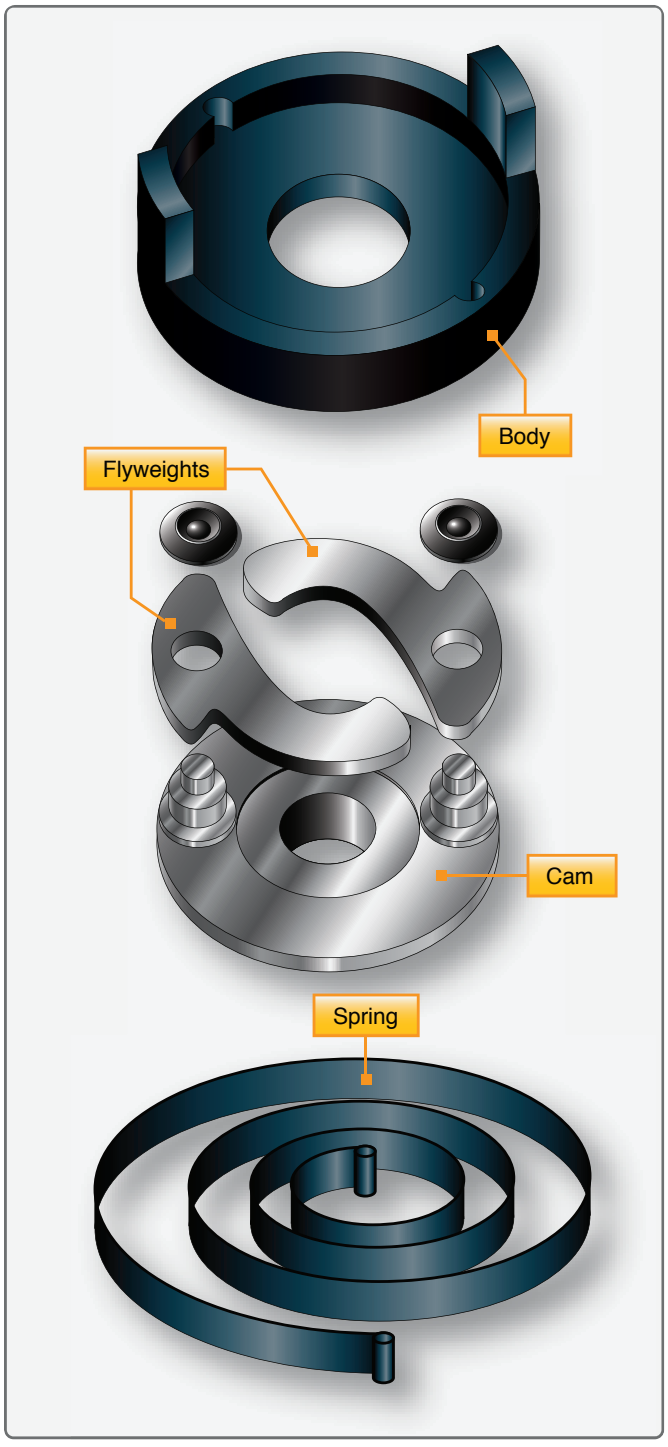


Figure 5-36. Impulse coupling, exploded view.

As the engine continues to turn, the vibrator breaker points open, collapsing the L4 magnetic field through T1 primary, inducing a high-voltage in the secondary of T1 to fire the spark plug.

When the engine fires, the starter switch is released, de-energizing L1 and L3. This opens the vibrator circuit and retard breaker points circuit. The ignition switch is then turned to the both position, permitting the right magneto to operate in time with the left magneto.

IMPULSE COUPLING

Many opposed reciprocating engines are equipped with an impulse coupling as the auxiliary starting system. An impulse coupling gives one, or both, of the magnetos attached to the engine, generally the left, a brief acceleration in terms of magnet shaft rotation, that produces an intense spark for starting. This device consists of a cam and flyweight assembly, spring, and a body assembly. ***(Figure 5-36)*** The assembled impulse coupling is shown installed on a typical magneto in ***Figure 5-37***.

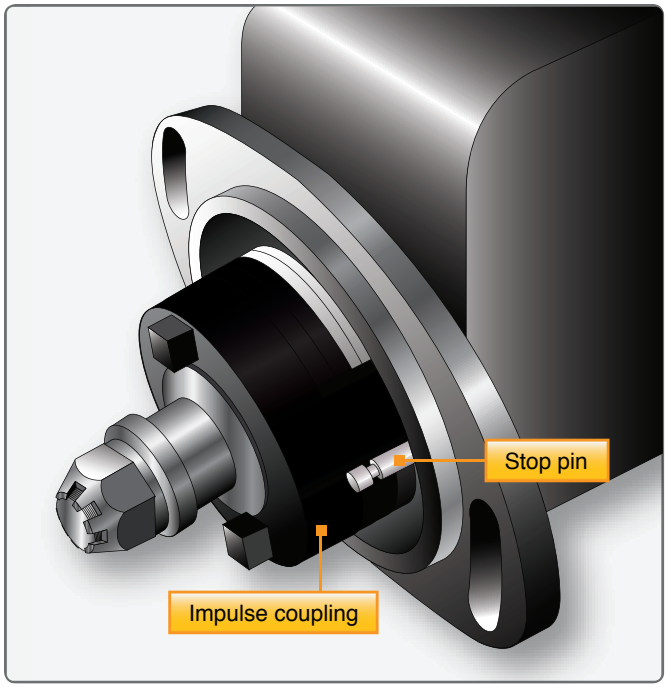


Figure 5-37. Impulse coupling installed on magneto shaft.

The magneto is flexibly connected through the impulse coupling by means of the spring so that at low speed the magneto is temporarily held. The flyweight, because of slow rotation, catches on a stud or stop pins, and the magneto spring is wound as the engine continues

to turn. The engine continues to rotate until the piston of the cylinder to be fired reaches approximately a top dead center position. At this point, the magneto flyweight contacts the body of the impulse coupling and is released. ***(Figure 5-38)*** The spring kicks back to its original position, resulting in a quick twist of the rotating magnet of the magneto. This, being equivalent to high-speed magneto rotation, produces a spark that jumps the gap at the spark plug electrodes. The impulse coupling has performed two functions: rotating the magneto fast enough to produce a hot spark and retarding the timing of the spark during the start cycle. After the engine is started and the magneto reaches a speed at which it furnishes sufficient current, the flyweights in the impulse coupling move outward due to centrifugal force generated during the rapid rotation of the magnet shaft. ***(Figure 5-39)*** This action prevents the two flyweight coupling members from making contact with the stop pin. That makes it a solid unit, returning the magneto to a normal timing position relative to the engine. The presence of an impulse coupling is identified by an audible clacking noise as the crankshaft is turned at starter cranking speed past top center on each cylinder.

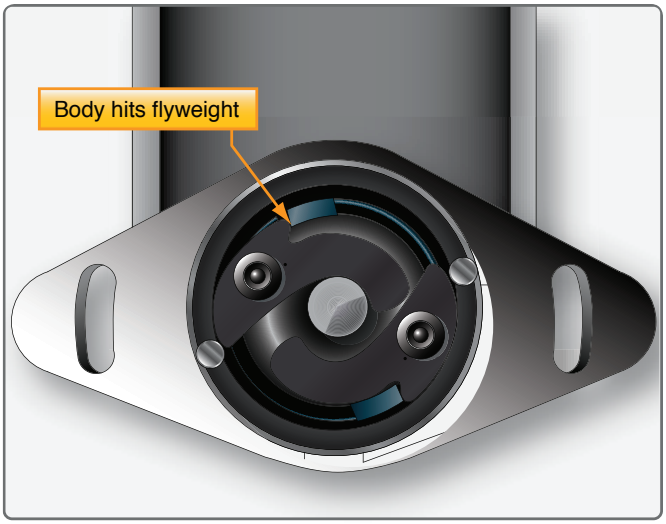


Figure 5-38. Impulse coupling release point.

A problem that can arise from the impulse coupling is that the flyweights can become magnetized and not engage the stop pins. Congealed oil or sludge on the flyweights during cold weather may produce the same results. This prevents the flyweights from engaging the stop pins, which results in no starting spark being produced. Wear can cause problems with impulse couplings. They should be inspected and any maintenance should be performed

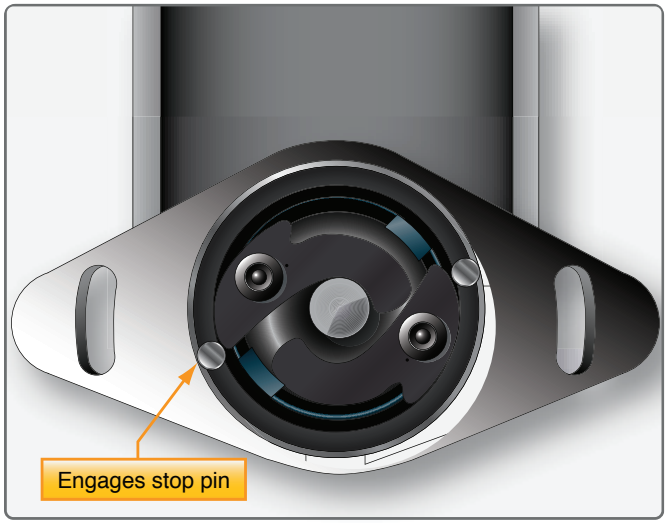


Figure 5-39. Impulse coupling flyweight arm engaged with stop Pin.

as set forth by the manufacturer. Another disadvantage of the impulse coupling is that it can produce only one spark for each firing cycle of the cylinder. This is a disadvantage when compared to the Shower of Sparks system, especially during adverse starting conditions. Even with these disadvantages, the impulse coupling is still in wide use.

SPARK PLUGS

The function of the spark plug in an ignition system is to conduct a short impulse of high-voltage current through the wall of the combustion chamber. Inside the combustion chamber, it provides an air gap across which the impulse can produce an electric spark to ignite the fuel/air charge. While the aircraft spark plug is simple in construction and operation, it can be the cause of malfunctions in aircraft engines. Despite this fact, spark plugs provide trouble-free operation when properly maintained and when correct engine operating procedures are practiced.

Spark plugs operate at extreme temperatures, electrical voltages, and very high cylinder pressures. A cylinder of an engine operating at 2,100 rpm must produce approximately 17 separate and distinct high-voltage sparks that bridge the air gap of a single spark plug each second. This would appear as a continuous spark across the spark plug electrodes at temperatures of over 3,000˚F (1,650˚C). At the same time, the spark plug is subjected to gas pressures as high as 2,000 pounds per square inch (psi) and electrical pressure as high as 20,000 volts. Given the extremes that spark plugs must operate under,

and the fact that the engine loses power if one spark does not occur correctly, proper operation of a spark plug in the performance of the engine is imperative.

The three main components of a spark plug are the electrodes, insulator, and outer shell. ***(Figure 5-40)*** The outer shell, threaded to fit into the cylinder, is usually made of finely machined steel and is often plated to prevent corrosion from engine gases and possible thread seizure. Close-tolerance screw threads and a gasket prevent cylinder gas pressure from escaping around the plug. Pressure that might escape through the plug is retained by inner seals between the outer metal shell and the insulator, and between the insulator and the center electrode assembly. The other end is threaded to receive the ignition lead from the magneto. All-weather plugs form a seal between the lead and the plug that is water proof to prevent moisture from entering this connection.

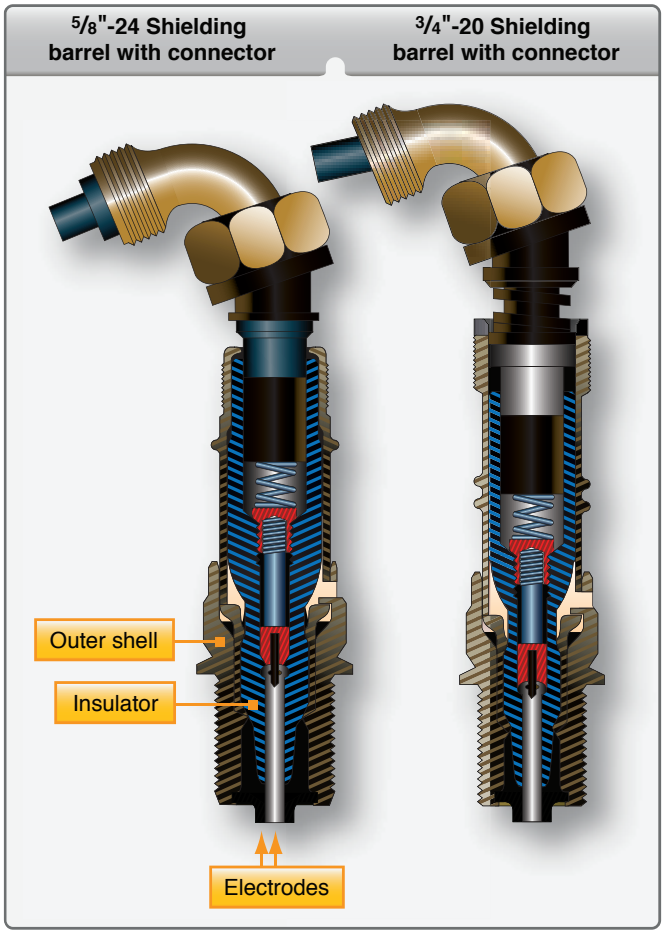


Figure 5-40. Spark plug design.

The insulator provides a protective core around the electrode. In addition to affording electrical insulation, the ceramic insulator core also transfers heat from the ceramic tip, or nose, to the cylinder. The insulator is made from aluminum oxide ceramic having excellent dielectric strength, high mechanical strength, and thermal conductivity. The types of spark plugs used in different engines vary in respect to heat range, reach, massive electrode, fine wire electrode (Iridium/platinum), or other characteristics of the installation requirements for different engines.



Figure 5-41. Fine wire spark plug.

The electrodes can be of several designs from massive electrodes or Nickel-base alloy to fine wire electrodes. ***(Figures 5-40 and 5-41)*** The massive electrode material has a lower melting point and is more susceptible to corrosion. The main differences include cost and length of service. Fine wire iridium and platinum electrodes have a very high melting point and are considered precious metals. Therefore, the cost of this type of spark plug is higher, but they have a longer service life with increased performance. Fine wire spark plugs are more effective than massive electrode plugs because the size of the massive electrode shields its own spark from some of the fuel/air mixture. Less efficient combustion occurs due to uneven ignition. The iridium electrode allows for a larger spark gap, which creates a more intense spark that increases performance. The spark gap of any electrode is vulnerable to erosion and the melting point of the electrode material.

The heat range of a spark plug is a measure of its ability to transfer the heat of combustion to the cylinder head. The plug must operate hot enough to burn off carbon deposits, which can cause fouling, a condition where the plug no longer produces a spark across the electrodes, yet remain cool enough to prevent a pre-ignition condition. Spark plug pre-ignition is caused by plug electrodes glowing red hot as a glow plug, setting off the fuel-air mixture before the normal firing position. The length of the nose core is the principal factor in establishing the plug's heat range. ***(Figure 5-42)*** Hot plugs have a long insulator nose that creates a long heat transfer path; cold plugs have a relatively short insulator to provide a rapid transfer of heat to the cylinder head.

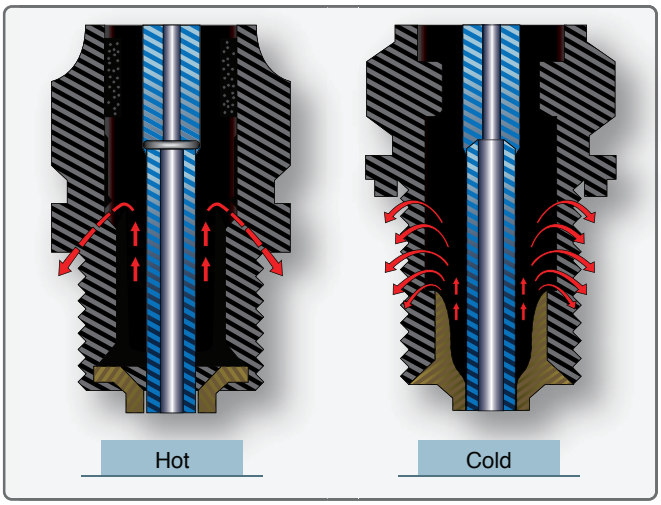


Figure 5-42. Comparison in heat range design.

If an engine were operated at only one speed, spark plug design would be greatly simplified. Because flight demands impose different loads on the engine, spark plugs must be designed to operate as hot as possible at slow speeds and light loads, and as cool as possible at cruise and takeoff power.

The choice of spark plugs to be used in a specific aircraft engine is determined by the engine manufacturer after extensive tests. When an engine is certificated to use hot or cold spark plugs, the plug used is determined by the compression ratio, the degree of supercharging, and how the engine is to be operated. High-compression engines tend to use colder range plugs while low-compression engines tend to use hot range plugs.

A spark plug with the proper reach ensures that the electrode end inside the cylinder is in the best position to achieve ignition. The spark plug reach is the length of the threaded portion that is inserted in the spark plug bushing of the cylinder. ***(Figure 5-43)*** Spark plug seizure and/or improper combustion within the cylinder can occur if a plug with the wrong reach is used. In extreme cases, if the reach is too long, the plug may contact a piston or valve and damage the engine. If the plug threads are too long, they extend into the combustion chamber and carbon adheres to the threads making it almost impossible to remove the plug. This can also be a source of pre-ignition. Heat of combustion can make some of the carbon a source for ignition, which can ignite the fuel-air mixture prematurely. It is very important to select the approved spark plugs for the engine.

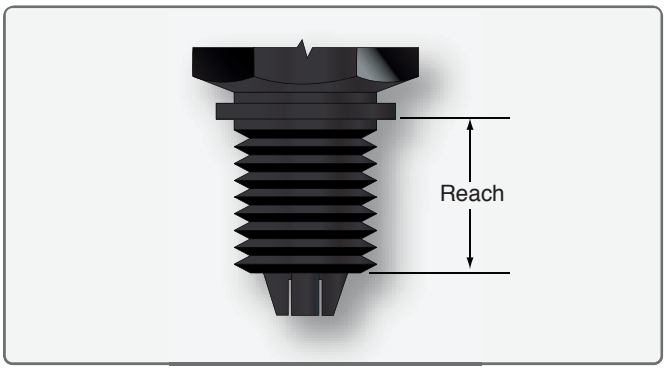


Figure 5-43. Spark plug thread reach.

Question: 5-1
The most basic form of an inertial starter is _____.

Question: 5-2
A typical direct cranking electric starter motor is _____ volts and _____ wound.

Question: 5-3
An electric direct cranking starter motor's speed varies directly with _____ and inversely with _____.

Question: 5-4
On a direct cranking electrical starter system, with the starter energized, and the engine firing, what causes the starter jaw to disengage from the engine?

Question: 5-5
What is the maximum amount of time a starter may be engaged before it must be stopped and allowed to cool down?

Question: 5-6
A dirty or glazed starter commutator is best cleaned with _____, but NOT with what type of material?

Question: 5-7
A quick inspection of a starter should include what three items:
_____,
_____,
_____.

Question: 5-8
Name three reasons why starting an aircraft engine in cold weather is difficult or harmful.
_____.
_____.
_____.

ANSWERS

Answer: 5-1
Hand propping.
page 5.2

Answer: 5-2
12 or 24 volts; Series wound.
page 5.3

Answer: 5-3
Voltage; Load.
page 5.4

Answer: 5-4
Sloping ramps of the jaw teeth push the jaw back into the starter housing.
page 5.6

Answer: 5-5
One minute.
page 5.7

Answer: 5-6
Fine sand paper, but not Emery cloth or carborundrum.
page 5.9

Answer: 5-7
Worn teeth on starter and ring gear;
Looseness or corrosion on electrical connections;
Security of its mount to engine.
page 5.9

Answer: 5-8
Oil is viscous; fuel difficult to atomize;
Cold oil impedes impulse coupling flyweights;
Diminished battery power.
page 5.9

Question: 5-9
Within an aircraft magneto system using a four-pole magnet rotor, how many times does the magnet reach maximum flux during each 360° rotation?

Question: 5-10
What are the three distinct circuits within a high tension magneto system?

Question: 5-11
What are the six main components in the secondary circuit of a magneto system?

_____.
_____.
_____.
_____.
_____.
_____.

Question: 5-12
By what method are corrosive gasses prevented from accumulating within magnetos?

Question: 5-13
What is the negative aspect of shielding in ignition leads?

Question: 5-14
In what way is an ignition switch different from all other electrical switches?

Question: 5-15
In a dual magneto system, which two major components are shared within the one unit?

Question: 5-16
Why is one of a variety of starting aids required on a magneto ignition system?

ANSWERS

Answer: 5-9
Four times per rotation.
page 5.12

Answer: 5-10
Magnetic circuit;
Primary circuit;
Secondary circuit.
page 5.11

Answer: 5-11
Secondary windings;
Coil;
Rotor;
Distributor cap;
Ignition lead;
Spark plug.
page 5.16

Answer: 5-12
Moisture drains and ventilation.
page 5.17

Answer: 5-13
The shielding acts as a capacitor requiring increased electrical energy from the magneto.
page 5.18

Answer: 5-14
In an ignition switch, the contacts are closed when in the off position.
page 5.19

Answer: 5-15
A dual magneto contains a single shared rotating magnet and cam.
page 5.21

Answer: 5-16
The low rotating speed within the magneto is insufficient to produce a strong spark.
page 5.23

Question: 5-17
How does an impulse coupling assist the starting process?

Question: 5-18
What device within a reciprocating engine must reliably function 17 times per second at a temperature of 3000˚ F, a gas pressure of 2000 psi, and an electrical pressure of 20,000 volts?

ANSWERS

Answer: 5-17
Flyweights and a spring briefly accelerates the magnet shaft to increase spark intensity.
page 5.27

Answer: 5-18
Spark plugs.
page 5.28



PART-66 SYLLABUS	LEVELS		
CERTIFICATION CATEGORY →	A	B1	B3

Sub-Module 06
Piston Engine - Induction, Exhaust, and Cooling Systems

16.6 - Induction, Exhaust, and Cooling Systems Construction and operation of induction systems including alternate air systems; Exhaust systems, engine cooling systems - liquid and air.	1	2	2

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

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

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

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

INDUCTION, EXHAUST, AND COOLING SYSTEMS

BASIC CARBURETOR INDUCTION SYSTEM

Figure 6-1 is a diagram of an induction system used in an engine equipped with a carburetor. In this induction system, the normal flow of air is admitted at the lower front nose cowling below the propeller spinner, and is passed through an air filter into air ducts leading to the carburetor. After passing through the carburetor, the fuel/air charge travels along the induction manifold to the intake ports. Both updraft and downdraft induction manifolds are presented in Module 16.3.



Figure 6-2. Air inlet filter (installed below the landing light).

The carburetor air filter, shown in ***Figures 6-1 and 6-2***, is installed in the carburetor air duct. Its purpose is to stop dust and other foreign matter from entering the engine through the carburetor. The screen consists of an aluminum alloy frame and a deeply crimped screen, normally constructed from heavy paper, arranged to present maximum screen area to the airstream. There are several types of air filters in use including paper, foam, and other types of filters. Most air filters require servicing or replacement at regular intervals and the specific instructions for the type of filter must be followed. See ***Figures 6-3 and 6-4***.

The carburetor air ducts provide a passage for outside air to the carburetor. Normally, the intake opening is located in the slipstream so the air is forced into the induction system giving a ram effect to the incoming airflow. Other aircraft use a recessed inlet duct to minimize the ingestion of water and ice during flight through precipitation. The inlet bound air passes through the air ducts to the carburetor. The carburetor meters the fuel in proportion to the air and mixes the air with the correct amount of fuel. The throttle plate of the carburetor is controlled from the cockpit to regulate the flow of air (manifold pressure), and in this way, power output of the engine is controlled.

Carburetor inlet air boxes may be constructed in a variety of ways. Many older systems use steel for this purpose. Aluminum is frequently used for air box

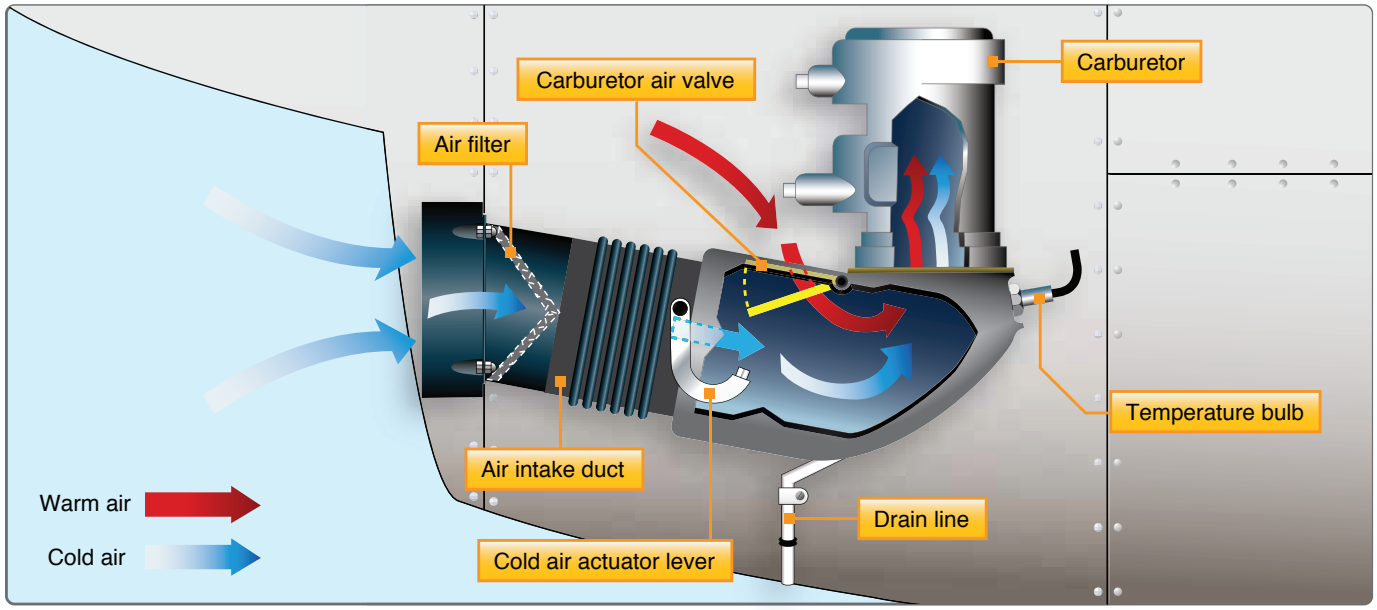


Figure 6-1. Induction inlet system.



Figure 6-3. Paper induction air filter.



Figure 6-4. Replaceable foam induction air filter element.

construction. Regardless of material selection for the air box, the construction of the unit is engineered to prevent the ingestion of hardware through the use of welding and rivets. The use of screws, washers, and nuts are normally limited to areas outside of the air box interior. Bearings or bushings are used to support the carburetor heat valve. This unit somewhat resembles a throttle valve and is used to select whether the engine is to ingest cold filtered air or hot unfiltered air. Also, the construction of the air box includes mounts for the air inlet filter and duct attachments for the alternate air or carburetor heat source. The carburetor inlet air box is typically bolted directly to the inlet side of the carburetor.

Although many newer aircraft are not so-equipped, some engines include a carburetor air temperature indicating systems that shows the temperature of the air at the carburetor inlet. When the temperature probe is located at the engine side of the carburetor, the system measures the temperature of the fuel/air mixture.

Another function placed upon the induction system is to drain liquids that accumulate in the intake network. For example, when oil and/or gasoline gather in the induction system, such liquids need a path to drain. If these liquids enter the combustion chamber in sufficient quantity, damage to the engine may occur via a hydraulic cylinder lock. Before starting a radial engine after a protracted period of inactivity, the pilot or ground crew pulls the engine through several revolutions to determine whether a hydraulic lock is present. A low point in the system is generally used to allow liquids to drain from the induction manifold as presented in ***Figure 6-5***. Carburetor inlet air boxes also include means for draining liquids that accumulate in the inlet (e.g., excess priming fuel, accelerator pump discharge fuel, etc.).



Figure 6-5. Air inlet filter (installed below the landing light).

INDUCTION SYSTEM FILTERING

Dust and dirt can be a serious source of trouble to an aircraft engine. Dust consists of small particles of hard, abrasive material that can be carried by the air and drawn into the engine cylinders. It can also collect on the fuel metering elements of the carburetor and fuel injector, upsetting the proper relation between airflow and fuel flow at all engine power settings. Dirt particles act on the cylinder walls by grinding down these surfaces and the piston rings. Then, they contaminate the oil and are carried through the engine, causing further wear on the bearings and gears. In extreme cases, an accumulation may clog an oil passage and cause oil starvation. Likewise, dirt accumulation on fuel injection nozzles affect the fuel/air mixture delivered to the engine. Although dust conditions are most critical at ground level, continued operation under such conditions without engine protection results in extreme engine wear and can produce excessive oil consumption. When operation in a dusty atmosphere is necessary, the engine may be protected by an alternate induction system air inlet that incorporates a dust filter. This type of air filter system normally consists of a filter

element, a door, and an electrically operated actuator. When the filter system is operating, air is drawn through a louvered access panel that does not face directly into the airstream. With this entrance location, considerable dust is removed as the air is forced to turn and enter the duct. Since the dust particles are solid, they tend to continue in a straight line, and most of them are separated at this point. Those that are drawn into the louvers are easily removed by the filter.

In flight, with air filters operating, consideration must be given to possible icing conditions that may occur from actual surface icing or from freezing of the filter element after it becomes rain soaked. Some installations have a spring-loaded filter door that automatically opens when the filter is excessively restricted. This prevents the airflow from being cut off when the filter is clogged with ice or dirt. Other systems use an ice guard in the filtered air entrance.

The ice guard consists of a coarse-mesh screen located a short distance from the filtered-air entrance. In this location, the screen is directly in the path of incoming air so that the air must pass through or around the screen. When ice forms on the screen, the air, which has lost its heavy moisture particles, passes around the iced screen and into the filter element. The efficiency of any filter system depends upon proper maintenance and servicing. Periodic removal and cleaning or replacement of the filter element is essential to satisfactory engine protection.

CARBURETOR HEAT SYSTEMS

A carburetor heat air valve is located in the air box upstream of the carburetor for selecting an alternate warm air source (carburetor heat) to prevent or remove carburetor ice. Carburetor icing occurs when the temperature is lowered in the throat of the carburetor and enough moisture is present to freeze and restrict or block the flow of air to the engine. The carburetor heat valve admits air, normally from a sheltered location, and it admits warm air from the carburetor heat source for operation during icing conditions. Often, carburetor heat is applied when the aircraft is operated at low throttle settings or in suspected icing conditions. The carburetor heat system is operated by a push-pull control in the cockpit. When the carburetor heat air door is opened to the carburetor, warm ducted air from around the exhaust system is directed into the carburetor. This raises the intake air temperature. On some aircraft, an automatic alternate air door is opened by engine suction if the normal route of airflow is blocked by something. In such installations, the alternate air valve is spring loaded closed and is sucked open by the intake action of the engine.

INDUCTION SYSTEM ICING

A short discussion concerning the formation and location of induction system ice is helpful, even though a technician's not normally concerned with operations that occur when the aircraft is in flight. Technicians should know something about induction system icing because of its effect on engine performance and troubleshooting. Even when an inspection shows that everything is in proper working order and the engine performs perfectly on the ground, induction system ice can cause an engine to act erratically and lose power in the air. Many engine troubles commonly attributed to other sources are actually caused by induction system icing.

Induction system icing is an operating hazard because it can cut off the flow of the fuel/air charge or vary the fuel/air ratio. Numerous accidents are attributed to loss of engine power due to carburetor ice. Ice can form in the induction system while an aircraft is flying in clouds, fog, rain, sleet, snow, or even clear air that has high moisture content (high humidity). Induction system icing is generally classified into three types:

- Impact ice
- Fuel evaporation ice
- Throttle ice

Induction system ice can be prevented or eliminated by raising the temperature of the air that passes through the system using a carburetor heat system located upstream near the induction system inlet and well ahead of the dangerous icing zones. This air is collected by a duct surrounding the exhaust manifold. Heat is usually obtained through a control valve that opens the induction system to the warm air circulating in the engine compartment and around the exhaust manifold.

Improper or careless use of carburetor heat can be just as dangerous as the most advanced stage of induction system ice. Increasing the temperature of the air causes it to expand and decrease in density. This action reduces the weight of the fuel/air charge delivered

to the cylinder and causes a noticeable loss in power because of decreased volumetric efficiency. In addition, high intake air temperature may cause detonation and engine failure, especially during takeoff and high power operation. Therefore, during all phases of engine operation, the carburetor temperature must afford the greatest protection against icing and detonation.

When there is danger of induction system icing, the cockpit carburetor heat control is moved to the hot position. Throttle ice or any ice that restricts airflow or reduces manifold pressure can best be removed by using full carburetor heat. If the heat from the engine compartment is sufficient and the application has not been delayed, it is only a matter of a few seconds or minutes until the ice is cleared.

When there is no danger of icing, the heat control is normally kept in the "COLD" position. It is best to leave the control in this position if there are particles of dry snow or ice in the air. The use of heat may melt the ice or snow, and the resulting moisture may collect and freeze on the walls of the induction system. To prevent damage to the heater valves in the case of backfire, carburetor heat should not be used while starting the engine. Also, during ground operation only enough carburetor heat should be used to give smooth engine operation.

Part-throttle operation can lead to icing in the throttle area. When the throttle is placed in a partly closed position, it, in effect, limits the amount of air available to the engine. When the aircraft is in a glide, a fixed-pitch propeller windmills, causing the engine to consume more air than it normally would at this same throttle setting, thus adding to the lack of air behind the throttle. The partly closed throttle, under these circumstances, establishes a much higher than normal air velocity past the throttle, and an extremely low-pressure area is produced. The low-pressure area lowers the temperature of the air surrounding the throttle valve. If the temperature in this air falls below freezing and moisture is present, ice forms on the throttles and nearby units restricting the airflow to the engine causing it to quit. Throttle ice may be minimized on engines equipped with controllable-pitch propellers by the use of a higher than normal brake mean effective pressure (BMEP) at this low power. The high BMEP decreases the icing tendency because a large throttle opening at low engine revolutions per minute (rpm) partially removes the temperature-reducing obstruction that part-throttle operation offers.

CARBURETOR HEAT SYSTEM OPERATIONAL CHECK

The pilot normally performs a pre-takeoff check of the carburetor heat system before each flight. Technicians frequently test the system as part of their engine evaluation during inspections or when performing engine troubleshooting measures. This test is typically conducted at the same rpm that is used to check the operation of the magnetos. Another check of the carburetor heat system may be performed while the engine is idling. A normal response during the application of carburetor heat is a slight reduction of rpm (e.g., 50 rpm). As the heated air results in an enrichment of the fuel/air mixture, the engine loses rpm when ingesting the heated air. Should the engine lose more than the normal amount of rpm, a system fault is present.

One source of excess rpm loss may be attributed to the exhaust system. If exhaust gases are leaking in the vicinity of the carburetor heat muffler and are being ingested by the engine during the application of carburetor heat, the engine will experience a greater than normal loss of rpm. Another source of problem may be attributed to system ducting. If the flexible hose(s) normally found with this system implodes, the fuel/air charge will be further enriched by the choking off of in flowing air.

Technicians should always ensure that the system rigging is correct. Should the carburetor heat system fail to reach full travel in either direction, operational problems will be encountered.

EXHAUST SYSTEM CONSTRUCTION

Aircraft exhaust system for reciprocating engines run from the exhaust ports of the cylinders to the atmosphere. The connection with the exhaust port is typically made using a gasket and flange. The flange is held to the exhaust port using a combination of studs and nuts. Washers are frequently included.

The exhaust pipe, or stack, is welded to a flange. Technicians should closely inspect the welds for cracks during maintenance operations. Some aircraft terminate the exhaust system at the stacks. Others manifold together stacks from two or more cylinders. Exhaust mufflers are commonly connected to the stacks. Tail

pipes run from the mufflers and extended beyond the cowling before discharging the exhaust gases to the atmosphere. The exhaust gases may be directed at turbines before being discharged into the atmosphere. Exhaust system turbines normally drive a compressor. The latter may be used to turbo-charge the engine. The output of the compressor may also be used to pressurize the interior of the aircraft. A few engines take the output of the turbine and apply horsepower generated to the crankshaft by mechanical means.

A corrosion-resistant steel is often used to construct the various components of the exhaust system. This material not only prevents corrosion, but its toughness provides longevity to the system. Older aircraft may use exhaust systems that are not corrosion-resistant. Such units will corrode over time and use.

Aside from transporting the exhaust gases from the exhaust ports to the atmosphere, exhaust systems may be used as a source of heat for aircraft and engine systems. The source of heat for the carburetor heat system originates from the exhaust system. A shroud is placed around an exhaust component that provides a path of flow for fresh heated air to reach the carburetor air box. As the air travels around the heated exhaust system member, the air becomes hot. This hot air enters the carburetor where it melts ice or prevents ice from forming.

In a similar fashion, the exhaust system provides heat for the interior of the aircraft and defrosting system. As with carburetor heat, fresh air travels through a shroud wrapped around the exhaust system and picks up heat from the exhaust member. The heated air then travels to the interior of the aircraft or defrosting duct. In most installations, a shroud is wrapped around a muffler to supply heat to the carburetor heat system and airframe needs. A word of caution. This arrangement provides a path for noxious fumes to enter the cabin and carburetor should there be leaks associated with these systems. Technicians must carefully and thoroughly check exhaust components to eliminate such leaks. Carbon monoxide poisoning is possible when leaks are present. Inhalation of carbon monoxide may incapacitate the crew and passengers, resulting in death.

The various exhaust components are connected using clamps. Often the hardware used to secure the clamps becomes corroded. Those maintaining aircraft must examine attaching hardware and replace same when they become corroded.

RECIPROCATING ENGINE COOLING SYSTEMS

An internal-combustion engine is a heat machine that converts chemical energy in the fuel into mechanical energy at the crankshaft. It does not do this without some loss of energy, however, and even the most efficient aircraft engines may waste 60 to 70 percent of the original energy in the fuel. Unless most of this waste heat is rapidly removed, the cylinders may become hot enough to cause complete engine failure. Excessive heat is undesirable in any internal combustion engine for three principal reasons:

1. It affects the behavior of the combustion of the fuel/air charge.

2. It weakens and shortens the life of engine parts.

3. It impairs lubrication.

If the temperature inside the cylinder is too great, the fuel-air mixture is preheated, and combustion occurs before the desired time. Since premature combustion may lead to detonation, knocking, and other undesirable conditions, there must be a way to eliminate heat before it causes damage.

One gallon of aviation gasoline has enough heat value to boil 75 gallons of water; thus, it is easy to see that an engine that burns 4 gallons of fuel per minute releases a tremendous amount of heat. About one-fourth of the heat released is changed into useful power. The remainder of the heat must be dissipated so that it is not destructive to the engine. In a typical aircraft power plant, half of the heat goes out with the exhaust and the other is absorbed by the engine. Circulating oil picks up part of this soaked-in heat and transfers it to the airstream through the oil cooler. The engine cooling system takes care of the rest. Cooling is a matter of transferring the excess heat from the cylinders to the air, but there is more to such a job than just placing the cylinders in the airstream. A cylinder on a large engine is roughly the size of a gallon jug or larger. Its outer surface, however, is increased by the use of cooling fins so that it presents a barrel-sized exterior to the cooling air. Such an arrangement increases the heat transfer by

radiation. If too much of the cooling fin area is broken off, the cylinder cannot cool properly, and a hotspot develops. Therefore, cylinders are normally replaced if a specified number of square inches of fins are missing.

Cowling and baffles are designed to force air over the cylinder cooling fins. ***(Figure 6-6)*** The baffles direct the air close around the cylinders and prevent it from forming hot pools of stagnant air while the main streams rush by unused. On some engines, blast tubes are built into the baffles to direct jets of cooling air onto the rear spark plug elbows of each cylinder to prevent overheating of ignition leads. Baffle seals are used to keep the cooling air flowing in the proper direction. When the condition of these seals deteriorates, engine cooling will be diminished.

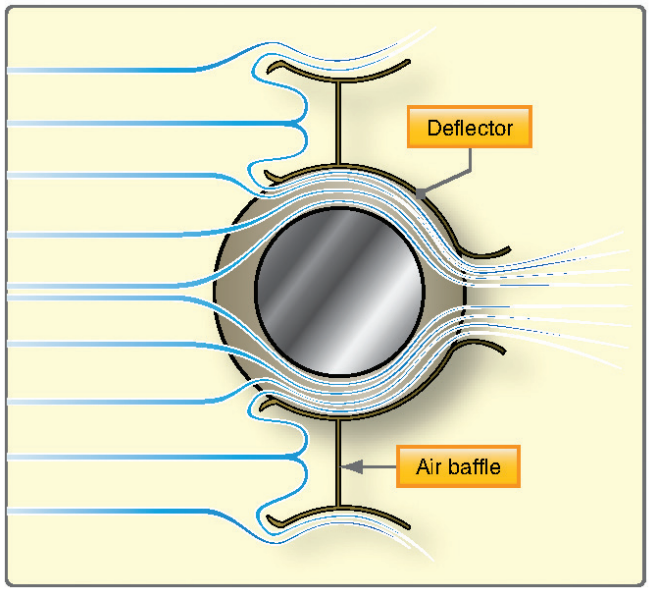


Figure 6-6. Cylinder baffles and deflectors.

Air-cooled aircraft power plants have a disagreeable set of circumstances during high power settings. They routinely generate the maximum amount of heat during takeoff and climb while experiencing a minimal amount of cooling by virtue of the nose up attitude of the aircraft and low air speed. To further compound the problem, the air cooling system often falls into a state of disrepair as the baffling becomes cracked and loose and the baffle seals become torn and ineffective over the years.

One reason for the decaying status of the baffling and baffle seals is that they don't bleed. Liquid-cooled systems receive prompt attention when they become defective. But the parts that compose the cooling network for air-cooled power plants are often allowed to wither away with little notice.

Another reason why baffles and seals of air-cooled engines are ignored is that the necessary repairs are often laborious affairs that involve dealing with chintzy hardware and springs. Many times, exhaust and intake pipes and other engine components are in the way of the needed repair area and technicians are reluctant to remove such items to implement repairs of the baffles.

In the final analysis, the components of the air-cooling system are regularly overlooked and ignored. Technicians should reevaluate the purpose of these items and implement needed repairs.

Cooling baffles should be arranged in a way to minimize the loss of cooling air. Seals must be intact and arranged in a fashion that reduces the amount of loss of cooling air flow. Arrange baffles and seals as though they are roofing shingles so there will be little loss of air flow. ***[Figure 6-7]***

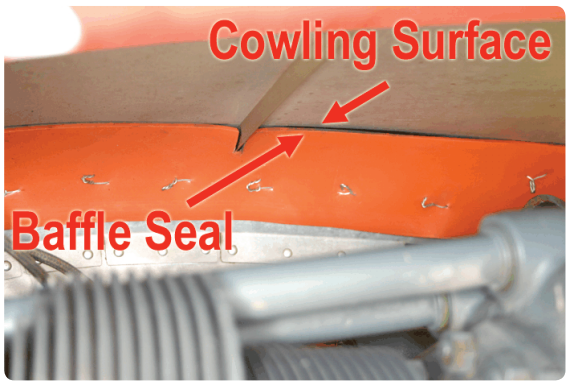


Figure 6-7. Baffle seal installation. Note the close fit between the baffle seal material and the interior surface of the cowling. This minimizes the loss of cooling air flow through the engine compartment and cylinders.

One technique for evaluating the effectiveness of the baffle seals is to closely examine the interior of the cowling. There should be evidence of contact made by the seal against the cowling. ***(Figure 6-8)*** When the aircraft is in flight, the air that enters the engine compartment builds a slight pressure in the upstream portion of the cowling. This pressurizing action forces the seals into contact with the interior of the cowling. The area where the air exits the cowling should be a low-pressure zone.

This pressure differential, along with the baffling, guides the flow of air through the engine compartment. If the seals are torn or if the baffling is loose, missing, or unable to block and direct air, the flow of air through the engine compartment will be adversely affected and the engine, or portions of the engine, will be improperly cooled.

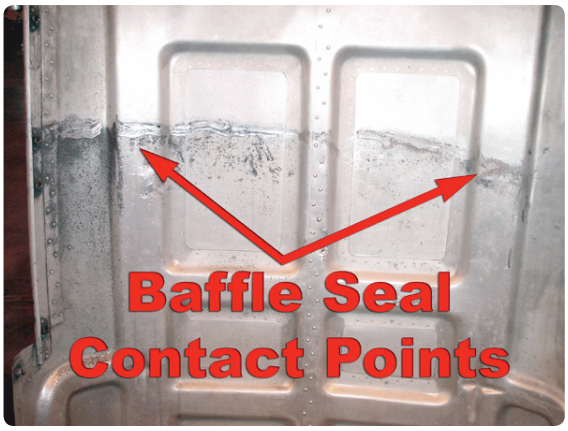


Figure 6-8. Evidence of baffle seal effectiveness.

An engine can have an operating temperature that is too low. For the same reasons that an engine is warmed up before takeoff, it is kept warm during flight. Fuel evaporation and distribution and oil circulation depend on an engine being kept at its optimum operating temperature. Many aircraft engines have temperature control mechanisms that regulate air circulation over the engine. Unless some controls are provided, the engine could overheat on takeoff and get too cold in high altitude, high speed and low-power letdowns.

The most common means of controlling cooling is the use of cowl flaps. ***(Figure 6-9)*** These flaps are opened and closed by electric motor-driven jackscrews, by hydraulic actuators, or manually in some light aircraft. When extended for increased cooling, the cowl flaps produce drag and sacrifice streamlining for the added cooling. On takeoff, the cowl flaps are opened only enough to keep the engine below the red-line temperature. Heating above the normal, green arc, range is allowed so that drag is as low as possible. During ground operations, the cowl flaps should be opened wide since drag does not matter and cooling needs to be set at maximum. Cowl flaps are commonly used with older aircraft and radial engine installations. Higher performance small aircraft may also be equipped with cowl flaps.

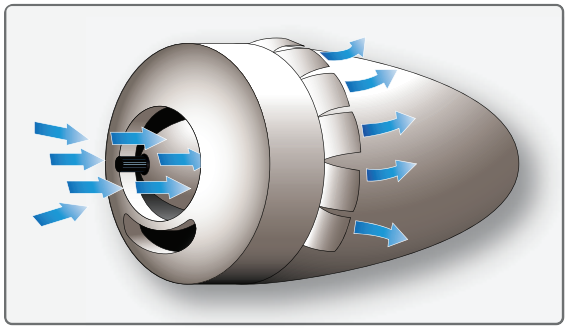


Figure 6-9. Cowl flaps as used with radial engines.

Some aircraft use augmentors to provide additional cooling airflow. ***(Figure 6-10)*** Each nacelle has two pairs of tubes running from the engine compartment to the rear of the nacelle. The exhaust collectors feed exhaust gas into the inner augmentor tubes. The exhaust gas mixes with air that has passed over the engine and

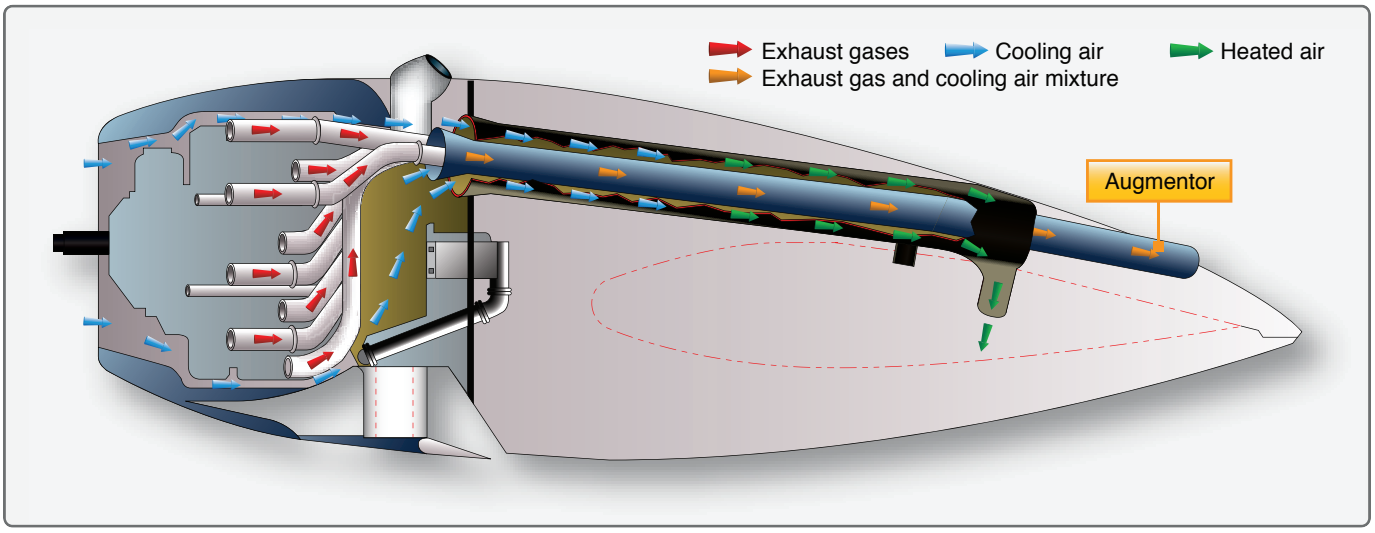


Figure 6-10. Augmentor system.

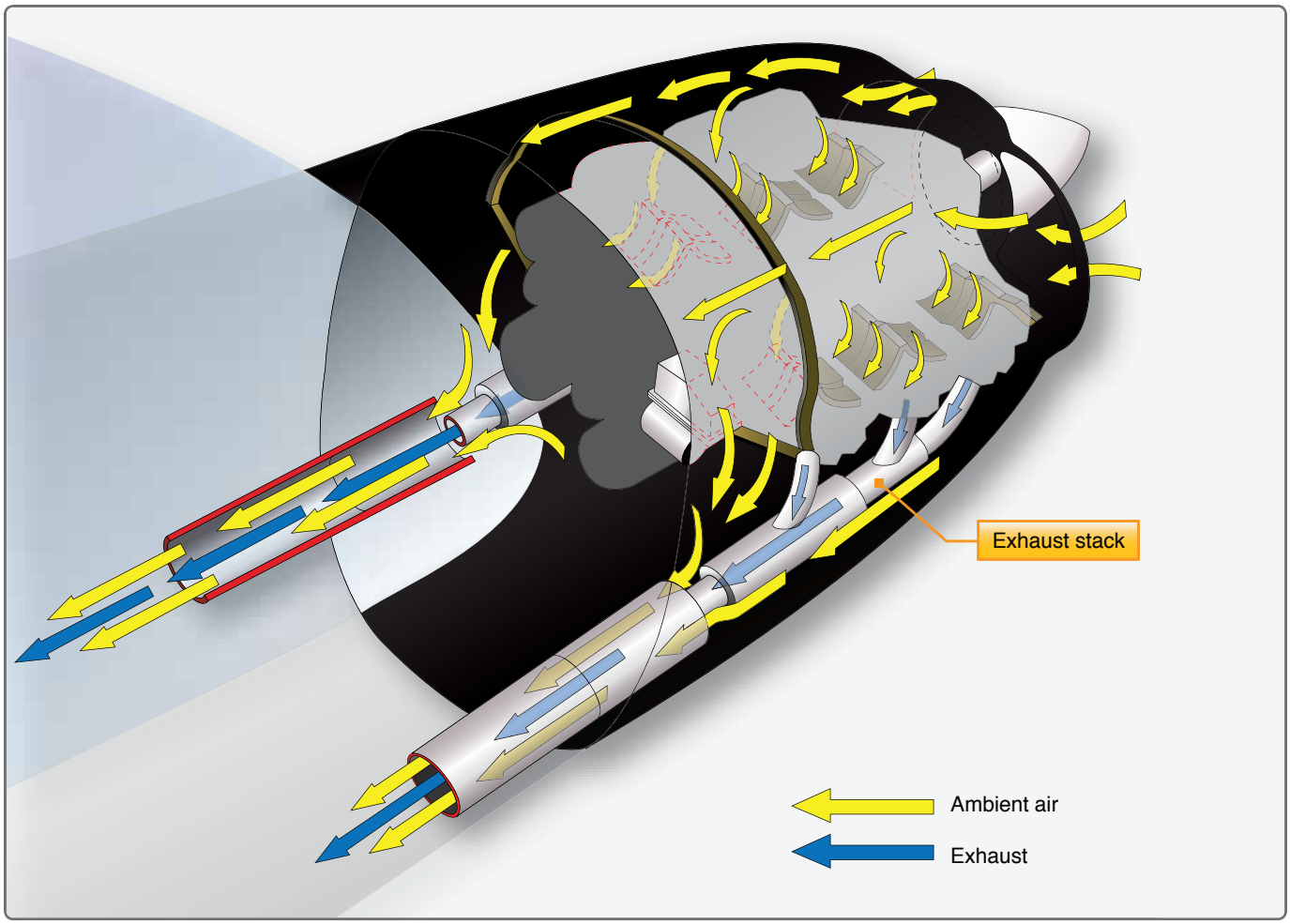


Figure 6-11. Augmentor system on opposed engines.

heats it to form a high temperature, low-pressure, jet-like exhaust. This low pressure area in the augmentors draws additional cooling air over the engine. Air entering the outer shells of the augmentors is heated through contact with the augmentor tubes but is not contaminated with exhaust gases. The heated air from the shell goes to the cabin heating, defrosting, and anti-icing system.

Augmentors use exhaust gas velocity to cause airflow over the engine so that cooling is not entirely dependent on the prop wash. Vanes installed in the augmentors control the volume of air. These vanes are usually left in the trail position to permit maximum flow. They can be closed to increase the heat for cabin or anti-icing use or to prevent the engine from cooling too much during descent from altitude. In addition to augmentors, some aircraft have residual heat doors or nacelle flaps that are used mainly to let the retained heat escape after engine shutdown. The nacelle flaps can be opened for more cooling than that provided by the augmentors. A modified form of the previously described augmentor cooling system is used on some light aircraft. ***(Figures 6-11 and 6-12)*** Augmentor systems are not used much on modern aircraft.

As shown in ***Figure 6-11***, the engine is pressure cooled by air taken in through two openings in the nose cowling, one on each side of the propeller spinner. A pressure chamber is sealed off on the top side of the engine with baffles properly directing the flow of cooling air to all parts of the engine compartment. Warm air is drawn from the lower part of the engine compartment by the pumping action of the exhaust gases through the exhaust ejectors. This type of cooling system eliminates the use of controllable cowl flaps and assures adequate engine cooling at all operating speeds.

When the engine compartment is equipped with an exhaust augmentor system, the collector tubes terminate at the exhaust ejector openings at the

firewall and are tapered to deliver the exhaust gases at the proper velocity to induce airflow through the exhaust ejectors. The exhaust ejectors consist of a throat-and-duct assembly that utilizes the pumping action of the exhaust gases to induce a flow of cooling air through all parts of the engine compartment (augmenter tube action). ***[Figure 6-12]***

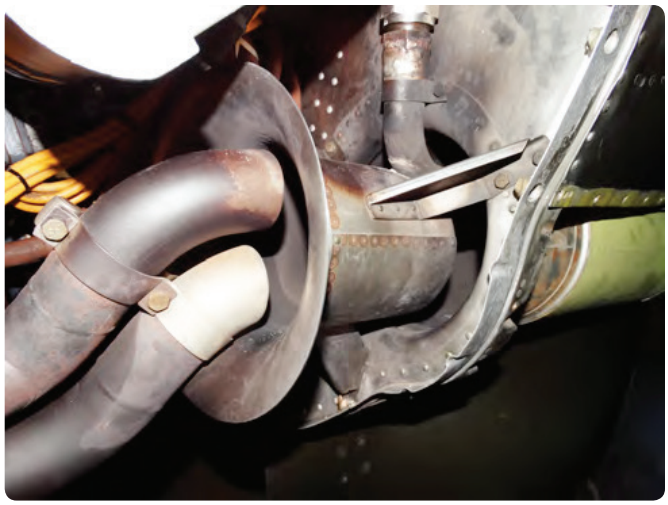


Figure 6-12. Exhaust augmentor system.

Liquid cooling is another option for reciprocation power plants. The automotive industry has employed liquid cooling for decades. During the Second World War, many aircraft engines were cooled by liquid. The twelve cylinder vee-type engines required liquid cooling as the cylinders could not be equipped with cooling fins and staggered in order to be air cooled. In such engines, liquid cooling kept the engines relatively compact in terms of physical size. Also, the engine cowling remained streamlined when compared to those used for air-cooled engines.

Where liquid cooling offers certain benefits, there are some negative attributes of liquid cooling. First, the components, hoses, and coolant needed to provide the cooling adds to the weight of the engine and empty weight of the aircraft. Second, if a leak developed during flight, the engine could over heat and fail before being able to implement a safe landing. Third, the additional equipment associated with liquid cooling consumes space within the engine compartment and may make it more difficult to maintain the engine. And, because the liquid cooling system includes a radiator(s), additional drag is generated by directing airflow through the heat exchanger(s).

Some engines employ a hybrid-cooling network were a portion of the engine remains air-cooled and other components are liquid cooled. For example, a Rotax engine cools the cylinder heads using liquid and uses air for the cylinder barrels. Liquid cooling is used with diesel engines emerging into the aviation industry. ***(Figure 6-13)*** Manufacturers incorporate the appropriate cooling network for their engines.



Figure 6-13. Liquid-cooled diesel engine.

Question: 6-1
Why might an induction systems have a small hole drilled through the lower side?

Question: 6-2
What is the typical source of heat in a carburetor heat system?

Question: 6-3
Why does an engine incur a loss of rpm when carburetor heat is applied?

Question: 6-4
If during an carburetor heat systems check, the engine rpm drops an excessive amount of rpm, what is a possible cause?

Question: 6-5
Worn out, torn, or missing _____ are often the cause of a gradually overheating reciprocating engine.

Question: 6-6
On an aircraft equipped with cowl flaps, the flaps are normally _____ during ground operations and takeoff and normally_____ during normal cruise flight

Question: 6-7
Liquid cooling is normally undesirable for aircraft engines for what three reasons?
_____,
_____,
_____.

ANSWERS

Answer: 6-1
As a drain for excess fuel and oil which may overflow from the carburetor.
page 6.3

Answer: 6-2
Air which has been ducted around the exhaust pipes, manifold, or muffler.
page 6.4

Answer: 6-3
Heated air is less dense, reducing the mass of the fuel air charge entering the cylinder resulting in an enriched fuel/air mixture.
page 6.4

Answer: 6-4
Leaky exhaust gasses near the carburetor heat ducting
page 6.5

Answer: 6-5
Baffle seals.
page 6.6

Answer: 6-6
Open during ground ops.
Closed during cruise flight.
page 6.7

Answer: 6-7
*Adds weight and complexity.
*Radiators cause aerodynamic drag.
*Inflight coolant leak could be catastrophic.
page 6.8



PART-66 SYLLABUS	LEVELS		
CERTIFICATION CATEGORY →	A	B1	B3

Sub-Module 07
Piston Engine - Supercharging and Turbocharging

16.7 - Supercharging and Turbocharging Principles and purpose of supercharging and it's effects on engine parameters; System terminology; Control systems; System protection.	1	2	2

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

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

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

SUPERCHARGING/ TURBOCHARGING

PRINCIPLES AND PURPOSE OF SUPERCHARGING

Some reciprocating aircraft power plants are equipped with supercharging systems. Those without superchargers are naturally aspirated or sea level engines. Sea level engines are able to produce rated power only at sea level. In other words, as a sea level engine climbs from sea level, engine power diminishes. By contrast, an altitude engine is able to produce rated power from sea level to a higher altitude, such as critical altitude. The critical altitude of an engine is the highest altitude at which the power plant is able to produce specified power, rpm, or manifold pressure in a standard atmosphere. It is typically distinguished as the maximum altitude at which, during maximum continuous rpm, the engine develops maximum continuous power or maximum continuous manifold pressure.

In general, supercharging supplements the engine's performance in terms of critical altitude and/or power output. In the area of critical altitude, unlike a naturally aspirated power plant that begins to lose power as the aircraft ascends above sea level, supercharged engines are able to generate rated power at higher altitudes (e.g., 16,000 feet). Operations at high altitudes offer numerous advantages, including superior mountain flying, reduced airframe drag, more cruise altitude options that provide advantages in selecting desirable winds and weather, and other similar benefits.

Supercharging basically creates an artificial environment for the engine's induction system. In certain respects, supercharging tricks the engine into thinking that it is operating at a lower altitude. If the engine has a continuous flow fuel injection system, several components are also connected to the output of the supercharger's compressor. They too must reference the same pressure ingested by the engine. Commonly, the air bleeds of continuous flow fuel injection nozzles and mechanical fuel flow meters receive the pressure generated by the compressor. This air is commonly referred to as upper deck pressure. The air bleeds of the nozzles use upper deck pressure to keep the air bleed pressure greater than manifold pressure. The interior of the case of the fuel flow meter needs to reference upper deck pressure so that increases in altitudes do not generate false fuel flow readings. In the Continental fuel injection system, the aneroid valve that controls high unmetered fuel pressure in the engine-driven fuel pump also receives upper deck pressure.

INTERNALLY DRIVEN SUPERCHARGERS

Some engines are equipped with superchargers that are driven by the rotation of the crankshaft. Normally a gear train is placed between the crankshaft and impeller shaft to increase the rotational speed of the compressor. Such action is necessary to increase the output from the impeller while maintaining a compact design.

A major benefit that accrues from driving the supercharger from the crankshaft is rapid response time. As the engine changes rpm, so does the rotational speed of the supercharger. By contrast, turbocharging systems are encumbered with a lag time between changes in power settings and the establishment of a new compressor rpm or output. Gear-driven superchargers may include a multiple-speed transmission whereby the speed of the compressor may be changed in relation to the engine rpm. In such cases, the impeller has a low boost and high boost option.

Centrifugal impellers are typically used as the compressor. When compared to axial flow compressors, centrifugal units are able to provide a high level of compression using a single stage. Axial flow compressors, as commonly found on turbojet engines, normally require multiple stages of compression to deliver a high level of compression. ***[Figure 7-1]***

The output from the impeller is directed to the diffuser. The diffuser has a divergent shape and is designed to decelerate the velocity of the discharge air and increase the pressure of the air as it departs the supercharger and enters the induction system or fuel-metering device. In the realm of supercharging, pressure is a key consideration.

Many fuel injection systems installed on engines with mechanical superchargers deliver their discharge fuel to the throat of the impeller. As fuel sprays from the injector nozzle, it thoroughly mixes with induction-bound air. If the engine uses a carburetor, the impeller compresses the fuel/air charge. The fuel/air charge departing the diffuser travels to the intake ports of the cylinders.



Figure 7-1. Mechanical Supercharger and Fuel Injection System. Note that inlet air first passes through the fuel metering unit at the bottom of the photograph before entering the supercharger and observe how the scroll departing the supercharger has a divergent shape.

TURBOCHARGERS

Turbochargers have been employed in aeronautics for decades. Late model turbochargers are composed of three subassemblies: (a) the turbine assembly, (b) the compressor assembly, and (c) the bearing and lubrication system. Additional elements making-up the turbocharger assembly include such items as mounting brackets and connections for the exhaust, intake, and lubrication systems. Heat shields are often employed for protection against the high level of heat concentration associated with this system. Such shields protect other systems, such as ignition, pneumatic, flexible hoses, etc., from the extreme heat associated with the turbocharger. ***[Figure 7-2]***

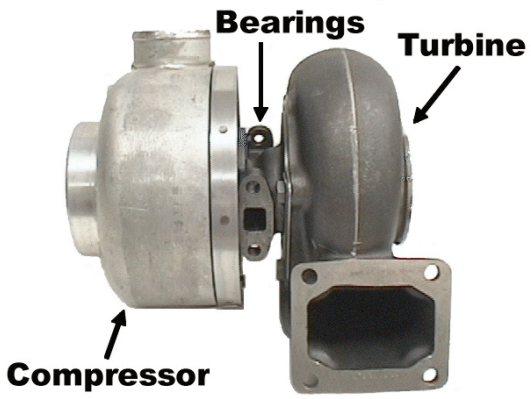


Figure 7-2. Turbocharger.

Turbocharging is a form of supercharging. Rather than driving the compressor mechanically from the engine, a turbine-powered compressor is used. The source of energy used to turn the compressor is derived from the exhaust gases. From the viewpoint of freeing the crankshaft from an additional load, driving the compressor using exhaust gases is preferred to driving the compressor using the crankshaft.

On the surface, the conversion of the energy contained in the exhaust into additional horsepower would appear to be a benefit provided at little cost. In reality, turbocharging complicates engine operation, places a greater strain on the engine's structure, generates additional heat in the engine compartment, increases the demands placed on the lubrication system, and requires upper deck connections to various components of continuous flow fuel injections systems. Turbocharging systems typically require some mechanism for controlling the output of the compressor. These systems range from basic mechanical controls manipulated directly by the operator to automatic systems that employ special controller(s).

Some basic items to keep in mind when considering the operation of a turbocharger equipped with automatic controller(s) are the waste gate actuator, the opening of the oil valves, and the rpm of the engine. The waste gate actuator is spring loaded in a direction that opens the waste gate to reduce the speed of the compressor. So any action that allows the waste gate actuator to spring load open works to reduce upper deck pressure. The oil valves housed in the various controllers are connected in parallel. This means that only one valve needs to open to allow oil to flow from the waste gate actuator. Such action causes the waste gate to spring load open.

The rpm of the power plant may serve as a limitation to the ability of the compressor to generate higher levels of upper deck pressure. Consider the relationship between the energy contained in the exhaust and engine rpm. At low rpm, the temperature of the exhaust is relatively low and the volume of exhaust flow is also low. This means that the amount of energy present in the exhaust is too low to drive the turbine at high speeds. As a consequence, the potential to generate higher levels of upper deck pressure at low engine rpm is not present. Stated another way, before high levels of upper deck may be reached, the exhaust gas temperature and the volume of exhaust must be substantial.

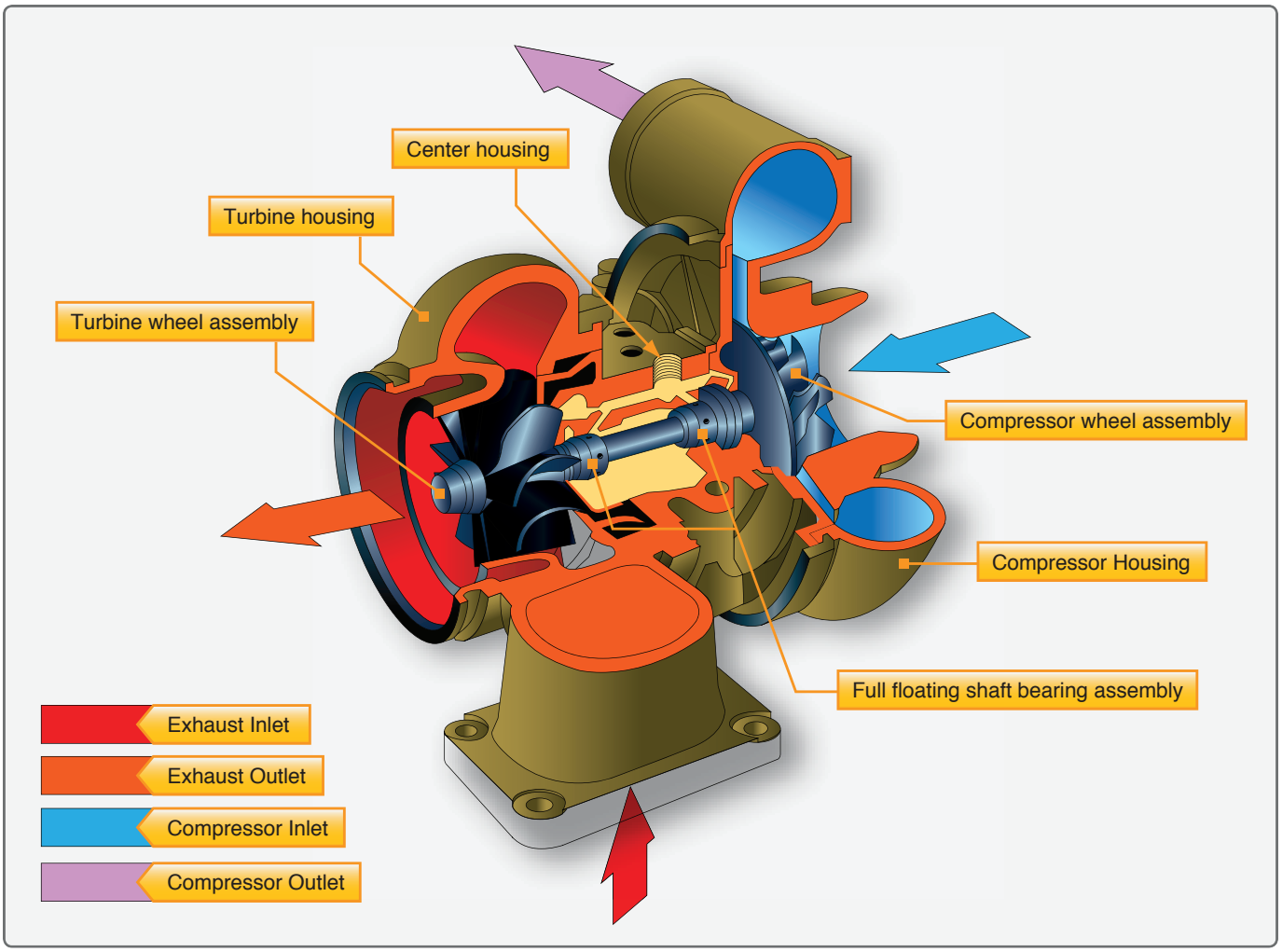


Figure 7-3. Turbocharger illustration.

The basic construction of the turbocharger is common throughout the industry. On one end of the unit is the turbine. On the other end is the compressor. A common shaft connects the two. A bearing and seal section separate the turbine end from the compressor end. A turbine nozzle encircles the turbine. This nozzle has a convergent shape. The diffuser receives the output from the compressor and has a divergent shape. See ***Figure 7-3***. The speed of the turbocharger may reach 75,000 rpm.

TURBINES

One of the principle elements of a turbocharger is the turbine. Its job is to extract heat energy from the exhaust gases and convert that energy into a motive force that drives the compressor. At and above cruise power settings, exhaust gases directed at the turbine contain ample energy to spin the compressor at speeds that provide pressurized air to the engine's inlet, or upper deck. Before being applied to the turbine, the exhaust gases are accelerated. This is accomplished by passing the exhaust through a nozzle. Because the speed of the exhaust needs to be accelerated, a ***convergent-shaped nozzle*** is used to direct the exhaust gases at the turbine. Gases departing the turbine are ported overboard. The outflow from the turbine is identified by the relatively large exhaust pipe associated with the exhaust system. Normally, a smaller, conventional size tailpipe is used to discharge exhaust gases that do not pass through the turbine. ***[Figure 7-4]***

COMPRESSORS

Directly connected to the turbine is a single-stage, centrifugal type compressor. This type of compressor is well-suited for the task as it provides a high pressure output in a single stage. By contrast, axial flow compressors are ill-suited for this purpose as multiple stages of compression would be required to meet the desired level of upper deck pressure. Such a design would necessitate a much longer compressor.

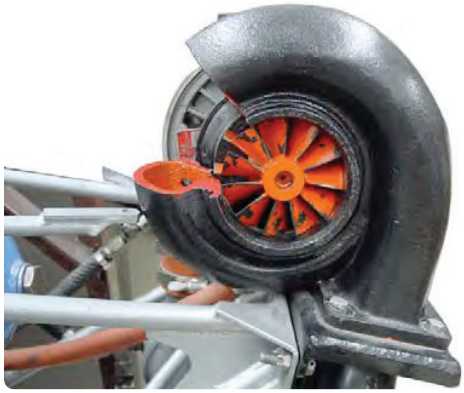


Figure 7-4. Turbine Section. Note the design of the turbine and the convergent scroll surrounding the turbine. Also note the size of the exhaust outlet in the center of the casing.



Figure 7-5. Turbocharger Compressor. Note the divergent-shaped scroll, or diffuser, around the impeller and the size of the main air inlet in the center of the housing.

A ***diffuser***, or ***divergent-shaped scroll***, surrounds the perimeter of the compressor. Its job is to reduce the velocity of the compressed air leaving the compressor. This action increases the pressure of the air.

The compressed air exiting the compressor assembly is directed to the fuel metering system. It is commonly called ***upper deck air***. Upper deck air is also ported to various components of the fuel injections system. As previously mentioned, such components include the air bleeds of the fuel nozzles, the fuel flow gauge in the cabin, and the aneroid of the Continental fuel pump. If these components do not sense upper deck pressure, severe operational problems will develop. Upper deck air may also be used for cabin pressurization. ***[Figure 7-5]***

WASTE GATE SYSTEM

Waste gates are special valves that are used to control the flow of exhaust gases through the turbine section of

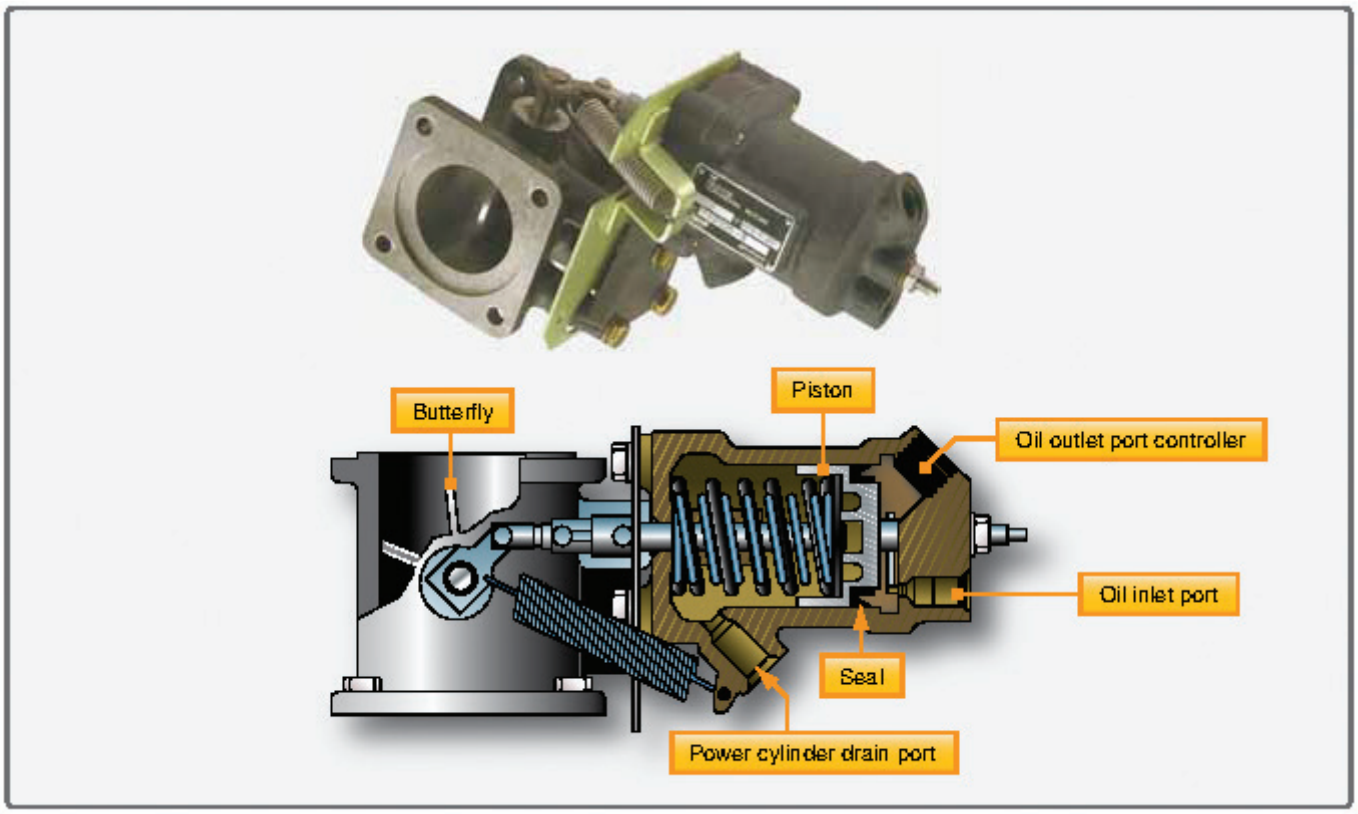


Figure 7-6. Waste gate and actuator.

a turbocharger. The waste gate is similar in shape to the butterfly valve typically found in fuel metering devices. The waste gate valve is normally made of cast iron and is installed in the exhaust system. ***[Figure 7-6]***

The purpose of the waste gate is to control the volume of exhaust flow through the turbine, thereby controlling the speed of the turbine, the speed of the compressor, and, as a consequence, the output from the compressor. When the waste gate is fully closed, the maximum flow of exhaust passes through the turbine. When the waste gate is fully open, the flow of exhaust is allowed to pass freely into the atmosphere without passing through the turbine. When the waste gate is between the full opened and full closed position, a proportion of the exhaust will flow through the turbine and the remainder will bypass the turbine.

The waste gate valve may be positioned directly by the action of the operator or by an actuator and controller(s). Mechanical controls may either employ a separate control or may be interconnected to the throttle lever. The latter employs a cable that runs from the throttle lever to the waste gate control lever. See ***Figures 7-7 and 7-8***.

On automatic systems, an actuator is used to change the position of the waste gate butterfly. The actuator is positioned by two forces: (a) hydraulic pressure and (b) spring tension. The spring mechanically moves the waste gate actuator so that the butterfly fully opens. In a way, this acts as a fail/safe measure on fixed-wing aircraft. ***[Figure 7-9]***

Physical attributes of the waste gate actuator are similar to that of ordinary hydraulic cylinders. The main differences are its spring-loaded operation to open the waste gate butterfly valve and an orificed inlet. The inlet is connected to a source of fluid flow. Normally engine oil is used as the source of hydraulic force connected to the inlet. The outlet of the actuator is connected to the valves of the various controllers. When the valves are closed, hydraulic fluid enters the actuators faster than it escapes. This hydraulic action causes the actuator to move in a direction that closes the waste gate butterfly.

The basic theory of positioning the waste gate actuator is to control how much fluid exits the actuator. The mechanical action of the spring takes care of moving the actuator to open the waste gate. Therefore, the primary role of the hydraulic system and valves is to move the waste gate valve toward closed. Because of the orificed inlet and a somewhat constant source of hydraulic pressure, the valve(s) that connect to the outlet of the actuator is(are) the key to its operation.

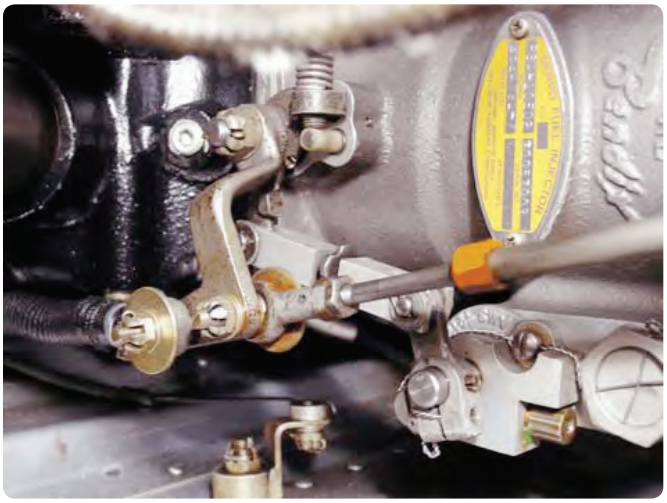


Figure 7-7. Direct Cable from fuel injector connects to waste gate.



Figure 7-8. Cable connection from fuel injector to waste gate lever.

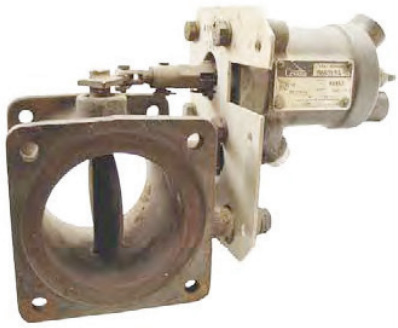


Figure 7-9. Waste gate and actuator in the spring-loaded opened position.

The oil valves, that are opened and closed by the action of the controllers, are connected in parallel with one another and therefore act independently of each other. Due to this configuration, when one valve opens, the waste gate valve springs loads open. When all the valves are closed, the waste gate closes by hydraulic action. When one, or more, valves are partially open, a balance between the inlet oil and the exiting oil holds the waste gate butterfly in some intermediate position.

LYCOMING TURBOCHARGING SYSTEM

One of the more popular turbocharging systems is used by Lycoming. As previously presented, one configuration involves the manually controlled system that allows the operator to physically position the waste gate. In such systems, either a separate control cable is attached to the waste gate valve or an interconnection between the throttle and waste gate is utilized as illustrated in ***Figures 7-7 and 7-8***. A typical automatic system includes the: (a) waste gate actuator, (b) density controller, and (c) differential pressure controller. A discussion of the operation of the controllers associated with the automatic design is given to provide insight into the operation of the system.

LYCOMING CONTROLLERS AND RELIEF VALVE

Most turbocharging systems have some means for controlling the output of the compressor. In this regard, several aspects of compressing air are taken into consideration. If some control mechanism is not used to safeguard against exceeding a number of parameters, damage to the power plant and the turbocharger may occur.

One concern regarding the use of a turbocharger is the temperature of the air ingested by the cylinders. When a gas is compressed, the temperature of the gas increases based on the amount of compression. The greater the compression, the greater the resultant increase in temperature.

It may be difficult to understand why it is important to worry about the temperature of the air when ultimately the temperature of the fuel/air charge skyrockets during the combustion process. The problem rests with the combustion characteristics of the fuel/air charge. If the fuel/air charge entering the cylinders is excessively hot, combustion characteristics of the fuel will be adversely affected. In particular, detonation becomes a major concern when the induction air is unduly heated. Remember that the cylinder receiving the fuel/air charge is going to subject the charge to its compression stroke before the ignition event. Compressing an overly heated fuel/air charge may increase the temperature to the point that the charge ignites. This action may be easier to visualize if one considers the combustion process of a diesel engine. The diesel achieves combustion solely through compressing the fuel/air charge. Where the compression ratio of a diesel power plant is far greater than that of a gasoline engine, the action of the turbocharger in chorus with the compression of the engine and the greater volatility of gasoline may result in premature ignition.

Some systems use an intercooler to reduce the temperature of the air before it enters the cylinders. An intercooler is shown in ***Figure 3-37***. This measure is used to lessen the chance of uncontrolled ignition of the fuel/air charge. Intercoolers are often employed when the turbocharger is used for cabin pressurization. The extra measure of compression needed for cabin pressurization necessitates the need for the air-to-air heat exchange provided by the intercooler.

Controllers associated with turbocharging systems also take into consideration the wear and tear placed on the turbocharger. If the ambient pressure provided by Nature is ample to supply the needs of the power plant at any given power setting, why spin the turbine or why spin it faster than its needs to turn? Needlessly spinning the turbine works against the longevity of the unit. Therefore, some controllers protect the system by spinning the compressor just fast enough to supply the necessary upper deck pressure.

For the most part, controllers keep a vigilance over certain operating parameters. Depending on the system and the particular manufacturer, they may sense the output of the compressor, the manifold pressure, the rate of increase of the upper deck pressure, the throttle position, the ambient nacelle pressure, and so forth. Normally, the controllers have the ability to work independent of each other. Stated another way, if a target parameter is exceeded, the controller in charge of that variable takes action to bring the system back to its safe operating range regardless of the conduct

of the other controllers. The controllers are engineered to manipulate the position of the waste gate actuator. By controlling the position of the waste gate actuator, the speed of the turbine and the output of the compressor are controlled. This issue is addressed in greater detail in the following sections.

Despite the apparent complexity of the controllers, keep in mind that the controllers have certain inputs that they monitor. In addition, they are generally unaware of parameters they don't monitor. Consider the controllers to have an acute case of tunnel vision in which they closely monitor their assigned variables and respond in the direction necessary to maintain their designated ranges of operation.

DENSITY CONTROLLER

Most Lycoming turbocharging systems that have automatic controllers include a device known as the density controller. It is similar to the absolute pressure controller used with Continental systems. The density controller, as its name implies, works to maintain the density of the upper deck air delivered to the fuel-metering unit. Density is determined by the pressure and temperature of the air.

The density controller contains a pressure sensitive device and a valve. The latter controls the flow of oil through the waste gate actuator. The aneroid, which senses compressor discharge pressure or upper deck pressure, is connected to the valve in a fashion whereby expansion and contraction of the aneroid alter the position of the oil valve. As the valve changes in terms of opening, the flow rate of the oil through the waste gate actuator varies. ***[Figure 7-10]***

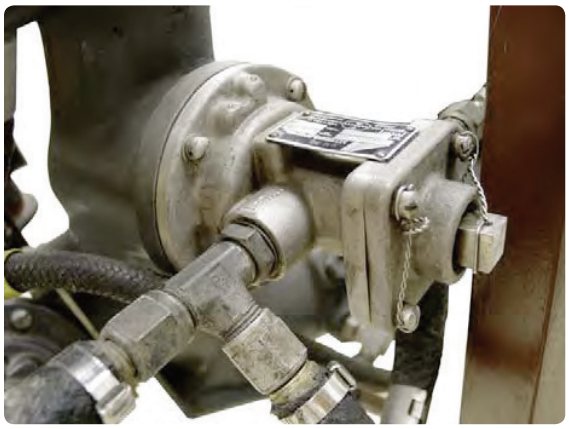


Figure 7-10. Density controller sensing compressor outlet.

In regard to operation, consider the density controller to be something of an upper deck limiter. It is adjusted to achieve and maintain a certain quantity of upper deck pressure. For example, a density controller is adjusted for 36"HG (inches of mercury). When the compressor discharge is less than 36"HG, the valve closes to minimize the loss of oil from the waste gate actuator. This, in turn, works to close the waste gate, thereby increasing the amount of exhaust gases directed at the turbine. The speed of rotation of the turbocharger is increased. And, as a consequence, the output from the compressor, or upper deck pressure, increases.

When the engine is operating above the target upper deck setting, the density controller opens its oil valve to bleed oil from the actuator. This causes the spring-loaded piston in the waste gate actuator to open the waste gate and allow exhaust gases to bypass the turbine. The result of such action causes the turbine to decelerate and, in the end, reduce upper deck pressure. However, once the excess upper deck pressure returns to the desired value, the valve positions itself to maintain that amount of upper deck pressure.

To further understand the operation of the density controller, consider the following scenarios. With the aircraft on the ground and the engine running at idle, the manifold pressure is low. Furthermore, upper deck pressure will basically be barometric pressure. Because barometric pressure is likely to be less than the density controller's setting (e.g., 36"HG), the controller closes its valve in an attempt to keep the oil in the waste gate actuator and accelerate the speed of the compressor. The intent of this action is to increase upper deck pressure to the target value. In the next section, a description on the operation of the differential pressure controller will demonstrate that despite the demand from the density controller to increase upper deck pressure, the differential pressure controller will override the action of the density controller. In addition, the low energy content of exhaust gases at idle is not capable of driving the turbine at the speeds necessary to generate high levels of upper deck pressure.

During takeoff another response is generated. Because the energy level of the exhaust is able to drive the turbine at high speeds, the compressor output may reach, or attempt to exceed, the upper deck limit. When the upper deck limit is attained, the density controller

opens its valve and allows oil to drain from the waste gate actuator. The latter spring loads open and allows a portion, or all, of the exhaust to bypass the turbine. This reduces the rpm of the turbine and lessens the upper deck pressure until the target value is attained. The density controller operates to hold this value until the critical altitude of the engine is exceeded or another controller intercedes by opening its valve. The critical altitude is the highest altitude that the engine continues to produce its rated power. Above critical altitude, the density controller remains closed.

DIFFERENTIAL PRESSURE CONTROLLER

Another unit commonly used with the density controller in the Lycoming system is the differential pressure controller. It compares the level of upper deck pressure to manifold pressure. The former represents the potential available power input while the latter indicates the actual power input consumed by the engine. ***[Figure 7-11]***

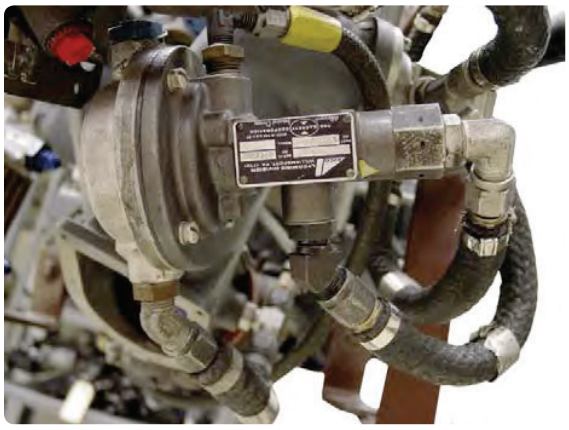


Figure 7-11. Density controller sensing compressor output and manifold pressure.

The role of the differential pressure controller is to maintain enough upper deck pressure to sustain the power demand made by the operator. In other words, the upper deck, or power input potential, must be at least as great as (actually greater than) the power input consumed by the power plant. The manifold pressure cannot exceed the upper deck. Normally the differential pressure controller works to maintain an upper deck pressure that is approximately 2.4"HG greater than manifold pressure. The name differential pressure controller accurately describes the function of the mechanism. For specific data regarding the value of a particular differential pressure controller, refer to the appropriate service information.

One benefit generated by the action of the differential pressure controller is that it works to spin the turbine only fast enough to supply an adequate level of upper deck pressure needed to sustain the desired manifold pressure. This results in less wear and tear on the turbine. Remember that the density controller wants to spin the turbine fast enough to produce maximum limit upper deck pressure all the time. But if the power demand placed upon the engine by the operator is low, why spin the turbine any faster than it needs to turn to supply the necessary upper deck pressure? For example, when the pilot is operating in the traffic pattern at low cruise power (e.g., 20"HG), the density controller is trying to rotate the turbine fast enough to produce maximum upper deck. The differential pressure controller, however, compares upper deck and manifold pressure. It realizes that if the manifold pressure is only 20"HG, that a minimum of approximately 22.4"HG of upper deck pressure is needed to sustain the manifold pressure consumed by the engine. In this scenario the ambient pressure provided by Nature is well above the 22.4"HG upper deck pressure targeted by the differential pressure controller. Because the minimum upper deck value has been met or exceeded by Nature, the differential pressure controller valve fully opens. This allows the waste gate actuator to spring load open and reduce the rpm of the turbocharger. In the final analysis, the turbine does not need to spin because the available upper deck provided by Nature meets or exceeds the demand of the engine.

Where the previous example did not require a boost from the compressor to sustain the manifold pressure, another situation will help to further illustrate the operation of the differential pressure controller. In this example the pilot is cruising at a manifold pressure greater than that provided by Nature (e.g., 25"HG at 10,000 feet altitude). Consequently, the differential pressure controller holds the position of the waste gate so that 27.4"HG upper deck pressure is supplied to the fuel metering unit. In comparison to the density controller that is attempting to raise the upper deck to its maximum value (e.g., 36"HG), the differential pressure controller saves wear and tear on the turbine by spinning it just fast enough to sustain 27.4"HG of upper deck pressure.

To understand the interaction between the two controllers, the pilot disturbs the power setting in the previous example by opening the throttle. As the manifold pressure increases, the differential pressure controller increases the upper deck pressure. This continues until the maximum upper deck value is reached. At this point, the density controller limits the upper deck.

If the aircraft in the previous example is placed into a climb, the density controller gradually closes as the altitude increases. At or above the aircraft's critical altitude, the density controller remains closed and the only controller that opens is the differential pressure controller. The latter opens and closes as needed to maintain the required surplus of upper deck pressure. This helps prevent a condition known as bootstrapping.

A surplus of upper deck pressure is needed to prevent bootstrapping. A turbocharged engine enters a bootstrapping condition when upper deck and manifold pressure are equal or near equal. When this occurs, a surge in rpm perpetuates additional rpm surges. This is because the surge in rpm produces a surge in the exhaust flow. The surge in exhaust flow generates a surge in the turbine speed which causes a surge in the upper deck pressure. The surge in the upper deck causes another rpm surge and the cycle repeats.

To stop bootstrapping, the operator needs to increase engine speed by at least 50 rpm. Do not attempt to increase rpm by opening the throttle. Further opening of the throttle will not allow the engine to exit from its bootstrapping condition. Instead, to break the bootstrapping cycle, the pilot needs to leave the throttle in the same position and move the propeller control toward its increase rpm or low pitch position. When the rpm increases for the same throttle position, manifold pressure goes down. This is because more air is removed from the manifold for the same throttle opening. With a drop in manifold pressure, a pressure differential between upper deck pressure and manifold pressure will be re-established.

ABSOLUTE PRESSURE RELIEF VALVE

A number of Lycoming turbocharged power plants are equipped with an absolute pressure relief valve. This mechanism serves the same purpose as the manifold pressure relief valve used on the Cessna turbocharging systems.

The absolute pressure relief valve is situated between the outlet of the compressor and the inlet to the fuel metering unit. When the upper deck pressure exceeds the rated value of the engine by approximately 2"HG, the valve unseats and bleeds upper deck pressure. Similar to the manifold pressure relief valve used on the Cessna turbocharging system, the placement of this valve in the upper deck area is needed to prevent induction leaks. If the valve is located in the induction manifold, every time it opened there would be an induction leak. The air exiting the absolute pressure relief valve vents harmlessly into the engine compartment. When the absolute pressure relief valve opens, the level on upper deck pressure is reduced, thereby limiting the absolute pressure applied to the engine. ***[Figure 7-12]***



Figure 7-12. Absolute pressure relief valve opens when upper deck pressure meets or exceeds specified limit.

CESSNA CONTROLLERS AND RELIEF VALVE

Cessna turbocharging mechanisms are configured into various systems. Different systems are designated based on the types of controllers used to position the waste gate.

A description of the various controllers is contained herein. Because the controllers serve the same function regardless of their installation, the focus is limited to controller input(s) and basic operation. Also, where this section is entitled “Cessna Controllers and Relief Valve,” it basically applies to Continental engines found in turbocharging systems used by other manufacturers (e.g., Beechcraft).

ABSOLUTE PRESSURE CONTROLLER

The ***absolute pressure controller (APC)*** is similar to the density controller of the Lycoming system. It measures compressor output and works to maintain a certain upper deck pressure (e.g., 36"HG). As with the other controllers, its name describes the role played by this mechanism. It controls the absolute pressure of the upper deck.

The aneroid in the APC is connected to the oil valve that controls the flow of oil from the waste gate actuator. Just like the Lycoming system, the positions of the waste gate actuator and the waste gate butterfly valve are manipulated by controlling how much oil is allowed to leave the spring-loaded waste gate actuator. Oil that enters the actuator passes through an orifice. The outlet from the actuator is ported to the various controllers. They are connected in parallel with one another. This arrangement means that any single valve may open to bleed oil from the actuator. A separate discussion on the waste gate actuator is provided in a previous section within this unit.

The APC is adjusted for a single value (e.g., 36"HG). When the pressure is below the set value, the valve is held closed in an attempt to keep oil in the waste gate actuator, thereby closing the waste gate butterfly and increasing the speed of the turbo compressor.

When the upper deck meets or exceeds the set value, the valve opens to allow oil to flow from the actuator. This action causes the waste gate actuator to move under spring pressure in a direction that opens the waste gate butterfly valve. When the waste gate butterfly opens, less exhaust passes through the turbine, causing a reduction in compressor rpm and a lowering of upper deck pressure. ***[Figure 7-13]***

VARIABLE ABSOLUTE PRESSURE CONTROLLER

The variable absolute pressure controller (VAPC) is a derivative of the absolute pressure controller (APC). Just like the APC, the VAPC senses upper deck pressure and uses an aneroid to position its oil valve housed in the controller. Where the APC only senses upper deck pressure, the VAPC also considers the position of the throttle valve as set by the operator. The main difference between the two controllers pertains to the upper deck pressure target.

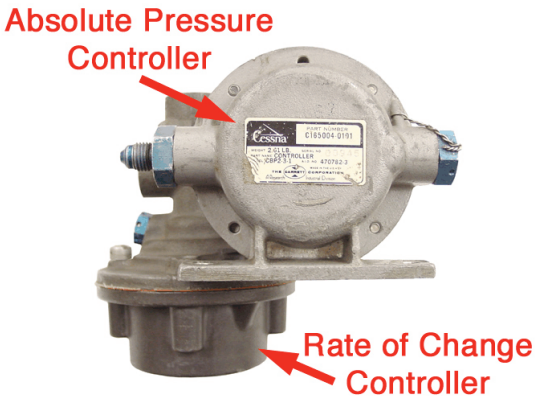


Figure 7-13. Duplex controller with absolute pressure controller (APC) and rate of change controller (RCC) sharing the same housing.

APCs are adjusted for a single set value. By comparison, VAPCs vary their upper deck pressure limit based on throttle position. In this way, the VAPC considers the manifold pressure demand. When the throttle position is near idle, the absolute pressure demand from the controller is low. Therefore, the turbine is instructed to provide just enough upper deck pressure to meet the demand placed on the engine rather than trying to deliver a fixed, high level of upper deck pressure. When there is a large throttle opening, the VAPC raises the absolute pressure target to an appropriate magnitude. Again, the name of the controller, variable absolute pressure controller, describes its function. Systems that use solely the VAPC typically place a special operating requirement on the pilot. At high altitude, the operator may have to adhere to maximum manifold pressure limit based on altitude limits. Manifold limits may also be assigned based on engine rpm. ***[Figure 7-14]***

PRESSURE RATIO CONTROLLER

Operators of aircraft equipped with supercharged reciprocating power plants must adhere to upper deck and manifold pressure limits established by the aircraft manufacturer. Where the engine instruments may be marked with red lines and other markings that depict various limits, such admonitions are often based on sea-level performance. At altitude, additional limits may appear in the form of placards and data included in the operator's manual.

The reason additional limitations are needed for supercharged engines is related to the characteristics of air. As air is compressed, a change of temperature occurs. The

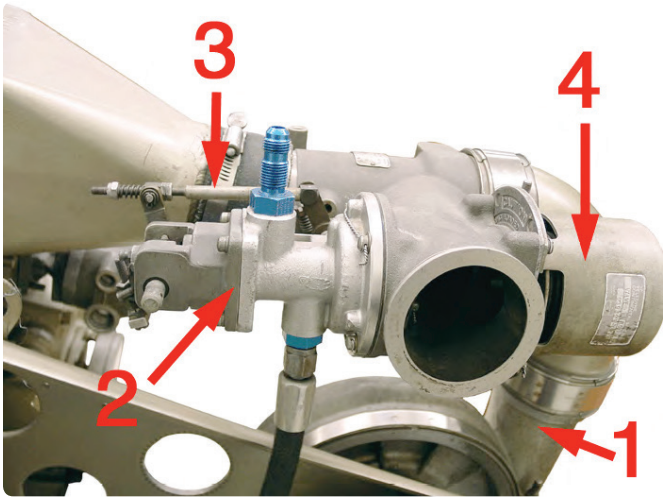


Figure 7-14. Variable absolute pressure controller (VAPC) and associated components: (1) compressor output, (2) VAPC, (3) throttle interconnect, and (4) manifold pressure relief valve.

relationship between pressure and temperature is a direct correlation. As air is compressed, its temperature increases.

Another variable that comes into play concerns changes in air pressure with altitude. Unless there is a pressure inversion, the barometric pressure drops with increases in altitude. This means that it becomes more and more difficult to maintain sea-level pressure as altitude increases. Superchargers attempt to overcome the loss of barometric pressure due to increases in altitude by compressing the air. A problem arises as the air experiences a great deal of compression to compensate for the associated pressure loss due to increases in altitude, the temperature increases to the point where uncontrolled ignition may occur. Refer to the explanation concerning uncontrolled ignition in the section entitled, "Lycoming Controllers and Relief Valve" for additional information concerning the problem with excessively heated induction air.

To guard against overheating compressor discharge air, either the pilot must adhere to the myriad of limits concerning upper deck pressure or some mechanism must be employed to prevent this problem. The pressure ratio controller is designed to limit upper deck at altitude. It senses ambient nacelle pressure and upper deck pressure. By sensing ambient nacelle pressure, the controller knows how much barometric pressure is provided by Nature. Where the APC still limits the maximum upper deck limit, the pressure ratio controller limits how much the air is compressed based on the ambient nacelle pressure. Just as its name implies, the pressure ratio controller restricts how much the air is compressed to protect the engine from excessively heated upper deck air. A common rate of compression is 2.2 times ambient nacelle pressure. Without the pressure ratio controller, operators have to closely monitor power settings and upper deck pressures on some aircraft to manually avoid excessively heated induction bound air. ***[Figure 7-15]***



Figure 7-15. Pressure ratio controller.

RATE OF CHANGE CONTROLLER

Thus far the Cessna controllers have limited absolute pressure and the pressure ratio between ambient nacelle air and upper deck. Another variable controlled on certain Cessna systems is the rate of change in the upper deck pressure.

The rate of change controller senses upper deck pressure. The sensor within the controller is divided into two sections. One side is connected directly to upper deck pressure while the opposing side senses upper deck after it passes through an orifice. This arrangement is similar to pneumatically operated rate of climb instrument. As its name implies, this unit controls the rate of change. It is primarily concerned with sudden and vigorous increases in upper deck pressure (e.g., 6.5"HG increase per second). Because the turbocharger system is cursed with lag time as changes to upper deck pressure occur, the risk of ***over boosting*** (exceeding the manifold pressure limit) or ***over shooting*** (going beyond the desired manifold pressure) is prevalent. This is due to the inherent characteristic of the system. Consider that

the controllers have to sense whatever input they receive. Then they must convert the signals into some command (e.g., open the oil valve, leave the oil valve alone, close the oil valve). Next, the oil must either escape the waste gate actuator or remain trapped within the actuator. Following this, the new volume of exhaust works on the turbine to change its speed. And finally, the new upper deck pressure reaches the fuel metering unit. To transform from one upper deck setting to another involves this time-consuming, chain reaction. Further consider that the rotating turbocharger has inertia that factors into these changes.

The rate of change controller is designed to minimize the risk of over boosting and over shooting. By controlling the rate of change of the upper deck as the pressure increases, the pilot has less to worry about in terms of over boosting and over shooting. Over boosting is dangerous because engine limitations are exceeding. Over shoots occur when the desired pressure is exceeded. Without this device, the operator has to cautiously increase power while monitoring the increase in upper deck. Refer to ***Figure 7-13*** for a depiction of the rate of change controller. In ***Figure 7-13***, the rate of change controller is housed along side of the absolute pressure controller. Combining two controllers into a single housing saves space in terms of component mounting and reduces hose clutter in the engine compartment by requiring fewer lines.

MANIFOLD PRESSURE RELIEF VALVE

Despite all the safeguards designed to keep the system from over boosting, some turbocharged engines include a manifold pressure relief valve. This device is not, as its name would lead one to believe, installed in the induction manifold. Rather, the valve is in the upper deck region. Because the upper deck is upstream of the induction manifold, the valve is designed to open when the upper deck reaches a predetermined limit. When the valve opens, the manifold is protected from over boosting. The operation of this unit is similar to the absolute pressure relief valve used on certain Lycoming turbocharging systems.

The manifold pressure relief valve is a spring-loaded, poppet valve. The poppet valve contains a certain surface area. When the pressure acts on this surface area, a force is produced. Remember that force equals area times pressure. On the non-upper deck side of the poppet valve is a spring. The strength of the spring is set so that the valve unseats when the pressure reaches a preset value. When the valve unseats, upper deck air escapes from the duct work thereby reducing the quantity of upper deck pressure. By controlling the upper limit of the upper deck pressure, protection against over boosting is provided.

The question becomes, "Why is the manifold pressure relief valve installed in the upper deck area rather than in the manifold, as its name suggests?" The reason is simple. If the manifold pressure relief valve is installed in the intake manifold rather than in the upper deck area, a manifold leak would occur each time the valve opened. Because the valve is upstream of the fuel-metering device, the opening of the valve does not disturb the fuel/air mixture, it only lessens the upper deck pressure. ***[Figure 7-16]***



Figure 7-16. Manifold pressure relief valve.

Question: 7-1
What is meant by critical altitude?

Question: 7-2
What is the principle difference between a turbocharger and a supercharger?

Question: 7-3
What causes exhaust gases to accelerate prior to entering the turbine?

Question: 7-4
A diffuser _____ the velocity of air leaving the compressor and _____ its pressure.

Question: 7-5
If the waste gate would malfunction by sticking in the _____ position, the turbine could overspeed to the point of over boosting the engine.

Question: 7-6
When is an intercooler system the desired method of controlling a turbo chargers output temperature?

Question: 7-7
Name four parameters which may be monitored by an automatic waste gate controllers.

Question: 7-8
A Lycoming density controller monitors the _____ and _____ of the upper deck air.

ANSWERS

Answer: 7-1
Highest altitude at which an engine is able to produce a specified amount of power.
page 7.2

Answer: 7-2
A turbocharger is driven by exhaust gases. A super charger is driven directly from the crankshaft.
page 7.3

Answer: 7-3
Passage through a convergent shaped nozzle.
page 7.4

Answer: 7-4
Decreases; Increases.
page 7.5

Answer: 7-5
Closed position.
page 7.6

Answer: 7-6
When the turbochargers output is also used for cabin pressurization.
page 7.7

Answer: 7-7
*Manifold pressure.
*Compressor output.
*Upper deck pressure rate of change.
*Nacelle pressure.
page 7.8

Answer: 7-8
Pressure; Temperature.
page 7.9

Question: 7-9
A Differential Pressure controller compares pressures what two areas of pressure?

Question: 7-10
When oil pressure is increased in a waste gate actuator, the speed of the turbo compressor _____.

ANSWERS

Answer: 7-9
Upper deck pressure and manifold pressure.
page 7.9

Answer: 7-10
Increases.
page 7.10



PART-66 SYLLABUS	LEVELS		
CERTIFICATION CATEGORY →	A	B1	B3

Sub-Module 08
Piston Engine - Lubricants and Fuels

16.8 - Lubricants and Fuels			
Properties and specifications;			
Fuel additives;			
Safety precautions.	1	2	2

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

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

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

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

LUBRICANTS AND FUELS

FUNCTIONS OF LUBRICANTS

Lubricants associated with aircraft power plants have a number of critical functions. They include:

1. Reducing friction.
2. Serving as a cushion.
3. Enhancing sealing between parts.
4. Transferring heat for engine cooling.
5. Cleaning the interior of the engine.
6. Serving as a hydraulic fluid.
7. Minimizing corrosion.

REDUCING FRICTION

Friction may be defined as the rubbing of one object or surface against another. One surface sliding over another surface causes sliding friction, as found in the use of plain bearings. The surfaces are not completely flat or smooth and have microscopic defects that cause friction between the two moving surfaces. Rolling friction is created when a roller or sphere rolls over another surface, such as with ball or roller bearings, also referred to as anti-friction bearings. The amount of friction created by rolling friction is less than that created by sliding friction and this bearing uses an outer race and an inner race with balls, or steel spheres, rolling between the moving parts or races. Another type of friction is wiping friction, which occurs between gear teeth. With this type of friction, pressure can vary widely and loads applied to the gears can be extreme, so the lubricant must be able to withstand the loads.

SERVING AS A CUSHION

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 crankshafts and connecting rods, which are subject to shock loading. As the piston is pushed down on the power stroke, it applies loads between the connecting rod bearing and the crankshaft journal. The load-bearing qualities of the oil must prevent the oil film from being squeezed out, causing metal-to-metal contact in the bearing.

ENHANCING SEALING BETWEEN PARTS

The oil aids in forming a seal between the piston and the cylinder wall to prevent leakage of the gases from the combustion chamber. Another component benefiting from the sealing action of oil is the oil pump. When oil pump members are dry, they may be unable to draw oil from the oil tank or sump and send the lubricant through the internal passageways of the engine. In such instances, the pump has lost its prime. Once the oil pump gears and housing are coated with oil, the action of the oil pump will be restored.

TRANSFERRING HEAT FOR ENGINE COOLING

As oil circulates through the engine, it absorbs heat from the pistons and cylinder walls. In reciprocating engines, these components are especially dependent on the oil for cooling. Oil also flows through every part of the engine. The oil absorbs heat from the interior of the engine and transfers the heat to the atmosphere as it travels through the oil cooler and oil tank.

CLEANING THE INTERIOR OF THE ENGINE

Oils clean the engine by reducing abrasive wear and by picking up foreign particles and carrying them to a filter where they are removed. The dispersant, an additive, in the oil holds the particles in suspension and allows the filter to trap them as the oil passes through the filter.

SERVING AS A HYDRAULIC FLUID

Oil is a hydraulic fluid. This property of oil is used in components such as the valve lifters, propeller governors, and waste gate actuators.

MINIMIZING CORROSION

The oil also prevents corrosion on the interior of the engine by leaving a coating of oil on parts when the engine is shut down. This is one of the reasons why the engine should not be inactive for long periods of time. The coating of oil preventing corrosion will not last on the parts, allowing them to rust or corrode. Special preservation oils are blended to cling to the metal surfaces for protracted periods of time.

TYPES OF LUBRICANTS

In general, lubricants are substances that are used to reduce friction between objects with relative motion. As previously mentioned, lubricants are also used to prevent or minimize corrosion, serve as a hydraulic fluid, transfer heat, act as a sealing agent, and transfer heat. Lubricants may be derived from natural sources, such as animal, vegetable, minerals, and petroleum, or they

may be made from synthetics. Lubricants made from animals are not suitable for use in traditional aircraft power plants. Such lubricants are generally unable to withstand high temperature environments.

Vegetable oils are also rarely used in aircraft engines. One exception is castor oil. The latter was used in the rotating-crankcase engines popular during the First World War. Pilots often suffered health-related issues from the use of castor oils.

Mineral lubricants in solid forms are not often used in aircraft engine. Graphite, mica, and soapstone and other such lubricants do not transfer heat and do not cushion reciprocating loads as well as liquid lubricants. They may be mixed with liquid lubricant to enhance the performance of the oil.

Petroleum lubricants have been a standard in aviation since the inception of powered flight. They are the main lubricants used in current aircraft power plants. Oils provide all of the functions required of engine lubricants. They are available in straight weights and multi-viscosity grades. Seasonal oil changes allow pilots to use thin oils for cold weather operations and thicker oils for warm weather periods. Multi-viscosity oils may be suitable for year-round use. Greases have limited uses in aircraft power plants. One application is to serve as a lubricant for the cam lobe of certain model magnetos. Some older power plants use grease to lubricate rocker arms and parts of the valve train. Greases have relatively high viscosity when compared to oils and are able to remain on the parts to which they are applied.

Synthetic oils are available in blended forms and pure synthetic. The blended products are mixed with petroleum oils. These products are available in a variety of grades.

TYPES OF AVIATION ENGINE OILS

Oils used in aircraft engines have evolved over the years. From the relatively crude products used in the early 1900s to the oils used today, the development of new products have enhanced aviation safety, engine longevity, and allowed high performance engines to be developed. When selecting an oil for an aircraft, refer to the appropriate technical information provided by the manufacturer. Certain engines may use special oils that are unique to a particular manufacturer or installation.

Early lubricants were straight mineral oils. Today straight mineral oils are used for most engine break-in periods and many radial engines. Multi-viscosity mineral oils are also available. Protracted use of mineral oils in an engine tends to form sludge and other deposits within the engine. Sufficient build up of sludge in the propeller shaft may hinder constant speed propeller operation. Technicians have to de-sludge propeller shafts in such cases.

Detergent oils were used for a period. These products were formulated to scrub the engine during operation to minimize the accumulation of sludge and other deposits. These oils were subsequently replaced by ashless dispersant oils during the 1950s.

Ashless dispersant or AD oils have been used in reciprocating aircraft power plants for over half a century. Rather than scrub the interior of the engine, they keep minute particles in suspension. The particles that do not get trapped in filters drain out with the oil during servicing periods. Because they suspend particles, this oil darkens with use more rapidly than other oils. AD oils do not clean deposits already contained in an engine. For example, if an operator runs mineral oil in an engine for 1,000 hours and switches to an AD oil, the ashless oil will not remove the sludge and deposits accumulated during the previous 1,000 hours of operation. AD oils are available in straight weights or multi-viscosity products.

Semi-synthetic oils are popular throughout the general aviation segment. These products combine mineral base oils with synthetic hydrocarbon base stocks. They offer excellent performance with superior cold weather operation and high temperature performance. They include anti-wear and anti-corrosion additives that protect the engine.

Synthetic oils are costly when compared to other engine lubricants. Oil change intervals are normally extended with synthetic oils. They further claim to have superior performance during cold weather starting.

PROPERTIES OF LUBRICANTS

Lubricants possess a number of properties that are germane to their function. These include: viscosity, pour point,cloud point, flash point, and fire point.

Viscosity is the internal fluid resistance to flow. In simple terms, the higher the viscosity of an oil, the more it resists flowing. Viscous oils flow more slowly than thin oils. Viscosity of an oil is determined using a special device. A number of organizations and industries have established their own system of indicating oil viscosity.

Pour point is considered to be the lowest temperature that an oil will flow. The lower the pour point, the easier an oil will flow at normal temperatures. Oils may contain additives to improve their pour point temperature.

Cloud point refers to the temperature that causes the wax contained in an oil to become visible. This temperature is normally slightly greater than the point at which an oil becomes a solid.

Flash point defines the temperature at which an oil emits sufficient vapors to form a combustible mixture. This combustion is momentary and must be triggered by a source of ignition.

Fire point, as its name implies, is the temperature at which an oil is able to continuously burn. As with the flash point, a source of ignition is needed to set the vapors on fire.

OIL GRADE DESIGNATIONS

Aviation oils use a unique system to identify oil grades or oil viscosities. A device, commonly referred to as a Saybolt Universal Viscosimeter, is used for determining oil viscosity. The device heats the sample oil to specific temperatures and measures the time it takes for a volume of oil to flow through a calibrated orifice.

Aviation oil grades have SAE (Society of Automotive Engineering) and military equivalent values. A grade 65 equals a SAE 30 weight oil and a military AN1065. Aviation grade 80 is the same as a SAE 40 weight oil and AN1080. Grade 100 oil is a SAE 50 weight and AN1100. A grade 120 oil equals a SAE 60 weight lubricant and AN1120. Aviation grade 140 oil is a SAE 70 weight oil. The higher the aviation grade, the thicker the oil, or the more viscous the oil.

Multi-viscosity oils are generally thinner oils that do not become as runny as straight weight oils when heated. For example, an oil designated as 20-50 is a 20 weight oil when cold but has the same viscosity as a straight 50 weight oil when heated to operating temperature. The advantages of multi-viscosity oils are that they flow easily during engine start and cold temperature operations and offer the protection of thicker oils when the engine is at operating temperatures. And, as previously mentioned, the multiviscosity oil may be used throughout the year without having to change from one viscosity to another.

The aircraft and engine manufacturers will specify the correct weight oil for their engines. One major determining factor is the ambient temperature in which the engine will operate.

Where many operators use a particular oil in their aircraft and prefer to only use that product, aviation oils may be mixed without fear of engine stoppage. For example, a plane is serviced with 20-50 multi-viscosity semi-synthetic oil. If the oil level falls below a safe level and the particular oil currently in the engine is not readily available, the addition of straight-weight oil (e.g., grade 100) will not have any ill-effects on the engine. Of course, adding the same brand and type of oil is generally preferred.

AVIATION FUELS

Most aircraft consume fuel to produce thrust for flight. Where efforts are undertaken to fly aircraft via electrical power sources, the typical aircraft burns a fuel source.

Fuels are available in a limit number of forms. Fuels may be classified as being: solid, liquid, or gaseous. A description of each is provided.

Solid fuels are mostly used for rocket-type engines. Solid fuel rocket engines are frequently used to help an aircraft accelerate during takeoff. Solid fuels are commonly used to propel rockets, both civilian and military, and are used to propel model rockets. The use of solid fuel in general and commercial aviation would be unusual.

Liquid fuels are extensively used throughout aviation. Two commonly used fuels are jet fuel and gasoline. They contain a useful energy level for volume and weight and are well-suited for general, commercial, and military aviation. Liquid fuels may be used for rocket engines.

Hypergolic fuels are unique liquid fuels in that they combust upon contact with each other. No source of ignition is required to trigger the reaction.

Hypergolic fuels are used in space vehicles to provide propulsion and vehicle steering.

Gaseous fuels are not well suited for aviation purposes. Due to the relatively low energy content of gaseous fuels, such as natural gas, this option is not a practical product for use in aviation.

As the majority of aircraft operate using either aviation gasoline or jet fuel, the focus of discussion will be placed on those fuels. They possess the basic requirements of a suitable aviation fuel. Such fuels must have high energy content for their volume and weight and must readily vaporize in order to form a combustible mixture in the engine.

AVIATION GASOLINE

Gasoline has been in production for over a century. The high heat content of gasoline makes it a suitable fuel for the internal combustion engine. A number of production methods have been used for the production of gasoline. Some techniques are employed to increase the number of gallons or liters of gasoline produced from a single barrel of crude oil.

Fractional Distillation is the oldest method for gasoline production. It generates what is referred to as straight run gasoline. In fractional distillation, crude oil is heated in a bubble tower that is used to extract a variety of petroleum products from crude based on the boiling point of the various items. Fractional distillation produces kerosene, diesel fuel, and gasoline in addition to other petroleum products. Straight run gasoline has a relatively low octane rating of about 70.

Cracking is a process whereby heavy hydrocarbons are broken down or "cracked" to elevate the quantity of gasoline derived from a barrel of crude oil. This technique usually involves heating the heavy hydrocarbons under increased pressure to break down the oil so that gasoline emerges.

Polymerization and hydrogenation is a process that is the opposite of cracking. During polymerization light hydrocarbons, such as ethylene, propylene, and butylene, are combined to make heavier hydrocarbons. This process may be accomplished thermally or with the use of a catalyst at lower temperatures. The hydrogenation process adds hydrogen to the polymer fuel. The result is isooctane fuel with a rating of 100.

Alkylation is a process where gaseous hydrocarbons are converted into liquid hydrocarbons. Various chemicals are used during the process that results in isooctane fuel.

GASOLINE RATINGS

Aviation fuels are produced following strict quality control measures. One critical specification that aviation gasoline must adhere to is its octane rating or performance number. This characteristic of the gasoline is a major element in combustion detonation. If an engine is burning a gasoline below its design rating, the engine will experience detonation. For example, an aircraft engine is certificated to operate with 100 octane fuel. This aircraft is accidentally refueled with a product less than 100 octane. It is likely that the engine will experience detonation during operation, probably during takeoff and climb. This could result in engine failure.

Because the octane ratings and performance numbers are critical in aviation, fuels are dyed for identification. This measure was more critical during a period where a number of octane ratings were readily available. Today nearly every airplane runs using 100 low lead. Some aircraft burn automotive gasoline. Unleaded aviation gasoline is being developed to substitute for 100 low lead.

In terms of lead added to enhance the anti-knock property of aviation fuel, the label 100 low lead refers to the comparison between 100LL and 100/130 fuels. 100 LL contains between 1.2 to 2.0 ml of lead per U.S. gallon. By comparison, 100/130 fuel has 3.0 to 4.0 ml of lead added per gallon. 80/87 has 0.5 ml per gallon. And 115/145 gasoline contains 4.6 ml of tetraethyl lead added to each gallon of gasoline.

The anti-knock qualities of aviation gasoline are represented by their octane ratings or performance numbers. Octane ratings extend to isooctane or 100. To attain fuels with anti-knock characteristics that exceed 100, tetraethyl lead (TEL) is added. When the anti-knock rating exceeds 100, they are referred to as performance numbers. Aviation fuels may be designated with two numbers (e.g., 80/87, 100/130, 115/145). The lower number represents the anti-knock characteristic of the fuel with a lean mixture while the higher number is used to indicate the anti-knock rating during operations with a rich mixture.

Dyes are added to the fuel to help technicians, pilots, and refuelers identify the octane rating or performance number of the gasoline. The exception is that automotive gasoline is not color-coded.

Green dye is used to identify 100/130 fuel or 100 high lead. Blue is used to color 100 low lead gasoline. Blue previously identified 91/96 gasoline. Purple is added to 82UL (unleaded) fuel. Purple dye is also used to code 115/145 aviation gasoline.

Another gasoline that emerged during the Second World War was aromatic fuel. This fuel contained solvents such as benzol, xylene, toluene, and cumene to boost performance numbers. This gasoline was able to operate in high-performance engines with high compression ratios without knocking. Aromatic fuels were detrimental to rubber components used by the fuel system. Consequently, special hoses, packings, diaphragms, and other flexible components were made from aromatic-resistant material.

GASOLINE ADDITIVES

The performance of aviation gasoline is enhanced by the addition of various fuel additives. Also, additives are used to protect the engine.

A common additive in aviation gasoline is tetraethyl lead or TEL. The addition of TEL to gasoline provides a boost in the octane rating or performance number for the fuel. This allows manufacturers to increase the compression ratios of their engines which results in increased performance and economy. A negative consequence of TEL is its neurotoxicity. The use of TEL has largely been discontinued for motor vehicles other than aircraft.

Another negative outcome of TEL in fuels is spark plug fouling. Lead residue collects in spark plugs and can cause the spark plug to foul out. To reduce the build up of lead within the combustion chamber, ethylene dibromide, or EDB, is added to the gasoline to help scavenge lead from the cylinders. This is accomplished by converting the lead deposits into lead bromides which remain in a gaseous state and exit the combustion chamber with the exhaust. Special spark plugs that have projected noses have been used to minimize the risk of lead fouling.

Other additives blended with aviation gasoline are dyes for fuel identification, oxidation inhibitors, corrosion inhibitors, and icing inhibitors. The additives are combined with fuel to ensure the product conforms to industry requirements.

Aviation fuels must meet very strict quality standards. One critical standard is vapor pressure. Vapor pressure refers to pressure acting of the surface of the fuel that prevents release of additional vapors at specific temperatures. In aviation the vapor pressure of the fuel is critical to the operation of the engine. If the vapor pressure is too high, the engine will encounter difficulties starting as the fuel will not readily vaporize. If the vapor pressure is too low, the fuel evaporates before being properly metered for combustion. This condition is known as vapor lock. Because the vapor pressure of aviation gasoline is critically controlled, instances of vapor lock are generally the result of the fuel being exposed to excess temperature (e.g., hot engine compartment).

A device used for measuring vapor pressure is the Reid Vapor Pressure Bomb Tester. This instrument has a pressure gauge attached to the top of a sealed chamber and measures the pressure given off by the fuel at different temperatures.

ANTI-DETONATE INJECTION

High performance piston engines may be equipped with an anti-detonate injection system or ADI. This is also known as water injection. The addition of a water/methanol mixture to the metered fuel provides superior suppression of detonation when compared to conventional power enrichment.

While operating under ADI, the fuel metering system reduces the level of power enrichment. The net result is a boost in engine power. This may prove especially beneficial during takeoff when the aircraft is operating in climates that are hot, humid, and elevated. Normally ADI operations are time-limited.

JET FUEL

There are some stark differences between jet fuel and aviation gasoline. Jet fuel, which is largely kerosene, contains less heat energy than gasoline by weight, but more heat energy than gasoline by volume. Stated another way, a pound of jet fuel has less heat

energy than a pound of gasoline, but a gallon, or liter, of jet fuel contains more heat energy than a similar quantity of gasoline.

When compared to gasoline, jet fuel has good lubricity. This serves as an advantage in terms of lubricating fuel systems components such as fuel pumps and fuel control units.

Jet fuel does not evaporate as readily as gasoline. Consequently, it is more difficult to vapor lock. However, in certain instances jet fuel may form vapor lock. For example, an aircraft at cruise altitude with high-mounted engines (e.g., installed in the tail) may generate vapor lock when the boost pumps fail and the fuel is lifted to the engines solely by the suction of the engine-driven pumps. Jet fuel is available in different grades. Each has a specific advantage and application. Available for civilian usage are the following fuels, Jet A, Jet A-1, and Jet B. Jet A and Jet A-1 are commonly used fuels in turbine engines throughout most countries associated with the International Civil Aviation Organization (ICAO). Jet B is preferred for cold weather operations.

The military also has a variety of turbine fuels in use. JP-4 is very similar to Jet B. JP-5 is another jet fuel option along with JP-8. The latter is the equivalent of JetA-1 with some minor differences. Other fuel grades are developed for special purposes.

Jet fuel is prone to the formation of microbiological growths. To combat this problem, biocides are added to the fuel.

Jet fuels also have a series of additives to protect fuel system components. Anti-oxidants prevent the formation of gum deposits. Static dissipaters minimize issues with the build up of static electricity associated with the high flow rates of fuel through the system. Corrosion inhibitors and icing inhibitors are included.

SAFETY PRECAUTIONS

The handling of aviation fuels and fuel-related components is a common practice for maintenance technicians. Before working with aviation fuels, ensure that the proper firefighting equipment is at hand and in working condition. Also, personnel should be trained in the proper use of the equipment. Beginning with refueling, technicians must ensure that they are refueling the aircraft with the correct fuel. Misfueling aircraft may result in engine failures. Using lower gasoline octane ratings or consuming jet fuel in a gasoline engine will generally result in engine stoppage or poor performance. Refueling nozzles for gasoline and jet fuel are designed differently to prevent the flow of jet fuel into gasoline tanks. Jet refueling nozzles have a larger dimension than the opening of a gasoline tank. Despite this design, misfueling occurs.

Diesel engines emerging into the general aviation fleet may be designed to consume jet fuel. This may lead to refueling confusion when the same basic model airplane, that normally uses gasoline, requires jet fuel.

Technicians, along with operators and pilots, must do their part to ensure that the fuel is the proper grade for the aircraft and that the fuel is free of contaminants. When taking a fuel sample be certain to check for water and particles. It will be helpful to take fuel samples in transparent containers. Gently spinning the fuel sample may help personnel spot water and suspended particles. Also make sure that the fuel is the proper color. Dispose of the fuel sample in a safe and environmentally friendly manner.

The build up and discharge of static electricity is a great concern during refueling and defueling operations. Prior to connecting the fuel nozzle to the aircraft, technicians must properly bond/ground the aircraft. By removing the electrical difference between the aircraft and refueling/defueling apparatus, the chance of a static discharge is minimal. Likewise, the build up of a static discharge is not likely when properly bonded/grounded. A standard procedure in many shops is to ground the aircraft before undertaking any maintenance procedure.

Aircraft fueling and defueling should not be accomplished in the hangar. Such operations should be conducted outdoors where there is ample ventilation. And in the case of an accident or fuel spill, the likelihood of damaging other aircraft is low. Technicians need to be aware that fuel vapors are heavier than air. Therefore, vapors associated with fuel will sink and form a combustible mixture on the hangar floor or ramp area. Any source of ignition may prove detrimental when fuel vapors are present.

Technicians should not use fuel as a cleaning solvent. Aviation fuels are highly flammable and potentially toxic

and should be only used as a fuel. Other chemicals are better suited as solvents.

When working on fuel system components, technicians should use non-sparking tools to prevent fires. Explosion proof electrical equipment, such as portable lights, should be used when working around fuels and on fuel systems. Protective eyewear and clothing are essential for safety as exposure to the chemicals contained in aviation fuels may prove hazardous to a person's health. Containers of fuel should be slowly opened to relieve pressure that may be present in the container. Do not enter fuel tanks without receiving proper training and understanding maintenance procedures and without suitable protective gear.

Technicians should not refuel the aircraft with contaminated fuel. Proper disposal of suspected fuel should be undertaken.

Question: 8-1
Name 7 functions of oil.
_____,
_____,
_____,
_____,
_____,
_____,
_____.

Question: 8-2
How do preservation oils help to minimize corrosion?

Question: 8-3
Why do Ashless oils darken as they are used?

Question: 8-4
A _____ viscosity oil is best to use in cold environments.

Question: 8-5
How will the use of a lower than recommended octane fuel affect engine operation?

Question: 8-6
What color dye is used to identify 100LL aviation gasoline?

Question: 8-7
In which phase of operation is the correct vapor pressure of a fuel critical?

Question: 8-8
A kilogram of jet fuel contains _____ energy than a kilogram of gasoline. A liter of jet fuel contains _____ energy than a liter of gasoline.

ANSWERS

Answer: 8-1
*Reduce friction.
*Cushion between metal parts.
*Enhance sealing between parts.
*Heat transfer.
*Cleaning the engine.
*Hydraulic fluid.
*Corrosion control.
page 8.2

Answer: 8-2
Preservation oils cling to internal engine parts for longer periods of time.
page 8.2

Answer: 8-3
Because small particles of debris become suspended in the oil.
page 8.3

Answer: 8-4
Low viscosity.
page 8.4

Answer: 8-5
The fuel/air charge will detonate under certain conditions.
page 8.5

Answer: 8-6
Blue.
page 8.5

Answer: 8-7
During engine start.
page 8.6

Answer: 8-8
Less; More.
page 8.6



PART-66 SYLLABUS	LEVELS		
CERTIFICATION CATEGORY →	A	B1	B3

Sub-Module 09
Piston Engine - Lubrication Systems

	A	B1	B3
16.9 - Lubrication Systems System operation/layout and components	1	2	2

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

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

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

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

LUBRICATION SYSTEMS

The primary purpose of a lubricant is to reduce friction between moving parts. Because liquid lubricants or oils can be circulated readily, they are used universally in aircraft engines. In theory, fluid lubrication is based on the actual separation of the surfaces so that no metal-to-metal contact occurs. As long as the oil film remains unbroken, metallic friction is replaced by the internal fluid friction of the lubricant. Under ideal conditions, friction and wear are held to a minimum. Oil is generally pumped throughout the engine to all areas that require lubrication. Overcoming the friction of the moving parts of the engine consumes energy and creates unwanted heat. The reduction of friction during engine operation increases the overall potential power output. Engines are subjected to several types of friction.

RECIPROCATING ENGINE LUBRICATION SYSTEMS

Aircraft reciprocating engine pressure lubrication systems can be divided into two basic classifications: wet sump and dry sump. The main difference is that the wet sump system stores oil in a reservoir inside the engine. After the oil is circulated through the engine, it is returned to this crankcase based reservoir. A dry sump engine pumps the oil from the engine's crankcase to an external tank that stores the oil. The dry sump system uses a scavenge pump, some external tubing, and an external tank to store the oil.

Other than this difference, the systems use similar types of components. Because the dry sump system contains all the components of the wet sump system, the dry sump system is explained as an example system.

COMBINATION SPLASH AND PRESSURE LUBRICATION

The lubricating oil is distributed to the various moving parts of a typical internal combustion engine by one of the three following methods: pressure, splash, or a combination of pressure and splash.

The pressure lubrication system is the principal method of lubricating aircraft engines. Splash lubrication may be used in addition to pressure lubrication on aircraft engines, but it is never used by itself; aircraft-engine lubrication systems are always either the pressure type or the combination pressure and splash type, usually the latter.

The advantages of pressure lubrication are:

1. Positive introduction of oil to the bearings.
2. Cooling effect caused by the large quantities of oil that can be pumped, or circulated, through a bearing.
3. Satisfactory lubrication in various attitudes of flight.

LUBRICATION SYSTEM REQUIREMENTS

The lubrication system of the engine must be designed and constructed so that it functions properly within all flight attitudes and atmospheric conditions that the aircraft is expected to operate. In wet sump engines, this requirement must be met when only half of the maximum lubricant supply is in the engine. The lubrication system of the engine must be designed and constructed to allow installing a means of cooling the lubricant. The crankcase must also be vented to the atmosphere to preclude leakage of oil from excessive pressure. The crankcase vent relieves the buildup of pressure that would otherwise occur from combustion blow-by seeping past the piston ring end gaps.

DRY SUMP OIL SYSTEMS

Many reciprocating and turbine aircraft engines have pressure dry sump lubrication systems. The oil supply in this type of system is carried in a tank. A pressure pump circulates the oil through the engine. Scavenger pumps then return it to the tank as quickly as it accumulates in the engine sumps. The need for a separate supply tank is apparent when considering the complications that would result if large quantities of oil were carried in the engine crankcase. On multiengine aircraft, each engine is supplied with oil from its own complete and independent system.

Although the arrangement of the oil systems in different aircraft varies widely and the units of which they are composed differ in construction details, the functions of all such systems are the same. A study of one system clarifies the general operation and maintenance requirements of other systems.

The principal units in a typical reciprocating engine dry sump oil system include an oil supply tank, an engine-driven pressure oil pump, a scavenge pump, an oil cooler with an oil cooler control valve, oil tank vent, necessary tubing, and pressure and temperature indicators. ***[Figure 9-1]***

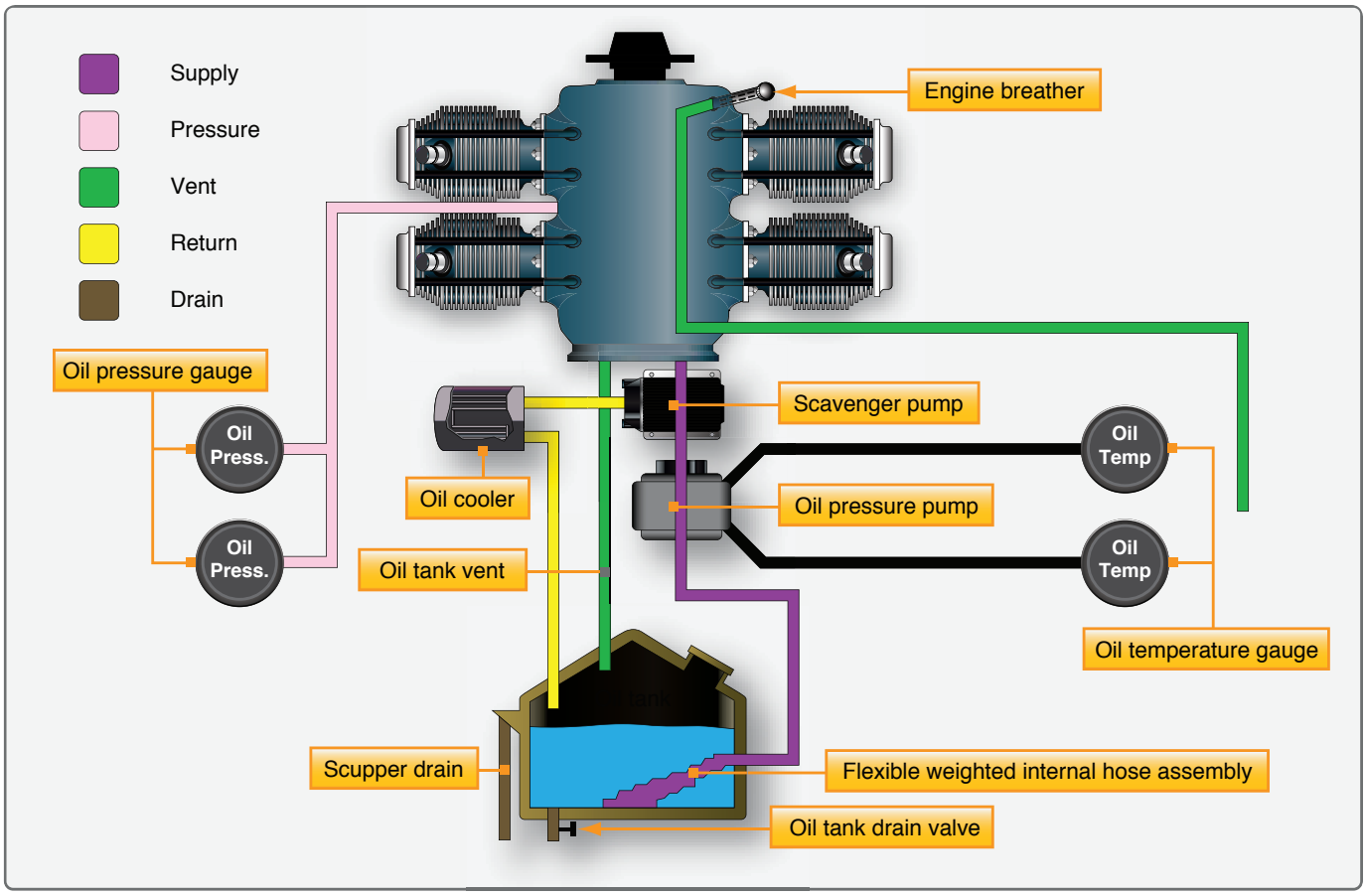


Figure 9-1. Typical dry-sump oil system.

OIL TANKS

Oil tanks are generally associated with a dry sump lubrication system, while a wet sump system uses the crankcase of the engine to store the oil. Oil tanks are usually constructed of aluminum alloy and must withstand any vibration, inertia, and fluid loads expected in operation.

Each oil tank used with a reciprocating engine must have expansion space of not less than the greater of 10 percent of the tank capacity or 0.5 gallons. Each filler cap of an oil tank that is used with an engine must provide an oil-tight seal. The oil tank usually is placed close to the engine and high enough above the oil pump inlet to ensure gravity feed.

Oil tank capacity varies with the different types of aircraft, but it is usually sufficient to ensure an adequate supply of oil for the total fuel supply. The tank filler neck is positioned to provide sufficient room for oil expansion and for foam to collect.

The oil filler cap or cover is marked with the word "OIL." A drain in the filler cap well disposes of any overflow or spillage caused by the filling operation. Oil tank vent lines are provided to ensure proper tank ventilation in all attitudes of flight. These lines are usually connected to the engine crankcase to prevent the loss of oil through the vents. This indirectly vents the tanks to the atmosphere through the crankcase breather.

Large radial engines have many gallons of oil in their tanks. To help with engine warm up, some oil tanks had a built in hopper or temperature accelerating well. ***(Figure 9-2)*** This well extended from the oil return fitting on top of the oil tank to the outlet fitting in the sump in the bottom of the tank. In some systems, the hopper tank is open to the main oil supply at the lower end. Other systems have flapper-type valves that separate the main oil supply from the oil in the hopper. The opening at the bottom of the hopper in one type and the flapper valve-controlled openings in the other allow oil from the main tank to enter the hopper and replace the oil consumed by the engine. Whenever the hopper tank includes the flapper controlled openings,

the valves are operated by differential oil pressure. By separating the circulating oil from the surrounding oil in the tank, less oil is circulated. This hastens the warming of the oil when the engine was started. Very few of these types of tanks are still in use and most are associated with radial engine installations.

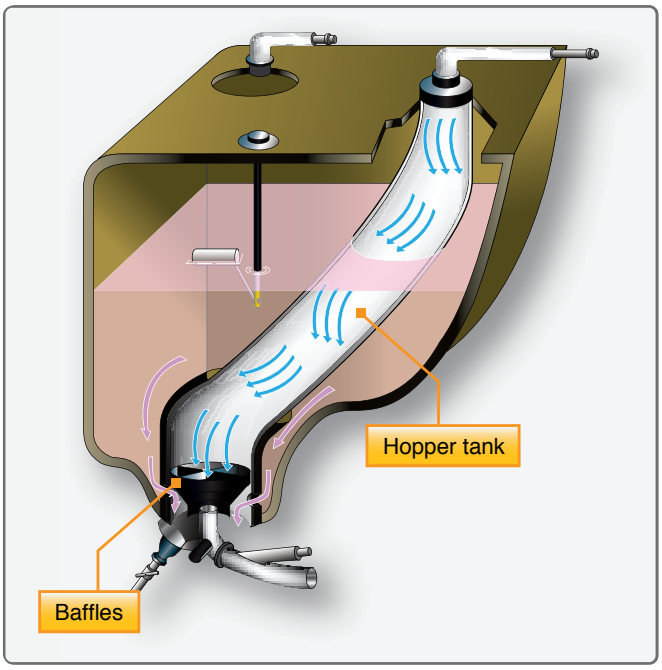


Figure 9-2. Hopper tank within oil tank used to expedite oil warm-up.

Generally, the return line in the top of the tank is positioned to discharge the returned oil against the wall of the tank in a swirling motion. This method considerably reduces foaming that occurs when oil mixes with air. Baffles in the bottom of the oil tank break up this swirling action to prevent air from being drawn into the inlet line of the oil pressure pump. Foaming oil increases in volume and reduces its ability to provide proper lubrication. In the case of oil-controlled propellers, the main outlet from the tank may be in the form of a standpipe so that there is always a reserve supply of oil for propeller feathering in case of engine failure. An oil tank sump, attached to the undersurface of the tank, acts as a trap for moisture and sediment. The water and sludge can be drained by manually opening the drain valve in the bottom of the sump as shown in ***Figure 9-3***.

Most aircraft oil systems are equipped with the dipstick-type quantity gauge, often called a bayonet gauge. Some larger aircraft systems also have an oil quantity indicating system that shows the quantity of oil



Figure 9-3. Oil Tank sump and drain valve.

during flight. One type system consists essentially of an arm and float mechanism that rides the level of the oil and actuates an electric transmitter on top of the tank. The transmitter is connected to a cockpit gauge that indicates the quantity of oil.

OIL PUMP

Oil entering the engine is pressurized, filtered, and regulated by units within the engine. They are discussed along with the external oil system to provide a concept of the complete oil system.

As oil enters the engine, it is pressurized by a gear-type pump. ***(Figure 9-4)*** This pump is a positive displacement pump that consists of two meshed gears that revolve inside the housing. The clearance between the teeth and housing is small. The pump inlet is located on the left and the discharge port is connected to the engine's system pressure line. One gear is attached to a splined drive shaft that extends from the pump housing to the crankshaft or an accessory drive shaft on the engine. Seals are used to prevent leakage around the drive shaft. As the lower gear is rotated counterclockwise, the driven idler gear turns clockwise.

As oil enters the gear chamber, it is picked up by the gear teeth, trapped between them and the sides of the gear chamber, is carried around the outside of the gears, and discharged from the pressure port into the oil screen passage. The pressurized oil flows to the oil filter, where any solid particles suspended in the oil are separated from it, preventing possible damage to moving parts of the engine.

Oil under pressure then opens the oil filter check valve mounted in the top of the filter. This valve is used mostly

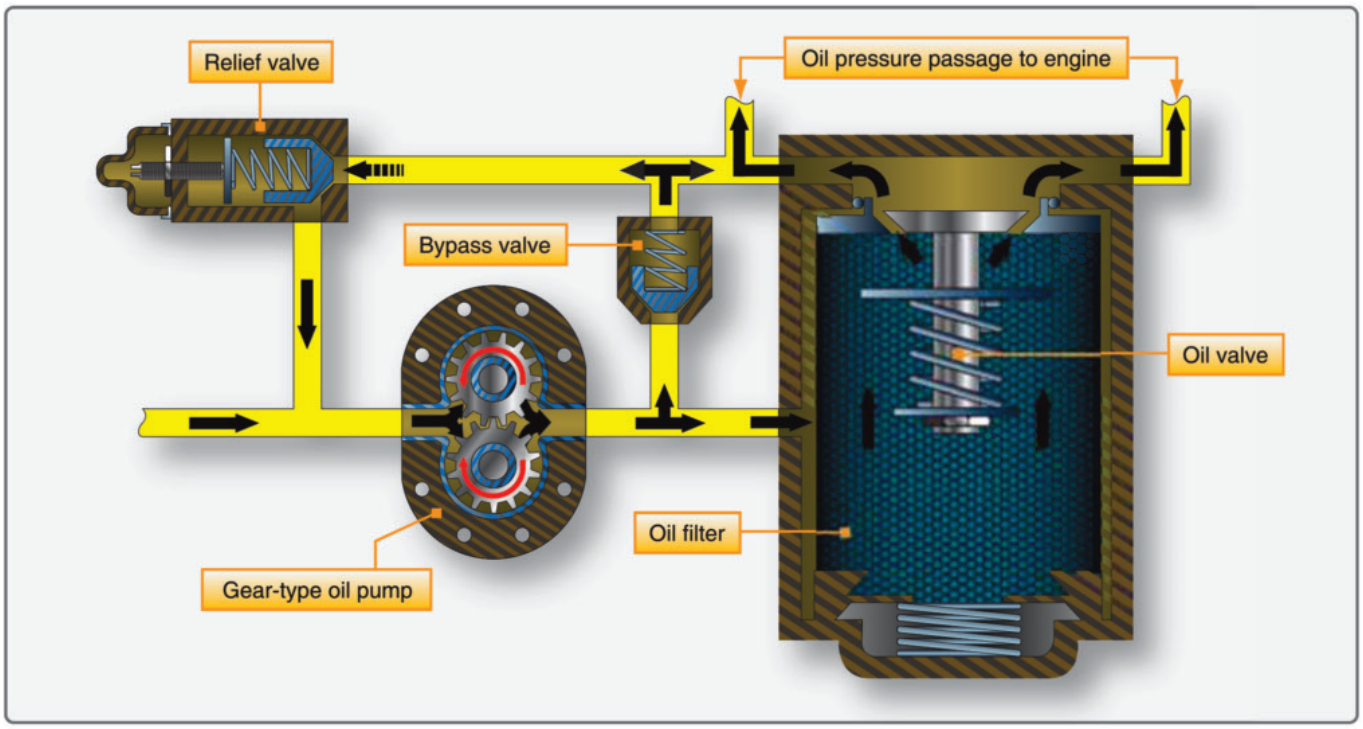


Figure 9-4. Oil pump and associated components.

with dry sump radial engines and is closed by a light spring loading of 1 to 3 pounds per square inch (psi) when the engine is not operating to prevent gravity-fed oil from entering the engine and settling in the lower cylinders or sump area of the engine. If oil were allowed to gradually seep by the rings of the piston and fill the combustion chamber, it could cause a liquid lock, also known as a hydraulic cylinder lock. This could happen if the valves on the cylinder were both closed and the engine was cranked for start. Damage could occur to the engine.

The oil filter bypass valve, located between the pressure side of the oil pump and the oil filter, permits unfiltered oil to bypass the filter and enter the engine if the oil filter is clogged or during cold weather if congealed oil is blocking the filter during engine start. The spring loading on the bypass valve allows the valve to open before the oil pressure collapses the filter; in the case of cold, congealed oil, it provides a low-resistance path around the filter. Dirty oil in an engine is better than no lubrication.

OIL FILTERS

The oil filter used on an aircraft engine is usually one of four types: screen, Cuno, canister, or spin-on. A screen-type filter with its double-walled construction provides a large filtering area in a compact unit. ***(Figure 9-4)*** As oil passes through the fine-mesh screen, dirt, sediment, and other foreign matter are removed and settle to the bottom of the housing. At regular intervals, the cover is removed and the screen and housing cleaned with a solvent. Oil screen filters are used mostly as suction filters on the inlet of the oil pump.

The Cuno oil filter has a cartridge made of disks and spacers. A cleaner blade fits between each pair of disks. The cleaner blades are stationary, but the disks rotate when the shaft is turned. Oil from the pump enters the cartridge well that surrounds the cartridge and passes through the spaces between the closely spaced disks of the cartridge, then through the hollow center, and on to the engine. Any foreign particles in the oil are deposited on the outer surface of the cartridge. When the cartridge is rotated, the cleaner blades comb the foreign matter from the disks. The cartridge of the manually operated Cuno filter is turned by an external handle. Automatic Cuno filters have a hydraulic motor built into the filter head. This motor, operated by engine oil pressure, rotates the cartridge whenever the engine is running. There is a manual turning nut on the automatic Cuno filter for rotating the cartridge manually during inspections. This filter is not often used on modern aircraft.

A canister housing filter has a replaceable filter element that is replaced with rest of the components other than seals and gaskets being reused. ***(Figure 9-5)*** The filter element is designed with a corrugated, strong steel center tube supporting each convoluted pleat of the filter media, resulting in a higher collapse pressure rating. The filter provides excellent filtration, because the oil flows through many layers of locked-in-fibers.

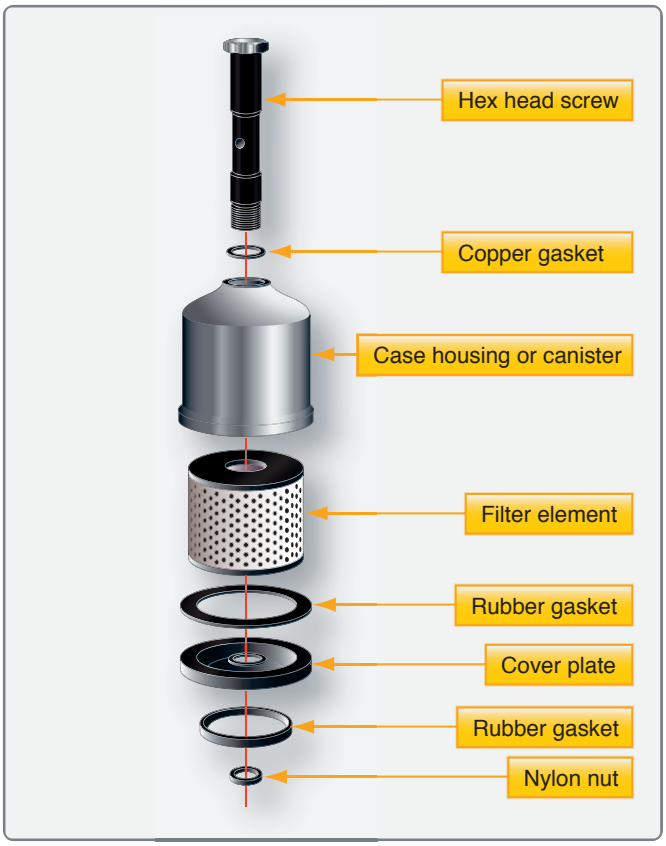


Figure 9-5. Exploded view of housing, filter element, and associated parts of canister filter.

Full flow spin-on filters are the most widely used oil filters for reciprocating engines. These filters are similar to those used in automotive engines. ***(Figure 9-6)*** Full flow means that all the oil is normally passed through the filter. In a full flow system, the filter is positioned between the oil pump and the engine bearings, which filters the oil of any contaminants before they pass through the engine bearing surfaces. The filter also contains an anti-drain back valve and a pressure relief valve, all sealed in a disposable housing. The relief valve is used in case the filter becomes clogged. It would open to allow the oil to bypass, preventing the engine components from oil starvation. A cutaway of the micronic filter element shows the resin-impregnated cellulosic full-pleat media that is used to trap harmful particles, keeping them from entering the engine. ***[Figure 9-7]***



Figure 9-6. Spin-on oil filter.

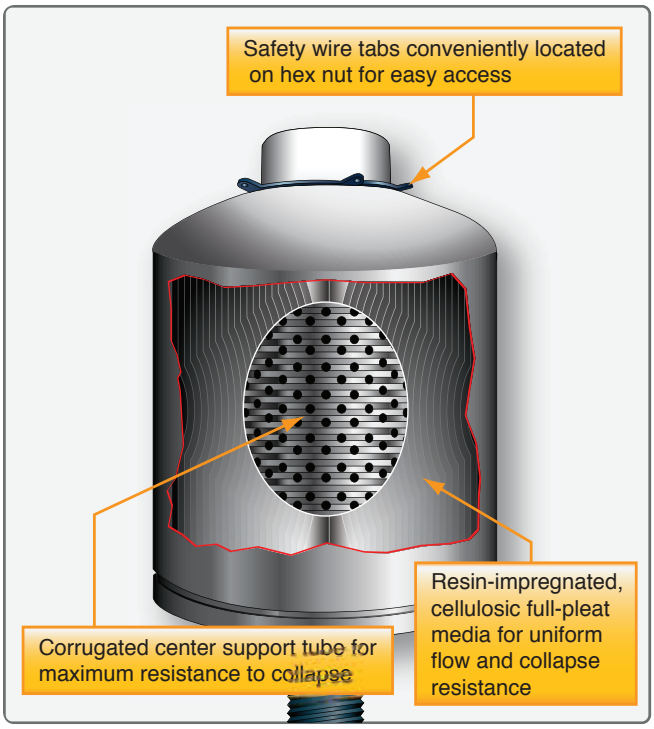


Figure 9-7. Spin-on filter cutaway.

OIL PRESSURE REGULATING VALVE

An oil pressure regulating valve limits oil pressure to a predetermined value, depending on the installation. ***(Figure 9-4)*** This valve is sometimes referred to as a pressure relief valve but its real function is to regulate the oil pressure at a present pressure level. The oil pressure must be sufficiently high to ensure adequate lubrication of the engine and its accessories at high speeds and powers. This pressure helps ensure that the

oil film between the crankshaft journal and bearing is maintained. However, the pressure must not be too high, as leakage and damage to the oil system may result. The oil pressure is generally adjusted by loosening the locknut and turning the adjusting screw. ***(Figure 9-8)*** On most aircraft engines, turning the screw clockwise increases the tension of the spring that holds the relief valve on its seat and increases the oil pressure; turning the adjusting screw counterclockwise decreases the spring tension and lowers the pressure. Some engines use common flat washers under the spring that are either removed or added to adjust the regulating valve and pressure. The oil pressure should be adjusted only after the engine's oil is at operating temperature and the correct viscosity is verified. The exact procedure for adjusting the oil pressure and the factors that vary an oil pressure setting are included in applicable manufacturer's instructions.

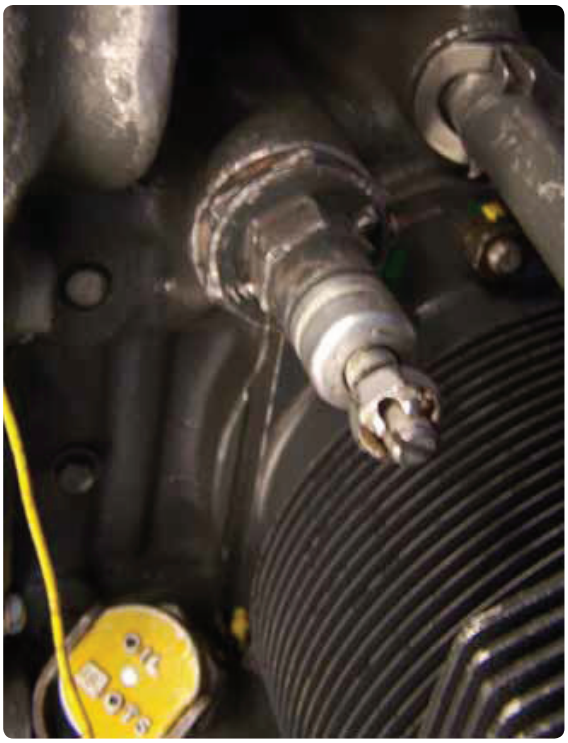


Figure 9-8. Oil pressure relief valve adjustment.

OIL COOLER

The cooler commonly used with radial engines, either cylindrical or elliptical shaped, consists of a core enclosed in a double-walled shell. The core is built of copper or aluminum tubes with the tube ends formed to a hexagonal shape and joined together in the honeycomb effect. ***(Figure 9-9)*** The ends of the copper tubes of the core are soldered, whereas aluminum tubes are brazed or mechanically joined. The tubes touch only at the ends so that a space exists between them along most of their lengths. This allows oil to flow through the spaces between the tubes while the cooling air passes through the tubes.

The space between the inner and outer shells is known as the annular or bypass jacket. Two paths are open to the flow of oil through a cooler. From the inlet, it can flow halfway around the bypass jacket, enter the core from the bottom, and then pass through the spaces between the tubes and out to the oil tank. This is the path the oil follows when it is hot enough to require cooling. As the oil flows through the core, it is guided by baffles that force the oil to travel back and forth several times before it reaches the core outlet. The oil can also pass from the inlet completely around the bypass jacket to the outlet without passing through the core. Oil follows this bypass route when the oil is cold or when the core is blocked with thick, congealed oil.

Oil coolers found on opposed engines have similar features. They are normally smaller and rectangular in shape. Items, such as oil temperature control and surge protection may be included in the engine or accessory case rather than in the cooler itself.

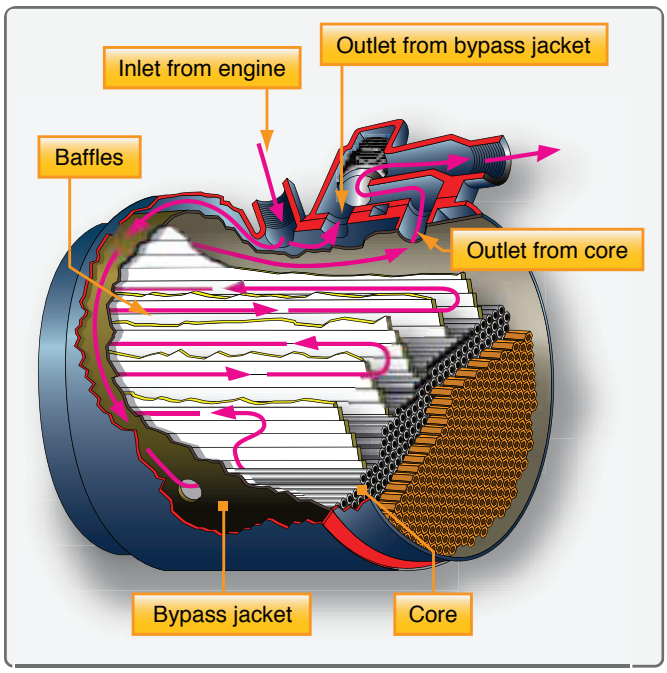


Figure 9-9. Typical radial engine oil cooler.

OIL COOLER FLOW CONTROL VALVE

As discussed previously, the viscosity of the oil varies with its temperature. Since the viscosity affects its lubricating properties, the temperature at which the oil enters an engine must be held within close limits. Generally, the oil leaving an engine must be cooled before it is re-circulated. Obviously, the amount of cooling must be controlled if the oil is to return to the engine at the correct temperature. The oil cooler flow control valve determines which of the two possible paths the oil takes through the oil cooler. ***[Figure 9-10]***

There are two openings in a flow control valve of a large radial engine or vee engine cooler that fit over the corresponding outlets at the top of the cooler. When the oil is cold, a bellows within the flow control contracts and lifts a valve from its seat. Under this condition, oil entering the cooler has a choice of two outlets and two paths. Following the path of least resistance, the oil flows around the bypass jacket and out past the thermostatic valve to the tank. This allows the oil to warm up quickly and, at the same time, heats the oil in the core of the cooler. As the oil warms up and reaches its operating temperature, the bellows of the thermostat expand and closes the outlet from the bypass jacket. The oil cooler flow control valve, located on the oil cooler, must now flow oil through the core of the oil cooler. No matter which path it takes through the cooler, the oil always flows over the bellows of the thermostatic valve. As the name implies, this unit regulates the temperature by either cooling the oil or passing it on to the tank without cooling, depending on the temperature at which it leaves the engine.

SURGE PROTECTION VALVES

When oil in the system is congealed, the scavenger pump may build up a very high pressure in the oil return line. To prevent this high pressure from bursting the oil cooler or blowing off the hose connections, some aircraft have surge protection valves in the engine lubrication systems. One type of surge valve is incorporated in the oil cooler flow control valve; another type is a separate unit in the oil return line. ***[Figure 9-10]***

The surge protection valve incorporated in a flow control valve is the more common type. Although this flow control valve differs from the one just described, it is essentially the same except for the surge protection feature. The high-pressure operation, or surge condition, is shown in ***Figure 9-10***, in which the high oil pressure at the control valve inlet has forced the surge valve (C) upward. Note how this movement has opened the surge valve and, at the same time, seated the poppet valve (E). The closed poppet valve prevents oil from entering the cooler proper; therefore, the scavenge oil passes directly

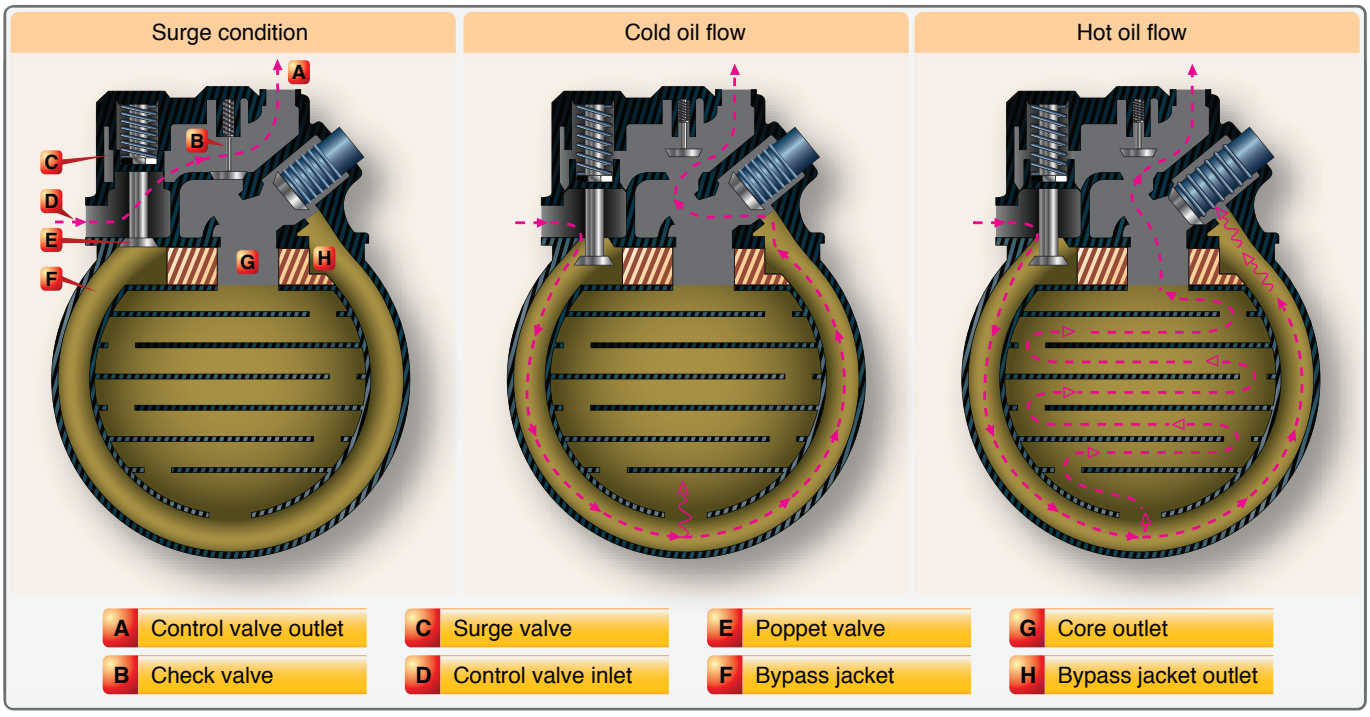


Figure 9-10. Flow paths through radial engine cooler under surge, cold oil, and hot oil conditions.

to the tank through outlet (A) without passing through either the cooler bypass jacket or the core. When the pressure drops to a safe value, the spring forces the surge and poppet valves downward, closing the surge valve (C) and opening the poppet valve (E). Oil then passes from the control valve inlet (D), through the open poppet valve, and into the bypass jacket (F). The thermostatic valve, according to oil temperature, determines oil flow either through the bypass jacket to port (H) or through the core to port (G). The check valve (B) opens to allow the oil to reach the tank return line.

AIRFLOW CONTROLS

By regulating the airflow through the cooler, the temperature of the oil can be controlled to fit various operating conditions. For example, the oil reaches operating temperature more quickly if the airflow is cut off during engine warm-up. There are two methods in general use: shutters installed on the rear of the oil cooler, and a flap on the air-exit duct. In some cases, the oil cooler air-exit flap is opened manually and closed by a linkage attached to a cockpit lever. More often, the flap is opened and closed by an electric motor.

One of the most widely used automatic oil temperature control devices is the floating control thermostat that provides manual and automatic control of the oil inlet temperatures. With this type of control, the oil cooler air-exit door is opened and closed automatically by an electrically operated actuator. Automatic operation of the actuator is determined by electrical impulses received from a controlling thermostat inserted in the oil pipe leading from the oil cooler to the oil supply tank. The actuator may be operated manually by an oil cooler air-exit door control switch. Placing this switch in the "open" or "closed" position produces a corresponding movement of the cooler door. Placing the switch in the "auto" position puts the actuator under the automatic control of the floating control thermostat. The thermostat shown in ***Figure 9-11*** is adjusted to maintain a normal oil temperature so that it does not vary more than approximately 5° to 8 °C, depending on the installation.

During operation, the temperature of the engine oil flowing over the bimetal element causes it to wind or unwind slightly. ***(Figure 9-11)*** This movement rotates the shaft (A) and the grounded center contact arm (C). As the grounded contact arm is rotated, it is moved toward either the open or closed floating contact arm (G). The two floating contact arms are oscillated by the cam (F), which is continuously rotated by an electric motor (D) through a gear train (E). When the grounded center contact arm is positioned by the bimetal element so that it touches one of the floating contact arms, an electric circuit to the oil cooler exit-flap actuator motor is completed, causing the actuator to operate and position the oil cooler air-exit flap. Newer systems use electronic control systems, but the function or the overall operation is basically the same regarding control of the oil temperature through control of the air

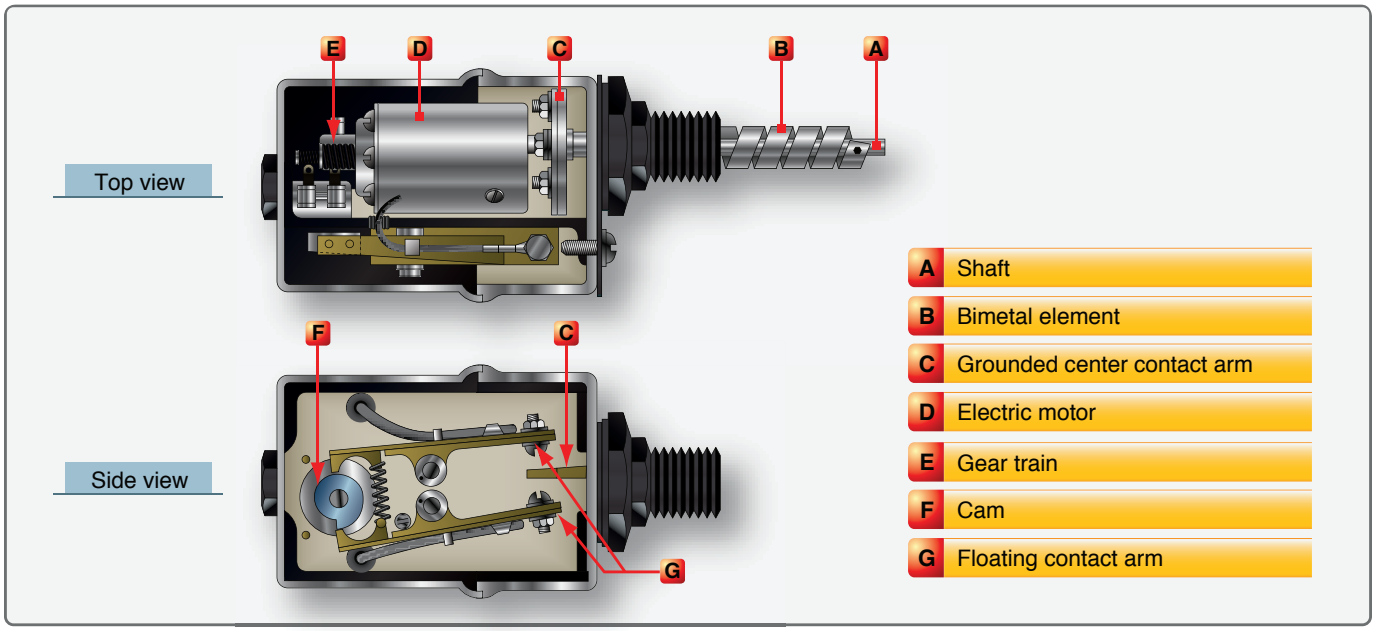


Figure 9-11. Oil cooler thermostat controller.

flow through the cooler.

In some lubrication systems, dual oil coolers are used. If the typical oil system previously described is adapted to two oil coolers, the system is modified to include a flow divider, two identical coolers and flow regulators, dual air-exit doors, a two-door actuating mechanism, and a Y-fitting. ***(Figure 9-12)*** Oil is returned from the engine through a single tube to the flow divider (E), where the return oil flow is divided equally into two tubes (C), one for each cooler. The coolers and regulators have the same construction and operations as the cooler and flow regulator previously described. Oil from the coolers is routed through two tubes (D) to a Y-fitting, where the floating control thermostat (A) samples oil temperature and positions the two oil cooler air-exit doors through the use of a two-door actuating mechanism. From the Y-fitting, the lubricating oil is returned to the tank

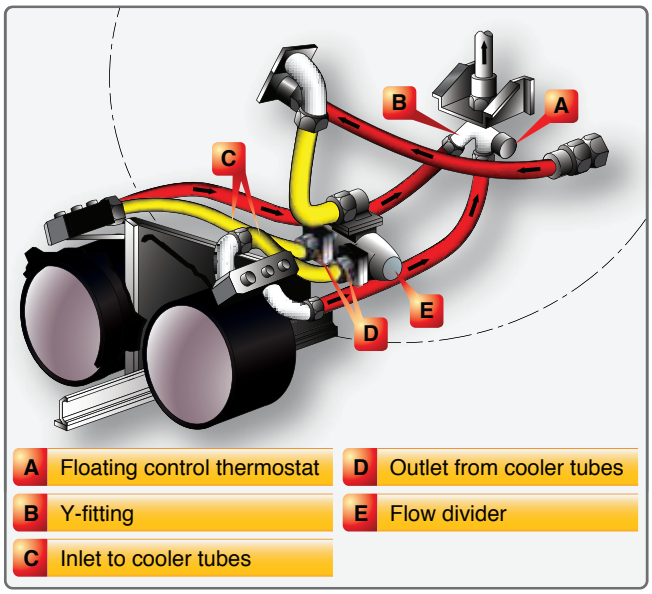


Figure 9-12. Dual oil cooler system.

where it completes its circuit.

DRY SUMP LUBRICATION SYSTEM OPERATION

The following lubrication system is typical of those on small, single-engine aircraft. The oil system and components are those used to lubricate a 220 horsepower (hp) six-cylinder, horizontally opposed, air-cooled engine.

In a typical dry sump pressure-lubrication system, a mechanical pump supplies oil under pressure to the bearings throughout the engine. See ***Figure 9-1.*** The oil flows into the inlet or suction side of the oil pump through a suction screen and a line connected to the external tank at a point higher than the bottom of the oil tank sump. This prevents sediment that falls into the oil tank sump from being drawn into the pump. The tank outlet is higher than the pump inlet, so gravity can assist the flow into the pump.

The engine-driven, positive-displacement, gear-type pump forces the oil into the full flow filter. ***(Figure 9-4)*** The oil either passes through the filter under normal conditions or, if the filter were to become clogged, the filter bypass valve would open as mentioned earlier. In the bypass position, the oil would not be filtered. As seen in ***Figure 9-4***, the regulating (relief) valve senses when system pressure is reached and opens enough to bypass oil to the inlet side of the oil pump. Then, the oil flows into a manifold that distributes the oil through drilled passages to the crankshaft bearings and other bearings throughout the engine. Oil flows from the main bearings through holes drilled in the crankshaft to the lower connecting rod bearings. ***[Figure 9-13]***

Oil reaches the camshaft (in an inline or opposed engine), or a cam plate or cam drum (in a radial engine), through a connection with the end bearing or the main oil manifold; it then flows out to the various camshaft, cam drum, or cam plate bearings and the cams.

The engine cylinder surfaces receive oil sprayed from the crankshaft and also from the crankpin bearings. Since oil seeps slowly through the small crankpin clearances before it is sprayed on the cylinder walls, considerable time is required for enough oil to reach the cylinder walls, especially on a cold day when the oil flow is more sluggish. This is one of the chief reasons for using modern multiviscosity oils that flow well at low temperatures.

When the circulating oil has performed its function of lubricating and cooling the moving parts of the engine, it drains into the sumps in the lowest parts of the engine. Oil collected in these sumps is picked up by gear or gerotor-type scavenger pumps as quickly as it accumulates. These pumps have a greater capacity in terms of volume than the pressure pump. This is needed because the volume of the oil has generally increased due to foaming (mixing with air) and heat. On dry sump engines, this oil leaves the engine, passes through the oil cooler, and returns to the supply tank.

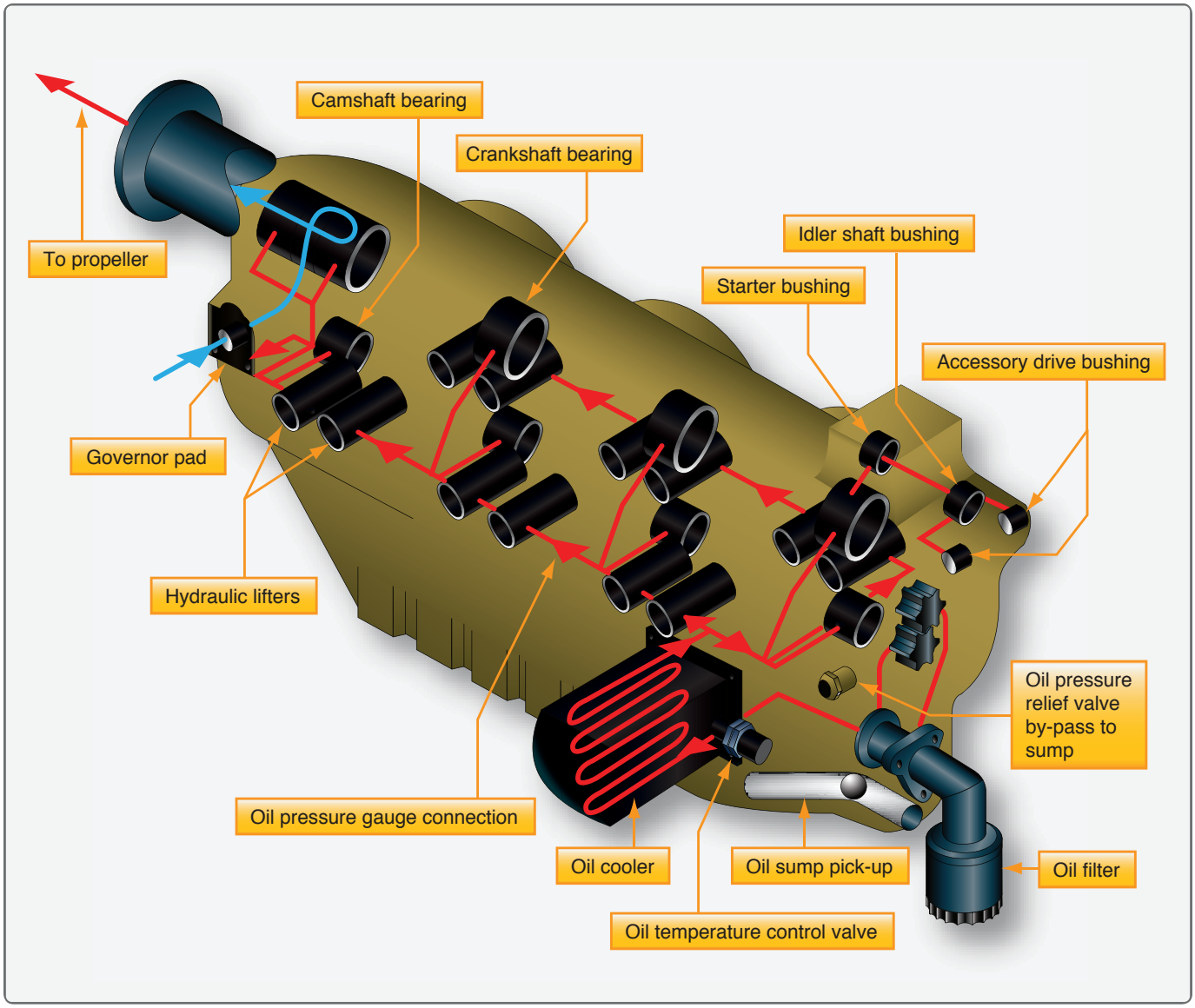


Figure 9-13. Oil flow network through opposed engine.

A thermostat attached to the oil cooler controls oil temperature by allowing part of the oil to flow through the cooler and part to flow directly into the oil supply tank. This arrangement allows hot engine oil with a temperature still below 65 °C (150 °F) to mix with the cold uncirculated oil in the tank. This raises the complete engine oil supply to operating temperature in a shorter period of time.

WET-SUMP LUBRICATION SYSTEM OPERATION

The wet-sump system consists of a sump or pan in which the oil supply is contained. The oil supply is limited by the sump (oil pan) capacity. The level (quantity) of oil is indicated or measured by a vertical rod, known as a dipstick, that protrudes into the oil from an elevated hole on top of the crankcase. In the bottom of the sump (oil pan) is a screen strainer having a suitable mesh, or series of openings, to strain undesirable particles from the oil and yet pass sufficient quantity to the inlet or (suction) side of the oil pressure pump. ***Figure 9-14*** shows a typical oil sump that has the intake tube running through it. This preheats the fuel-air mixture before it enters the cylinders.

The rotation of the pump, which is driven by the engine, causes the oil to pass around the outside of the gears. ***(Figure 9-4)*** This develops a pressure in the crankshaft oiling system (drilled passage holes). The variation in the

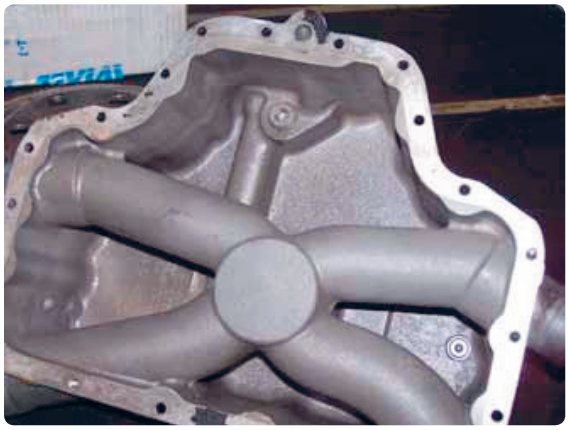


Figure 9-14. Oil sump. Note intake manifold passing through the sump.

speed of the pump from idling to full-throttle operating range of the engine and the fluctuation of oil viscosity because of temperature changes are compensated by the tension on the relief valve spring. The pump is designed to create a greater pressure than required to compensate for wear of the bearings or thinning out of oil. The parts oiled by pressure throw a lubricating spray into the cylinder and piston assemblies. After lubricating the various units it sprays, the oil drains back into the sump and the cycle is repeated. The system is not readily adaptable to inverted flying.

OIL DILUTION

Aircraft are often operated in very cold climates. In the era before multi-viscosity oils, operators had to change the weight of their oil based on seasonal requirements (e.g., thin oil during the winter, medium weigh oil in the spring and fall, and thick oil during the summer). Radial engines tend to use relatively thick oil throughout the year. Under arctic conditions, the thick oil makes it difficult to spin the engine for starting. To thin the oil, operators use oil dilution. The oil dilution system works by adding gasoline to engine oil just prior to engine shutdown. The gasoline mixes with the oil and reduces the viscosity of the oil. After shutdown, the engine cools off. The oil mixed with gasoline remains fluid even under extreme cold conditions. The result is that the next time the engine is cranked for starting purposes, it will rotate with greater ease than it would otherwise turn without diluted oil.

The oil dilution mechanism is basically a normally closed valve that opens by solenoid action. The crew has to manually hold the oil dilution switch as it is a momentary switch that does not remain in the ON position. Fuel under pressure passes through the open valve and mixes with the engine oil. By keeping the engine running for a brief period following the infusion of gasoline, the diluted oil is circulated throughout the engine. When the engine cools, the diluted oil remains in position, making it easier to rotate with the starter the next time the engine is cranked.

Where the gasoline easily mixes with engine oil and reduces the viscosity of the oil, there is no harmful outcome of oil dilution. As the engine warms-up, the gasoline evaporates and harmlessly exits the engine via the crankcase breather vent.

Operators learn from experience how much gasoline to add to the fuel. They base their oil dilution period of application based on predicted temperatures.

Multi-viscosity and synthetic oils reduces the need for oil dilution. Preheating also minimizes the importance of oil dilution. However, depending on the size of the fleet and operating schedule and availability of preheating equipment, oil dilution may still be needed.

LUBRICATION SYSTEM MAINTENANCE PRACTICES

DRAINING OIL

Oil, in service, is constantly exposed to many harmful substances that reduce its ability to protect moving parts. The main contaminants are:

- Gasoline
- Moisture
- Acids
- Dirt
- Carbon
- Metallic particles

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

In engines that have been operating on straight mineral oil for several hundred hours, a change to ashless dispersant oil should be made with a degree of caution as the cleaning action of some ashless dispersant oils

slightly tends to loosen sludge deposits and that may result in plugged oil passages. When an engine has been operating on straight mineral oil, and is known to be in excessively dirty condition, some operators defer the switch to ashless dispersant oil until after the engine is overhauled for fear that the change may loosen sludge within the engine and plug passageways and oil jets. This risk is minimum as ashless dispersant oils do not thoroughly clean dirty engine. Instead, they are formulated to keep particle in suspension to prevent engines from becoming dirty.

When changing from straight mineral oil to ashless dispersant oil, the following precautionary steps are recommended:

1. Do not add ashless dispersant oil to straight mineral oil. Drain the straight mineral oil from the engine and fill with ashless dispersant oil.
2. Do not operate the engine longer than 5 hours before the first oil change.
3. Check all oil filters and screens for evidence of sludge or plugging. Change oil every 10 hours if sludge conditions are evident. Repeat 10-hour checks until clean screen is noted, then change oil at recommended time intervals.
4. All turbocharged engines must be broken in and operated with ashless dispersant oil. Check appropriate technical data for recommended break-in oil.

OIL AND FILTER CHANGE AND SCREEN CLEANING

One manufacturer recommends that for new, remanufactured, or newly overhauled engines and for engines with any newly installed cylinders, the oil should be changed after the first replacement/screen cleaning at 25 hours. The oil should be changed, filter replaced or pressure screen cleaned, and oil sump suction screen cleaned and inspected. A typical interval for oil change is 25 hours, along with a pressure screen cleaning and oil sump suction screen check for all engines employing a pressure screen system. Typical 50-hour interval oil changes generally include the oil filter replacement and suction screen check for all engines using full-flow filtration systems. A maximum calendar period of 4 months between servicing is also recommended for oil system service. Check manufacturer's recommendation to determine the oil change requirements of a particular model aircraft.

OIL FILTER REMOVAL CANISTER TYPE HOUSING

Remove the filter housing from the engine by removing the safety wire and loosening the hex head screw and housing by turning counterclockwise and removing the filter from the engine. ***(Figures 9-5 and 9-6)*** On the canister system, remove the nylon nut that holds the cover plate on the engine side of the filter. Remove the cover plate, hex head screw from the housing. To remove the spin-on type of filter, cut the safety wire and use the wrench pad on the rear of the filter to turn the filter counterclockwise, and remove filter. Inspect the filter element as described in the following paragraph. Discard old gaskets and replace with new replacement kit gaskets. Where the canister oil filter was popular decades ago, most aircraft use the spin-on filter. Many engine still use the wire mesh screens.

PRESSURE AND SCAVENGE OIL SCREENS

Sludge accumulates on the pressure and suction oil screens during engine operation. ***(Figure 9-15)*** These screens must be removed, inspected, and cleaned at the intervals specified by the manufacturer.

Typical removal procedures include removing the safety devices and loosening the oil screen housing or cover plate. A suitable container should be used to catch the oil that drains from the filter housing or cavity. The container must be clean so that the oil collected in it can be examined for foreign particles. Any contamination already present in the container gives a false indication of the engine condition. This could result in a premature engine removal.

After the screens are removed, they should be inspected for contamination and for the presence of metal particles that may indicate possible engine internal wear, damage, or in extreme cases, pending engine failure. The screen must be cleaned prior to reinstalling in the engine. In some cases, it is necessary to disassemble the filter for inspection and cleaning. The manufacturer's procedures should be followed when disassembling and reassembling an oil screen assembly. When reinstalling a filter or screen, use new O-rings, gaskets, or crush rings, as required, and tighten the filter housing or cover retaining nuts to the torque value specified in the applicable maintenance

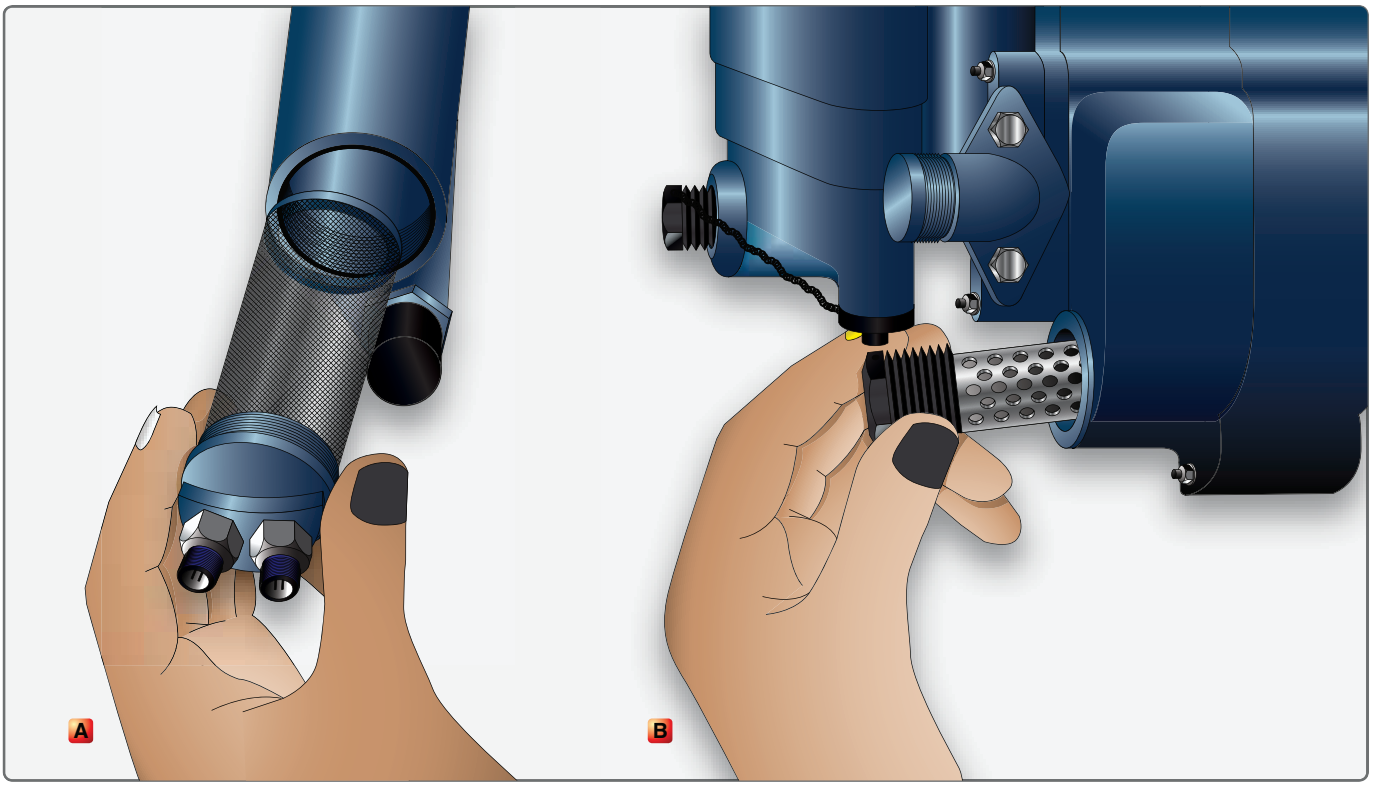


Figure 9-15. Oil screens.

manual. Filters should be safetied as required. After completing the oil system servicing, the engine should be started and the system checked for operation and leaks.

OIL FILTER/SCREEN CONTENT INSPECTION

Check for premature or excessive engine component wear that is indicated by the presence of metal particles, shavings, or flakes in the oil filter element or screens. The oil filter can be inspected by opening the filter paper element. Check the condition of the oil from the filter for signs of metal contamination. Then, remove the paper element from the filter and carefully unfold the paper element; examine the material trapped in the filter. If the engine employs a pressure screen system, check the screen for metal particles. After draining the oil, remove the suction screen from the oil sump and check for metal particles. ***(Figure 9-16)*** Not all aircraft engines will have removable suction screens for routine inspection.

If the examination of the used oil filter or pressure screen and the oil sump suction screen indicates abnormal metal content, additional service may be required to determine the source and possible need



Figure 9-16. Removable oil suction screen.

for corrective maintenance. To inspect the spin on filter the can must be cut open to remove the filter element for inspection. Using the special filter cutting tool, slightly tighten the cutter blade against filter and rotate 360º until the mounting plate separates from the can. ***(Figure 9-17)*** The filter cutter works in a fashion similar to a pipe cutter. This device makes a clean cut of the filter case without producing filings. Do not cut the filter case open using tools like a hacksaw as the filings will contaminate the filter inspection.

If you prefer to perform a filter wash rather than an ordinary visual inspection, use a clean plastic bucket containing solvent, place the filter in the solvent and

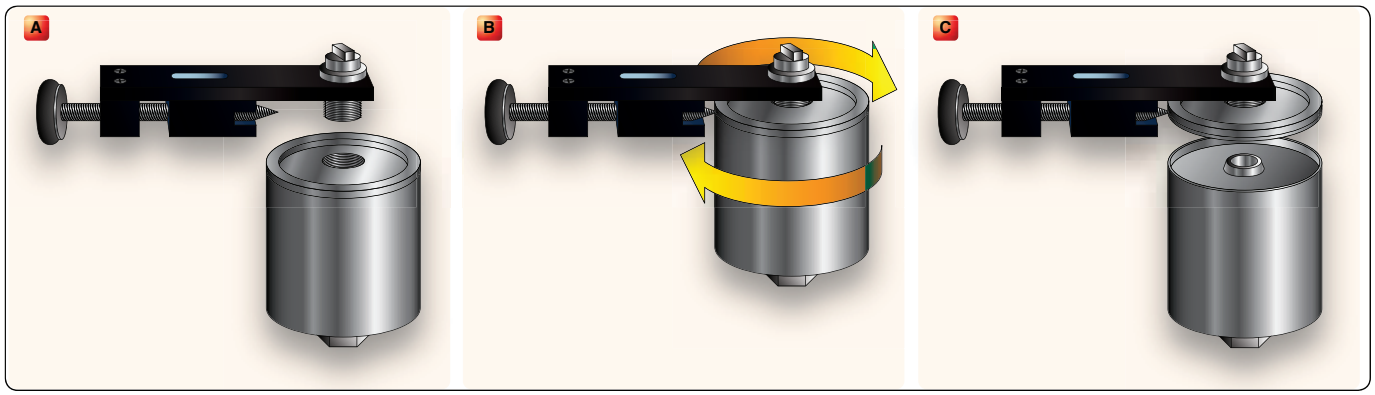


Figure 9-17. Spin-on oil filter cutter.

swish it around to remove contaminants and particles. With a clean magnet and check for any ferrous metal particles in the filter and solvent solution. Visually inspect the filter for particles. Then, take the remaining solvent and pour it through a clean filter or shop towel or coffee filter. Using a bright light, inspect for any nonferrous metals and other particles.

ASSEMBLY AND INSTALLATION OF OIL FILTERS

After cleaning the parts, installation of the canister or filter element type filter is accomplished by lightly oiling the new rubber gaskets and installing a new copper gasket on the hex head screw. Assemble the hex head screw into the filter case using the new copper gasket. Install the filter element and place the cover over the case, then manually thread on the nylon nut by hand. Install the housing on the engine by turning it clockwise, then torque and safety it.

Spin-on filters generally have installation instructions on the filter. Place a coating of engine oil, or specified product, on the rubber gasket, install the filter, torque and safety it. Always follow the manufacturer's current instructions when performing any maintenance.

It is important that the engine be started and operated long enough to determine whether there is a fault in the system or if there is a system leak. Any defect should be corrected before returning the engine to service.

OIL ANALYSIS

Oil analysis is a method of measuring metal wear by collecting oil samples and testing them for the amount of specific metals contained in the specimen. The process is somewhat like forensic science as minute particles are detected. The sensitivity of oil analysis machines may reach one tenth part per million. Generally, results are provided in parts per million (ppm).

As the engine wears, it produces metal particles. A certain amount of wear is normal. As parts wear at abnormal rates, excess quantities of particles are generated. Such increases in the wear rate may be detected through oil analysis. Oil analysis may be the only means available, in some cases, to detect an impending failure of a part or parts within an engine. Monitoring the wear rate of various metals is often referred to as spectrometric oil analysis program or SOAP.

Aside from measuring wear rates, oil analysis detects the quantity of silicon in the oil. Silicon levels indicate how much dirt the engine is ingesting. Often, an increase in the level of silicon, resulting from poor air inlet filtration, is accompanied by an increase in the wear rates of combustion chamber metals (e.g., chrome, aluminum, and iron).

Generally speaking, a one time oil analysis produces little knowledge in regard to wear rates or impending failure. A wear trend for an engine must be established by taking samples at regular intervals.

After a wear rate is established, an increase in the wear suggests possible failure. If an alarming wear rate arises from the oil analysis, the laboratory will promptly notify the owner or shop of the news. It must be pointed out that without establishing a wear trend, oil analysis information is not very accurate unless an obvious condition exists. Consequently, it becomes necessary to use the same oil analysis laboratory. Laboratories normally keep records of previous test

results to monitor wear trends.
A sample wear trend is provided in ***Figure 9-18***. Data for this graph were taken from an aircraft following a major overhaul. The graph shows the accumulation of aluminum in parts per million taken at 12 hours, 51 hours, 85 hours, and 135 hours of operation. The level of aluminum in this illustration drops into the normal range during the break-in of the power plant. A wear trend for

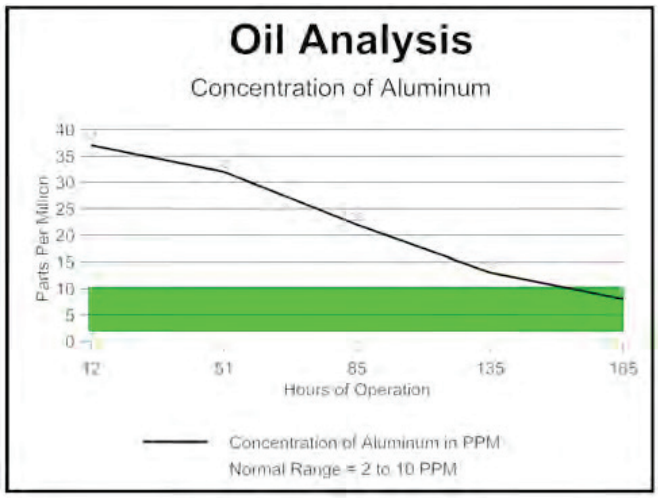


Figure 9-18. Oil analysis of aluminum.

each element is established with each oil analysis.
Oil analysis is normally not required when maintaining general and commercial aviation aircraft. It is, however, a useful instrument for determining when an engine, gearbox, or accessory should be removed from service or investigated further. It also provides information concerning the ingestion of silicon. Oil analysis gives the maintenance technician a method for monitoring engine wear in locations that are otherwise not visible. In some instances, maintenance tasks may be scheduled based on oil analysis results. Likewise, overhaul periods of reciprocating power plants may be determined by the results of regular oil analyses.

The need for regular oil filter inspections is still necessary when using oil analyses. Oil analyses do not see large particles of metal, they only see microscopic fragments. Therefore, normal visual inspections of filters and screens are fundamental in the engine inspection process, regardless of any oil analyzing process utilized.

CHIP DETECTORS

Chip detectors may be described as magnetic probes located in oil sumps used for the purpose of indicating the presence of substantial metallic particles in the oil. Chip detectors are found in strategic locations in the oil system. Their use is more common with larger aircraft, especially turbine-powered aircraft and aircraft with large radial engines. They are also found on helicopters to warn the flight crew of the possibility of impending failures. The uses of chip detectors are not limited to power plants, but are commonly found in transmissions and gearboxes.

There are two conventional styles of chip detector systems. ***(Figure 9-19 and 9-20)*** They are:

1. Warning Light - gives warning light in the flight compartment. This type of system warns the flight crew of a possible hazardous condition.
2. Ohmmeter Type - technician measures across terminals with an ohmmeter. Low resistance indicates the presence of metal across the probes.

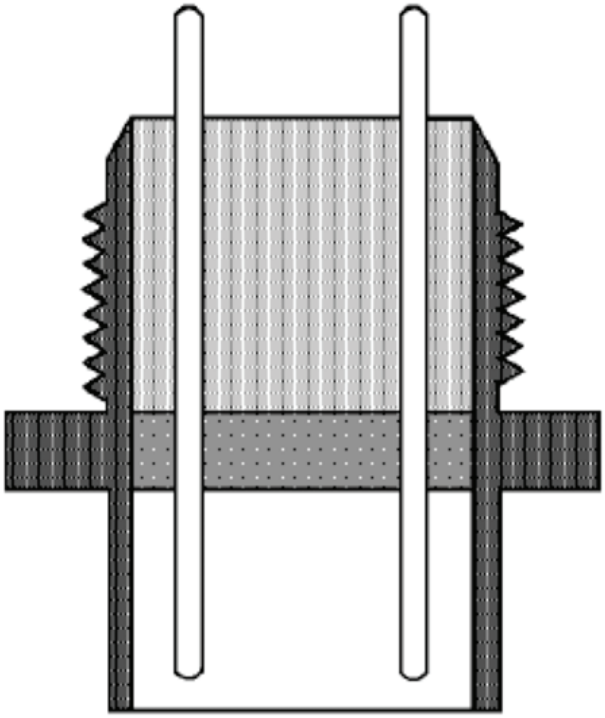


Figure 9-19. Chip detector.

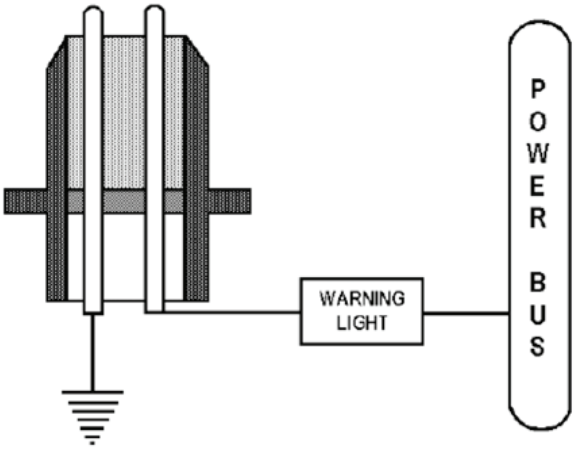


Figure 9-20. Automatic chip detector light.

Chip detectors are generally placed in the oil sumps. They contain a magnet to attract ferromagnetic particles. As the engine produces metal chips, the particles that are not caught, or never reach the oil filter, accumulate in the oil sump. When the chips build up to a level that bridges across the probes, a warning light comes on in the flight deck. If the ohmmeter style detector is used, a low resistance reading exists across the terminals when they are bridged by metallic particles.

To eliminate erroneous high levels of chips over a period of time, the chip detectors are usually removed at the oil change interval, or sooner, and cleaned of accumulated metal particles. Some systems incorporate a "fuzz burning" procedure. Such systems allow the operator to send an electrical current through the probes of the chip detector to burn off any "fuzz" across the probes. If the fuzz burning cancels the light, chances are that a false positive response was displayed by the system. If the probes are bridged by chips rather than fuzz, the fuzz burning process will not, or should not, open the circuit.

The concept regarding chip detectors is that they will show an unsafe condition in time to complete a safe landing or for maintenance personnel to catch a low resistance reading before a component fails. There is probably no way of determining with certainty how many aircraft and lives have been saved by chip detectors.

Question: 9-1
What type of lubrication system is required in reciprocating aircraft engines?

Question: 9-2
What type of sump system is most common on larger reciprocating engines?

Question: 9-3
Two sources used to drive the oil pump may be:

Question: 9-4
What causes hydraulic cylinder lock?

Question: 9-5
What is the principle benefit of a canister type oil filter over a full flow spin on filter?

Question: 9-6
Between what engine components is a full flow oil filter positioned?

Question: 9-7
Specific details and procedures for adjusting an engine's oil pressure

Question: 9-8
The surge protection valve on a _____ sump system redirect overly pressurized oil to the _____?

ANSWERS

Answer: 9-1
Pressure lubrication.
page 9.2

Answer: 9-2
Dry Sump.
page 9.3

Answer: 9-3
*Crankshaft.
*Gears in accessory case.
page 9.4

Answer: 9-4
Oil seeping past the rings of inverted cylinders and into the combustion chamber.
page 9.4

Answer: 9-5
Canister filters have replaceable filtering elements.
page 9.5

Answer: 9-6
Between the oil pump and engine bearings.
page 9.6

Answer: 9-7
Referring to the engine's maintenance manual.
page 9.7

Answer: 9-8
Dry; Oil storage tank.
page 9.9

Question: 9-9
What is the purpose of intake manifolds passing through the oil sump of a wet sump system?

Question: 9-10
What is the caution when switching from mineral oil to ashless dispersant oil?

Question: 9-11
In most cases engines with oil filters (as opposed to pressure screens) should have a full oil change and filter replacement every _____ hours or _____ months, whichever comes first.

Question: 9-12
During a series of several oil analysis, a steady parts per million count of aluminum indicates_____.

ANSWERS

Answer: 9-9
Preheats the fuel air mixture prior to entering the cylinders.
Page 9.12

Answer: 9-10
Ashless dispersant oil will loosen and disperse the sludge left on components by mineral oil.
page 9.13

Answer: 9-11
50 hours; 4 months.
page 9.14

Answer: 9-12
Normal wear.
page 9.15



PART-66 SYLLABUS	LEVELS		
CERTIFICATION CATEGORY →	A	B1	B3

Sub-Module 10
Piston Engine - Engine Indicating Systems

	A	B1	B3
16.10 - Engine Indicating Systems Engine speed; Cylinder head temperature; Coolant temperature; Oil pressure and temperature; Exhaust gas temperature; Fuel pressure and flow; Manifold pressure.	1	2	2

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

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

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

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

ENGINE INDICATING SYSTEMS

ENGINE INSTRUMENTATION

Aviation technicians must fully understand the readings taken from the power plant instruments to perform routine testing and complex troubleshooting. It is also important for technicians to realize that these instruments are measuring their assigned facet of the engine operation. Furthermore, instruments are unaware of what causes their readings, they only know the specific quantity of the assigned engine function. For example, the manifold pressure gauge does not inform the pilot as to specific causes for a particular manifold pressure reading. It only reports the quantity of absolute pressure in the manifold, regardless of how well the power plant is functioning. As a general rule, an operational or performance problem with the power plant will show up on more than one gauge.

Technicians should also have knowledge regarding the operation of the engine instruments. Such information may prove beneficial to testing and troubleshooting endeavors. This is especially true in instances when the instruments are suspected of being defective. Technicians should always consider the possibility of faulty or inaccurate instrumentation systems when abnormal readings are attained or reported.

The following instruments may be used to monitor the operation of a reciprocating power plant and power plant related systems.

1. Tachometer
2. Manifold Pressure
3. Torquemeter
4. Exhaust Gas Temperature (EGT)
5. Cylinder Head Temperature (CHT)
6. Coolant Temperature
7. Oil Pressure
8. Oil Temperature
9. Fuel Pressure
10. Fuel Flow Meter
11. Carburetor Air Temperature Gauge
12. Electrical System
13. Pneumatic System
14. Hour Meter

TYPICAL INSTRUMENT MARKINGS

Instrument markings indicate ranges of operation, minimum limits, and maximum limits. Specific colors and markings are used to depict limits and ranges. A line is generally used to indicate a limit. Colored arcs, or intermediate blank arcs, denote operational ranges. The bottom of an arc shows the minimum allowable operational limit of the range. The top of the arc shows the maximum continuous limit of the operating range. Operation beyond an arc may be time limited or dependent on special conditions (e.g., full rich mixture). Check appropriate service and operational data for specific information regarding ranges and limits.

The following are typical examples of power plant instrument markings:

A red line indicates a minimum or maximum limit.

A red arc denotes a dangerous operational range. Red arcs on tachometers normally indicate harmful vibration ranges. Acceleration and deceleration through a red arc is permitted, but protracted operation within the red arc is not recommended.

A yellow arc is used to define a precautionary range. Yellow arcs may be used to identify time-limited ranges or warnings related to operating temperatures or other critical parameters.

An intermediate blank arc is frequently used to connect the top of an arc to a red line. They are often utilized to define time-limited ranges. For example, a tachometer might have a green arc that extends from 2,000 to 2,600 rpm. In this example a blank arc runs from 2,600 rpm to the red line at 2,700 rpm. With the top of the green indicating the maximum continuous rpm at 2,600 and the red line indicating 2,700 rpm maximum, operations within the blank arc (between 2,600 and 2,700 rpm) are time limited. Check the appropriate data information or operator's manual for specific limitations.

A blue arc indicates a special range of operation. A typical blue arc on a power plant instrument is used to indicate the operational range while running the engine with a lean mixture. The blue arc may be used for other purposes

A green arc is used to indicate a normal or desirable operating range. On certain engine instruments it denotes operational ranges while running with enriched mixtures.

A white line extending from the glass onto the bezel of the instrument is used to indicate glass slippage, when used. Such a slippage mark is necessary whenever the operational ranges and limits are marked on the glass rather than on the face of the instrument.

TACHOMETER

The tachometer, as used on a reciprocating power plant, provides the speed of the crankshaft in revolutions per minute. On some aircraft, tachometers are equipped with hour meters to record hours of engine operation. Tachometers used with turbine power plants may register rpm for multiple spools in either percent rpm or in revolutions per minute.

A blue arc, when present, is normally used to indicate the operational range of the engine while running with a lean mixture. Blue arcs are commonly used with power plants equipped with large pressure carburetors. Such markings are employed to show appropriate rpm ranges while operating with the mixture control set in the "automatic lean" position.

A green arc may be used to show the operational range requiring a rich carburetor setting. Engines with large pressure carburetors use green arcs to indicate rpm ranges requiring "automatic rich" mixtures. On smaller aircraft, the blue arc may be absent and the green arc will be used to show the normal operating range.

The top of the green arc indicates the maximum continuous rpm. If the green arc does not extend to the red line, operations above the green arc and below the red line usually have a time limit. If the green arc extends to the red line, the engine is rated to run continuously at red line power if not otherwise prohibited in the operator's manual.

Some tachometers have a multi-tiered arc. For example, an airplane may have a multi-tiered green arc that limits the maximum continuous rpm based on altitude. Note in ***Figure 10-1*** that the engine has a maximum continuous rpm of 2,550 at sea level and 2,650 at 5,000 feet. At 10,000 feet, the engine has a maximum continuous rpm of 2,750 or red line rpm. The reason for the allowing such increases in the maximum continuous rpm is due to the reduction in ambient pressure as the aircraft ascends. In other words, because the ambient pressure is less at altitude, there is no way to overstress the engine at those speeds. This reduction in the available manifold pressure for naturally-aspirated power plants serves a safety net for the engine. In reality, it is very unlikely that a naturally-aspirated power plant could ever attain 2,750 rpm in straight and level flight while flying at 10,000 feet. It may also experience difficulties running continuously at 2,650 in straight and level flight while flying between 5,000 feet and 10,000 feet.



Figure 10-1. Multi-tiered green arc. Note: hour metered included in tachometer.

The red line denotes the maximum permissible rpm. Operation beyond the red line is an over speed and must be avoided.

Under normal operation, the tachometer may be used as an indication of power output. The technician must be aware, however, that the tachometer is actually measuring the speed of the main shaft(s) of the engine and not the true power output. For example, an inoperative engine that is windmilling has an rpm indication but is not generating power. Check the appropriate service information and the engine data to obtain the specific rpm ranges and limits.

Often multi-engine aircraft will combine tachometers into a single instrument. For example, a twin engine aircraft may contain two needles, one for the left engine and the other for the right engine. Some multi-engine tachometers include a synchronizing indicator to assist pilots with setting the rpm equal

between the engines as seen in ***Figure 10-2***. In this example, when the wheel spins clockwise, the right engine is running faster than the left engine and vice versa when the wheel spins counterclockwise.



Figure 10-2. Multi-engine tachometer with engine RPM synchronizer. Note: left engine and right engine needles are superimposed at 2,300 RPM.

Aircraft tachometers may be driven mechanically or electrically. Mechanical tachometers are commonly used on single-engine aircraft while multi-engine aircraft use electronic tachometers. The latter use a tach generator to produce a signal that is delivered to the tachometer. Another form of electronic tachometer uses points within the magnetos or a separate sensor.

Later generation electronic instrument panels include tachometer displays along with other engine and flight instrument. These instrument panels are gaining popularity in general, commercial, and military aircraft. In certain cases, mechanical instruments are included in the instrument panel as back-up gauges in the event that the electronic display fails.

Tachometers may become inaccurate over time. Technicians should be aware of how inaccurate tachometers impact the operation of the aircraft and other issues, such as adjusting fuel injection pressures. Electronic tachometer checkers are commonly used to check the accuracy of tachometers. ***[Figure 10-3]***



Figure 10-3. Electronic tachometer checker.

MANIFOLD PRESSURE GAUGE

The manifold pressure gauge measures the absolute pressure in the induction system downstream of the throttle valve and upstream of the intake valves. This pressure is commonly known as ***manifold absolute pressure*** or ***MAP***. Under normal operating conditions, the manifold pressure is indicative of the power input as it measures the magnitude of the fuel/air charge entering the combustion chambers. The gauge is calibrated in inches of mercury (“HG).

The manifold pressure gauge shown in ***Figure 10-4*** is from a twin-engine aircraft. This aircraft uses turbocharged engines. Observe the multi-tiered green arc. At 2,300 rpm the maximum continuous MAP is 34”HG. At 2,450 rpm the maximum continuous MAP is 31.5”HG. Operations above 34”HG are time-limited. The MAP redline is 37”HG.

Note on the gauge that the blue arc is serving a special purpose. The numbers on the blue arc refer to altitudes. Multiply the number by 1,000 and the blue arc reveals the maximum MAP for those altitudes. For example, at 30,000 feet (9,144m) the maximum manifold pressure is 25”HG. At 26,000 feet (7,925m) the manifold pressure limit is 30”HG. When flying at 20,000 feet (6,096m) the MAP limit is redline. The arrangement of the blue arc on the face of the gauge simplifies the task



Figure 10-4. Manifold absolute pressure gauge or MAP on twin engine aircraft flying at 22,000 feet.

of maintaining the manifold pressure limits. The pilot simply adjusts the MAP by placing the needles directly over the flying altitude.

The engines of this aircraft are equipped with the variable absolute pressure controllers (VAPCs) and manifold pressure relief valves discussed in Module 16.7. Because the turbocharging on this airplane does not include the pressure ratio controller, the pilot has to manually limit the MAP as indicated on the instrument.

When used in combination with the tachometer, pilots can precisely adjust engine power. This helps the crew calculate fuel consumption and other parameters critical to the flight. ***[Figure 10-5]***



Figure 10-5. MAP and engine RPM used for setting engine power.

There are three variables that control manifold pressure. The first is ambient pressure. Naturally-aspirated aircraft operating at sea level have a greater supply of barometric pressure than those operating in mountainous regions. Likewise, naturally-aspirated power plants begin to lose manifold pressure as they ascend toward their service ceilings. Supercharged engines experience a similar decrease in manifold pressure above their critical altitudes. The operator of the aircraft has minimum control over the amount of ambient pressure available to the engine.

The second variable affecting manifold pressure is engine rpm. The number of intake strokes, or volume of air consumed by the engine, is directly related to rpm. The operator of the aircraft has direct control over engine rpm. On engines equipped with fixed-pitch propellers, rpm is controlled by throttle position and aircraft attitude. During constant-speed operations of engines equipped with variable-pitch propellers, the governor controls engine rpm as dictated by the operator.

The position of the throttle is the third element that controls manifold pressure. The size of the throttle opening directly affects the amount of air entering the manifold. In effect, manifold pressure is dependent on the size of the butterfly opening and the quantity of air evacuated by the intake action of the cylinders. The larger the throttle opening, the greater the flow of air into the intake manifold when all other conditions are equal. Aircraft operators control the amount of butterfly opening by positioning the throttle control.

The build-up of ice in the carburetor may affect manifold pressure. When a significant accumulation occurs, air entry into the manifold is restricted. Such action serves to reduce manifold pressure.

Before addressing the various markings used on manifold pressure gauges, a brief explanation of the dynamics involving the induction system is in order. The reciprocating power plant is, in reality, a constant displace pump. For each revolution of the crankshaft, half of the engine's displacement is ingested by the intake action of the cylinders. Before reaching the cylinders, the air must flow past the throttle valve and through the induction manifold. This continuous transfer of air through the fuel control unit and induction manifold occurs whenever the engine is rotating. In this regard, the induction manifold is constantly receiving and discharging air. Whatever remains in the manifold is manifold pressure. Therefore to understand manifold pressure, the rate at which

the air enters versus the rate at which it exists must be analyzed. For example, given a certain rpm and throttle position, when rpm increase, the amount of air remaining in the manifold, or manifold pressure, decreases. The reason is evident when the number of intake strokes is taken into consideration. An increase in rpm means an increase in the number of intake strokes. This further translates into an increase volume of air removed from the manifold. For a given throttle setting, increasing the volume of air removed from the manifold results in a reduction of manifold pressure.

In terms of markings, a blue arc may be used to show the range of manifold pressure while operating with the carburetor in a lean mixture setting. In such cases, the green arc is used to label the operational range of the engine requiring a rich carburetor setting. Most small aircraft use a green arc to denote the normal operating range of manifold pressure. The top of the green arc is used to show the maximum continuous power setting. Operation of the engine with the manifold pressure set above the green arc and below the red line may be time limited. A red line is used to show the maximum allowable manifold pressure. MAP gauges associated with naturally-aspirated power plants are often devoid of instrument markings. In such cases, Nature limits MAP.

Engines equipped with an anti-detonant injection system may use a second red line to show the maximum allowable manifold pressure during wet operations. Operation beyond the appropriate red line is an over boost and should be avoided. Over boosting may result in severe damage to the power plant or complete failure. Check the appropriate service information and appropriate engine data for specific manifold pressure ranges and limits.

TORQUEMETER

The torquemeter measures actual engine output. One cannot fool the torquemeter like some other instruments. As an example, pretend there is an in flight engine shutdown. While the propeller is windmilling, the manifold pressure gauge (power input) and the tachometer (power output) each have readings. In other words, there is an indication of power input and power output. But in reality the engine is absorbing energy from the forward motion of the aircraft. Remember that the tachometer indicates the speed of the main shaft(s) of the power plant and the manifold pressure gauge measures absolute pressure in the manifold. These instruments only measure their respective parameters. They have no idea what causes the crankshaft to rotate or why a certain pressure exists in the manifold. However, under normal operating conditions, engine rpm is indicative of power output and manifold pressure may be used to show power input. Together they serve as good reference sources for determining power settings. In contrast, torquemeters measure the torque produced by the engine. If the engine is windmilling, no torque is produced.

Torquemeters are commonly installed on aircraft that are equipped with large radial engines. Turboprop and turboshaft equipped aircraft also use torquemeters. ***[Figure 10-6]***



Figure 10-6. Torquemeter.

Markings on the torquemeter may include a blue arc to show the operating range with the carburetor mixture control set on automatic lean. The green arc indicates the operating range requiring an automatic rich carburetor setting. The top of the green arc shows the maximum continuous setting. Operating beyond the green arc, and below the red line, is usually restricted in terms of time. The red line shows the maximum allowable torque setting. Wet engines, those with ADI, may have a second red line to indicate the maximum allowable limit for engine operations using an anti-detonate injection system. Check the appropriate service information and the engine data for specific ranges and limits.

EXHAUST GAS TEMPERATURE

An exhaust gas temperature (EGT) indicating system measures the temperature of exhaust gases. Typical systems sample the temperature at one of the following locations: (a) exhaust stack, (b) exhaust manifold, or (c) tailpipe. The temperature of the exhaust gas varies with power settings, rpm, and mixtures.

The EGT system is very useful for adjusting the mixture at altitude. For any given power setting, changes in the mixture produce changes in EGT. As the mixture is leaned from full rich, the exhaust temperature increases until it peaks. After peaking, further leaning results in decreases in temperature followed by engine roughness, if leaned excessively. Because it is possible to establish a peak temperature, the operator may use the EGT system for precise adjustment of the mixture during cruise. This is of particular importance when the aircraft is equipped with a constant speed propeller.

When leaning the mixture for cruise flight with engines equipped with constant-speed propellers, one manufacturer recommends the use of the airspeed indicator when the EGT gauge is inoperative or not installed. They advocate leaning from full rich until there is a slight, but discernable increase in airspeed. On fixed-pitch propeller equipped models, the tachometer and airspeed indicator peak when best power is attained.

The reason these alternative instruments are effective when the EGT system is inoperative is due to the reaction of the power plant and propeller during the leaning operation. Engines with fixed-pitch propellers gain rpm when the mixture is leaned from an overly rich condition. The increase of rpm augments airspeed. On constant-speed propeller systems, when the governor is in an "on-speed" condition, leaning the mixture from its full rich position at altitude causes the propeller to increase pitch. The change in pitch is attributed to the engine's desire to gain rpm during the leaning process. The governor, however, converts the impulse to accelerate into a higher propeller pitch. If leaned excessively, the constant-speed propeller will experience a decrease in pitch. This relationship between mixture and propeller pitch means that the best mixture produces the maximum propeller pitch. This, in turn, corresponds to increases in airspeed.

In most leaning procedures, actual temperatures do not matter much. Operators need to know when they have peaked the EGT. Many EGT instruments do not specify temperatures. Instead they are incremented in 25˚F intervals. An example of using the EGT system for setting the mixture might be to lean until peak EGT is reached, then enrich one increment or 25˚F for best economy. For best power, after peaking enrich the mixture by 2 increments or 50˚F. These instruments are often equipped with a reference needle that may be set to mark maximum EGT. Follow the aircraft manufacturer's instructions for specific leaning instructions. The mixture should never be leaned to the extent that other parameters (e.g., CHT, oil temperature, etc.) are exceeded. ***[Figure 10-7]***



Figure 10-7. EGT gauge foe twin-engine aircraft. Note: adjustable white needles to manually set for maximum EGT to serve as reference.

In some instances a limit on the EGT is mandated. Usually, turbocharged engines have restrictions regarding EGT. Check the appropriate data source or appropriate manufacturer's service information for information regarding EGT limits.

In addition to assistance in leaning operations, the EGT system may be used for troubleshooting or locating cylinders with defects. When comparing EGT systems to CHT indicators, the former has a very quick response time to changes in combustion temperature. Also, multiple-probe EGT systems are excellent for pinpointing troubled cylinders.

The reason EGT systems are so quick to respond to changes in combustion temperature is that the EGT probe is placed in direct contact with the exhaust gases. This is also the reason why EGT systems are more expensive. Materials used to make EGT probes must be impervious to the effects of the hot, corrosive exhaust gases. ***[Figure 10-8]***

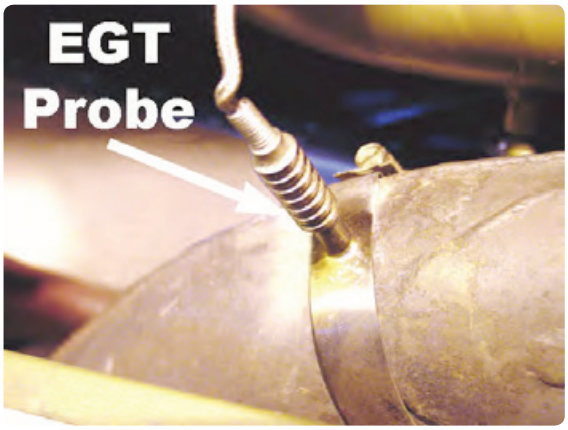


Figure 10-8. EGT probe installed in exhaust manifold.

By contrast, CHT probes are placed in contact with some portion of the cylinder. Before changes in temperatures are registered, the entire mass of metal in the vicinity of the CHT probe must change its temperature. This results in lag time. Check appropriate service information for specific ranges and limits.



Figure 10-9. EGT, CHT, and turbine inlet temperature gauge for twin-engine aircraft. Note that all six cylinders EGT and CHT readings are given along with turbine inlet temperature. Maximum EGT and CHT readings are provided.

Later generations of EGT instruments provide electronic displays. When these units simultaneously show the EGT of each cylinder, crew members are able to easily compare the EGT readings of each cylinder. Some electronic instruments reveal EGT, Cylinder Head Temperature, and Turbine Inlet Temperature on a continuous basis.

CYLINDER HEAD TEMPERATURE

Cylinder head temperatures (CHT) are measured by thermocouples placed under spark plugs or in special wells located in the heads of the cylinders. In comparison to an exhaust gas temperature (EGT) indicating system, the CHT system has the advantage of being relatively simple to install and inexpensive to purchase. The drawbacks that CHT systems have in comparison to EGT systems are that they are very slow in showing fresh changes in combustion temperatures and are usually not available in multiple cylinder configurations. Later generation instrumentation packages do offer multiple CHT probes. The slowness of temperature change indications is due to the lag time required to heat or cool the cylinder head when changes in temperature occur. ***[Figure 10-10]***



Figure 10-10. CHT gauge. Note: Intermediate blank arc from 230˚C to 245˚C denotes time limited operation.

A blue arc, when used, reveals the permitted temperature range while operating with the carburetor set on automatic lean. If a blue arc is present, a green arc reveals the temperature range while running with

the carburetor mixture set on automatic rich. Smaller aircraft generally use a green arc to indicate the normal, or desirable, temperature range. The top of the green arc is the maximum continuous operating temperature. Operation above the green arc and below the red line is usually time limited. The red line shows the maximum allowable cylinder head temperature. Check the appropriate service information and technical data sheet for specific ranges and temperatures. ***[Figure 10-11]***

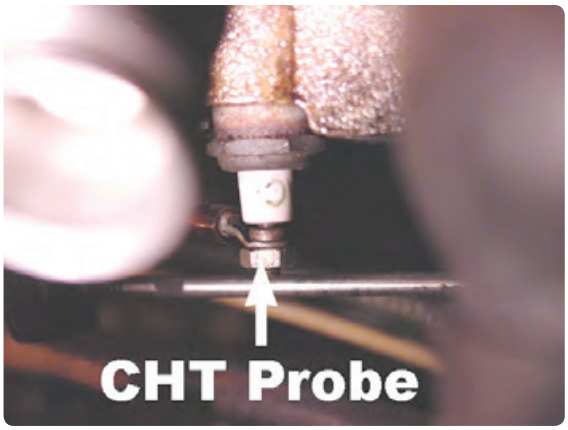


Figure 10-11. Cylinder head well-type CHT probe.

COOLANT TEMPERATURE

Aircraft equipped with engine that are liquid cooled have temperature gauges to show the temperature of the coolant. Problems that occur to the cooling system will be displayed by unusual readings.

OIL PRESSURE GAUGE

The oil pressure gauge measures the fluid pressure on the outlet side of the oil pump. It indicates regulated oil pressure when regulators are incorporated. ***[Figure 10-12]***



Figure 10-12. Oil pressure gauge showing maximum and minimum limits, yellow arcs, and normal operating range.

Typical markings found on an oil pressure gauge include a red line to indicate the minimum oil pressure limit, a green arc to show the normal operating range, and a red line to denote the maximum allowable oil pressure. Yellow arcs or intermediate blank arcs denote precautionary ranges. Check the appropriate data for specific ranges and limits. The oil pressure gauge may be one of the most important engine instruments in regards to flight safety.

Many small aircraft use oil pressure gauges that are mechanically driven. The instrument uses a bourdon tube that is connected to the oil pressure port on the engine. Other systems involve electronic sensors that convert the hydraulic pressure of the oil system into an electronic signal.

It is common to see the oil pressure gauge combined with other instruments. This conserves space on the instrument panel and helps the operator monitor multiple parameters with little eye movement.

OIL TEMPERATURE GAUGE

The oil temperature gauge displays the temperature of the oil. The gauge is marked to indicate whether the oil temperature is low, normal, or excessive. ***[Figure 10-13]***



Figure 10-13. Oil temperature instrument.

Generally, a green arc depicts the desired oil temperature range and a red line is used to show the maximum allowable oil temperature. If there is a minimum oil temperature, a red line will be used to indicate the minimum oil temperature. Yellow and intermediate blank arcs provide warnings or indicate limited ranges. The temperature of the oil is usually measured at the inlet of the oil to the engine. Check the engine data sheet for specific oil temperature ranges

and limits. The oil temperature gauge may be used to confirm oil pressure difficulties.

As with the oil pressure instrument, oil temperature gauges may be either mechanical or electronic. Oil temperature bulbs are installed in the oil system to sample oil temperature. It may vary slightly from one engine to another in terms of oil temperature sampling location. This is also true when comparing the sampling location of dry-sump versus wet-sump engines. The mechanical gauges normally use a contained fluid that senses oil temperature. As the fluid heats up, it expands and acts on a bourdon tube to provide the operator with oil temperature information. Electronic units use temperature bulbs to sense oil temperature and convert the temperature into an electronic signal.

FUEL PRESSURE GAUGE

The fuel pressure gauge is calibrated in pounds per square inch or other unit of measurement. Normally the fuel pressure is measured at the inlet of the carburetor or fuel metering unit.

The fuel pressure gauge is typically marked with a red line to indicate the minimum allowable fuel pressure limit, a green arc to show the normal operating range, and a red line to mark the maximum allowable fuel pressure. Check the appropriate service information and the engine data sheet for specific fuel pressure ranges and limits. ***[Figure 10-14]***



Figure 10-14. Fuel pressure gauge showing minimum limit normal range, and maximum limit.

On large aircraft, multiple engine instruments are grouped into a single case. The **Figure 10.15** shows fuel pressure, oil pressure, and oil temperature. Such gauges



Figure 10-15. Cluster gauge with fuel pressure, oil pressure, and oil temperature.

save considerable space on the instrument panel and makes it easier for the crew to monitor multiple systems.

FUEL FLOW METER

Aircraft equipped with continuous flow fuel injection typically include a fuel flow meter as part of the instrumentation package. This gauge provides the operator with information concerning the fuel consumption of the power plant throughout its range of operation. Because the instrument reveals flow, it is incremented in volume over a period of time (e.g., gallons per hour, pounds per hour, etc.).

The standard flow meter used with the continuous flow fuel injection system is not a true flow meter but rather a pressure gauge calibrated in terms of flow. The instrument is connected to the flow divider or manifold valve where it senses the fuel pressure applied to the nozzles. Because the size of the orifices within the nozzles is known, the flow through the nozzles at specific pressures may be determined. From this relationship between the pressure applied to the nozzles and the flow through same, the pressure gauge serves the function of a flow meter when it is properly incremented. ***[Figure 10-16]***

An interesting scenario comes into play when troubleshooting continuous flow fuel injection systems using standard flow meters. The fuel flow gauge may experience reverse indication. It may indicate that the engine is receiving too much fuel when in reality too



Figure 10-16. Fuel flow meter for twin-engine aircraft. Note series of markings including minimum and maximum redline with PSI readings, green arc in gallons per hour, and special blue and green flow blocks.

little fuel is discharged from the nozzles. As a general rule, when faults in this indicating system are located upstream of the pressure tap, the gauge responds in the proper direction. Conversely, defects downstream of the pressure tap produce reverse indications. Technicians should gather a full set of operational data (e.g., flow at idle, midrange, high power, and etc.) before making system adjustments. In addition, the mixture control may be used to determine whether the excessively high or low reading is correct or a case of reverse indication.

Discrepancies in fuel flow are often more difficult to identify on single-engine aircraft than on multi-engine aircraft. The latter offers two readings for comparison. The operator may notice that when the mixture is moved to peak exhaust gas temperature (EGT) that the flow meter readings are not identical. Also, when matching EGT or synchronizing fuel flow readings, the mixture control levers become misaligned.

Reverse indications occur when the fuel injection system develops faults downstream of the flow meter connection point. For example, as the system accrues time in service, the nozzles build a coating of carbon on its surfaces. This carbon build-up impedes fuel delivery as the flow paths through the nozzles become more constricted. In terms of pressure, the constriction generated by the build-up of carbon causes the pressure on the upstream side of the nozzles to increase. Because the flow meter senses pressure, the increase of pressure is registered as additional fuel flow. In reality, less fuel is flowing through the nozzles.

One technique to assist the technician in determining whether the mixture is too rich or too lean is to slowly move the mixture control toward cutoff. If the mixture is too rich, the engine will gain an inordinate amount of rpm. If the mixture is too lean, there will be no rise in rpm. Instead, the engine will begin to die. If the technician wants to confirm whether the engine is running too rich or too lean, as indicated by the flow meter, the mixture control check may be implemented.

Electronic flow meters have become popular on many engines equipped with continuous flow fuel injection systems. These instruments have the advantage of providing the operator with an accurate flow reading. Also, they are less likely to generate reverse responses. [Figure 10-17]



Figure 10-17. Electronic fuel flow meter.

On the RSA system, the sensor for electronic fuel flow indicators is typically located either upstream of the fuel/air controller or between the fuel/air controller and flow divider. Continental injected engines place the sensor between the outlet of the throttle control valve and the inlet of the manifold valve. If the Continental system placed the sensor prior to the fuel pump, fuel departing the fuel pump and returning to a fuel tank via the vapor

ejection system would be included in the fuel flow reading, thereby exaggerating the flow. Likewise, if the electronic sensor was placed between the fuel pump and mixture control valve, the indicated flow would only be accurate when the mixture control is in its FULL RICH position. Fuel returning to the fuel pump as the mixture control is moved from FULL RICH to CUTOFF would be included in the fuel flow reading. Again, such action would exaggerate the actual fuel flow delivered to the engine. To accurately measure the fuel flow consumed by an engine equipped with the Continental continuous flow fuel injection system, the sensor should be placed in series between the outlet of the throttle valve and the inlet of the manifold valve. ***[Figure 10-18]***

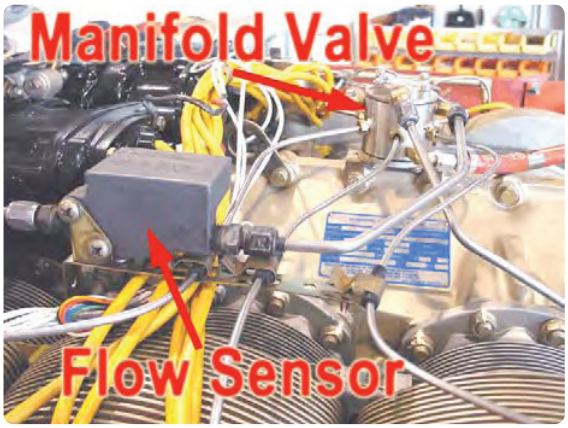


Figure 10-18. Continental fuel injection electronic flow sensor placed in series between the fuel control unit and manifold valve.

CARBURETOR AIR TEMPERATURE GAUGE

The carburetor air temperature instrument is primarily used to detect favorable conditions for ice formation in the carburetor. In addition to ice detection, it can be used to warn the flight crew of excessively hot, induction bound air. If the inlet air is significantly overheated, detonation may result.

Some carburetor air temperature probes are located in the carburetor heat box. Others are installed in the carburetor. In any case, the instrument markings provide the proper information. A yellow arc is placed to show the temperatures likely to produce ice in the carburetor, the green arc is used to indicate the safe temperature range, and the red line is used to show the maximum safe limit. Operation beyond the red line may lead to or cause detonation. Continued operation within the yellow arc may lead to ice formation. Check the appropriate service information and the engine data sheet for specific ranges and limits. ***[Figure 10-19]***



Figure 10-19. Carburetor air temperature gauge with air box temperature gauge.

ELECTRICAL SYSTEM

A major system associated with the power plant is the electrical system. Aside from a number of antique airplanes that do not have electrical systems, most aircraft are equipped with batteries, starters, generators or alternators, lights, radios, and other electrical equipment. As the engine is used to drive the generator or alternator, such system have gauges to confirm operation or reveal faults. Generator or alternator output may be checked by means of an ammeter, voltmeter, loadmeter, and discharge light.

The ammeter has a zero in the center of the gauge. When the needle is deflected to the left of zero, the negative side, the battery is being discharged. Movement of the needle to the right of zero, the positive side, indicates that the battery is being charged. The degree of charging or discharging may be determined by the value depicted by the needle. ***[Figure 10-20]***

The voltmeter shows battery voltage. With the charging system in operation, the voltmeter shows regulated voltage. If the charging system becomes inoperative, the voltmeter reveals battery voltage. As the battery drains, the voltage diminishes. ***[Figure 10-21]***



Figure 10-20. Ammeter. When needle moves to the left of zero, the battery is being discharged. When the needle moves to the right of zero, the battery is being charged.



Figure 10-21. Voltmeter.

The loadmeter shows the load absorbed by the generator or alternator. An inoperative generator or alternator indicates zero load. ***[Figure 10-22]***

Discharge lights illuminate when the generator, or alternator, is not charging the battery. When the light is off, the battery is being charged.

An aircraft may incorporate more than one indication system. For instance, an aircraft might use a discharge light in conjunction with an ammeter or a voltmeter with a loadmeter. Various combinations exist.



Figure 10-22. Loadmeter shows electrical load placed on system.

Multiengine aircraft may share a common indicator. In such cases, a selector switch is typically used to provide a means whereby each system may be tested for proper operation. On some aircraft, multiple function gauges are used. For example, a gauge may primarily show system load until a button is pressed to provide system voltage. ***[Figure 10-23]***



Figure 10-23. Multi function gauge. Reads electrical system load until knob in bottom left corner is pushed, then reads system voltage.

PNEUMATIC SYSTEM

A variety of flight instruments use gyroscopes to establish and maintain a reference (e.g., artificial horizon, gyro-compass, turn and slip, etc.). The gyroscopes may be driven by either pneumatic flow or electric motors. Many aircraft manufacturers will run the majority of the instruments using pneumatics and one instrument electrically. In the event that the pneumatic pump fails, the electrically driven gyroscopic instrument may be used and vice-versa should the electrical motor fails in the electrically-driven instrument.

The pneumatic power used for powering the gyroscopes may either be a positive pressure or a vacuum-type system. When the engine is running, the pneumatic pump should be delivering the appropriate force to keep the gyroscopes spinning at the proper speeds. Technicians should check this pressure when testing the system.

On multi-engine aircraft, the output from the pneumatic pump mounted on each engine may be combined into a single pneumatic source. In such instances, failure indicators are included in the instrument. ***[Figure 10-24]***



Figure 10-24. Instrument vacuum gauge for gyroscopic instruments on twin-engine aircraft. Note pump failure indicator for left and right vacuum pumps.

HOUR METER

Aircraft are commonly equipped with an hour meter. This device is used for determining hours of operation. Such data is crucial when performing maintenance based on time in service. Even routine oil changes are based on hours of operation. Pilots use this instrument to determine flight time for their logbook entries.

An hour meter is normally turned on by a switch that senses oil pressure. When the engine is running, the hour meter is running. These switches are connected to the hot battery bus and do not require that the master switch be ON. Other techniques for switching on the hour meter include an air speed switch or a switch connected to the landing gear. When the former detects a target airspeed (e.g., 70 knots), the hour meter begins recording time. In the case of the landing gear switch, when the strut extends because the weight of the aircraft is removed from the gear as during flight, the clock begins. ***[Figure 10-25]***



Figure 10-25. Hour meter. Black and white wheel at the 9 o'clock position revolves when the instrument is working.

MULTIFUNCTION DISPLAY (MFD)

The latest generation of instrumentation is the multifunction display or MFD. The MFD display screen is capable of showing multiple gauges at one time. They are useful as flight instruments as well as engine instruments. Many include radio functions. Compared to analog instruments, MFDs may be switched from one screen to another. Analog instruments permanently display data and cannot be rearranged for specific purposes. Also, MFDs are relatively efficient in terms of all that may be displayed versus the amount of instrument panel space consumed. Note in **Figure 10.25** the small amount of space consumed by the engine instruments when compared to analog gauges. The MFD is showing the following engine-related instruments: rpm, fuel flow, oil pressure, oil temperature, EGT, vacuum, fuel quantity, hour meter, electrical bus voltage, and battery voltage along the left border. ***[Figure 10-26]***

Most MFDs have a series of selector buttons, knobs, and switches that may be used for a variety of different screens. Beyond instrumentation, MFDs may be programmed to include a series of checklists. The system will include all checklists from the normal procedures to a series of emergency checklists.



Figure 10-26. MFD showing engine instruments along left edge and GPS data in rest of the screen. Note series of selector buttons along the bottom and switches and knobs on left and right borders and SD memory cards on right border for updating data. This unit further saves space as it includes the radios.

Personnel using these devices should receive training on the various features available in MFDs to maximize the benefits provided by these units. ***[Figure 10-27]***



Figure 10-27. Digital display of engine instruments. Note the quantity and quality of engine information provided on this MFD page.

Another beneficial feature of MFDs is the ability to warn flight crew members of dangerous conditions. If a parameter, such as cylinder head temperature, was to exceed its limit, the MFD may alert the crew by changing color to red. By comparison, an analog gauge would show the over temperature condition but it would require an observant crew member to notice the fault.

Question: 10-1
An above normal, but not urgent reading would be indicated by what color arc on an instrument?

Question: 10-2
What is meant on a tachometer when the green arc reduces to smaller widths near the red line?

Question: 10-3
What three factors affect manifold pressure?

Question: 10-4
How will ice buildup in the carburetor effect the reading on a manifold pressure gauge?

Question: 10-5
Which instrument gives the truest indication of power output on a reciprocating engine?

Question: 10-6
What is the primary purpose of the exhaust gas temperature gauge?

Question: 10-7
With the EGT gauge inoperative, what other two instruments may be used to assess peak engine efficiency?

Question: 10-8
Where is fuel pressure normally measured?

ANSWERS

Answer: 10-1
Yellow arc or gaps intermediate between the green arc and red line.
page 10.2

Answer: 10-2
Changing maximum rpm limits at various altitudes.
page 10.3

Answer: 10-3
*Ambient barometric pressure.
*Engine rpm.
*Throttle position.
page 10.4

Answer: 10-4
Manifold pressure will be reduced.
page 10.5

Answer: 10-5
Torque meter.
page 10.5

Answer: 10-6
To adjust the fuel/air mixture.
page 10.6

Answer: 10-7
Tachometer or airspeed indicator.
page 10.6

Answer: 10-8
At the inlet to the carburetor.
page 10.9

Question: 10-9
Dirty fuel injector nozzles would be indicated by _____ reading on a _____ gauge.

Question: 10-10
What potentially serious problem is indicated by a higher than normal carburetor temperature?

Question: 10-11
A condition in which electrical power is being consumed faster than the alternator can replenish it would be directly indicated by which instrument?

Question: 10-12
What operational function drives the hour meter?

ANSWERS

Answer: 10-9
An increased; Fuel flow gauge.
page 10.10

Answer: 10-10
Conditions leading to detonation.
page 10.11

Answer: 10-11
An ammeter.
page 10.12

Answer: 10-12
Oil pressure.
page 10.13



PART-66 SYLLABUS	LEVELS		
CERTIFICATION CATEGORY →	A	B1	B3

Sub-Module 11
Piston Engine - Power Plant Installation

16.11 - Power Plant Installation Configuration of firewalls, cowlings, acoustic panels, engine mounts, antivibration mounts, hoses, pipes, feeders, connectors, wiring looms, control cables and rods, lifting points, and drains.	1	2	2

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

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

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

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

POWER PLANT INSTALLATION

FIREWALL

The firewall is usually the foremost bulkhead of the engine nacelle and differs from most other aircraft bulkheads in that it is constructed of stainless steel or some other fire-resistant material. ***(Figure 11-1)*** The primary purpose of the firewall is to confine any engine fire to the engine nacelle. It also provides a mounting surface for units within the engine nacelle and a point of disconnect for lines, linkages, and electrical wiring that are routed between the engine and the aircraft. Without this firewall, an engine fire would have ready access to the interior of the aircraft. Since the consequences of an engine fire are obvious, the necessity of sealing all unused openings in the firewall cannot be overstressed.

Technicians inspect the firewall for entry points involving noxious fumes. Items passing through the firewall in addition to engine-related controls include fuel line(s), instrumentation lines and wires, cabin heat and defroster hot air supply, nose wheel steering linkages, nose wheel retraction and extension mechanisms, and similar items. Many aircraft have the battery mounted on the firewall along with relays and select fuses. Another item frequently attached to the firewall is the nose wheel. In such instances landing loads are transmitted through the firewall to the aircraft structure.



Figure 11-1. Firewall of a typical single-engine airplane.

COWLING

Engine cowlings serve a couple of functions in terms of engine installation. First, the cowling provides an aerodynamic function. Save for a few aircraft equipped with radial engines that are not cowled, most aircraft enshroud their engines within a cowling system. Next, the cowling plays a major role in engine cooling. As presented in Section 16.6, the cowling in conjunction with engine baffles control the flow of cooling air through the engine compartment. Without proper airflow, the engine, or portions of the engine, will overheat. Also, the cowling is often responsible to ensure the engine compartment has the correct pneumatic pressures. This is critical when the aircraft is equipped with a continuous flow fuel injection system. When the engine installation includes a fire fighting system, the cowling will augment the effectiveness of the fire fighting agent discharged into the engine compartment.

The cowling also includes access to the engine, oil filler port, pre-flight fuel drain access, and other items such as a mounting point for the landing light. Air entry into the fuel metering system typically begins at the cowling or opening provided in the cowling.

Some aircraft have cowlings that are simple and easy to remove and install. Other aircraft have cowlings that are difficult and tedious to remove and install. Technician should ensure that the cowling is in good condition and serving all the assigned functions.

ENGINE MOUNTS

Mounting the engine to the airframe is the function of the engine mounts. The critical nature of this installation is highlighted when one considers that the thrust produced by the engine is transmitted through the engine mount to the airframe.

Engine mounts may be broken into two components: the airframe portion and the engine portion. The airframe portion of the engine mount runs from the firewall to the engine attachment point. It is often manufactured from welded steel tubing. Some engine mounts are composed of riveted structures. In a number of airplanes, the nose gear is attached to the engine mount frame.

The attachment of the engine to the engine mount is normally accomplished using rubber components. The rubber mounting absorbs engine and propeller vibrations

and flight loads generated by turbulence and hard maneuvers. Bolts run through the engine mounts and rubber members and secure the crankcase or accessory case to the engine mount frame. Over years of service, the rubber members deteriorate. Similarly, protracted exposure to oil, solvents, fuel, and other chemicals may accelerate the deterioration of the rubber engine mounts. New rubber mounts are installed with the engine following overhaul or engine replacement.

HOSES AND TUBING

The installation of an aircraft engine involves the use of a variety of flexible hoses and rigid tubing. Hoses are used with the fuel system as well as the hydraulic and pneumatic systems. Engine instrumentation systems frequently employ flexible hoses. Airplanes equipped with air conditioning units have the additional hoses needed to connect the different components associated with air conditioning. Some engine components use flexible hoses to drain fluids overboard (e.g., the seal drain on a fuel or hydraulic pump, induction system drains, etc.).

The need for flexible hoses is because of the relative motion between the engine and airframe when the engine is operating. The rubber mounts used to secure the engine to the engine mount provides a slight amount of movement between the engine and airframe. If a rigid tubing was installed in place of a flexible hose, the tubing would crack and fail over time due to movement and vibrations.

Flexible hoses are use to connect various component of fuel metering systems. The continuous flow fuel injection system use flexible hoses to connect fuel control units to flow dividers and manifold valves and other components. Controllers used with turbo-charging system are connected using flexible hoses.

Maintenance personnel must take special care to preserve the integrity of flexible hoses. They should not be exposed to extreme heat and should be adequately anchored to prevent excess movement and chafing. Hoses should not be twisted. Many hoses have a stripe running along the exterior surface. This stripe is used for determining twist.

There are places where rigid tubing is used in the engine installations. In each case, the rigid tubing is used to connect two components that do not have relative motion with each other. Examples include the connection from the engine-driven fuel pump to a metering device. Some aircraft engines use rigid tubing to connect a propeller governor mounted in the rear of the engine to the passageways located in the nose section of the engine. Oil drains from rocker covers may use rigid tubing. Fuel injection system use rigid lines to connect the outlet of their flow dividers or manifold valves to the inlet of the injector nozzles.

When connecting and disconnecting the hoses and tubing, care should be taken to minimize spills and prevent the entry of foreign objects into the system. The use of plugs and caps will keep hoses and lines from dripping fluids and prevent dirt from entering the system. Technicians should plug all lines even those used for pneumatics. The entry of dirt into a line or hose connected to the vacuum pump may cause the pump to fail. Likewise, the fittings on the components connected to the lines and hoses should also be capped and plugged.

CONTROL CABLES AND PUSH-PULL RODS

A number of control cables and push-pull rods are used to connect the various engine systems to the cabin. The list of controls include: the throttle, mixture, carburetor heat or alternate air, cabin heat and defroster, and nose wheel steering links. And, when installed, propeller pitch, cowl flaps, landing gear extension and retraction, and others. ***[Figure 11-2]***

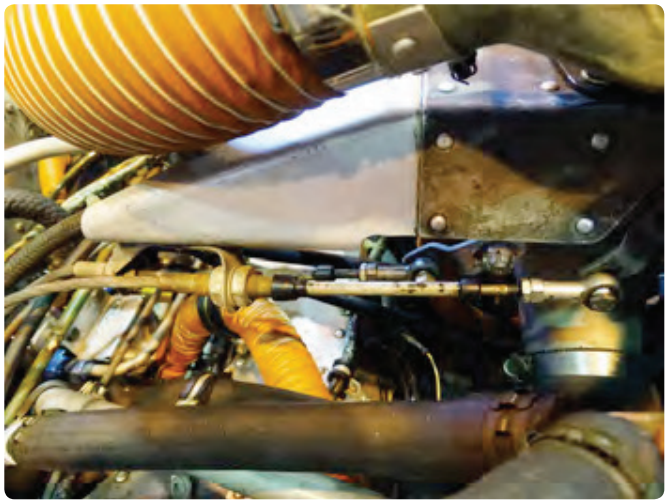


Figure 11-2. Control cable attached to throttle valve. Note double nut and bracket used to anchor the conduit.

Care should be taken with disconnected controls. Letting disconnected controls dangle may allow them to become bent or damaged in some fashion. A kink in a control will adversely affect the smoothness of motion. Lightly anchor disconnected controls to prevent physical damage. Every effort should be taken to keep from misadjusting cable ends that will result in rigging issues when the controls are reconnected. Of course, checking control rigging and smoothness of movement are basic steps that are taken after a control is connected to its component.

Push-pull rods are employed where cables are ill-suited for the task. Braided cables only have strength in the pulling direction. Pushing a braided cable has very limited applications. To use a braided cable in an application where it can push and pull heavy loads, a closed circuit is needed, as used with flight controls. Some control cables are made from a heavy single-strand material, such as piano wire. It too has limited strength in the pushing direction. For applications where strength is needed in both the push and pull directions (e.g., cowl flaps doors), push-pull rods are ideal. ***[Figure 11-3]***



Figure 11-3. Push-pull rod connected to throttle valve of RSA fuel injection system. Note idle RPM adjuster and mixture adjustment link.

Controls cable conduits must be properly anchored upon installation. Failure to use the proper hardware and correctly anchor the conduit will result in sloppy control action and full travel issues. As a rule, the throttle, mixture, carburetor heat, and, if used, propeller control should be have their conduit anchored to the engine or component that shakes with the engine. Also, the conduit clamp located near the end of the cable should provide a metal-to-metal contact. If clamps with rubber inserts are used, over time the rubber will decay and the conduit will develop unwanted movement.

LIFTING POINTS

Aircraft engines are subjected to scheduled overhauls. At times engines need to be removed from the aircraft before its scheduled overhaul period (e.g., engine sudden stoppage, unscheduled engine disassembly, airframe repairs, etc.). Consequently, there needs to be a mechanism whereby engines may be safely removed and installed onto the aircraft. Technicians should closely follow instructions provided by the manufacturer regarding engine removal and installation. The following are provided as general rules to be observed during the operation.

Most engines are equipped with a lifting attachment(s). These devices are normally installed during the assembly of the engine as part of the overhaul. Technicians preparing to remove an engine should examine the location of the lifting point to determine which way the engine will tip when unbolted from the engine mounts. One major consideration in this prediction is whether the propeller will remain on the engine when removing the power plant from the aircraft. ***[Figure 11-4]***

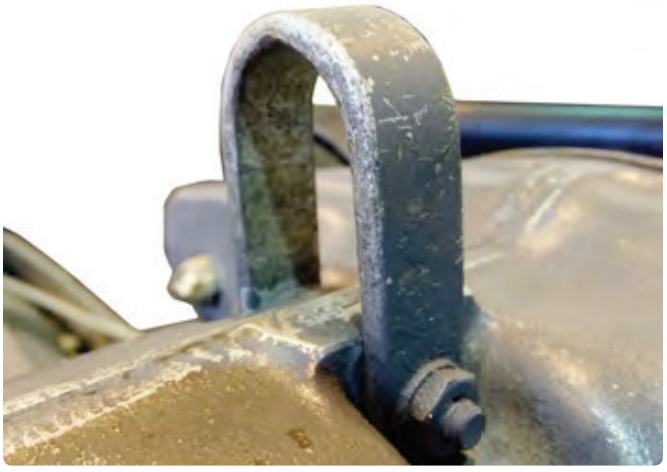


Figure 11-4. Engine lifting point.

Another precaution to consider is cable/chain twisting. When the engine is freed from the engine mount, the cable or chain connecting the engine to the hoist will often twist or spin the engine. If there are no major issues, this action should be slight, but something

to consider as a twisting action could cause parts (e.g., accessories) to strike objects (e.g., engine mount frame) and sustain damage.

Prior to hoisting an engine, the technician must perform a series of operations to prepare the engine for removal. This includes preparing a stand or location where the removed engine will be placed. A series of safety precautions should be implemented prior to disconnecting the engine. One task that should be taken is to disconnect the battery. Wires will be disconnected during the engine removal process and having the battery disconnected will prevent electrical mishaps. Because flammable fluid lines will be disconnected and possible fuel spillage will occur, the aircraft should be grounded and chocked and adequate fire fighting equipment should be at hand. The equipment should be in proper working order. Be certain that the fuel supply valve is turned to the OFF position before disconnecting fuel lines. Ensure that the ignition system is disabled. Aside from checking the magneto switch for being in the OFF position, technicians should remove all the spark plug leads and one spark plug from each cylinder or pull the distributor caps from the magnetos.

The instructions from the manufacturer should extensively detail the procedure to follow. The main concerns are safety and technicians need to prevent damage to the engine, propeller, and accessories during the procedure.

DRAINS

Engine drains vary from one style to another. Aside from the oil drain, the engine installation may include a series of drains. One drain may be from the induction system. Seal drains from fuel and hydraulic pumps may be used. A drain may run from the manifold valve or flow divider of an injected engine. Such drains will normally protrude from the cowling. If the battery is mounted on the firewall a drain from the battery box may be present.

The drain plugs used with carburetors are likely to be either 1/8" or ¼" pipe thread. Such fittings may prove difficult to remove if they have been untouched for an extended period. It may be helpful to capture the fuel from the float bowl in a clean, transparent container. This fuel should be inspected for contaminants and water. Caution should be taken to eliminate or minimize fuel spillage. ***[Figure 11-5]***



Figure 11-5. Induction system drain.

Draining the oil from the engine is a common procedure undertaken when removing the power plant from the aircraft. Technicians should pre-plan the operation and ensure that the oil quantity removed from the engine will be less in terms of volume than the container used to capture the oil. A dry-sump engine may have more oil to capture than a wet-sump engine. The receiving container should be clean so that an inspection for particles may take place following the removal of the oil from the engine. Technicians should safeguard against exposure to the petroleum products encountered during the draining process.

Oil drain hardware is available in two general designs. One type is the solid plug. These may either be pipe threaded or they may have straight thread. The latter uses a gasket, either crush-type or flat gasket. Technicians should follow torquing procedures when dealing with this hardware. The other type of drain plug is commonly referred to as a quick drain. They are threaded into the drain plug hole and have a valve that may be opened by pressing and sometimes pressing and twisting. A length of hose attached to the outlet of the quick drain may be used to direct the oil into the receiving drain bucket. Be certain to securely close the quick drain following the removal of the oil from the engine. ***[Figure 11-6 and 11-7]***

Following the draining of the fluids from the engine, a thorough cleaning of the area and associated tools should be accomplished. Leaving oil, hydraulic fluid, and other liquids on the floor generates a workplace hazard. Properly dispose of drained fluids to prevent the possibility of fire and environmental hazards.



Figure 11-6. Solid drain plug.



Figure 11-7. Quick drain. To open quick drain, place hose over outlet and push valve up. Pull valve down to close.

WIRING LOOMS AND CONNECTORS

The engine compartment of an aircraft contains numerous wires. If the battery is mounted inside the engine compartment, a number of relays will be located near the battery box.

Other wires found in the engine compartment include the ground wire to the engine, the starter cable, wires to the alternator/generator and regulator, and magneto P-leads. If the airplane has heating elements on the propeller blades wires running from the firewall to the brush block will be present. If the cowling contains a landing light, the associated wires are included in the wiring bundle. There may be a number of wires used for engine instrumentation.

When removing an engine from the aircraft, the technicians must carefully disconnect the series of wires included in the engine installation. Beyond the electrical connections, there may be a number of clamps and other devices used to anchor the wires to keep them from moving. It is prudent to accurately label the wires and produce a layout diagram to assist in the re-installation process.

Sophisticated airplanes will often bundle the wires into a series of plugs. Disconnecting the plugs allow the technician to hoist the engine without dealing with the tedious job of disconnecting and labeling one wire at a time. If the new engine has been built-up with the bundle installed, re-connecting the plugs greatly simplifies the engine installation.

ACOUSTIC PANELS AND INSULATION

To reduce sound levels within the cabin of the airplane acoustical panels are installed. These items are installed on the cabin side of the firewall. Insulation is added in some cases to reduce the level of engine compartment heat transmitted through the firewall. The acoustical material has a better visual appeal than bare sheet metal.

The installation of acoustical panels and insulation is made in such a fashion to accommodate all the controls, hoses, and wires that pass through the firewall. Technicians need to be careful when working around this material to maintain its effectiveness.

Insulation is used on certain model aircraft around heating system components. The insulation protects against burns and keeps the level of heat inside the system as high as possible. Insulation may also be used with air conditioner components. The insulation is needed to prevent condensation on low pressure lines and cold ducts.

QUESTIONS

Question: 11-1
Any opening in the firewall made to allow the passage of wires, hoses and other devices must be carefully sealed to _____.

Question: 11-2
What are the three primary functions of an engine cowling?
_____,
_____,
_____.

Question: 11-3
Why is rigid tubing not used when connecting items on the firewall to the engine?

Question: 11-4
When lifting an engine for removal from an airframe, a critical concern is that _____.

Question: 11-5
What is the advantage of push-pull rods versus braided control cables?

Question: 11-6
What is the principle danger of using rubber inserts on conduit clamps when securing off control cable conduits?

ANSWERS

Answer: 11-1
Prevent the flow of smoke or fumes in the event of a fire.
page 11.2

Answer: 11-2
*Aerodynamic function.
*Engine cooling.
*Establishing correct pneumatic pressures around the engine.
page 11.3

Answer: 11-3
The relative movement of the engine on its mounts would quickly cause the tube to fail.
page 11.3

Answer: 11-4
ALL wires, hoses, linkages, supports, etc… have been completely disconnected and out of the way.
page 11.4

Answer: 11-5
Braided cables can only exert force in the pulling direction.
page 11.4

Answer: 11-6
The rubber cushion will degrade over time.
page 11.5



PART-66 SYLLABUS	LEVELS		
CERTIFICATION CATEGORY →	A	B1	B3

Sub-Module 12
Piston Engine - Engine Monitoring and Ground Operation

	A	B1	B3
16.12 - Engine Monitoring and Ground Operation			
Procedures for starting and ground run-up;	1	3	2
Interpretation of engine power output and parameters;			
Inspection of engine and components; criteria, tolerances, and data specified by engine manufacturer.			

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

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

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

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

Level 3
A detailed knowledge of the theoretical and practical aspects of the subject and a capacity to combine and apply the separate elements of knowledge in a logical and comprehensive manner.

Objectives:
(a) The applicant should know the theory of the subject and interrelationships with other subjects.
(b) The applicant should be able to give a detailed description of the subject using theoretical fundamentals and specific examples.
(c) The applicant should understand and be able to use mathematical formula related to the subject.
(d) The applicant should be able to read, understand and prepare sketches, simple drawings and schematics describing the subject.
(e) The applicant should be able to apply his knowledge in a practical manner using manufacturer's instructions.
(f) The applicant should be able to interpret results from various sources and measurements and apply corrective action where appropriate.

ENGINE MONITORING AND GROUND OPERATION

PROCEDURES FOR STARTING AND GROUND RUN-UP

Aircraft engines require repeated testing. Before takeoff, engines are tested to ensure they fulfill basic requirements for flight. During flight, engines are constantly monitored to detect problems that may develop along the flight route. Consequently, pilots and technicians need to fully understand engine operations, testing procedures, and normal and abnormal readings and responses.

The engine testing operation is divided into four tasks, the prestart inspection, engine priming and starting, after start operation and testing, and the post-testing evaluation of the engine's performance.

PRESTART INSPECTION

Before operating the engine(s), the technician should check the aircraft to ensure that it is in condition for safe operation. If the power plant has not been operated for an extended period, it should be pre-oiled and properly prepared for operation before attempting to start the engine(s). (See module 16.13 for pre-oiling procedures.) The technician should use a checklist to prepare the aircraft for the testing operation. If a checklist is not available, the technician should, as a minimum, check for problems such as fuel, oil, and hydraulic leaks; visible damage or defects to the aircraft, the general condition of the propeller(s), oil and fuel quantities, contaminates in the fuel, adequate brakes and wheel chocks, proper inflation of tires and oleo struts, and select a suitable run up site. A general engine prestart checklist is provided.

The purpose of the prestart inspection is to spot problems with the aircraft prior to running the power plant. Some situations are potentially dangerous and costly. The following items should be checked before operating the engine(s):

1. Check the oil level.
2. Check the security of the controls and travel limits.
   A. Throttle
   B. Mixture
   C. Propeller, if used
   D. Carburetor Heat or Alternate Air Source
3. Check the air inlet for obstructions.
4. Check the propeller for security of installation and damage.
5. Check the engine mounts for security of installation and cracks.
6. Check for any disconnected wiring or plumbing.
7. Check magnetos and P-leads.
8. Check for loose spark plug wires.
9. Clean any excess oil and fuel spills.
10. Clear the engine and run up area of tools, towels, and other unnecessary items.
11. The engine must be pointed into the wind, to the extent possible.
12. Ground power units (GPUs), when needed, will be properly positioned and operated.
13. When necessary, a fireguard will be on hand.
14. The operator must be familiar with the controls and instruments and operation procedures.
15. Clear the area prior to starting.

ENGINE PRIMING AND STARTING

The starting and testing of an aircraft power plant should only be conducted by individuals with the appropriate skill and knowledge. Technicians who are unfamiliar with the craft should have a person qualified to perform the run-up operate the aircraft. Operating an aircraft without the requisite knowledge and skill may result in injuries and damage to the aircraft/engine. A checklist detailing the procedures for engine starting should be followed.

If the aircraft does not include an electrical system, the engine must be started by hand cranking or propping. Such procedures are more dangerous than cranking an engine equipped with a starter. Individuals should not attempt to hand crank an aircraft power plant without the proper training.

If the aircraft has a boost pump, the operation of the boost pump is normally tested before cranking the engine. Confirmation of boost pump pressure is taken from the fuel pressure gauge. Operation of the boost pump may be necessary to fill the float bowl of a carburetor. It also provides fuel flow through a solenoid primer or continuous flow fuel injection system.

ENGINE PRIMING

If the aircraft engine is equipped with a carburetor, the preparatory phase of the procedure will call for engine priming. This is normally accomplished by use of a single-action piston plunger that takes gasoline

from the firewall strainer and pumping the fuel into the induction system of the engine. A typical start of a cold engine will involve around three pumps of the primer. Some engines used on light-sport aircraft use a choke for cold engine starting.

Aircraft equipped with large pressure carburetors will have an electric solenoid primer. To send priming fuel to the induction system, the operator must have the boost pump running while the primer switch is activated. Often the starting procedure has the operator apply primer fuel while cranking the engine and after the initial starting of the engine. The mixture control is in the CUTOFF position during start. Once the engine starts and becomes stabilize, the mixture control is placed into AUTO RICH and the primer switch is released. Starting such engines requires considerable training and practice.

Priming an engine with a fuel injection system normally involves the use of the fuel-metering unit. Again the people operating the aircraft should follow the appropriate checklist. As a general rule, the following two procedures will prime an engine with a continuous flow fuel injection system. In the first list of steps, the boost pump is cycled ON and OFF. The second procedure cycles the mixture control valve from idle cutoff (ICO) to FULL RICH and back to ICO.

Cycling the Boost Pump Method:
1. Throttle - cracked 1/4"
2. Propeller - FULL INCREASE RPM or LOW PITCH
3. Mixture - FULL RICH
4. Fuel Shutoff - ON
5. Boost Pump - ON
6. Boost Pump - OFF after metered fuel psi has stabilized for several seconds

Cycling the Mixture Control Method:
1. Throttle - cracked 1/4"
2. Propeller - FULL INCREASE RPM or LOW PITCH
3. Mixture - IDLE CUTOFF
4. Fuel Shutoff - ON
5. Boost Pump - ON
6. Mixture - FULL RICH
7. Mixture - IDLE CUTOFF after metered fuel psi has stabilized for several seconds

Starting an aircraft engine is considerably different than starting an automobile engine. Aside from the numerous procedural steps contained in the checklist, an aircraft engine start involves the operation of more switches and controls. By comparison, starting an automobile engine is as simple as twisting a key.

The person starting and operating the aircraft engine must be capable of handling the craft. For example, the aircraft will likely have separate brakes for the left and right wheels and if the airplane needs to taxi to a run-up area, the operator needs to know how to taxi the airplane and communicate with ground controllers. Unqualified personnel should not be allowed to taxi the aircraft.

Engine starts may be divided into normal starts and abnormal starts. The latter may be necessary when the engine has a fault or becomes flooded or vapor locked. Starting procedures further differ depending on the type of fuel-metering device used and starting aid.

Technicians should closely adhere to the procedures provided by the manufacturer when operating an aircraft. The list of steps contained herein are of a general nature.

NORMAL ENGINE START

A normal start for a carburetor engine following the priming process:

1. Fuel Valve – ON or desired tank selected
2. Throttle - Cracked (pull all the way to idle an open a slight amount)
3. Mixture Control – FULL RICH
4. Propeller (if controllable) – FULL INCREASE RPM or LOW PITCH
5. Master Switch - ON
6. Magnetos – ON (as required)
7. “Clear Prop” – announce
8. Starter – ENGAGED
9. After Start – adjust engine rpm to approximately 1,000
10. Check oil pressure – Shut the engine off with the mixture control if no oil pressure is attained within 30 seconds or if the oil pressure does not meet or exceed the minimum oil pressure limit. Under arctic conditions, shut engine down if oil pressure is not reached within one minute after start.

Starting an engine with a small pressure carburetor or RSA continuous fuel inject system is different. The main issue involves the boost pump and mixture control. The following are general procedures for starting such engines.

1. Fuel Valve – ON or desired tank selected
2. Throttle - Cracked (pull all the way to idle an open a slight amount)
3. Mixture Control – IDLE CUTOFF
4. Boost Pump – ON
5. Propeller (if controllable) – FULL INCREASE RPM or LOW PITCH
6. Master Switch - ON
7. Magnetos – ON (as required)
8. "Clear Prop" – announce
9. Starter – ENGAGED
10. Mixture Control – FULL RICH after engine starts. Note: If additional prime is needed, advance mixture control briefly to FULL RICH
11. After Start – adjust engine rpm to approximately 1,000
12. Check oil pressure – Shut the engine off with the mixture control if no oil pressure is attained within 30 seconds or if the oil pressure does not meet or exceed the minimum oil pressure limit. Under arctic conditions, shut engine down if oil pressure is not reached within one minute after start.

Operators should follow the prescribed procedures for starting an aircraft with a large pressure carburetor. Overall the process will be similar to those listed for the small pressure carburetor and RSA system save for the use of the solenoid primer. The engine is started with fuel delivered from the primer and kept running briefly off the primer. After the engine stabilizes, the mixture control is moved from the idle cutoff position and the engine transitions to the metering provided by the carburetor. The primer is released during this transition as the mixture becomes excessively rich with fuel from both the carburetor and priming system.

Engines equipped with the Continental continuous flow fuel injection may be started using the procedures listed for the float carburetor provided the boost pump remains OFF. Continental injected engines may also be started using the procedures used to start an engine with a small pressure carburetor or RSA system.

FLOODED ENGINE STARTING PROCEDURES

A difficult challenge awaits those who attempt to start a flooded aircraft power plant. If circumstances permit, the operator should let the engine stand for a period of several minutes to allow excess fuel the opportunity to drain from the manifold. A flooded engine is a breeding ground for induction fires because the manifold contains an excess amount of fuel. Also, tailpipe fires are likely to occur. This is due to the collection of gasoline that accumulates in the exhaust system during engine cranking.

If the power plant is difficult to start, perhaps a fault is present in the fuel metering unit or ignition system, thereby combining a flooded engine with a faulty system(s). The likelihood of a fire is further compounded if the battery is in a low state of charge while attempting to start a flooded power plant.

The following procedure is provided for instances when the need for engine operation is paramount. One difficult element of performing a flooded engine start involves control movements. Because the throttle is in its full opened position and the mixture control is initially in idle cutoff, the operator must, in a near simultaneous fashion, reduce the throttle while advancing the mixture to full rich. The speed at which the mixture control is moved may affect the start. If moved too briskly or too slowly, the engine may die.

1. Throttle - FULL OPEN
2. Mixture - IDLE CUTOFF
3. Propeller (if controllable) - FULL INCREASE RPM
4. Master Switch - ON
5. Fuel shutoff - ON
6. Boost pump - OFF
7. "Clear Prop" – announce
8. Magnetos - ON
9. Starter - ENGAGED
10. After start, Mixture - FULL RICH
11. Throttle - Adjust warm-up speed 1,000 rpm
12. Check oil psi - Shut down the engine with the Mixture Control if no oil psi is detected within 30 seconds (one minute under arctic conditions)

VAPOR LOCK

One undesirable characteristic of fuel injected aircraft power plants is vapor locking of the fuel system. Vapor lock often occurs as a result of heat in the engine

compartment following engine shut down. This heat, in the area of 230°F (which is higher than the boiling point of water), acts on the fuel in the lines within the engine compartment. Such intense heat may convert liquid fuel into vapors. Ordinarily the conversion of liquid fuel into vapors would be welcomed since the goal of the fuel metering system is to perform that function. However, it should be noted that the fuel pump and the fuel control unit are not designed to meter vaporized fuel. Instead they are engineered and built to pump and meter liquid fuel and later atomize the fuel into a vaporous state.

Aside from heat, pressure affects the boiling of liquids. As the absolute pressure applied to a liquid is lessened, its boiling point is reduced. On higher altitude aircraft, vapor lock may occur at altitude. This is especially the case when operating at high altitudes, without the use of boost pumps, and engines that mounted higher than the fuel tanks. In such instances, the suction of the inlet of the engine-driven fuel pump lowers the pressure of the fuel in the lines. When the pressure becomes low enough, the boiling point of the fuel may be reached and the fuel may turn into a vaporous state within the fuel lines. To minimize this possibility, boost pumps are placed within the fuel tanks to push the fuel from the tanks to the engine-driven fuel pumps, when necessary. This design keeps the fuel pressurized and shields it from low pressure. If the boost pumps become inoperative, certain altitude restrictions may take effect. Check the operator's manual for specific details.
There are three ways of converting the vaporous fuel back into a liquid state. One method is to cool the fuel vapors. This action causes the vapors to condense back into a liquid. A second method is to place the vapors under pressure. Increasing pressure raises the boiling point of the fuel and returns the vapors to a liquid state. And the final method is to combine both cooler temperatures and higher pressure. To achieve the latter, the inside diameter of the fuel lines is cooled and the vapors are subjected to boost pump pressure.

The following procedure accelerates the conversion of vapors into liquid and may be employed when the operator has to start a hot Continental injected power plant without having the option of allowing the engine and fuel to cool down. RSA fuel injection systems do not have a vapor ejection system that allows free circulation of the fuel through some of the lines. Consequently, to purge vapors from a RSA system a protracted priming operation may be employed. This pushes vapors through the system and out of the injector nozzles. After removing the vapor lock, the technician should perform a normal or flooded start, depending on conditions.

In the event that the Continental fuel injection system becomes vapor locked, the following procedure may be used to purge the vapors from the system. If specific procedures are provided by the manufacturer, follow those steps.

VAPOR LOCK REMOVAL OF A CONTINENTAL INJECTED POWER PLANT

1. Throttle - FULL OPEN (to activate High Boost operation in some models)
2. Mixture - IDLE CUTOFF
3. Propeller (if controllable) - FULL INCREASE RPM
4. Master Switch - ON
5. Fuel shutoff - ON
6. Boost Pump - ON 30 seconds, then OFF (select HIGH-BOOST if available)
7. Perform Normal or Flooded Engine Start as dictated by conditions

AFTER START OPERATION AND TESTING

Technicians should use a checklist during the testing of the power plant. In particular, results of the various tests and instrument readings should be recorded as it may be very difficult to recall all of the results using memory alone. Having a written record of the test results will prove useful in determining the airworthiness of the engine and in performing subsequent troubleshooting measures to systems that are not performing according manufacturer's recommendations.

ENGINE TESTING, EVALUATING, INTERPRETATION, AND TROUBLESHOOTING

Actual testing of the power plant begins after the engine starts. The procedures and parameters provided herein are not intended to supersede manufacturer instructions or data. Instead, they serve as general guides for testing reciprocating power plants. As always, use the current and appropriate measures when conducting any test to the power plant and associated systems.

BOOST PUMP PRESSURE CHECK BEFORE STARTING ENGINE

The following test is not required on aircraft employing gravity-fed fuel systems. It is, however, necessary to check on aircraft equipped with pressurized fuel systems.

The electric boost pump(s), or auxiliary pumps, should be capable of providing green arc fuel pressure without the engine-driven fuel pump. To check the electric boost pump's pressure capability, the technician must turn on the fuel selector and/or shut-off valve, place the engine controls in their proper positions, switch the master switch on, and operate the boost pump. While observing the fuel pressure or flow gauge, the technician should witness the fuel pressure climb into the green arc range. On continuous flow fuel injection systems, the position of the throttle affects the metered fuel pressure reading. Judge your readings accordingly. Power plants using a float carburetor should have their boost pump pressure within the green arc range as shown in ***Figure 10-14***. The green arc range on fuel pressure gauges of power plants using float carburetors will be relatively narrow in comparison to the green arcs used on flow meters of fuel injected power plants.

The reason for checking the boost pump pressure by itself is the ever present possibility of an in flight engine-driven fuel pump failure. Because the design of the boost pump is of sufficient capacity to sustain fuel flow to the engine throughout the entire range of operation, the boost pump should be tested prior to starting the engine. This limited test does not reflect in absolute terms how the boost pump will respond in the event that the engine-driven fuel pump fails (as the engine is not in operation during this check). For aircraft equipped with float carburetors, record the boost pump pressure reading on your checklist.

OIL PRESSURE

Aircraft engines commonly used today will not run long without proper lubrication. The oil pressure and volume of flow must be high enough to provide proper lubrication and cooling to all parts and areas of the engine under all operating speeds, loads, and conditions. There is a limit to how high the oil pressure can be during operation. If the oil pressure is too high, oil leaks and damage to the oil system may result.

After starting the engine, check the oil pressure gauge. The operator must visually observe the gauge. Do not focus on the tachometer as one is able to generally determine engine rpm. Do not concentrate on the manifold pressure gauge (if used) as when the engine is running and the throttle is only cracked, manifold pressure will not be an immediate, if any, problem. Ammeters, vacuum gauges, and other such instruments are not priority gauges during start. As a general rule, if there is no oil pressure within 30 seconds after starting, one minute for winter operation, abort the start.

Oil pressure should exceed the minimum oil pressure limit. Most engines have a minimum oil pressure of 25 psi. Some engines run a minimum pressure of 10 psi. In any case, make certain that the oil pressure needle exceeds the minimum pressure red line.

The engine's lubrication system must be capable of maintaining the oil pressure within its normal or desirable operating range. The green arc indicates the normal operating range. The oil pressure should not be allowed to exceed the maximum pressure limit. The upper pressure red line shows the maximum allowable pressure. Exact oil pressure specifications may commonly be located in the engine data sheet, aircraft operator's manual, aircraft service manual, and the engine overhaul manual.

OIL PRESSURE IN GENERAL

Before troubleshooting or investigating low and high oil pressure problems, the discussion should begin with the following understanding of fluid dynamics. The relative pressure of any liquid equals the amount of fluid flow versus the total resistance to the quantity of flow, including viscosity. For example, if a high volume of flow encounters zero resistance, the relative pressure for that fluid will be low. Conversely, a minute flow experiencing infinite resistance will produce very high pressures. The latter scenario will attempt to produce infinite pressure until a mechanical or structural failure of the system occurs.

In terms of instrumentation, the typical, mechanical-type pressure gauge used with reciprocating aircraft power plants contains a bourdon tube. Bourdon tubes used with pressure instruments are sealed at one end and connected to the fluid being measured at the other

end. The tube itself is curved to form an arc. As the pressure applied to the interior of the bourdon tube is increased, the pressure differential between the interior and exterior of the unit causes it to straighten out. This motion is transmitted to the instrument's gear train to position the needle according to the pressure sensed by the bourdon tube.

LOW OIL PRESSURE

Listed are typical reasons for low engine oil pressure:

Insufficient Oil Quantity: When the oil quantity is critically low, each drop of oil has to absorb more heat than it is designed to safely handle. It also gets recirculated back through the engine at a rate faster than normal and, therefore, does not have the time to cool off before passing through the engine again. This causes a higher oil temperature that thins the oil and results in lower viscosity. With less resistance to flow, oil pressure will be lower, particularly when the oil pressure relief valve is fully closed. Oil pressure problems associated with low oil volume often manifest themselves at low engine rpm.

High Oil Temperature: Excessive oil temperature may result in a lower pressure due to the thinning of the oil. Problems, such as defective cowlings, damaged engine baffling, faulty ducting, plugged oil cooler fins, improper operations, and inappropriate use of winterizing kits, may result in or add to high oil temperatures.

Too Low of Oil Viscosity: Low oil viscosity may generate a lower oil pressure by way of excessively heating and thinning of the oil. The oil is already too thin, therefore, normal heating of the oil further reduces its viscosity. It might be noted that after the engine is hot, oil pressure at idle may be noticeably lower than normal, even if the minimum pressure limit is not violated. Check the operator's manual, aircraft service manual, placards near the oil filler port, and technical data published by the engine manufacturer for proper oil grade usage based on seasonal requirements.

The reason low oil pressure problems are more pronounced at idle is due to the design attributes of the typical oil system. Because a constant displacement pump is used, low engine rpm yields a low volume of oil flow. When such a volume is combined with low resistance to flow, oil pressure is reduced.

Oil Suction Screen Defects: Restrictions in the oil pick-up system may limit the amount of oil supplied to the pump. This type of problem may be more critical at higher rpms. Leaks in the pick-up system may result in the ingestion of crankcase vapors by the oil system. Such action may cause a fluctuation in the oil pressure.

Defective Instrumentation: A defective instrument may falsely indicate low oil pressure. To troubleshoot the instrumentation system, install a test gauge at the firewall connection or swap instrument lines on twin engine aircraft. Aircraft with extended periods of inactivity might have a plugged oil pressure line as a result of congealed oil. Technicians should have suspected instruments tested.

Worn Bearings: Worn bearings reduce the amount of resistance encountered by the flowing oil. Because pressure is the result of the amount of oil flow versus the restriction to flow, a reduction in the restriction to flow causes a decrease in oil pressure, particularly when the self-adjusting pressure regulator is closed. Keep in mind that the oil pressure regulator is a variable orifice.

HIGH OIL PRESSURE

High oil pressure is most commonly caused by cold oil, particularly of high viscosity. Normally, as the oil warms up, oil pressure returns to normal.

Improper Operation of the Relief Valve: A relief valve stuck in the closed position is incapable of opening to the extent necessary to regulate oil pressure. In such cases, oil pressure at lower rpms should not pose a problem. A symptom associated with this problem is that oil pressure increases and decreases in proportion to engine rpm.

Defective Instrumentation: A malfunction of the instrumentation system might account for false, high oil pressure indications. Troubleshooting instructions previously detailed for investigating defective instrumentation regarding low oil pressure may be employed to check for instrumentation problems concerning high oil pressure readings.

OIL PRESSURE FLUCTUATION

Gauge fluctuations are generally caused by air in the instrument line or other defects in the instrumentation network. Mechanical gauges are less prone to be the cause of fluctuation. Generally speaking, when readings

fluctuate on mechanical gauges, the fault is likely due to low oil quantity or unusual flight attitudes or maneuvers or defects in the oil suction screen system.

Low oil supply might be responsible for gauge fluctuation. Such fluctuations are generated when the oil pump ingests crankcase vapors instead of liquid oil. Erratic performance of the pressure regulator may also result in variances in pressure readings.

OIL TEMPERATURE

The temperature of the oil while the engine is operating is crucial. The oil must be hot enough to circulate freely. It must also be hot enough to evaporate off moisture that builds-up in the crankcase. If the oil is too hot, lubrication properties may diminish and the engine may experience a reduction in oil pressure. In addition, the flash and fire points may be reached. Check the engine data sheet, engine overhaul manual, the operator's manual, or other appropriate sources to determine the proper temperature ranges and limits.

The typical mechanical-type oil temperature gauge uses a bourdon tube. Unlike oil pressure instruments that connect the open end of the bourdon tube to the oil system, the temperature gauge is a closed system that contains a gas charge. The probe is placed in contact with the oil and the gas expands and contracts according to its temperature. The bourdon tube reacts to the expansion and contraction of the gas. The mechanism within the instrument translates the position of the bourdon tube into a temperature reading.

OIL TEMPERATURE DEFECTS

Oil temperature defects generally fall into two categories: (a) high oil temperature and (b) low oil temperature. In addition, oil temperature instrument problems may arise in the form of fluctuation or complete failure. The following discussion addresses the aforementioned problems.

HIGH OIL TEMPERATURE

Improper Grade of Oil: Using low viscosity oil could result in high oil temperatures. Ensure that the oil grade is proper for the ambient temperature.

Winterizing Kits: Failure to remove winterizing kits might render the engine's cooling system incapable of passing the proper flow of air over crucial components.

Improper Operation: Improper operation may superheat the oil. Prolonged application of high power (particularly with nose-high attitudes), too lean of mixture, and etc. may boost oil temperature. Any combination of the above could result in a higher oil temperature.

Defective Instrumentation: Oil temperature instrumentation systems might falsely indicate a high temperature reading, if defective. Troubleshooting suspected gauges may involve gauge replacement or in the event of a multiengine aircraft, switching systems from one engine to other.

COOL OIL TEMPERATURE

Cool oil temperatures may be related to climatic conditions. The oil should be properly warmed prior to the application of high loads on the engine. Too high of oil viscosity might impede oil warm-up.

Engines operating with low oil temperatures will be unable to adequately evaporate water from the crankcase. Water forms in the interior of the power plant after each shutdown. This is due to the nature of water vapor. Because hot gases are able to hold more water vapor than cold gases, as the fumes in the crankcase cool following shutdown, water vapor condenses in the engine. The water covers exposed engine components and contaminates the oil. If the oil temperature remains below 180° F, water will not adequately evaporate and depart the engine by way of the breather. To thoroughly purge water from the oil, the engine should be operated for at least 30 minutes with the temperature of the oil at or above 180°F. If operated for less than 30 minutes or cooler than 180°F, water will accumulate in the oil. In time, water accumulation will cause internal engine corrosion. It also adversely affects the chemistry of the oil. At all times, maintain the temperature of the oil below its maximum limit.

Improper Operation: Depending on operational conditions, improper use of devices, such as cowl flaps and oil cooler shutter doors, might result in cool oil temperature. Furthermore, such misuse of the aforementioned may hamper engine warm-up.

Failure to Utilize Winterizing Devices: Oil temperatures may be adversely affected as a result of failure to use winterizing devices as required. Such action may keep the oil temperature cooler than the desired range.

Faulty Instrumentation: Defective instrumentation systems may show cool readings. To check the operation of an oil temperature gauge, perform the following steps. Remove the sensor probe from the power plant. Submerge the probe in a pan of oil. Place a candy or cooking thermometer in the oil next to the oil temperature probe. The accuracy of the test thermometer is critical to the veracity of the results of this examination. Apply heat to the oil using a hot plate or similar device. Compare the reading between the oil temperature gauge with that of the test thermometer.

OIL TEMPERATURE FLUCTUATIONS

Oil temperature fluctuations are generally instrument related. In particular, rapid fluctuations fall under the realm of instrumentation defects. Electronic systems are more likely to develop faults that produce fluctuating readings. Faulty transmitters, intermittent opens and shorts in the wiring, and defective gauges generate unusual temperature readings.

It should be stressed that the actual oil temperature does not change instantaneously. Therefore, instantaneous oil temperature changes of any great magnitude, (e.g., the temperature suddenly increases and/or decreases by 100˚F) is likely due to faulty instrumentation.

INOPERATIVE OIL TEMPERATURE

Under normal conditions with the engine warmed-up and operating, an inoperative oil temperature gauge reading is likely caused by a defective instrumentation system. Under arctic conditions, the oil temperature may remain so cold that the oil temperature gauge may appear inoperative. This is due to oil temperatures that are cooler than the lowest reading offered by the gauge.

FUEL PRESSURE

When evaluating engine fuel pressure, one has to remember that fuel systems have the same hydrodynamic properties as any other fluid system. Therefore, the relationship between volume of flow versus the restriction to flow is in effect. Fuel pressure readings vary from system-to-system. Use gauge markings as appropriate.
Most gravity fed systems do not have or need a fuel pressure gauge. As long as there is enough fuel in the tank and the fuel selector is on, gravity will do the rest, barring other defects in the fuel delivery or vent system.

Some fuel systems require an engine-driven fuel pump. Normally when an engine-driven fuel pump is needed, an auxiliary fuel pump is also used in the fuel system. In such cases, the boost pump(s) should be capable of producing and maintaining green arc fuel pressure on its(their) own. Auxiliary pumps should also be capable of supplying ample flow to the fuel metering unit. A section on checking the operation of the auxiliary pump was presented at the beginning of the engine testing section.

The engine-driven pump must be capable of keeping the fuel pressure within the green arc from idle to maximum rpm at full throttle. Also, the fuel pressure should stay within the green arc with both the boost pump and the engine-driven pump operating from idle to maximum rpm at full throttle.

Generally speaking, injected engines have a broader metered fuel pressure range (a.k.a. flow meter) than pump-fed carburetors. Use gauge markings, as appropriate, in conjunction with information provided in the appropriate data sheets and manufacturer's instructions to verify proper operation.

HIGH FUEL PRESSURE

On pump-fed carburetors, maladjusted or defected fuel pressure regulators may cause high fuel pressure. A stuck regulator valve might result in fuel pressure that increases and decreases directly with engine rpm. A steady, high reading might be the result of a faulty or maladjusted regulator. Also check filters for blockage.

Injected engines might register high pressure, or excess flow, when in reality a restriction to flow is present. High flow readings could be caused by maladjustment of the system pump or mixture. In addition, faulty manifold valves, flow dividers, the installation of primer lines in place of injector lines, and restricted fuel nozzles could falsely indicate high flow rates. Suspected flow problems may be verified by moving the mixture control toward idle cutoff. A true high flow condition yields a significant increase in rpm during the idle cutoff check. A false high flow reading only loses rpm as the mixture control travels from full rich to idle cutoff.

LOW FUEL PRESSURE

On pump-fed engines, low fuel pressure might stem from a number of defects. Several possibilities

include a worn pump, dirt in the system, blockage of the pump's fuel inlet, a faulty pump check valve, a defect in the regulator, a maladjusted regulator, or any combination of the above.

On injected engines, low fuel flow readings could be caused by improper mixture control rigging, misadjustment of the throttle valve, improper pressure adjustments, faulty valves, or any decrease in the level of restriction offered by the metering components. A combination of the aforementioned may serve to compound the problem. In some cases, a lower reading might actually occur when the engine is receiving too much fuel. Use of the mixture control may be implemented to determine whether the engine is operating rich or lean. Thorough understanding of the system is necessary for proper troubleshooting and data interpretation.

Some helpful troubleshooting techniques include the use of the boost pump and the mixture control. Switching on the boost pump may show deficiencies in the engine-driven pump. Leaning the mixture using the mixture control discloses the type of mixture the engine is receiving. Excessively rich mixtures run smoother and faster as the mixture is leaned toward the proper fuel-to-air ratio. Normal mixtures experience a small rpm rise followed by a loss of rpm as the mixture control reaches its idle cutoff position. Lean mixtures respond by running poorly as the mixture control is moved toward idle cutoff. As might be expected, the degree to which the engine responds to the idle cutoff test is related to the degree of richness or leanness experienced by the engine and the type of fuel metering system (e.g., carbureted, Continental injected, etc.).

CHECKING THE GENERATOR OR ALTERNATOR SYSTEM

During the engine run up, all power plant related components should be checked for proper operation. Generator or alternator output may be checked by means of an ammeter, voltmeter, loadmeter, and discharge light.

The ammeter has a zero in the center of the gauge as shown in ***Figure 10-20***. When the needle is deflected to the left of zero, the negative side, the battery is being discharged. Movement of the needle to the right of zero, the positive side, indicates that the battery is being charged. The degree of charging or discharging may be determined by the value depicted by the needle.

The voltmeter shows battery voltage as presented in ***Figure 10-21***. With the charging system in operation, the voltmeter shows regulated voltage. If the charging system becomes inoperative, the voltmeter reveals battery voltage. As the battery drains, the voltage diminishes.

The loadmeter shows the load absorbed by the generator or alternator. See ***Figure 10-22***. An inoperative generator or alternator indicates zero load.

Discharge lights illuminate when the generator, or alternator, is not charging the battery. When the light is off, the battery is being charged.

An aircraft may incorporate more than one indication system. For instance, an aircraft might use a discharge light in conjunction with an ammeter or a voltmeter with a loadmeter. Various combinations exist.

OUTPUT DEFECTS

Whenever the charging system is not in proper working order, the maintenance technician should troubleshoot the electrical system and correct the malfunction. Isolation is the key to troubleshooting. By eliminating the components that are operating properly, the faulty component(s) will ultimately be located and isolated. One technique for troubleshooting requires the technician to check simple, common problems first. Failure to adhere to this technique may lead to unnecessary maintenance operations, damage to components, and undue expenditures.

LOW, OR NO, OUTPUT

The following faults could result in a low or no output situation:

- Popped circuit breaker
- Blown fuse(s)
- Lost drive
- Improper wiring
- Grounded armature
- Reverse current cutout relay (RCCR) inoperative
- Regulator defects
- Brushes
- Slipping belt
- Field defects
- Dirty commutator
- Weak brush springs
- Maladjustment of the system
- Lost residual magnetism

EXCESS OUTPUT

High output problems occur whenever proper regulation of the system does not exist. Some causes may be the following:

- Improper voltage regulator adjustment or operation
- Improper current limiter adjustment or operation
- Defects in wiring

CHECKING MAGNETO OPERATION

Because small aircraft ignition systems generally include two magnetos, there is a procedure for checking each magneto's performance. This is accomplished by briefly operating the engine solely on one magneto. Each magneto is tested in this fashion.

A typical magneto switch includes at least the following positions: (a) OFF, (b) RIGHT, (c) LEFT, and (d) BOTH. Some switches include starting and priming features. With the magneto switch, the operator may select either both, a single magneto, or no magneto. When testing a magneto, the switch is placed in the desired position. The magneto not selected no longer functions by virtue that its primary circuit is grounded out. Instead of a comprehensive magneto switch, some aircraft use individual toggle switches to control the operation of their magnetos. In such cases, the operator manually grounds out one magneto to check the operation of the other magneto.

Check magnetos after the performance of any maintenance to the ignition system. This measure is necessary to determine whether or not something went amiss during the maintenance operation. Such investigations fall under the category of post-assembly testing.

LOW-RPM MAGNETO CHECK

A low-rpm magneto check should be undertaken prior to conducting a high-rpm magneto check. Perform the low-rpm magneto check at engine warm-up speed (e.g., 1,000 rpm).

The purpose of a low-rpm magneto check is to catch any dead or poor running magneto. Magnetos that run improperly should not be checked at high rpm until the problem is corrected. Bad magneto drops may prove harmful to muffler baffling and other exhaust system components, if performed at high rpm.

HIGH-RPM MAGNETO CHECK

At low rpm the actual condition of the magneto is difficult to distinguish. By raising the rpm and manifold pressure, a load is placed on the ignition system that it did not have at warm-up speed. On the other hand, there is no need to use excessive rpm and manifold pressure. One reason is that any serious magneto difficulty may damage the engine. Also combustion temperature problems may occur while operating on one magneto. Moreover, it may be difficult to properly cool the engine if it is operated for an excessively long period at high power.

Helicopters equipped with reciprocating engines have their magneto drops checked at maximum rpm. Even though the helicopter engine is operated at maximum rpm, the manifold pressure is low due the zero or low pitch of the rotor blades. Running at maximum rpm does not always require maximum power. Engine rpm by itself does not necessarily indicate power. The load placed on the crankshaft must also be considered.

ITEMS TO BE CHECKED WHILE PERFORMING A MAGNETO DROP CHECK

Switching from both magnetos to a single unit generates a number of changes in the operation of the power plant. The most noticeable transformation is the loss of engine rpm. Aircraft operators, as well as maintenance technicians, evaluate the amount of rpm loss to determine airworthiness of the ignition system. In addition, the difference in the rpm loss from one magneto to the next, or rpm spread, is considered.

The loss of rpm is but one issue. Whether the engine runs in a smooth or rough manner on a single magneto should be detected during the magneto check.

Other elements of the power plant are affected when operating on a single magneto. These include the manifold pressure and the exhaust gas temperature.

MAXIMUM RPM DROP

Maximum rpm drop refers to the total allowable rpm loss. This figure varies from aircraft to aircraft. A maximum rpm drop limit is set to ensure safe power plant operation for the duration of the flight.

Check the operator's manual, or other publication, as applicable, for the maximum rpm drop limit. In most cases, a 150-rpm drop is considered to be the maximum allowable rpm loss while running on one magneto. If the maximum rpm drop is exceeded, an ignition problem exists and should be corrected before the next flight.

Where it is true that when the rpm drop exceeds the specified limit the system is defective, the reverse cannot be said. There are many instances when problems in an ignition system are not revealed by the amount of rpm loss. This is particularly true when defects exist in each magneto or both magnetos have relatively the same degree of problem. In other words, when a magneto drop is bad, the system is certainly bad, but when the rpm drop is good, the magneto is only likely to be good. To further evaluate the airworthiness of the ignition system, a series of static tests (e.g., engine timing, magneto internal timing, etc.) should be conducted in conjunction with the dynamic testing of the magnetos.

It is imperative for the maintenance technician to be able to separate ignition problems from other operational defects. It is possible for a fault to exist in a peripheral system, (e.g., fuel metering, valves, exhaust, induction, etc.) and appear to be an ignition problem. Also, there should be no fault in the ignition system before making adjustments to the fuel metering system and other engine-related components.

RPM SPREAD

The magneto drop rpm spread is calculated by subtracting the smallest magneto drop reading from the largest drop reading. For example: the right magneto drops 175 rpm and the left magneto drops 50 rpm. The spread is 125 rpm in this case. The magneto drop spread provides the maintenance technician with considerable insight into the relative condition of each magneto. In this example it reveals that the right magneto is in poor condition when compared to the left magneto.

Synchronized timed engines should have a magneto drop spread of zero if everything is operating properly in each ignition unit. When a problem occurs in only one ignition unit, a spread of rpm usually appears. This spread informs the maintenance technician that a problem is present. Staggered timed engines may have a slight built-in rpm spread caused by the differences in magneto-to-engine timing.

The importance of interpreting the rpm spread is related to the comparative nature of the magneto drop check. In reality, the performance of the engine under a single magneto operation is really a comparison between the two magnetos. For example, in the previous scenario the left magneto has a 50 rpm drop when selected. Such a small loss of rpm is probably caused by a defective right magneto. If the right magneto has a serious defect, the left magneto will have almost no loss unless it too has a serious defect. This is due to the fact that the left magneto is delivering the bulk of the ignition action. When both magnetos have serious problems, it is likely that the engine will perform poorly even when both magnetos are operating.

An unusual turn of events may transpire after fixing a magneto that exceeded the specified spread. The magneto that had little loss will now have a larger rpm drop. Because the magneto drop test is somewhat comparative in nature, when a weak magneto is repaired, it assumes a greater portion of the ignition operation. This means that in the previous example, the left magneto will no longer drop just 50 rpm, it may now lose 100 rpm or more. In some cases, the left magneto may lose so much rpm that it exceeds the maximum limit. This issue is confusing when it is taken under consideration that perhaps no maintenance whatsoever was performed to the left magneto that previously lost only 50 rpm. How could it now lose so much rpm that it too requires maintenance? The answer in such cases is that before it was matched against another magneto that had a more serious fault, therefore the left magneto appeared to be operating in a satisfactory manner. But when compared against a stronger running unit its faults become apparent. As a consequence, the faults manifest themselves. In the end, the spread between the magnetos should not exceed the specified limit.

In most cases, whether synchronized or staggered timed, a 50-75 rpm spread is considered to be the maximum allowable, provided the maximum allowable rpm drop is not exceeded. Check the operator's manual, or other appropriate source, for specific limits on rpm spread.

SMOOTH MAGNETO DROP

A smooth magneto drop refers to the fact that while operating on a single magneto system the engine runs smoothly. Beyond a certain point, increases in the amount of rpm loss during a magneto drop greatly multiply the

likelihood of having a rough drop. A smooth magneto drop is usually required for flight operations.

It should be stressed that a smooth operating magneto does not automatically mean the magneto system is free from faults or operating satisfactorily. It is possible to have a smooth running magneto that has an unacceptable, excessive rpm loss or other defect(s).

ROUGH MAGNETO DROP

A rough magneto drop exists whenever a single magneto produces a rough running engine. A rough operating condition exists when one or more cylinders fail to run with regularity.

Rough magneto drops are considered unacceptable in nearly all cases. It should be pointed out that a rough running magneto often exceeds the maximum allowable rpm drop and spread. Be aware of unusual conditions that may falsely produce acceptable numbers and seemingly normal operations during the magneto drop check.

An example of a condition in which the numbers may be deceiving occurs when an engine has an inoperative cylinder. Four-cylinder power plants run with a severe roughness with an inoperative cylinder. However, engines with six or more cylinders are so smooth that detecting a dead cylinder is more difficult than when the engine has four or fewer cylinders. Radial engines are comparatively rough and, as a consequence, may mask a dead cylinder. For example, both spark plugs of cylinder number four are fouled. The remaining plugs are functioning without a fault. When conducting a magneto drop check, both magnetos will have similar responses provided no other fault is present. To further confuse the technician, the amount of rpm drop and spread may be within prescribed tolerances. This response is misleading as each magneto has a fouled spark plug, yet the symptom does not manifest itself during the magneto drop check. The main indicators that a problem is present include lack of power, sluggish performance, a roughness that may or may not be clearly discernable, and low EGT and CHT for that cylinder.

EXHAUST GAS TEMPERATURE CHANGE

By comparison to operating a cylinder with a dual spark plug system, running on a single spark plug, as in the case of performing a normal magneto drop, increases the exhaust gas temperature. The reason for the rise in the EGT is due to the slower burning of the fuel/air mixture. This slower burning rate lessens the amount of energy absorbed by the piston and increases the amount of heat escaping through the exhaust system. In this regard, the engine is less efficient when operating on a single ignition system.

The increase in EGT temperature is approximately 100°F. The technician may employ this relationship between the rise of EGT on a single spark plug to locate fouled plugs and other ignition defects.

MANIFOLD PRESSURE CHANGE

The manifold pressure increases while performing a magneto drop. The reason for the manifold pressure increase is that for the same throttle setting there is a reduction of rpm during the magneto drop check. This means that less intake strokes are taken, thereby reducing the volume of air removed from the induction system. The final outcome is an increase in manifold pressure.

There is a proportional relationship between the loss of rpm and the rise in manifold pressure. The greater the rpm drop, the larger the rise in manifold pressure. If, for example, there is a magneto with a small drop and a magneto with a large drop, the latter will have a greater increase in manifold pressure.

REASONS FOR SMOOTH, EXCESSIVE RPM DROPS

Probable causes for smooth, excessive magneto rpm drops are usually timing and/or point gap related. Because there are two separate timings, e-gap and magneto-to-engine, each are discussed.

E-GAP ADJUSTMENT

It is possible for the points to open too close to the neutral position or too late after the proper e-gap setting. If the points are set outside of their tolerances, the likelihood of having a smooth, excessive magneto rpm drop is great. Out of limit opening of the points, timing-wise and/or clearance-wise, reduces the magneto's output. This, in turn, increases rpm loss.

MAGNETO-TO-ENGINE TIMING

Magneto-to-engine timing also affects the rpm drop. A normal rpm drop occurs when the magneto-to-engine

timing is correct or nearly correct. Deviations in the magneto-to-engine timing increases the rpm drop.

Another factor that may affect rpm drops is differences in magneto-to-engine timing between the two magnetos. When, for example, the left magneto is correctly timed to the engine while the timing of the right magneto is off, the left magneto will have a smaller than normal rpm loss and the right magneto will have a larger than normal rpm drop. As previously discussed, correcting the engine timing of the right magneto results in the left magneto having a normal drop.

OTHER DEFECTS

It may be possible for defects in the coil, condenser, points, and etc. to cause smooth, excessive rpm drops. Such problems may develop into rough drops or even dead ignition systems.

REASONS FOR ROUGH MAGNETO DROPS

The most probable cause for a rough magneto drop is a fouled spark plug. Among all the reasons for a rough magneto drop, defects in the spark plugs are the most common.

Other causes for rough magneto drops include flashover (when the high tension current finds a path to ground other than through the proper spark plug electrode), faulty ignition leads, improper point settings, incorrect magneto-to-engine timing, defective coils, bad condensers, damaged p-leads, distributor gear defects, and etc. Any combination of the faults listed herein may serve to aggravate the drop. Many of the aforementioned problems may generate a dead ignition system.

CARBURETOR HEAT/ALTERNATE AIR CHECK

To check the operation of the carburetor heat or alternate air system, move the control from the "OFF" or "NORMAL" position to the "HOT" or "ALTERNATE AIR" position at the same rpm used to check the magnetos. With carbureted engines, the rpm should decrease while operating in the "HOT" position and recover to its original operating rpm when the control is returned to the "COLD" position. Alternate air systems, such as those used with continuous flow fuel injected power plants, often show little response when selecting "ALTERNATE AIR." Typically the heat rise associated with alternate air systems is less than that used with carburetor heat systems. This is due to the differences in icing characteristics between carburetors and fuel injection systems.

The application of heated air to the inlet of the fuel metering unit has an impact on the operation of the engine. Because the heated air is expanded when compared to cold inlet air, the cylinder ingests less oxygen (O_2) per unit volume. The outcome is an enrichment of the mixture and a corresponding reduction of rpm. The normal rpm loss varies from one aircraft to another, but is generally between 50 to 75 rpm.

In most cases, carburetor heat and alternate air systems provide the power plant with unfiltered induction air. Carburetor heat systems, and many alternate air systems, supply the induction system with air heated by the exhaust system. This association with the exhaust system increases the potential for operational problems. Exhaust fumes from leaky exhaust system components may enter the induction system and cause undesirable engine performance when carburetor heat or alternate air is applied. The technician should note any discrepancy in the operation of the system and make the necessary corrections. Return the control to its "COLD" or "NORMAL" position after the system test is completed. The engine rpm should return to the original value established before the test.

Several possibilities account for a power plant that experiences an unusually large loss of rpm during the carburetor heat or alternate air check. The accumulation of ice could generate such a response. To check for ice build up, continue to run the engine with carburetor heat. In time, the ice should melt and the engine's operation will return to normal.

Another reason that might cause the engine to lose a large amount of rpm during the application of carburetor heat or alternate air is an exhaust leak. When an exhaust leak is located within the carburetor heat system, the engine ingests exhaust fumes when carburetor heat is applied. Such gases lack an adequate amount of free oxygen to support proper combustion.

A third reason an engine might experience a large rpm drop during the application of carburetor heat or alternate air could be related to ducting. If the aeroduct, a flexible

hose commonly used to connect the heat source to the air box, implodes (collapses), the engine will be choked. A faulty wire coil in the interior of the aeroduct or a separated interior wall may generate this problem. To minimize the possibility of aeroduct implosion, double-wall ducting should not be used for carburetor heat or alternate air systems. Also, ensure that the integrity of the wire coil is intact for the entire length of the aeroduct.

If the engine gains rpm when carburetor heat or alternate air is applied, the technician should check a couple of items. First, the main air inlet leading from the air filter to the fuel metering unit may be restrictive or imploding. Also, the air filter could be clogged. Because carburetor heat or alternate air uses a separate source of air, the engine may gain rpm when the restrictive passageway is not feeding air to the engine.

Another reason an engine may gain rpm when carburetor heat or alternate air is applied may be due to a fuel metering fault. If the mixture is excessively lean, the associated enrichment provided by the heated inlet air may improve the fuel/air mixture, allowing the engine to gain a small amount of rpm.

PNEUMATIC SYSTEM CHECK

When a pneumatic pump is driven by the power plant, it should be tested during the run up. Air pumps are often driven by the engine to power gyroscopic instruments. Pneumatic pumps may also be used to inflate deicing system boots, power pneumatically-driven servos for autopilot systems, and other purposes.

During the run up, the pneumatic system gauge(s) should be checked for green arc indications at the same rpm the magneto drop check was performed. In addition, or as an alternate, warning lights or indicators may be utilized. If these lights or indicators are used, they should extinguish when adequate pressure or suction is attained.

Aircraft using venturi tubes for instrument vacuum are unable to produce adequate suction without sufficient airspeed. Therefore, the pilot should be queried about the system's ability to develop proper instrument vacuum or the aircraft will have to be flown to perform this check.

A common pneumatic system issue is the neglect of filter servicing. Change or service these filters at intervals recommended by the aircraft manufacturer. When the aircraft is operated in adverse conditions where more dirt is prevalent (e.g., agricultural spraying, grass airstrips, etc.), the servicing frequency is normally adjusted to compensate for the additional level of contaminants.

CYLINDER HEAD TEMPERATURE

The cylinder head temperature limit should never be exceeded. Excessive cylinder head temperatures may prove harmful, if not catastrophic, to the power plant. Severe damage to the piston, combustion chamber, cylinders, and members of the cylinder head group may result if they are exposed to temperatures that exceed their safe limit.

High combustion temperatures may be the result of poor carburetion, faulty ignition, detonation, preignition, improper operation, or any other similar defect. Any combination of these problems may serve to escalate cylinder head temperatures. The cylinder head temperature reflects the temperature in the combustion chamber.

EXHAUST GAS TEMPERATURE

A simple exhaust gas temperature system uses a single probe to measure the temperature of the exhaust gas. Multiple probe EGT systems may be helpful in pinpointing the location of engine faults.

Newer engine temperature systems combine CHT with EGT. Such instruments simultaneously display the CHT and EGT readings for each cylinder. The combination of CHT with EGT provides valuable data regarding the combustion properties of the cylinders. See ***Figure 10-9***.

To find fouled spark plugs, dead cylinders, or other temperature altering defects using a multiple probe EGT system, run the engine in the defective mode and search through each cylinder's EGT until a discrepancy is found. For example, to find a fouled spark plug using a multiple probe EGT system, operate the power plant on the rough magneto and note the temperature of each cylinder. The cylinder with the cool reading contains the fouled spark plug. Because the faulty magneto and associated cylinder have been identified, the defective spark plug has been pinpointed. In this example, the reason for the cool reading is attributed to the shutting off of the good spark plug when the rough magneto was selected. With neither spark plug firing, the EGT will be cool. Fluctuation in the EGT tells the technician that

the spark plug is firing intermittently. A dead cylinder, or one that is firing intermittently, will respectively generate cool or fluctuating readings.

An alternate method for pinpointing the location of fouled spark plugs using a multiple probe EGT system is to operate the power plant on both magnetos and check the temperature of each cylinder. Cylinders with hotter readings are suspected of containing fouled plugs. To discover which magneto is connected to suspected plugs, monitor cylinders with high EGTs and perform a magneto drop check. If the spark plug is fouled, the EGT will become cool when running solely on the rough magneto(s).

Induction flange leaks, defective valves, plugged injection nozzles, and various other defects may be located with the multiple probe style EGT system. Even simple changes to the operation of the engine, such as engine timing, will affect EGT. For example, if the magnetos are timed to the engine and set to fire too retarded, the EGT increases due to the lack of energy transferred to the piston. Advanced timed engines reduce EGT readings as more heat is absorbed by the pistons.

When troubleshooting, remember that it is possible for one fault to cause another problem. In such cases, identifying and correcting the root problem may be difficult. In-depth system understanding is required to pinpoint hidden defects.

PROPELLER CHECKS

Many aircraft are equipped with controllable-pitch propellers. Before delving into the various checks performed to the propeller system, a basic concept concerning the propeller governor is warranted.

Hydromechanical governors (e.g., Woodward, McCauley, etc.) are gear-driven directly by the engine. This feature provides a means of perpetually sensing engine rpm. Inside the governor is a flyweight assembly. The centrifugal force generated by this device is opposed by spring tension. This spring is commonly known as the ***speeder spring***. The tension generated by the speeder spring is adjustable. As the flyweight assembly builds its centrifugal force in response to increases in engine rpm, it pushes against the spring with greater force. Movement of the flyweight assembly against the spring also positions a valve within the governor. When the movement of the valve is sufficient, oil passages connecting the governor to the propeller mechanism are opened and closed. This results in a change of propeller pitch, which subsequently alters the load on the crankshaft and produces a change in engine rpm.

When spring tension is greater than flyweight action, the governor is in an ***under-speed condition***. Conversely, when the centrifugal force generated by the flyweight assembly is greater than spring tension, an ***over-speed condition*** exists. If the flyweight force and spring tension are equal, the governor is ***on-speed***.

Propeller governors attempt to run continuously in an on-speed condition, but are often prevented from doing so by the low-pitch limit of the propeller. For example, when the power plant is operating at idle, the governor is experiencing an under-speed condition. Although it would prefer to run on-speed, it is unable to further reduce the pitch of the propeller because of the low pitch stop. As rpm increases beyond the on-speed mode, the flyweight assembly generates sufficient force to compress the spring and position the valve to increase propeller pitch. As the propeller increases its pitch, the load placed on the crankshaft increases, thereby reducing engine rpm. As the rpm is reduced, the flyweight mechanism loses a portion of its force until it comes into balance with the spring's tension. At this point, the governor is in an on-speed condition.

The operator may set the rpm that the on-speed condition occurs by positioning the propeller control. As the propeller control is moved from the low-pitch position toward the high-pitch position, spring tension within the governor is reduced. This results in the governor attaining an on-speed condition at a lower engine rpm. Conversely, movement of the propeller control toward low pitch raises the on-speed rpm. When properly adjusted with the propeller control set to full low pitch, the governor will reach its on-speed condition when the engine is running at its maximum rated rpm.

PROPELLER CYCLE CHECK

The purpose of cycling the propeller is to check for proper operation. As the propeller changes from low to high pitch, the technician will notice a decrease in rpm and an increase in manifold pressure. The change from high pitch to low pitch produces an increase in rpm and a decrease in manifold pressure.

The propeller should be cycled prior to performing the static rpm test. Cycling the propeller before the static rpm check helps to reduce the chance of experiencing an over-speed during the static rpm test. This is due to the near instantaneous response capability of the propeller system once it has been cycled.

To cycle the propeller, move the propeller control from low pitch to high pitch at the rpm specified by the aircraft manufacturer. Most aircraft have their propellers cycled between 2,000 and 2,200 rpm. Allow sufficient time for the system to operate. After receiving the response from the propeller system, return the propeller control to low pitch. Note the time necessary to produce the rpm changes, the amount of rpm loss, and whether or not the rpm returned to its original value. If the response of the system was sluggish, cycle the propeller another time until its reaction time is more instantaneous.

Propellers used with multi-engine airplanes typically have the ability to ***feather***. In this position, the propeller pitch is increased until it offers minimum resistance to the flow of the relative wind during flight. Some propellers with the feathering feature separate the feathering test from the propeller cycling operation. In such cases the operator is instructed to move the propeller control from low pitch to the detent at the rpm used to check the operation of the magnetos (e.g., 2,100 rpm). Movement of the propeller control until it reaches, but does not enter, the detent allows the propeller to cycle without using the feathering system. If the operator moved the propeller control into the detent, it would be difficult to ascertain whether the loss of engine rpm was attributed to the propeller cycling action or feathering system.

To conduct the check of the feathering system, the engine rpm is reduced below the operating range of the governor (e.g., 1,500 rpm). Movement of the propeller control from low pitch up to the detent produces no change in engine rpm. Placing the propeller control within the detent area sets into action the feathering system. The engine should aggressively lose rpm and gain manifold pressure. The technician should promptly return the propeller control to low pitch before the engine dies as a result of the drag generated by the high pitch angle of the propeller. Performing separate checks of the governor and feathering systems provides a thorough analysis of the propeller system.

Some aircraft propeller systems attain feathering through the use of a propeller feathering motor. Operators monitor the current draw used by the system during feathering and unfeathering operations in addition to the rpm loss and increases in manifold pressure.

CONSTANT RPM CHECK

To further check the operation of the propeller system conduct the following tests. Run the engine to the rpm specified by the manufacturer (2,200 rpm). Using the propeller control, adjust the rpm until the engine is on-speed approximately 200 rpm less than the original rpm (2,000 rpm in this example). To determine whether the propeller system is able to hold the rpm constant when an acceleration force is applied, slowly open the throttle. Further opening of the throttle increases the propeller pitch and the manifold pressure. Rpm should remain relatively constant. In this case, the propeller governor is on-speed at 2,000 rpm. As the throttle setting is increased, the governor senses an attempt to increase the rpm beyond the present on-speed rpm. The governor responds by increasing the propeller load on the engine to keep from exceeding the established on-speed rpm.

Other changes experienced by the engine during the aforementioned test include an increase in fuel flow and an increase in horsepower. On Continental injected engines, the unmetered fuel pressure decreases as the throttle is opened. The reason for the decrease in Continental unmetered pressure is due to the increase in the throttle valve opening while maintaining a constant rpm or fuel pump output. Refer to the fuel metering section for additional information concerning Continental unmetered fuel pressure.

UNDER-SPEED AND OVER-SPEED CHECK

To perform under-speed and over-speed tests, establish an on-speed condition by running the engine to 2,200 rpm with the propeller control in the low pitch position and gradually move the control toward the high pitch position until the engine stabilizes at 2,000 rpm. Test the system's ability to recover from under-speed and over-speed conditions by performing a magneto drop check. This determines whether the propeller system is able to return to its on-speed rpm when the engine changes rpm.

When a magneto is grounded out, the governor, which was on-speed, senses the loss of rpm. The momentary loss of rpm is accompanied by a temporary increase of manifold pressure. The governor is momentarily in an under-speed condition, but because the propeller is not against its low pitch stop the governor lowers the propeller pitch, as necessary, to regain the rpm lost. The rpm and manifold pressure return to the original settings they had prior to grounding out a magneto. At this point, the engine is running on-speed using only one magneto. Rpm and manifold pressure equal the settings they had while operating on two magnetos because the throttle setting and the rpm are the same as they were prior to losing a magneto.

The casualties of losing one magneto are propeller pitch and EGT. The propeller pitch was lowered by the governor to hold the rpm at 2,000. The EGT went up because of the slower burning rate present while operating on a single magneto.

From the single magneto configuration, returning the engine to dual magneto operation generates the following responses. Engine rpm increases and the manifold pressure decreases, both on a temporary basis. The governor is now experiencing an over-speed condition. When an over-speed condition exists, the governor increases the propeller pitch, as needed, to load the engine down to reestablish the on-speed rpm. Manifold pressure, propeller pitch, and EGT return to their original, dual magneto values.

STATIC RPM POWER CHECK

A power check is performed to check the engine's maximum output. Without a torquemeter or dynamometer, the technician relies on the tachometer and, if included, the manifold pressure gauge to determine engine performance. Certain deviations from ideal conditions may alter results attained during the power check. These factors include ambient temperature, humidity, density altitude, and engine condition. Because the reciprocating aircraft power plant is an “air breather,” any element that affects the atmosphere also affects engine performance.

Some thoughts concerning the relationship between power input and power output is appropriate at this time. Because the reciprocating power plant converts potential energy into heat and extracts heat and the expansion of gases to generate an output, the power output of a reciprocating power plant cannot be greater than its power input. This means that before a high power output may be attained from a reciprocating power plant, it must first receive a large power input.

Power input refers to the fuel/air charge ingested by the cylinders. The important issue concerning power input is that fuel alone does not determine power input. If a gallon of gasoline was poured into a cylinder of a reciprocating aircraft power plant, it would probably not fire. The reason is not associated with the potential energy of the fuel, but rather with the lack of air and improper atomization of the fuel. Before the energy contained within the fuel may be release, it must first be properly and proportionately mixed with air. Because the volume of air consumed by a reciprocating power plant is determined by its displacement, throttle position, and rpm, the maximum amount of fuel consumed by the engine is limited by the air intake ability of the engine at any given rpm. Again, the fuel must be vaporized and mixed with air before its full potential is released.

Power output and rpm are not always one and the same. The rpm of an engine may be high while producing a low power output. The reason is associated with the factors that control rpm. Engine rpm is determined by the power input received by the cylinders, the power output produced by the engine, and the load placed on the crankshaft. For other conditions the same, rpm may be increased by reducing the load on the crankshaft as in the following example. An airplane with a fixed-pitch propeller is flying at 8,000 feet (2,500m). The operator reduces the throttle to idle during cruise flight. The pilot then lowers the nose of the airplane until the craft is in a steep dive. This action generates a high engine rpm, but with low power input. In this example, the power input, or manifold pressure, is quite low even though the engine rpm is high. The high rpm is attributed to the action of the propeller as it responds to the large quantity of air passing through the propeller disk during the high-speed dive. In the end, the power input and power output are low while the engine rpm is high.

To further enhance the concept of power input, power output, and rpm, the next example is provided. Under normal operations, an increase of power input increases power output. But when the engine is operating poorly, a higher than normal power input is required to generate

the same power output when other conditions are the same. Consider the following scenario. An aircraft engine is operating at 2,000 rpm with a manifold pressure of 17"HG. While the engine is running, both spark plug wires of the left rear cylinder are removed. This act causes the power plant to lose some 200 rpm. As a result, the manifold pressure increases due to the reduction of rpm for the same throttle position. To regain the 200 rpm lost by this operation, the operator has to further open the throttle, or increase the power input. The net result is that the engine is once again operating at 2,000 rpm, but now the manifold pressure is at 22"HG. The message provided by this example is that in order to generate the same power output, or engine rpm, when the engine is running poorly, a higher than normal manifold pressure is required. This relationship between power input and power output is important as many operators and technicians automatically assume that if the manifold pressure is high, the power output will be high. As in the previous example, the higher than normal manifold pressure indicates that the engine is performing poorly. Power plant technicians must have a deep understanding in the area of power input, power output, and crankshaft load to successfully test and troubleshoot engine-related faults. Refer to the sample power chart that reveals the relationship between rpm, manifold pressure, and horsepower. ***[Figure 12-1]***

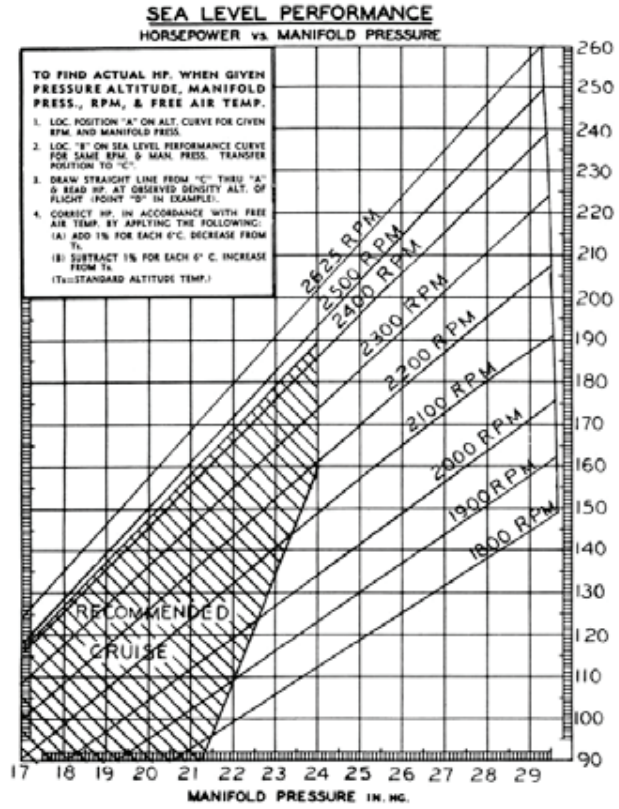


Figure 12-1. Engine performance chart.

In the realm of performing a power check, engines that have faults require a higher than normal manifold pressure to generate the static rpm. When the fault is significant, the engine will be unable to produce static rpm.

When performing a static rpm power check, ensure that the following steps are taken. Point the aircraft into the wind as directly as possible, open the cowl flaps (if so equipped), use a full rich mixture, place the propeller control in the high rpm or low pitch setting, and set the carburetor heat or alternate air control to its cold or normal position. Due to cooling deficiencies, do not run the engine at full power for excessive periods of time. Take whatever precautions necessary (e.g., wheel chocks, moor the aircraft, etc.) to ensure that the aircraft remains stationary to prevent a runaway airplane or rotorcraft.

To perform the static rpm check, slowly and smoothly advance the throttle to its full opened position. The technician should observe all power plant related instruments. The oil pressure, tachometer, manifold pressure, and upper-deck pressure (if turbo-supercharged) should be closely monitored during acceleration. Fuel pressure, fuel flow, oil temperature, EGT/CHT, generator/alternator, and pneumatic pressure should all be checked at full power. Any specialized measurements, not mentioned in this unit, should also be taken in accordance with the aircraft manufacturer's current instructions. Check the aircraft manufacturer's specifications and data sheets for specific readings and use instrument markings to determine performance.

For aircraft equipped with fixed-pitch propellers, check the aircraft data sheet for specific static rpm information concerning a particular aircraft/engine/propeller combination. Because some airplanes offer a variety of available power plants and each power plant may have a number of acceptable propellers, specific data for the aircraft/engine/propeller combination should be found and used to determine performance. On fixed-pitch propellers, the static rpm will be less than red line rpm. Often the limits will be given in terms of the minimum and maximum static rpm limits and the limits regarding the length of the propeller.

On variable-pitch propellers, the maximum rpm should be reached while performing the run up. It is possible for an engine equipped with a variable-pitch propeller to not reach red line on the ground. Elements, such as temperature, humidity, and density altitude, may keep the engine from reaching its maximum rpm. When the propeller is in its full low pitch position, it acts like a comparable fixed-pitch propeller and is unable to further reduce the load on the crankshaft for the sake of increasing rpm. If necessary, fly the aircraft to accurately check the governor setting. With the exceptions of initial governor installations, over-speed conditions, and obvious under-speed conditions, do not reset the governor without flying the aircraft first. Also, prior to adjusting the governor, check the accuracy of the tachometer. See **Figure 10.3** for an example of a tachometer checker.

FAILURE TO REACH STATIC RPM

Any fault responsible for preventing the attainment of the specified rpm must be identified and corrected, if appropriate. A worn engine, weak cylinders, and other such defects are common among high-time engines. Faults, such as poor ignition, overly heated induction air, faulty carburetion, excess propeller loads, restricted induction air, induction leaks, incorrect throttle rigging, and other similar defects, may limit the power output of the engine.

When performing static rpm tests on power plants equipped with constant speed propellers, the technician should determine whether the governor setting is keeping the engine from reaching static rpm or whether some other factor is involved. This may be accomplished through careful observation of the tachometer and manifold pressure gauge. As the throttle is advanced, note whether the rpm stops ascending before the throttle reaches the full-opened position. In such cases, the manifold pressure gauge becomes very sensitive to further movement of the throttle to full open. If the preceding condition is noted, chances are the governor has reached its on-speed condition. If the rpm is at red line, the static rpm is properly set. Test results above red line are over-speed conditions and those below red line are under-speed conditions.

If some factor other than the governor setting is limiting the maximum rpm of the engine, the technician will notice that both rpm and manifold pressure increase with throttle opening. Both gauges stop increasing when full throttle is reached. If the rpm is below or above red line, at least one fault or limiting condition exists. If red line rpm is attained, the technician should perform a high-speed taxi, or fly the aircraft, to ensure a proper governor setting. Failure to confirm proper rpm attainment might lead to over-speed conditions during flight.

Before reaching the conclusion that the power plant has failed to produce the required static rpm based solely on the reading of the tachometer, the technician should verify the accuracy of the instrument. Electronic tachometer checkers, as well as mechanical units, are commonly used for this purpose. If a tachometer checker is not available, the technician may either switch the tachometer with a known good instrument or strobe the propeller using an aircraft equipped with an accurate tachometer. The test aircraft must have an appropriate rpm range and identical number of propeller blades to accurately strobe the suspected tachometer.

To strobe a tachometer, observe the propeller disc of the suspected aircraft while gazing through the propeller disc of the test aircraft. When both engines are operating at the same rpm, there will be a distinct silhouette of the propeller. This image will remain stationary in terms of clock angle. If the silhouette rotates in either a clockwise or counter-clockwise direction, the engines are not operating at the same rpm. Also, various optical harmonics may appear when the rpms are different. In such instances, a two-bladed propeller may appear to have four or more blades. The propeller strobing technique is relatively complicated and requires skilled operators. Using an electronic tachometer is a simpler and safer approach to checking the accuracy of a tachometer installed in an aircraft.

After operating the engine at full power, run it at high idle for several minutes. This allows the combustion chambers an opportunity to cool. During power checks, extremely high temperatures are produced in the combustion chambers. The relationship between heat and power output is a direct correlation as high power outputs require high combustion chamber temperatures.

ENGINE RESPONSE TO POWER CHANGES

The technician should monitor the engine's response throughout the entire run up. Any hesitation or tendency

to sputter or die during acceleration or deceleration may point to mechanical defects. Problems, such as induction leaks, lean idle mixtures, too low of unmetered fuel pressure in Continental fuel injection systems, worn accelerator pumps or leaky accelerator check valves, defective primer systems, faulty ignition systems, improper control rigging, and a variety of other faults may lead to operational difficulties.

Bear in mind that during the course of the run up and testing procedure, the technician is determining whether or not the power plant, in its entirety, is operating in a proper fashion. This includes all engine-mounted accessories. Any defect in the engine or concomitant accessories may seriously compromise operation and safety during flight.

IDLE SPEED AND MIXTURE

The idle speed and mixture of the engine should be checked for proper adjustment. Improper adjustments may present some operational problems. Do not adjust the idle speed and mixture to compensate for induction leaks, rigging problems, and other such defects.

Idle speeds and mixtures vary from aircraft-to-aircraft. Specific information concerning these parameters should be obtained from the aircraft manufacturer's service manual. The instructions provided in this text are applicable in certain situations, but always refer to the most current published information provided in the aircraft service manual or other appropriate source.

The idle speed and mixture check should be performed near the completion of the engine run to obtain an accurate result. Checking the idle speed and mixture of a cold engine will be different than the check of an engine operating at normal temperatures. The technician should further check oil pressure with the engine at idle. The idle oil pressure of an engine with hot oil will be different than the idle oil pressure of an engine with cold oil.

To check idle speed, bring the throttle control to its idle position. This is normally attained when the throttle is moved as far aft as possible. Compare the idle rpm to the figure provided in the aircraft service information. Most opposed engines idle at 600 rpm ± 50 rpm. The idle speed should also be checked with the application of carburetor heat.

To check idle mixture, slowly move the mixture control from its FULL RICH position to IDLE CUTOFF. As the control reaches the extent of its travel, there should be a slight increase in rpm before the engine dies. A typical setting for a carbureted engine is 25 to 50 rpm rise. Pressure carbureted engines and those with fuel injection normally have a rise of 10 to 25 rpm. Check the data provided by the manufacturer for specifics regarding the correct idle mixture. If the idle speed and mixture are incorrect, perform the adjustments in accordance with the appropriate technical data.

MAGNETO SWITCH GROUND OUT CHECK

The magneto switch ground out check should be performed while the engine is idling. The main purpose of the ground out test is to check the OFF position of the magneto switch. This action is taken to ensure safety. Up to this point in the run up process, the magneto switch has been tested in the BOTH, LEFT, and RIGHT positions. The OFF position has not been checked. The OFF position is not crucial for airborne operations, but on the ground the OFF position plays a dominant role in terms of safety.

To perform the ground out check, idle the engine and turn the magneto switch past its OFF position. If it is apparent that the power plant dies in this position, release the key or lever so the switch seeks its normal OFF position. Once again make certain that the engine is dying. Before the propeller stops spinning, return the magneto switch to the BOTH position and shut the engine down using standard procedures.

It is important for the ground out check to be performed at idle. Grounding out the magnetos at high rpm will often produce a loud explosion sound in the exhaust system and cause possible damage to the muffler baffling. The reason for this reaction is that at high rpm, when both magnetos are grounded out, the combustible mixture of fuel and air passes through the cylinders and collects in the exhaust system. When the magneto switch is returned to the BOTH position, the mixture in the exhaust system may be ignited. The exhaust system is not designed to take direct combustion temperatures and pressures. The end result is damage to the exhaust system.

RECIPROCATING POWER PLANT SHUTDOWN

Follow the manufacturer's procedure for shut down located in the Operator's Manual. The procedure provided in this section may be used for shutting down many small aircraft.

Most manufacturers have a recommendation concerning how long a power plant should be operated on the ground. Generally, ground operations should be confined to a 15-minute interval as cooling may become a factor with the aircraft remaining stationary. After allowing the engine to properly cool down, the SLIM method may be employed for shutdown.

- S = Switches: turn OFF unnecessary electrical equipment
- L = Lean: place the Mixture Control in IDLE CUTOFF (See Note 1)
- I = Ignition: turn the Magneto Switch(es) OFF (See Note 2)
- M = Master: turn the Master Switch OFF

Note 1: Carburetors equipped with back-suction mixture controls are incapable of engine shut down using the mixture control. In such cases, kill the engine by placing the magneto switch(es) in the OFF position.

Note 2: Wait until the propeller comes to a complete stop before placing the Magneto Switch in its OFF position. As long as the Magneto Switch is ON, the fuel vapors that enter the cylinders are likely to be burned. Failure to wait for the power plant to stop spinning allows a fuel/air charge to accumulate in the combustion chambers.

During the shutdown operation, the technician should observe a couple of patterns: (a) ***coast down*** and (b) ***bounce back***. Coast down refers to how many revolutions the power plant takes to come to a complete stop. If the coast down is significantly short, the engine may be on the verge of seizure. If the coast down is excessive, the compression of the cylinders may be low.

Bounce back occurs when the propeller nearly comes to a stop in its normal direction of rotation and experiences a minute amount of travel in its opposite direction of rotation. A healthy amount of bounce back is attributed to strong cylinder compression. This occurs because as the engine coasts down, the cylinders continue to intake, compress, and exhaust. When it attempts to come to rest on the compression stroke of a cylinder that has good compression, the compressed air in the combustion chamber pushes the crankshaft backwards.

If the engine does not bounce back during shut down, the problem may be one of the following. Occasionally the engine comes to rest with a cylinder at top dead center compression. The alignment of the wrist pin, connecting rod bearing, and main bearing prevents the engine from bouncing back. In such cases, nothing is wrong with the engine. Another reason for not having bounce back is associated with weak cylinder compression. If the engine comes to rest on the compression stroke of a cylinder with weak compression, the less than normal amount of compressed air in the combustion chamber is unable to push the crankshaft backwards. When coupled with unusually long coast down, this could indicate that the engine is in need of cylinder maintenance or major overhaul.

Another item that should be checked during the shutdown is the operation of the impulse coupling(s), if so equipped. As the engine dies, the technician should be able to hear the clacking sound of the impulse couplings. The clacks should not skip a beat as the engine comes to a rest. If the impulse coupling clacks intermittently, the engine may experience hard starting. Reasons for not having a consistent operation of the impulse coupling may be that the coupling and/or stop pin are badly worn, a flyweight assembly is magnetized and unable to move freely, or other similar defects.

If a regular cadence of the impulse coupling is not detected, accomplish the following. Remove a spark plug from each cylinder to eliminate the possibility of a start. Pull the engine through by hand and note the operation of the impulse coupling(s).

POST-TESTING EVALUATION

Following the testing of the power plant and related systems, the technician should evaluate the data amassed during the run-up and compare the data to the appropriate technical information. Results that fall outside the established limits should be investigated and resolved. Following the engine run-up, technicians may perform additional tests to determine the condition of the power plant.

Power plant technicians have at their disposal a series of tests that are useful for predicting and detecting engine

faults. One basic philosophy that must be considered when evaluating the results of these tests is that "airworthy results" do not mean that the component is completely free of faults. Rather, a fault could exist that has not reached a level adequate enough to generate an unairworthy result. For example, an exhaust valve has a small crack forming at the perimeter of its head. If this crack is too small to cause a leak, a compression test will not reveal this fault. However, if this fault is not detected, it may generate cylinder failure and/or catastrophic failure of the engine.

Where "airworthy results" do not guarantee fault-free components, "unairworthy results" either mean that the test equipment is defective, an improper procedure was used, or there is a fault in the component. For example, if weak cylinder compression is detected during the performance of a compression test, then either the tester is malfunctioning, the technician is not adhering to proper procedures, or the cylinder contains a fault significant enough to produce a loss of compression. A combination of the aforementioned may serve to produce inaccurate readings.

To summarize the basic philosophy of interpreting test results, a good reading means only that maybe there are no faults while an unairworthy reading indicates that either the tester has a fault, improper test procedures were used, the component is faulty, or a combination of tester fault(s) with component fault(s) exists. In any event, further investigation of the component and testing process is necessary to determine the actual condition of the suspected component or system.

In this section a number of power plant tests are presented. Included are: (a) compression tests, (b) borescopic inspections, (c) oil filter(s) inspections, (d) oil analysis, and (e) pre-oiling. These common tests are useful for troubleshooting the power plant. They, along with a thorough review of the maintenance records, are valuable when conducting an inspection and other maintenance operations.

COMPRESSION TESTS

Mechanics of aircraft equipped with reciprocating power plants rely on results from compression tests to determine the internal condition of the cylinders. Aside from being an indication of the condition of the combustion chamber, compression tests are commonly required during the inspection of a power plant.

Two types of compression testers are available, the ***differential*** and the ***direct***. Most often, technicians perform the differential compression test. Whether or not a source of compressed air is available may impact on the decision concerning which compression tester to use. The direct compression tester, similar to automotive compression testers, does not require a source of compressed air. Nor does it require precise positioning of the crankshaft. The direct method is frequently used on reciprocating powered helicopters. It is also used when compressed air is not available.

Beyond the general standards established regarding compression tests, engine manufacturers typically publish service information addressing the performance of compression tests on their products. Included in these documents is the criteria for determining satisfactory compression results.

DIFFERENTIAL COMPRESSION TEST

A popular technique for checking compression is the differential compression test. This method is commonly used when checking the compression of reciprocating power plants equipped with propellers. Because this tests requires precise positioning of the engine to top dead center compression (TDCC), engines without propellers may make this test difficult to perform (e.g., piston-powered helicopters).

Another limitation to this style of compression testing is that an ample source of compressed air must be available. The inlet to the tester should be approximately 100 psi. Furthermore, the source must be able to sustain an appropriate inlet pressure. If a suitable source of compressed air is not available, a differential compression test should not be performed.

TEST THEORY

The differential compression test, also known as the ***leakdown test***, works by applying compressed air to the cylinder and measuring how much pressure is retained by same. There is a relationship between how much air the cylinder is able to retain and how much combustion pressure it is able to convert into horsepower.

Two types of compression leaks may exist: (a) ***static*** and (b) ***dynamic***. Static leaks involve such things as seepage past the valves, spark plug holes, head-to-barrel joints, and so forth. Static leaks are often the result of serious

faults and are generally unacceptable. Dynamic leaks, on the other hand, are forever present because the end gaps of the piston rings provide a flow path into the crankcase. Undesirable dynamic leaks involve air flow past the piston rings and cylinder walls and piston rings and piston ring grooves. Such leakage may be the result of deformities and defects to the cylinder walls, piston rings, and piston ring grooves. When the amount of air loss reaches a significant magnitude, engine output will diminish to an unacceptable level. In addition, the volume of oil consumption by the engine may become undesirable.

The differential compression tester is constructed using an air pressure regulator with a gauge, an orifice situated immediately after the regulator outlet, a second pressure gauge located downstream of the orifice, and hoses and adapters used to connect the apparatus to the cylinder being tested. Its operation is based on the fact that as air passes through an orifice, a drop of pressure occurs. The larger the volume of airflow, the greater the drop in pressure. Consequently, the greater the leak past the valves, cylinder walls, and rings, the greater the drop in pressure and the lower the retention by the cylinder.

The attributes of the orifice are critical to the operation and accuracy of the tester. Two orifices are specified. One is for engines with cylinders that have less than 5-inch bores (12.7cm). The other is for power plants with cylinders that have 5-inch (12.7cm) or larger bores. The orifice for small cylinders measures 0.250" (6.35mm) in length, has an approach angle of 60˚, and an inside diameter of 0.040" (1.016mm). Large cylinders require the same length and approach angle but have an inside diameter of 0.060" (1.524mm). ***[Figure 12-2]***

TESTING PROCEDURE

As with any form of testing, the technician must follow a prescribed procedure. Failure to properly perform the procedure may generate erroneous readings. Such data may further lead to improper decisions concerning the condition of the power plant. The following list of steps are given as a guide and are not intended to replace information provided by the manufacturer or other appropriate sources.

STEPS FOR CONDUCTING THE DIFFERENTIAL COMPRESSION TEST

1. Warm the power plant to its operating temperature.
2. Chock the wheels.
3. Remove the spark plug wires.

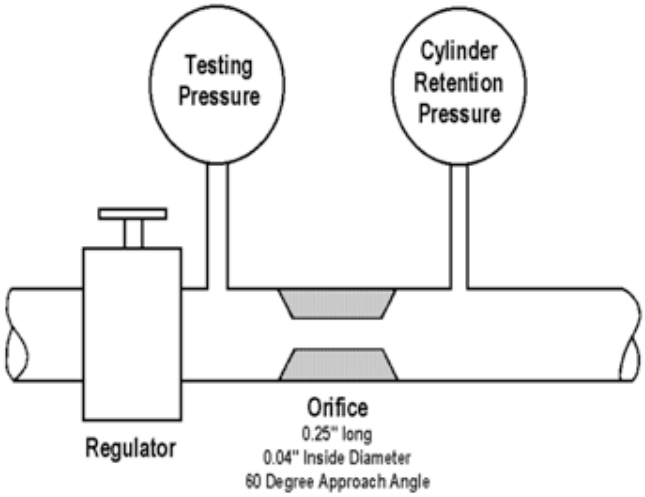


Figure 12-2. Differential compression tester.

4. Remove the most accessible spark plug from each cylinder.
5. Check the compression tester for accuracy.
6. Install the cylinder adapter in the vacated spark plug hole.
7. Clear the propeller.
8. Apply air pressure (30-40 psi) for locating Top Dead Center Compression (TDCC).
9. Position the piston at TDCC.
10. Adjust the regulator to 80 PSI testing pressure.
11. Reposition the propeller for TDCC reading.
12. Record the reading.
13. Release the air pressure and remove the adapter.
14. Proceed to the next cylinder.

Step 1 requires the technician to thoroughly warm the power plant to its operating temperature. This measure ensures that the internal tolerances of the engine will more closely match the actual condition of the power plant during flight. It further serves to lubricate the internal components of the engine.

The wheels should be chocked as per Step 2. This step prevents unwanted movement of the aircraft when moving the propeller. Because the compression check is conducted under pressure, the resistance encountered while rotating the engine may cause the plane to move.

Steps 3 and 4 not only prepared the cylinders to accept the adapter, they also disarmed the engine to prevent an inadvertent firing of a cylinder while rotating the engine. By removing a spark plug from each cylinder and

disconnecting all of the spark plug wires, the engine is unable to deliver sparks to the cylinders. One additional activity that should accompany Step 4 is the inspection of the spark plugs as they are removed. Check for fouling, the accumulation of lead deposits, the level of electrode wear, oil, and other abnormalities.

To verify the accuracy of the compression tester as suggested in Step 5, connect the inlet of the tester to a source of compressed air. Disconnect the cylinder adapter so no air flows from the tester. Adjust the regulator until the testing pressure is 80 psi. The cylinder pressure gauge should also read 80 psi. If the cylinder retention pressure gauge reads higher or lower than the testing pressure gauge, the instrument is inaccurate. ***[Figure 12-3]***



Figure 12-3. Testing gauges for reading symmetry. Note that the cylinder retention gauge reads nearly 2 PSI lower than the test pressure gauge.

Steps 6 and 7 are self-explanatory acts. The cylinder adapter is needed to connect the tester to the cylinder undergoing the test. This device is generally constructed with a quick-release coupler for rapid connection to the tester. Step 7 advises the technician to stay clear of the propeller. This advice should not be taken lightly. When compressed air enters the cylinder, there is a possibility that the engine may rotate. Objects in the path of the propeller will be struck. Also, technicians should ensure that the work area is clear and clean. If there is oil or fuel spills on the floor and or electric cords and pneumatic hoses in the work area, the technician may slip or trip during the compression test, increasing the likelihood of injury.

Apply air pressure as listed in Step 8. A beginning pressure of 30-40 psi should be sufficient to find top dead center compression (TDCC). If necessary, adjust this pressure to facilitate the finding of TDCC. If the cylinder compression is weak, a little higher inlet pressure is beneficial for finding TDCC. If the cylinder compression is strong, reduce the pressure to lessen the likelihood of injury.

To complete Step 9, find TDCC. One technique to find TDCC is to slowly rotate the crankshaft in its normal direction of rotation. As the piston travels toward TDCC, the amount of resistance transmitted through the propeller changes. Note in ***Figure 12-4*** that as the incoming air pressure acts on the piston, the force is transmitted to the crankshaft along the line labeled A-B. Because there is an angular relationship between lines A-B and B-C, the crankshaft will rotate unless firmly held by the technician. As the crankshaft reaches its TDCC position, line B-C becomes more aligned with A-B. The gradual alignment of A-B and B-C causes the rotational moment transmitted to the crankshaft to become less. The technician finds that the engine becomes easier to turn in the direction of rotation. At TDCC, A-B and B-C are aligned as shown in Figure 12-5. At this position, if the crankshaft does not have a tendency to rotate, the technician releases the propeller. The crankshaft remains stationary at TDCC. With this knowledge, the technician may locate TDCC by applying 30-40 psi to the cylinder and rotating the propeller in direction of rotation until the force required to turn the engine is minimal. This technique may be employed to expedite the completion of the compression test. Use of this practice eliminates the need for finding TDCC through other means, such as trying to place a thumb on a spark plug hole to find compression and observing the position of the piston through the spark plug hole. In particular, placing a thumb, even a gloved-thumb, on the hot cylinder head will generate a level of physical discomfort.

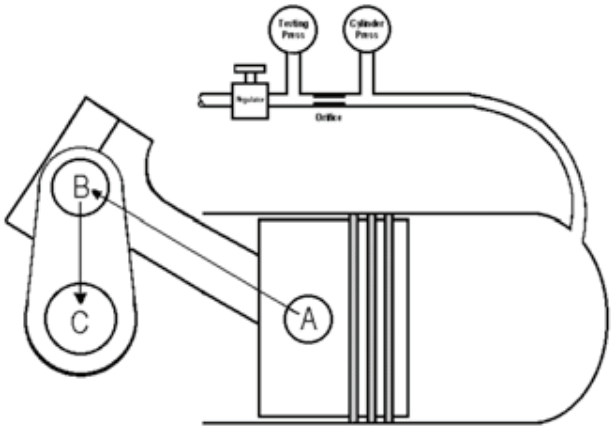


Figure 12-4. Crankshaft 90˚ from TDCC.

An alternate technique for identifying top dead center compression involves the use of the cylinder retention gauge. Securely grab the propeller and apply compressed air to the cylinder being tested. Rotate the engine in direction of rotation until compression is felt. Observe the reading of the cylinder retention gauge. Briskly rotate the power plant in direction of rotation a few degrees at a time while maintaining a grip on the propeller. Hold the propeller stationary after inputting the rotation. Note the reaction of the cylinder retention gauge to this movement of the crankshaft. If the piston is below top dead center compression, the cylinder retention gauge momentarily deflects upwards and bleeds down to its current reading. This is because the volume in the combustion chamber is reduced by the upward motion of the piston. The result is a slight compressing action on the air. When the piston remains stationary for a few seconds, the momentary increase of compression from the upward movement of the piston bleeds past the ring end gaps until the current compression value is displayed on the gauge. Continue moving the propeller a few degrees at a time until top dead center compression is located. ***[Figure 12-5]***

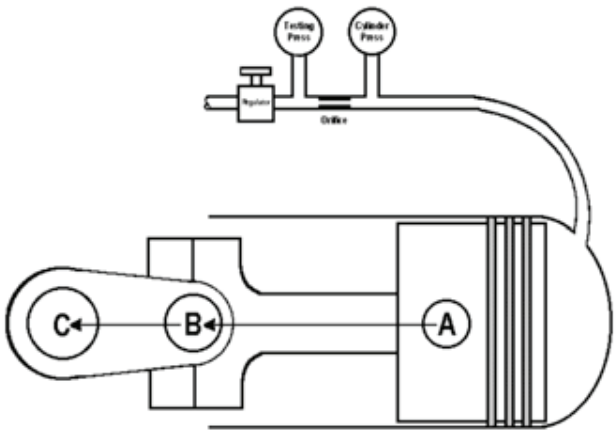


Figure 12-5. Crankshaft at TDCC during differential compression test.

When the piston is at or very near top dead center compression, the quick movement of the propeller for a few degrees has virtually no impact on the reading shown on the cylinder retention gauge. This is because the piston does not have much linear movement within the cylinder at or near TDCC.

Once the piston passes top dead center compression, the few degrees of rotation cause the reading to momentarily dip and then recover after the piston remains stationary for a few seconds. This reaction is due to the increase in the combustion chamber volume resulting from the downward motion of the piston. Observing the cylinder retention gauge while moving the crankshaft a few degrees at a time is an excellent technique for those undertaking this form of compression testing for the first time.

Once the crankshaft is positioned at TDCC, stay clear of the propeller disk and increase the testing pressure until 80 psi is attained as listed in Step 10. In the event that the crankshaft is not at, or near, TDCC, the engine will rotate. If necessary, reposition the crankshaft to TDCC to perform Step 11. Make certain to turn the engine in direction of rotation. If the propeller is turn against its direction of rotation, bring it back to TDCC by rotating the engine in the proper direction. This ensures that the piston rings are properly positioned in their grooves. Read the cylinder retention gauge and record this reading as per Step 12.

Once the compression is measured, perform Step 13 by releasing the pressure from the cylinder and disconnecting the tester from the cylinder adapter. Remove the cylinder adapter and proceed to the next cylinder. Be aware that the cylinder adapter becomes hot during the course of the compression test. Take necessary precautions to avoid burns.

COMPRESSION TEST RESULTS

Using the U.S. Federal Aviation Administration's (FAA) acceptable methods, techniques, and practices listed in Advisory Circular (AC) 43.13-1A and AC 43.13-1B, a minimum acceptable reading for a cylinder subjected to a differential compression test is the retention of 75% of the testing pressure. If the mechanic applies 80 psi to the cylinder, it must retain a minimum of 60 psi. As a general rule, 80 psi is the industry's standard for performing a differential compression test in the U.S. Use of the data contained within this document is limited in that cannot be contrary to data provided by manufacturers. Therefore, technicians must follow instructions provided by the manufacturers, when issued, instead of using general guidelines.

One engine manufacturer addresses the performance of compression checks. To determine suitability for return to service, they focus on differences between cylinder readings in addition to pressure retention. They prefer to

see no more than a 5 psi spread between cylinder readings. A difference of 10 to 15 psi warrants further investigation. If the difference exceeds 15 psi, removal and investigation of the low cylinder(s) is suggested.

This company prefers to have all readings equal to or greater than 70 psi. Cylinders that fall below 65 psi indicate that wear is present. They recommend the performance of additional compression tests at 100 hour intervals to monitor the wear rate of the engine. Cylinders that experience high wear rates or significant wear should be removed and repaired. They further recommend removal and overhaul of cylinders that fall below 60 psi retention.

Another manufacturer recommends comparing the cylinder retention pressure to the pressure generated when applying 80 psi to a master orifice. Technicians are instructed to attach the cylinder adapter of the compression tester to the master orifice and apply 80 psi. The value shown on the cylinder retention gauge is the minimum pressure that a cylinder may retain and be returned to service. As many aircraft use this brand of engine, compression test equipment may include the master orifice for convenience. ***[Figure 12-6]***



Figure 12-6. Differential pressure tester equipped with master orifice. To determine minimum acceptable pressure, open valves and adjust testing pressure to 80 PSI and read retention gauge. In this illustration the minimum acceptable pressure is 46 PSI.

PINPOINTING DEFECTS

The differential compression test is well suited for identifying the leaky component(s). The following list is provided to link leaks with their defective component(s):

1. Excess leakage through the crankcase breather indicates worn or defective piston rings, piston ring grooves, and/or damaged cylinder walls.
2. Leakage from the induction air inlet indicates a defective intake valve and/or valve seat.
3. Leakage from the exhaust stack or tail pipe indicates a faulty exhaust valve and/or valve seat.

SUMMARY OF DIFFERENTIAL COMPRESSION TEST

The differential compression test is an accurate method for providing the technician with information from which to evaluate the overall condition of the cylinder. It is not absolute as defects may be present and yet invisible to the test. By comparison, the leakdown compression test tends to be more consistent than its alternative, the direct compression test. It also helps the technician to more readily pinpoint defects and is generally preferred over the direct compression test method when a source of compressed air is available and crankshaft position manipulation is easily accomplished.

DIRECT COMPRESSION TEST

The direct compression test works on a completely different approach than the differential compression test. Rather than apply air pressure to the cylinder and gauge its ability to retain pressure, the direct method measures how well the cylinder assembly compresses ambient air. In effect, each cylinder becomes an air compressor during the test.

The direct method is commonly used to measure the compression of automobile engines. Where its popularity in the automotive industry cannot be denied, direct compression tests are not commonly employed throughout the aviation industry. Most often it is used when there is a lack of compressed air (remember the cylinders act as air compressors) or when it is difficult to readily position the engine to top dead center compression (TDCC). Many reciprocating powered rotorcraft have engine installations that limit the ability of the technician to readily position the crankshaft at TDCC.

Another delimitation to the direct compression test is its ability to pinpoint sources of problems. Unlike the differential test where the technician listens for hissing sounds associated with faulty components, leaks are harder to detect when using the direct compression method.

TEST THEORY

The direct compression test measures the cylinder's ability to compress ambient air during cranking, or propping, and divulges compression in terms of relative pressure. The direct compression tester is actually a relative pressure gauge in that it measures how much force is generated over ambient pressure. [Figure 12-7]

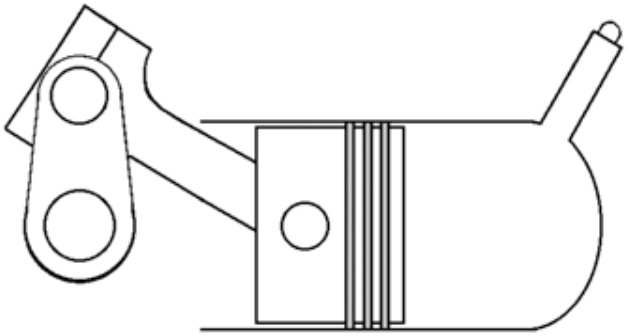


Figure 12-7. Direct compression test piston moving toward TDCC.

During the course of the direct compression test, the crankshaft completes the four strokes of the Otto cycle. As the piston travels up the cylinder during the compression stroke, the volume of the combustion chamber decreases. The gaseous mixture within the cylinder experiences an increase in pressure during this process. The pressure reaches its peak by the end of the stroke. The pressure developed as the compression stroke is completed is dependent on the condition of the cylinder assembly and the rotational speed of the crankshaft. ***[Figure 12-8]***

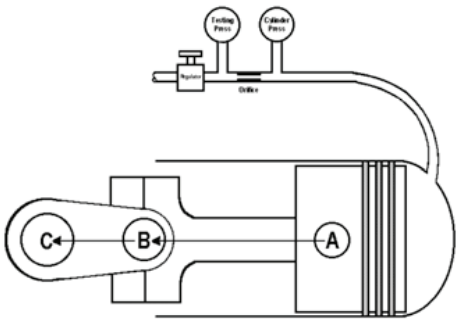


Figure 12-8. Direct compression test with piston at TDCC.

TESTING PROCEDURE

The following steps serve as a guide for conducting a direct compression test. They are provided solely as a guide and do not supersede instructions provided by a manufacturer.

1. Warm the power plant to its operating temperature.
2. Remove all the spark plug wires.
3. Remove the most accessible spark plug from each cylinder. Examine the spark plugs upon removal.
4. Install the tester(s).
5. Open the throttle to its full open position.
6. Crank the power plant until the readings peak.
7. Compare the cylinder readings.
8. If necessary, switch the testers from highest to lowest reading and repeat steps 6, 7, and 8, as required.
9. Record the readings.

As with the differential compression test, the power plant should be adequately warmed as dictated in Step 1. Operating the engine until the combustion chambers reach their normal temperature is beneficial on two fronts. First, the internal parts of the engine expand to their operational dimensions. Because the engine normally runs with its temperature elevated, this measure produces readings that more accurately reflect the condition of the combustion chambers during operation. Second, if a compression test is performed when the engine is cold, it is likely that the quantity of oil in the cylinders is less than when the engine is operating. Furthermore, oil settles to the bottom of the cylinders. Because oil forms a seal between the rings and the cylinder walls, lack of lubrication along the upper portion of the cylinders may adversely affect the outcome of the compression test. By running the power plant immediately before performing a compression test, engine oil is thoroughly distributed throughout the cylinders.

All the spark plugs wires, as provided in Step 2, should be disconnected before undertaking the compression test. Failure to unhook the leads from all of the spark plugs may allow the engine to fire as the crankshaft is rotated. One reason for this is that the starter switch is often combined with the magneto switch. As a consequence, when the starter is engaged, the ignition system is activated. This in combination with the opening of the throttle may cause unwanted combustion. When the throttle is opened, the accelerator pump delivers a dose of fuel into the induction manifold. This action is similar to priming the engine.

Step 3 instructs the technician to remove the most accessible spark plug. The upper spark plugs of opposed engines are generally the most accessible plugs. Similarly, the forward plugs of radial engines are frequently the most accessible spark plugs. Cylinder baffles and other obstacles may warrant the removal of the lower plug of a horizontally-opposed engine or the rear plug of a radial engine. The condition of the spark plug should be evaluated upon removal. Use a spark plug caddy and place the plugs in their assigned locations. This measure facilitates troubleshooting in the event that the results of the compression test warrants further investigation. It also makes it easier to rotate the spark plugs during installation.

Install the tester(s). Be careful not to damage the seal of the instrument. If over tightened, the gasket that provides the seal between the spark plug boss and the tester may be damaged. If a leak is generated, the reading will be adversely affected. This, in turn, may lead to inappropriate decisions concerning the condition of the cylinder.

In Step 5, open the throttle to its fullest extent. This step lessens the likelihood that the flow of air into the manifold will be blocked as the engine is rotated. If the flow of air into the manifold is impeded, spurious low reading may result. As the throttle is opened, a discharge from the accelerator pump will produce a gasoline odor around the engine. Minimize the chance of fire by taking the necessary precautions to eliminate sources of ignition. A fire extinguisher should be nearby.

Rotate the crankshaft until peak readings are attained to complete Step 6. This step requires monitoring of the instrument(s) during the cranking operation. If the starter is to be used, ensure that the battery is adequately charged. If possible, a power cart should be used for maximum cranking action. Hand cranking the engine may be required if the engine is not equipped with a starter or the starter is inoperative. This option should be used as a last resort as the outcome of the test is dependent on the speed of engine rotation.

After checking the compression of each cylinder, compare the readings as required in Step 7. If the readings are significantly different and multiple testers were used, the disparity between readings may be associated with variances between testers (e.g., one tester reads 5 psi higher than another tester). Switch the testers so that the one that previously had the highest reading is now inserted into the cylinder that had the lowest compression. Likewise, insert the second highest reading probe in the cylinder that had the second lowest result and so on. Perform the test a second time and compare results. If high and low readings stay with the probes, they may be defective. If the high and low readings remain with the cylinders, the low cylinders are probably defective. If a single tester is used and the test repeated for each cylinder, make certain that the battery remains fully charged. Multiple engagement of the starter may drain the battery. This will cause a successive reduction of cranking rpm during the performance of the compression test. In such cases, the last cylinders checked will have lower than true readings. Once again, inappropriate decisions concerning the condition of the power plant could be made. The use of a power cart should alleviate any differences in cranking rpm between cylinders. ***[Figure 12-9]***

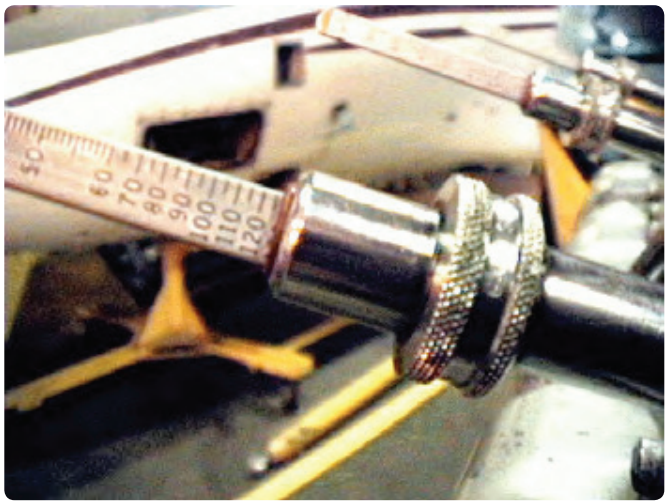


Figure 12-9. Direct compression results.

The technician should be aware that a weak cylinder affects the next cylinder in the firing order. As the starter cranks the engine, the compression generated in each cylinder provides opposition to the cranking motion. If a cylinder has weak compression, the starter is able to motor through the compression stroke of that cylinder with less resistance than the other cylinders. This allows the engine to gain a little speed during the cranking operation. The next cylinder in the firing order benefits from this additional speed. The result is that it may have a slight increase in its compression reading. This is due

to the relationship between the speed of rotation and the compression generated by the cylinder. The faster the rotation, the greater the compression.

INTERPRETING READINGS

Attempting to determine whether or not an engine has weak cylinder compression is somewhat difficult when using the direct compression test. Overhaul manuals for many engines do not specify a minimum psi for direct compression. Because the pressure developed is highly dependent on the speed of rotation during the test, a faulty or weak starting system could produce inaccurate results.

Rather than trying to achieve a specific psi value, the spread between cylinder readings is appraised. When utilizing the direct compression test method, an acceptable power plant, in regards to compression, is one in which a 15 pound per square inch spread between cylinder readings is not exceeded.

Do not misinterpret the intent of this criterion. As an example, if all the cylinders produced 40 psi, they would have weak cylinder compression regardless of the spread. For an approximate reading of what the cylinder should be capable of producing, multiply the engine's compression ratio by 15 psi. For example: an engine with a compression ratio of 8:1 should produce 8 x 15 psi or 120 psi of direct compression. Note: this method is not accepted as a standard and should only be used as a guide to estimate what a good cylinder should be capable of producing.

PINPOINTING DEFECTS

Pinpointing the reason for low compression when using the direct compression test method is a difficult task. Unlike the differential compression method, identification of faults cannot be determined by hissing sounds.

SUMMARY OF DIRECT COMPRESSION TEST

The direct compression test provides an alternate technique for checking the internal condition of the cylinders. It offers several advantages over the differential method in that no source of compressed air is required and precise positioning of the crankshaft is unnecessary. Generally speaking, the direct compression test is not the most popular method of testing compression in the field of aviation. One reason for its lack of acceptance is that no minimum psi is listed for each engine. Instead, the technician compares each cylinder of an engine to all other cylinders.

BORESCOPE

The borescope provides the maintenance technician with a method for visually inspecting areas that would normally be difficult to see, require extensive disassembly to gain viewing access, or otherwise would be impossible to examine. Borescopes have evolved over the years. Initially used to inspect the machining work of barrels, sophisticated borescopic inspections have become routine procedures in the aviation industry. Similarly, borescopes have been adopted by other industries (e.g., endoscopy in the field of medicine).

Early borescopes were relatively crude to modern units. They were little more than a length of tubing with a simple form of optics and a light source. Current units may be equipped with video cameras, a fiberoptic light source, and special channels to accommodate the passage of tools. Regardless of the type of borescope, the investigation performed is a visual inspection.

Borescope are available in two general styles: (a) rigid and (b) flexible. Rigid scopes have been in existence for many years. Their use is limited to straight-line entry. Flexscopes have been widely used since the late 1970s. They offer the advantage of entering and examining areas that do not offer straight-line access. Many flexscopes have viewing tips that are steerable. The operator is able to insert the flexscope, then aim the viewing tip in the desired direction. ***[Figure 12-10 and 12-11]***



Figure 12-10. Rigid borescope.

APPLICABILITY

Borescopes have been widely adapted to accommodate many needs. They are commonly used to inspect critical areas of power plants, gearboxes, transmissions, rotor blades, and airframes. Once familiar with the borescope,



Figure 12-11. Flexible borescope with steerable viewing tip.



Figure 12-12. Digital borescope. Such units are able to take digital photographs and movies of images.

the technician is able to make sound decisions as to the condition of a component. Generally, the technician is able to inspect a part with as much accuracy as if the part was readily visible for inspection. Often, a more thorough inspection may be performed due to the ability of the borescope to focus at point-blank ranges and magnify the image. Special focal length lenses and the ability to optically zoom in and out also serve to enhance the inspection.

Modern borescopic equipment has the ability to capture images and videos using electronic media. With this feature, technicians may send pictures and movies of suspected faults to other inspection entities (e.g., the manufacturer, an engineer, etc.) for a second opinion and additional expertise. The electronic images and movies may be saved as permanent records. Also, the ability to overlay graphs and scales helps identify the length and exact position of a suspected fault. ***[Figure 12-12]***

INSPECTING CYLINDERS WITH THE BORESCOPE

The following presentation describes the images of the main parts of a cylinder. Where the narrative provided describes the internal view of a cylinder, technicians must perform repeated borescopic inspections to develop skills in this area of inspection and distinguish normal from abnormal conditions. Such experience enhances the verbal description contained herein.

Cylinder walls, piston heads, and the appearance of cylinder heads are described as seen through a borescope. Viewing techniques and hints regarding defects and normal conditions are presented.

Cylinder Wall - place the crankshaft in a position where the majority of cylinder wall area is visible, (e.g., bottom dead center). Adjust the light intensity to suit the operator's needs and preference. The technician may discover various defects that require personal judgment in concluding the severity of the condition(s). Some common defects are pitting, scuffing, gouging, corrosion, and scoring. Note whether the marks extend beyond the travel reach of the top piston ring. Also, use shadows and judicious viewing techniques to distinguish between sharp gouges and scuffing. It is common for the carbon buildup above the top piston ring and around the piston to cause some discernable damage to the cylinder. Such conditions are typical of high-time engines.

Piston Head - the piston head may be inspected with the borescope. Normally the top of the piston is coated with carbon. The borescope is capable of denoting conditions not visible to compression tester. These conditions are, for example, piston meltdown in its early stage, (evidence of a meltdown will likely appear on the spark plugs for that cylinder), another example would be damage resulting from foreign object ingestion or by broken piston ring fragments. Often, the aftermath of foreign object damage is present on the cylinder head. Evidence that the valve struck the piston may be found via a borescopic inspection. This condition is normally associated with a bent push rod.

Cylinder Head - particular attention should be given to the valves. The exhaust valve normally has a brownish color to its carbon accumulation. The intake valve is similar in appearance to the exhaust valve. At times, the intake valve

has a darker hue in terms of color. If a valve develops a crack, the technician will notice localized discoloration in the area of the crack. Metal erodes away from the crack. The hot looking, nearly white, color is caused by the edge of the crack becoming very hot, or incandescent. This action burns away the carbon in the area of extreme heat as the crack glows red hot. If cracked valves are not replaced in time, the result will usually be zero compression in that cylinder. In addition, valve failure may result in extreme damage to the cylinder assembly and engine and may cause engine stoppage. Other cracks that are visible to the borescope while remaining invisible to the compression tester are those that run from valve seat pocket to valve seat pocket or from a valve seat pocket to one of the spark plug holes. ***(Figure 12-13)*** Such faults appear as cracks in the formation of the carbon coating. Carefully analyze suspicious cracks in the carbon when they extend from one valve seat to another or to a spark plug hole. A crack in this area may allow the valve seat to become loose from the valve seat pocket machined in the cylinder head. The valve seat is held in the cylinder head by an interference fit meaning that the outside diameter of the valve seat is larger than the inside diameter of the valve seat pocket. When the crack reaches the valve seat pocket, the grip of the interference fit is reduced and the valve seat may be free to leave its installation as seen in ***Figure 12-14.***

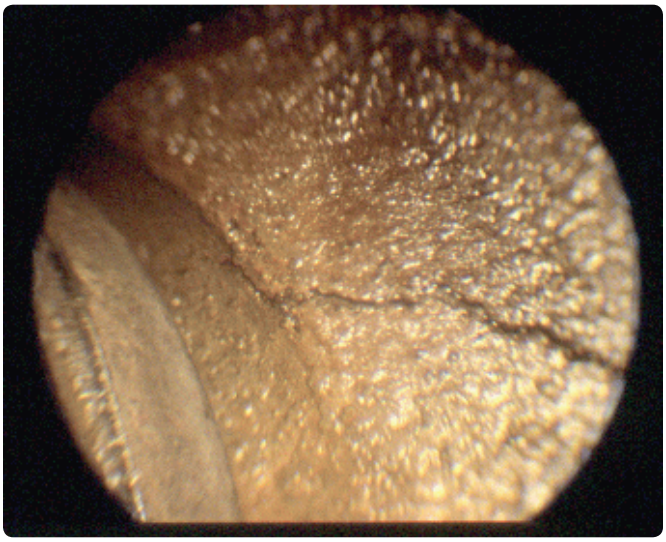


Figure 12-13. Crack in cylinder head running from the valve seat pocket to the spark plug hole. (A portion of the exhaust valve margin and valve seat is visible in the left side of the image.) This defect was discovered before the engine failed in flight.

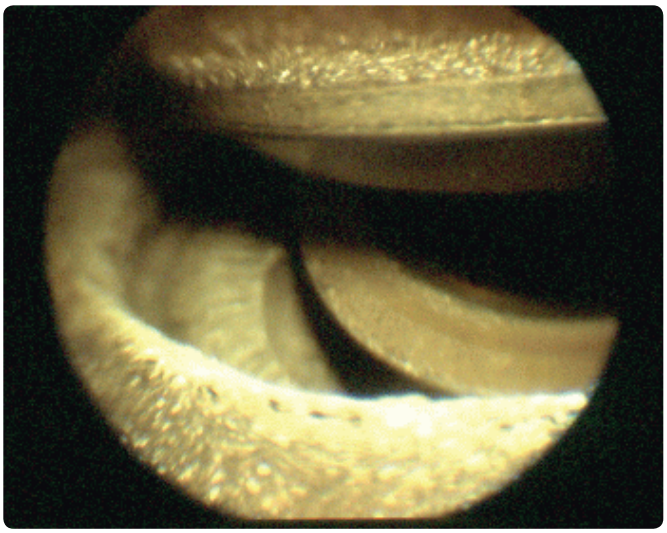


Figure 12-14. Valve seat shown wedged between valve head and valve seat pocket. A crack in the cylinder head running from one valve seat to the other generated this condition. This engine failed in flight resulting in an emergency landing.

SUMMARY TO BORESCOPE

Although borescopic inspections are not widely required or used in many facets of general aviation, they can greatly increase aviation safety and reduce maintenance costs and labor hours. The borescopic inspection provides the technician with valuable information concerning the condition of the parts inspected. And with moderate practice, the technician will master the borescope to the extent that in most cases a superior visual inspection will emerge from its use. In general aviation, the borescope is the ideal tool to use to supplement a compression check as it provides a means whereby the technician may check the internal condition of each cylinder. One engine manufacturer recommends that a borescopic inspection be conducted in conjunction with the compression test.

OIL FILTER EXAMINATION

General information regarding oil system components, operation, and servicing was discuss in Module 16.9. Before dismantling the oil system for examination of particle accumulation, follow the instructions provided by the manufacturer.

After the screen(s) and/or filter(s) are removed, the technician must examine the components for particles. The accumulation of particles will reveal the condition of the engine. Before forming a conclusion as to the condition of the engine, the technician should take into consideration

the total time in service of the power plant and the amount of time that has accrued since the previous filter/screen installation. For example, the particle accumulation on a filter following 10 hours of operation will be less than the accumulation after 50 hours of use.

Particles caught by the screen or filter will be of the following categories: (a) carbon flakes, (b) non-ferrous metal, (c) ferrous metal, and (d) foreign object. Through experience, technicians establish normal levels of particle accumulations. ***[Figure 12-15]***



Figure 12-15. Normal oil filter.

Carbon flakes form from the combustion gases that blow by the piston ring end gaps in the cylinders. They appear as black flakes. As a rule, the more worn the engine, the greater the accumulation of carbon flakes. When technicians observe a large quantity of carbon flakes in the filter, chances are the engine has one of more cylinders with low or marginal compression.

Non-ferrous particles are typically small slivers of aluminum, brass, copper, and other such metals. They appear as shiny, small pieces of metal.

Ferromagnetic particles contain iron and are associated with highly stressed components of the engine (e.g., crankshaft, connecting rods, cam drive components, accessory and propeller speed reduction system gears, piston rings and cylinder walls, etc.). Passing a magnet across the surface of the filter will separate ferrous particles from non-ferrous metal particles. A large accumulation of metal particles is likely associated with a defect within the engine requiring further investigation. ***[Figure 12-16]***

Foreign objects in the filter may originate from a variety of sources. One item that is sometimes discovered during filter inspection is the plastic ring used on the pouring spout of an oil bottle. These rings may split when the cap is removed from the bottle of oil and remain on the pouring spout. The oil bottle is commonly inserted into the oil filler neck of the engine. The split plastic ring may become dislodged from the pouring spout when pulling the bottle away from the oil filler neck resulting in the ring falling into the oil sump. Other objects are that may enter the oil system and caught by the filter are pieces of gaskets that fall into the oil sump during the process of scraping off portions of gaskets that bond to the engine (e.g., magneto gaskets).

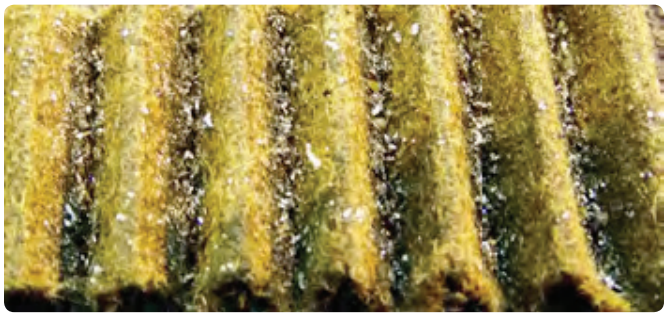


Figure 12-16. Oil filter with excess accumulation of metal.

Although generally not required, safety may be boosted through the repeated use of oil analysis. Presented in Module 16.9, oil analysis is able to measure extremely small levels of metal concentrations. Comparing the results of a sample to normal wear trends alerts maintenance technicians and operators of potentially dangerous conditions long before the level reaches the failure point.

Question: 12-1
Name at least 5 things to inspect prior to starting an engine.

_____,
_____,
_____,
_____,
_____.

Question: 12-2
When operating an engine for ground inspection, in which direction should the aircraft be turned?

Question: 12-3
Before starting a carbureted engine, three controls which need to be in the ON position include:

_____,
_____,
_____.

Question: 12-4
What additional system must be turned on when starting a fuel injected engine versus a carbureted engine?

Question: 12-5
In what circumstance can vapor lock occur while in flight?

Question: 12-6
Name three factors that are causes for low oil pressure.

_____,
_____,
_____.

Question: 12-7
A fluctuating mechanical type oil pressure gauge is often caused by_____.

Question: 12-8
At what oil temperature does water in the system and crankcase begin to evaporate.

ANSWERS

Answer: 12-1
*Oil level
*Control travel, free and clear
*Loose wires and plumbing
*Propeller security
*Puddles of fuel or oil
*Air inlet free and clear
*Engine mount condition and security
*Tools or rags left on engine or airplane
*Nearby objects, equipment, and people on the ground
page 12.2

Answer: 12-2
Pointed into the wind.
page 12.2

Answer: 12-3
Master switch; Magneto switch; Fuel valve.
page 12.3

Answer: 12-4
Fuel boost pump.
page 12.3

Answer: 12-5
At high altitudes when ambient pressure is reduced.
page 12.5

Answer: 12-6
*Insufficient oil quantity
*High oil temperature
*Too low oil viscosity
page 12.6

Answer: 12-7
Air in the instrument line.
page 12.7

Answer: 12-8
180˚ F (83˚ C)
page 12.8

Question: 12-9
A significant increase in rpm during idle cutoff normally indicates what?

Question: 12-10
If the alternator or other component of the charging system fails, what will the volt meter indicate?

Question: 12-11
During a magneto check, how high of an rpm drop is permissible from either magneto prior to removing the aircraft from service?

Question: 12-12
During a successful magneto check, when one magneto is turned off, exhaust gas temperature _____ and manifold pressure _____.

Question: 12-13
If an engine runs rough during a magneto check, what is the most likely faulty component?

Question: 12-14
During a propeller cycle check, when changing from high pitch to low pitch, RPM will _____ and manifold pressure will _____.

Question: 12-15
What is indicated if during idle cutoff of a carbureted engine, the engine increases by 50 rpm before stopping?

Question: 12-16
What is the proper method for shutting down a reciprocating engine?

ANSWERS

Answer: 12-9
Excessively rich idle mixture.
page 12.9

Answer: 12-10
Battery voltage.
page 12.9

Answer: 12-11
150 rpm.
page 12.10

Answer: 12-12
Increases; Increases.
page 12.12

Answer: 12-13
Fouled spark plug.
page 12.12

Answer: 12-14
Increase; Decrease.
page 12.15

Answer: 12-15
No problem exists. This is normal.
page 12-18

Answer: 12-16
Turn off electrical devices such as radios and lights. Then turn the mixture control to full lean. Then magneto switch OFF and master switch OFF.
page 12.19

Question: 12-17
What is the required position of a piston when performing a differential compression test?

Question: 12-18
A differential compression test is done at normal operating temperatures for what two reasons: _____ and _____.

Question: 12-19
What is indicated if you observe a hissing sound from the exhaust system during a differential compression check?

Question: 12-20
A cylinder with low compression may be indicted by a large accumulation of _____ flakes within the pleats of an oil filter.

ANSWERS

Answer: 12-17
Top dead center compression (TDCC).
page 12.20

Answer: 12-18
*Internal tolerances due to heat expansion is similar to during operation.
*All components are properly lubricated.
page 12.21

Answer: 12-19
A leaky exhaust valve/seat.
page 12.24

Answer: 12-20
Carbon.
page 12.29



PART-66 SYLLABUS	LEVELS		
CERTIFICATION CATEGORY →	A	B1	B3
		2	1

Sub-Module 13
Piston Engine - Engine Storage and Preservation

16.13 - Engine Storage and Preservation

Preservation and depreservation for the engine and accessories/systems.

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

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

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

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

ENGINE STORAGE AND PRESERVATION

Aircraft engines, like most other mechanical contrivances, are subject to decay from periods of inactivity. Too often, aircraft owners, operators, and technicians run power plants on the ground instead of performing flight operations to circulate oil and fluids through the engines. Where on the surface this appears to be an appropriate measure, in reality such operations in repeated fashion are harmful to the engine.

Each time an engine is operated, chemicals from the gasoline enter the oil during priming and starting operations. In addition, as the engine reaches operating temperature, the interior of the crankcase heats up. This elevated temperature augments the ability of the gases within the engine to hold more water vapor. As the gases in the crankcase absorb more water vapor due to their increase in temperature, the water vapor has two options. It can either escape through the breather or remain in the crankcase. The water vapor that remains in the engine condenses as the temperature of the crankcase gases cool after engine shutdown. The water ultimately coats the interior of the engine and contaminates the oil. This occurrence takes place each time the engine is shutdown.

Ordinarily, as the aircraft is flown, the water from the previous shutdown is largely removed from the engine as the temperature of the oil reaches 180˚F (82˚C). Operating a minimum of 30 minutes at 180˚F (82˚C) is needed to expel water from the previous shutdown. Operations that span less than 30 minutes or with oil temperatures cooler than 180˚F (82˚C) do not adequately purge water from the engine. Instead, an undesirable portion of the water from the previous shutdown remains in the system. If operations repeatedly fail to extract the water from the engine flight-after-flight, an accumulation level of harmful water builds in the system. Failure to install winterizing kits during operations in cold climates may generate low oil temperatures during flight resulting in excess water accumulation over hours of operation.

Ground runs generally fail to meet the minimum length of time or temperature threshold needed to expel the water from the system. Instead, after each ground operation, the water that is deposited into the crankcase accumulates with little chance of escape during the next ground run. The end result is that an excess level of water builds in the oil system. This water contaminates the oil in terms of its chemical attributes and causes corrosion within the engine. So unless the engine is flown at the temperature listed for the period specified, ground operations are counterproductive in terms of attempting to keep the engine free of internal corrosion.

In the area of corrosion, additional concerns are placed on low time engines. Because power plants with few hours of operation do not have a protective coating of glaze on the internal surfaces of the engine, corrosion easily forms on the walls of the cylinders and other metallic components. To guard against corrosion, engine manufacturers have adopted corrosion preventative measures. The degree of engine preservation depends on the projected period of inactivity and the ambient storage environment. Three general levels of preservation are available. They are: (a) flyable storage, (b) temporary storage, and (c) indefinite storage. A summary of each preservation level is presented. The steps listed in this section are for instructional purposes. Refer to specific procedures provided by the manufacturer when maintaining their product.

FLYABLE STORAGE

Flyable storage is appropriate for aircraft that are not flown each 15 to 30 days. The frequency of action is dictated by the time in service of the engine. The decision is based on whether or not the engine has at least 50 hours time in service.

If the engine has less than 50 hours time in service, the following action is to be taken every five days. In addition, the aircraft is to be flown for at least 30 minutes at operating temperatures every 15 days. After 5 days of inactivity, rotate the engine by hand 10 revolutions for 4- and 6-cylinder direct drive engines. Prior to turning the engine, note the clock angle of the propeller. Ensure that the subsequent resting position of the propeller is 45˚ to 90˚ from the original clock angle. This repositions the piston rings in relation to the cylinder wall to minimize dissimilar metal corrosion. If the engine is geared, rotate the propeller 5 revolutions and stop the propeller so that it is 30˚ to 60˚ from its original position. After 15 days, fly the aircraft as previously specified. If the aircraft cannot be flown, additional preservation measures should be implemented.

Flyable storage for engines with more than 50 hours time in service follow the same procedures save for the frequency. The propeller should be rotated after 7 days of inactivity as previously listed. Likewise, the aircraft should be flown every 30 days. Note, if the flying portion cannot be accomplished due to weather or maintenance related reasons, rotate the propeller daily until the flight is accomplished. As before, if more than 30 days are to pass between flights, the operator should consider additional preservation measures.

TEMPORARY STORAGE

Most manufacturers limit temporary storage to 90 days. If the power plant is not returned to flyable status after 90 days, the preservation level should be changed to indefinite storage.

To prepare an engine for temporary storage, the technician should remove the spark plugs from the power plant. Place a cylinder at bottom dead center and spray it with an appropriate preservative using a pressure pot or garden sprayer. Insert the tip of the sprayer through the spark plug holes to apply the preservative. Rotate the engine and spray each cylinder at bottom dead center. After spraying all the cylinders, re-spray each cylinder without rotating the engine. Thoroughly coat all surfaces before reinstalling the spark plugs. Insert the spray nozzle through the oil filler port, if possible, and spray the interior of the engine with the preservative. ***[Figure 13-1]***



Figure 13-1. Cylinder preservation oil, spray rig, and crankcase preservation oil.

To prevent accidental turning of the engine during storage, the propeller should be placarded with the following or similarly worded message: "DO NOT TURN PROPELLER - ENGINE PRESERVED. PRESERVATION DATE (insert date)." If the engine is turned while under temporary storage, the preservative should be reapplied.

In addition to the application of the preservation fluid, the engine should be sealed. Basically all open ports of the engine (e.g., intake, breather, exhaust system, etc.) must be sealed from the atmosphere. The technician should use material that is non-hygroscopic (does not absorb moisture) to plug entry ports. Expandable rubber plugs, plastic tapes, and similar material are appropriate for this purpose. Included in this process is the "whistle slot" on the breather, if present. Whistle slots are openings somewhere along the breather line that act like an alternate breather outlet in case the main exit plugs up or becomes clogged with ice during flight.

The purpose of sealing entry ports to the power plant is to isolate the interior of the engine from the atmosphere. This helps reduce the level of water vapor that reaches the engine over the preservation period. Consider that as the air in the engine heats up during the day, it expands and a portion leaves the engine. As the air in the engine cools at night, it contracts. Such contraction pulls fresh air into the engine through the breather and opened intake and exhaust valves. This fresh air contains water vapor. Because of this action, an engine that does not have its entry points plugged exhales and inhales air over its storage period.

The technician should carefully mark each engine plug with a non-hygroscopic red streamer. The attached streamer should not act as a wick for moisture entry into the engine. Attach the streamer in a fashion that prevents wicking. A comprehensive list of all the areas plugged and the preservation processes applied should be entered in the service records. A separate list of preservation activities should be posted inside the aircraft to ensure that items are not overlooked during the depreservation process.

To return the engine to service, all the seals, plugs, and streamers previously installed should be removed before starting the engine. Remove the bottom spark plugs and rotate the engine to dispel residual preservation fluid. It may be necessary to clean the spark plugs before starting the engine. The engine should be pre-oiled before

starting. After completing the reassembly of the power plant, start and test the engine.

INDEFINITE STORAGE

Indefinite storage is for engines that are to be inactive for more than 90 days. Because of the long term nature of indefinite storage, extra measures are taken to protect the lubrication system, fuel system, cylinder assemblies, and other elements of the power plant.

The first step in the process is to drain the engine oil and replenish the crankcase with Mil-C-6529 Type II or similar product. Fly the engine for 30 minutes making certain that the oil and cylinder temperature limits are not exceeded. After the engine cools, preserve the cylinders and engine interior in accordance with the procedures used for temporary storage.

Some manufacturers recommend ***fogging*** the engine for preservation. This technique involves spraying the cylinder preservative oil into the engine inlet while it is running. The flow rate of the preservative is increased until the engine dies. Extreme caution should be exercised when spraying preservative into the air inlet of a running engine One suggestion is to remove the cowling and alternate air or carburetor heat air supply feed to the airbox. Place the carburetor heat or alternate air control in the HOT or ALTERNATE AIR position and spray the preservative oil into the airbox through the disconnected supply port. Engines equipped with pressure carburetors and RSA fuel injectors should not be fogged as the preservative oil will enter the regulator and come in contact with the pneumatic diaphragm. The technician should only proceed with preservation measures in a safe manner and according to the manufacturer's instructions. ***[Figure 13-2]***

Dehydrator plugs should be installed in the upper spark plug holes. When using desiccants treated with cobalt chloride, the plugs should be blue in color. If the desiccant turns pink, the dehydrator plug has been exposed to high levels of moisture. Desiccants are salts that readily absorb moisture from the atmosphere. Pink dehydrator plugs may be dried to restore the blue color.

The spark plug leads should be disconnected and protected against damage. Fuel metering units should be preserved in accordance with the instructions provided in



Figure 13-2. Dehydrator spark plugs. Note the top plug's cobalt chloride is blue (dry) while the bottom dehydrator plug's cobalt chloride is pink (wet).

manufacturer's manuals. The air passage to the induction manifold should be stuffed with a bag of desiccant. The opening must be sealed with a non-hygroscopic material and a red streamer attached to the area. Stuff a desiccant bag in the tailpipe(s) of the exhaust system and seal with non-hygroscopic material and attach a red streamer. Seal and mark other air entry points, such as the air inlet for the carburetor heat or alternate air system, breather system, and etc. in the method previously described. ***[Figure 13-3]***



Figure 13-3. Desiccant bag, red streamer, and expandable rubber plug. The desiccant bag may be dried and reused.

If the fuel tank(s) contain automotive fuel, defuel the aircraft. As automotive fuel spoils over time, failure to drain the fuel during the preservation process may result in numerous problems when returning the aircraft to service in the distant future.

The propeller should be placarded as listed under the procedures for temporary storage. Items sealed and

preserved (e.g., fuel injector body) should be noted in the service records and on a separate list. If not accurately listed, the person returning the aircraft to service might miss one or more items.

Engines under indefinite storage should be inspected every 15 days. If a dehydrator plug changes color, it should be replaced. If one-half or more of the dehydrator plugs change color, replace all the desiccants in the engine. Inspect the interior of the cylinders. If corrosion is detected, spray corrosion preventative fluid into the affected cylinders, turn the engine at least 10 revolutions, and re-spray all the cylinders. Remove at least one rocker box cover and inspect the valve mechanism for corrosion. If corrosion is detected, remove the remaining rocker box covers and spray the valve mechanisms for every cylinder with the preservative fluid. Reinstall the rocker box covers.

Preservation measures should be renewed every six months or more often, as dictated by conditions. This requires the reapplication of the preservation fluid and replacement of desiccants, including the dehydrator plugs.

The depreservation process is, for the most part, similar to that listed under temporary storage. The main differences are the bags of desiccants stuffed in different parts of the engine, the possibility that more items may be sealed, the preservative oil in the sump needs to be drained and replaced with regular engine oil, the fuel metering unit may need to be depreserved, and the dehydrator plugs should be removed and replaced with standard spark plugs. Do not use the preservative oil, MIL-C-6529, in the crankcase for more than 25 hours of operation. Refer to the appropriate service data for specific precautions and instructions.

STORAGE CONTAINERS

Engines that are not installed on an airframe may be encased in a storage container. Such units are air-tight and may be evacuated of air and filled with dry nitrogen. The nitrogen charge, approximately 5 psi, pressurizes the container so the technician may inspect the pressure gauge to determine whether the container has a leak.

Engines properly preserved and stored in these containers will remain free of corrosion for an extended period. In essence, this storage method hermetically seals the engine until it is removed from the container. ***[Figure 13-4]***



Figure 13-4. Engine storage container.

PRESERVATION AND DEPRESERVATION OF FUEL METERING DEVICES

FLOAT CARBURETORS

A technique for preserving float carburetors is provided by a manufacturer. The process is recommended for carburetors that have been overhauled and will be placed in storage. Technicians are instructed to remove the float bowl drain plug and flush the interior of the carburetor with MIL-C-4339 corrosion preventative oil. After coating the interior of the carburetor, the excess preservation oil is drained from the carburetor and the bowl drain plug reinstalled and safetied.

To depreserve the carburetor, connect the inlet to a fuel source, remove the drain plug, and flush the interior of the carburetor with gasoline. Cycle the throttle control several times to flush the acceleration system. Reinstall and safety the drain plug.

PRESSURE CARBURETORS AND RSA FUEL INJECTORS

RSA fuel injectors and pressure carburetors that are scheduled to remain inactive for a protracted period should be preserved in accordance with the current manufacturer's instructions. The information and advice contained in this section are for instructional purposes. They do not replace the latest instructions from the manufacturer.

An important issue regarding the preservation process involves the ambient environment. When possible, the pressure carburetor or RSA fuel injector should be stored in an area where there is proper climate control. Unduly exposing the fuel metering unit to a hostile environment serves to expedite its deterioration.

To prepare the RSA or PS series carburetor for storage, first remove the plugs from the various passageways and drain the fuel from the unit. Purge the remaining fuel from the unit by applying compressed air pressurized from 10 to 15 pounds per square inch. Continue purging until all the fuel has been discharged from the outlet. Do not exceed the pressures specified as damage to the unit may result. The technician should avoid the entry of water by ensuring that the compressed air is dry. Also, caution should be exercised to prevent injuries and fires stemming from the discharged fuel.

Replace all the plugs and inject filtered oil through the unit. The specified oil is MIL-L-6081 Grade 1010. The filter should be a 10-micron unit. Pressure used to flush oil through the unit should be between 13-15 pounds per square inch. After passing oil through the metering device, plug the fuel inlet. Protect the component from dirt and moisture.

Technicians should exercise caution during this process to prevent the entry of petroleum products into the pneumatic chambers. Such products may damage the air diaphragm. This precaution extends to spraying the engine with solvents and other cleaning fluids during routine maintenance. Technicians should avoid spraying solvents into the air entrance of the pressure carburetor or injector body. Reckless spraying of solvent may expose the air diaphragm to the cleaning solution.

When storing the device near salt water or when shipping overseas, additional measures should be taken to protect the unit. The exterior of the carburetor should be sprayed with preservative oil. As previously mentioned, take the necessary measures to prevent the entry of preservative oil into the pneumatic chambers. Pack the carburetor in a dust proof container. Include one-half pound of desiccant in the container. Cobalt chloride treated desiccants are useful for indicating levels of moisture exposure. Blue indicates a dry environment. Pink colored cobalt chloride reveals exposure to harmful levels of moisture. Measures must be taken to prevent contact between the metering device body and the desiccant material. Wrap the container containing the carburetor or RSA injector and the desiccant with moisture and vapor proof material. Pack the sealed container in a suitable shipping cartoon.

Removing the carburetor from storage entails the expulsion of the preservative oil from the interior and exterior of the unit and the ***seasoning of the fuel diaphragms***. After wiping away the preservative oil from the exterior of the carburetor, if used, remove the various passageway plugs and drain the preservative oil from the interior of the metering device. Aviation gasoline should then be used to fill the fuel chambers. Reinstall the plugs and allow the diaphragm to soak for at least 8 hours before using the unit. It is best to allow a 24-hour soaking period. This soaking action restores the pliable status of the diaphragms to match their condition at the time that the unit was calibrated. As previously warned, do not allow the entry of petroleum products into the air chambers.

POWER PLANT PRE-OILING

Pre-oiling a power plant is a task that should be accomplished prior to starting an engine that has been inactive for an extended period of time. It is also recommended to pre-oil inactive engines, from time-to-time, to circulate and replenish oil through the passageways and to lubricate parts when oil has drained off of the interior components of an engine. If an engine is to have an extended period of storage, preserve it in accordance with the manufacturer's recommendations.

Pre-oiling is not limited to stored engines. Newly assembled power plants may benefit from pre-oiling. Benefits offered by pre-oiling include the reduction of metal-to-metal contact during the initial start and post-assembly testing of the oil system. If the engine successfully pre-oils after its assembly, it will generate oil pressure upon starting.

PRE-OILING STEPS

The following procedure is offered as general process for pre-oiling reciprocating power plants. Refer to specific steps provided by the manufacturer when such data are available. It is not the intent of the material contained herein to supersede the recommendations of the manufacturer.

If for some reason the engine fails to pre-oil, the oil pump may need to be primed. As previously indicated in module 16.8, one of the functions of oil is to act as a seal. If the oil pump gears do not have an adequate coating of oil, they may be unable to lift oil from the sump. Priming procedures are included in this process. However, be aware that priming the pump does not substitute for pre-oiling. After the pump is primed, the pre-oiling process needs to be implemented.

1. Remove the top spark plug from each cylinder and squirt engine oil into the cylinders.
2. Rotate the engine using the starter with one spark plug removed from each cylinder until oil pressure reaches its peak. The oil pressure should exceed the minimum oil pressure limit. It is likely that the oil pressure will be within the green arc during the pre-oiling process. Rotating the engine by hand should also generate oil pressure but requires considerable physical effort on the part of the technician.

2a. If no oil pressure is produced, prime the oil pump. A simple method for priming the oil pump is to remove an oil galley plug or oil line from the crankcase or accessory case. Be certain to remove the plug from a passageway connected to the oil pump. Assemble a hand-operated pump capable of pumping oil and connect this unit to the engine where the plug or oil line was removed. Pump oil into the engine. If the removed plug is located downstream of the oil pump in terms of flow, turn the engine in its opposite direction of rotation as oil enters the system. Some power plants equipped with right-angle starter drives resist rotation in the opposite direction of rotation. It may be necessary to remove the starter motors from such power plants in order to turn the engine against its normal direction of rotation. Because the gear pump used by most engines is bidirectional, turning the engine in its opposite direction of rotation reverses the pump's inlet and outlet. Oil will flow from the hand pump, through the passageways, into the oil pump cavity, and into the oil sump. After priming the oil pump, reassemble the engine and retry the pre-oiling steps listed in steps 1 and 2. It will be necessary to clean the spark plugs before starting the engine.

NOTE: It is beneficial, from an oil quantity standpoint, to use oil from the engine's oil sump to prime the oil pump. On dry sump power plants, the oil inlet line to the engine may be connected to the oil priming pump. In such cases, rotate the power plant in the normal direction of rotation while applying oil pressure to the engine.

SUMMARY OF PRE-OILING

Pre-oiling an engine is a good practice to use before starting an engine for the first time after overhaul or for engines that experience extended periods of inactivity. Pre-oiling is arguably the next best thing to flying an engine. This is because running an aircraft engine solely on the ground for the purpose of oil circulation is often not recommended due to water condensation within the crankcase and breather system. Check the manufacturer's recommendations regarding ground operations and storage.

Question: 13-1
Why is ground running an underused engine for the purpose of circulating oil a bad idea?

Question: 13-2
At what point of inactivity should flyable storage procedures give way to temporary storage procedures?

Question: 13-3
What are the two primary goals of any storage procedure?

Question: 13-4
If using a desiccant plug in place of spark plugs during long term storage, what indicates if the plug is still capable of absorbing moisture?

Question: 13-5
What is recommended for the long term storage of carburetors?

Question: 13-6
When is it advisable to pre-oil an engine?

Question: 13-7
If measurable oil pressure is not produced upon pre-oiling, what is the likely reason?

ANSWERS

Answer: 13-1
It introduces condensation without adequate heat and time to evaporate it out.
page 13.2

Answer: 13-2
After 30 days.
page 13.3

Answer: 13-3
Maintain lubrication and eliminate atmospheric condensation.
page 13.3

Answer: 13-4
Color change. Typically blue to pink with a cobalt chloride plug.
page 13.4

Answer: 13-5
Remove the float bowl drain plug and flush interior with corrosion protection oil.
page 13.5

Answer: 13-6
*First start of a new engine.
*First start after overhaul.
*After extended storage.
page 13.6

Answer: 13-7
The oil pump needs to be primed.
page 13.7



PART-66 SYLLABUS **LEVELS**

CERTIFICATION CATEGORY → A B1 B3

Sub-Module 14
Piston Engine - Light Sport Aircraft Engines

16.14 - Light Sport Aircraft Engines

LIGHT SPORT AIRCRAFT ENGINES

ENGINE GENERAL REQUIREMENTS

Engines used for light-sport aircraft and other types of aircraft, such as some experimental aircraft, ultralight aircraft, and powered parachutes, must be very light for the power they develop. Each aircraft requires thrust to provide enough forward speed for the wings to provide lift to overcome the weight of the aircraft. An aircraft that meets the requirements of the light-sport categories must meet the following requirements.

NOTE: All of the following requirements and regulations are subject to change. Always refer to the latest Federal Aviation Regulations for current information.

A light-sport aircraft means an aircraft, other than a rotorcraft or powered-lift, since its original certification, has continued to meet the following:

1. A maximum takeoff weight of not more than 1,320 pounds (lb) (600 kilograms (kg)) for aircraft not intended for operation on water; or 1,430 lb (650 kg) for an aircraft intended for operation on water.
2. A maximum airspeed in level flight with maximum continuous power (VH) of not more than 120 knots calibrated airspeed (CAS) under standard atmospheric conditions at sea level.
3. A maximum never-exceed speed (VNE) of not more than 120 knots CAS for a glider.
4. A maximum stalling speed or minimum steady flight speed without the use of lift-enhancing devices (VS1) of not more than 45 knots CAS at the aircraft's maximum certificated takeoff weight and most critical center of gravity.
5. A maximum seating capacity of no more than two persons, including the pilot.
6. A single, reciprocating engine, if powered.
7. A fixed or ground-adjustable propeller, if a powered aircraft other than a powered glider.
8. A fixed or auto-feathering propeller system, if a powered glider.
9. A fixed-pitch, semirigid, teetering, two-blade rotor system, if a gyroplane.
10. A non-pressurized cabin, if equipped with a cabin.
11. Fixed landing gear, except for an aircraft intended for operation on water or a glider.
12. Fixed or retractable landing gear, or a hull, for an aircraft intended for operation on water.
13. Fixed or retractable landing gear for a glider.

Powered parachute means a powered aircraft comprised of a flexible or semirigid wing connected to a fuselage so that the wing is not in position for flight until the aircraft is in motion. The fuselage of a powered parachute contains the aircraft engine, a seat for each occupant, and is attached to the aircraft's landing gear.

Weight shift control aircraft means a powered aircraft with a framed pivoting wing and a fuselage controllable only in pitch and roll by the pilot's ability to change the aircraft's center of gravity with respect to the wing. Flight control of the aircraft depends on the wing's ability to flexibly deform rather than the use of control surfaces.

As the weight of an engine is decreased, the useful load that an aircraft can carry and the performance of the aircraft are obviously increased. Every excess pound of weight carried by an aircraft engine reduces its performance. Since lightsport aircraft have a narrow margin of useful load, engine weight is a very important concern with all of the light, low airspeed aircraft. Tremendous gains in reducing the weight of the aircraft engine through improvements in design, operating cycles, and metallurgy have resulted in engines with a much improved power to weight ratio.

A light-sport aircraft engine is reliable when it can perform at the specified ratings in widely varying flight attitudes and in extreme weather conditions. The engine manufacturer ensures the reliability and durability of the product by design, research, and testing. Although most of these engines are not certificated by the Federal Aviation Administration (FAA), close control of manufacturing and assembly procedures is generally maintained, and normally each engine is tested before it leaves the factory and meets certain American Society for Testing and Materials (ASTM) standards. Some engines used on light-sport aircraft are certificated by the FAA and these engines are maintained as per the manufacturer's instructions and Title 14 of the Code of Federal Regulations (14 CFR).

Most light-sport engines require a definite time interval between overhauls. This is specified or implied by the engine manufacturer. The time between overhauls (TBO) varies with the type of engine (cycle), operating

Designation of Engine Type	For Engine S/N	Time Between Overhaul (TBO)	SB To Be Carried Out To Increase TBO
914 F	to 4,420.313	1,000 hours or 10 years, whichever comes first	SB-914-027 1,000 hours to 1,200 hours or 12 years, whichever comes first
914 F	from 4,420.314	1,200 hours or 12 years, whichever comes first	None
914 UL	to 4,418.103	1,000 hours or 10 years, whichever comes first	SB-914-027 1,000 hours to 1,200 hours or 12 years, whichever comes first
914 UL	from 4,418.104	1,200 hours or 12 years, whichever comes first	None

Figure 14-1. Examples of TBO and calendar life for engines.

conditions, such as engine temperatures, amount of time the engine is operated at high-power settings, and the maintenance received. After reaching the time limit, the engine has to be overhauled. Sometimes this requires the engine to be shipped to an authorized manufacturer's overhaul facility. ***[Figure 14-1]***

One consideration when selecting a light-sport engine is the shape, size, and number of cylinders of the engine. Since these engines range from single cylinder to multicylinder engines, the mounting in the airframe is important to maintain the view of the pilot, aircraft center of gravity, and to reduce aircraft drag.

PERSONNEL AUTHORIZED TO PERFORM INSPECTION AND MAINTENANCE ON LIGHT SPORT ENGINES

Given they meet all applicable regulations, the holder of a powerplant certificate can perform maintenance and inspections on light-sport engines. The holder of at least a sport pilot certificate may approve any aircraft owned and operated by that pilot and issue a special Airworthiness Certificate in the light-sport category for return to service after performing preventive maintenance under the provisions of 14 CFR part 43, section 43.3 (g). All maintenance must be performed in accordance with 14 CFR part 65, section 65.81, which describes specific experience requirements and current instructions for performing maintenance.

The following is used to determine eligibility for a repairman certificate (light-sport aircraft) and appropriate rating. To be eligible for a repairman certificate (light-sport aircraft), you must:

- Be at least 18 years old.
- Be able to read, speak, write, and understand English. If for medical reasons you cannot meet one of these requirements, the F A A may place limits on the repairman certificate necessary to safely perform the actions authorized by the certificate and rating.
- Demonstrate the requisite skill to determine whether a light-sport aircraft is in a condition for safe operation.
- Be a citizen of the United States, or a citizen of a foreign country who has been lawfully admitted for permanent residence in the United States.
- To be eligible for a repairman certificate (light-sport aircraft) with an inspection rating, the applicant must:
  - o Meet the requirements stated above for a repairman's certificate.
  - o Complete a 16-hour training course acceptable to the FAA on inspecting the particular class of experimental light-sport aircraft for which these privileges are intended to be exercised.
- To be eligible for a repairman certificate (light-sport aircraft) with a maintenance rating, the applicant must:
  - o Meet the requirements stated above for a repairman's certificate.
  - o Complete a training course acceptable to the F A A on maintaining the particular class of light-sport aircraft upon which the privileges are intended to be exercised. The training course must, at a minimum provide the following number of hours of instruction:
  - For airplane class privileges: 120 hours.
  - Weight-shift control aircraft class privileges: 104 hours.

- Powered parachute class privileges: 104 hours.
- Lighter-than-air class privileges: 80 hours. Glider class privileges: 80 hours.

The holder of a repairman certificate (light-sport aircraft) with an inspection rating may perform the annual condition inspection on a light-sport aircraft that is owned by the holder, has been issued an experimental certificate for operating a light-sport aircraft under 14 CFR part 21, section 21.191(i), and is in the same class of light-sport aircraft for which the holder has completed the training specified in the above paragraphs. The holder of a repairman certificate (light-sport aircraft) with a maintenance rating may approve and return to service an aircraft that has been issued a special Airworthiness Certificate in the light-sport category under 14 CFR part 21, section 21.190, or any part thereof, after performing or inspecting maintenance (to include the annual condition inspection and the 100-hour inspection required by 14 CFR part 91, section 91.327), preventive maintenance, or an alteration (excluding a major repair or a major alteration on a product produced under an FAA approval). They may perform the annual condition inspection on a light-sport aircraft that has been issued an experimental certificate for operating a light-sport aircraft under 14 CFR part 21, section 21.191(i).

However, they may only perform maintenance, preventive maintenance, and an alteration on a light-sport aircraft for which the holder has completed the training specified in the preceding paragraphs. Before performing a major repair, the holder must complete additional training acceptable to the FAA and appropriate to the repair performed.

The holder of a repairman certificate (light-sport aircraft) with a maintenance rating may not approve for return to service any aircraft or part thereof unless that person has previously performed the work concerned satisfactorily. If that person has not previously performed that work, the person may show the ability to do the work by performing it under the direct supervision of a certificated and appropriately rated mechanic, or a certificated repairman who has had previous experience in the specific operation concerned. The repairman may not exercise the privileges of the certificate unless the repairman understands the current instructions of the manufacturer and the maintenance manuals for the specific operation concerned.

AUTHORIZED PERSONNEL THAT MEET FAA REGULATIONS

All applicable aviation regulatory authority regarding maintenance procedures must be met. Maintenance organizations and personnel are encouraged to contact the manufacturer for more information and guidance on any of the maintenance procedures.

It is a requirement that every individual or maintenance provider possess the required special tooling, training, or experience to perform all tasks outlined. Maintenance providers that meet the following conditions outlined below may perform engine maintenance providing they meet all of the following FAA requirements:

- Knowledge of the specific task as a result of receiving authorized training from a training provider.
- Previous experience in performing the task and formal instruction from a manufacturer's authorized training facility or "on-the-job" instruction by a manufacturer's representative.
- A suitable work environment to prevent contamination or damage to engine parts or modules is needed.
- Suitable tools and fixtures as outlined in the manufacturers' Maintenance Manual should be used while performing maintenance requiring such tooling.
- Reasonable and prudent maintenance practices should be utilized.

TYPES OF LIGHT-SPORT AND EXPERIMENTAL ENGINES

Note: All information in this text is for educational illustrational purposes and is not to be used for actual aircraft maintenance. This information is not revised at the same rate as the maintenance manual; always refer to the current maintenance information when performing maintenance on any engine.

LIGHT-SPORT AIRCRAFT ENGINES

Light-sport/ultralight aircraft engines can be classified by several methods, such as by operating cycles, cylinder arrangement, and air or water cooled. An inline engine generally has two cylinders, is two-cycle, and is available in several horsepower ranges. These engines may be either liquid cooled, air cooled, or a combination of both. They have only one crankshaft that drives the reduction gear box or propeller directly. Most of the other cylinder

configurations used are horizontally opposed, ranging from two to six cylinders from several manufacturers. These engines are either gear reduction or direct drive.

TWO-CYCLE, TWO CYLINDER ROTAX ENGINE SINGLE CAPACITOR DISCHARGE IGNITION (SCDI) DUAL CAPACITOR DISCHARGE IGNITION (DCDI)

ROTAX 447 UL (SCDI) AND ROTAX 503 UL (DCDI)

The Rotax inline cylinder arrangement has a small frontal area and provides improved streamlining. ***(Figure 14-2)*** The two cylinder, inline two-stroke engine, which is piston ported with air cooled cylinder heads and cylinders, is available in a fan or free air cooled version. Being a two-stroke cycle engine, the oil and fuel must be mixed in the fuel tank on some models. Other models use a lubrication system, such as the 503 oil injection lubrication system. This system does not mix the fuel and oil as the oil is stored in a separate tank.

As the engine needs lubrication, the oil is injected directly from this tank. The typical ignition system is a breakerless ignition system with a dual ignition system used on the 503, and a single ignition system used on the 447 engine series. Both systems are of a magneto capacitor discharge design.

The engine is equipped with a carburetion system with one or two piston-type carburetors. One pneumatic driven fuel pump delivers the fuel to the carburetors. The propeller is driven via a flange connected gearbox with an incorporated shock absorber. The exhaust system collects the exhaust gases and directs them overboard. These engines come with an integrated alternating current (AC) generator (12V 170W) with external rectifier-regulator as an optional extra.

ROTAX 582 UL DCDI

The Rotax 582 is a two-stroke engine, two cylinder inline with rotary valve inlet, has liquid cooled cylinder heads and cylinders that use an integrated water pump. ***(Figure 14-3)*** The lubrication system can be a fuel/oil mixture or oil injection lubrication. The ignition system is a dual ignition using a breakerless magneto capacitor discharge design. Dual piston type carburetors and a pneumatic fuel pump deliver the fuel to the cylinders. The propeller is driven via the prop flange connected gearbox with an incorporated torsional vibration shock absorber. This engine also uses a standard version exhaust system with an electric starter or manual rewind starter.



Figure 14-2. Rotax inline cylinder arrangement.



Figure 14-3. Rotax 582 engine.

DESCRIPTION OF SYSTEMS FOR TWO-STROKE ENGINES

COOLING SYSTEM OF ROTAX 447 UL SCDI AND ROTAX 503 UL DCDI

Two versions of air cooling are available for these engines. The first method is free air cooling, which is a process of engine cooling by an air-stream generated by aircraft speed and propeller. The second is fan cooling, which is cooling by an air-stream generated by a fan permanently

driven from the crankshaft via a V-belt.

COOLING SYSTEM OF THE ROTAX 582 UL DCDI

Engine cooling for the Rotax 582 is accomplished by liquid cooled cylinders and cylinder heads. ***(Figure 14-4)*** The cooling system is in a two circuit arrangement. The cooling liquid is supplied by an integrated pump in the engine through the cylinders and the cylinder head to the radiator. The cooling system has to be installed, so that vapor coming from the cylinders and the cylinder head can escape to the top via a hose, either into the water tank of the radiator or to an expansion chamber. The expansion tank is closed by a pressure cap (with excess pressure valve and return valve). As the temperature of the coolant rises, the excess pressure valve opens, and the coolant flows via a hose at atmospheric pressure to the transparent overflow bottle. When cooling down, the coolant is sucked back into the cooling circuit.

LUBRICATION SYSTEMS

OIL INJECTION LUBRICATION OF ROTAX 503 UL DCDE, 582 UL DCDI, AND 582 UL DCDI

Generally, the smaller two cycle engines are designed to run on a mixture of gasoline and 2 percent oil that is premixed in the fuel tank. The engines are planned to run on an oilgasoline mixture of 1:50. Other engines use oil injection systems that use an oil pump driven by the crankshaft via the pump gear that feeds the engine with the correct amount of fresh oil. The oil pump is a piston type pump with a metering system. Diffuser jets in the intake inject pump supplied twostroke oil with the exact proportioned quantity needed. The oil quantity is defined by the engine rotations per minute and the oil pump lever position. This lever is actuated via a cable connected to the throttle cable. The oil comes to the pump from an oil tank by gravity.

NOTE: In engines that use oil injection, the carburetors are fed with pure gasoline (no oil/gasoline mixture). The oil quantity in the oil tank must be checked before putting the engine into service as the oil is consumed during operation and needs to be replenished.

ELECTRIC SYSTEM

The 503 UL DCDI, 582 UL DCDI engine types are equipped with a breakerless, single capacitor discharge ignition unit with an integrated generator. ***(Figure 14-5)*** The 447 UL SCDI engine is equipped with a breakerless, single capacitor discharge ignition unit with integrated generator. The ignition unit is completely free of maintenance and needs no external power supply. Two charging coils fitted on the generator stator, independent

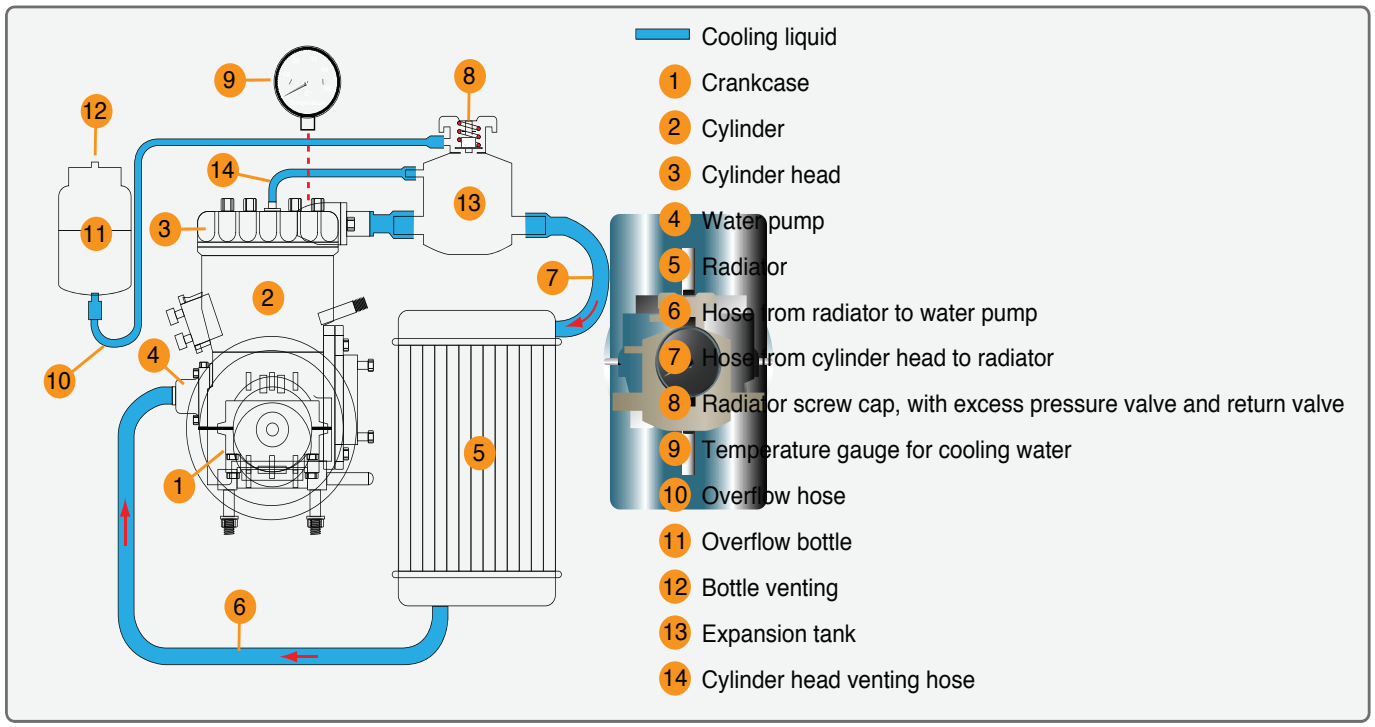


Figure 14-4. Rotax 582 cooling system.

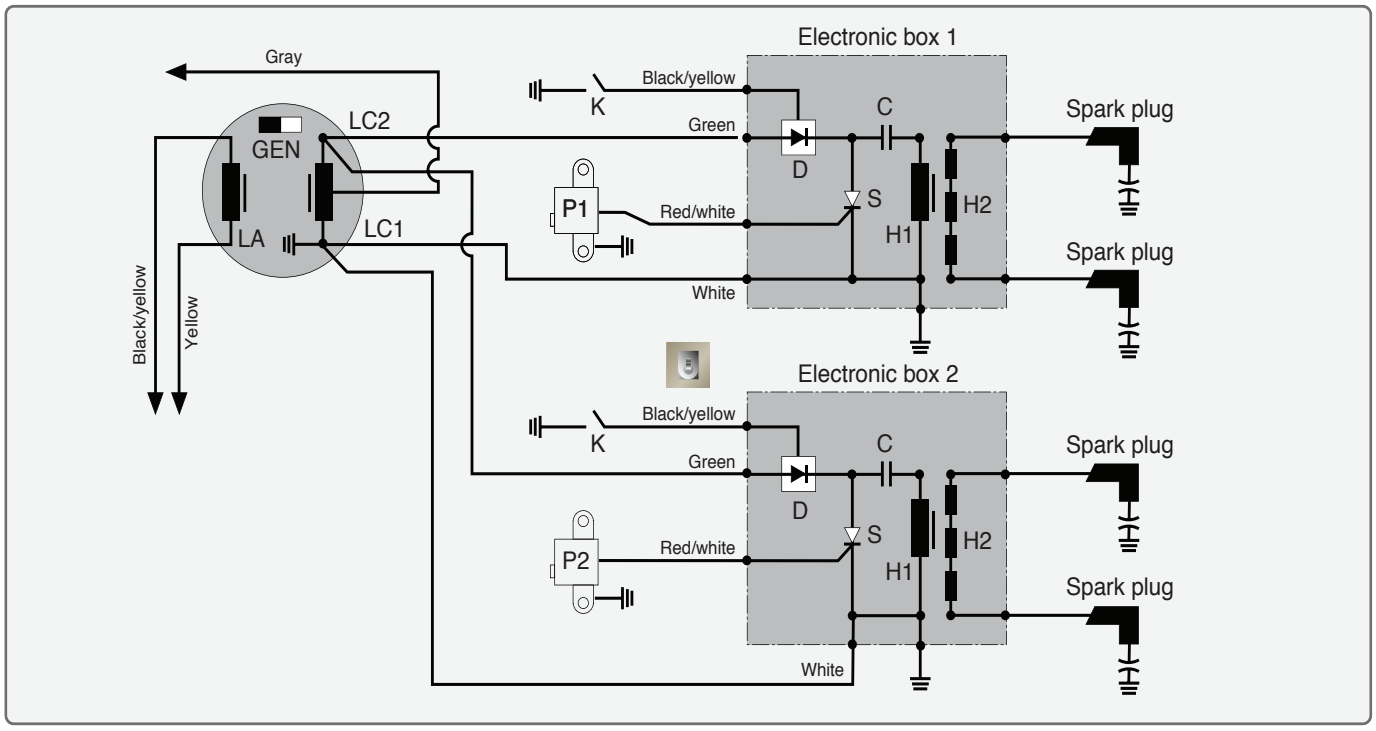


Figure 14-5.: Rotax 503 and 582 electrical system.

from each other, each feed one ignition circuit. The energy supplied is stored in the ignition capacitor. At the moment of ignition, the external triggers supply an impulse to the control circuits and the ignition capacitors are discharged via the primary winding of the ignition coil. The secondary winding supplies the high voltage for the ignition spark.

FUEL SYSTEM

Due to higher lead content in aviation gas (AVGAS), operation can cause wear and deposits in the combustion chamber to increase. Therefore, AVGAS should only be used if problems are encountered with vapor lock or if the other fuel types are not available. Caution must be exercised to use only fuel suitable for the relevant climatic conditions, such as using winter fuel for summer operation.

FUEL/OIL MIXING PROCEDURE

The following describes the process for fuel/oil mixing. Use a clean approved container of known volume. To help predilute the oil, pour a small amount of fuel into the container. Fill known amount of oil (two-stroke oil ASTM/Coordinating European Council (CEC) standards, API-screen. Replace the container cap and shake the container thoroughly. Then, using a funnel with a fine mesh screen to prevent the entry of water and foreign particles, transfer mixture from container into the fuel tank.

WARNING: To avoid electrostatic charging at refueling, use only metal containers and ground the aircraft in accordance with the grounding specifications.

OPPOSED LIGHT-SPORT, EXPERIMENTAL, AND CERTIFIED ENGINES

Many certified engines are used with light-sport and experimental aircraft. Generally, cost is a big factor when considering this type of powerplant. The certified engines tend to be much more costly than the non-certified engines, and are not ASTM approved.

ROTAX 912/914

Figure 14-6 shows a typical four cylinder, four-stroke Rotax horizontally opposed engine. The opposed-type engine has two banks of cylinders directly opposite each other with a crankshaft in the center. The pistons of both cylinder banks are connected to the single crankshaft. The engine cylinder heads are both liquid cooled and air cooled; the aircooling is mostly used on the cylinder. It is generally mounted with the cylinders in a horizontal position. The opposed-type engine has a low weight to horsepower ratio, and its narrow silhouette makes it



Figure 14-6. Typical four cylinder, four-stroke horizontally opposed engine.

ideal for horizontal installation on the aircraft wings (twin-engine applications). Another advantage is its low vibration characteristics. It is an ideal replacement for the Rotax 582 two-cylinder, two-stroke engine, which powers many of the existing light aircraft, as it is the same weight as the Rotax 582. These engines are ASTM approved for installation into light-sport category aircraft, with some models being FAA certified engines.

DESCRIPTION OF SYSTEMS

COOLING SYSTEM

The cooling system of the Rotax 914, shown in ***Figure 14-7***, is designed for liquid cooling of the cylinder heads and ram-air cooling of the cylinders. The cooling system of the cylinder heads is a closed circuit with an expansion tank. ***(Figure 14-8)*** The coolant flow is forced by a water pump driven from the camshaft, from the radiator, to the cylinder heads. From the top of the cylinder heads, the coolant passes on to the expansion tank (1). Since the standard location of the radiator (2) is below engine level, the expansion tank located on top of the engine allows for coolant expansion. The expansion tank is closed by a pressure cap (3) (with excess pressure valve and return valve). As the temperature of the coolant rises, the excess pressure valve opens and the coolant flows via a hose at atmospheric pressure to the transparent overflow bottle (4). When cooling down, the coolant is sucked back into the cooling circuit. Coolant temperatures are measured by means of temperature probes installed in the cylinder heads 2 and 3. The readings are taken on measuring the hottest point of cylinder head depending on engine installation.

FUEL SYSTEM

The fuel flows from the tank (1) via a coarse filter/water trap (2) to the two electric fuel pumps (3) connected in series. ***(Figure 14-9)*** From the pumps, fuel passes on via the fuel pressure control (4) to the two carburetors (5). Parallel to each fuel pump is a separate check valve

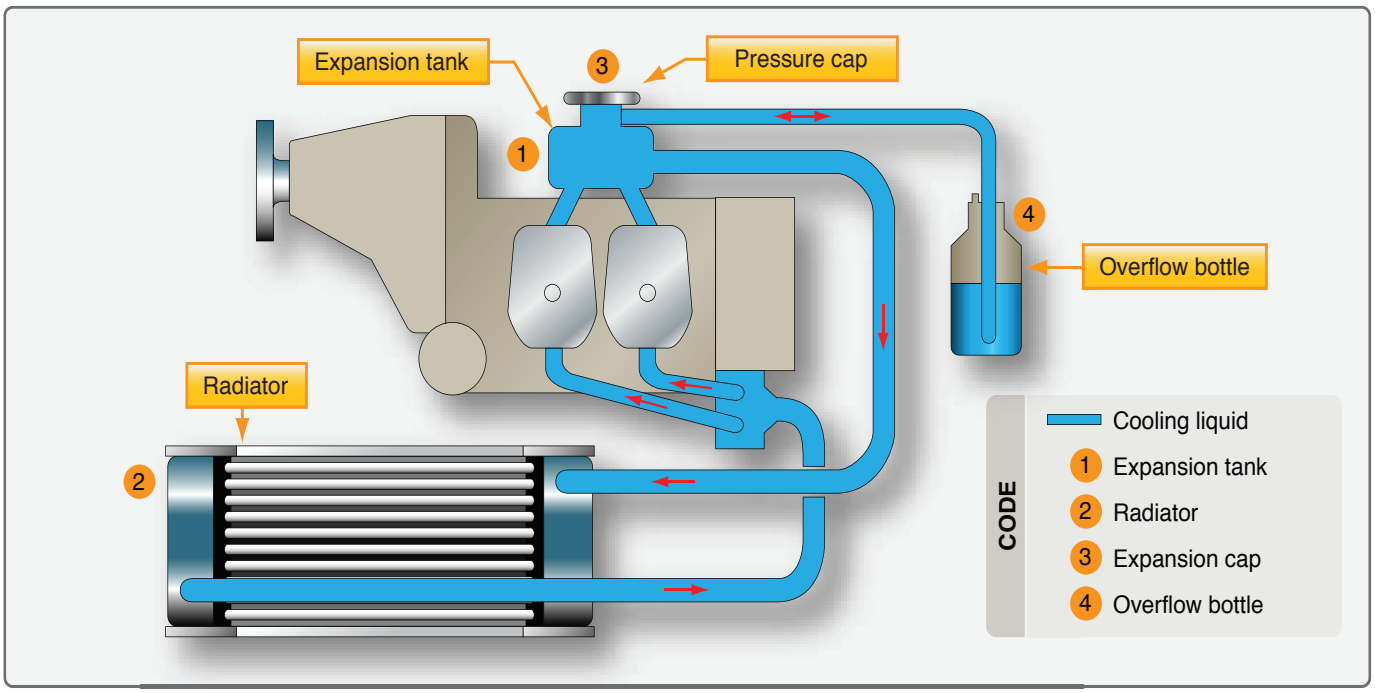


Figure 14-7. Rotax 914 cooling system.



Figure 14-8. Water-cooled heads.

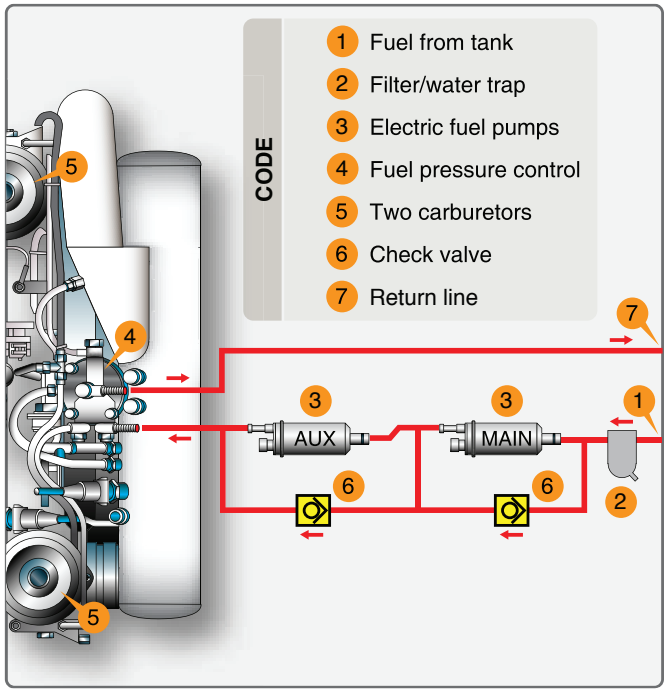


Figure 14-9. Water-cooled heads.

(6) installed via the return line (7) that allows surplus fuel to flow back to the fuel tank. Inspection for possible constriction of diameter or obstruction must be accomplished to avoid overflowing of fuel from the carburetors. The return line must not have any resistance to flow. The fuel pressure control ensures that the fuel pressure is always maintained approximately 0.25 bar (3.63 pounds per square inch (psi)) above the variable boost pressure in the airbox and thus, ensures proper operation of the carburetors.

LUBRICATION SYSTEM

The Rotax 914 engine is provided with a dry, sump-forced lubrication system with a main oil pump with integrated pressure regulator and an additional suction pump. ***(Figure 14-10)*** The oil pumps are driven by the camshaft. The main oil pump draws oil from the oil tank (1) via the oil cooler (2) and forces it through the oil filter to the points of lubrication. It also lubricates the plain bearings of the turbocharger and the propeller governor. The surplus oil emerging from the points of lubrication accumulates on the bottom of crankcase and is forced back to the oil tank by the blow-by gases. The turbocharger is lubricated via a separate oil line (from the main oil pump). The oil emerging from the lower placed turbocharger collects in the oil sump by a separate pump and is pumped back to the oil tank via the oil line (3). The oil circuit is vented via bore (5) in the oil tank. There is an oil temperature sensor in the oil pump flange for reading of the oil inlet temperature.

ELECTRIC SYSTEM

The Rotax 914 engine is equipped with a dual ignition unit that uses a breakerless, capacitor discharge design with an integrated generator. ***(Figure 14-11)*** The ignition unit is completely free of maintenance and needs no external power supply. Two independent charging coils (1) located on the generator stator supply one ignition circuit each. The energy is stored in capacitors of the electronic modules (2). At the moment of ignition, two each of the four external trigger coils (3) actuate the discharge of the capacitors via the primary circuit of the dual ignition coils (4). The firing order is as follows: 1-4-2-3. The fifth trigger coil (5) is used to provide the revolution counter signal.

TURBOCHARGER AND CONTROL SYSTEM

The Rotax 914 engine is equipped with an exhaust gas turbocharger making use of the energy in the exhaust gas for compression of the intake air or for providing boost pressure to the induction system. The boost pressure in the induction system (airbox) is controlled by means of an electronically controlled valve (wastegate) in the exhaust gas turbine. The wastegate regulates the speed of the turbocharger and consequently the boost pressure in the induction system. The required nominal boost pressure in the induction system is determined by the throttle position sensor mounted on the carburetor 2/4. The sensor's transmitted position is linear from 0 to 115 percent, corresponding to a throttle position from idle to full power. ***(Figure 14-12)*** For correlation

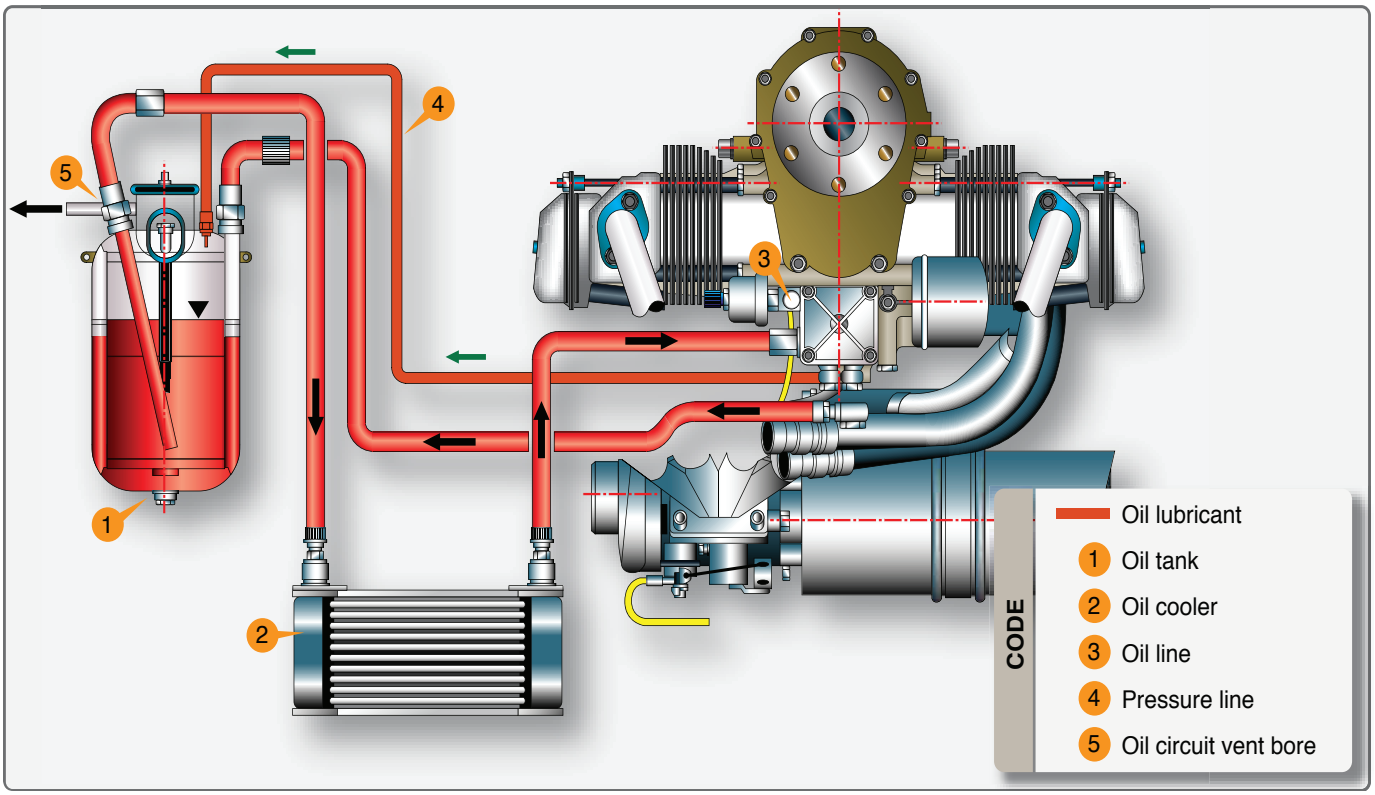


Figure 14-10. Lubrication system.

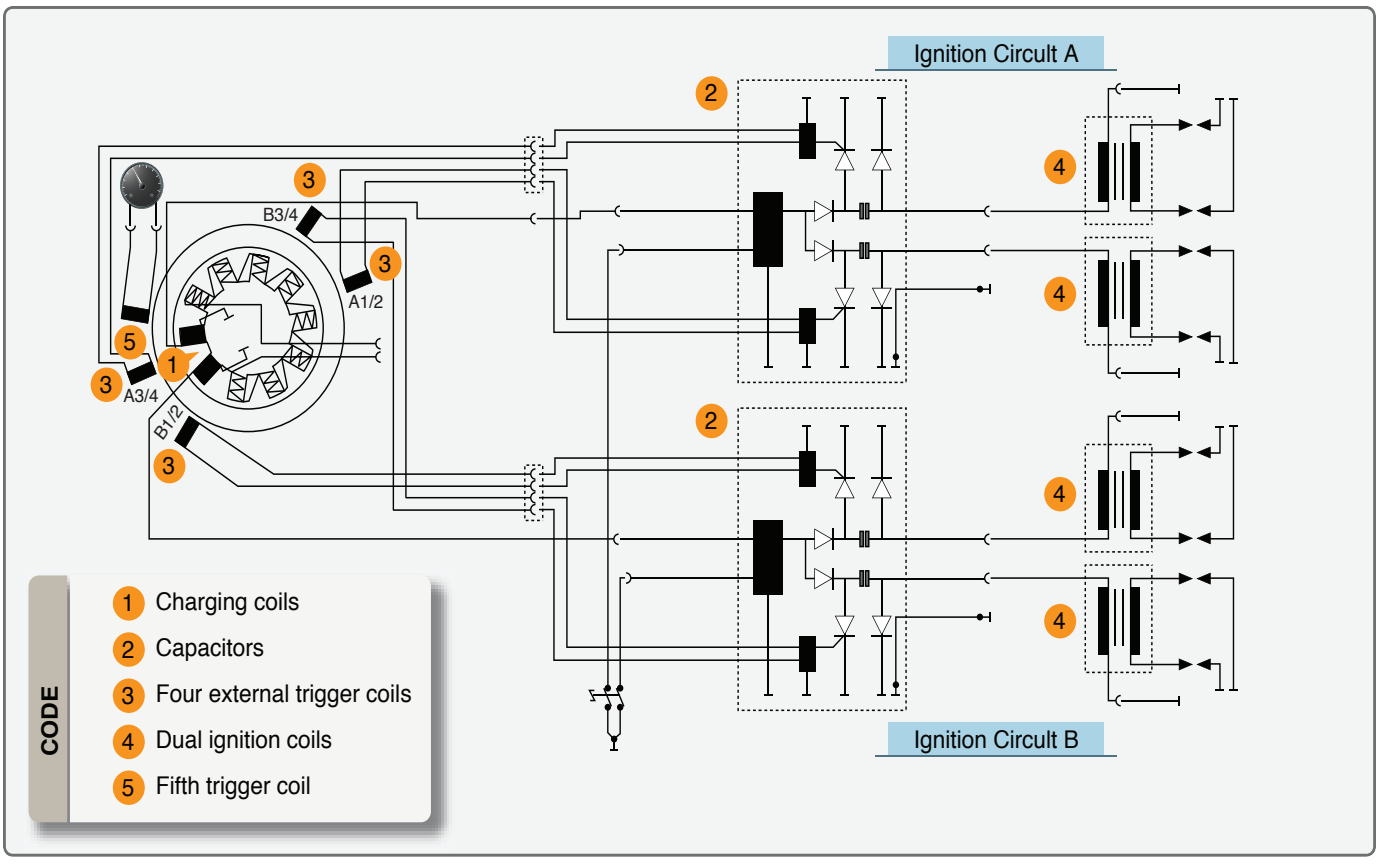


Figure 14-11. Electric system.

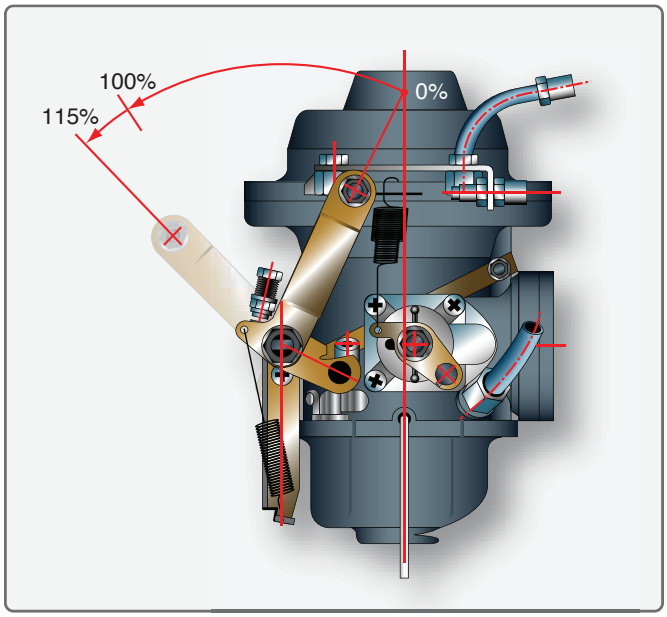


Figure 14-12. Turbocharger control system throttle range and position.

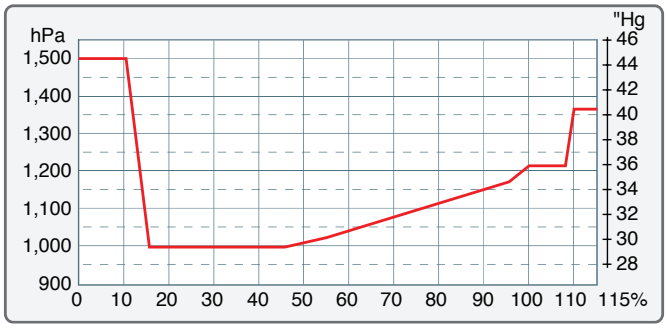


Figure 14-13. Correlation between throttle position and nominal boost pressure.

between throttle position and nominal boost pressure in the induction, refer to ***Figure 14-13***. As shown in the diagram, with the throttle position at 108–110 percent results in a rapid rise of nominal boost pressure. To avoid unstable boost, the throttle should be moved smoothly through this area either to full power (115 percent) or at a reduced power setting to maximum continuous power. In this range (108–110 percent throttle position), small changes in throttle position have a big effect on engine performance and speed. These changes are not apparent to the pilot from the throttle lever position. The exact setting for a specific performance is virtually impossible in this range and has to be prevented, as it might cause control fluctuations or surging. Besides the throttle position, overspeeding of the engine and too high intake air temperature have an effect on the nominal boost pressure. If one of the stated factors exceeds the specified limits, the boost pressure is automatically reduced, thus protecting the engine against over boost and detonation.

The turbo control unit (TCU) is furnished with output connections for an external red boost lamp and an orange caution lamp for indications of the functioning of the TCU. When switching on the voltage supply, the two lamps are automatically subject to a function test. Both lamps illuminate for one to two seconds, then they extinguish. If they do not, a check per the engine maintenance manual is necessary. If the orange caution lamp is not illuminated, then this signals that TCU is ready for operation. If the lamp is blinking, this indicates a malfunction of the TCU or its periphery systems. Exceeding of the admissible boost pressure activates and illuminates the red boost lamp continuously. The TCU registers the time of full throttle operation (boost pressure). Full throttle operation for longer than 5 minutes, with the red boost light illuminated, makes the red boost lamp start blinking. The red boost lamp helps the pilot to avoid full power operation for longer than 5 minutes or the engine could be subject to thermal and mechanical overstress.

HKS 700T ENGINE

The HKS 700T engine is a four-stroke, two cylinder turbocharged engine equipped with an intercooler. ***(Figure 14-14)*** The horizontally opposed cylinders house four valves per cylinder, with a piston displacement of 709 cc. It uses an electronic control fuel injection system. A reduction gearbox is used to drive

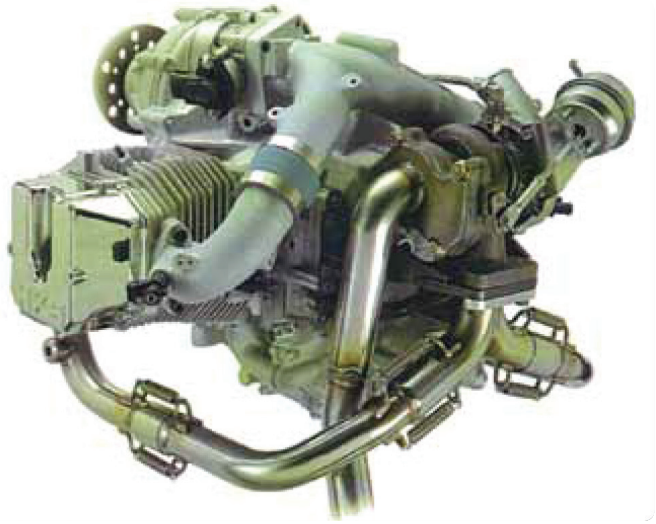


Figure 14-14. HKS 700T engine.

the propeller flange at a speed reduction ratio of 2.13 to 1. The engine is rated at 77 horsepower continuous and 80 horsepower takeoff (3 minutes) at 4,900 rpm and 5,300 rpm, respectively. A total engine weight of 126 pounds provides a good power to weight ratio. The 700T has a TBO of 500 hours.

JABIRU LIGHT-SPORT ENGINS

Jabiru engines are designed to be manufactured using the latest manufacturing techniques. ***(Figure 14-15)*** All Jabiru engines are manufactured, assembled, and ran on a Dynometer, then calibrated before delivery. The crankcase halves, cylinder heads, crankshaft, starter motor housings, gearbox cover (the gearbox powers the distributor rotors), together with many smaller components are machined from solid material. The sump (oil pan) is the only casting. The cylinders are machined from bar 4140 chrome molybdenum alloy steel, with the pistons running directly in the steel bores. The crankshaft is also machined from 4140 chrome molybdenum

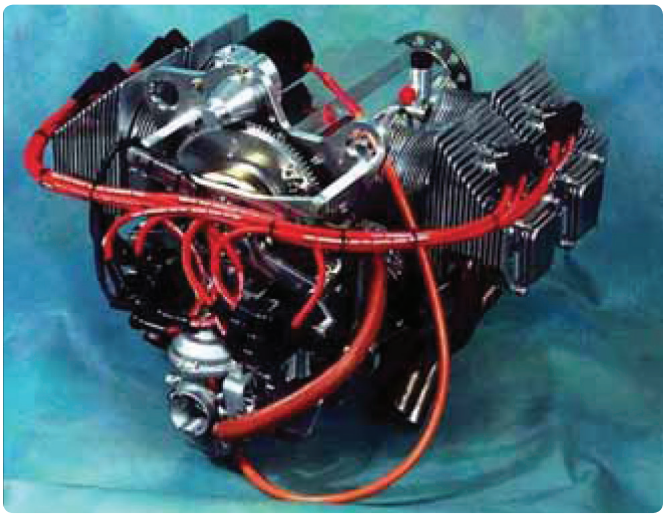


Figure 14-15. Jabiru engines.

alloy steel, the journals of which are precision ground prior to being Magnaflux inspected. The camshaft is manufactured from 4140 chrome molybdenum alloy steel with nitrided journals and cams.

The propeller is direct crankshaft driven and does not use a reduction gearbox. This facilitates its lightweight design and keeps maintenance costs to a minimum. The crankshaft features a removable propeller flange that enables the easy replacement of the front crankshaft seal and provides for a propeller shaft extension to be fitted, should this be required for particular applications. Cylinder heads are machined from a solid aluminum billet that is purchased directly from one company, thereby providing a substantive quality control trail to the material source. Connecting rods are machined from 4140 alloy steel and the 45 millimeters big end bearings are of the automotive slipper type. The ignition coils are sourced from outside suppliers and are modified by Jabiru for their own particular application.

An integral alternator provides AC rectification for battery charging and electrical accessories. The alternator is attached to the flywheel and is driven directly by the crankshaft. The ignition system is a transistorized electronic system; two fixed coils mounted adjacent to the flywheel are energized by magnets attached to the flywheel. The passing of the coils by the magnets creates the high voltage current, that is transmitted by high tension leads to the center post of two automotive type distributors, which are simply rotors and caps, before distribution to automotive spark plugs (two in the top of each cylinder head). The ignition system is fixed timing and, therefore, removes the need for timing adjustment. It is suppressed to prevent radio interference.

The ignition system is fully redundant, self-generating, and does not depend on battery power. The crankshaft is designed with a double bearing at the propeller flange end and a main bearing between each big end. Thrust bearings are located fore and aft of the front double bearing, allowing either tractor or pusher installation. Pistons are remachined to include a piston pin, circlip, and groove. They are all fitted with three rings, the top rings being cast iron to complement the chrome molybdenum cylinder bores. Valves are 7mm (stem diameter) and are manufactured specifically for the Jabiru engine. The valve drive train includes pushrods from the camshaft from the camshaft followers to valve rockers. The valves are Computer Numerical Control (CNC) machined from steel billet, induction hardened, polished on contact surfaces, and mounted on a shaft through Teflon coated bronze-steel bush. Valve guides are manufactured from aluminum/ bronze. Replaceable valve seats are of nickel steel and are shrunk into the aluminum cylinder heads. The valve train is lubricated from the oil gallery. Engines use hydraulic lifters that automatically adjust valve clearance. An internal gear pump is driven directly by the camshaft and provides engine lubrication via an oil circuit that includes an automotive spinon filter, oil cooler and built-in relief valve.

The standard engines are supplied with two ram-air cooling ducts, that have been developed by Jabiru to facilitate the cooling of the engine by directing air from the propeller to the critical areas of the engine, particularly the cylinder heads and barrels. The use of these ducts remove the need to design and manufacture baffles and the establishment of a plenum chamber, which is the traditional method of cooling air-cooled, aircraft engines. The fact that these baffles and plenum chamber are not required also ensures a cleaner engine installation, which in turn facilitates maintenance and inspection of the engine and engine components.

The engine is fitted with a 1.5 kilowatt starter motor that is also manufactured by Jabiru and provides very effective starting. The engine has very low vibration level; however, it is also supported by four large rubber shock mounts attached to the engine mounts at the rear of the engine. The fuel induction system uses a pressure compensating carburetor. Following the carburetor, the fuel/air mixture is drawn through a swept plenum chamber bolted to the sump casting, in which the mixture is warmed prior to entering short induction tubes attached to the cylinder heads.

An effective stainless steel exhaust and muffler system is fitted as standard equipment ensuring very quiet operations. For owners wanting to fit vacuum instruments to their aircraft, the Jabiru engines are designed with a vacuum pump drive direct mounted through a coupling on the rear of the crankshaft.

JABIRU 2200 AIRCRAFT ENGINE

The Jabiru 2200cc aircraft engine is a four-cylinder, fourstroke horizontally opposed air cooled engine. At 132 pounds (60kgs) installed weight, it is one of the lightest four-cylinder, four-stroke aircraft engines. Small overall dimensions give it a small frontal area width (23.46 in, 596mm) that makes it a good engine for tractor applications. The Jabiru engine is designed for either tractor or pusher installation. The Jabiru engine specifications are listed in ***Figure 14-16***.

The Jabiru 3300 (120 hp) engine features ***(Figure 14-17)***:

- 4-stroke
- 3300cc engine (200 cubic inches)
- 6-cylinder horizontally opposed
- 1 central camshaft
- Fully machined aluminum alloy crankcase
- Overhead valves (OHV) - push rod operated
- Ram-air cooled
- Wet sump lubrication - 4 liter capacity
- Direct propeller drive
- Dual transistorized magneto ignition
- Integrated AC generator
- Electric starter
- Mechanical fuel pump
- Naturally aspirated - 1 pressure compensation carburetor

AEROMAX AVIATION 100 (IFB) AIRCRAFT ENGINE

Aeromax Aviation produces a version of a 100 hp engine called the Integral Front Bearing. The engine features a special made integral front bearing. ***(Figure 14-18)*** The engine uses an integral permanent magnet 35 amp alternator, lightweight starter, and dual ignition. The compact alternator and starter allow for a streamlined and aerodynamic cowl which improves the fuel efficiency of an experimental aircraft. The Aeromax aircraft engine is an opposed sixcylinder, air-cooled, and direct drive. Being a six-cylinder engine, it has smooth operation. The Aeromax engines are known for their heat dissipation qualities, provided the proper amount of cooling air is provided.

It features a crank extension supported by a massive integral front bearing (IFB) and bearing housing. These engines start out as a GM Corvair automobile core engine. These basic core engines are disassembled and each component that is reused is refurbished and remanufactured. The crankshaft in the Areomax 100 IFB aircraft engine is thoroughly inspected, including a magnaflux inspection. After ensuring the crank is free of any defects, it is extended by mounting the crank extension hub on its front. Then, the crank is ground true, with all five bearings' surfaces (four original and the new extended crank's front bearing), being true to each other and perpendicular to the crank's prop flange. ***(Figure 14-19)*** All radiuses are smooth with no sharp corners where stress could concentrate. Every crankshaft is nitrated, which is a heat/chemical process that hardens the crank surfaces. The crank reinforcement coupled with the IFB is required to counter the additional dynamic and bending loads introduced on the crank in an aircraft application. The engine case is totally refurbished and checked for wear. Any studs or bolts that show wear are replaced. The engine heads are machined to proper

specifications and all new valves, guides, and valve train components are installed. A three-angle valve grind and lapping ensure a good valve seal.

Once the engine is assembled, it is installed on a test stand, pre-lubricated, and inspected. The engine is, then, run several times for a total of two hours. The engine is carefully inspected after each run to ensure it is in excellent operating condition. At the end of test running the engine, the oil filter is removed and cut for inspection. Its interna condition is recorded. This process is documented and kept on file for each individual engine. Once the engine's proper performance is assured, it is removed and packaged in a custom built crate for shipping. Each engine is shipped with its engine service and operations manual. This manual contains information pertaining to

Specifications: Jabiru 2200cc 85 HP Aircraft Engine	
Engine Features	Four-stroke
	Four-cylinder horizontally opposed
Opposed	One central camshaft
	Push rods
	Overhead valves (OHV)
(OHV)	Ram-air cooled
	Wet sump lubrication
	Direct propeller drive
	Dual transistorized magneto ignition
Magneto Ignition	Integrated AC generator 20 amp
Generator 20 Amp	Electric starter
	Mechanical fuel pump
	Naturally aspirated - 1 pressure compensating carburetor
Pressure Compensating Carburetor	Six bearing crankshaft
Displacement	2200 cc (134 cu.in.)
Bore	97.5 mm
Stroke	74 mm
Compression Ratio	8:1
Directional Rotation of Prop Shaft	Clockwise - pilot's view tractor applications
Ramp Weight	132 lb complete including exhaust, carburetor, starter motor, alternator, and ignition system
Ignition Timing	25□ BTDC
Firing Order	1–3–2–4
Power Rating	85 hp @ 3300 rpm
Fuel Consumption at 75% power	4 US gal/hr
Fuel	AVGAS 100LL or auto gas 91 octane minimum
Oil	Aeroshell W100 or equivalent
Oil Capacity	2.3 quarts
Spark Plugs	NGK D9EA - automotive

Figure 14-16. Jabiru 2200cc specifications.

Jabiru 3300cc Aircraft Engine	
Displacement	3300 cc (202cu.in.)
Bore	97.5 mm (3.838")
Stroke	74 mm (2.913")
Aircraft Engine	Jabiru 3300cc 120hp
Compression Ratio	8:1
Directional Rotation of Prop Shaft	Clockwise - Pilot's view tractor applications
Ramp Weight	178 lbs (81kg) complete including exhaust, carburetor, starter motor, alternator and ignition system
Ignition Timing	25□ BTDC fixed timing
Firing order	1–4–5–2–3–6
Power Rating	120 hp @ 3300 rpm
Fuel Consumption at 75% power	26 l/hr (6.87 US gal/hr)
Fuel	AVGAS 100LL or auto gas 91 octane minimum
Oil	Aeroshell W100 or equivalent
Oil Capacity	3.51 (3.69 quarts)
Spark Plugs	NGK D9EA - automotive

Figure 14-17. Jabiru 3300cc aircraft engine.



Figure 14-18. Aeromax direct drive, air-cooled, six-cylinder engine.



Figure 14-19. Front-end bearing on the 1000 IFB engine.

installation, break–in, testing, tune-up, troubleshooting, repair, and inspection procedures. The specifications for the Aeromax 100 engine are outlined in ***Figure 14-20***.

DIRECT DRIVE VW ENGINES

The Revmaster R-2300 engine maintains Revmaster's systems and parts, including its RM-049 heads that feature large fins and a hemispherical combustion chamber. ***(Figure 14-21)*** It maintains the earlier R-2200 engine's top horsepower (82) at 2950 rpm continuous. ***(Figure 14-22)*** Takeoff power is rated at 85 at 3350 rpm. The additional power comes from a bore of 94mm plus lengthening of the R-2200's connecting rods, plus increasing the stroke from 78 to 84 mm. The longer stroke results in more displacement, and longer connecting rods yield better vibration and power characteristics. The lower cruise rpm allows the use of longer propellers, and the higher peak horsepower can be felt in shorter takeoffs and steeper climbs.

Aeromax 100 Engine Specifications	
Power Output: 100 hp continuous at 3200 rpm	Air cooled
Displacement: 2.7 L	Six cylinders
Compression: 9:1	Dual ignition–single plug
Weight: 210 lb	Normally aspirated
Direct Drive	CHT max: 475 F
Rear Light weight. Starter and 45 amp alternator	New forged pistons
Counterclockwise rotation	Balanced and nitrated crank shaft
Harmonic balancer	New hydraulic lifters
Remanufactured case	New main/rod bearings
Remanufactured heads with new guides, valves, valve train, intake	New all replaceable parts
Remanufactured cylinders	New spark plug wiring harness
New light weight aluminum cylinder - optional	Remanufactured dual ignition distributor with new points set and electronic module
New high torque cam	New oil pump
New CNC prop hub and safety shaft	New oil pan
New Aeromax top cover and data plate	Engine service manual

Figure 14-20. Aeromax 100 engine specifications.



Figure 14-21. Revmaster R-2300 engine.



Figure 14-22. Hemispherical combustion chamber within the Revmaster R-2300 Heads.

The Revmaster's four main bearing crankshaft runs on a 60 mm center main bearing, is forged from 4340 steel, and uses nitrided journals. Thrust is handled by the 55 mm #3 bearing at the propeller end of the crank. Fully utilizing its robust #4 main bearing, the Revmaster crank has built in oil-controlled propeller capability, a feature unique in this horsepower range; non-wood props are usable with these engines.

Moving from the crankcase and main bearings, the cylinders are made by using centrifugally cast chilled iron. The pistons are forged out of high quality aluminum alloy, machined and balanced in a set of four. There are two sizes of pistons, 92mm and 94mm, designed to be compatible with a 78mm to 82mm stroke crankshafts. The cylinder set also contains piston rings, wrist pins, and locks. The direct-drive R-2300 uses a dual CDI ignition with eight coil spark to eight spark plugs, dual 20-amp alternators, oil cooler, and its proprietary Rev-Flo carburetor, while introducing the longer cylinders

that do not require spacers. The automotive-based bearings, valves, valve springs, and piston rings (among others) make rebuilds easy and inexpensive.

GREAT PLAINS AIRCRAFT VOLKSWAGEN (VW) CONVERSIONS

Great Plains Aircraft is one company that offers several configurations of the Volkswagen (VW) aircraft engine conversion. One very popular model is the front drive long block kits that offer a four-cycle, four-cylinder opposed engine with horsepower ranges from approximately 60-100. ***(Figure 14-23)*** The long block engine kits, which are the complete engine kits that are assembled, in the field or can be shipped completely assembled, are available from 1600 cc up through 2276 cc. All the engine kits are built from proven time tested components and are shipped with a Type One VW Engine Assembly Manual. This manual was written by the manufacturer, specifically for the assembly of their engine kits. Also included are how to determine service and maintenance procedures and many tips on how to set up and operate the engine correctly. The crankshaft used in the 2180 cc to 2276 cc engines is a 82 mm crankshaft



Figure 14-23. Great Plain's Volkswagen conversion.

made from a forged billet of E4340 steel, machined and magnafluxed twice. The end of the crankshaft features a ½-inch fine thread versus a 20 mm thread found on the standard automotive crank.

TELEDYNE CONTINENTAL 0-200 ENGINE

The 0-200 Series engine has become a popular engine for use in light-sport aircraft. The 0-200-A/B is a four-cylinder, carbureted engine producing 100 brake hp and has a crankshaft speed of 2750 rpm. ***(Figure 14-24)*** The engine has horizontally opposed air cooled cylinders. The engine cylinders have an overhead valve design with updraft intake inlets and downdraft exhaust outlets mounted on the bottom of the cylinder. The 0-200-A/B engines have a 201 cubic inch displacement achieved by using a cylinder design with a 4.06- inch diameter bore and a 3.88-inch stroke. The dry weight of the engine is 170.18 pounds without accessories. The weight of the engine with installed accessories is approximately 215 pounds. The engine is provided with four integral rear engine mounts. A crankcase breather port is located on the 1-3 side of the crankcase forward of the number 3 cylinder. The engine lubrication system is a wet sump, high-pressure oil system. The engine lubrication system includes the internal engine-driven pressure oil pump, oil pressure relief valve, pressure oil screen mounted on the rear of the accessory case and pressure instrumentation. A fitting is provided at the 1-3 side of the crankcase for oil pressure measurement. The oil sump capacity is six quarts maximum. The 0-200-A/B induction system consists of an updraft intake manifold with the air intake and throttle mounted below the engine. Engine



Figure 14.24: 0-200 Continental Engine.

manifold pressure is measured at a port located on the 2-4 side of the intake air manifold. The 0-200-A/B is equipped with a carburetor that meters fuel flow as the flightdeck throttle and mixture controls are changed.

LYCOMING 0-233 SERIES LIGHT-SPORT AIRCRAFT ENGINE

Lycoming Engines, a Textron Inc. company, produces an experimental non-certified version of its 233 series lightsport aircraft engine. ***(Figure 14-25)*** The engine is light and capable of running on unleaded automotive fuels, as well as AVGAS. The engine features dual CDI spark ignition, an optimized oil sump, a streamlined accessory housing, hydraulically adjusted tappets, a lightweight starter, and a lightweight alternator with

integral voltage regulator. It has a dry weight of 213 pounds (including the fuel pump) and offers continuous power ratings up to 115 hp at 2800 rpm. In addition to its multi-gasoline fuel capability, it has proven to be very reliable with a TBO of 2,400 hours. The initial standard version of the engine is carbureted, but fuel injected configurations of the engine are also available.

GENERAL MAINTENANCE PRACTICES ON LIGHT-SPORT ROTAX ENGINES

Some specific maintenance practices that differ from conventional certified engines is covered for background and educational acquaintance purposes only. Always refer to the current manufacturer's information when performing maintenance on any engine.

Safety regulations must be adhered to ensure

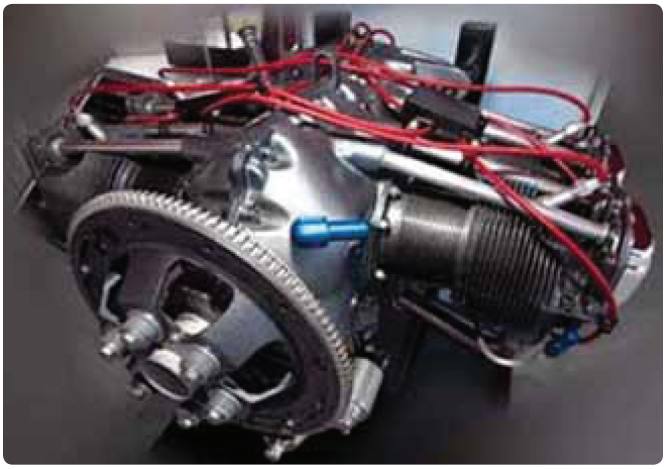


Figure 14-25. Lycoming 0-233 engine.

maintenance personnel safety when performing maintenance and service work on any engine installation. The following information should be followed while performing maintenance.

The ignition should be off and the ignition system grounded with the battery disconnected. Secure the engine against unintentional operation. During maintenance work that requires ignition on and battery connected, secure the propeller against unintentional turning by hand, and secure and observe a propeller safety zone. This precautionary measure serves to avoid any injuries in case of an unintentional start of the engine, which can result in injuries or death. Remember, as long as the ground-cable (plead) is not properly connected to ground, the ignition is switched ON (hot).

Prevent contamination, such as metal chips, foreign material, and/or dirt, from entering the cooling, lubricating, and fuel system during maintenance. Severe burns and scalds may result if the engine is not allowed to cool down to outside air temperature before starting any work. Before reusing disassembled parts, clean with a suitable cleaning agent, check, and refit per instructions. Before every re-assembly, check for missing components. Only use adhesives, lubricants, cleaning agents, and solvents listed for use in the maintenance instructions. Observe the tightening torques for screws and nuts; overtorque or too loose connection could cause serious engine damage or failure.

The following are some general maintenance practices that provide for safety and good technique:

- Work only in a non-smoking area and not close to sparks or open flames.
- Always use the specified tools.
- During disassembling/reassembling the removal of any safety items (e.g., safety wiring, self-locking fastener) must always be followed with replacement of a new one.
- Once loosened, always replace self-securing (locking) nuts.
- Use clean screws and nuts only and inspect face of nuts and thread for damage.
- Check the contact faces and threads for damage and replace if any damaged is detected.
- At reassembly of the engine, replace all sealing rings, gaskets, securing elements, O-rings, and oil seals.
- At disassembly of the engine, mark the engine's components as necessary to provide for locating the original position of the part.
- Parts should be replaced in the same position upon reassembly.
- Any used components have wear patterns that should be replaced or matched if reused. Ensure that these marks are not erased or washed off.

To perform maintenance, the technician must follow the manufacturer's instructions. Obtain, read, and understand the information pertaining to servicing of the light-sport or experimental engine.

MAINTENANCE SCHEDULE PROCEDURES AND MAINTENANCE CHECKLIST

All stated checks are visual inspections for damage and wear, unless otherwise stated. All listed work must be carried out within the specified period. For the intervals between maintenance work, a tolerance of + or – 0 hour is permissible, but these tolerances must not be exceeded. This means that if a 100 hour check is actually carried out at 110 hour, the next check is due at 200 hour + or – 10 hour and not at 210 hour + or – 10 hour. If maintenance is performed before the prescribed interval, the next maintenance check is to be done at the same interval (e.g., if first 100-hour check is done after 87 hours of operation, the next 100-hour check must be carried out after 187 hours of operation).

Checks are carried out per the maintenance checklists, where type and volume of maintenance work is outlined in key words. The lists must be photocopied and filled out for each maintenance check. The respective check (e.g., 100- hour check) must be noted on the top of each page of the maintenance checklist. All the maintenance work carried out must be initialed in the signature area by the aircraft mechanic performing the task. After maintenance, the completed checklists must be entered in the maintenance records. The maintenance must be confirmed in the log book. All discrepancies and remedial action must be recorded in a report of findings to be generated and maintained by the company authorized to carry out maintenance work. It is the responsibility of the aircraft operator to store and keep the records. Replacement of equipment (e.g., carburetor, fuel pump, governor) and execution of Service Bulletins must be entered in the log book, stating required information.

CARBURETOR SYNCHRONIZATION

For smooth idling, synchronization of the throttle valves is necessary. When synchronizing, slacken both Bowden cables, and detach the resonator hose (3) of the compensating tube (2) to separate the two air intake systems. ***(Figure 14-26)*** In this condition, no significant difference in the engine running should be noticeable. If adjustment is needed for synchronous basic throttle adjustments (mechanical synchronization), proceed as follows. ***[Figures 14-27 and 14-28]***

Adjust the two Bowden cables for simultaneous opening of the throttle valves. Remove the cable fixation (4) on the throttle lever (1). Next, release the return spring (5) from its attachment on the throttle lever (1), and return the throttle lever (1) to its idle stop position (3) by hand.

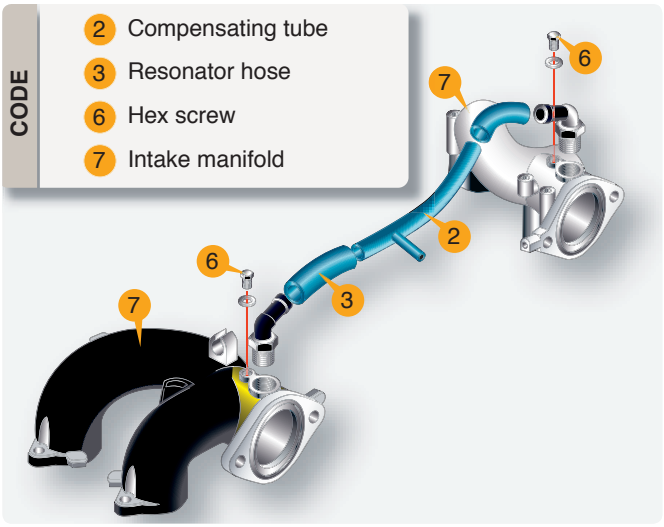


Figure 14-26. Resonator hose and compensating tube.

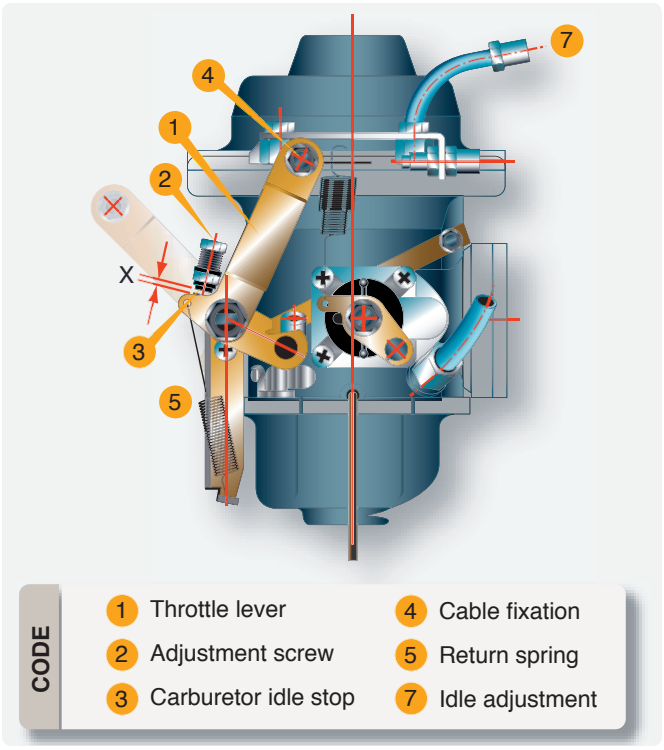


Figure 14-27. Carburetor throttle lever.

There should be no resistance during this procedure. Unscrew the idle speed adjustment screw (2) until it is free of the stop. Insert a 0.1 mm (0.004 in) feeler gauge (gap X) between the idle speed adjustment screw (2) and the carburetor idle stop (3), then gently turn the idle screw clockwise until contact is made with the 0.1 mm (0.004 in) feeler gauge. Pull out the feeler gauge and turn each idle speed adjustment screw (2) 1.5 turns in clockwise direction. Gently turn each idle mixture screw (6) clockwise until it is fully inserted and, then, open by

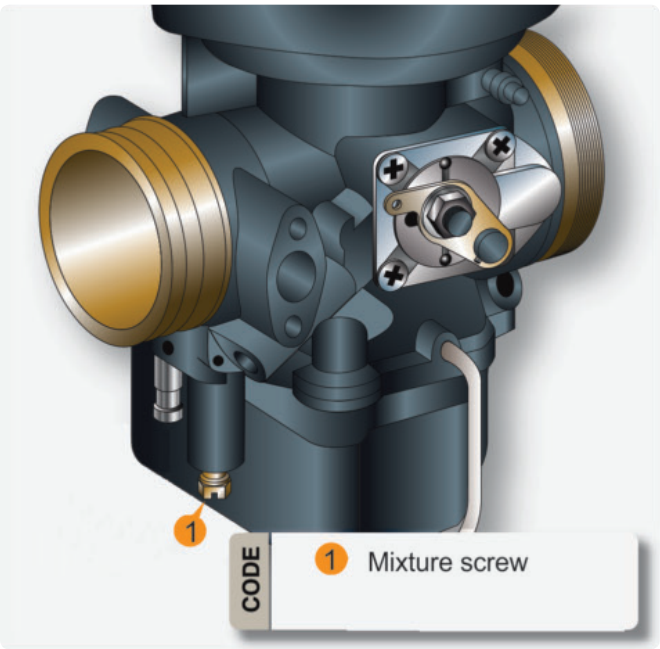


Figure 14-28. Idle mixture screw.

1½ turns counterclockwise. Hook the return spring (5) back up to the throttle lever (1) in its original position. Check that the throttle valve opens fully, automatically. Carry out the above procedure on both carburetors.

NOTE: The mechanical carburetor synchronization is sufficiently exact.

At this point, place the throttle lever in the flightdeck to the idle stop position. Ensure that the throttle lever remains in this position during the next steps of the synchronization process. With the throttle lever in the idle stop position, move the throttle lever (1) to the carburetor idle stop position, using the cable fixation (4), and secure the Bowden cable accordingly. As soon as the two carburetor Bowden cables are installed (throttle lever idle position), check that the idle speed adjustment screw (2) rests fully on the idle stop (3) without pressure.

CAUTION: An idle speed that is too low results in gearbox damage, and if an idle speed is too high, the engine is harder to start. Start the engine and verify the idle speed. If the idle speed is too high or too low, adjust accordingly with idle speed adjustment screw (2). Check the operational idle mixture of the engine. If necessary, adjust with the idle mixture screw (6).

PNEUMATIC SYNCHRONIZATION

Mechanical synchronization should have already been accomplished. The two carburetors are adjusted to equal flow rate at idling by use of a suitable flow meter or vacuum gauges (1).

There are two possible methods to connect test equipment. One option is to remove hex screw (6) M6 x 6 from the intake manifold (7) and connect the vacuum gauge(s). ***(Figure 14-26 and Figure 14-29)*** Remove the compensating tube (2) with attached hoses (12) (connection between intake manifolds) and plug the connections in the intake manifolds. The other hook up option is to remove the compensating tube hose (2) from the push-on connection (5) after removing the tension clamp (4). Using the push-on connection (5), install a flexible rubber hose (8) leading to the vacuum gauge (1), using the balance tube (4). Install the other flexible rubber hose leading to the vacuum gauge. ***(Figure 14-29)*** Before proceeding any further, secure the aircraft on the ground using wheel chocks and ropes.

WARNING: Secure and observe the propeller zone during engine operation.

Start the engine, verify the idle speed, and make any necessary corrections. If a setting correction of more than ½ turn is required, repeat mechanical synchronization to prevent too high a load on the idle stops. If the idle speed is too high, the maximum the idle screw can be unscrewed is a complete turn. If no satisfactory result can be achieved, inspect the idle jets for contamination and clean if necessary.

Caution: Also check for translucent, jelly-like contamination. Inspect for free flow.
Once the proper idling speed has been established, it is necessary to check the operating range above the idle speed. First, establish that the engine is developing full takeoff performance or takeoff rpm when selected in the flightdeck. Then, the setting of the operating range (idle to full throttle) can be checked or adjusted.

Start and warm up engine as per the operator's manual. Select full power and check that both pressure gauges are registering the same readings. If the same reading is not made on both gauges, shut down the engine and check that carburetor actuation has full travel and that the chokes are in the full off-position. If necessary, fit/modify the carburetor actuation as required to achieve full power on both carburetors. Once full power has been

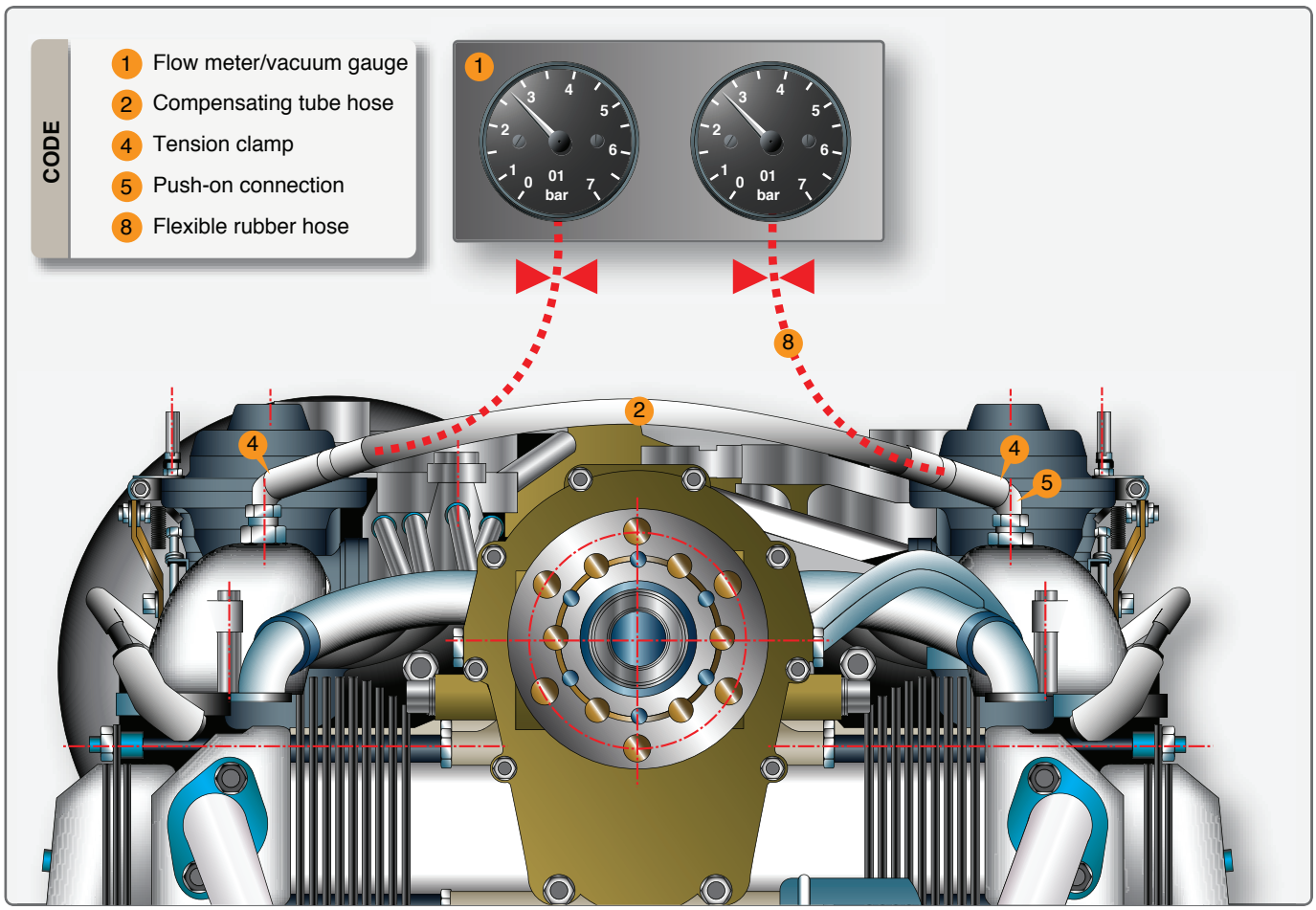


Figure 14-29. Gauges attached to the engine.

established on both carburetors, retard the throttle and observe the pressure gauge settings. The pressure gauges should show the same reading for both carburetors. Discrepancies must be compensated for by adjusting the off idle adjustment (7). ***(Figure 14-27)*** The carburetor with the lower indication must be advanced to match the higher one. This is done by shutting down the engine and loosening the locknut on the Bowden cable and screwing the off idle adjustment in by ½ turn, then tightening the locknut and retesting the engine. Final idle speed adjustment may be required by resetting the idle speed adjustment screws (2). ***(Figure 14-27)*** Equal adjustment must be made on both carburetors.

Any major adjustments require retesting to verify all parameters mentioned in this procedure are within limits. Install compensation tube assembly on the engine in reverse sequence of removal. Any minor differences in balance at idle speed is compensated for. Always follow the instructions of the instrument manufacturer.

IDLE SPEED ADJUSTMENT

If satisfactory idle speed adjustment cannot be achieved, inspection of the idle jet or additional pneumatic synchronization is necessary. Always carry out idle speed adjustment when the engine is warm. Basic adjustment of the idle speed is first accomplished by using the idle speed adjustment screw (2) of the throttle valve. ***[Figure 14-27]***

OPTIMIZING ENGINE RUNNING

Optimizing the engine run is necessary only if not accomplished at carburetor synchronization. Close the idle mixture screw (6) by turning clockwise to screw in fully and, then, opening again by 1½ turns counterclockwise. ***(Figures 14-27 and 14-28)*** Starting from this basic adjustment, the idle mixture screw (6) is turned until the highest motor speed is reached. The optimum setting is the middle between the two positions, at which an rpm drop is noticed. Readjustment of the idle speed is carried out using the idle speed adjustment screw (2) and, if necessary, by slightly turning the idle

mixture screw again. Turning the idle mixture control screw in a clockwise direction results in a leaner mixture and turning counterclockwise in a richer mixture.

CHECKING THE CARBURETOR ACTUATION

The Bowden cables should be routed in such a way that carburetor actuation is not influenced by any movement of the engine or airframe, thus possibly falsifying idle speed setting and synchronization. ***(Figure 14-30)*** Each carburetor is actuated by two Bowden cables. At position 1, connection for throttle valve and at position 2, make the connection for the choke actuator. The Bowden cables must be adjusted so that the throttle valve and the choke actuation of the starting carburetor can be fully opened and closed. Bowden cables and lever must operate freely and not jam.

WARNING: With carburetor actuation not connected, the throttle valve is fully open. The initial position of the carburetor is full throttle. Never start the engine with the actuation disconnected. Inspect Bowden cables and levers for free movement. Cables must allow for full travel of lever from stop to stop. Adjust throttle cables to a clearance of 1 mm (0.04 in). Inspect and lubricate linkage on carburetor and carburetor joints with engine oil. Inspect return springs (3) and engagement holes for wear.

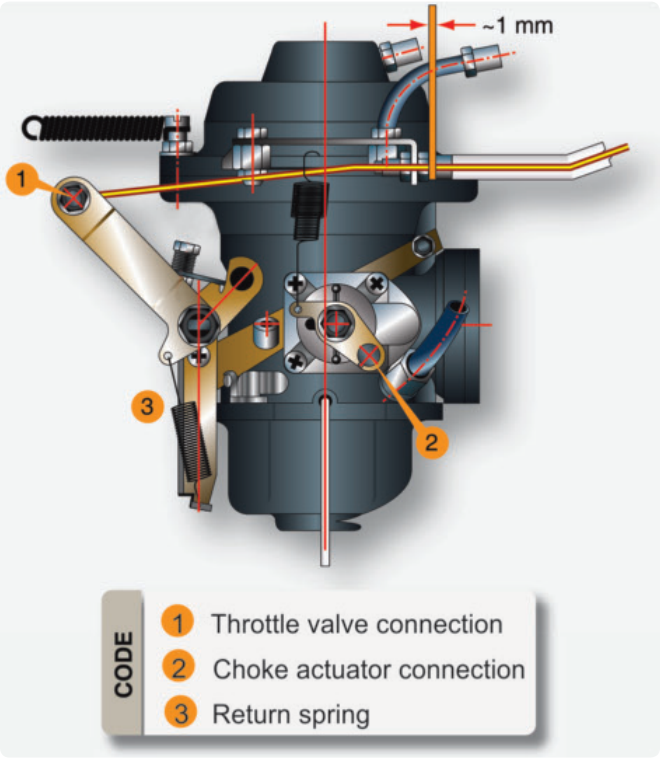


Figure 14-30. Bowden cable routing.

LUBRICATION SYSTEM

OIL LEVEL CHECK

Always allow engine to cool down to ambient temperature before starting any work on the lubrication system. Severe burns and scalds may result from hot oil coming into contact with the skin. Switch off ignition and remove ignition key. To assure that the engine does not turn by the starter, disconnect the negative terminal of aircraft battery. Before checking the oil level, make sure that there is not excess residue oil in the crankcase. Prior to oil level check, turn the propeller several times by hand in the direction of engine rotation to pump all the oil from the engine to the oil tank. This process is completed when air flows back to the oil tank. This air flow can be perceived as a gurgling noise when the cap of the oil tank is removed. The oil level in the oil tank should be between the two marks (maximum/minimum) on the oil dipstick, but must never fall below the minimum mark. ***(Figure 14-31)*** Replenish oil as required, but for longer flights, replenish oil to maximum mark to provide for more of an oil reserve. During standard engine operation, the oil level should be mid-way between the maximum and minimum marks a higher oil level (over servicing). Oil can escape through the venting (breather) passage.

OIL CHANGE

It is advisable to check the oil level prior to an oil change, as it provides information about oil consumption. Run engine to warm the oil before beginning the procedure. Taking proper precautions, crank the engine by hand to transfer the oil from the crankcase. Remove the safety wire and oil drain screw (1) from the oil tank, drain the used oil, and dispose of as per environmental regulations. ***(Figure 14-32)*** Remove and replace oil filter at each oil change. It is not necessary to remove oil lines and other oil connections. Draining the suction lines, oil cooler, and return line is not necessary and must be avoided, as it results in air entering the oil system. Replacement of the oil filter and the oil change should be accomplished quickly and without interruption to prevent a draining of the oil system and the hydraulic tappets. Compressed air must not be used to blow through the oil system (or oil lines, oil pump housing, oil bores in the housing). Replace the oil drain screw torque and safety wire. Only

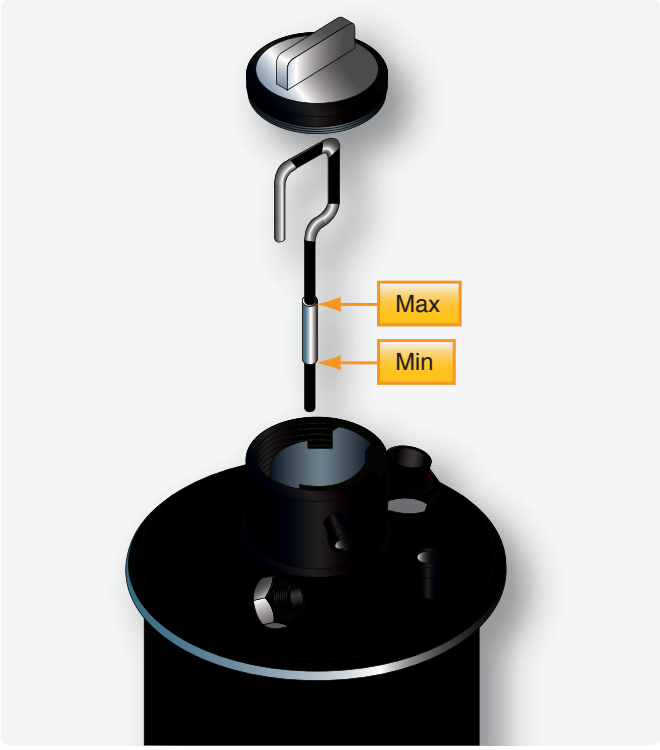


Figure 14-31. Oil dipstick minimum and maximum marks.

use the appropriate oil in accordance with the latest operator's manual and service instruction. The engine must not be cranked when the oil system is open. After the oil change is accomplished, the engine should be cranked by hand in the direction of engine rotation (approximately 20 turns) to completely refill the entire oil circuit.

CLEANING THE OIL TANK

Cleaning the oil is optional and requires venting of the oil system. It is only necessary to clean the oil tank and the inner parts if there is heavy oil contamination. The procedure for cleaning the oil tank is shown in ***Figure 14-32***. Detach the profile clamp (2) and remove the oil tank cover (3), together with the O-ring (4) and the oil lines. Remove the inner parts of the oil tank, such as the baffle insert (5) and the partition (6). Clean oil tank (8) and inner parts (5, 6), and check for damage. Be aware that incorrect assembly of the oil tank components can cause engine faults or engine damage. Replace the drain screw with a new sealing ring (7) and tighten to 25 Newton meters (Nm) (18.5 ft/lb) and safety wire. Reassemble the oil tank by following the same steps in reverse order.

INSPECTING THE MAGNETIC PLUG

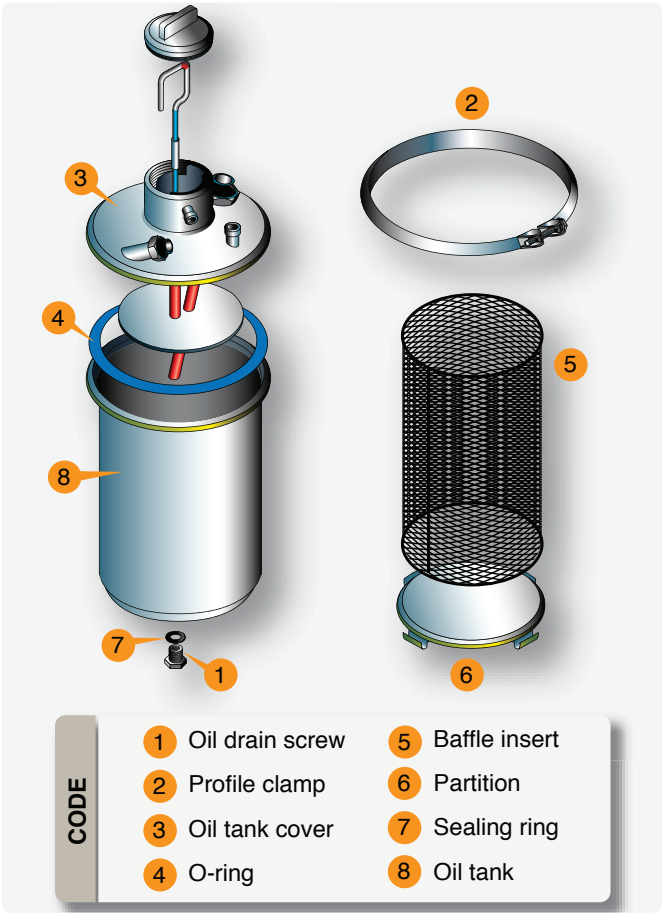


Figure 14-32. Oil tank.

Remove the magnetic plug and inspect it for accumulation of chips. ***(Figure 14-33)*** The magnetic plug (torx screw) is located on the crankcase between cylinder 2 and the gearbox. This inspection is important because it allows conclusions to be drawn on the internal condition of the gearbox and engine, and reveals information about possible damage. If a significant amount of metal chips are detected, the engine must be inspected, repaired, or overhauled. Steel chips in low numbers can be tolerated if the accumulation is below 3 mm (0.125 in). ***(Figure 14-33)*** In the case of unclear findings, flush the oil circuit and fit a new oil filter. Afterwards, conduct an engine test run and inspect the oil filter once more. If there are larger accumulations of metal chips on the magnetic plug, the engine must be repaired or overhauled in accordance with the manufacturer's instructions for continued airworthiness. A detailed inspection of affected engine components must be performed. If the oil circuit is contaminated, replace the oil cooler and flush the oil circuit, then trace the cause and remedy the situation. If the magnetic chip is found to have no metal, then clean and reinstall. Tighten the plug to a torque of

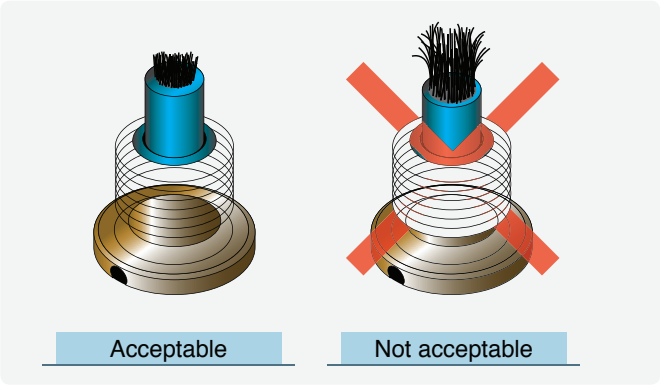


Figure 14-33. Inspecting the magnetic plug.

25 Nm (18.5 ft/lb). Safety wire the plug and inspect all systems for correct function.

CHECKING THE PROPELLER GEARBOX

The following free rotation check and friction torque check are necessary only on certified engines and on engines with the overload clutch as an optional extra. Engines without the overload clutch (slipper clutch) still incorporate the torsional shock absorption. This design is similar to the system with overload clutch, but without free rotation. For this reason, the friction torque method cannot be applied on engines without the overload clutch.

CHECKING THE FRICTION TORQUE IN FREE ROTATION

Fit the crankshaft with a locking pin. ***(Figure 14-34)*** With the crankshaft locked, the propeller can be turned by hand 15 or 30 degrees, depending on the profile of the dog gears installed. This is the maximum amount of movement allowed by the dog gears in the torsional shock absorption unit.

WARNING: Ignition OFF and system grounded. Disconnect negative terminal of aircraft battery.

Turn the propeller by hand back and forth between ramps, taking into consideration the friction torque. No odd noises or irregular resistance must be noticeable during this movement. Attach a calibrated spring scale to the propeller at a certain distance (L) from the center of the propeller. Measure the force required to pull the propeller through the 15 or 30 degree range of free rotation. Calculate friction torque Nm by multiplying the force Newton's (N) or pounds (lb) obtained on the

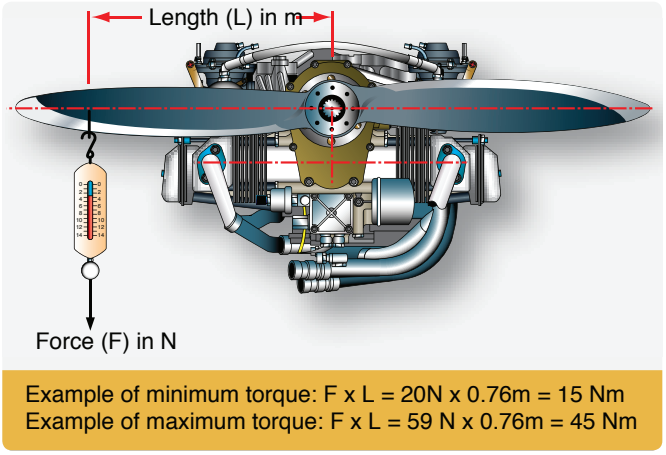


Figure 14-34: Checking propeller gearbox.

spring scale by the distance the scale is attached from the center of the propeller (L). The distance measurement and torque measurement must be in the same units either standard or metric and cannot be mixed up. The friction torque must be between a minimum of 25 Nm and maximum of 60 Nm (18.5 to 44.3 ft/lb). A calculation example is as follows:

Friction Torque (FT) = Length (meters) × Newtons (torque)
FT = .5 meters × 60 Newtons
FT = 30Nm

Remove crankshaft locking pin and reinstall plug with new gasket. Reconnect negative terminal of aircraft battery. If the above mentioned friction torque is not achieved, inspect, repair, or overhaul the gearbox in accordance with the manufacturer's instructions for continued airworthiness. Testing the propeller flange is not normal maintenance but can be carried out if defects or cracks are suspected.

DAILY MAINTENANCE CHECKS

The following checklist should be used for daily maintenance checks. Repair, as necessary, all discrepancies before flight.

1. Verify ignition OFF.
2. Drain water from fuel tank sump and/or water trap (if fitted).
3. Inspect carburetor rubber socket or flange for cracks and verify secure attachment.
4. Inspect carburetor float chamber for water and dirt.
5. Verify security and condition of intake silencer and air filter.

6. Verify security of radiator mounting. Inspect radiators for damage and leaks.
7. Verify coolant level in overflow bottle and security of cap.
8. Verify coolant hoses for security, and inspect for leaks and chafing.
9. Inspect engine for coolant leaks (cylinder head, cylinder base, and water pump).
10. Verify oil content for rotary valve gear lubrication and security of oil cap.
11. Verify oil hoses for security, and inspect for leaks and chafing (rotary valve gear lubrication system and oil injection system).
12. Verify ignition coils/electronic boxes for secure mounting, and check ignition leads and all electrical wiring for secure connections and chafing.
13. Verify electric starter for secure mounting, and inspect cover for cracks.
14. Verify engine to airframe mounting for security and inspect cracks.
15. Verify fuel pump mounting for security, and inspect all fuel hose connections (filters, primer bulbs, and taps for security, leakage, chafing and kinks).
16. Verify fuel pump impulse hose for secure connections, and inspect for chafing and kinks.
17. Verify safety wiring of gearbox drain and level plugs.
18. Inspect rubber coupling for damage and aging (C type gearbox only).
19. Rotate engine by hand and listen for unusual noises (first, double verify ignition OFF).
20. Check propeller shaft bearing for clearance by rocking propeller.
21. Inspect throttle choke and oil pump lever cables for damage (end fittings, outer casing, and kinks).

PRE-FLIGHT CHECKS

The following checklist should be performed for all preflight checks. Repair, as necessary, all discrepancies and shortcoming before flight.

1. Verify ignition OFF.
2. Check fuel content.
3. Inspect for coolant leaks.
4. Verify oil tank content (oil injection engines).
5. Verify spark plug connectors for security.
6. Inspect engine and gearbox for oil leaks.
7. Inspect engine and gearbox for loose or missing nuts, bolts, and screws, and verify security of gearbox to engine mounting.
8. Inspect propeller for splits and chips. If any damage, repair and/or rebalance before use.
9. Verify security of propeller mounting.
10. Check throttle, oil injection pump, and choke actuation for free and full movement.
11. Verify that cooling fan turns when engine is rotated (air cooled engines).
12. Inspect exhaust for cracks, security of mounting, springs, and hooks for breakage and wear, and verify safety wiring of springs.
13. Start engine after assuring that area is clear of bystanders.
14. Single ignition engines: check operation of ignition switch (flick ignition off and on again at idling).
15. Dual ignition engines: check operation of both ignition circuits.
16. Check operation of all engine instruments during warm up.
17. If possible, visually check engine and exhaust for excessive vibration during warm up (indicates propeller out of balance).
18. Verify that engine reaches full power rpm during takeoff roll.

TROUBLESHOOTING AND ABNORMAL OPERATION

The information in this section is for training purposes and should never be used for maintenance on the actual aircraft. Only qualified personnel (experienced two-stroke technicians) trained on this particular type of engine are allowed to carry out maintenance and repair work. If the following information regarding the remedy of the malfunction does not solve the malfunction, contact an authorized facility. The engine must not be returned to service until the malfunction is rectified. As described earlier in the text, engines require basically two essentials to run: spark and correct fuel/air mixture. The majority of problems quite often are a simple lack of one or the other.

TROUBLESHOOTING

Follow an organized method of troubleshooting. This facilitates the identification of discrepancies or malfunctions.

- Fuel—start by checking the supply (tank), fittings (loose), filter (plugged), and float chamber (fouled).
- Spark—check for spark at the spark plugs.

Problems of a more complex nature are best left to an engine technician. The following are examples of engine troubles and potential fixes.

Engine Keeps Running With Ignition OFF
Possible cause: Overheating of engine.
Remedy: Let engine cool down at idling at approximately 2,000 engine rpm.

Knocking Under Load
Possible cause: Octane rating of fuel too low.
Remedy: Use fuel with higher octane rating.
Possible cause: Fuel starvation, lean mixture.
Remedy: Check fuel supply.

ABNORMAL OPERATING

Exceeding the Maximum Admissible Engine Speed
Reduce engine speed. Any overage of the maximum admissible engine speed must be entered by the pilot into the logbook, stating duration and extent of over-speed.

Exceeding of Maximum Admissible Cylinder Head Temperature
Reduce engine power, setting to the minimum necessary, and carry out precautionary landing. Any exceeding of the maximum admissible cylinder head temperature must be entered by the pilot into the logbook, stating duration and extent of excess-temperature condition. Exceeding of Maximum Admissible Exhaust Gas Temperature Reduce engine power, setting to the minimum necessary, and carry out precautionary landing. Any exceedence of the maximum admissible exhaust gas temperature must be entered by the pilot into the logbook, stating duration and extent of excess-temperature condition.

ENGIN PRESERVATION

If the engine is not going to be used for an extended period of time, certain measures must be taken to protect engine against heat, direct sun light, corrosion, and formation of residues. In particular, the water bonded by the alcohol in the fuel causes increased corrosion problems during storage. After each flight, activate choke for a moment before stopping engine. Close all engine openings like exhaust pipe, venting tube, and air filter to prevent entry of contamination and humidity. For engine storage of one to four weeks, proceed with preservation prior to engine stop or on the engine at operating temperature. Let the engine run at increased idle speed. Shut the engine down and secure against inadvertent engine start. Remove air filters and inject approximately 3 cubic cm of preservation oil or equivalent oil into the air intake of each carburetor. Restart the engine and run at increased idle speed for 10–15 seconds. Shut engine down and secure against inadvertent engine start. Close all engine openings, such as exhaust pipe, venting tube, and air filter, to prevent entry of contamination and humidity.

For engine storage of engine for longer than four weeks and up to one year, proceed with preservation prior to engine stop and on the engine at operating temperature. Let the engine run at increased idle speed. Remove air filters and inject approximately 6 cubic cm of preservative oil or equivalent oil into the air intake of each carburetor. Stop the engine. Remove spark plugs and inject approximately 6 cubic cm preservation oil or equivalent oil into each cylinder and slowly turn crankshaft 2 to 3 turns by hand to lubricate top end parts. Replace and re-torque the spark plugs. Drain gasoline from float chambers, fuel tank, and fuel lines. Drain coolant on liquid cooled engines to prevent any damage by freezing. Lubricate all carburetor linkages using the proper lubricates. Close all openings of the engine, such as exhaust pipe openings, venting tube, and air intake, to prevent entry of any foreign material and humidity. Protect all external steel parts by spraying with engine oil.

ENGIN MAINTENANCE PRACTICES FOR THE LIGHT-SPORT JABIRU ENGINES

NOTE: Some specific maintenance practices that differ from conventional certified engines is covered for background and educational acquaintance purposes only. Always refer to the current manufacturer's information when performing maintenance on any engine.

ENGINE AND ENGINE COMPARTMENT INSPECTION

Check for oil, fuel exhaust, and induction leaks and clean the entire engine and compartment before inspection. Check flywheel screw tensions to 24 foot pounds. Check the carburetor air filter and clean it by removing it from the intake housing and blowing compressed air against the direction of the intake flow. For operation in heavy dust conditions, clean air filter at shorter intervals than recommended for normal conditions. A clogged

filter reduces engine performance, as well as promotes premature engine wear. The engine baffles and air ducts should be checked for condition and functionality.

Two methods can be used to check the cylinders compression. The compression gauge method is used to measure compression using a compression tracer. Readings are taken with a fully open throttle valve at engine oil temperature between 30 °C and 70 °C (90 °F to 160 °F). If readings are below 6 bar (90 psi) a check of the pistons, cylinders, valves, and cylinder heads must be undertaken.

The second method uses the pressure differential test. Check using a maximum allowable pressure loss is 25 percent. As an alternative to a compression test, a pressure differential test (leak down) can be accomplished. This is a much better test of the condition of rings, bore, head sealing, and valves. This is the normal test used in aviation and requires specific equipment. The test is carried out with the engine in warm to hot condition. Input pressure is best set at 80 psi; a second gauge reads the differential. This is done with piston on TDC on the firing stroke.

NOTE: The propeller needs to be restrained. A differential of lower than 80/60 (generally a 25 percent loss) indicates a problem.

Problems can be better identified by observing where air is escaping from the cylinder, blow-by. Some examples are as follows:

1. Blow-by through the crankcase vent indicates worn rings or bore.
2. Leaking from carby indicates a poor intake valve seal.
3. Leaking from exhaust indicates a poor exhaust valve seal.
4. Head leak indicates poor head to cylinder seal.

With the problem identified, the malfunction can then be corrected. Poor compression can be an indication of a serious problem. For example, continued operation with poor compression due to a poorly sealing valve can lead to eventual valve failure and heavy damage to the piston, connecting-rod, barrel, and head.

LUBRICATION SYSTEM

The oil should be changed as required by the manufacturer. When changed, the oil filter should also be changed. Change the oil filter at every 50 hourly inspection. Drain the oil while engine is still warm and visually check for leaks. Fill the engine with oil (approximately 2.3 liters) and check oil level. Never exceed the maximum mark. Use only registered brand oils meeting the correct specifications. Do not drain the oil cooler during a normal oil change. The cooler holds only a small amount of old oil that has negligible effect on the new oil. Taking the hoses on and off the cooler can prematurely age the oil lines and lead to hoses slipping off the cooler.

CARBURETOR ADJUSTMENT AND CHECKS

To adjust the engine's idle speed, adjust the idle stop screw (7 mm screw) against throttle lever. Standard idle mixture screw position is 1¼ turns out from the seated position. Fine adjustment may be necessary to give a smooth idle.

The mixture is set by selecting jet sizes. As supplied, the engine has jets to suit a majority of installations; however, the mixture may be affected by operation with a propeller that does not meet the requirements listed in the installation manual or by ambient temperature extremes. If an engine is to be used in these situations, an exhaust gas temperature (EGT) gauge should be fitted and monitored against the limits specified above. Do not change carburetor settings if EGT readings fall outside the range given without consulting with Jabiru Aircraft or our local authorized representative. The carburetor automatically adjusts the mixture to account for altitude. Visual inspection should include checks for carburetor joint degradation and carburetor linkage for full and free movement, correct positioning of stops and security.

SPARK PLUGS

When plugs are removed from a warm engine, the inspection of the tip of the spark plug can be used to indicate the health of the engine. If the tip of the plug is a light brown color, the plug is operating correctly. A black velvet, sooty looking plug tip generally is an indication of an overly rich mixture (check the choke and the air filter and intake). If the firing end tip is covered with oil, it is an indication of too much oil in the combustion chamber (check for worn piston rings and cylinder walls). When servicing the spark plugs, do not use steel or brass brushes for cleaning and never sandblast plugs. Clean

the spark plugs with plastic brush in a solvent. Check electrode gap and, if necessary, adjust to 0.55–0.6mm (0.022 in–0.024 in) by carefully bending the electrode. Use the recommended Plugs (NGK D9EA) and place a suitable anti-seize compound on threads of the plug before installing them in the engine. Tighten spark plugs when the engine is cold and adjust engine to the correct torque value. Reconnect the ignition lead.

EXHAUST SYSTEM

Visually check the exhaust system for security of mounting, damage, rubbing, leaks, and general condition. Check nuts and bolts for tightness and condition; re-torque and replace if necessary.

HEAD BOLTS

Check the head bolt torque after five hours of operation, and again after ten hours of operation. The bolts should, thereafter, be checked annually. Head bolts torque when cold to 20 ft/lb.

TACHOMETER AND SENDER

Many apparent engine problems can be caused through inaccurate tachometers. Where engine performance is observed to be outside limits, the tachometer should be checked against a calibrated instrument. Tachometer sender gap is 0.4mm (0.016 inches). The sender must have at least 60 percent covered by the tags fitted to the gearbox side of the flywheel. Ensure both tags are equal distance from sender.

ENGINE INSPECTION CHARTS

NOTE: Read all inspection requirement paragraphs prior to using these charts. ***[Figure 14-35]***

Propeller	Engine and Engine Compartment
Spinner * *	Check flywheel screw tensions to 24 foot pounds*
Spinner flange * *	Carburetor air filter * *
Spinner screws * *	Engine baffles and air ducts *
Propeller * *	Cylinders *
Propeller bolts/nuts - Tension *	Crankcase & front crankcase seal *
Spinner/prop tracking * *	Hoses, lines and fittings * *
	Intake and exhaust systems *
	Ignition harness, distributor caps & rotors *
	NOTE: Check for oil, fuel exhaust and induction leaks, then clean entire engine and compartment before inspection.
Annual Inspection **Each 100 Hours***	

Figure 14-35. Engine inspection charts.

Question: 14-1
What is the maximum speed, stall speed, and weights for an airplane to qualify as an FAA Light Sport Aircraft for land operations?

Question: 14-2
What is the preferred fuel type and fuel/oil mix ratios on Rotax 2 cycle engines?

Question: 14-3
How is excess fuel pressure in a Rotax 914 engine relieved?

Question: 14-4
What controls the movement of lubricating oil from the crankcase back the oil tank on a rotax 914 engine.

Question: 14-5
What provides data for the tachometer on a Rotax 914 engine?

Question: 14-6
What two factors can lead to a red light warning in a turbocharged Rotax 914 engine?

Question: 14-7
If a scheduled 100 hour inspection of a light sport engine is accomplished early after just 94 hours of use, when must the next scheduled inspection be carried out?

Question: 14-8
For reasons of safety, prior to commencing work on the lubrication system of a light sport aircraft, what three steps should be taken?

ANSWERS

Answer: 14-1
maximum takeoff weight - 1320 pounds;
maximum level flight airspeed - 120 knots
maximum stall speed – 45 knots
page 14.2

Answer: 14-2
automotive fuel; 2% oil mix or 50:1 ratio
page 14.6

Answer: 14-3
surplus fuel is routed back to the fuel tank
page 14.7

Answer: 14-4
blow-by circulation of gases within the crankcase
page 14.8

Answer: 14-5
a 5th trigger coil in the ignition system
page 14.8

Answer: 14-6
excess engine speed; excess intake air temperature
page 14.10

Answer: 14-7
at 194 hours
page 14.17

Answer: 14-8
allow engine to cool to ambient temperature
switch off the ignition system
disconnect the negative terminal of the battery
page 14.20

AC	/	Alternating Current
ACARS	/	Aircraft Communications Addressing and Reporting System
ATC	/	Air Traffic Control
ATE	/	Automatic Test Equipment
BITE	/	Built In Test Equipment
CDU	/	Control Display Unit
CMC	/	Central Maintenance Computer
CRT	/	Cathode Ray Tube
DC	/	Direct Current
EASA	/	European Aviation Safety Administration
FAA	/	Federal Aviation Administration
FMS	/	Flight Management System
HF	/	High Frequency
IFR	/	Instrument Flight Rules
IT	/	Internal Tolerances
LCD	/	Liquid Chrystal Display
LRU	/	Line Replaceable Unit
LSK	/	Line Select Key
NAV/COM	/	Navigation / Communication
SSTDR	/	Spread Spectrum Time Domain Reflectometer
TDR	/	Time Domain Reflectometer
VHF	/	Very High Frequency
VME	/	Versa Model Eurocard
VXI	/	VME Expansion for Instrumentation

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