CHAPTER 10

ENGINE MAINTENANCE AND OPERATION

RECIPROCATING ENGINE OVERHAUL

Both maintenance and overhaul operations are performed on aircraft powerplants at specified intervals. This interval is usually governed by the number of hours the powerplant has been in operation. Tests and experience have shown that operation beyond this period of time will be inefficient and even dangerous because certain parts will be worn beyond their safe limits. For an overhauled engine to be as airworthy as a new one, worn parts as well as damaged parts must be detected and replaced during overhaul. The only way to detect all unairworthy parts is to perform a thorough and complete inspection while the engine is disassembled. The major purpose of overhaul is to inspect the engine parts. Inspection is the most precise and the most important phase of the overhaul. Inspection cannot be slighted or performed in a careless or incomplete manner.

Each engine manufacturer provides very specific tolerances to which his engine parts must conform, and provides general instructions to aid in determining the airworthiness of the part. However, in many cases, the final decision is left up to the mechanic. He must determine if the part is serviceable, repairable, or should be rejected. A knowledge of the operating principles, strength, and stresses applied to a part is essential in making this decision. When the powerplant mechanic signs for the overhaul of an engine, he certifies that he has performed the work using methods, techniques, and practices acceptable to the FAA Administrator.

Top Overhaul

Modern aircraft engines are constructed of such durable materials that top overhaul has largely been eliminated. Top overhaul means overhaul of those parts "on top" of the crankcase without completely dismantling the engine. It includes removal of the units, such as exhaust collectors, ignition harness, and intake pipes, necessary to remove the cylinders. The actual top overhaul consists of reconditioning the cylinder, piston, and valve-operating mechanism, and replacing the valve guides and piston rings, if needed. Usually at this time the accessories require no attention other than that normally required during ordinary maintenance functions.

Top overhaul is not recommended by all aircraft engine manufacturers. Many stress that if an engine requires this much dismantling it should be completely disassembled and receive a major overhaul.

Major Overhaul

Major overhaul consists of the complete reconditioning of the powerplant. The actual overhaul period for a specific engine will generally be determined by the manufacturer's recommendations or by the maximum hours of operation between overhaul, as approved by the FAA.

At regular intervals, an engine should be completely dismantled, thoroughly cleaned, and inspected. Each part should be overhauled in accordance with the manufacturer's instructions and tolerances for the engine involved. At this time all accessories are removed, overhauled, and tested. Here again, instructions of the manufacturer of the accessory concerned should be followed.

GENERAL OVERHAUL PROCEDURES

Because of the continued changes and the many different types of engines in use, it is not possible to treat the specific overhaul of each in this manual. However, there are various overhaul practices and instructions of a nonspecific nature which apply to all makes and models of engines. These general instructions will be described in this section.

Any engine to be overhauled completely should receive a runout check of its crankshaft or propeller shaft as a first step. Any question concerning crankshaft or propeller shaft replacement is resolved at this time, since a shaft whose runout is beyond limits must be replaced.

Disassembly

Inasmuch as visual inspection immediately follows disassembly, all individual parts should be laid out in an orderly manner on a workbench as they are removed. To guard against damage and to prevent loss, suitable containers should be available in which to place small parts, nuts, bolts, etc., during the disassembly operation.

Other practices to observe during disassembly include:

(1) Dispose of all safety devices as they are removed. Never use safety wire, cotter pins, etc., a second time. Always replace with new safety devices.

(2) All loose studs and loose or damaged fittings should be carefully tagged to prevent their being overlooked during inspection.

(3) Always use the proper tool for the job and the one that fits. Use sockets and box end wrenches wherever possible. If special tools are required, use them rather than improvising.

(4) Drain the engine oil sumps and remove the oil filter. Drain the oil into a suitable container, strain it through a clean cloth. Check the oil and the cloth for metal particles.

(5) Before disassembly, wash the exterior of the engine thoroughly.

Inspection

The inspection of engine parts during overhaul is divided into three categories:

(1) Visual.

(2) Magnetic.

(3) Dimensional.

The first two methods are aimed at determining structural failures in the parts, while the last method deals with the size and shape of each part. Structural failures can be determined by several different methods. Nonaustenitic steel parts can readily be examined by the magnetic particle method. Other methods such as X-ray or etching can also be used.

Visual inspection should precede all other inspection procedures. Parts should not be cleaned before a preliminary visual inspection, since indications of a failure often may be detected from the residual deposits of metallic particles in some recesses in the engine.

Several terms are used to describe defects detected in engine parts during inspection. Some of the more common terms and definitions are:

(1) Abrasion—An area of roughened scratches or marks usually caused by foreign matter between moving parts or surfaces.

(2) Brinelling—One or more indentations on bearing races usually caused by high static loads or application of force during installation or removal. Indentations are rounded or spherical due to the impression left by the contacting balls or rollers of the bearing.

(3) Burning—Surface damage due to excessive heat. It is usually caused by improper fit, defective lubrication, or overtemperature operation.

(4) Burnishing—Polishing of one surface by sliding contact with a smooth, harder surface. Usually no displacement' nor removal of metal.

(5) Burr—A sharp or roughened projection of metal usually resulting from machine processing.

(6) Chafing—Describes a condition caused by a rubbing action between two parts under light pressure which results in wear.

(7) Chipping—The breaking away of pieces of material, which is usually caused by excessive stress concentration or careless handling.

(8) Corrosion—Loss of metal by a chemical or electrochemical action. The corrosion products generally are easily removed by mechanical means. Iron rust is an example of corrosion.

(9) Crack—A partial separation of material usually caused by vibration, overloading, internal stresses, defective assembly, or fatigue. Depth may be a few thousandths to the full thickness of the piece.

(10) Cut—Loss of metal, usually to an appreciable depth over a relatively long and narrow area, by mechanical means, as would occur with the use of a saw blade, chisel or sharp-edged stone striking a glancing blow.

(11) Dent—A small, rounded depression in a surface usually caused by the part being struck with a rounded object.

(12) Erosion—Loss of metal from the surface by mechanical action of foreign objects, such as grit or fine sand. The eroded area will be rough and may be lined in the direction in which the foreign material moved relative to the surface.

(13) Flaking—The breaking loose of small pieces of metal or coated surfaces, which is usually caused by defective plating or excessive loading.

(14) Fretting—A condition of surface erosion caused by minute movement between two parts usually clamped together with considerable unit pressure.

(15) Galling—A severe condition of chafing or fretting in which a transfer of metal from one part to another occurs. It is usually caused by a slight movement of mated parts having limited relative motion and under high loads.

(16) ***Gouging***—A furrowing condition in which a displacement of metal has occurred (a torn effect). It is usually caused by a piece of metal or foreign material between close moving parts.

(17) ***Grooving***—A recess or channel with rounded and smooth edges usually caused by faulty alignment of parts.

(18) ***Inclusion***—Presence of foreign or extraneous material wholly within a portion of metal. Such material is introduced during the manufacture of rod, bar, or tubing by rolling or forging.

(19) ***Nick***—A sharp sided gouge or depression with a "V" shaped bottom which is generally the result of careless handling of tools and parts.

(20) ***Peening***—A series of blunt depressions in a surface.

(21) ***Pick Up or Scuffing***—A buildup or rolling of metal from one area to another, which is usually caused by insufficient lubrication, clearances, or foreign matter.

(22) ***Pitting***—Small hollows of irregular shape in the surface, usually caused by corrosion or minute mechanical chipping of surfaces.

(23) ***Scoring***—A series of deep scratches caused by foreign particles between moving parts, or careless assembly or disassembly techniques.

(24) ***Scratches***—Shallow, thin lines or marks, varying in degree of depth and width, caused by presence of fine foreign particles during operation or contact with other parts during handling.

(25) ***Stain***—A change in color, locally, causing a noticeably different appearance from the surrounding area.

(26) ***Upsetting***—A displacement of material beyond the normal contour or surface (a local bulge or bump). Usually indicates no metal loss.

Defects in nonmagnetic parts can be found by careful visual inspection along with a suitable etching process. If it is thought that a crack exists in an aluminum part, clean it by brushing or gritblasting very carefully to avoid scratching the surface. Cover the part with a solution made from 1¼ lbs. of sodium hydroxide and 1 pint of water at room temperature. Rinse the part thoroughly with water after about 1 minute's contact with the solution. Immediately neutralize the part with a solution of one part nitric acid and three parts of water heated to 100° F. Keep the part in this solution until the black deposit is dissolved. Dry the part with compressed air. If a crack exists, the edges will turn black after this treatment, thus aiding in its detection. For magnesium parts, a 10% solution of acetic acid at room temperature can be applied for a maximum of 1 minute. The part should then be rinsed with a solution of 1 ounce of household ammonia in 1 gallon of water.

Examine all gears for evidence of pitting or excessive wear. These conditions are of particular importance when they occur on the teeth; deep pit marks in this area are sufficient cause to reject the gear. Bearing surfaces of all gears should be free from deep scratches. However, minor abrasions usually can be dressed out with a fine abrasive cloth.

All bearing surfaces should be examined for scores, galling, and wear. Considerable scratching and light scoring of aluminum bearing surfaces in the engine will do no harm and should not be considered a reason for rejecting the part, provided it falls within the clearances set forth in the Table of Limits in the engine manufacturer's overhaul manual. Even though the part comes within the specific clearance limits, it will not be satisfactory for re-assembly in the engine unless inspection shows the part to be free from other serious defects.

Ball bearings should be inspected visually and by feel for roughness, flat spots on balls, flaking or pitting of races, or scoring on the outside of races. All journals should be checked for galling, scores, misalignment, or out-of-round condition. Shafts, pins, etc., should be checked for straightness. This may be done in most cases by using V-blocks and a dial indicator.

Pitted surfaces in highly stressed areas resulting from corrosion can cause ultimate failure of the part. The following areas should be examined carefully for evidence of such corrosion:

(1) Interior surfaces of piston pins.
(2) The fillets at the edges of crankshaft main and crankpin journal surfaces.
(3) Thrust bearing races.

If pitting exists on any of the surfaces mentioned to the extent that it cannot be removed by polishing with crocus cloth or other mild abrasive, the part usually must be rejected.

Parts, such as threaded fasteners or plugs, should be inspected to determine the condition of the threads. Badly worn or mutilated threads cannot be tolerated; the parts should be rejected. However, small defects such as slight nicks or burrs may be dressed out with a small file, fine abrasive cloth, or stone. If the part appears to be distorted, badly galled, or mutilated by overtightening, or from the use of improper tools, replace it with a new one.

Cleaning

After visually inspecting engine recesses for deposits of metal particles, it is important to clean all engine parts thoroughly to facilitate inspection. Two processes for cleaning engine parts are:

(1) Degreasing to remove dirt and sludge (soft carbon).

(2) The removal of hard carbon deposits by decarbonizing, brushing or scraping, and grit-blasting.

Degreasing can be done by immersing or spraying the part in a suitable commercial solvent. Extreme care must be used if any water-mixed degreasing solutions containing caustic compounds or soap are used. Such compounds, in addition to being potentially corrosive to aluminum and magnesium, may become impregnated in the pores of the metal and cause oil foaming when the engine is returned to service. When using water-mixed solutions, therefore, it is imperative that the parts be rinsed thoroughly and completely in clear boiling water after degreasing. Regardless of the method and type of solution used, coat or spray all parts with lubricating oil immediately after cleaning to prevent corrosion.

While the degreasing solution will remove dirt, grease, and soft carbon, deposits of hard carbon will almost invariably remain on many interior surfaces. To remove these deposits, they must be loosened first by immersion in a tank containing a decarbonizing solution (usually heated). A great variety of commercial decarbonizing agents are available. Decarbonizers, like the degreasing solutions previously mentioned, fall generally into two categories, water-soluble and hydrocarbons; the same caution concerning the use of water-soluble degreasers is applicable to water-soluble decarbonizers.

Extreme caution should be followed when using a decarbonizing solution on magnesium castings. Avoid immersing steel and magnesium parts in the same decarbonizing tank, because this practice often results in damage to the magnesium parts from corrosion.

Decarbonizing usually will loosen most of the hard carbon deposits remaining after degreasing; the complete removal of all hard carbon, however, generally requires brushing, scraping, or grit-blasting. In all of these operations, be careful to avoid damaging the machined surfaces. In particular, wire brushes and metal scrapers must never be used on any bearing or contact surface.

When grit-blasting parts, follow the manufacturer's recommendations for the type abrasive material to use. Sand, rice, baked wheat, plastic pellets, glass beads, or crushed walnut shells are examples of abrasive substances that are used for grit-blasting parts.

All machined surfaces must be masked properly and adequately, and all openings tightly plugged before blasting. The one exception to this is the valve seats, which may be left unprotected when blasting the cylinder head combustion chamber. It is often advantageous to grit-blast the seats, since this will cut the glaze which tends to form (particularly on the exhaust valve seat), thus facilitating subsequent valve seat reconditioning. Piston ring grooves may be grit-blasted if necessary; extreme caution must be used, however, to avoid the removal of metal from the bottom and sides of the grooves. When grit-blasting housings, plug all drilled oil passages with rubber plugs or other suitable material to prevent the entrance of foreign matter.

The decarbonizing solution generally will remove most of the enamel on exterior surfaces. All remaining enamel should be removed by grit-blasting, particularly in the crevices between cylinder cooling fins.

At the conclusion of cleaning operations, rinse the part in petroleum solvent, dry and remove any loose particles of carbon or other foreign matter by air-blasting, and apply a liberal coating of preservative oil to all surfaces.

Repair and Replacement

Damage such as burrs, nicks, scratches, scoring, or galling should be removed with a fine oil stone, crocus cloth, or any similar abrasive substance. Following any repairs of this type, the part should be cleaned carefully to be certain that all abrasive has been removed, and then checked with its mating part to assure that the clearances are not excessive. Flanged surfaces that are bent, warped, or nicked can be repaired by lapping to a true surface on a surface plate. Again, the part should be cleaned to be certain that all abrasive has been removed. Defective threads can sometimes be repaired with a suitable die or tap. Small nicks can be removed satisfactorily with Swiss pattern files or small, edged stones. Pipe threads should not be tapped deeper to clean them, because this practice will result in an oversized tapped hole. If galling or scratches are removed from a bearing surface of a journal, it should be buffed to a high finish.

In general, welding of highly-stressed engine parts is not recommended for unwelded parts. However, welding may be accomplished if it can be reasonably expected that the welded repair will not adversely affect the airworthiness of the engine. A part may be welded when:

(1) The weld is located externally and can be inspected easily.

(2) The part has been cracked or broken as the result of unusual loads not encountered in normal operation.

(3) A new replacement part of an obsolete type of engine is unavailable.

(4) The welder's experience and the equipment used will ensure a first-quality weld and the restoration of the original heat treatment in heat-treated parts.

Many minor parts not subjected to high stresses may be safely repaired by welding. Mounting lugs, cowl lugs, cylinder fins, rocker box covers, and many parts originally fabricated by welding are in this category. The welded part should be suitably stress-relieved after welding. However, before welding any engine part, consult the manufacturer's instructions for the engine concerned to see if it is approved for repair by welding.

Parts requiring use of paint for protection or appearance should be re-painted according to the engine manufacturer's recommendations. One procedure is outlined in the following paragraphs.

Aluminum alloy parts should have original exterior painted surfaces rubbed smooth to provide a proper paint base. See that surfaces to be painted are thoroughly cleaned. Care must be taken to avoid painting mating surfaces. Exterior aluminum parts should be primed first with a thin coat of zinc chromate primer. Each coat should be either air dried for 2 hrs. or baked at 177° C. (350° F.) for one-half hr. After the primer is dry, parts should be painted with engine enamel, which should be air dried until hard or baked for one-half hr. at 82° C. (180° F.). Aluminum parts from which the paint has not been removed may be repainted without the use of a priming coat, provided no bare aluminum is exposed.

Parts requiring a black gloss finish should be primed first with zinc chromate primer and then painted with glossy black cylinder enamel. Each coat should be baked for 1-1/2 hrs. at 177° C. (350° F.). If baking facilities are not available, cylinder enamel may be air dried; however, an inferior finish will result. All paint applied in the above operations preferably should be sprayed; however, if it is necessary to use a brush, use care to avoid an accumulation of paint pockets.

Magnesium parts should be cleaned thoroughly with a dichromate treatment prior to painting. This treatment consists of cleaning all traces of grease and oil from the part by using a neutral, noncorrosive degreasing medium followed by a rinse, after which the part is immersed for at least 45 minutes in a hot dichromate solution (three-fourths of a pound of sodium dichromate to 1 gallon of water at 180° to 200° F.). Then the part should be washed thoroughly in cold running water, dipped in hot water, and dried in an air blast. Immediately thereafter, the part should be painted with a prime coat and engine enamel in the same manner as that suggested for aluminum parts.

Any studs which are bent, broken, damaged, or loose must be replaced. After a stud has been removed, the tapped stud hole should be examined for size and condition of threads. If it is necessary to re-tap the stud hole, it also will be necessary to use a suitable oversize stud. Studs that have been broken off flush with the case must be drilled and removed with suitable stud remover. Be careful not to damage any threads. When replacing studs, coat the coarse threads of the stud with anti-seize compound.

CYLINDER ASSEMBLY RECONDITIONING

Cylinder and piston assemblies are inspected according to the procedures contained in the engine manufacturer's manuals, charts, and service bulletins. A general procedure for inspecting and reconditioning cylinders will be discussed in the following section to provide an understanding of the operations involved.

Cylinder Head

Inspect the cylinder head for internal and external cracks. Carbon deposits must be cleaned from the inside of the head, and paint must be removed from the outside for this inspection.

Exterior cracks will show up on the head fins where they have been damaged by tools or contact with other parts because of careless handling. Cracks near the edge of the fins are not dangerous if the portion of the fin is removed and contoured properly. Cracks at the base of the fin are a reason for rejecting the cylinder. Cracks may also occur on the rocker box or in the rocker bosses.

Interior cracks will radiate almost always from the valve seat bosses or the spark plug bushing boss. They may extend completely from one boss to the other. These cracks are usually caused by improper installation of the seats or bushings.

Use a bright light to inspect for cracks, and investigate any suspicious areas with a magnifying glass or microscope. Cracks in aluminum alloy cylinder heads generally will be jagged because of the granular nature of the metal. Do not mistake casting marks or laps for a crack. One of the best methods to double check your findings is to inspect by means of the Zyglo process. Any crack in the cylinder head, except those on the fins which can be worked out, is reason for rejecting the cylinder.

Inspect the head fins for other damage besides cracks. Dents or bends in the fins should be left alone unless there is danger of cracking. Where pieces of fin are missing, the sharp edges should be filed to a smooth contour. Fin breakage in a concentrated area will cause dangerous local hot spots. Fin breakage near the spark plug bushings or on the exhaust side of the cylinder is obviously more dangerous than in other areas. When removing or re-profiling a cylinder fin, follow the instructions and the limits in the manufacturer's manual.

Inspect all the studs on the cylinder head for looseness, straightness, damaged threads, and proper length. Slightly damaged threads may be chased with the proper die. The length of the stud should be correct within $\pm 1/32$ (0.03125) inch to allow for proper installation of pal nuts or other safety devices.

Be sure the valve guides are clean before inspection. Very often carbon will cover pits inside the guide. If a guide in this condition is put back in service, carbon will again collect in the pits, and valve sticking will result. Besides pits, scores, and burned areas inside the valve guide, inspect them for wear or looseness. Most manufacturers provide a maximum wear gage to check the dimension of the guide. This gage should not enter the guide at all at either end. Do not confuse this gage with the "go and no-go" gage used to check new valve guides after reaming.

Inspection of valve seat inserts before they are re-faced is mostly a matter of determining if there is enough of the seat left to correct any pitting, burning, scoring, or out-of-trueness.

Inspect spark plug inserts for the condition of the threads and for looseness. Run a tap of the proper size through the bushing. Very often the inside threads of the bushing will be burned. If more than one thread is missing, the bushing is rejectable. Tighten a plug in the bushing to check for looseness.

Inspect the rocker shaft bosses for scoring, cracks, oversize, or out-of-roundness. Scoring is generally caused by the rocker shaft turning in the bosses, which means either the shaft was too loose in the bosses or a rocker arm was too tight on the shaft. Out-of-roundness is usually caused by a stuck valve. If a valve sticks, the rocker shaft tends to work up and down when the valve offers excessive resistance to opening. Inspect for out-of-roundness and oversize using a telescopic gage and a micrometer.

Cylinder Barrel

Inspect the cylinder barrel for wear, using a dial indicator, a telescopic gage and micrometer, or an inside micrometer. Dimensional inspection of the barrel consists of the following measurements:

(1) Maximum taper of cylinder walls.

(2) Maximum out-of-roundness.

(3) Bore diameter.

(4) Step.

(5) Fit between piston skirt and cylinder.

All measurements involving cylinder barrel diameters must be taken at a minimum of two positions 90° apart in the particular plane being measured. It may be necessary to take more than two measurements to determine the maximum wear. The use of a dial indicator to check a cylinder bore is shown in figure 10–1.

Taper of the cylinder walls is the difference between the diameter of the cylinder barrel at the bottom and the diameter at the top. The cylinder is usually worn larger at the top than at the bottom. This taper is caused by the natural wear pattern. At the top of the stroke, the piston is subjected to greater heat and pressure and more errosive environment than at the bottom of the stroke. Also, there is greater freedom of movement at the top of the stroke. Under these conditions, the piston will wear the cylinder wall. In most cases, the taper will end with a ridge (see figure 10–2) which must be removed during overhaul. Where cylinders are

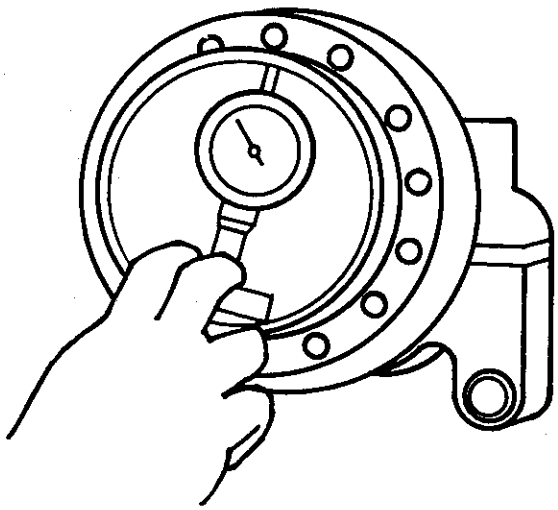


FIGURE 10–1. Checking cylinder bore with a dial indicator.

built with an intentional choke, measurement of taper becomes more complicated. It is necessary to know exactly how the size indicates wear or taper. Taper can be measured in any cylinder by a cylinder dial gage as long as there is not a sharp step. The dial gage tends to ride up on the step and causes inaccurate readings at the top of the cylinder.

The measurement for out-of-roundness is usually taken at the top of the cylinder. However, a reading should also be taken at the skirt of the cylinder to detect dents or bends caused by careless handling. A step or ridge (figure 10–2) is formed in the cylinder by the wearing action of the piston rings. The greatest wear is at the top of the ring travel limit. The ridge which results is very likely to cause damage to the rings or piston. If the step exceeds tolerances, it should be removed by grinding the cylinder oversize or it should be blended by hand stoning to break the sharp edge.

A step also may be found where the bottom ring reaches its lowest travel. This step is vary rarely found to be excessive, but it should be checked.

Inspect the cylinder walls for rust, pitting, or scores. Mild damage of this sort can be removed when the rings are lapped. With more extensive damage, the cylinder will have to be reground or honed. If the damage is too deep to be removed by either of these methods, the cylinder usually

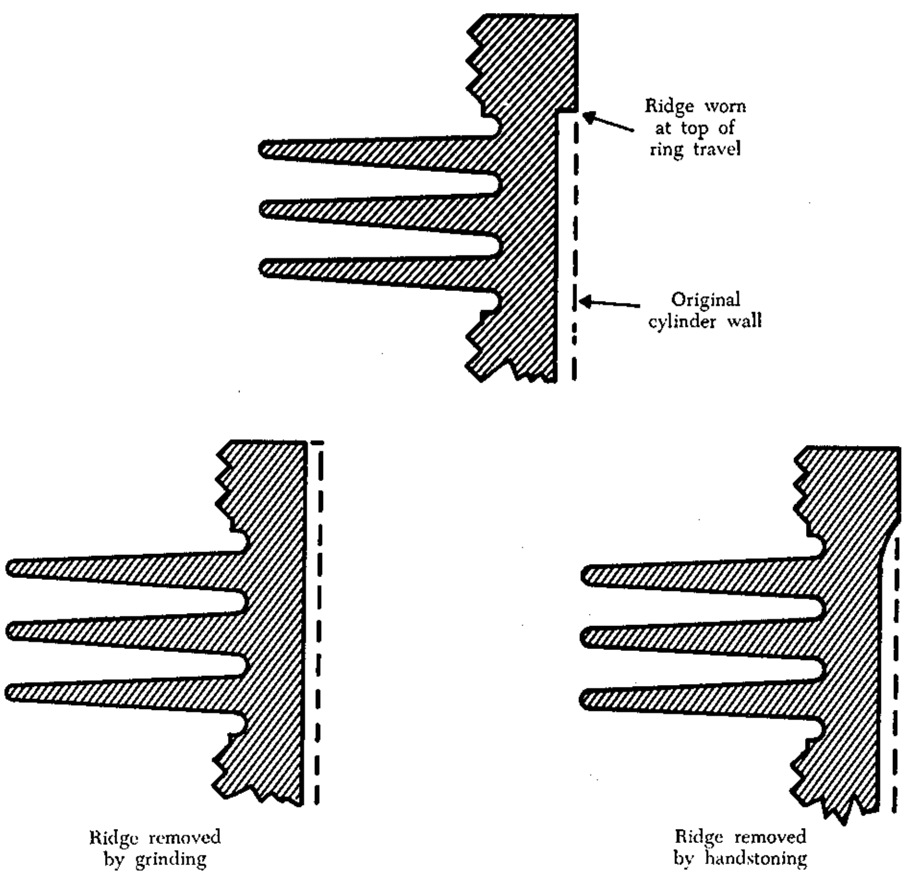


FIGURE 10–2. Ridge or step formed in an engine cylinder.

will have to be rejected. Most engine manufacturers have an exchange service on cylinders with damaged barrels.

Check the cylinder flange for warpage by placing the cylinder on a suitable jig. Check to see that the flange contacts the jig all the way around. The amount of warp can be checked by using a thickness gage (figure 10–3). A cylinder whose flange is warped beyond the allowable limits should be rejected.

Valves and Valve Springs

Remove the valves from the cylinder head and clean them to remove soft carbon. Examine the valve visually for physical damage and damage from burning or corrosion. Do not re-use valves that indicate damage of this nature. Check the valve face runout. The locations for checking runout and edge thickness are shown in figure 10–4.

Measure the edge thickness of valve heads. If, after re-facing, the edge thickness is less than the limit specified by the manufacturer, the valve must not be re-used. The edge thickness can be measured with sufficient accuracy by a dial indicator and a surface plate.

Using a magnifying glass, examine the valve in the stem area and the tip for evidence of cracks, nicks, or other indications of damage. This type of damage seriously weakens the valve, making it susceptible to failure. If superficial nicks and scratches on the valve indicate that it might be cracked, inspect it using the magnetic particle or dye penetrant method.

Critical areas of the valve include the face and tip, both of which should be examined for pitting and excessive wear. Minor pitting on valve faces can sometimes be removed by grinding.

Inspect the valve for stretch and wear, using a micrometer or a valve radius gage. Checking valve stretch with a valve radius gage is illustrated in figure 10–5. If a micrometer is used, stretch will be found as a smaller diameter of the valve stem near the neck of the valve. Measure the diameter of the valve stem and check the fit of the valve in its guide.

Examine the valve springs for cracks, rust, broken ends, and compression. Cracks can be located by visual inspection or the magnetic particle method. Compression is tested with a valve spring tester. The spring is compressed until its total height is that specified by the manufacturer. The dial on the tester should indicate the pressure (in pounds) required to compress the spring to the specified height. This must be within the pressure limits established by the manufacturer.

Rocker Arms and Shafts

Inspect the valve rockers for cracks and worn, pitted, or scored tips. See that all oil passages are free from obstructions.

Inspect the shafts for correct size with a micrometer. Rocker shafts very often are found to be scored and burned because of excessive turning in the cylinder head. Also, there may be some pickup on the shaft (bronze from the rocker bushing transferred to the steel shaft). Generally this is caused by overheating and too little clearance between shaft and bushing.

Inspect the rocker arm bushing for correct size. Check for proper clearance between the shaft and the bushing. Very often the bushings are scored because of mishandling during disassembly. Check to see that the oil holes line up. At least 50% of the hole in the bushing should align with the hole in the rocker arm.

On engines that use a bearing, rather than a bushing, inspect the bearing to make certain it has not been turning in the rocker arm boss. Also inspect the bearing to determine its serviceability.

Piston and Piston Pin

Inspect the piston for cracks. As an aid to this, heat the piston carefully with a blow torch. If there is a crack, the heat will expand it and will also force out residual oil that remains in the crack no matter how well the piston has been cleaned. Cracks are more likely to be formed at the highly stressed points; therefore, inspect carefully at the base of the pin bosses, inside the piston at the junction of the walls and the head, and at the base of the ring lands, especially the top and bottom lands.

When applicable, check for flatness of the piston head using a straightedge and thickness gage as shown in figure 10–6. If a depression is found, double check for cracks on the inside of the piston. A depression in the top of the piston usually means that detonation has occurred within the cylinder.

Inspect the exterior of the piston for scores and scratches. Scores on the top ring land are not cause for rejection unless they are excessively deep. Deep scores on the side of the piston are usually a reason for rejection.

Examine the piston for cracked skirts, broken ring lands, and scored piston-pin holes.

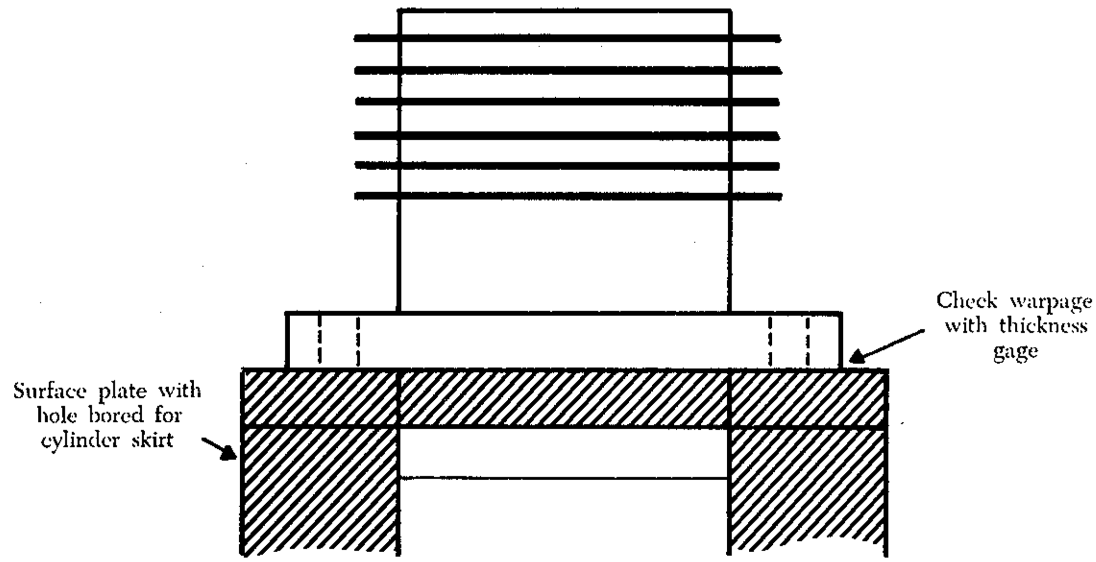


FIGURE 10–3. A method for checking cylinder flange warpage.

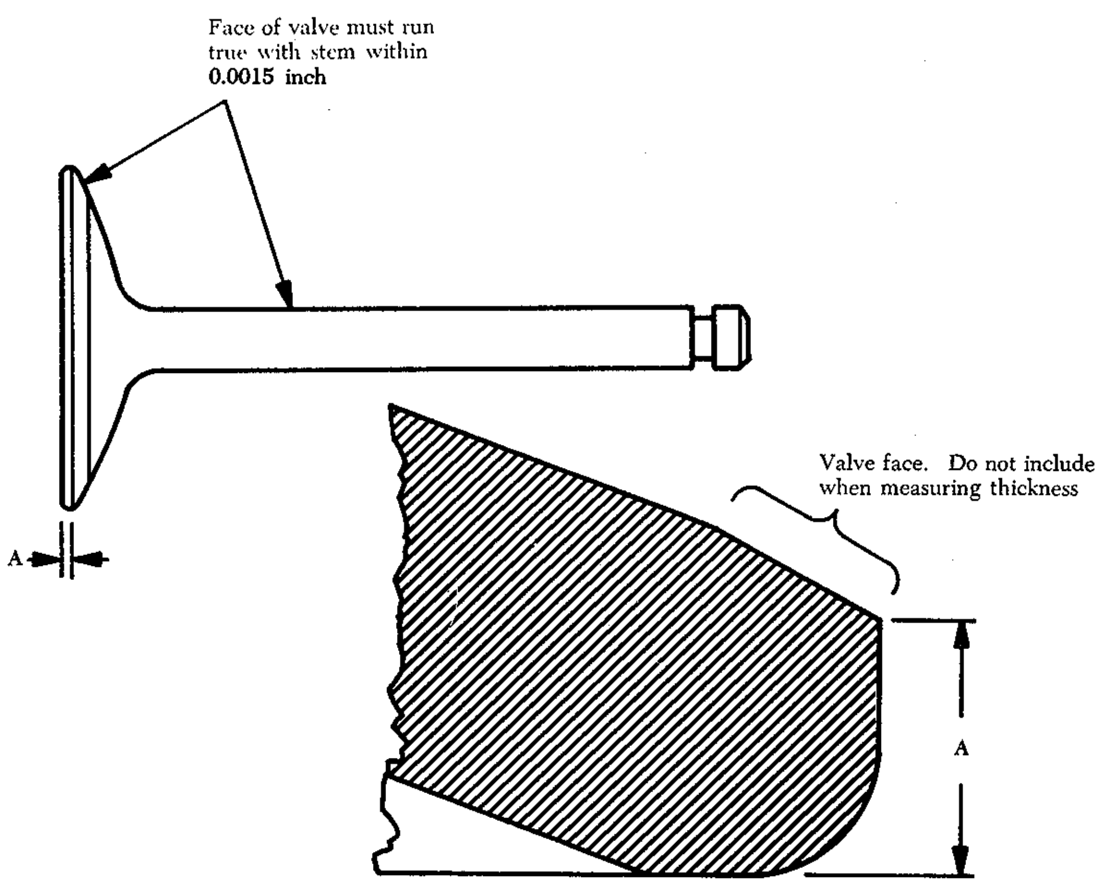


FIGURE 10–4. Valve, showing locations for checking runout and section for measuring edge thickness.

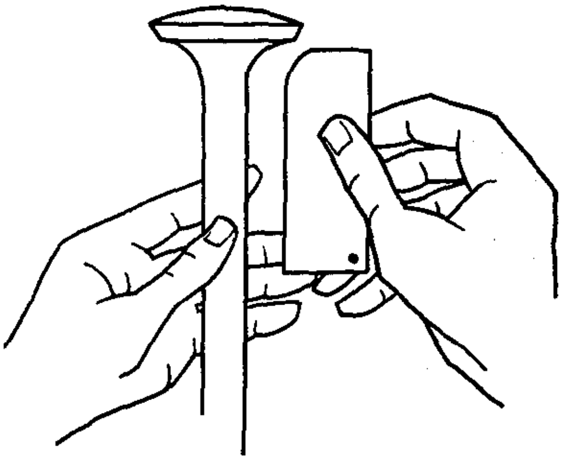


FIGURE 10–5. Checking valve stretch with a manufacturer's gage.

Measure the outside of the piston by means of a micrometer. Measurements must be taken in several directions and on the skirt, as well as on the lands section. Check these sizes against the cylinder size. Several engines now use cam ground pistons to compensate for the greater expansion parallel to the pin during engine operation. The diameter of these pistons measures several thousandths of an inch larger at an angle to the piston pin hole than parallel to the pin hole.

Inspect the ring grooves for evidence of a step. If a step is present, the groove will have to be machined to an oversize width. Use a standard piston ring and check side clearance with a feeler gage to locate wear in the grooves or to determine if the grooves have already been machined oversize. The largest allowable width is usually 0.020 in. oversize, because any further machining weakens the lands excessively.

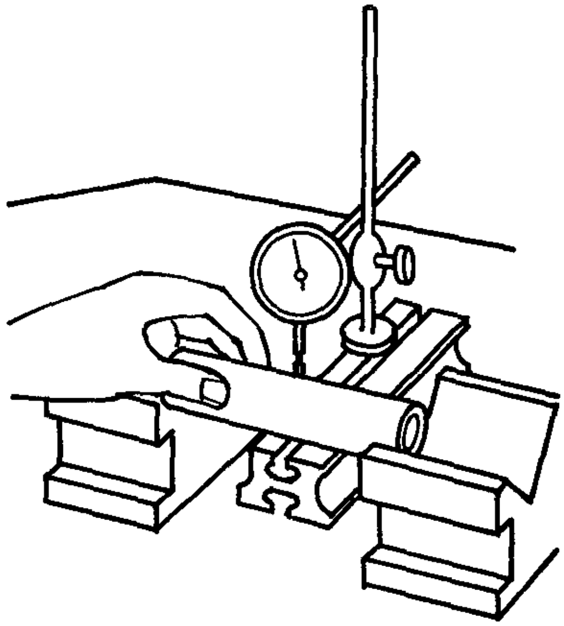


FIGURE 10–7. Checking a piston pin for bends.

Examine the piston pin for scoring, cracks, excessive wear, and pitting. Check the clearance between the piston pin and the bore of the piston pin bosses using a telescopic gage and a micrometer. Use the magnetic particle method to inspect the pin for cracks. Since the pins are often case hardened, cracks will show up inside the pin more often than they will on the outside.

Check the pin for bends (figure 10–7), using V-blocks and a dial indicator on a surface plate. Measure the fit of the plugs in the pin.

Re-facing Valve Seats

The valve seat inserts of aircraft engine cylinders

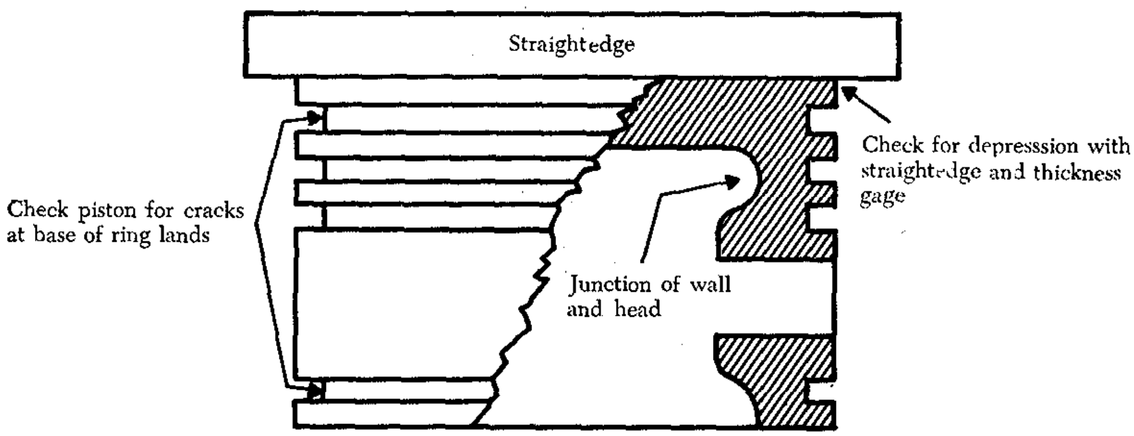


FIGURE 10–6. Checking a piston head for flatness.

usually are in need of re-facing at every overhaul. They are re-faced to provide a true, clean, and correct size seat for the valve. When valve guides or valve seats are replaced in a cylinder, the seats must be trued-up to the guide.

Modern engines use either bronze or steel seats. Steel seats are commonly used as exhaust seats and are made of a hard, heat-resistant, and often austenitic steel alloy. Bronze seats are used for intake or for both seats; they are made of aluminum bronze or phosphor bronze alloys.

Steel valve seats are re-faced by grinding equipment. Bronze seats are re-faced preferably by the use of cutters or reamers, but they may be ground when this equipment is not available. The only disadvantage of using a stone on bronze is that the soft metal loads the stone to such an extent that much time is consumed in re-dressing the stone to keep it clean.

The equipment used on steel seats can be either wet or dry valve seat grinding equipment. The wet grinder uses a mixture of soluble oil and water to wash away the chips and to keep the stone and seat cool; this produces a smoother, more accurate job than the dry grinder. The stones may be either silicon carbide or aluminum oxide.

Before re-facing the seat, make sure that the valve guide is in good condition, is clean, and will not have to be replaced.

Mount the cylinder firmly in the holddown fixture. An expanding pilot is inserted in the valve guide from the inside of the cylinder, and an expander screw is inserted in the pilot from the top of the guide as shown in figure 10–8. The pilot must be tight in the guide because any movement can cause a poor grind. The fluid hose is inserted through one of the spark plug inserts.

The three grades of stones available for use are classified as rough, finishing, and polishing stones. The rough stone is designed to true and clean the seat. The finishing stone must follow the rough to remove grinding marks and produce a smooth finish. The polishing stone does just as the name implies, and is used only where a highly polished seat is desired.

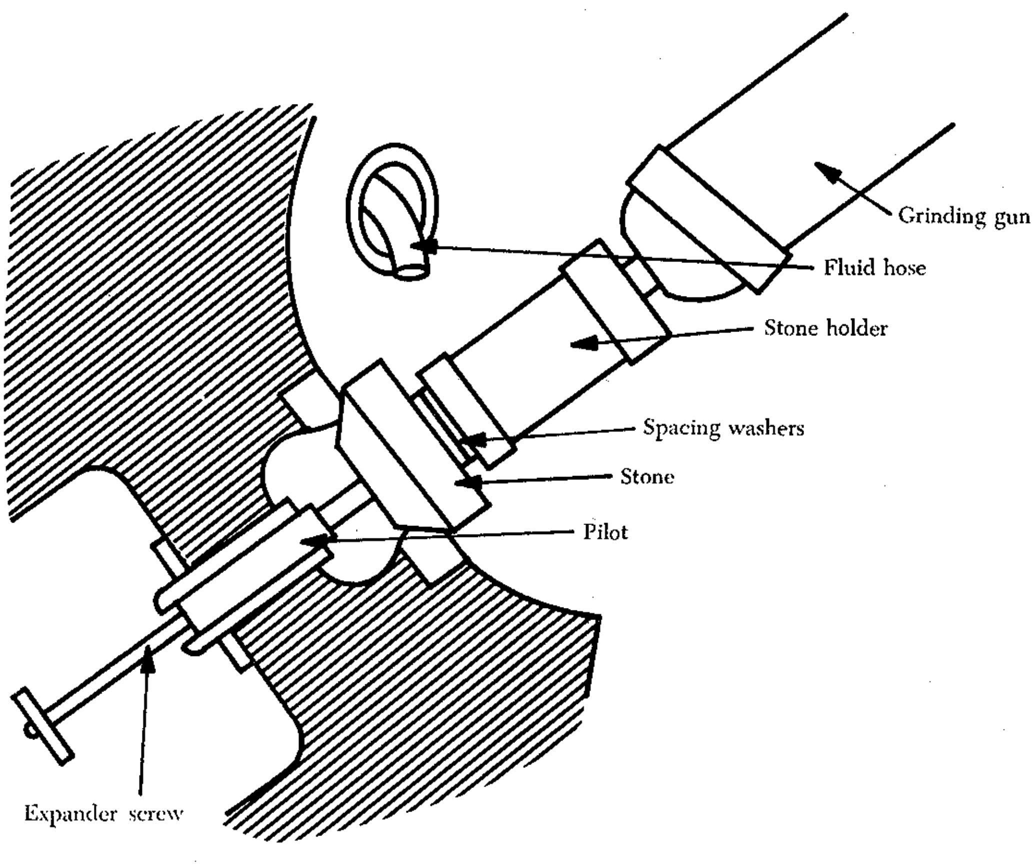


FIGURE 10–8. Valve seat grinding equipment.

The stones are installed on special stone holders. The face of the stone is trued by a diamond dresser. The stone should be re-faced whenever it is grooved or loaded and when the stone is first installed on the stone holder. The diamond dresser also may be used to cut down the diameter of the stone. Dressing of the stone should be kept to a minimum as a matter of conservation; therefore, it is desirable to have sufficient stone holders for all the stones to be used on the job.

In the actual grinding job, considerable skill is required in handling the grinding gun. The gun must be centered accurately on the stone holder. If the gun is tilted off-center, chattering of the stone will result and a rough grind will be produced. It is very important that the stone be rotated at a speed that will permit grinding instead of rubbing. This speed is approximately 8,000 to 10,000 r.p.m. Excessive pressure on the stone can slow it down. It is not a good technique to let the stone grind at slow speed by putting pressure on the stone when starting or stopping the gun. The maximum pressure used on the stone at any time should be no more than that exerted by the weight of the gun.

Another practice which is conducive to good grinding is to ease off on the stone every second or so to let the coolant wash away the chips on the seat; this rhythmic grinding action also helps keep the stone up to its correct speed. Since it is quite a job to replace a seat, remove as little material as possible during the grinding. Inspect the job frequently to prevent unnecessary grinding.

The rough stone is used until the seat is true to the valve guide and until all pits, scores, or burned areas (figure 10–9) are removed. After re-facing, the seat should be smooth and true.

The finishing stone is used only until the seat has a smooth, polished appearance. Extreme caution should be used when grinding with the finishing stone to prevent chattering.

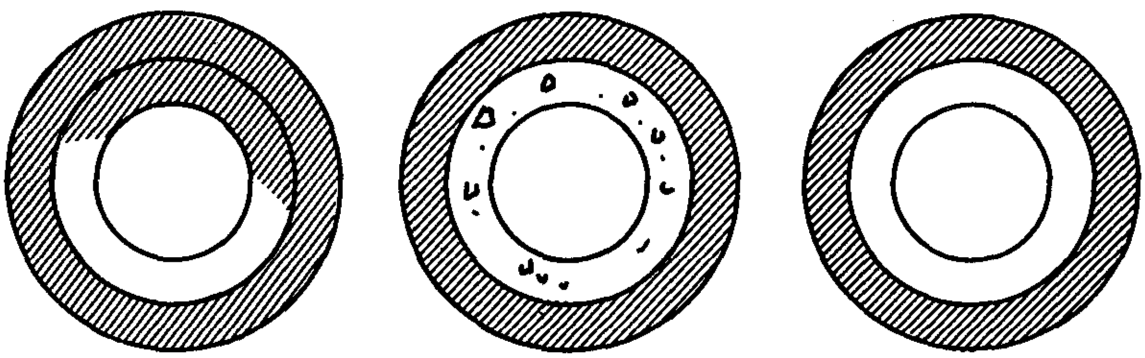
The size and trueness of the seat can be checked by several methods. Runout of the seat is checked with a special dial indicator and should not exceed 0.002 in. The size of the seat may be determined by using prussian blue. To check the fit of the seat, spread a thin coat of prussian blue evenly on the seat. Press the valve onto the seat. The blue transferred to the valve will indicate the contact surface. The contact surface should be one-third to two-thirds the width of the valve face and in the middle of the face. In some cases, a-go and no-go gage is used in place of the valve when making the prussian blue check. If prussian blue is not used, the same check may be made by lapping the valve lightly to the seat. Examples of test results are shown in figure 10–10.

If the seat contacts the upper third of the valve face, grind off the top corner of the valve seat as shown in figure 10–11. Such grinding is called "narrowing grinding." This permits the seat to contact the center third of the valve face without touching the upper portion of the valve face.

If the seat contacts the bottom third of the valve face, grind off the inner corner of the valve seat as shown in figure 10–12.

The seat is narrowed by a stone other than the standard angle. It is common practice to use a 15° angle and 45° angle cutting stone on a 30° angle valve seat, and a 30° angle and 75° angle stone on a 45° angle valve seat (see figure 10–13).

If the valve seat has been cut or ground too much, the valve will contact the seat too far up into the cylinder head, and the valve clearance,



Seat out of alignment with guide — Excessive pitting — True and clean Ready for finish grind

Needs further rough grinding

FIGURE 10–9. Valve seat grinding.

spring tension, and the fit of the valve to the seat will be affected. To check the height of a valve, insert the valve into the guide and hold it against the seat. Check the height of the valve stem above the rocker box or some other fixed position.

Before re-facing a valve seat, consult the overhaul manual for the particular model engine. Each manufacturer specifies the desired angle for grinding and narrowing the valve seat.

Valve Reconditioning

One of the most common jobs during engine overhaul is grinding the valves. The equipment used should preferably be a wet valve grinder.

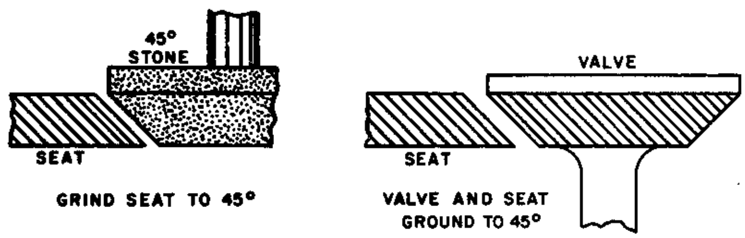


FIGURE 10–10. Fitting of the valve and seat.

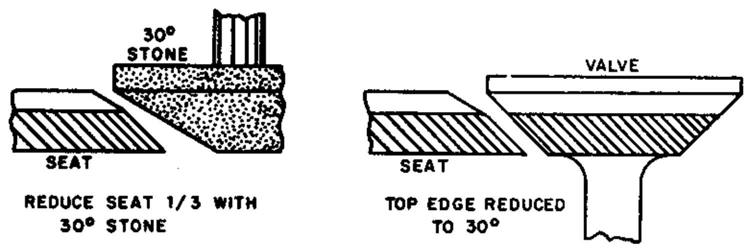
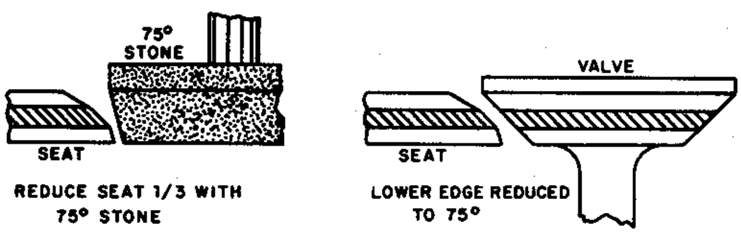


FIGURE 10–11. Grinding top surface of the valve seat.



PROPER CONTACT VALVE TO VALVE SEAT

FIGURE 10–12. Grinding the inner corner of the valve seat.

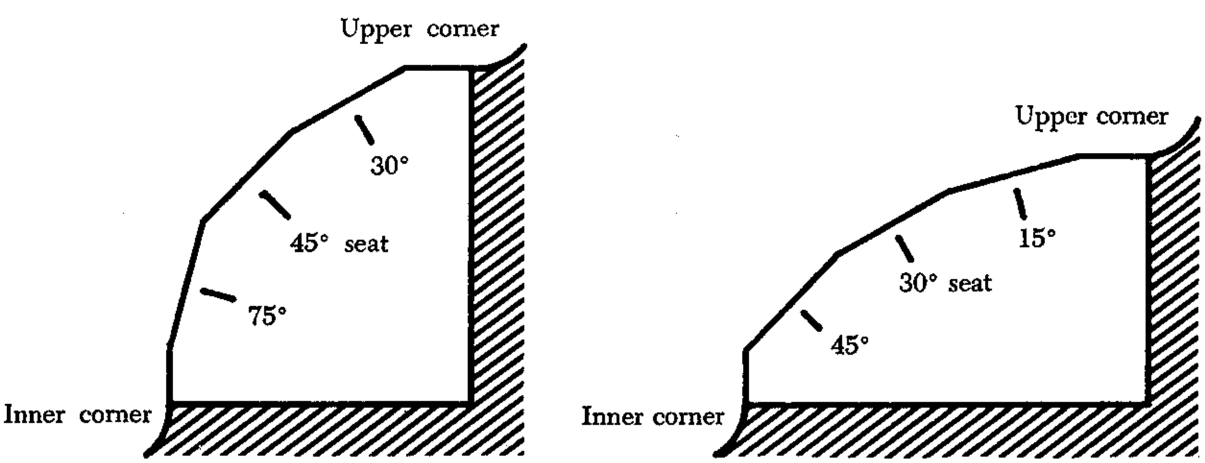


FIGURE 10–13. Valve seat angles.

With this type of machine, a mixture of soluble oil and water is used to keep the valve cool and carry away the grinding chips.

Like many machine jobs, valve grinding is mostly a matter of setting up the machine. The following points should be checked or accomplished before starting a grind.

True the stone by means of a diamond nib. The machine is turned on, and the diamond is drawn across the stone, cutting just deep enough to true and clean the stone.

Determine the face angle of the valve being ground and set the movable head of the machine to correspond to this valve angle. Usually, valves are ground to the standard angles of 30° or 45°. However, in some instances, an interference fit of 0.5° or 1.5° less than the standard angle may be ground on the valve face.

The interference fit (figure 10–14) is used to obtain a more positive seal by means of a narrow contact surface. Theoretically, there is a line contact between the valve and seat. With this line contact, all the load that the valve exerts against the seat is concentrated in a very small area, thereby increasing the unit load at any one spot. The interference fit is especially beneficial during the first few hours of operation after an overhaul. The positive seal reduces the possibility of a burned valve or seat that a leaking valve might produce. After the first few hours of running, these angles tend to pound down and become identical.

Notice that the interference angle is ground into the valve, not the seat. It is easier to change the angle of the valve grinder work head than to change the angle of a valve seat grinder stone. Do not use an interference fit unless the manufacturer approves it.

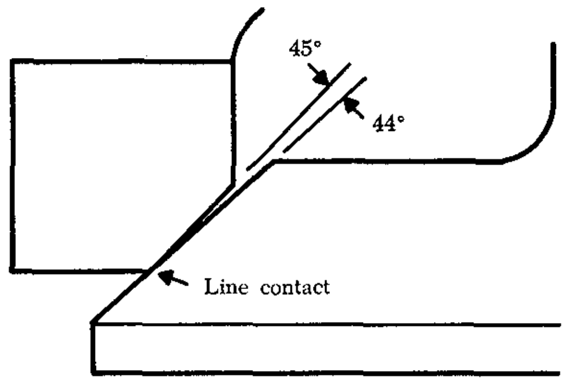


FIGURE 10–14. Interference fit of valve and valve seat.

Install the valve into the chuck (figure 10–15) and adjust the chuck so that the valve face is approximately 2 in. from the chuck. If the valve is chucked any further out, there is danger of excessive wobble and also a possibility of grinding into the stem.

There are various types of valve grinding machines. In one type the stone is moved across the valve face; in another, the valve is moved across the stone. Whichever type is used, the following procedures are typical of those performed when re-facing a valve.

Check the travel of the valve face across the stone. The valve should completely pass the stone

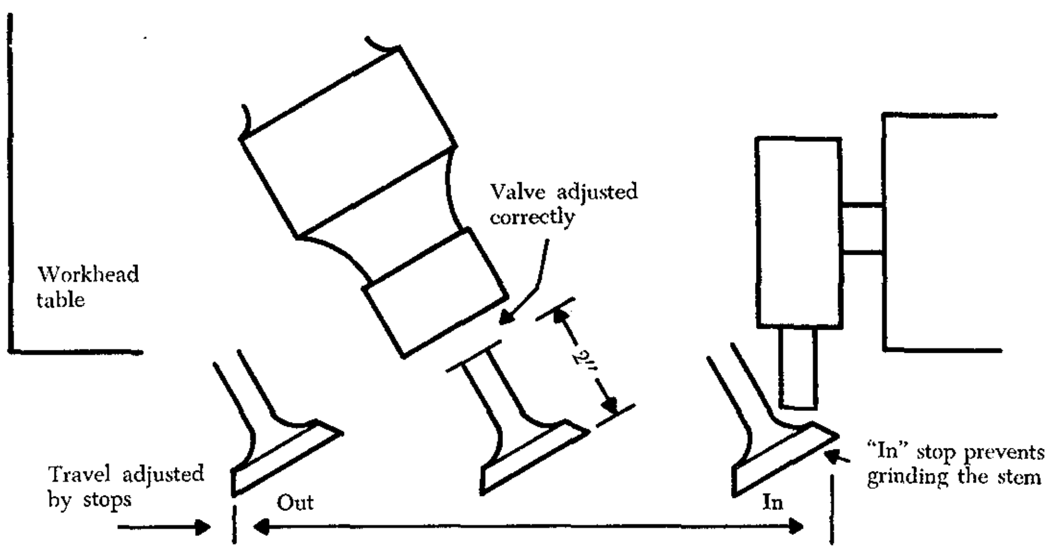


FIGURE 10–15. Valve installed in grinding machine.

on both sides and yet not travel far enough to grind the stem. There are stops on the machine which can be set to control this travel.

With the valve set correctly in place, turn on the machine and turn on the grinding fluid so that it splashes on the valve face. Back the grinding wheel off all the way. Place the valve directly in front of the stone. Slowly bring the wheel forward until a light cut is made on the valve. The intensity of the grind is measured by sound more than anything else. Slowly draw the valve back and forth across the stone without increasing the cut. Move the workhead table back and forth using the full face of the stone but always keep the valve face on the stone. When the sound of the grind diminishes, indicating that some valve material has been removed, move the workhead table to the extreme left to stop rotation of the valve. Inspect the valve to determine if further grinding is necessary. If another cut must be made, bring the valve in front of the stone, then advance the stone out to the valve. Do not increase the cut without having the valve directly in front of the stone.

An important precaution in valve grinding, as in any kind of grinding, is to make light cuts only. Heavy cuts cause chattering, which may make the valve surface so rough that much time is lost in obtaining the desired finish.

After grinding, check the valve margin to be sure that the valve edge has not been ground too thin. A thin edge is called a "feather edge" and can lead to preignition. The valve edge would burn away in a short period of time and the cylinder would have to be overhauled again. Figure 10–16 shows a valve with a normal margin and one with a feather edge.

The valve tip may be re-surfaced on the valve grinder. The tip is ground to remove cupping or wear and also to adjust valve clearances on some engines.

The valve is held by a clamp (figure 10–17) on the side of the stone. With the machine and grinding fluid turned on, the valve is pushed lightly against the stone and swung back and forth. Do not swing the valve stem off either edge of the stone. Because of the tendency for the valve to overheat during this grinding, be sure plenty of grinding fluid covers the tip.

Grinding of the valve tip may remove or partially remove the bevel on the edge of the valve. To restore this bevel, mount a vee-way approximately 45° to the grinding stone. Hold the valve

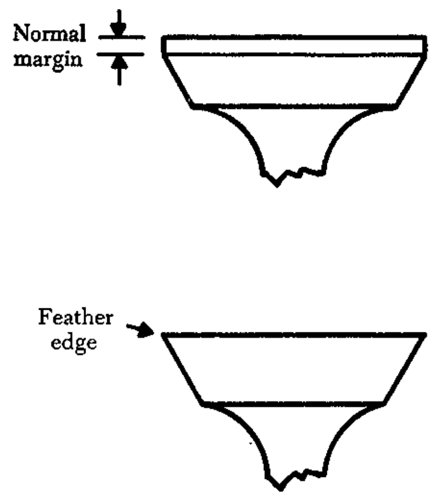


FIGURE 10–16. Engine valves showing normal margin and a feather edge.

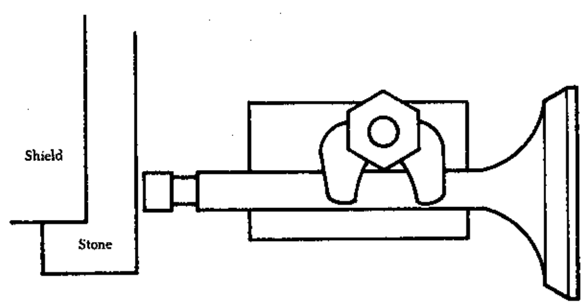


FIGURE 10–17. Grinding a valve tip.

onto the vee-way with one hand, then twist the valve tip onto the stone, and with a light touch grind all the way around the tip. This bevel prevents scratching the valve guide when the valve is installed.

Valve Lapping and Leak Testing

After the grinding procedure is finished, it is sometimes necessary that the valve be lapped to the seat. This is done by applying a small amount of lapping compound to the valve face, inserting the valve into the guide, and rotating the valve with a lapping tool until a smooth, gray finish appears at the contact area. The appearance of a correctly lapped valve is shown in figure 10–18.

After the lapping process is finished, be sure that all lapping compound is removed from the valve face, seat, and adjacent areas.

The final step is to check the mating surface for leaks to see if it is sealing properly. This is done by installing the valve in the cylinder, holding the valve by the stem with the fingers, and pouring

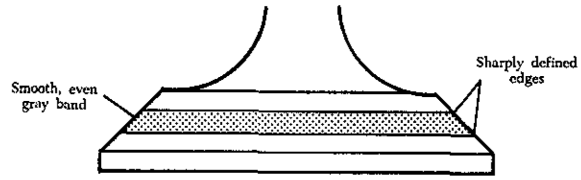


FIGURE 10–18. A correctly lapped valve.

kerosene or solvent into the valve port. While holding finger pressure on the valve stem, check to see if the kerosene is leaking past the valve into the combustion chamber. If it is not, the valve re-seating operation is finished. If kerosene is leaking past the valve, continue the lapping operation until the leakage is stopped.

Any valve face surface appearance that varies from that illustrated in figure 10–19 is correct. However, the incorrect indications are of value in diagnosing improper valve and valve seat grinding. Incorrect indications, their cause and remedy, are shown in figure 10–19.

Piston Repairs

Piston repairs are not required as often as cylinder repairs since most of the wear is between the piston ring and cylinder wall, valve stem and guide, and valve face and seat. A lesser amount of wear is encountered between the piston skirt and cylinder, ring and ring groove, or piston pin and bosses.

The most common repair will be the removal of scores. Usually these may be removed only on the piston skirt if they are very light. Scores above the top ring groove may be machined or sanded out, as long as the diameter of the piston is not reduced below the specified minimum. To remove these scores, set the piston on a lathe. With the piston revolving at a slow speed, smooth out the scores with number 320 wet or dry sandpaper. Never use anything rougher than crocus cloth on the piston skirt.

On engines where the entire rotating and reciprocating assembly is balanced, the pistons **must** weigh within one-fourth ounce of each other. When a new piston is installed it must be within the same weight tolerance as the one removed. It is not enough to have the pistons matched alone; they must be matched to the crankshaft, connecting rods, piston pins, etc. To make weight adjustments on new pistons, the manufacturer provides a heavy section at the base of the skirt. To decrease weight file metal evenly off the inside of this heavy section. The piston weight can be decreased easily, but welding, metalizing, or plating cannot be done to increase the piston weight.

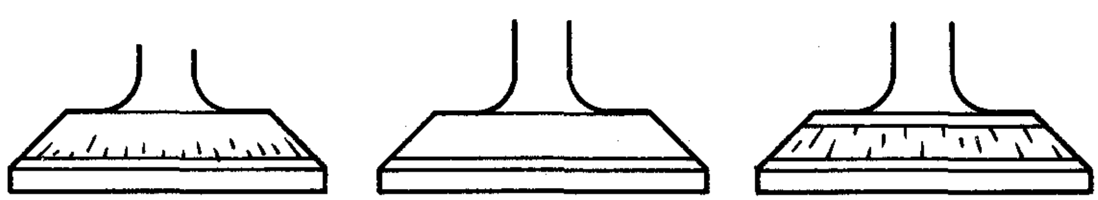
If ring grooves are worn or stepped, they will have to be machined oversize so that they can accommodate an oversize width ring with the proper clearance. After machining, check to be sure that the small radius is maintained at the back of each ring groove. If it is removed, cracks may occur due to localization of stress. Ring groove oversizes are usually 0.005 in., 0.010 in., or 0.020 in. More than that would weaken the ring lands.

A few manufacturers sell 0.005-in.-oversize piston pins. When these are available, it is permissible to bore or ream the piston-pin bosses to 0.005 in. oversize. However, these bosses must be in perfect alignment.

Small nicks on the edge of the piston-pin boss may be sanded down. Deep scores inside the boss or anywhere around the boss are definite reasons for rejection.

Cylinder Grinding and Honing

If a cylinder has excessive taper, out-of-roundness, step, or its maximum size is beyond limits, it can be re-ground to the next allowable oversize. If the cylinder walls are lightly rusted, scored, or



Indication	Fuzzy edge	Too narrow contact	Two lap bands
Cause	Rough grind	Unintentional interference fit	Improper narrowing of seat
Remedy	Regrind valve or continue lapping	Grind both valve and seat	Renarrow seat

FIGURE 10–19. Incorrectly lapped valves.

pitted, the damage may be removed by honing or lapping.

Regrinding a cylinder is a specialized job that the powerplant mechanic usually is not expected to be able to do. However, the mechanic must be able to recognize when a cylinder needs re-grinding, and he must know what constitutes a good or bad job.

Generally, standard aircraft cylinder oversizes are 0.010 in., 0.015 in., 0.020 in., or 0.030 in. Unlike automobile engines which may be re-bored to oversizes of 0.075 in. to 0.100 in., aircraft cylinders have relatively thin walls and may have a nitrided surface, which must not be ground away. Any one manufacturer usually does not allow all of the above oversizes. Some manufacturers do not allow regrinding to an oversize at all. The manufacturer's overhaul manual or parts catalog usually lists the oversizes allowed for a particular make and model engine.

To determine the re-grind size, the standard bore size must be known. This usually can be determined from the manufacturer's specifications or manuals. The re-grind size is figured from the standard bore. For example, a certain cylinder has a standard bore of 3.875 in. To have a cylinder ground to 0.015 in. oversize, it is necessary to grind to a bore diameter of 3.890 in. (3.875+0.015). A tolerance of ±0.0005 in. is usually accepted for cylinder grinding.

Another factor to consider when determining the size to which a cylinder must be re-ground is the maximum wear that has occurred. If there are spots in the cylinder wall that are worn larger than the first oversize, then obviously it will be necessary to grind to the next oversize to clean up the entire cylinder.

An important consideration when ordering a regrind is the type of finish desired in the cylinder. Some engine manufacturers specify a fairly rough finish on the cylinder walls, which will allow the rings to seat even if they are not lapped to the cylinder. Other manufacturers desire a smooth finish to which a lapped ring will seat without much change in ring or cylinder dimensions. The latter type of finish is more expensive to produce.

The standard used when measuring the finish of a cylinder wall is known as microinch root-mean-square, or microinch r.m.s. In a finish where the depth of the grinding scratches are one-millionth (0.000001) of an inch deep, it is specified as 1 microinch r.m.s. Most aircraft cylinders are ground to a finish of 15 to 20 microinch r.m.s. Several low-powered engines have cylinders that are ground to a relatively rough 20- to 30-microinch r.m.s. finish. On the other end of the scale, some manufacturers require a superfinish of approximately 4- to 6-microinch r.m.s.

Cylinder grinding (figure 10–20) is accomplished by a firmly mounted stone that revolves around the cylinder bore, as well as up and down the length of the cylinder barrel. Either the cylinder, the stone, or both may move to get this relative movement. The size of the grind is determined by the distance the stone is set away from the center line of the cylinder. Some cylinder bore grinding machines will produce a prefectly straight bore, while others are designed to grind a choked bore. A choked bore grind refers to the manufacturing process in which the cylinder walls are ground to produce a smaller internal diameter at the top than at the bottom. The purpose of this type grind or taper is to main-

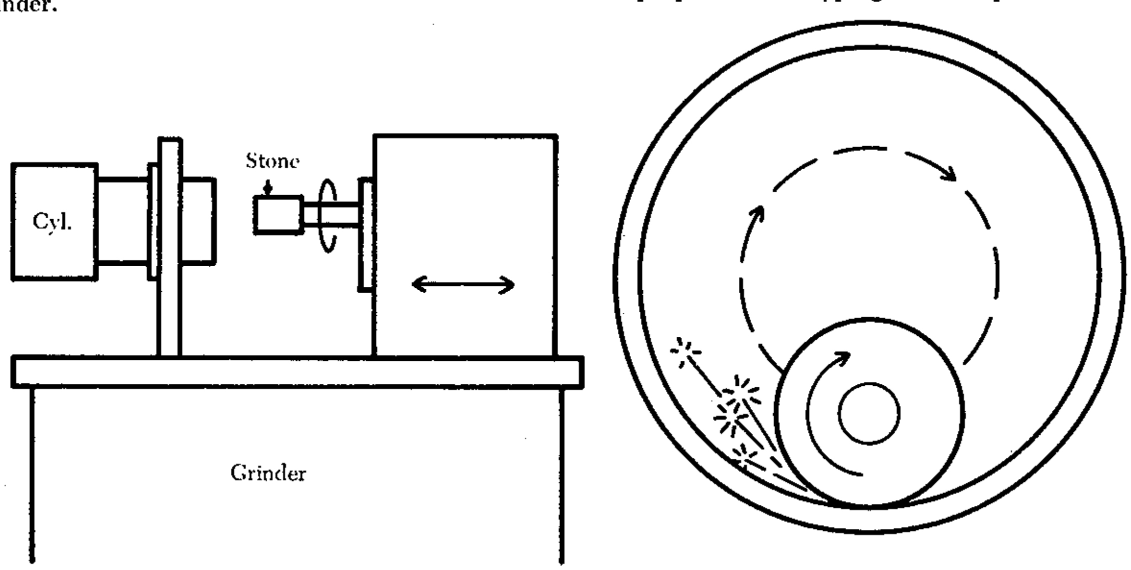


Figure 10–20. Cylinder bore grinding.

tain a straight cylinder wall during operation. As a cylinder heats up during operation, the head and top of the cylinder are subjected to more heat than the bottom. This causes greater expansion at the top than at the bottom, thereby maintaining the desired straight wall.

After grinding a cylinder, it may be necessary to hone the cylinder bore to produce the desired finish. If this is the case, specify the cylinder re-grind size to allow for some metal removal during honing. The usual allowance for honing is 0.001 in. If a final cylinder bore size of 3.890 in. is desired, specify the re-grind size of 3.889 in., and then hone to 3.890 in.

There are several different makes and models of cylinder hones. The burnishing hone is used only to produce the desired finish on the cylinder wall. The more elaborate micromatic hone can also be used to straighten out the cylinder wall. A burnishing hone (figure 10–21) should not be used in an attempt to straighten cylinder walls. Since the stones are only spring loaded, they will follow the contour of the cylinder wall and may aggravate a tapered condition.

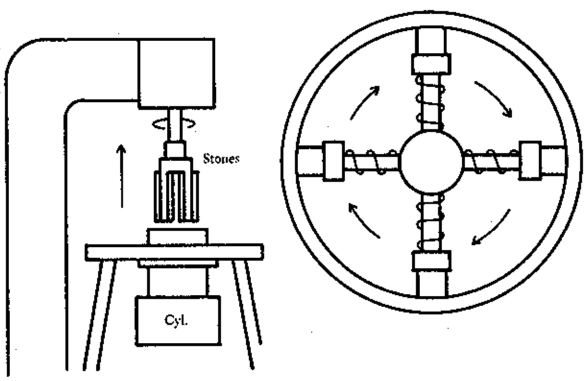


FIGURE 10–21. Cylinder honing.

After the cylinders have been re-ground, check the size and wall finish, and check for evidence of overheating or grinding cracks before installing on an engine.

CRANKSHAFT INSPECTION

Carefully inspect all surfaces of the shaft for cracks. Check the bearing surfaces for evidence of galling, scoring, or other damage. When a shaft is equipped with oil transfer tubes, check them for tightness. Some manufacturers recommend supplementing a visual inspection with one of the other forms of nondestructive testing, such as magnetic particle or radiography.

Use extreme care in inspecting and checking the crankshaft for straightness. Place the crankshaft in vee-blocks supported at the locations specified in the applicable engine overhaul manual. Using a surface plate and a dial indicator, measure the shaft runout. If the total indicator reading exceeds the dimensions given in the manufacturer's table of limits, the shaft must not be re-used. A bent crankshaft should not be straightened. Any attempt to do so will result in rupture of the nitrided surface of the bearing journals, a condition that will cause eventual failure of the crankshaft.

Measure the outside diameter of the crankshaft main and rod-bearing journals. Compare the resulting measurements with those in the table of limits.

Sludge Chambers

Some crankshafts are manufactured with hollow crankpins that serve as sludge removers. The sludge chambers may be formed by means of spool-shaped tubes pressed into the hollow crankpins or by plugs pressed into each end of the crankpin.

The sludge chamber or tubes must be removed for cleaning at overhaul. If these are not removed, accumulated sludge loosened during cleaning may clog the crankshaft oil passages and cause subsequent bearing failures. If the sludge chambers are formed by means of tubes pressed into the hollow crankpins, make certain they are re-installed correctly to avoid covering the ends of the oil passages.

CONNECTING RODS

The inspection and repair of connecting rods include: (1) Visual inspection, (2) checking of alignment, (3) re-bushing, and (4) replacement of bearings. Some manufacturers also specify a magnetic particle inspection of connecting rods.

Visual Inspection

Visual inspection should be done with the aid of a magnifying glass or bench microscope. A rod which is obviously bent or twisted should be rejected without further inspection.

Inspect all surfaces of the connecting rods for cracks, corrosion, pitting, galling, or other damage. Galling is caused by a slight amount of movement between the surfaces of the bearing insert and the connecting rod during periods of high loading, such as that produced during overspeed or excessive manifold pressure operation. The visual evidence produced by galling appears as if particles from one contacting surface had welded to the other. Evidence of any galling is sufficient reason for rejecting the complete rod assembly. Galling is a distortion in the metal and is comparable to corrosion in the manner in which it weakens the metallic structure of the connecting rod.

Checking Alignment

Check bushings that have been replaced to determine if the bushing and rod bores are square and parallel to each other. The alignment of a connecting rod can be checked several ways. One method requires a push fit arbor for each end of the connecting rod, a surface plate, and two parallel blocks of equal height.

To measure rod squareness (figure 10–22), or twist, insert the arbors into the rod bores. Place the parallel blocks on a surface plate. Place the ends of the arbors on the parallel blocks. Check the clearance at the points where the arbors rest on the blocks, using a thickness gage. This clearance, divided by the separation of the blocks in inches, will give the twist per inch of length.

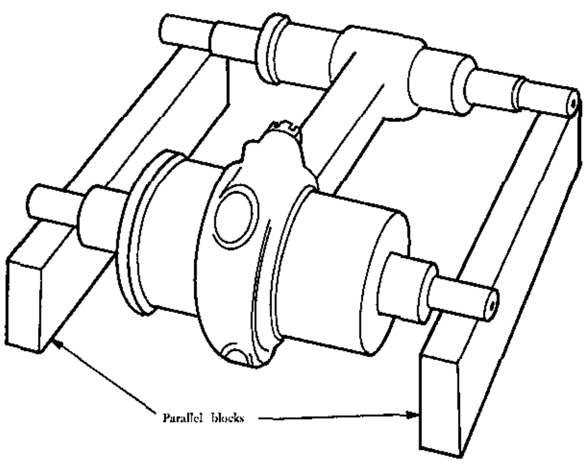


FIGURE 10–22. Checking connecting rod squareness.

To determine bushing or bearing parallelism (convergence), insert the arbors in the rod bores. Measure the distance between the arbors on each side of the connecting rod at points that are equidistant from the rod center line. For exact parallelism, the distances checked on both sides should be the same. Consult the manufacturer's table of limits for the amount of misalignment permitted.

The preceding operations are typical of those used for most reciprocating engines and are included to introduce some of the operations involved in engine overhaul. It would be impractical to list all the steps involved in the overhaul of an engine. It should be understood that there are other operations and inspections that must be performed. For exact information regarding a specific engine model, consult the manufacturer's overhaul manual.

BLOCK TESTING OF RECIPROCATING ENGINES

The information in this chapter on block testing of engines is intended to familiarize you with the procedures and equipment used in selecting for service only those engines that are in top mechanical condition.

Like a new or recently overhauled automobile engine, the aircraft engine must be in top mechanical condition. This condition must be determined after the engine has been newly assembled or completely overhauled. The method used is the block test, or run-in, which takes place at overhaul prior to delivery of the engine. It must be emphasized that engine run-in is as vital as any other phase of engine overhaul, for it is the means by which the quality of a new or newly overhauled engine is checked, and it is the final step in the preparation of an engine for service.

In many instances an engine has appeared to be in perfect mechanical condition before the engine run-in tests, but the tests have shown that it was actually in poor and unreliable mechanical condition. Thus, the reliability and potential service life of an engine is in question until it has satisfactorily passed the block test.

Block Test Purpose

The block test serves a dual purpose: first, it accomplishes piston ring run-in and bearing burnishing; and second, it provides valuable information that it used to evaluate engine performance and determine engine condition. To provide proper oil flow to the upper portion of the cylinder barrel walls with a minimum loss of oil, it is important that piston rings be properly seated in the cylinder in which they are installed. The process is called piston ring run-in and is accomplished chiefly by controlled operation of the engine in the high-speed range. Improper piston ring conditioning or run-in may result in unsatisfactory engine operation. A process called "bearing burnishing" creates a highly polished surface on new bearings and bushings installed during overhaul. The burnishing is usually accomplished during the first periods of the engine run-in at comparatively slow engine speeds.

Block-Test Requirements

The operational tests and test procedures vary with individual engines, but the basic requirements are discussed in the following paragraphs. The failure of any internal part during engine run-in requires that the engine be returned for replacement of the necessary units, and then be completely re-tested. If any component part of the basic engine should fail, a new unit is installed; a minimum operating time is used to check the engine with the new unit installed.

After an engine has successfully completed block-test requirements, it is then specially treated to prevent corrosion. During the final run-in period at block test, the engines are operated on the proper grade of fuel prescribed for the particular kind of engine. The oil system is serviced with a mixture of corrosion-preventive compound and engine oil. The temperature of this mixture is maintained at 105° to 121° C. Near the end of final run-in CPM (corrosion-preventive mixture) is used as the engine lubricant; and the engine induction passages and combustion chambers are also treated with CPM by an aspiration method (CPM is drawn or breathed into the engine).

Mobile Stand Testing of Reciprocating Engines

The mobile stand testing of reciprocating engines is much the same as for the block testing of reciprocating engines. They both have the same purpose; *i.e.*, to ensure that the engine is fit to be installed on an aircraft. Once the engine has been operated on the mobile test stand and any faults or troubles corrected, it is presumed that the engine will operate correctly on the aircraft.

A typical mobile test stand consists of a frame, engine mount, control booth, and trailer welded or bolted together. The engine test stand mount and firewall are located toward the rear of the trailer deck and afford accessibility to the rear of the engine. The engine test stand mount is a steel structure of uprights, braces, and crossmembers welded and bolted together forming one unit. The rear stand brace has nonskid steel steps welded in place to permit the mechanic to climb easily to the top of the engine accessory section. The front side of the engine mount has steel panels incorporating cannon plugs for the electrical connections to the engine. Also, there are fittings on the steel panels for the quick connection of the fluid lines to the engine. The hydraulic tank is located on the rear side of the engine test stand mount. Finally, the mobile engine test stand has outlet plugs for the communication system.

The control booth is located in the middle of the trailer and houses the engine controls and instrument panels.

The most important thing about positioning a mobile test stand is to face the propeller directly into the wind. If this is not done, engine testing will not be accurate.

Block Test Instruments

The block-test operator's control room houses the controls used to operate the engine and the instruments used to measure various temperatures and pressures, fuel flow, and other factors. These devices are necessary in providing an accurate check and an evaluation of the operating engine. The control room is separate from, but adjacent to, the space (test cell) that houses the engine being tested.

The safe, economical, and reliable testing of modern aircraft engines depends largely upon the use of instruments. In engine run-in procedures, the same basic engine instruments are used as when the engine is installed in the aircraft, plus some additional connections to these instruments and some indicating and measuring devices that cannot be practically installed in the aircraft. Instruments used in the testing procedures are inspected and calibrated periodically, as are instruments installed in the aircraft; thus, accurate information concerning engine operation is ensured.

Engine instruments are operated in several different fashions, some mechanically, some electrically, and some by the pressure of a liquid. This chapter will not discuss how they operate, but rather the information they give, their common names, and the markings on them. The instruments to be covered are:

(1) Carburetor air temperature gage.
(2) Fuel pressure gage.
(3) Fuel flowmeter.
(4) Manifold pressure gage.
(5) Oil temperature gage.
(6) Oil pressure gage.
(7) Tachometer.
(8) Cylinder head temperature gage.
(9) Torquemeter.
(10) Suction gage.
(11) Oil-weighing system.
(12) Metering differential manometer.

Instrument markings and the interpretation of these markings will be discussed before considering the individual instruments.

Instrument markings indicate ranges of operation or minimum and maximum limits, or both. Generally, the instrument marking system consists of four colors (red, yellow, blue, and green) and intermediate blank spaces.

A red line, or mark indicates a point beyond which a dangerous operating condition exists, and a red arc indicates a dangerous operating range. Of the two, the red mark is used more commonly and is located radially on the cover glass or dial face.

The yellow arc covers a given range of operation and is an indication of caution. Generally, the yellow arc is located on the outer circumference of the instrument cover glass or dial face.

The blue arc like the yellow, indicates a range of operation. The blue arc might indicate, for example, the manifold pressure gage range in which the engine can be operated with the carburetor control set at automatic lean. The blue arc is used only with certain engine instruments, such as the tachometer, manifold pressure, cylinder head temperature, and torquemeter.

The green arc shows a normal range of operation. When used on certain engine instruments, however, it also means that the engine must be operated with an automatic rich carburetor setting when the pointer is in this range.

When the markings appear on the cover glass, a *white line* is used as an index mark, often called a slippage mark. The white radial mark indicates any movement between the cover glass and the case, a condition that would cause mislocation of the other range and limit markings.

The instruments illustrated in figures 10–23 through 10–31 are range marked. The portion of the dial that is range marked on the instruments is also shown expanded for instructional purposes. The expanded portion is set off from the instrument to make it easier to identify the instrument markings.

Carburetor Air Temperature Indicator

Measured at the carburetor entrance, CAT (carburetor air temperature) is regarded by many as an indication of induction system ice formation. Although it serves this purpose, it also provides many other important items of information.

The powerplant is a heat machine, and the temperature of its components or the fluids flowing through it affects the combustion process either directly or indirectly. The temperature level of the induction air affects not only the charge density but also the vaporization of the fuel.

In addition to the normal use of CAT, it will be found useful for checking induction system condition. Backfiring will be indicated as a momentary rise on the gage, provided it is of sufficient severity for the heat to be sensed at the carburetor air-measuring point. A sustained induction system fire will show a continuous increase of carburetor air temperature.

The CAT should be noted before starting and just after shutdown. The temperature before starting is the best indication of the temperature of the fuel in the carburetor body and tells whether vaporization will be sufficient for the initial firing or whether the mixture must be augmented by priming. If an engine has been shut down for only a short time, the residual heat in the carburetor may make it possible to rely on the vaporizing heat in the fuel and powerplant, and priming would then be unnecessary. After shutdown, a high CAT is a warning that the fuel trapped in the carburetor will expand, producing high internal pressure. When a high temperature is present at this time, the fuel line and manifold valves should be open so that the pressure can be relieved by allowing fuel passage back to the tank.

The carburetor air temperature gage indicates the temperature of the air before it enters the carburetor. The temperature reading is sensed by a bulb. In the test cell the bulb is located in the air intake passage to the engine, and in an aircraft it is located in the ram-air intake duct. The carburetor air temperature gage is calibrated in the centigrade scale. Figure 10–23 shows a typical carburetor air temperature gage or CAT. This gage, like many other multi-engine aircraft instruments, is a dual gage; that is, two gages, each with a separate pointer and scale, are used in the same case. Notice the range markings used. The yellow arc indicates a range from −10° C. to +15° C., since the danger of icing occurs between these temperatures. The green range indicates the normal operating range from +15° C. to +40° C. The red line indicates the maximum operating temperature of 40° C.; any operation at a temperature over this value places the engine in danger of detonation.

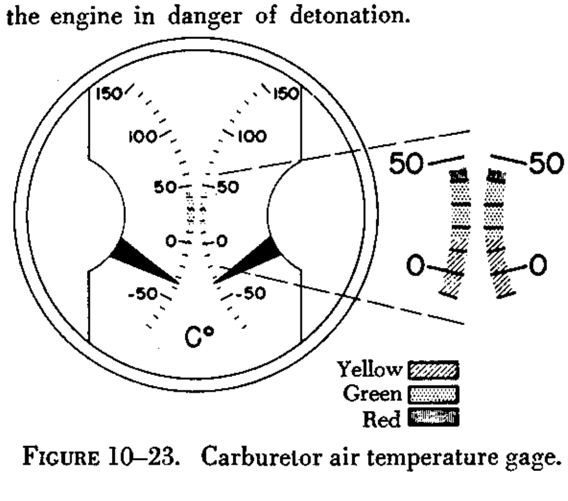


FIGURE 10–23. Carburetor air temperature gage.

Fuel Pressure Indicator

The fuel pressure gage is calibrated in pounds per square inch of pressure. It is used during the block test run-in to measure engine fuel pressure at the carburetor inlet, the fuel feed valve discharge nozzle, and the main fuel supply line. Fuel gages are located in the operator's control room and are connected by flexible lines to the different points at which pressure readings are desired during the testing procedures.

In some aircraft installations, the fuel pressure is sensed at the carburetor inlet of each engine, and the pressure is indicated on individual gages (figure 10–24) on the instrument panel. The dial is calibrated in 1-p.s.i. graduations, and every fifth graduation line is extended and numbered. The numbers range from 0 to 25. The red line on the dial at the 16-p.s.i. graduation shows the minimum fuel pressure allowed during flight. The green arc shows the desired range of operation, which is 16 to 18 p.s.i. The red line at the 18-p.s.i. graduation indicates the maximum allowable fuel pressure. Fuel pressures vary with the type of carburetor installation and the size of the engine. In most reciprocating engines that use pressure injection carburetion, the fuel pressure range is the same as illustrated in figure 10–24.

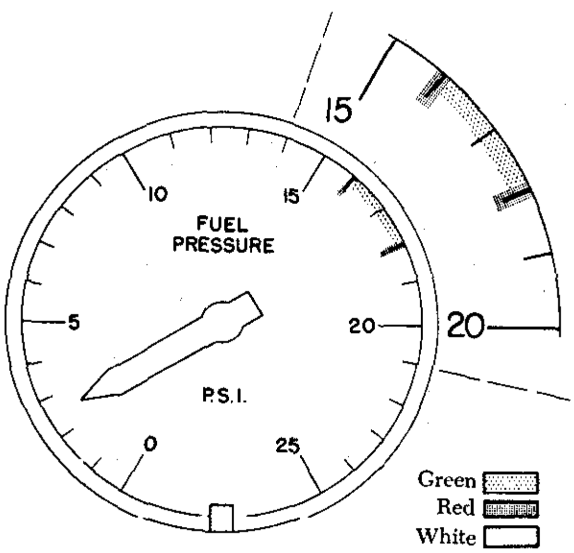


FIGURE 10–24. Fuel pressure gage.

When float-type carburetors or low-pressure carburetion systems are used, the fuel pressure range is of a much lower value; the minimum allowable pressure is 3 p.s.i., and the maximum is 5 p.s.i. with the desired range of operation between 3 and 5 p.s.i.

Fuel Flowmeter

The fuel flowmeter measures the amount of fuel delivered to the carburetor. During engine block-test procedures, the fuel flow to the engine is measured by a series of calibrated tubes located in the control room. The tubes are of various sizes to indicate different volumes of fuel flow. Each tube contains a float that can be seen by the operator, and as the fuel flow through the tube varies, the float is either raised or lowered, indicating the amount of fuel flow. From these indications, the operator can determine whether an engine is operating at the correct fuel/air mixture for a given power setting.

In an aircraft installation, the fuel flow indicating system consists of a transmitter and an indicator for each engine. The fuel flow transmitter is conveniently mounted in the engine's accessory section and measures the fuel flow between the engine-driven fuel pump and the carburetor. The transmitter is an electrical device that is connected electrically to the indicator located on the aircraft operator's panel. The reading on the indicator is calibrated to record the amount of fuel flow in pounds of fuel per hour.

Manifold Pressure Indicator

The preferred type of instrument for measuring the manifold pressure is a gage that records the pressure as an absolute pressure reading. A mercury manometer, a tube calibrated in inches, is used during block-test procedures. It is partially filled with mercury and connected to the manifold pressure adapter located on the engine. Since it is impractical to install mercury manometers in an aircraft to record the manifold pressure of the engines, a specially designed manifold pressure gage that indicates absolute manifold pressure in inches of mercury is used.

On the manifold pressure gage, the blue arc represents the range within which operation with the mixture control in the "automatic-lean" position is permissible, and the green arc indicates the range within which the engine must be operated with the mixture control in the "normal" or rich position. The red arc indicates the maximum manifold pressure permissible during takeoff.

The manifold pressure gage range markings and indications vary with different kinds of engines and installations. Figure 10–25 illustrates the dial of a typical manifold pressure gage and shows how the range markings are positioned. The blue arc starts at the 24-in. Hg graduation, the minimum manifold pressure permissible in flight. The arc continues to the 35-in. Hg graduation and shows the range where operation in the "automatic-lean" position is permissible. The green arc starts at 35 in. Hg and continues to the 44-in. Hg graduation, indicating the range in which the operation in the "rich" position is required. Any operation above the value indicated by the high end of the green arc (44 in. Hg on the instrument dial in figure 10–25) would be limited to a continuous operation not to exceed 5 minutes. The red line at 49 in. Hg shows the manifold pressure recommended for takeoff; this pressure should not be exceeded. On installations where water injection is used, a second red line is located on the dial to indicate the maximum permissible manifold pressure for a "wet" takeoff.

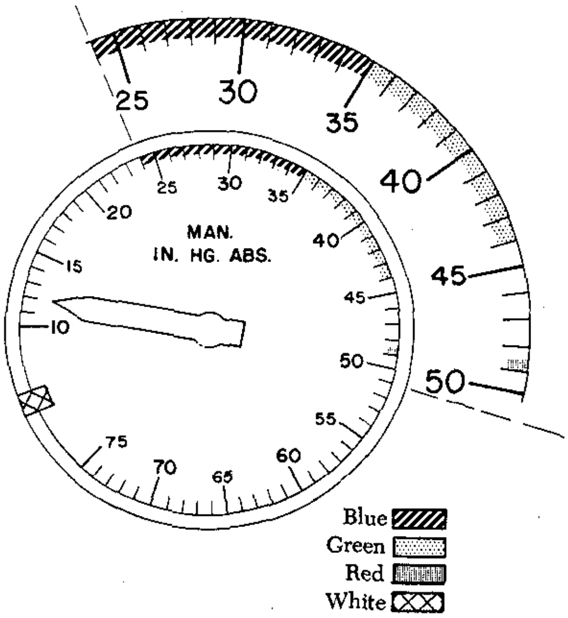


FIGURE 10–25. Manifold pressure gage.

Oil Temperature Indicator

During engine run-in at block test, engine oil temperature readings are taken at the oil inlet and outlet. From these readings, it can be determined if the engine heat transferred to the oil is low, normal, or excessive. This information is of extreme importance during the "breaking-in" process of large reciprocating engines. The oil temperature gage line in the aircraft is connected at the oil inlet to the engine.

Three range markings are used on the oil temperature gage. The red mark in figure 10–26, at 40° C. on the dial, shows the minimum oil temperature permissible for ground operational checks or during flight. The green mark between 60° and 75° C. shows the desired oil temperature for continuous engine operation. The red mark at 100° C. indicates the maximum permissible oil temperature.

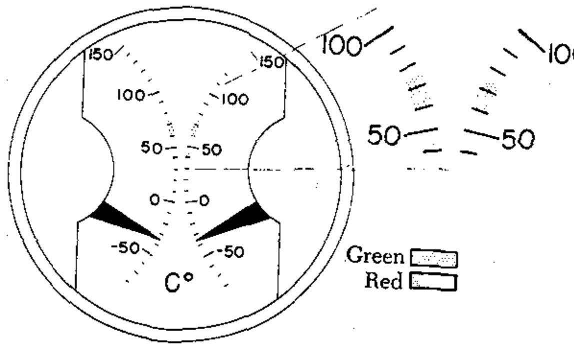


FIGURE 10–26. Oil temperature gage.

Oil Pressure Indicator

The oil pressure on block-test engines is checked at various points. The main oil pressure reading is taken at the pressure side of the oil pump. Other pressure readings are taken from the nose section and blower section; and when internal supercharging is used, a reading is taken from the high- and low-blower clutch.

Generally, there is only one oil pressure gage for each aircraft engine, and the connection is made at the pressure side (outlet) of the main oil pump.

The oil pressure gage dial, marked as shown in figure 10–27, does not show the pressure range or limits for all installations. The actual markings for specific aircraft may be found in the Aircraft Specifications or Type Certificate Data Sheets. The lower red line at 50 p.s.i. indicates the minimum oil pressure permissible in flight. The green arc between 60 to 85 p.s.i. shows the desired operating oil pressure range. The red line at 110 p.s.i. indicates maximum permissible oil pressure.

The oil pressure gage indicates the pressure (in p.s.i.) that the oil of the lubricating system is being supplied to the moving parts of the engine. The engine should be shut down immediately if the gage fails to register pressure when the engine is operating. Excessive oscillation of the gage pointer indicates that there is air in the lines leading to the gage or that some unit of the oil system is functioning improperly.

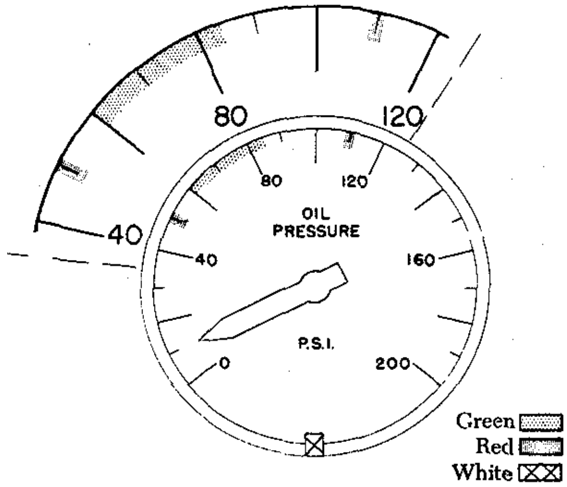


FIGURE 10–27. Oil pressure gage.

Tachometer Indicator

The tachometer shows the engine crankshaft r.p.m. The system used for block testing the engine is the same as the system in the aircraft installation.

Figure 10–28 shows a tachometer with range markings installed on the cover glass. The tachometer, often referred to as "TACH," is calibrated in hundreds with graduations at every 50-r.p.m. interval. The dial shown here starts at 5 (500 r.p.m.) and goes to 40 (4,000 r.p.m.).

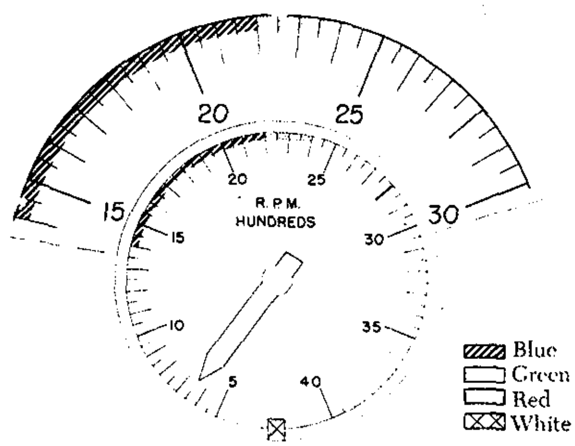


FIGURE 10–28. Tachometer.

The blue arc on the tachometer indicates the r.p.m. range within which auto-lean operation is permitted. The bottom of this arc, 1,400 r.p.m., indicates the minimum r.p.m. desirable in flight. The top of this blue arc, 2,200 r.p.m., indicates the r.p.m. at which the mixture control must be moved to auto-rich. The green arc indicates the r.p.m. range within which auto-rich operation is required. The top of the green arc, 2,400 r.p.m., indicates maximum continuous power. All operation above this r.p.m. is limited in time (usually 5 or 15 min.). The red line indicates the maximum r.p.m. permissible during takeoff; any r.p.m. beyond this value is an overspeed condition.

Cylinder Head Temperature Indicator

During the engine block-test procedures, a pyrometer indicates the cylinder head temperatures of various cylinders on the engine being tested. Thermocouples are connected to several cylinders, and by a selector switch any cylinder head temperature can be indicated on the pyrometer. There is one thermocouple lead and indicator scale for each engine installed in an aircraft.

Cylinder head temperatures are indicated by a gage connected to a thermocouple attached to the cylinder which tests show to be the hottest on an engine in a particular installation. The thermocouple may be placed in a special gasket located under a rear spark plug or in a special well in the top or rear of the cylinder head.

The temperature recorded at either of these points is merely a reference or control temperature; but as long as it is kept within the prescribed limits, the temperatures of the cylinder dome, exhaust valve, and piston will be within a satisfactory range. Since the thermocouple is attached to only one cylinder, it can do no more than give evidence of general engine temperature. While normally it can be assumed that the remaining cylinder temperatures will be lower, conditions such as detonation will not be indicated unless they occur in the cylinder that has the thermocouple attached.

The cylinder head temperature gage range marking is similar to that of the manifold pressure and tachometer indicator. The cylinder head temperature gage illustrated in figure 10–29 is a dual gage that incorporates two separate temperature scales. The scales are calibrated in increments of 10, with numerals at the 0°, 100°, 200°, and 300° graduations. The space between any two graduation marks represents 10° C.

The blue arc on the gage indicates the range within which operation is permitted in auto-lean. The bottom of this arc, 100° C., indicates the minimum desired temperature to ensure efficient engine operation during flight. The top of the blue arc, 230° C., indicates the temperature at which the mixture control must be moved to the "auto-rich" position. The green arc describes the range within which operation must be in auto-rich. The top of this arc, 248° C., indicates maximum continuous power; all operation above this temperature is limited in time (usually 5 to 15 min.). The red line indicates maximum permissible temperature, 260° C.

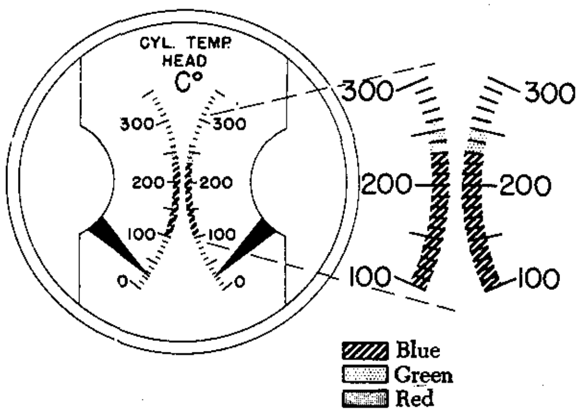


FIGURE 10–29. Cylinder head temperature gage.

Torquemeter

The torque pressure system is used to indicate actual engine power output at various power settings. The torquemeter indicates the amount of torque pressure in p.s.i. The instrument is usually numbered as shown in figure 10–30 and calibrated at 5-p.s.i. intervals.

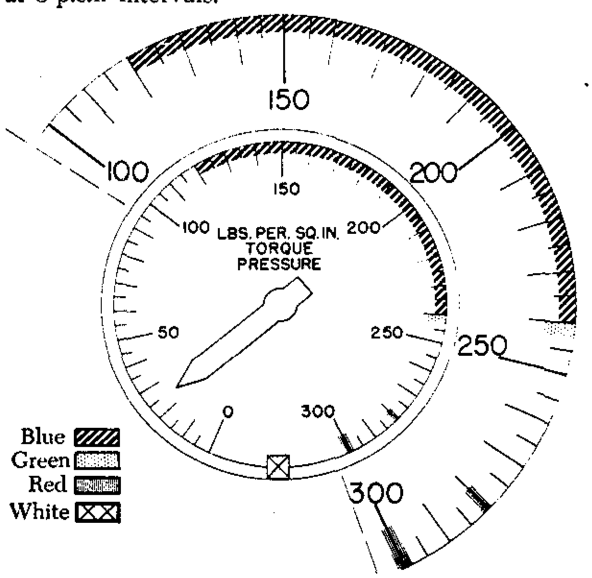


FIGURE 10–30. Torquemeter.

The blue arc on the torquemeter indicates the permissible range of operation in auto-lean. The bottom of this arc, 120 p.s.i., is the minimum desirable during flight, as determined by the particular engine characteristics. The top of this arc, 240 p.s.i., indicates the torque pressure at which the mixture control must be moved to "auto-rich."

The green line indicates the point of maximum continuous power. At and above this point the "auto-rich" setting must be used. Any operation above this indicated torque pressure must be limited in time (usually 5 to 15 min.). If a green arc is used in place of the green line, the bottom of the arc is the point above which operation must be limited.

Two red radial marks are generally shown on the torquemeter. The short red line at 280 p.s.i. indicates maximum torque pressure when water injection is not used. The long red line (300 p.s.i.) represents maximum torque pressure when using water injection.

Suction Gage

The suction gage is not classed as an engine instrument, since it does not indicate any information in determining efficient engine operation. The mechanic is concerned with it because he is responsible for adjusting the suction regulator and checking the suction gage reading during the engine operational checks.

The suction gage (figure 10–31) is calibrated to indicate reduction of pressure below atmospheric pressure in inches of mercury; the space between the graduation lines represents 0.2 in. Hg. The red line at 3.75 in. Hg indicates minimum desirable suction. The green arc shows the desirable suction range, 3.75 in. to 4.25 in. Hg. The red line at 4.25 in. Hg indicates the maximum desirable suction.

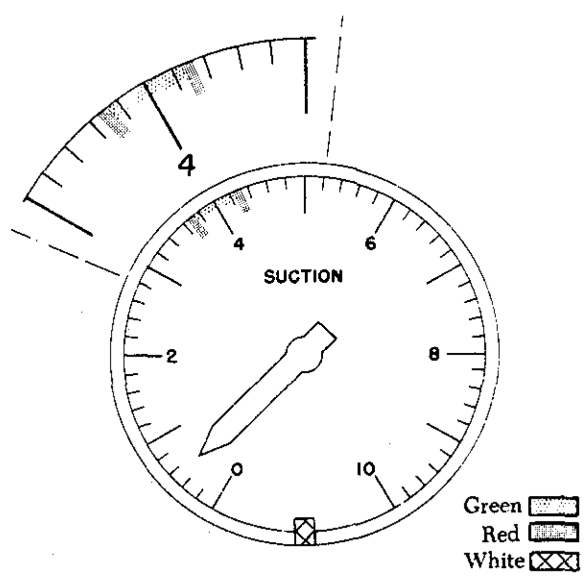


FIGURE 10–31. Suction gage.

Oil-Weighing System

The oil-weighing system determines oil consumption during engine run-in at block test and measures the exact amount of oil consumed by the engine during various periods of operation. The system consists of a tank supplying oil to the engine, an oil-inlet line to the engine, a return line from the engine oil scavenging and cooling system, and a weighing scale that registers weights up to and including the weight of the full oil tank. The oil consumed by the engine is determined merely by subtracting the scale reading at any given time from the full-tank weight.

Metering Differential Manometer

The metering differential manometer, used during block testing, is a 100-in., single-tube water manometer (a gage for measuring pressure). It is connected to the carburetor in such a manner that it measures the pressure difference (air metering force) between A-chamber and B-chamber (on engines that use pressure injection carburetion). Through the use of this instrument, the metering characteristics of the carburetor are closely observed during the engine run-in tests.

General Instrumentation

Many of the miscellaneous gages and devices indicate only that a system is functioning or has failed to function. On some aircraft a warning light illuminates when the fuel presure is low. A similar light is used for oil pressure systems.

RECIPROCATING ENGINE OPERATION

General

The operation of the powerplant is controlled from the cockpit. Some installations have numerous control handles and levers connected to the engine by rods, cables, bellcranks, pulleys, etc. The control handles, in most cases, are conveniently mounted on quadrants in the cockpit. Placards or markings are placed on the quadrant to indicate the functions and positions of the levers. In some installations, friction clutches are installed to hold the controls in place.

Manifold pressure, r.p.m., engine temperature, oil temperature, carburetor air temperature, and the fuel/air ratio can be controlled by manipulating the cockpit controls. Coordinating the movement of the controls with the instrument readings protects against exceeding operating limits.

Engine operation is usually limited by specified operating ranges of the following:

(1) Crankshaft speed (r.p.m.).
(2) Manifold pressure.
(3) Cylinder head temperature.
(4) Carburetor air temperature.
(5) Oil temperature.
(6) Oil pressure.
(7) Fuel pressure.
(8) Fuel/air mixture setting.

The procedures, pressures, temperatures and r.p.m.'s used throughout this section are solely for the purpose of illustration and do not have general application. The operating procedures and limits used on individual makes and models of aircraft engines vary considerably from the values shown here. For exact information regarding a specific engine model, consult the applicable instructions.

Engine Instruments

The term "engine instruments" usually includes all instruments required to measure and indicate the functioning of the powerplant. The engine instruments are generally installed on the instrument panel so that all of them can easily be observed at one time.

Some of the simple, light aircraft may be equipped only with a tachometer, oil pressure gage, and oil temperature gages. The heavier, more complex aircraft will have all or part of the following engine instruments:

(1) Oil pressure indicator and warning system.
(2) Oil temperature indicator.
(3) Fuel pressure indicator and warning system.
(4) Carburetor air temperature indicator.
(5) Cylinder head temperature indicator for air-cooled engines.
(6) Manifold pressure indicator.
(7) Tachometer.
(8) Fuel quantity indicator.
(9) Fuel flowmeter or fuel mixture indicator.
(10) Oil quantity indicator.
(11) Augmentation liquid quantity indicator.
(12) Fire-warning indicators.
(13) A means to indicate when the propeller is in reverse pitch.
(14) BMEP (brake mean effective pressure) indicator.

Engine Starting

Correct starting technique is an important part of engine operation. Improper procedures often are used because some of the basic principles involved in engine operation are misunderstood. Typical procedures for starting reciprocating engines are discussed in the Airframe and Powerplant Mechanics General Handbook, AC 65–9, Chapter 11. In general, two different starting procedures will cover all engines. One procedure is for engines using float-type carburetors, and the other for engines with pressure-injection carburetors. The specific manufacturer's procedures for a particular engine and aircraft combination should always be followed.

Engine Warm-up

Proper engine warm-up is important, particularly when the condition of the engine is unknown. Improperly adjusted idle mixture, intermittently firing spark plugs, and improperly adjusted engine valves all have an overlapping effect on engine stability. Therefore, the warm-up should be made at the engine speed where maximum engine stability is obtained. Experience has shown that the optimum warm-up speed is from 1,000 to 1,600 r.p.m. The actual speed selected should be the speed at which engine operation is the smoothest, since the smoothest operation is an indication that all phases of engine operation are the most stable.

Most Pratt and Whitney engines incorporate temperature-compensated oil pressure relief valves. This type of relief valve results in high engine oil pressures immediately after the engine starts, if oil temperatures are below 40° C. Consequently, start the warm-up of these engines at approximately 1,000 r.p.m. and then move to the higher, more stable engine speed as soon as oil temperature reaches 40° C.

During warm-up, watch the instruments associated with engine operation. This will aid in making sure that all phases of engine operation are normal. For example, engine oil pressure should be indicated within 30 sec. after the start. Furthermore, if the oil pressure is not up to or above normal within 1 min. after the engine starts, the engine should be shut down. Cylinder head or coolant temperatures should be observed continually to see that they do not exceed the maximum allowable limit.

A lean mixture should not be used to hasten the warm-up. Actually, at the warm-up r.p.m., there is very little difference in the mixture supplied to the engine, whether the mixture is in a "rich" or "lean" position, since metering in this power range is governed by throttle position.

Carburetor heat can be used as required under conditions leading to ice formation. For engines equipped with a float-type carburetor, it is desirable to raise the carburetor air temperature during warm-up to prevent ice formation and to ensure smooth operation.

The magneto safety check can be performed during warm-up. Its purpose is to ensure that all ignition connections are secure and that the ignition system will permit operation at the higher power settings used during later phases of the ground check. The time required for proper warm-up gives ample opportunity to perform this simple check, which may disclose a condition that would make it inadvisable to continue operation until after corrections have been made.

The magneto safety check is conducted with the propeller in the high r.p.m. (low pitch) position, at approximately 1,000 r.p.m. Move the ignition switch from "both" to "right" and return to "both"; from "both" to "left" and return to "both"; from "both" to "off" momentarily and return to "both."

While switching from "both" to a single magneto position, a slight but noticeable drop in r.p.m. should occur. This indicates that the opposite magneto has been properly grounded out. Complete cutting out of the engine when switching from "both" to "off" indicates that both magnetos are grounded properly. Failure to obtain any drop while in the single magneto position, or failure of the engine to cut out while switching to "off" indicates that one or both ground connections are not secured.

Ground Check

The ground check is performed to evaluate the functioning of the engine by comparing power input, as measured by manifold pressure, with power output, as measured by r.p.m. or torque pressure.

The engine may be capable of producing a prescribed power, even rated takeoff, and not be functioning properly. Only by comparing the manifold pressure required during the check against a known standard will an unsuitable condition be disclosed. The magneto check can also fail to show up shortcomings, since the allowable r.p.m. dropoff is only a measure of an improperly functioning ignition system and is not necessarily affected by other factors. Conversely, it is possible for the magneto check to prove satisfactory with an unsatisfactory condition present elsewhere in the engine.

The ground check is made after the engine is thoroughly warm. It consists of checking the operation of the powerplant and accessory equipment by ear, by visual inspection, and by proper interpretation of instrument readings, control movements, and switch reactions.

During the ground check, the aircraft should be headed into the wind, if possible, to take advantage of the cooling airflow. A ground check may be performed as follows:

Control Position Check—

Cowl flaps....................Open.
Mixture ....Rich.
Propeller ....High r.p.m.
Carburetor heat..........Cold.
Carburetor air filter ..As required.
Supercharger control..Low, neutral, or off position (where applicable).

Procedure—

(1) Check propeller according to propeller manufacturer's instruction.
(2) Open throttle to manifold pressure equal to field barometric pressure.
(3) Switch from "both" to "right" and return to "both." Switch from "both" to "left" and return to "both." Observe the r.p.m. drop while operating on the right and left positions. The maximum drop should not exceed that specified by the engine manufacturer.
(4) Check the fuel pressure and oil pressure. They must be within the established tolerance for the subject engine.
(5) Note r.p.m.
(6) Retard throttle.

In addition to the operations outlined above, check the functioning of various items of aircraft equipment, such as generator systems, hydraulic systems, etc.

Propeller Pitch Check

The propeller is checked to ensure proper operation of the pitch control and the pitch-change mechanism. The operation of a controllable pitch propeller is checked by the indications of the tachometer and manifold pressure gage when the propeller governor control is moved from one position to another. Because each type of propeller requires a different procedure, the applicable manufacturer's instructions should be followed.

Power Check

Specific r.p.m. and manifold pressure relationship should be checked during each ground check. This can be done at the time the engine is run-up to make the magneto check. The basic idea of this check is to measure the performance of the engine against an established standard. Calibration tests have determined that the engine is capable of delivering a given power at a given r.p.m. and manifold pressure. The original calibration, or measurement of power, is made by means of a dynamometer. During the ground check, power is measured with the propeller. With constant conditions of air density, the propeller, at any fixed-pitch position, will always require the same r.p.m. to absorb the same horsepower from the engine. This characteristic is used in determining the condition of the engine.

With the governor control set for full low pitch, the propeller operates as a fixed-pitch propeller. Under these conditions, the manifold pressure for any specific engine, with the mixture control in auto-rich, indicates whether all the cylinders are operating properly. With one or more dead or intermittently firing cylinders, the operating cylinders must provide more power for a given r.p.m. Consequently, the carburetor throttle must be opened further, resulting in higher manifold pressure. Different engines of the same model using the same propeller installation and in the same geographical location should require the same manifold pressure, within 1 in. Hg, to obtain r.p.m. when the barometer and temperature are at the same readings. A higher-than-normal manifold pressure usually indicates a dead cylinder or late ignition timing. An excessively low manifold pressure for a particular r.p.m. usually indicates that the ignition timing is early. Early ignition can cause detonation and loss of power at takeoff power settings.

Before starting the engine, observe the manifold pressure gage, which should read approximately atmospheric (barometric) pressure when the engine is not running. At sea level this is approximately 30 in. Hg, and at fields above sea level the atmospheric pressure will be less, depending on the height above sea level.

When the engine is started and then accelerated, the manifold pressure will decrease until about 1,600 or 1,700 r.p.m. is reached, and then it will begin to rise. At approximately 2,000 r.p.m., with the propeller in low-pitch position, the manifold pressure should be the same as the field barometric pressure. If the manifold pressure gage reading (field barometric pressure) was 30 in. Hg before starting the engine, the pressure reading should return to 30 in. Hg at approximately 2,000 r.p.m. If the manifold pressure gage reads 26 in. Hg before starting, it should read 26 in. Hg again at approximately 2,000 r.p.m. The exact r.p.m. will vary with various models of engines or because of varying propeller characteristics. In certain installations, the r.p.m. needed to secure field barometric pressure may be as high as 2,200 r.p.m. However, once the required r.p.m. has been established for an installation, any appreciable variation indicates some malfunctioning. This variation may occur because the low-pitch stop of the propeller has not been properly set or because the carburetor or ignition system is not functioning properly.

The accuracy of the power check may be affected by the following variables:

(1) ***Wind.*** Any appreciable air movement (5 m.p.h. or more) will change the air load on the propeller blade when it is in the fixed-pitch position. A head wind will increase the r.p.m. obtainable with a given manifold pressure. A tail wind will decrease the r.p.m.

(2) ***Atmospheric Temperatures.*** The effects of variations in atmospheric temperature tend to cancel each other. Higher carburetor intake and cylinder temperatures tend to lower the r.p.m., but the propeller load is lightened because of the less dense air.

(3) ***Engine and Induction System Temperature.*** If the cylinder and carburetor temperatures are high because of factors other than atmospheric temperature, a low r.p.m. will result since the power will be lowered without a compensating lowering of the propeller load.

(4) ***Oil Temperature.*** Cold oil will tend to hold down the r.p.m. since the higher viscosity results in increased friction horsepower losses.

The addition of a torquemeter can increase the accuracy of the power check by providing another measurement of power output. As long as the check is performed with the blades in a known fixed-pitch position, the torquemeter provides no additional information, but its use can increase accuracy; in the frequent instances where the tachometer scales are graduated coarsely, the tachometer gage reading may be a more convenient source of the desired information.

Ignition System Operational Check

In performing the ignition system operational check (magneto check), the power-absorbing characteristics of the propeller in the low fixed-pitch position are utilized. In switching to individual magnetos, cutting out the opposite plugs results in a slower rate of combustion, which gives the same effect as retarding the spark advance. The drop in engine speed is a measure of the power loss at this slower combustion rate.

When the magneto check is performed, a drop in torquemeter pressure indication is a good supplement to the variation in r.p.m.; and in cases where the tachometer scale is graduated coarsely, the torquemeter variation may give more positive evidence of the power change when switching to the individual magneto condition. A loss in torquemeter pressure not to exceed 10% can be expected when operating on a single magneto. By comparing the r.p.m. drop with a known standard, the following are determined:

(1) Proper timing of each magneto.

(2) General engine performance as evidenced by smooth operation.

(3) Additional check of the proper connection of the ignition leads.

Any unusual roughness on either magneto is an indication of faulty ignition caused by plug fouling or by malfunctioning of the ignition system. The operator should be very sensitive to engine roughness during this check. Lack of dropoff in r.p.m. may be an indication of faulty grounding of one side of the ignition system. Complete cutting out when switching to one magneto is definite evidence that its side of the ignition system is not functioning. Excessive difference in r.p.m. dropoff between the left and right switch positions can indicate a difference in timing between the left and right magnetos.

Sufficient time should be given the check on each single switch position to permit complete stabilization of engine speed and manifold pressure. There is a tendency to perform this check too rapidly with resultant wrong indications. Single ignition operation for as long as 1 min. is not excessive.

Another point that must be emphasized is the danger of a sticking tachometer. The tachometer should be tapped lightly to make sure the indicator needle moves freely. In some cases, tachometer sticking has caused errors in indication to the extent of 100 r.p.m. Under such conditions the ignition system could have had as much as a 200-r.p.m. drop with only a 100-r.p.m. drop indicated on the instrument. In most cases, tapping the instrument eliminates the sticking and results in accurate readings.

In recording the results of the ignition system check, record the amount of the total r.p.m. drop which occurs rapidly and the amount which occurs slowly. This breakdown in r.p.m. drop provides a means of pinpointing certain troubles in the ignition system. It can save a lot of time and unnecessary work by confining maintenance to the specific part of the ignition system which is responsible for the trouble.

Fast r.p.m. drop is usually the result of either faulty spark plugs or faulty ignition harness. This is true because faulty plugs or leads take effect at once. The cylinder goes dead or starts firing intermittently the instant the switch is moved from "both" to the "right" or "left" position.

Slow r.p.m. drop usually is caused by incorrect ignition timing or faulty valve adjustment. With late ignition timing, the charge is fired too late with relation to piston travel for the combustion pressures to build up to the maximum at the proper time. The result is a power loss greater than normal for single ignition because of the lower peak pressures obtained in the cylinder. However, this power loss does not occur as rapidly as that which accompanies a dead spark plug. This explains the slow r.p.m. drop as compared to the instantaneous drop with a dead plug or defective lead. Incorrect valve clearances, through their effect on valve overlap, can cause the mixture to be too rich or too lean. The too-rich or too-lean mixture may affect one plug more than another, because of the plug location, and show up as a slow r.p.m. drop on the ignition check.

Cruise Mixture Check

The cruise mixture check is a check of carburetor metering. Checking the carburetor metering characteristics at 200- to 300-r.p.m. intervals, from 800 r.p.m. to the ignition system check speed, gives a complete pattern for the basic carburetor performance.

To perform this test, set up a specified engine speed with the propeller in full low pitch. The first check is made at 800 r.p.m. With the carburetor mixture control in the "automatic-rich" position, read the manifold pressure. With the throttle remaining in the same position, move the mixture control to the "automatic lean" position. Read and record the engine speed and manifold pressure readings. Repeat this check at 1,000, 1,200, 1,500, 1,700, and 2,000 r.p.m. or at the r.p.m.'s specified by the manufacturer. Guard against a sticking instrument by tapping the tachometer.

Moving the mixture control from the "auto-rich" position to the "auto-lean" position checks the cruise mixture. In general, the speed should not increase more than 25 r.p.m. or decrease more than 75 r.p.m. during the change from "auto-rich" to "auto-lean."

For example, suppose that the r.p.m. change is above 100 for the 800 to 1,500 r.p.m. checks; it is obvious that the probable cause is an incorrect idle mixture. When the idle is adjusted properly, carburetion will be correct throughout the range.

Idle Speed and Idle Mixture Checks

Plug fouling difficulty is the inevitable result of failure to provide a proper idle mixture setting. The tendency seems to be to adjust the idle mixture on the extremely rich side and to compensate for this by adjusting the throttle stop to a relatively high r.p.m. for minimum idling. With a properly adjusted idle mixture setting, it is possible to run the engine at idle r.p.m. for long periods. Such a setting will result in a minimum of plug fouling and exhaust smoking and it will pay dividends from the savings on the aircraft brakes after landing and while taxiing.

If the wind is not too strong, the idle mixture setting can be checked easily during the ground check as follows:

(1) Close throttle.

(2) Move the mixture control to the "idle cutoff" position and observe the change in r.p.m. Return the mixture control back to the "rich" position before engine cutoff.

As the mixture control lever is moved into idle cutoff, and before normal dropoff, one of two things may occur momentarily:

(1) The engine speed may increase. An increase in r.p.m., but less than that recommended by the manufacturer (usually 20 r.p.m.), indicates proper mixture strength. A greater increase indicates that the mixture is too rich.

(2) The engine speed may not increase or may drop immediately. This indicates that the idle mixture is too lean.

The idle mixture should be set to give a mixture slightly richer than best power, resulting in a 10- to 20-r.p.m. rise after idle cutoff.

The idle mixture of engines equipped with electric primers can be checked by flicking the primer switch momentarily and noting any change in manifold pressure and r.p.m. A decrease in r.p.m. and an increase in manifold pressure will occur when the primer is energized if the idle mixture is too rich. If the idle mixture is adjusted too lean, the r.p.m. will increase and manifold pressure will decrease.

Two-Speed Supercharger Check

To check the operation of the two-speed blower mechanism, set the engine speed to a sufficiently high r.p.m. to obtain the minimum oil pressure required for clutch operation. Move the supercharger control to the "high" position. A momentary drop in oil pressure should accompany the shift. Open the throttle to obtain not more than 30 in. Hg manifold pressure. When the engine speed has stabilized, observe the manifold pressure, and shift the supercharger control to the "low" position without moving the throttle. A sudden decrease in manifold pressure indicates that the two-speed supercharger drive is functioning properly. If no decrease occurs, the clutch may be inoperative.

As soon as the change in manifold pressure has been checked, reduce the engine speed to 1,000 r.p.m., or less. If the shift of the supercharger did not appear to be satisfactory, operate the engine at 1,000 r.p.m. for 2 or 3 min. to permit heat generated during the shift to dissipate from the clutches, and then repeat the shifting procedure. Blower shifts should be made without hesitation or dwelling between the control positions to avoid dragging or slipping the clutches. Make sure the supercharger control is in the "low" position when the ground check is completed.

Acceleration and Deceleration Checks

The acceleration check is made with the mixture control in both auto-rich and auto-lean. Move the throttle from idle to takeoff smoothly and rapidly. The engine r.p.m. should increase without hesitation and with no evidence of engine backfire.

This check will, in many cases, show up borderline conditions that will not be revealed by any of the other checks. This is true because the high cylinder pressures developed during this check put added strain on both the ignition system and the fuel metering system. This added strain is sufficient to point out certain defects that otherwise go unnoticed. Engines must be capable of rapid acceleration, since in an emergency, such as a go-around during landing, the ability of an engine to accelerate rapidly is sometimes the difference between a successful go-around and a crash landing.

The deceleration check is made while retarding the throttle from the acceleration check. Note the engine behavior. The r.p.m. should decrease smoothly and evenly. There should be little or no tendency for the engine to afterfire.

Engine Stopping

With each type of carburetor installation, specific procedures are used in stopping the engine. The general procedure outlined in the following paragraphs reduces the time required for stopping, minimizes backfiring tendencies, and, most important, prevents overheating of tightly baffled air-cooled engines during operation on the ground.

In stopping any aircraft engine, the controls are set as follows, irrespective of carburetor type or fuel system installation.

(1) Cowl flaps are always placed in the "full open" position to avoid overheating the engine, and are left in that position after the engine is stopped to prevent engine residual heat from deteriorating the ignition system.

(2) Oil cooler shutters should be "full open" to allow the oil temperature to return to normal.

(3) Intercooler shutters are kept in the "full open" position.

(4) Carburetor air-heater control is left in the "cold" position to prevent damage which may occur from backfire.

(5) Turbocharger waste gates are set in the "full open" position.

(6) Two-speed supercharger control is placed in the "low blower" position.

(7) A two-position propeller will usually be stopped with the control set in the "high pitch" (decrease r.p.m.) position. Open the throttle to approximately 1,200 r.p.m. and shift the propeller control to "high pitch" position. Allow the engine to operate approximately 1 minute before stopping, so that the oil dumped into the engine from the propeller may be scavenged and returned to the oil tank. However, to inspect the propeller piston for galling and wear and for other special purposes, this propeller may be stopped with the propeller control in "low pitch" (increase r.p.m.) position when the engine is stopped.

No mention is made of the throttle, mixture control, fuel selector valve, and ignition switches in the preceding set of directions because the operation of these controls varies with the type of carburetor used with the engine.

Engines equipped with a float-type carburetor without an idle cutoff unit are stopped as follows:

(1) Adjust the throttle to obtain an idling speed of approximately 600 to 800 r.p.m., depending on the type of engine.

(2) Close the fuel selector valve.

(3) Open the throttle slowly until the engine is operating at approximately 800 to 1,000 r.p.m.

(4) Observe the fuel pressure. When it drops to zero, turn the ignition switch to the "off" position and simultaneously move the throttle slowly to the "full open" position. This operation will remove the accelerating charge from the induction system and avoid the possibility of accidental starting.

(5) When the engine has stopped, place the fuel selector valve in the "on" position and refill the carburetor and fuel lines by using the auxiliary pump.

An engine equipped with a carburetor incorporating an idle cutoff is stopped as follows:

(1) Idle the engine by setting the throttle for 800 to 1,000 r.p.m.

(2) Move the mixture control to the "idle cutoff" position. In a pressure-type carburetor, this causes the cloverleaf valve to stop the discharge of fuel through the discharge nozzle. In a float-type carburetor, it equalizes the pressure in the float chamber and at the discharge nozzle.

(3) After the propeller has stopped rotating, place the ignition switch in the "off" position.

BASIC ENGINE OPERATING PRINCIPLES

A thorough understanding of the basic principles on which a reciprocating engine operates and the many factors which affect its operation is necessary to diagnose engine malfunctions. Some of these basic principles are reviewed not as a mere repetition of basic theory, but as a concrete, practical discussion of what makes for good or bad engine performance.

The conventional reciprocating aircraft engine operates on the four-stroke-cycle principle. Pressure from burning gases acts upon a piston, causing it to reciprocate back and forth in an enclosed cylinder. This reciprocating motion of the piston is changed into rotary motion by a crankshaft, to which the piston is coupled by means of a connecting rod. The crankshaft, in turn, is attached or geared to the aircraft propeller. Therefore, the rotary motion of the crankshaft causes the propeller to revolve. Thus, the motion of the propeller is a direct result of the forces acting upon the piston as it moves back and forth in the cylinder.

Four strokes of the piston, two up and two down, are required to provide one power impulse to the crankshaft. Each of these strokes is considered an event in the cycle of engine operation. Ignition of the gases (fuel/air mixture) at the end of the second, or compression, stroke makes a fifth event. Thus, the five events which make up a cycle of operation occur in four strokes of the piston.

As the piston moves downward on the first stroke (intake), the intake valve is open and the exhaust valve is closed. As air is drawn through the carburetor gasoline is introduced into the stream of air forming a combustible mixture.

On the second stroke, the intake closes and the combustible mixture is compressed as the piston moves upward. This is the compression stroke.

At the correct instant, an electric spark jumps across the terminals of the spark plug and ignites the fuel/air mixture. The ignition of the fuel/air mixture is timed to occur just slightly before the piston reaches top dead center.

As the mixture burns, temperature and pressure rise rapidly. The pressure reaches maximum just after the piston has passed top center. The expanding and burning gas forces the piston downward, transmitting energy to the crankshaft. This is the power stroke. Both intake and exhaust valves are closed at the start of the power stroke.

Near the end of the power stroke, the exhaust valve opens, and the burned gases start to escape through the exhaust port. On its return stroke, the piston forces out the remaining gases. This stroke, the exhaust stroke, ends the cycle. With the introduction of a new charge through the intake port, the action is repeated and the cycle of events occurs over and over again as long as the engine is in operation.

Ignition of the fuel charge must occur at a specific time in relation to crankshaft travel. The igniting device is timed to ignite the charge just before the piston reaches top center on the compression stroke. Igniting the charge at this point permits maximum pressure to build up at a point slightly after the piston passes over top dead center. For ideal combustion, the point of ignition should vary with engine speed and with degree of compression, mixture strength, and other factors governing the rate of burning. However, certain factors, such as the limited range of operating r.p.m. and the dangers of operating with incorrect spark settings, prohibit the use of variable spark control in most instances. Therefore, most aircraft ignition system units are timed to ignite the fuel/air charge at one fixed position (advanced).

On early models of the four-stroke-cycle engine, the intake valve opened at top center (beginning of the intake stroke). It closed at bottom center (end of intake stroke). The exhaust valve opened at bottom center (end of power stroke) and closed at top center (end of exhaust stroke). More efficient engine operation can be obtained by opening the intake valve several degrees before top center and closing it several degrees after bottom center. Opening the exhaust valve before bottom center, and closing it after top center, also improves engine performance. Since the intake valve opens before top-center exhaust stroke and the exhaust valve closes after top-center intake stroke, there is a period where both the intake and exhaust valves are open at the same time. This is known as valve lap or valve overlap. In valve timing, reference to piston or crankshaft position is always made in terms of before or after the top and bottom center points, *e.g.*, ATC, BTC, ABC, and BBC.

Opening the intake valve before the piston reaches top center starts the intake event while the piston is still moving up on the exhaust stroke. This aids in increasing the volume of charge admitted into the cylinder. The selected point at which the intake valve opens depends on the r.p.m. at which the engine normally operates. At low r.p.m., this early timing results in poor efficiency since the incoming charge is not drawn into and the exhaust gases are not expelled out of the cylinder with sufficient speed to develop the necessary momentum. Also, at low r.p.m. the cylinder is not well scavenged, and residual gases mix with the incoming fuel and are trapped during the compression stroke. Some of the incoming mixture is also lost through the open exhaust port. However, the advantages obtained at normal operating r.p.m. more than make up for the poor efficiency at low r.p.m. Another advantage of this valve timing is the increased fuel vaporization and beneficial cooling of the piston and cylinder.

Delaying the closing of the intake valve takes advantage of the inertia of the rapidly moving fuel/air mixture entering the cylinder. This ramming effect increases the charge over that which would be taken in if the intake valve closed at bottom center (end of intake stroke). The intake valve is actually open during the latter part of the exhaust stroke, all of the intake stroke, and the first part of the compression stroke. Fuel/air mixture is taken in during all this time.

The early opening and late closing of the exhaust valve goes along with the intake valve timing to improve engine efficiency. The exhaust valve opens on the power stroke, several crankshaft degrees before the piston reaches bottom center. This early opening aids in obtaining better scavenging of the burned gases. It also results in improved cooling of the cylinders, because of the early escape of the hot gases. Actually, on aircraft engines, the major portion of the exhaust gases, and the unused heat, escapes before the piston reaches bottom center. The burned gases continue to escape as the piston passes bottom center, moves upward on the exhaust stroke, and starts the next intake stroke. The late closing of the exhaust valve still further improves scavenging by taking advantage of the inertia of the rapidly moving outgoing gases. The exhaust valve is actually open during the latter part of the power stroke, all of the exhaust stroke, and the first part of the intake stroke.

From this description of valve timing, it can be seen that the intake and exhaust valves are open at the same time on the latter part of the exhaust stroke and the first part of the intake stroke. During this valve overlap period, the last of the burned gases are escaping through the exhaust port while the fresh charge is entering through the intake port.

Many aircraft engines are supercharged. Supercharging increases the pressure of the air or fuel/air mixture before it enters the cylinder. In other words, the air or fuel/air mixture is forced into the cylinder rather than being drawn in. Supercharging increases engine efficiency and makes it possible for an engine to maintain its efficiency at high altitudes. This is true because the higher pressure packs more charge into the cylinder during the intake event. This increase in weight of charge results in corresponding increase in power. In addition, the higher pressure of the incoming gases more forcibly ejects the burned gases out through the exhaust port. This results in better scavenging of the cylinder.

Combustion Process

Normal combustion occurs when the fuel/air mixture ignites in the cylinder and burns progressively at a fairly uniform rate across the combustion chamber. When ignition is properly timed, maximum pressure is built up just after the piston has passed top dead center at the end of the compression stroke.

The flame fronts start at each spark plug and burn in more or less wavelike forms (figure 10–32). The velocity of the flame travel is influenced by the type of fuel, the ratio of the fuel/air mixture, and the pressure and temperature of the fuel mixture. With normal combustion, the flame travel is about 100 ft./sec. The temperature and pressure within the cylinder rises at a normal rate as the fuel/air mixture burns.

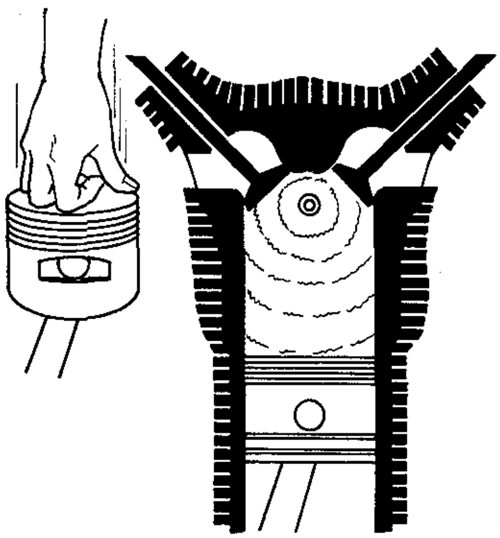


FIGURE 10–32. Normal combustion within a cylinder.

There is a limit, however, to the amount of compression and the degree of temperature rise that can be tolerated within an engine cylinder and still permit normal combustion. All fuels have critical limits of temperature and compression. Beyond this limit, they will ignite spontaneously and burn with explosive violence. This instantaneous and explosive burning of the fuel/air mixture or, more accurately, of the latter portion of the charge, is called detonation.

As previously mentioned, during normal combustion the flame fronts progress from the point of ignition across the cylinder. These flame fronts compress the gases ahead of them. At the same time, the gases are being compressed by the upward movement of the piston. If the total compression on the remaining unburned gases exceeds the critical point, detonation occurs. Detonation (figure 10–33) then, is the spontaneous combustion of the unburned charge ahead of the flame fronts after ignition of the charge.

The explosive burning during detonation results in an extremely rapid pressure rise. This rapid pressure rise and the high instantaneous temperature, combined with the high turbulence generated,

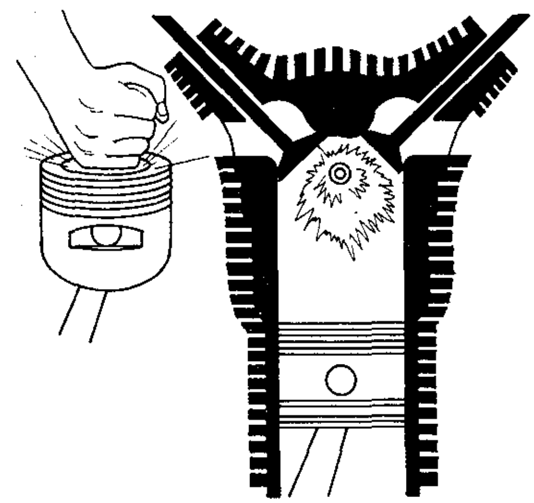


FIGURE 10–33. Detonation within a cylinder.

cause a "scrubbing" action on the cylinder and the piston. This can burn a hole completely through the piston.

The critical point of detonation varies with the ratio of fuel to air in the mixture. Therefore, the detonation characteristic of the mixture can be controlled by varying the fuel/air ratio. At high power output, combustion pressures and temperatures are higher than they are at low or medium power. Therefore, at high power the fuel/air ratio is made richer than is needed for good combustion at medium or low power output. This is done because, in general, a rich mixture will not detonate as readily as a lean mixture.

Unless detonation is heavy, there is no cockpit evidence of its presence. Light to medium detonation does not cause noticeable roughness, temperature increase, or loss of power. As a result, it can be present during takeoff and high-power climb without being known to the crew.

In fact, the effects of detonation are often not discovered until after teardown of the engine. When the engine is overhauled, however, the presence of severe detonation during its operation is indicated by dished piston heads, collapsed valve heads, broken ring lands, or eroded portions of valves, pistons, or cylinder heads.

The basic protection from detonation is provided in the design of the engine carburetor setting, which automatically supplies the rich mixtures required for detonation suppression at high power; the rating limitations, which include the maximum operating temperatures; and selection of the correct grade of fuel. The design factors, cylinder cooling, magneto timing, mixture distribution, supercharging, and carburetor setting are taken care of in the design and development of the engine and its method of installation in the aircraft.

The remaining responsibility for prevention of detonation rests squarely in the hands of the ground and flight crews. They are responsible for observance of r.p.m. and manifold pressure limits. Proper use of supercharger and fuel mixture, and maintenance of suitable cylinder head and carburetor-air temperatures are entirely in their control.

Pre-ignition, as the name implies, means that combustion takes place within the cylinder before the timed spark jumps across the spark plug terminals. This condition can often be traced to excessive carbon or other deposits which cause local hot spots. Detonation often leads to pre-ignition. However, pre-ignition may also be caused by high-power operation on excessively lean mixtures. Pre-ignition is usually indicated in the cockpit by engine roughness, backfiring, and by a sudden increase in cylinder head temperature.

Any area within the combustion chamber which becomes incandescent will serve as an igniter in advance of normal timed ignition and cause combustion earlier than desired. Pre-ignition may be caused by an area roughened and heated by detonation erosion. A cracked valve or piston, or a broken spark plug insulator may furnish a hot point which serves as a "glow plug."

The hot spot can be caused by deposits on the chamber surfaces resulting from the use of leaded fuels. Normal carbon deposits can also cause pre-ignition. Specifically, pre-ignition is a condition similar to early timing of the spark. The charge in the cylinder is ignited before the required time for normal engine firing. However, do not confuse pre-ignition with the spark which occurs too early in the cycle. Pre-ignition is caused by a hot spot in the combustion chamber, not by incorrect ignition timing. The hot spot may be due to either an overheated cylinder or a defect within the cylinder.

The most obvious method of correcting pre-ignition is to reduce the cylinder temperature. The immediate step is to retard the throttle. This reduces the amount of fuel charge and the amount of heat generated. If a supercharger is in use and is in high ratio, it should be returned to low ratio to lower the charge temperature. Following this, the mixture should be enriched, if possible, to lower combustion temperature.

If the engine is at high power when pre-ignition occurs, retarding the throttle for a few seconds may provide enough cooling to chip off some of the lead, or other deposit, within the combustion chamber. These chipped-off particles pass out through the exhaust. They are visible at night as a shower of sparks. If retarding the throttle does not permit a return to uninterrupted normal power operation, deposits may be removed by a sudden cooling shock treatment. Such treatments are water injection, alcohol from the deicing system, full-cold carburetor air, or any other method that provides sudden cooling to the cylinder chamber.

Backfiring

When a fuel/air mixture does not contain enough fuel to consume all the oxygen, it is called a lean mixture. Conversely, a charge that contains more fuel than required is called a rich mixture. An extremely lean mixture either will not burn at all or will burn so slowly that combustion is not complete at the end of the exhaust stroke. The flame lingers in the cylinder and then ignites the contents in the intake manifold or the induction system when the intake valve opens. This causes an explosion known as backfiring, which can damage the carburetor and other parts of the induction system.

A point worth stressing is that backfiring rarely involves the whole engine. Therefore, it is seldom the fault of the carburetor. In practically all cases, backfiring is limited to one or two cylinders. Usually it is the result of faulty valve clearance setting, defective fuel injector nozzles, or other conditions which cause these cylinders to operate leaner than the engine as a whole. There can be no permanent cure until these defects are discovered and corrected. Because these backfiring cylinders will fire intermittently and therefore run cool, they can be detected by the cold cylinder check. The cold cylinder check is discussed later in this chapter.

In some instances, an engine backfires in the idle range, but operates satisfactorily at medium and high power settings. The most likely cause, in this case, is an excessively lean idle mixture. Proper adjustment of the idle fuel/air mixture usually corrects this difficulty.

Afterfiring

Afterfiring, sometimes called afterburning, often results when the fuel/air mixture is too rich. Overly rich mixtures are also slow burning. Therefore, charges of unburned fuel are present in the exhausted gases. Air from outside the exhaust stacks mixes with this unburned fuel which ignites. This causes an explosion in the exhaust system. Afterfiring is perhaps more common where long exhaust ducting retains greater amounts of unburned charges. As in the case of backfiring, the correction for afterfiring is the proper adjustment of the fuel/air mixture.

Afterfiring can also be caused by cylinders which are not firing because of faulty spark plugs, defective fuel-injection nozzles, or incorrect valve clearance. The unburned mixture from these dead cylinders passes into the exhaust system, where it ignites and burns. Unfortunately, the resultant torching or afterburning can easily be mistaken for evidence of a rich carburetor. Cylinders which are firing intermittently can cause a similar effect. Again, the malfunction can be remedied only by discovering the real cause and correcting the defect. Either dead or intermittent cylinders can be located by the cold cylinder check.

FACTORS AFFECTING ENGINE OPERATION

Compression

To prevent loss of power, all openings to the cylinder must close and seal completely on the compression and power strokes. In this respect, there are three items in the proper operation of the cylinder that must be right for maximum efficiency. First, the piston rings must be in good condition to provide maximum sealing during the stroke of the piston. There must be no leakage between the piston and the walls of the combustion chamber. Second, the intake and exhaust valves must close tightly so that there will be no loss of compression at these points. Third, and very important, the timing of the valves must be such that highest efficiency is obtained when the engine is operating at its normal rated r.p.m. A failure at any of these points results in greatly reduced engine efficiency.

Fuel Metering

The induction system is the distribution and fuel metering part of the engine. Obviously, any defect in the induction system seriously affects engine operation. For best operation, each cylinder of the engine must be provided with the proper fuel/air mixture, usually metered by the carburetor. On some fuel-injection engines, fuel is metered by the fuel injector flow divider and fuel-injection nozzles.

The relation between fuel/air ratio and power is illustrated in figure 10–34. Note that, as the fuel mixture is varied from lean to rich, the power output of the engine increases until it reaches a maximum. Beyond this point, the power output falls off as the mixture is further enriched. This is because the fuel mixture is now too rich to provide perfect combustion. Note that maximum engine power can be obtained by setting the carburetor for one point on the curve.

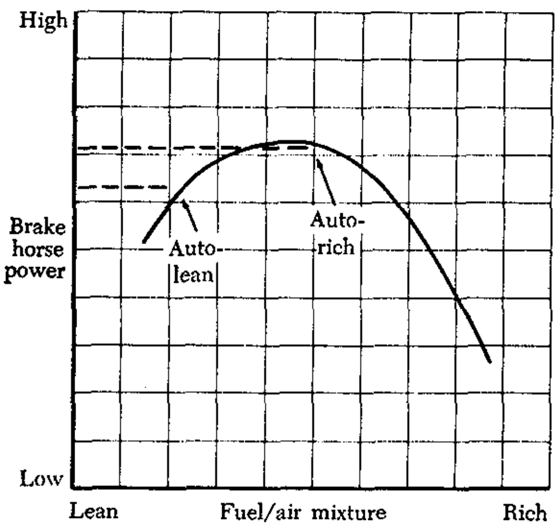


FIGURE 10–34. Power versus fuel/air mixture curve.

In establishing the carburetor settings for an aircraft engine, the design engineers run a series of curves similar to the one shown. A curve is run for each of several engine speeds. If, for example, the idle speed is 600 r.p.m., the first curve might be run at this speed. Another curve might be run at 700 r.p.m., another at 800 r.p.m., and so on, in 100-r.p.m. increments, up to takeoff r.p.m. The points of maximum power on the curves are then joined to obtain the best-power curve of the engine for all speeds. This best-power curve establishes the automatic rich setting of the carburetor.

In establishing the detailed engine requirements regarding carburetor setting, the fact that the cylinder head temperature varies with fuel/air ratio must be considered. This variation is illustrated in the curve shown in figure 10–35. Note that the cylinder head temperature is lower with the auto-lean setting than it is with the auto-rich mixture. This is exactly opposite common belief, but it is true. Furthermore, knowledge of this fact can be used to advantage by flight crews. If, during cruise, it becomes difficult to keep the cylinder head temperature within limits, the fuel/air mixture may be leaned out to get cooler operation. The desired cooling can then be obtained without going to auto-rich with its costly waste of fuel. The curve shows only the variation in cylinder head temperature. For a given r.p.m., the power output of the engine is less with the best-economy setting (auto-lean) than with the best-power mixture.

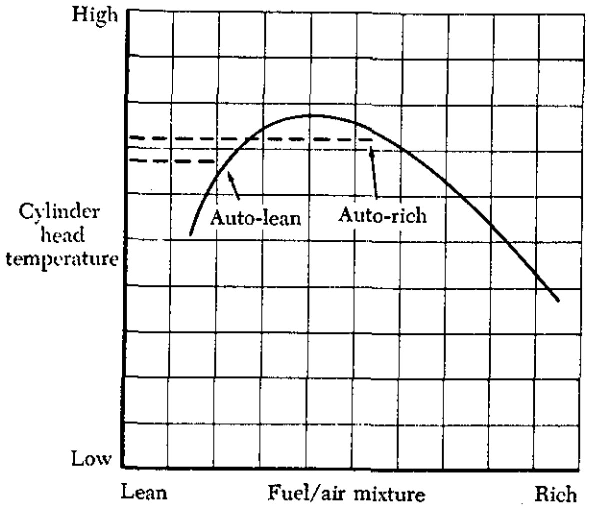


FIGURE 10–35. Variation in head temperature with fuel/air mixture (cruise power).

The decrease in cylinder head temperature with a leaner mixture holds true only through the normal cruise range. At higher power settings, cylinder temperatures are higher with the leaner mixtures. The reason for this reversal hinges on the cooling ability of the engine. As higher powers are approached, a point is reached where the airflow around the cylinders will not provide sufficient cooling. At this point, a secondary cooling method must be used. This secondary cooling is done by enriching the fuel/air mixture beyond the best-power point. Although enriching the mixture to this extent results in a power loss, both power and economy must be sacrificed for engine cooling purposes.

To further investigate the influence of cooling requirements on fuel/air mixture, the effects of water injection must be examined. Figure 10–36 shows a fuel/air curve for a water-injection engine. The dotted portion of the curve shows how the fuel/air mixture is leaned out during water injection. This leaning is possible because water, rather than extra fuel, is used as a cylinder coolant.

This permits leaning out to approximately best-power mixture without danger of overheating or

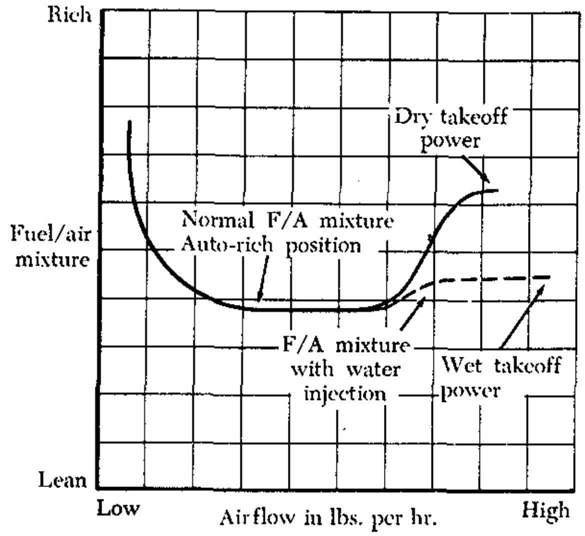


FIGURE 10–36. Fuel/air curve for a water-injection engine.

detonation. This leaning out gives an increase in power. The water does not alter the combustion characteristics of the mixture. Fuel added to the auto-rich mixture in the power range during "dry" operation is solely for cooling. A leaner mixture would give more power.

Actually, water or, more accurately, the antidetonant (water/alcohol) mixture is a better coolant than extra fuel. Therefore, water injection permits higher manifold pressures and a still further increase in power.

In establishing the final curve for engine operation, the engine's ability to cool itself at various power settings is, of course, taken into account. Sometimes the mixture must be altered for a given installation to compensate for the effect of cowl design, cooling airflow, or other factors on engine cooling.

The final fuel/air mixture curves take into account economy, power, engine cooling, idling characteristics, and all other factors which affect combustion.

The chart in figure 10–37 shows a typical final curve for injection-type carburetors. Note that the fuel/air mixture at idle and at takeoff power is the same in auto-rich and auto-lean. Beyond idle, a gradual spread occurs as cruise power is approached. This spread is maximum in the cruise range. The spread decreases toward takeoff power. This spread between the two curves in the cruise range is the basis for the cruise metering check.

Figure 10–38 shows a typical final curve for a float-type carburetor. Note that the fuel/air mixture at idle is the same in rich and in manual lean.

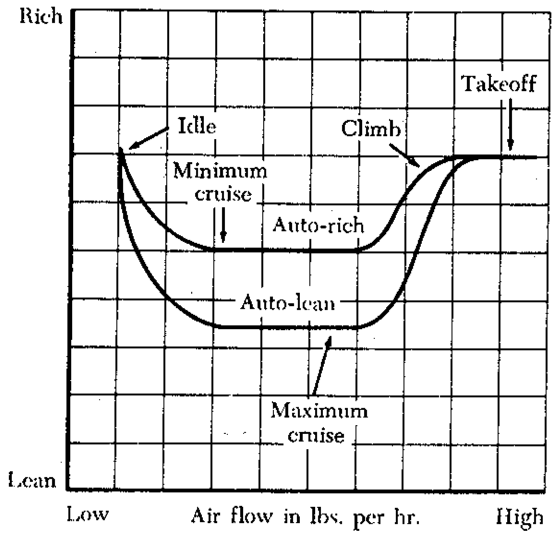


FIGURE 10–37. Typical fuel/air mixture curve for injection-type carburetor.

The mixture remains the same until the low cruise range is reached. At this point, the curves separate and then remain parallel through the cruise and power ranges.

Note the spread between the rich and lean setting in the cruise range of both curves. Because of this spread, there will be a decrease in power when the mixture control is moved from auto-rich to auto-lean with the engine operating in the cruise range. This is true because the auto-rich setting in the cruise range is very near the best-power mixture ratio. Therefore, any leaning out will give a mixture which is leaner than best power.

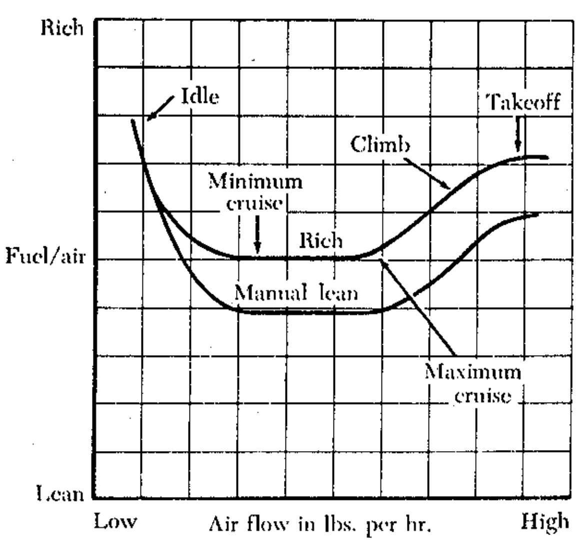


FIGURE 10–38. Typical fuel/air mixture curve for float-type carburetor.

Idle Mixture

The idle mixture curve (figure 10–39) shows how the mixture changes when the idle mixture adjustment is changed. Note that the greatest effect is at idling speeds. However, there is some effect on the mixture at airflows above idling. The airflow at which the idle adjustment effect cancels out varies from minimum cruise to maximum cruise. The exact point depends on the type of carburetor and the carburetor setting. In general, the idle adjustment affects the fuel/air mixture up to medium cruise on most engines having pressure-injection-type carburetors, and up to low cruise on engines equipped with float-type carburetors. This means that incorrect idle mixture adjustments can easily give faulty cruise performance as well as poor idling.

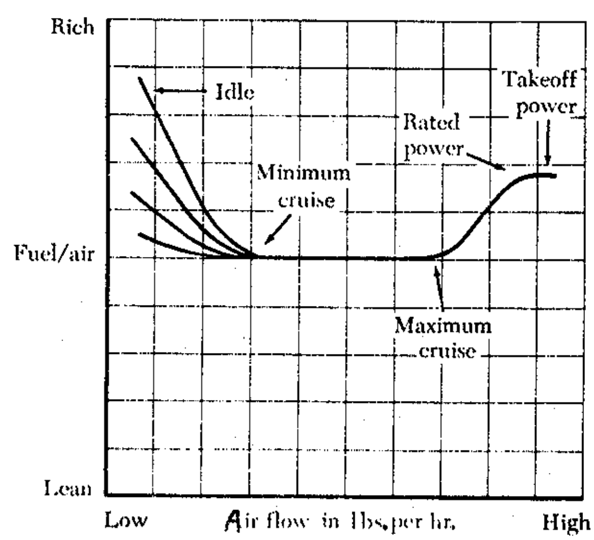


FIGURE 10–39. Idle mixture curve.

There are variations in mixture requirements between one engine and another because of the fuel distribution within the engine and the ability of the engine to cool. Remember that a carburetor setting must be rich enough to supply a combustible mixture for the leanest cylinder. If fuel distribution is poor, the overall mixture must be richer than would be required for the same engine if distribution were good. The engine's ability to cool depends on such factors as cylinder design (including the design of the cooling fins), compression ratio, accessories on the front of the engine which cause individual cylinders to run hot, and the design of the baffling used to deflect airflow around the cylinder. At takeoff power, the mixture must be rich enough to supply sufficient fuel to keep the hottest cylinder cool.

The Induction Manifold

The induction manifold provides the means of distributing air, or the fuel/air mixture, to the cylinders. Whether the manifold handles a fuel/air mixture or air alone depends on the type of fuel metering system used. On an engine equipped with a carburetor, the induction manifold distributes a fuel/air mixture from the carburetor to the cylinders. On a fuel-injection engine, the fuel is delivered to injection nozzles, one in each cylinder, which provide the proper spray pattern for efficient burning. Thus, the mixing of fuel and air takes place in the cylinders or at the inlet port to the cylinder. On a fuel-injection engine the induction manifold handles only air.

The induction manifold is an important item because of the effect it can have on the fuel/air mixture which finally reaches the cylinder. Fuel is introduced into the airstream by the carburetor in a liquid form. To become combustible, the fuel must be vaporized in the air. This vaporization takes place in the induction manifold, which includes the internal supercharger if one is used. Any fuel that does not vaporize will cling to the walls of the intake pipes. Obviously, this affects the effective fuel/air ratio of the mixture which finally reaches the cylinder in vapor form. This explains the reason for the apparently rich mixture required to start a cold engine. In a cold engine, some of the fuel in the airstream condenses out and clings to the walls of the manifold. This is in addition to that fuel which never vaporized in the first place. As the engine warms up, less fuel is required because less fuel is condensed out of the airstream and more of the fuel is vaporized, thus giving the cylinder the required fuel/air mixture for normal combustion.

Any leak in the induction system has an effect on the mixture reaching the cylinders. This is particularly true of a leak at the cylinder end of an intake pipe. At manifold pressures below atmospheric pressure, such a leak will lean out the mixture. This occurs because additional air is drawn in from the atmosphere at the leaky point. The affected cylinder may overheat, fire intermittently, or even cut out altogether.

Operational Effect of Valve Clearance

While considering the operational effect of valve clearance, keep in mind that all aircraft reciprocating engines of current design use valve overlap.

Figure 10–40 shows the pressures at the intake and exhaust ports under two different sets of operating conditions. In one case, the engine is operating at a manifold pressure of 35 in. Hg. Barometric pressure (exhaust back pressure) is 29 in. Hg. This gives a pressure differential of 6 in. Hg (3 p.s.i.) acting in the direction indicated by the arrow.

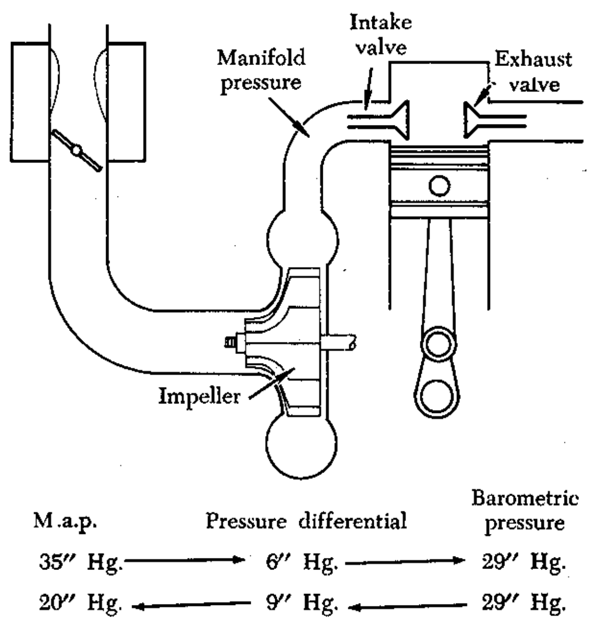


FIGURE 10–40. Effect of valve overlap.

During the valve overlap period, this pressure differential forces the fuel/air mixture across the combustion chamber toward the open exhaust. This flow of fuel/air mixture forces ahead of it the exhaust gases remaining in the cylinder, resulting in complete scavenging of the combustion chamber. This, in turn, permits complete filling of the cylinder with a fresh charge on the following intake event. This is the situation in which valve overlap gives increased power.

In a situation where the manifold pressure is below atmospheric pressure, 20 in. Hg, for example, there is a pressure differential of 9 in. Hg (4.5 p.s.i.) in the opposite direction. This causes air or exhaust gas to be drawn into the cylinder through the exhaust port during valve overlap.

In engines with collector rings, this inflow through the exhaust port at low power settings consists of burned exhaust gases. These gases are pulled back into the cylinder and mix with the incoming fuel/air mixture. However, these exhaust gases are inert; they do not contain oxygen. Therefore, the fuel/air mixture ratio is not affected much. With open exhaust stacks, the situation is entirely different. Here, fresh air containing oxygen is pulled into the cylinders through the exhaust. This leans out the mixture. Therefore, the carburetor must be set to deliver an excessively rich idle mixture so that, when this mixture is combined with the fresh air drawn in through the exhaust port, the effective mixture in the cylinder will be at the desired ratio.

At first thought, it does not appear possible that the effect of valve overlap on fuel/air mixture is sufficient to cause concern. However, the effect of valve overlap becomes apparent when considering idle fuel/air mixtures. These mixtures must be enriched 20 to 30% when open stacks instead of collector rings are used on the same engine. This is shown graphically in figure 10–41. Note the spread at idle between an open stack and an exhaust collector ring installation for engines that are otherwise identical. The mixture variation decreases as the engine speed or airflow is increased from idle into the cruise range.

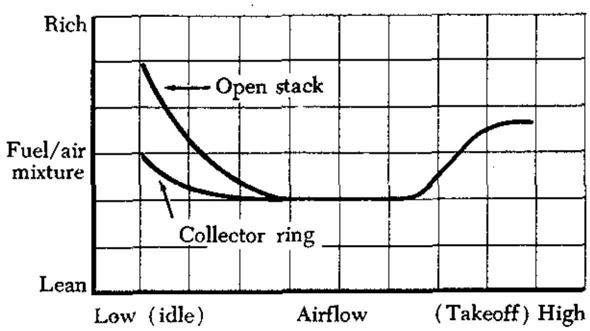


FIGURE 10–41. Comparison of fuel/air mixture curves for open stack and collector ring installations.

Engine, airplane, and equipment manufacturers provide a powerplant installation that will give satisfactory performance. Cams are designed to give best valve operation and correct overlap. But valve operation will be correct only if valve clearances are set and remain at the value recommended by the engine manufacturer. If valve clearances are set wrong, the valve overlap period will be longer or shorter than the manufacturer intended. The same is true if clearances get out of adjustment during operation.

Where there is too much valve clearance, the valves will not open as wide or remain open as long as they should. This reduces the overlap period. At idling speed, it will affect the fuel/air mixture, since a less-than-normal amount of air or exhaust gases will be drawn back into the cylinder during the shortened overlap period. As a result, the idle mixture will tend to be too rich.

When valve clearance is less than it should be, the valve overlap period will be lengthened. This permits a greater-than-normal amount of air or exhaust gases to be drawn back into the cylinder at idling speeds. As a result, the idle mixture will be leaned out at the cylinder. The carburetor is adjusted with the expectation that a certain amount of air or exhaust gases will be drawn back into the cylinder at idling. If more or less air or exhaust gases are drawn into the cylinder during the valve overlap period, the mixture will be too lean or too rich.

When valve clearances are wrong, it is unlikely that they will all be wrong in the same direction. Instead, there will be too much clearance on some cylinders and too little on others. Naturally, this gives a variation in valve overlap between cylinders. This, in turn, results in a variation in fuel/air ratio at idling and lower-power settings, since the carburetor delivers the same mixture to all cylinders. The carburetor cannot tailor the mixture to each cylinder to compensate for variation in valve overlap.

The effect of variation in valve clearance and valve overlap on the fuel/air mixture between cylinders is illustrated in figure 10–42. Note how the cylinders with too little clearance run rich and those with too much clearance run lean. Note also the extreme mixture variation between cylinders. On such an engine, it would be impossible to set the idle adjustment to give correct mixtures on all cylinders, nor can all cylinders of such an engine be expected to produce the same power. Variations in valve clearance of as little as 0.005 in. have a definite effect on mixture distribution between cylinders.

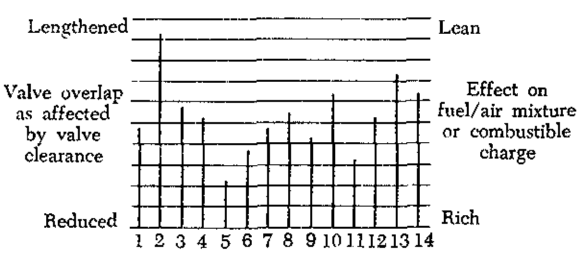


FIGURE 10–42. Effect of variation in valve overlap on fuel/air mixture between cylinders.

Another aspect of valve clearance is its effect on volumetric efficiency. Considering the intake valve first, suppose valve clearance is greater than that specified. As the cam lobe starts to pass under the cam roller, the cam step or ramp takes up part of this clearance. However, it doesn't take up all the clearance as it should. Therefore, the cam roller is well up on the lobe proper before the valve starts to open. As a result, the valve opens later than it should. In a similar way, the valve closes before the roller has passed from the main lobe to the ramp at its end. With excessive clearance, then, the intake valve opens late and closes early. This produces a throttling effect on the cylinder. The valve is not open long enough to admit a full charge of fuel and air. This will cut down the power output, particularly at high-power settings.

Insufficient intake valve clearance has the opposite effect. The clearance is taken up and the valve starts to open while the cam roller is still on the cam step. The valve doesn't close until the riser at the end of the lobe has almost completely passed under the roller. Therefore, the intake valve opens early, closes late, and stays open longer than it should. At low power, early opening of the intake valve can cause backfiring because of the hot exhaust gases backing out into the intake manifold and igniting the mixture there.

Excessive exhaust valve clearance causes the exhaust valve to open late and close early. This shortens the exhaust event and causes poor scavenging. The late opening may also lead to cylinder overheating. The hot exhaust gases are held in the cylinder beyond the time specified for their release.

When exhaust valve clearance is insufficient, the valve opens early and closes late. It remains open longer than it should. The early opening causes a power loss by shortening the power event. The pressure in the cylinder is released before all the useful expansion has worked on the piston. The late closing causes the exhaust valve to remain open during a larger portion of the intake stroke than it should. This may result in good mixture being lost through the exhaust port.

As mentioned before, there will probably be too little clearance on some cylinders and too much on others whenever valve clearances are incorrect. This means that the effect of incorrect clearances on volumetric efficiency will usually vary from cylinder to cylinder. One cylinder will take in a full charge while another receives only a partial charge. As a result, cylinders will not deliver equal power. One cylinder will backfire or run hot while another performs satisfactorily.

On some direct fuel-injection engines, variations in valve clearance will affect only the amount of air taken into the cylinders. This is true when the induction manifold handles only air. In this case there will be no appreciable effect on the distribution of fuel to the individual cylinders. This means that, when clearances vary between cylinders, air charges will also vary but fuel distribution will be uniform. This faulty air distribution, coupled with proper fuel distribution, will cause variations in mixture ratio.

In all cases, variations in valve clearance from the value specified have the effect of changing the valve timing from that obtained with correct clearance. This is certain to give something less than perfect performance.

Ignition System

The next item to be considered regarding engine operation is the ignition system. Although basically simple, it is sometimes not understood clearly.

An ignition system consists of four main parts:

(1) The basic magneto.

(2) The distributor.

(3) The ignition harness.

(4) The spark plug.

The basic magneto is a high-voltage generating device. It must be adjusted to give maximum voltage at the time the points break and ignition occurs. It must also be synchronized accurately to the firing position of the engine. The magneto generates a series of peak voltages which are released by the opening of the breaker points. A distributor is necessary to distribute these peak voltages from the magneto to the cylinders in the proper order. The ignition harness constitutes the insulated and shielded high-tension lines which carry the high voltages from the distributor to the spark plugs.

The magnetos used on aircraft engines are capable of developing voltages as high as 15,000 volts. The voltage required to jump the specified gap in a spark plug will usually be about 4,000 to 5,000 volts maximum. The spark plugs serve as safety valves to limit the maximum voltage in the entire ignition system. As spark plug gaps open up as a result of erosion, the voltage at the plug terminals increases. A higher voltage is required to jump the larger gap. This higher voltage is transmitted through the secondary circuit. The increased voltage in the circuit becomes a hazard. It is a possible source of breakdown in the ignition harness and can cause flashover in the distributor.

The distributor directs the firing impulses to the various cylinders. It must be timed properly to both the engine and the magneto. The distributor finger must align with the correct electrode on the distributor block at the time the magneto points break. Any misalignment may cause the high voltage to jump to a cylinder other than the one intended. This will cause severe backfiring and general malfunctioning of the engine.

The manufacturer has selected the best compromise and specified an alignment with the No. 1 electrode for timing. However, even with perfect distributor timing, the finger is behind on some electrodes and ahead on others. For a few electrodes (cylinders), the alignment is as far from perfect as it can safely be. A slight error in timing, added to this already imperfect alignment, may put the finger so far from the electrode that the high voltage will not jump from finger to electrode, or the high voltage may be routed to the wrong cylinder. Therefore, the distributor must be timed perfectly. The finger must be aligned with the No. 1 electrode exactly as prescribed in the maintenance manual for the particular engine and airplane.

Although the ignition harness is simple, it is a critical part of the ignition system. A number of things can cause failure in the ignition harness. Insulation may break down on a wire inside the harness and allow the high voltage to leak through to the shielding (and to ground), instead of going to the spark plug. Open circuits may result from broken wires or poor connections. A bare wire may be in contact with the shielding, or two wires may be shorted together.

Any serious defect in an individual lead prevents the high voltage impulse from reaching the spark plug to which the lead is connected. As a result, only one spark plug in the cylinder will fire. This causes the cylinder to operate on single ignition. This is certain to result in detonation, since dual ignition is required to prevent detonation at takeoff and during other high-power operation. Two bad leads to the same cylinder will cause the cylinder to go completely dead. On engines with separate distributors, a faulty magneto-to-distributor lead can cut out half the ignition system.

Among the most common ignition harness defects, and the most difficult to detect, are high-voltage leaks. However, a complete harness check will reveal these and other defects.

Although the spark plug is simple both in construction and in operation, it is, nevertheless, the direct or indirect cause of a great many malfunctions encountered in aircraft engines. Proper precaution begins with plug selection. Be sure to select and install the plug specified for the particular engine. One of the reasons a particular plug is specified is its heat range. The heat range of the spark plug determines the temperature at which the nose end of the plug operates. It also affects the ability of the spark plug to ignite mixtures which are borderline from the standpoint of high oil content or excessive richness or leanness.

A great many troubles attributed to spark plugs are the direct result of malfunctions somewhere else in the engine. Some of these are excessively rich idle mixtures, improperly adjusted valves, and impeller oil seal leaks.

Propeller Governor

The final item to be considered regarding engine operation is the effect of the propeller governor on engine operation. In the curve shown in figure 10–43, note that the manifold pressure change with r.p.m. is gradual until the propeller governor cut-in speed is reached. Beyond this point, the manifold pressure increases, but no change occurs in the engine r.p.m. as the carburetor throttle is opened wider.

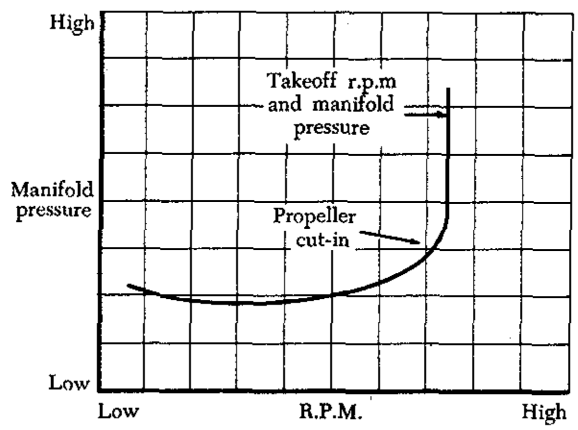


FIGURE 10–43. Effect of propeller governor on manifold pressure.

A true picture of the power output of the engine can be determined only at speeds below the propeller governor cut-in speed. The propeller governor is set to maintain a given engine r.p.m. Therefore, the relationship between engine speed and manifold pressure as an indication of power output is lost, unless it is known that all cylinders of the engine are functioning properly.

In fact, on a multi-engine aircraft, an engine can fail and still produce every indication that it is developing power. The propeller governor will flatten out the propeller blade angle and windmill the propeller to maintain the same engine r.p.m. Heat of compression within the cylinder will prevent the cylinder head temperature from falling rapidly. The fuel pressure will remain constant and the fuel flow will not change unless the manifold pressure is changed. On an engine not equipped with a turbocharger, the manifold pressure will remain where it was. On a turbocharged engine, the manifold pressure will not drop below the value which the mechanical supercharger can maintain. This may be well above atmospheric pressure, depending upon the blower ratio of the engine and the specific conditions existing. Thus, the pilot has difficulty in recognizing that he has encountered a sudden failure unless the engines are equipped with torquemeters, or he notices the fluctuation in r.p.m. at the time the engine cuts out.

Overlapping Phases of Engine Operation

Up to this point, the individual phases of engine operation have been discussed. The relationship of the phases and their combined effect on engine operation will now be considered. Combustion within the cylinder is the result of fuel metering, compression, and ignition. Since valve overlap affects fuel metering, proper combustion in all the cylinders involves correct valve adjustment in addition to the other phases. When all conditions are correct, there is a burnable mixture. When ignited, this mixture will give power impulses of the same intensity from all cylinders.

The system which ignites the combustible mixture requires that the following five conditions occur simultaneously if the necessary spark impulse is to be delivered to the cylinder at the proper time:

(1) The breaker points must be timed accurately to the magneto (E-gap).

(2) The magneto must be timed accurately to the engine.

(3) The distributor finger must be timed accurately to the engine and the magneto.

(4) The ignition harness must be in good condition with no tendency to flashover.

(5) The spark plug must be clean, have no tendency to short out, and have the proper electrode gap.

If any one of these requirements is lacking or if any one phase of the ignition system is maladjusted or is not functioning correctly, the entire ignition system can be disrupted to the point that improper engine operation results.

As an example of how one phase of engine operation can be affected by other phases, consider spark plug fouling. Spark plug fouling causes malfunctioning of the ignition system, but the fouling seldom results from a fault in the plug itself. Usually some other phase of operation is not functioning correctly, causing the plug to foul out. If excessively rich fuel/air mixtures are being burned because of either basically rich carburetion or improperly adjusted idle mixture, spark plug fouling will be inevitable. Generally, these causes will result in fouled spark plugs appearing over the entire engine, and not necessarily confined to one or a few cylinders.

If the fuel/air mixture is too lean or too rich on any one cylinder because of a loose intake pipe or improperly adjusted valves, improper operation of that cylinder will result. The cylinder will probably backfire. Spark plug fouling will occur continually on that cylinder until the defect is remedied.

Impeller oil seal leaks, which can be detected only by removal of intake pipes, will cause spark plug fouling. Here, the fouling is caused by excess oil being delivered to one or more cylinders. Stuck or broken rings will cause oil pumping in the affected cylinders with consequent plug fouling and high oil consumption. Improperly adjusted cylinder valves cause spark plug fouling, hard starting, and general engine malfunctioning. They may also cause valve failure as a result of high-seating velocities or of the valve holding open, with subsequent valve burning.

Whenever the true cause of engine malfunctioning is not determined and whenever the real disorder is not corrected, the corrective measure taken will provide only temporary relief. For example, the standard "fix" for engine backfiring is to change the carburetor. However, as a result of many tests, it is now known that the usual cause of engine backfiring is an improperly adjusted or defective ignition system or improperly adjusted engine valves.

Backfiring is usually caused by one cylinder, not all the cylinders. To remedy backfiring, first locate which cylinder is causing it, and then find out why that cylinder is backfiring.

ENGINE TROUBLESHOOTING

The need for troubleshooting normally is dictated by poor operation of the complete powerplant. Power settings for the type of operation at which any difficulty is encountered in many cases will indicate which part of the powerplant is the basic cause of difficulty.

The cylinders of an engine, along with the supercharger impeller, form an air pump. Furthermore, the power developed in the cylinders varies directly with the rate of air consumption. Therefore, a measure of air consumption or airflow into the engine is a measure of power input. Ignoring for the moment such factors as humidity and exhaust back pressure, the manifold pressure gage and the engine tachometer provide a measure of engine air consumption. Thus, for a given r.p.m. any change in power input will be reflected by a corresponding change in manifold pressure.

The power output of an engine is the power absorbed by the propeller. Therefore, propeller load is a measure of power output. Propeller load, in turn, depends on the propeller r.p.m., blade angle, and air density. For a given angle and air density, propeller load (power output) is directly proportional to engine speed.

The basic power of an engine is related to manifold pressure, fuel flow, and r.p.m. Because the r.p.m. of the engine and the throttle opening directly control manifold pressure, the primary engine power controls are the throttle and the r.p.m. control. An engine equipped with a fixed-pitch propeller has only a throttle control. In this case, the throttle setting controls both manifold pressure and engine r.p.m.

With proper precautions, manifold pressure can be taken as a measure of power input, and r.p.m. can be taken as a measure of power output. However, the following factors must be considered:

(1) Atmospheric pressure and air temperature must be considered, since they affect air density.

(2) These measures of power input and power output should be used only for comparing the performance of an engine with its previous performance or for comparing identical powerplants.

(3) With a controllable propeller, the blades must be against their low-pitch stops, since this is the only blade position in which the blade angle is known and does not vary. Once the blades are off their low-pitch stops, the propeller governor takes over and maintains a constant r.p.m. regardless of power input or engine condition. This precaution means that the propeller control must be set to maximum or takeoff r.p.m., and the checks made at engine speeds below this setting.

If the engine is equipped with a torquemeter, the torquemeter reading rather than the engine speed should be used as a measure of power output.

Having relative measures of power input and power output, the condition of an engine can be determined by comparing input and output. This is done by comparing the manifold pressure required to produce a given r.p.m. with the manifold pressure required to produce the same r.p.m. at a time when the engine (or an identical powerplant) was known to be in top operating condition.

An example will best show the practical application of this method of determining engine condition. With the propeller control set for takeoff r.p.m. (full low blade angle), an engine may require 32 in. of manifold pressure to turn 2,200 r.p.m. for the ignition check. On previous checks, this engine required only 30 in. of manifold pressure to turn 2,200 r.p.m. at the same station (altitude) and under similar atmospheric conditions. Obviously, something is wrong; a higher power input (manifold pressure) is now required for the same power output (r.p.m.). There is a good chance that one cylinder has cut out.

There are several standards against which engine performance can be compared. The performance of a particular engine can be compared with its past performance provided adequate records are kept. Engine performance can be compared with that of other engines on the same aircraft or aircraft having identical installations.

If a fault does exist, it may be assumed that the trouble lies in one of the following systems:

(1) Ignition system.
(2) Fuel metering system.
(3) Induction system.
(4) Power section (valves, cylinders, etc.).
(5) Instrumentation.

If a logical approach to the problem is taken and the instrument readings properly utilized, the malfunctioning system can be pinpointed and the specific problem in the defective system can be singled out.

The more information available about any particular problem, the better will be the opportunity for a rapid repair. Information that is of value in locating a malfunction includes:

(1) Was any roughness noted? Under what conditions of operation?
(2) What is the time on the engine and spark plugs? How long since last inspection?
(3) Was the ignition system operational check and power check normal?
(4) When did the trouble first appear?
(5) Was backfiring or afterfiring present?

(6) Was the full throttle performance normal?

From a different point of view, the powerplant is in reality a number of small engines turning a common crankshaft and being operated by two common phases: (1) Fuel metering, and (2) ignition. When backfiring, low power output, or other powerplant difficulty is encountered, first find out which system (fuel metering or ignition) is involved and then determine whether the entire engine or only one cylinder is at fault.

For example, backfiring normally will be caused by:

(1) Valves holding open or sticking open in one or more of the cylinders.
(2) Lean mixture.
(3) Intake pipe leakage.
(4) An error in valve adjustment which causes individual cylinders to receive too small a charge or one too large, even though the mixture to the cylinders has the same fuel/air ratio.

Ignition system reasons for backfiring might be a cracked distributor block or a high-tension leak between two ignition leads. Either of these conditions could cause the charge in the cylinder to be ignited during the intake stroke. Ignition system troubles involving backfiring normally will not be centered in the basic magneto, since a failure of the basic magneto would result in the engine not running, or it would run well at low speeds but cut out at high speeds. On the other hand, replacement of the magneto would correct a difficulty caused by a cracked distributor where the distributor is a part of the magneto.

If the fuel system, ignition system, and induction system are functioning properly, the engine should produce the correct b.hp. unless some fault exists in the basic power section.

Trouble—Cause—Remedy

Troubleshooting is a systematic analysis of the symptoms which indicate engine malfunction. Since it would be impractical to list all the malfunctions that could occur in a reciprocating engine, only the most common malfunctions are discussed. A thorough knowledge of the engine systems, applied with logical reasoning, will solve any problems which may occur.

Table 10 lists general conditions or troubles which may be encountered on reciprocating engines, such as "engine fails to start." They are further divided into the probable causes contributing to such conditions. Corrective actions are indicated in the "remedy" column. The items are presented with consideration given to frequency of occurrence, ease of accessibility, and complexity of the corrective action indicated.

TABLE 10. Troubleshooting opposed engines.

Trouble	Probable Causes	Remedy
Engine fails to start.	Lack of fuel.	Check fuel system for leaks. Fill fuel tank. Clean dirty lines, strainers, or fuel valves.
	Underpriming.	Use correct priming procedure.
	Overpriming.	Open throttle and "unload" engine by rotating the propeller.
	Incorrect throttle setting.	Open throttle to one-tenth of its range.
	Defective spark plugs.	Clean and re-gap or replace spark plugs.
	Defective ignition wire.	Test and replace any defective wires.
	Defective or weak battery.	Replace with charged battery.
	Improper operation of magneto or breaker points.	Check internal timing of magnetos.
	Water in carburetor.	Drain carburetor and fuel lines.
	Internal failure.	Check oil sump strainer for metal particles.

TABLE 10. Troubleshooting opposed engines—con.

Trouble	Probable Causes	Remedy
	Magnetized impulse coupling, if installed.	Demagnetize impulse coupling.
	Frozen spark plug electrodes.	Replace spark plugs or dry out plugs.
	Mixture control in idle cutoff.	Open mixture control.
	Shorted ignition switch or loose ground.	Check and replace or repair.
Engine fails to idle properly.	Incorrect carburetor idle speed adjustment.	Adjust throttle stop to obtain correct idle.
	Incorrect idle mixture.	Adjust mixture. (Refer to engine manufacturer's handbook for proper procedure.)
	Leak in the induction system.	Tighten all connections in the induction system. Replace any defective parts.
	Low cylinder compression.	Check cylinder compression.
	Faulty ignition system.	Check entire ignition system.
	Open or leaking primer.	Lock or repair primer.
	Improper spark plug setting for altitude.	Check spark plug gap.
	Dirty air filter.	Clean or replace.
Low power and engine running uneven.	Mixture too rich; indicated by sluggish engine operation, red exhaust flame, and black smoke.	Check primer. Re-adjust carburetor mixture.
	Mixture too lean; indicated by overheating or backfiring.	Check fuel lines for dirt or other restrictions. Check fuel supply.
	Leaks in induction system.	Tighten all connections. Replace defective parts.
	Defective spark plugs.	Clean or replace spark plugs.
	Improper grade of fuel.	Fill tank with recommended grade.
	Magneto breaker points not working properly.	Clean points. Check internal timing of magneto.
	Defective ignition wire.	Test and replace any defective wires.
	Defective spark plug terminal connectors.	Replace connectors on spark plug wire.
	Incorrect valve clearance.	Adjust valve clearance.
	Restriction in exhaust system.	Remove restriction.
	Improper ignition timing.	Check magnetos for timing and synchronization.
Engine fails to develop full power.	Throttle lever out of adjustment.	Adjust throttle lever.
	Leak in induction system.	Tighten all connections and replace defective parts.
	Restriction in carburetor airscoop.	Examine airscoop and remove restriction.
	Improper fuel.	Fill tank with recommended fuel.
	Propeller governor out of adjustment.	Adjust governor.
	Faulty ignition.	Tighten all connections. Check system. Check ignition timing.
Rough running engine.	Cracked engine mount(s).	Repair or replace engine mount(s).
	Unbalanced propeller.	Remove propeller and have it checked for balance.
	Defective mounting bushings.	Install new mounting bushings.
	Lead deposit on spark plugs.	Clean or replace plugs.
	Primer unlocked.	Lock primer.

TABLE 10. Troubleshooting opposed engines—con.

Trouble	Probable Causes	Remedy
Low oil pressure.	Insufficient oil.	Check oil supply.
	Dirty oil strainers.	Remove and clean oil strainers.
	Defective pressure gage.	Replace gage.
	Air lock or dirt in relief valve.	Remove and clean oil pressure relief valve.
	Leak in suction line or pressure line.	Check gasket between accessory housing crankcase.
	High oil temperature.	See "high oil temperature" in trouble column.
	Stoppage in oil pump intake passage.	Check line for obstruction. Clean suction strainer.
	Worn or scored bearings.	Overhaul engine.
High oil temperature.	Insufficient air cooling.	Check air inlet and outlet for deformation or obstruction.
	Insufficient oil supply.	Fill oil tank to proper level.
	Clogged oil lines or strainers.	Remove and clean oil lines or strainers.
	Failing or failed bearings.	Examine sump for metal particles and, if found, overhaul engine.
	Defective thermostats.	Replace thermostats.
	Defective temperature gage.	Replace gage.
	Excessive blow-by.	Usually caused by weak or stuck rings. Overhaul engine.
Excessive oil consumption.	Failing or failed bearing.	Check sump for metal particles and, if found, an overhaul of engine is indicated.
	Worn or broken piston rings.	Install new rings.
	Incorrect installation of piston rings.	Install new rings.
	External oil leakage.	Check engine carefully for leaking gaskets or O-rings.
	Leakage through engine fuel pump vent.	Replace fuel pump seal.
	Engine breather or vacuum pump breather.	Check engine, and overhaul or replace vacuum pump.

CYLINDER MAINTENANCE

Each cylinder of the engine is, in reality, an engine in itself. In most cases the cylinder receives its fuel and air from a common source such as the carburetor. Every phase of cylinder operation, such as compression, fuel mixture, and ignition must function properly, since even one type of malfunctioning will cause engine difficulty. Engine backfiring, for example, may be caused by a lean fuel/air mixture in one of the cylinders. The lean mixture may be caused by such difficulties as an improper valve adjustment, a sticking intake or exhaust valve, or a leaking intake pipe. Most engine difficulties can be traced to one cylinder, or a small number of cylinders. Therefore, engine difficulty can be corrected only after malfunctioning cylinders have been located and defective phases of cylinder operation brought up to normal.

Hydraulic Lock

Whenever a radial engine remains shut down for any length of time beyond a few minutes, oil or fuel may drain into the combustion chambers of the lower cylinders or accumulate in the lower intake pipes ready to be drawn into the cylinders when the engine starts (figure 10–44). As the piston approaches top center of the compression stroke (both valves closed), this liquid, being incompressible, stops piston movement. If the crankshaft continues to rotate, something must give. Therefore, starting or attempting to start an engine with a hydraulic lock of this nature may cause the affected cylinder to blow out or, more likely, may result in a bent or broken connecting rod.