Chapter 10
Engine Maintenance & Operation

Reciprocating Engine Overhaul

Both maintenance and complete engine overhauls are performed normally at specified intervals. This interval is usually governed by the number of hours the powerplant has been in operation. The actual overhaul period for a specific engine is generally determined by the manufacturer's recommendations. Each engine manufacturer sets a total time in service when the engine should be removed from service and overhauled. Depending upon how the engine is used in service, the overhaul time can be mandatory. The overhaul time is listed in hours and is referred to as time before overhaul (TBO). For example, if an engine had a life of 2,000 hours and had operated 500 hours, it would have a TBO of 1,500 hours. Tests and experience have shown that operation beyond this period of time could result in certain parts being 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 overhaul process while the engine is disassembled. The major purpose of overhaul is to inspect, repair, and replace worn engine parts.

A complete overhaul process includes the following ten steps: receiving inspection; disassembly; visual inspection; cleaning; structural inspection; non-destructive testing (NDT) inspection; dimensional inspection; repair and replacement; reassembly; and testing and break in. The inspection phases are the most precise and the most important phases of the overhaul. Inspection cannot be slighted or performed in a careless or incomplete manner. It is always recommended that complete records be made of the inspection process and kept with the engine records.

Each engine manufacturer provides very specific tolerances to which the engine parts must conform and provides general instructions to aid in determining the airworthiness of the part. However, in many cases, the final determination must be made by the technician. Although the determination must be made if the part is serviceable, repairable, or should be rejected, the technician should follow the manufacturer's manuals and information. When dimensional tolerances are concerned, the manufacturer publishes a new minimum and serviceable dimension for all critical component parts. Knowledge of the operating principles, strength, and stresses applied to a part is essential in making decisions regarding visible wear. When the powerplant technician signs the release for the return to service for an overhauled engine, this certifies that the complete overhaul process has been performed using methods, techniques, and practices acceptable to the Federal Aviation Administration (FAA) Administrator.

Top Overhaul

Reciprocating piston aircraft engines can be repaired by a top overhaul. This means an overhaul of those parts on top of the crankcase, without completely dismantling the engine. It includes removal of the units (i.e., exhaust collectors, ignition harness, intake pipes) necessary to remove the cylinders. The actual top overhaul consists of reconditioning the engine's cylinders by replacing or reconditioning the piston and piston rings, and reconditioning or plating the cylinder wall and valve-operating mechanism, including valve guides if needed. A top overhaul is a little misleading, because it is really an engine repair procedure and not a real overhaul as described earlier. Usually at this time, the accessories require no attention other than that normally required during ordinary maintenance functions. This repair is generally due to valves or piston rings wearing prematurely. Many stress that if an engine requires this much dismantling, it should be completely disassembled and receive a major overhaul.

Major Overhaul & Major Repairs

Major overhaul consists of the complete reconditioning of the powerplant. A reciprocating engine would require that the crankcase be disassembled per the FAA; a major overhaul is not generally a major repair. A certified powerplant-rated technician can perform or supervise a major overhaul of an engine if it is not equipped with an internal supercharger or has a propeller reduction system other than spur-type gears. 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. Again, instructions from 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 engine in this text. However, there are various overhaul practices and instructions of a nonspecific nature that apply to all makes and models of engines.

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.

Throughout the life of a product (whether type-certificated or not), manufacturing defects, changes in service, or design improvements often occur. When that happens, the OEM frequently uses a safety bulletin (SB) to distribute the information to the operator of the aircraft. SBs are good information and should be strongly considered by the owner for implementation to the aircraft. However, SBs are not required unless they are referred to in an airworthiness directive (AD) note or if compliance is required as a part of the authorized inspection program. Refer to 14 CFR part 39, section 39.27.

Receiving Inspection

The receiving inspection consists of determining the general condition of the total engine as received, along with an inventory of the engine's components. The accessory information should be recorded, such as model and serial numbers, and the accessories should be sent to overhaul if needed. The overhaul records should be organized, and the appropriate manuals obtained and reviewed along with a review of the engine's history (log books). The engine's service bulletins, airworthiness directives, and type certificate compliance should be checked. The exterior of the engine should be cleaned after mounting it on an overhaul stand. *[Figure 10-1]*

Figure 10-1. *Engine mounted on an overhaul stand.*

Disassembly

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. 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.

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

3. All loose studs, and loose or damaged fittings, should be carefully tagged to prevent being overlooked during inspection.

4. Always use the proper tool for the job. Use sockets and box end wrenches wherever possible. If special tools are required, use them rather than improvising.

Inspection Process

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

1. Visual.
2. Structural.
3. Dimensional.

Many defects on the engine components can be detected visually, and a determination of airworthiness can be made at this time. If, by visual inspection, the component is determined to be unairworthy, the part is rejected, and no further inspection or repair is required. Structural failures can be determined by several different methods. Magnetic parts can readily be examined by the magnetic particle method. Other methods, such as dye penetrate, eddy current, ultra sound, and X-ray, can also be used. 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. By using very accurate measuring equipment, each engine component can be dimensionally evaluated and compared to service limits and standards (tolerances) set by the manufacturer.

Visual Inspection

Visual inspection should precede all other inspection procedures. Parts should not be cleaned before a preliminary visual inspection, since indications of a failure may often 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 over-temperature 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—a condition caused by a rubbing action between two parts under light pressure that results in wear.
7. Chipping—breaking away of pieces of material, that is usually caused by excessive stress concentration or careless handling.
8. Corrosion—loss of metal by a chemical or electrochemical action. The corrosion products 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 is rough and may be lined in the direction that the foreign material moved relative to the surface.
13. Flaking—the breaking loose of small pieces of metal or coated surfaces, that 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 entirely 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, that 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, that 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.

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 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 is not 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, mutilated by overtightening, or from the use of improper tools, replace it with a new one.

Cylinder Head

Inspect the cylinder head for internal and external cracks. Use a bright light to inspect for cracks and investigate any suspicious areas with a magnifying glass or microscope. Carbon deposits must be cleaned from the inside of the head, and paint must be removed from the outside for this inspection.

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

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 $\pm \frac{1}{32}$ (0.03125) inch to allow for proper installation of safety devices.

Be sure the valve guides are clean before inspection. Often, carbon covers pits inside the guide. If a guide in this condition is put back in service, carbon again collects in the pits and valve sticking results. Besides pits, scores, and burned areas inside the valve guide, inspect them for wear or looseness.

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 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 gauge and a micrometer.

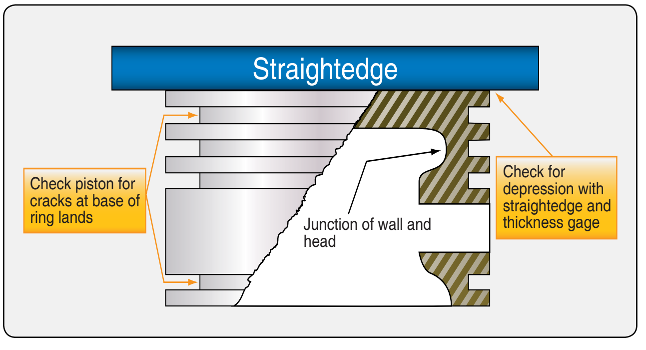


Figure 10-2. *Checking a piston head for flatness.*

Piston, Valve Train, & Piston Pin

When applicable, check for flatness of the piston head using a straightedge and thickness gauge. *[Figure 10-2]* If a depression is found, 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. Do not mistake casting marks or laps for a crack. During major overhaul, most pistons are generally replaced, as it requires more labor to clean and inspect the piston than it costs to replace it.

Crankshaft & Connecting Rods

Carefully inspect all surfaces of the crankshaft 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.

Visual inspection of connecting rods should be done with the aid of a magnifying glass or bench microscope. A rod that 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 over-speed 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.

Cleaning

After visually inspecting engine recesses for deposits of metal particles, it is important to clean all engine parts thoroughly to facilitate further 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

Degreasing can be done by immersing or spraying the part in a suitable commercial solvent. *[Figure 10-3]* 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. Therefore, when using water-mixed solutions, 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.

Removing Hard Carbon

While the degreasing solution removes dirt, grease, and soft carbon, deposits of hard carbon almost invariably remain on many interior surfaces. To remove these deposits, they must first be loosened 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.

Caution: When using a decarbonizing solution on magnesium castings, avoid immersing steel and magnesium parts in the same decarbonizing tank, as this practice often results in damage to the magnesium parts from corrosion.

Decarbonizing will usually loosen most of the hard carbon deposits remaining after degreasing. However, the complete removal of all hard carbon 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.

Follow the manufacturer's recommendations when grit-

Figure 10-3. *Typical solvent degreasing tank.*

blasting parts for the abrasive material being used. Sand, rice, baked wheat, plastic pellets, glass beads, or crushed walnut shells are examples of abrasive substances that are used for grit-blasting parts. A grit-blasting machine is shown in *Figure 10-4*.

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; however, extreme caution must be used 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 will generally 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.

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 °F 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.

Figure 10-4. *Grit-blasting machine.*

Some older engines used sludge chambers in the crankshafts, which were manufactured with hollow crankpins that serve as sludge removers. The sludge chambers require inspection and cleaning at overhaul. Sludge chambers are formed by means of spool-shaped tubes pressed into the hollow crankpins, or by plugs pressed into each end of the crankpin. If an engine has a sludge chamber or tubes, they 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. Due to improved oils, sludge chambers are no longer used with modern engines.

Structural Inspection

One of the best methods to double check your visual inspection findings is to supplement them with one of the forms of nondestructive testing, such as magnetic particle, dye penetrate, eddy current, ultrasound, and x-ray inspections. Defects in nonmagnetic parts (aluminum parts) can be found by all these methods except for magnetic particle inspection, which is used for magnetic or ferrous materials (steel).

Dye Penetrant Inspection

Dye penetrant inspection is a nondestructive test for defects open to the surface in parts made of any nonporous material. It is used with equal success on such metals as aluminum, magnesium, brass, copper, cast iron, stainless steel, and titanium. Dye penetrant inspection uses a penetrating liquid that enters a surface opening and remains there, making it clearly visible to the inspector. It calls for visual examination of the part after it has been processed, increasing the visibility of the defect so that it can be detected. Visibility of the penetrating material is increased by the addition of one of two types of dye: visible or fluorescent. When using a fluorescent dye, the inspection is accomplished using an ultraviolet (UV) light source (black light).

The steps for performing a dye penetrant inspection are:

1. Thorough cleaning of the metal surface.
2. Applying penetrant.
3. Removing penetrant with remover emulsifier or cleaner.

4. Drying the part.
5. Applying the developer.
6. Inspecting and interpreting results.

Eddy Current Inspection

Eddy currents are composed of free electrons under the influence of an induced electromagnetic field, that are made to drift through metal. Different meter readings are seen when the same metal is in different hardness states. Readings in the affected area are compared with identical materials in known unaffected areas for comparison. A difference in readings indicates a difference in the hardness state of the affected area. Eddy current inspection can frequently be performed without removing the surface coatings, such as primer, paint, and anodized films. It can be effective in detecting surface and subsurface corrosion, pots, and heat treat condition.

Ultrasonic Inspection

Ultrasonic detection equipment makes it possible to locate defects in all types of materials. There are three basic ultrasonic inspection methods:

1. Pulse-echo.
2. Through transmission.
3. Resonance.

Pulse-Echo

Flaws are detected by measuring the amplitude of signals reflected and the time required for these signals to travel between specific surfaces and the discontinuity.

Through Transmission

Through transmission inspection uses two transducers, one to generate the pulse and another placed on the opposite surface to receive it. A disruption in the sound path indicates a flaw and is displayed on the instrument screen. Through transmission is less sensitive to small defects than the pulse-echo method.

Resonance

This system differs from the pulse-echo method, in that the frequency of transmission may be continuously varied. The resonance method is principally used for thickness measurements when the two sides of the material being tested are smooth and parallel, and the backside is inaccessible. The point at which the frequency matches the resonance point of the material being tested is the thickness determining factor.

Magnetic Particle Inspection

Magnetic particle inspection is a method of detecting invisible cracks and other defects in ferromagnetic materials, such as iron and steel. It is not applicable to nonmagnetic materials. The inspection process consists of magnetizing the part, and then applying ferromagnetic particles to the surface area to be inspected. The ferromagnetic particles (indicating medium) may be held in suspension in a liquid that is flushed over the part; the part may be immersed in the suspension liquid; or the particles, in dry powder form, may be dusted over the surface of the part. The wet process is more commonly used in the inspection of aircraft parts.

If a discontinuity is present, the magnetic lines of force are disturbed, and opposite poles exist on either side of the discontinuity. The magnetized particles form a pattern in the magnetic field between the opposite poles. This pattern, known as an indication, assumes the approximate shape of the surface projection of the discontinuity. A discontinuity may be defined as an interruption in the normal physical structure or configuration of a part.

X-ray

X-rays can penetrate material and disclose discontinuities through the metal or non-metal components, making it an excellent inspection process when needed to determine the structural integrity of an engine component. The penetrating radiation is projected through the part to be inspected and produces an invisible or latent image in the film. When processed, the film becomes a radiograph, or shadow picture, of the object. This inspection medium, as a portable unit, provides a fast and reliable means for checking the integrity of engine components.

Additional and more thorough information on NDT inspection is covered in detail in the Aviation Maintenance Technician Handbook - General (FAA-H-8083-30, as amended).

Dimensional Inspection

The dimensional inspection is used to assure that the engine's component parts and clearances meet the manufacturer's specifications. These specs are listed in a table of limits, which lists serviceable limits and the manufacturer's new part maximum and minimum dimensions. Many measuring tools are used to perform the dimensional inspection of the engine. Some examples of these devices are discussed as the procedure for measuring the engine's components for dimensional inspection is explained in the following paragraphs.

Cylinder Barrel

Inspect the cylinder barrel for wear, using a cylinder bore gauge *[Figure 10-5]*, a telescopic gauge, 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.

Figure 10-5. *A cylinder bore gauge.*

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.

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 erosive 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 wears the cylinder wall more at the top of the cylinder. In most cases, the taper ends with a ridge, that must be removed during overhaul. *[Figure 10-6]*

Where cylinders are built with an intentional choke, measurement of taper becomes more complicated. Cylinder choke is where the top of the cylinder has been made with the very top diameter of the cylinder smaller, to compensate for wear and expansion during operation. It is necessary to know exactly how the size indicates wear or taper. Taper can be measured in any cylinder by a cylinder dial gauge as long as there is not a sharp step. The dial gauge 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, is formed in the cylinder by the wearing action of the piston rings. *[Figure 10-6]* The greatest wear is at the top of the ring travel limit. The ridge that results is 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 the lowest travel. This step is 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 cylinders are deglazed. With more extensive damage, the cylinder has to be reground or honed. If the damage is too deep to be removed by either of these methods, the cylinder usually will have to be rejected. Most engine manufacturers, or engine overhaul repair stations, 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 warpage can be checked by using a thickness gauge. A cylinder whose flange is warped beyond the limits should be rejected.

Rocker Arms & Shafts

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

Inspect the shaft's diameter for correct size with a micrometer. Rocker shafts are often 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. The clearance between the shaft and the bushing is most important.

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.

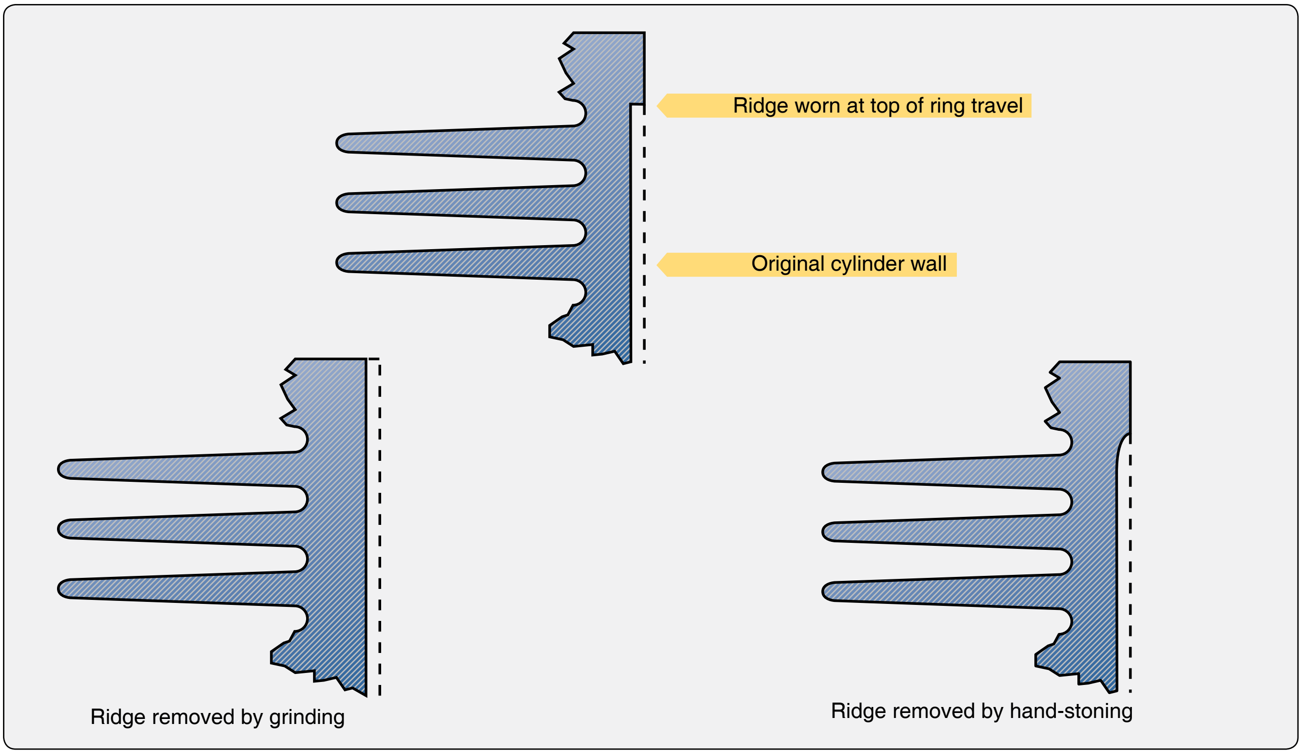


Figure 10-6. *Ridge or step formed in an engine cylinder.*

Crankshaft

Use extreme care in inspecting and checking the crankshaft for straightness. Place the crankshaft in V-blocks, supported at the locations specified in the applicable engine overhaul manual as in *Figure 10-7.* 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 results in rupture of the nitrided surface of the bearing journals, a condition that causes eventual failure of the crankshaft. Measure the outside diameter of the crankshaft main and rod-bearing journals using a micrometer. *[Figure 10-8]* Internal measurements can be made by using telescoping gauges, and then measuring the telescoping gauge with a micrometer. *[Figure 10-9]* Compare the resulting measurements with those in the table of limits.

Figure 10-7. *Checking crankshaft runout.*

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, or twist, insert the arbors into the rod bores. *[Figure 10-10]* Place the parallel blocks on

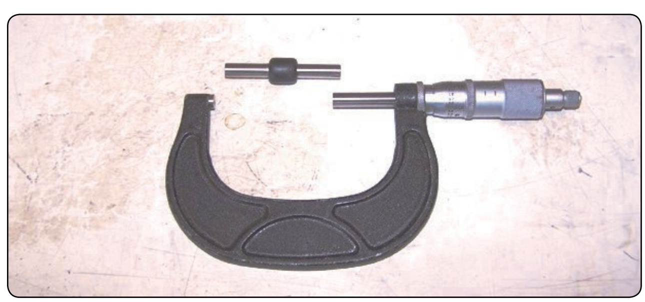


Figure 10-8. *A micrometer.*

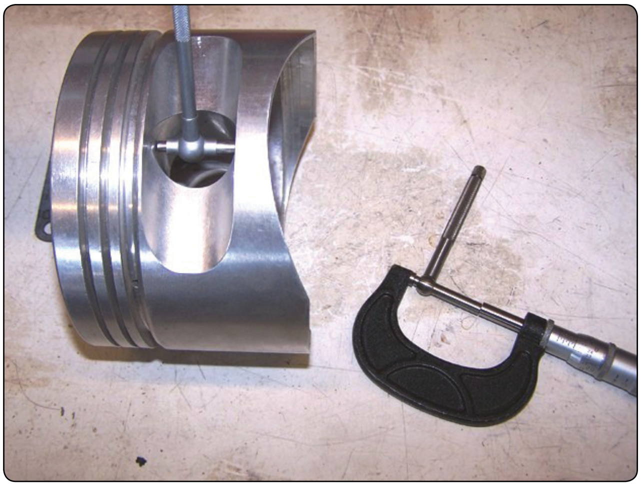


Figure 10-9. *Telescoping gauges and micrometer combination.*

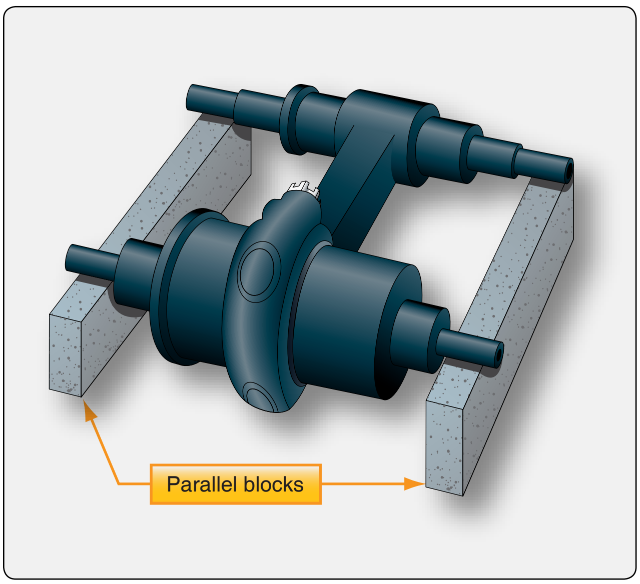


Figure 10-10. *Checking connecting rod squareness.*

a surface plate. Place the ends of the arbors on the parallel blocks. Using a thickness gauge, check the clearance at the points where the arbors rest on the blocks. This clearance, divided by the separation of the blocks in inches, gives the twist per inch of length.

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 centerline. 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.

Repair & Replacement

The engine components that have failed inspection, or are unrepairable, should have been discarded. The component parts that need repair and replacement are now given the attention required. The replacement components (new parts) are organized and laid out for reassembly.

Minor damage to engine parts, 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 satisfactorily removed with Swiss pattern files or small, edged stones. Pipe threads should not be tapped deeper to clean them, because this practice results 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 polished finish.

In general, welding of highly-stressed engine parts can be accomplished only when approved by the manufacturer. However, welding may be accomplished using methods that are approved by the engine manufacturer, and if it can be reasonably expected that the welded repair will not adversely affect the airworthiness of the engine.

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 repainted according to the engine manufacturer's recommendations. 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. After the primer is dry, parts should be painted with engine enamel, that should be air dried until hard, or baked for ½ hour 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.

Any studs that 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 is 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 an 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 is discussed in the following section to provide an understanding of the operations involved.

Visually 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 causes 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 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 are burned. If more than one thread is missing, the bushing should be rejected. Tighten a plug in the bushing to check for looseness.

Piston & Piston Pins

If the old piston is to be reused, or a new piston is to be used, 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. Most engines 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 wear. The groove needs to be checked for side clearance with a feeler gauge to determine the amount of wear in the grooves. 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 gauge and a micrometer. Use the magnetic particle method to inspect the pin for cracks. Since the pins are often case hardened, cracks show up inside the pin more often than they do on the outside. Check the pin for bends using V-blocks and a dial indicator on a surface plate. *[Figure 10-11]* Measure the fit of the plugs in the pin. In many cases, the pistons and piston pins are routinely replaced at overhaul.

Valves & Valve Springs

The locations for checking runout and edge thickness of the valves are shown in *Figure 10-12*. 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 a structural inspection method described later. Examine the valve springs for cracks, rust, broken ends, and compression. Cracks can be located by visual inspection or the magnetic particle method.

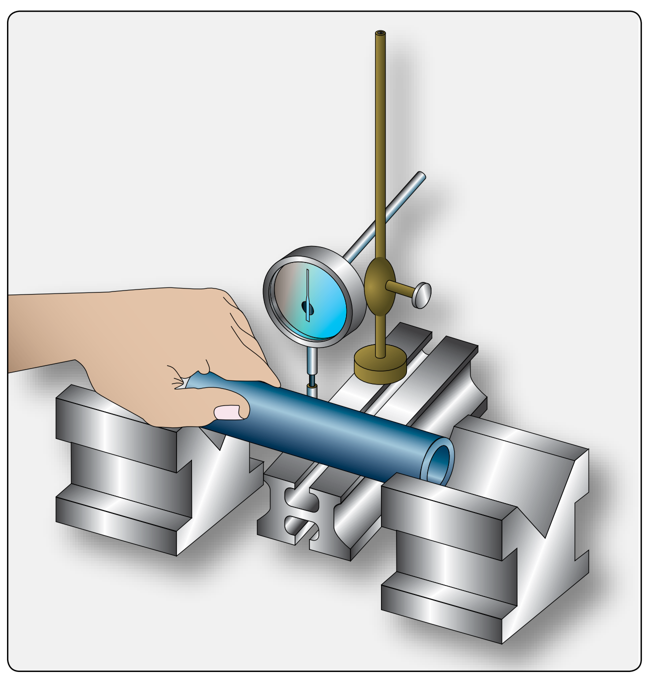


Figure 10-11. *Checking a piston pin for bends.*

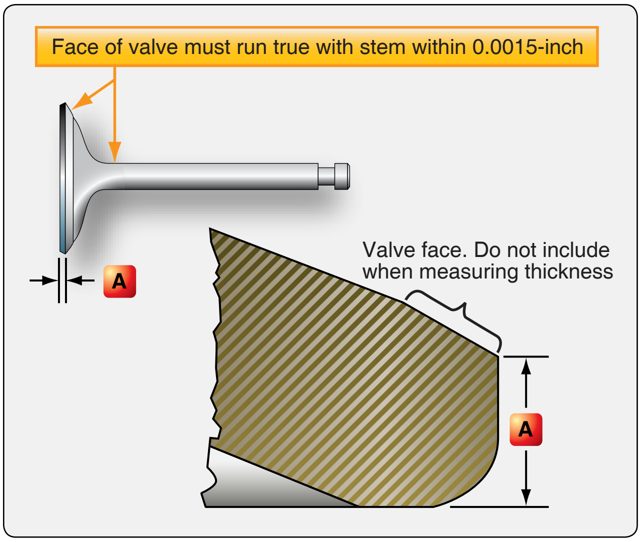


Figure 10-12. *Valve showing locations for checking runout and section for measuring edge thickness.*

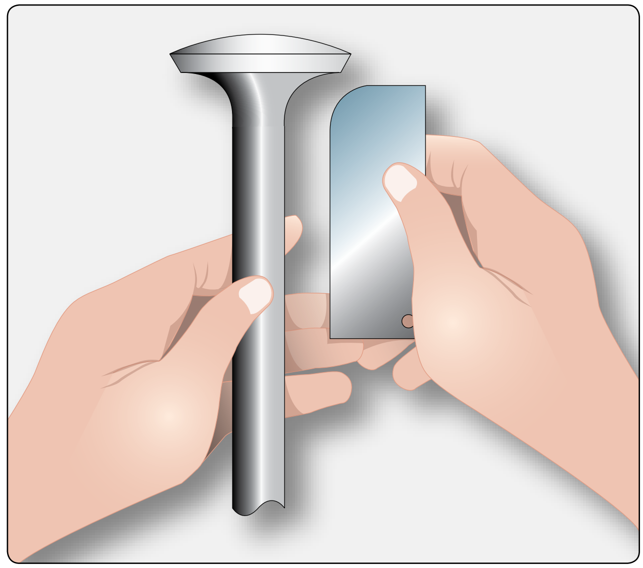


Figure 10-14. *Checking valve stretch with a manufacturer's gauge.*

Critical areas of the valve include the face and tip *[Figure 10-13]*, 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 gauge. *[Figure 10-14]* If a micrometer is used, stretch is 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 visually for physical damage and damage from burning or corrosion. Do not re-use valves that indicate damage of this nature.

Compression is tested with a valve spring compression tester. *[Figure 10-15]* 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

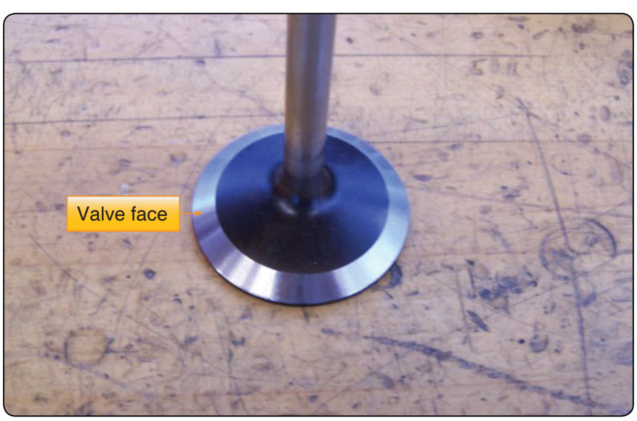


Figure 10-13. *Valve face surface.*

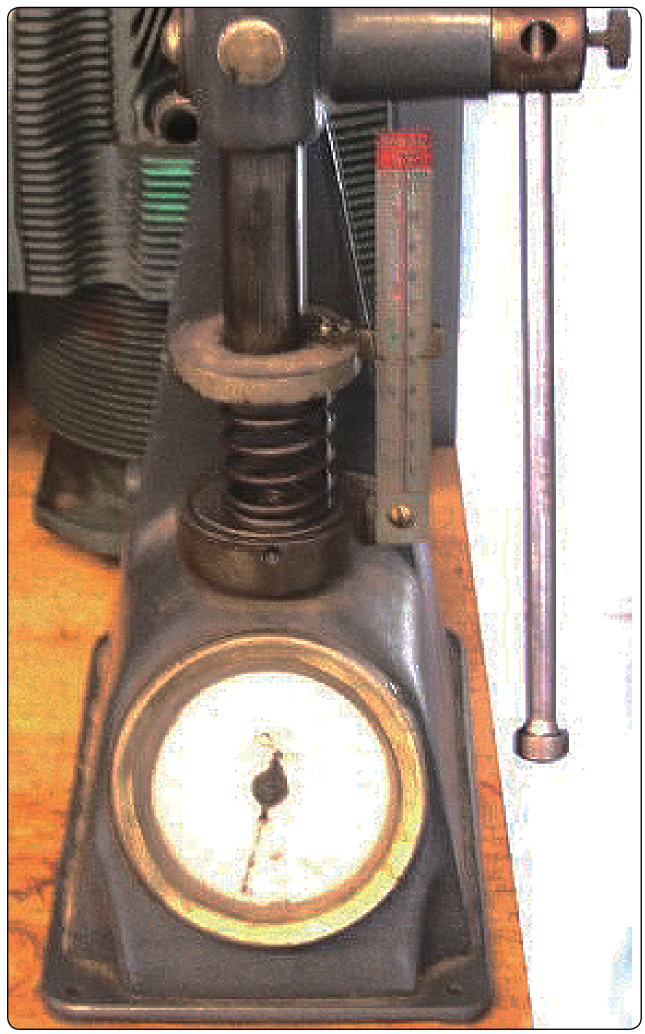


Figure 10-15. *Valve spring compression tester.*

the spring to the specified height. This must be within the pressure limits established by the manufacturer.

Refacing Valve Seats

The valve seat inserts of aircraft engine cylinders usually are in need of refacing at every overhaul. They are refaced 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 made concentric with the valve guide.

Low power engines can use either bronze or steel seats. Bronze seats, although not widely used on current engines, are made of aluminum bronze or phosphor bronze alloys. Steel seats are commonly used for valve seats on higher powered engines and are made of heat-resistant steel with a layer of stellite steel alloy on the valve contact surface. Stellite seats can require a special stone to grind this very hard material.

Steel valve seats are refaced by grinding equipment. *[Figure 10-16]* Bronze seats are refaced 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 redressing 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 refacing the seat, make sure that the valve guide is in good condition, clean, and does not have to be replaced. Mount the cylinder firmly in the hold down 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. *[Figure 10-17]* 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.

The stones are installed on special stone holders. The face of the stone is trued by a diamond dresser. The stone should be refaced 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 results, and a rough grind is produced. It is very important that the stone be rotated at a speed that permits grinding instead of rubbing. This speed is approximately 8,000 to 10,000 revolutions per minute (rpm). 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.

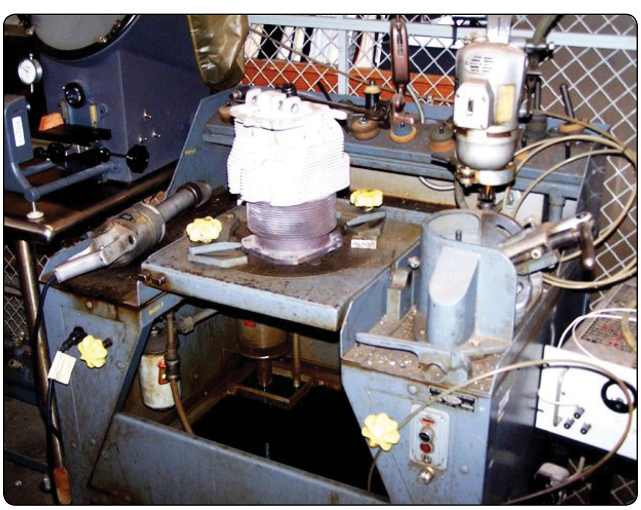


Figure 10-16. *Valve seat grinding equipment.*

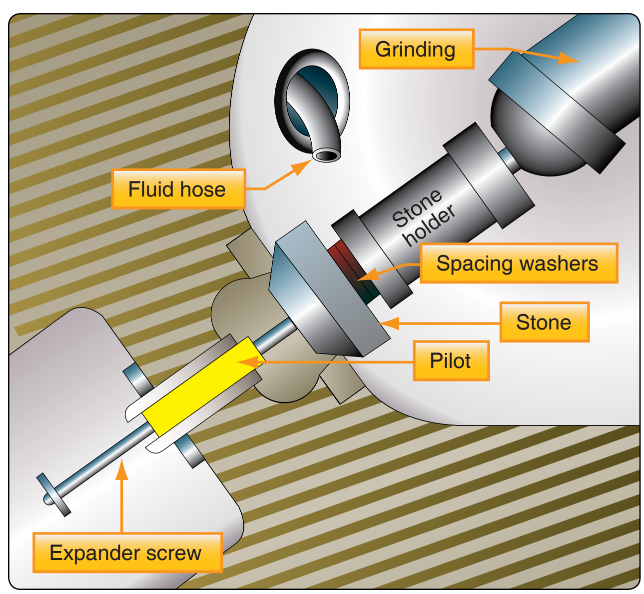


Figure 10-17. *Valve seat grinding setup.*

Another practice, 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 are removed. *[Figure 10-18]* After refacing, 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 inch. The size of the seat may be determined by using Prussian blue. Prussian blue is used to check for contact transfer from one surface to the other. 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 indicates 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 gauge 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. Lapping is accomplished by using a small amount of lapping compound placed between the valve face and seat. The valve is then moved in a rotary motion back and forth until the lapping compound grinds slightly into the surface. After cleaning the lapping contact compound off, a contact area can be seen. Examples of test results are shown in *Figure 10-19*.

If the seat contacts the upper third of the valve face, grind off the top corner of the valve seat. *[Figure 10-20]* 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. *[Figure 10-21]* 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. *[Figure 10-22]*

If the valve seat has been cut or ground too much, the valve contacts the seat too far up into the cylinder head, and the valve clearance, spring tension, and the fit of the valve to the seat is 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 refacing 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. 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.

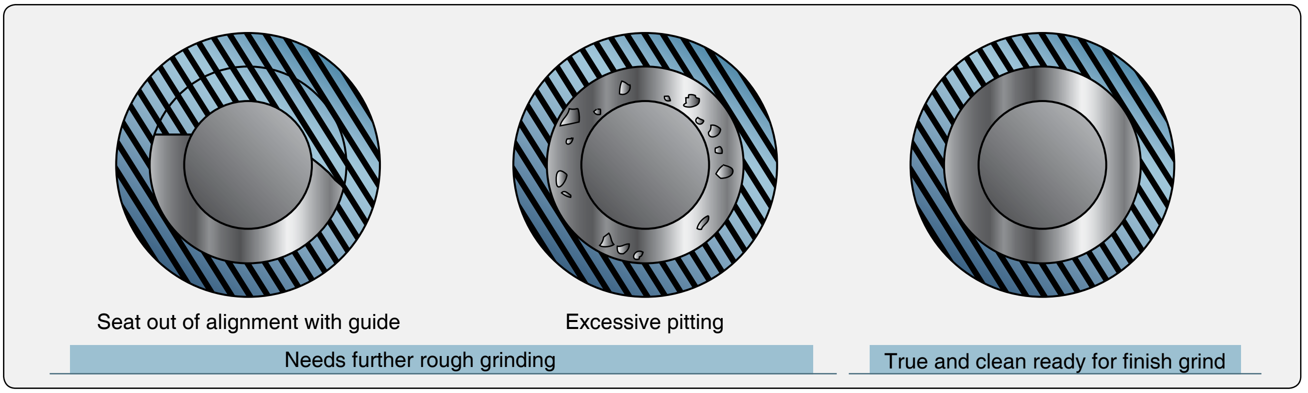


Figure 10-18. *Valve seat grinding.*

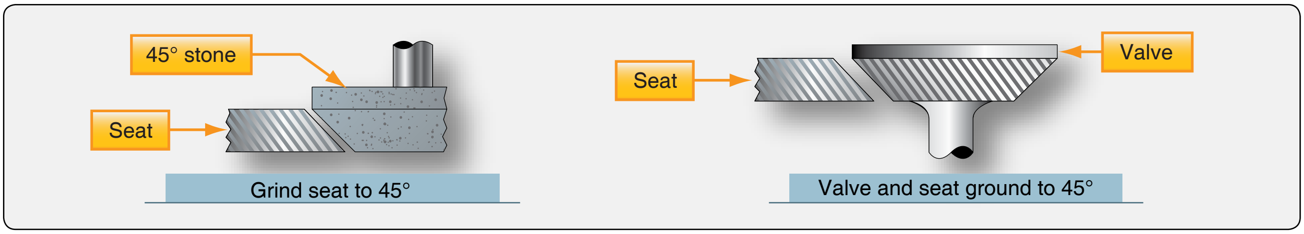


Figure 10-19. *Fitting the valve and seat.*

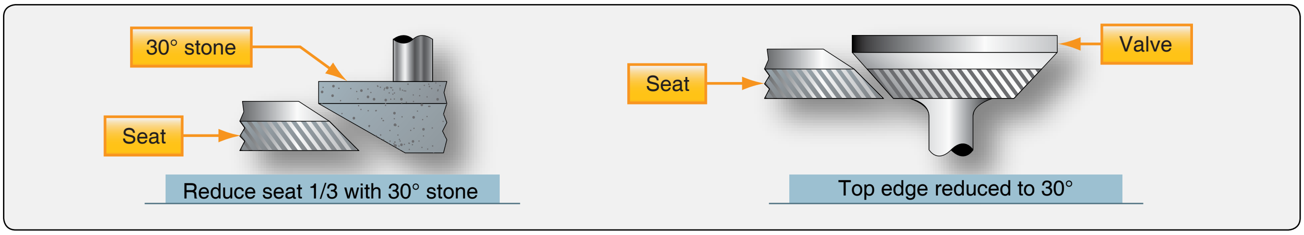


Figure 10-20. *Grinding top surface of the valve seat.*

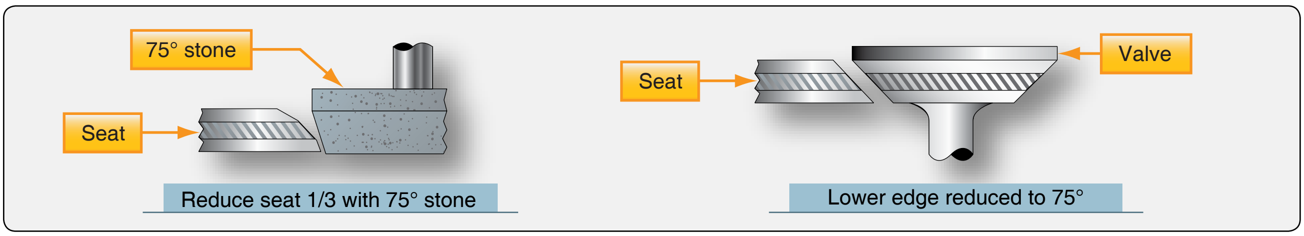


Figure 10-21. *Grinding the inner corner of the valve seat.*

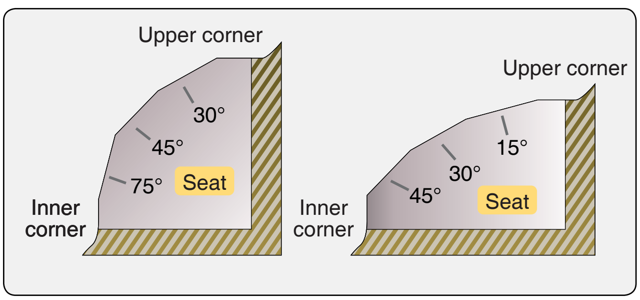


Figure 10-22. *Valve seat angles.*

The interference fit is used to obtain a more positive seal by means of a narrow contact surface. *[Figure 10-23]* Theoretically, there is a line contact between the valve and seat. With this line contact, 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.

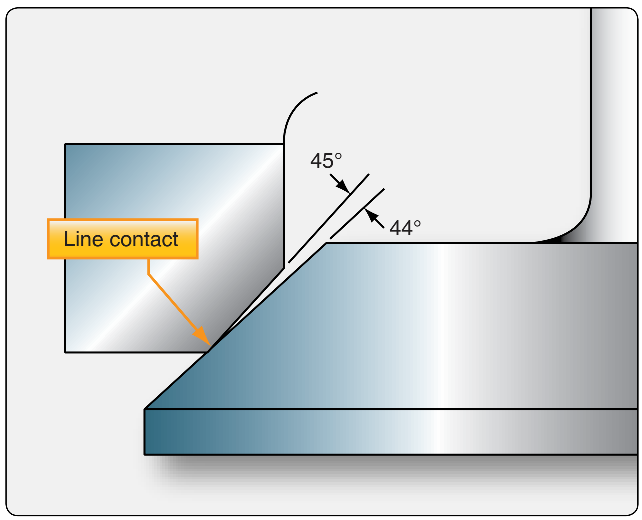


Figure 10-23. *Interference fit of valve and valve seat.*

Install the valve into the chuck and adjust the chuck so that the valve face is approximately 2 inches from the chuck. *[Figure 10-24]* 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 refacing a valve.

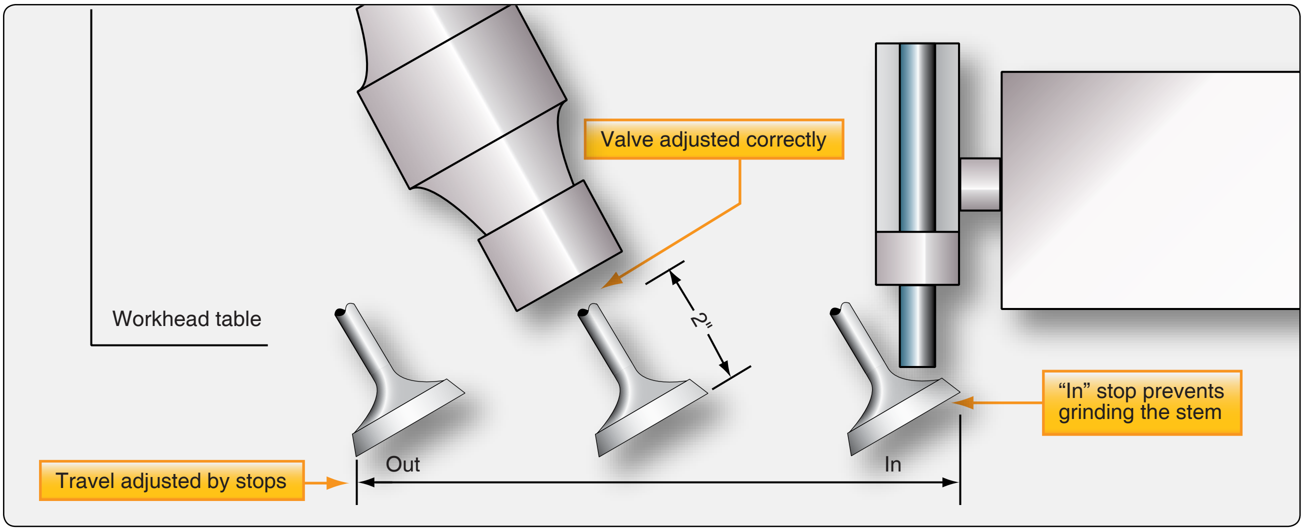


Figure 10-24. *Valve installed in grinding machine.*

Check the travel of the valve face across the stone. The valve should completely pass the stone on both sides, yet not travel far enough to grind the stem. There are stops on the machine that can be set to control this travel.

With the valve set correctly in place, turn on the machine and 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. *[Figure 10-25]* 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 work head 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, that 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 pre-ignition; the valve edge would burn away in a short period of time, and the cylinder would have to be overhauled again. *Figure 10-26* shows a valve with a normal margin and one with a feather edge.

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

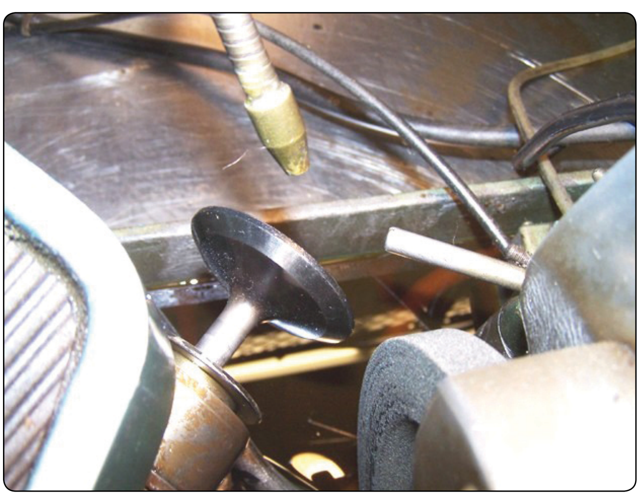


Figure 10-25. *Valve in chuck ready to grind.*

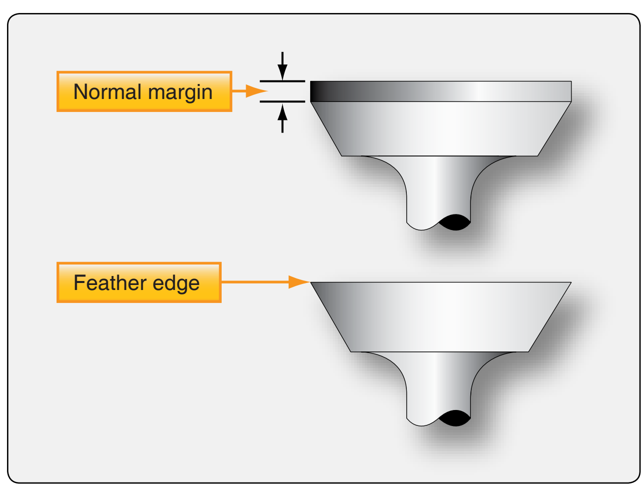


Figure 10-26. *Engine valves showing normal margin and a feather edge.*

The valve is held by a clamp on the side of the stone. *[Figure 10-27]* 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 V-way approximately 45° to the grinding stone. Hold the valve onto the V-way and twist the valve tip onto the stone. 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 & 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 10-28*.

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 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. The incorrect indications are of value in diagnosing improper valve and valve seat grinding. Incorrect indications, their cause, and remedy are shown in *Figure 10-29*.

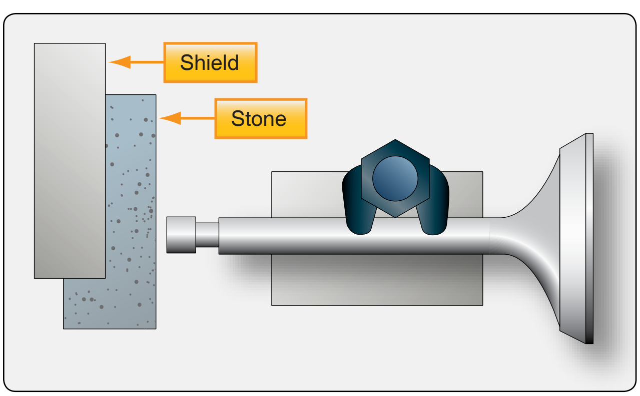


Figure 10-27. *Grinding a valve tip.*

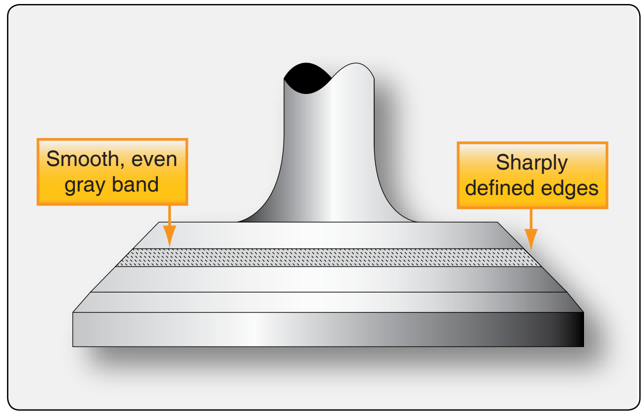


Figure 10-28. *A correctly lapped valve.*

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 is the removal of scores. Usually, these may be removed only on the piston skirt if they are very light. 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, the pistons are normally replaced. 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. It has become more economical to replace pistons rather than reconditioning and reusing old ones, especially during overhaul.

Cylinder Grinding & Honing

If a cylinder has excessive taper, out-of-roundness, step, or its maximum size is beyond limits, it can be reground to the next allowable oversize. If the cylinder walls are lightly rusted, scored, or pitted, the damage may be removed by honing or lapping.

Regrinding a cylinder is a specialized job that the powerplant mechanic is not usually expected to be able to do. However,

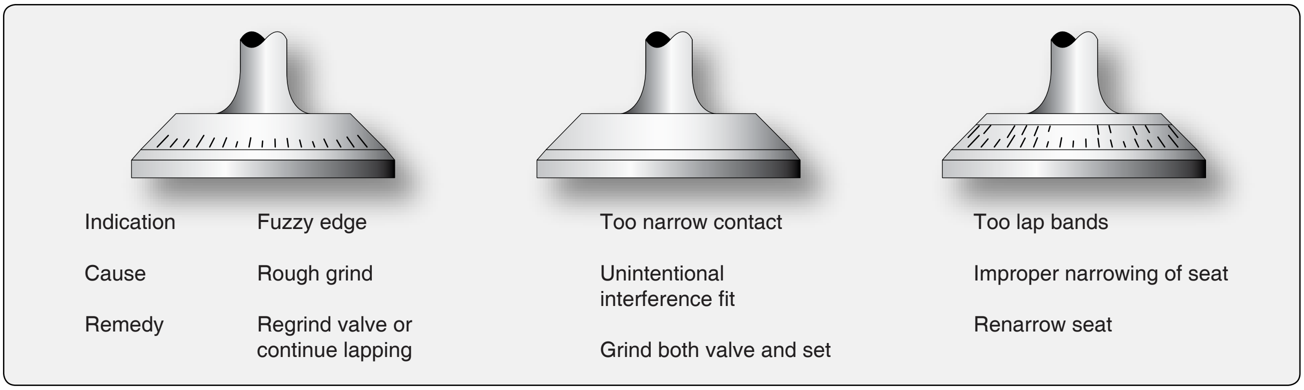


Figure 10-29. *Incorrectly lapped valves.*

the mechanic must be able to recognize when a cylinder needs regrinding, and they must know what constitutes a good or bad job.

Generally, standard aircraft cylinder oversizes are 0.010 inch, 0.015 inches, 0.020 inch, or 0.030 inch. Aircraft cylinders have relatively thin walls and may have a nitrided surface, that must not be ground away. Nitriding is a surface hardening process that hardens the steel surface to a depth of several thousandths of an inch. 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 regrind size, the standard bore size must be known. This usually can be determined from the manufacturer's specifications or manuals. The regrind size is figured from the standard bore. For example, a certain cylinder has a standard bore of 3.875 inches. To have a cylinder ground to 0.015 inches oversize, it is necessary to grind to a bore diameter of 3.890 inch (3.875 + 0.015). A tolerance of ±0.0005 inches is usually accepted for cylinder grinding.

Another factor to consider when determining the size to which a cylinder must be reground 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 is necessary to grind to the next oversize to clean up the entire cylinder.

The type of finish desired in the cylinder is an important consideration when ordering a regrind. Some engine manufacturers specify a fairly rough finish on the cylinder walls, that allows the rings to seat even if they are not lapped to the cylinder. Other manufacturers desire a smooth finish to which a lapped ring seats 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 micro-inch root mean square (micro-inch RMS). In a finish where the depth of the grinding scratches are one-millionth (0.000001) of an inch deep, it is specified as 1 micro-inch RMS. Most aircraft cylinders are ground to a finish of 15 to 20 micro-inch RMS. Several low-powered engines have cylinders that are ground to a relatively rough 20- to 30-micro-inch RMS finish. On the other end of the scale, some manufacturers require a superfinish of approximately 4- to 6-micro-inch RMS.

Cylinder grinding 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. *[Figure 10-30]* 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 centerline of the cylinder. Some cylinder bore grinding machines produce a perfectly 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 arc ground to produce a smaller internal diameter at the top than at the bottom. The purpose of this type grind or taper is to maintain 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. In this case, specify the cylinder regrind size to allow for some metal removal during honing. The usual allowance for honing is 0.001 inch. If a final cylinder bore size of 3.890 inches is desired, specify the regrind size of 3.889 inches, and then hone to 3.890 inches.

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

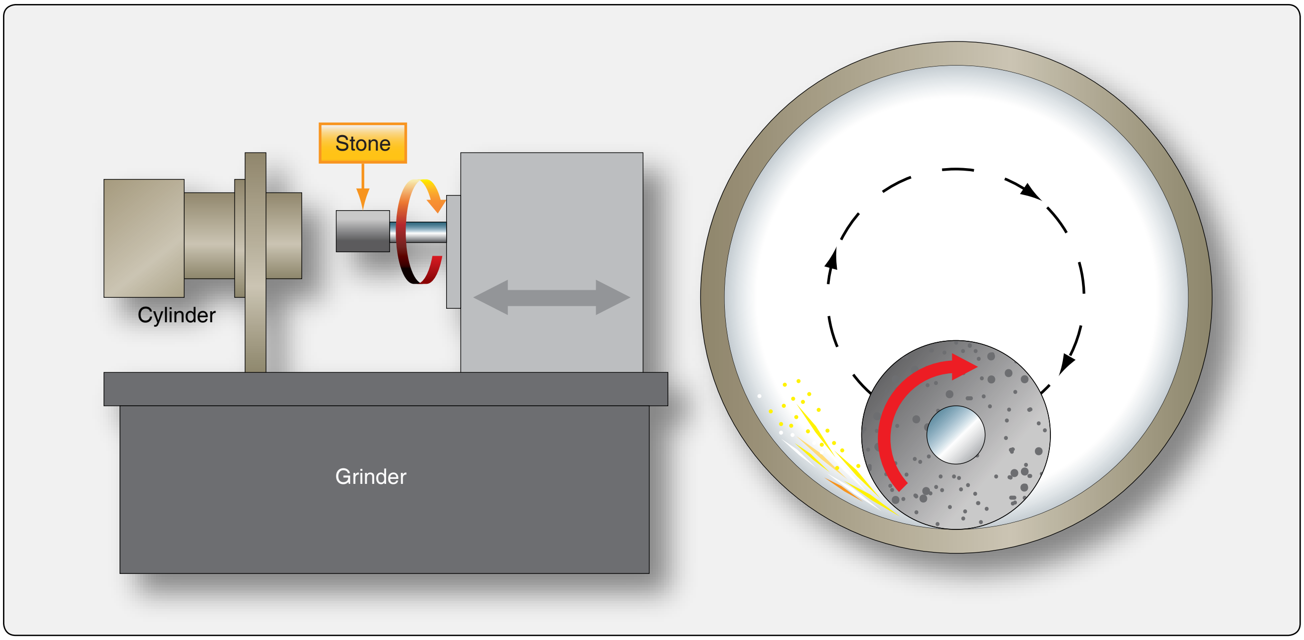


Figure 10-30. *Cylinder bore grinding.*

micromatic hone can also be used to straighten out the cylinder walls. A burnishing hone should not be used in an attempt to straighten cylinder walls. *[Figure 10-31]* Since the stones are only spring loaded, they follow the contour of the cylinder wall and may aggravate a tapered condition.

Deglazing the cylinder walls is accomplished with the use of a deglazing hone. A cross-hatch pattern must be placed on the cylinder wall to allow for piston ring break-in. This is accomplished by a deglazing hone turned by a drill being moved in and out of the cylinder rapidly. *[Figure 10-32]*

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

Reassembly

Before starting reassembly, all serviceable and new engine components need to be cleaned, organized, and laid out in the order they are to be assembled. A popular method of engine assembly is for the engine to be assembled at one work station with the same technicians completing the total assembly of the engine. It is also important to refer to the parts catalog to ensure that the correct hardware is used during the assembly of the engine. The engine overhaul manual should be referred to for information on the use of safety wire, self-locking nuts, and torque values. During assembly, the components should be pre-lubricated as the overhaul manual sets forth. It is important to follow the manufacturer's overhaul assembly procedures completely and perform all checks and procedures that are called for in the manual.

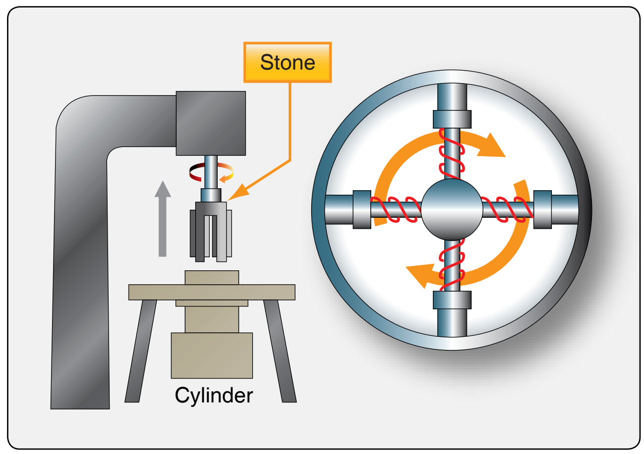


Figure 10-31. *Cylinder honing.*

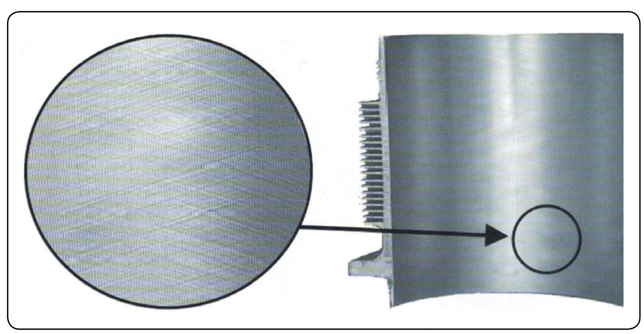


Figure 10-32. *Cross-hatch pattern on cylinder wall.*

Installation & Testing

Testing Reciprocating Engines

The procedures and equipment used in determining that an engine is ready for airworthy service and is in excellent mechanical condition, normally requires the use of a test stand, or test cell, although the aircraft can be used.

[Figure 10-33] The method of engine testing or run-in that takes place during overhaul prior to delivery of the engine is critical to the airworthiness 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. Thus, the reliability and potential service life of an engine is in question until it has satisfactorily passed the cell test.

The test serves a dual purpose. First, it accomplishes piston ring run-in and bearing burnishing. 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 (break-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 with high oil consumption. 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.

The failure of any part during engine testing or run-in requires that the engine be returned, repaired, and completely retested. After an engine has successfully completed test requirements, it is then specially treated to prevent corrosion, if it is shipped or stored before being installed in an aircraft. During the final run-in period during testing, 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 °C to 121 °C. Near the end of final run-in, corrosion-preventive mixture (CPM) is used as the engine lubricant. The engine induction passages and combustion chambers are also treated with CPM by an aspiration method. CPM is drawn or breathed into the engine.

Test Cell Requirements

The test cell requires an area to mount and hold the engine for testing. The cell needs to have the controls, instruments, and any special equipment to evaluate the total performance of the engine. A test club should be used for testing instead of a flight propeller. *[Figure 10-34]* A test club provides more cooling air flow and the correct amount of load. The operational tests and test procedures vary with individual engines, but the basic requirements are generally closely related.

Engine Instruments

The test cell control room contains 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 can operate using different methods, some mechanically, some electrically, and some by sensing

Figure 10-33. *Test stand.*

Figure 10-34. *Test club.*

the direct pressure of air or liquid. Some of the basic instruments are:

1. Carburetor air temperature gauge.
2. Fuel pressure gauge.
3. Fuel-flow meter.
4. Manifold pressure gauge.
5. Oil temperature gauge.
6. Oil pressure gauge.
7. Tachometer.
8. Exhaust gas temperature gauge.
9. Cylinder head temperature gauge.
10. Torquemeter.

Instrument markings, ranges of operation, minimum and maximum limits, and the interpretation of these markings are general to all the instruments. Generally, the instrument marking system consists of three colors: red, yellow, and green. A red line, or mark, indicates a point beyond which a dangerous operating condition exists. A red arc indicates a dangerous operating range due generally to an engine propeller vibration range. This arc can be passed through, but the engine cannot be operated in this area. 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 green arc shows a normal and safe range of operation. 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.

Carburetor Air Temperature (CAT) Indicator

Measured at the carburetor entrance, carburetor air temperature (CAT) 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. CAT is also useful for checking induction system condition. Backfiring is indicated as a momentary rise on the gauge, provided it is of sufficient severity for the heat to be sensed at the carburetor air-measuring point. A sustained induction system fire shows a continuous increase of CAT.

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 is 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. 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 CAT gauge indicates the temperature of the air before it enters the carburetor. The temperature reading is sensed by a bulb or electric sensor. In the test cell, the sensor is located in the air intake passage to the engine and, in an aircraft, it is located in the ram-air intake duct. The CAT gauge is calibrated in the centigrade scale. *[Figure 10-35]* This gauge, like many other multi-engine aircraft instruments, is a dual gauge; two gauges, 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.

Fuel Pressure Indicator

The fuel pressure gauge is calibrated in pounds per square inch (psi) of pressure. It is used during the test run-in to measure engine fuel pressure at the carburetor inlet, the fuel

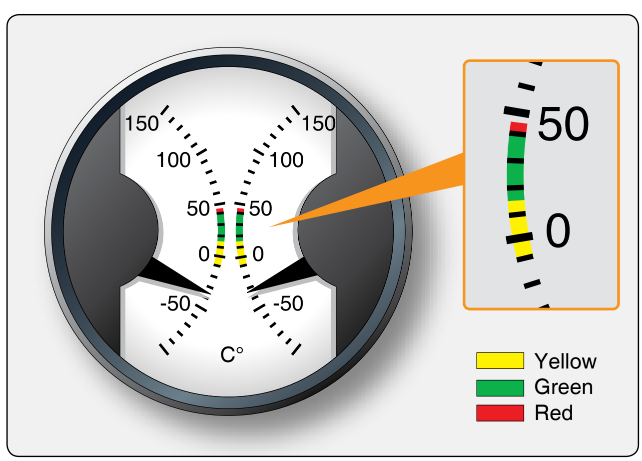


Figure 10-35. *Carburetor air temperature gauge.*

feed valve discharge nozzle, and the main fuel supply line. Fuel gauges 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 or fuel injection unit inlet of each engine, and the pressure is indicated on individual gauges on the instrument panel. *[Figure 10-36]* The dial is calibrated in graduations and is extended and numbered. The numbers range from 0 to 10 in this example. The red line on the dial at the 2 pounds psi graduation shows the minimum fuel pressure allowed during flight. The green arc shows the desired range of operation, which is 2 to 9 psi. The red line at the 9 psi graduation indicates the maximum allowable fuel pressure. Fuel pressures vary with the type of fuel system installation and the size of the engine. When fuel injection systems are used, the fuel pressure range is much higher; the minimum allowable pressure is approximately 10 psi, and the maximum is generally 25 psi.

Oil Pressure Indicator

The main oil pressure reading is taken at the pressure side of the oil pump. Generally, there is only one oil pressure gauge for each aircraft engine. The oil pressure gauge dial does not show the pressure range or limits for all installations. *[Figure 10-36]* The actual markings for specific aircraft may be found in the aircraft specifications or Type Certificate Data Sheets. The lower red line at 25 psi indicates the minimum oil pressure permissible in flight. The green arc between 60 to 85 psi illustrates the desired operating oil pressure range. The red line at 100 psi indicates maximum permissible oil pressure.

Figure 10-36. *Engine instrument clusters.*

The oil pressure gauge indicates the pressure, in psi, 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 gauge fails to register pressure when the engine is operating. Excessive oscillation of the gauge pointer indicates that there is air in the lines leading to the gauge, or that some unit of the oil system is functioning improperly.

Oil Temperature Indicator

During engine run-in in the test cell, 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 gauge line in the aircraft is connected at the oil inlet to the engine.

Three range markings are used on the oil temperature gauge. The green arc in *Figure 10-36*, on the dial, shows the minimum oil temperature permissible for ground operational checks or during flight. The green mark between 25 °F and below 245 °F shows the desired oil temperature for continuous engine operation. The red mark at 245 °F indicates the maximum permissible oil temperature.

Fuel-Flow Meter

The fuel-flow meter measures the amount of fuel delivered to the engine. During engine testing procedures, the fuel-flow to the engine can be measured by three different methods: a direct flow meter, a pressure-based flow meter, or a turbine sensor-based flow meter. The direct reading flow meter uses 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 air-fuel mixture for a given power setting. Reciprocating engines on light aircraft usually use a fuel pressure gauge that is also used for the flow meter. This is because the fuel-flow is proportional to the fuel pressure in this system. Fuel-flow is normally measured in gallons per hour.

In most turbine aircraft installations, 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 fuel control device. The transmitter is an electrical device that contains a turbine that turns faster as the flow increases, which increases the electrical signal to the indicator. The fuel-flow transmitter is connected electrically to the indicator located on the aircraft flight deck, or on the test cell operator's panel. The reading on the indicator on turbine aircraft 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 on reciprocating engines is a gauge that records the pressure as an absolute pressure reading. Absolute pressure takes into account the atmospheric pressure plus the pressure in the intake manifold. To read the manifold pressure of the engines, a specially designed manifold pressure gauge that indicates absolute manifold pressure in inches of mercury ("Hg) is used. The red line indicates the maximum manifold pressure permissible during takeoff.

The manifold pressure gauge range markings and indications vary with different kinds of engines and installations. *Figure 10-37* illustrates the dial of a typical manifold pressure gauge and shows how the range markings are positioned. The green arc starts at 35 "Hg and continues to the 44 "Hg. The red line on the gauge, at 49 "Hg shows the manifold pressure recommended for takeoff. This pressure should not be exceeded.

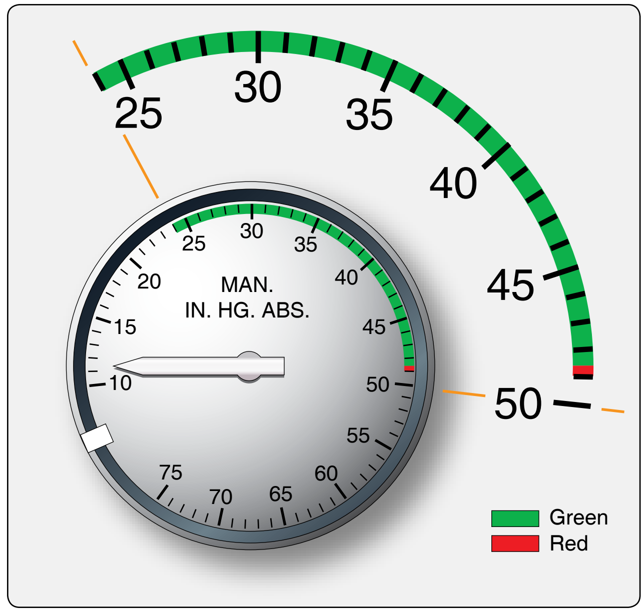


Figure 10-37. *Manifold pressure gauge.*

Tachometer Indicator

The tachometer for reciprocating engines shows the engine crankshaft rpm. The system used for testing the engine is the same as the system in the aircraft installation. The tachometer, often referred to as TACH, is calibrated in hundreds with graduations at every 100-rpm interval. The dial shown in *Figure 10-38* starts at 0 rpm and goes to 35 (3,500 rpm). The green arc indicates the rpm range within operation that is permissible. The red line indicates the maximum rpm permissible during takeoff; any rpm beyond this value is an overspeed condition.

Figure 10-38. *Tachometer.*

Turbine engines use percent rpm indicators due to the high rpm that the engines generally operate. Each rotating assembly in an engine has its own percent rpm indicator. The tachometer indicates speed of the compressor section. The 100 percent position on the indicator is the highest rpm at which the engine can operate. Red lines and green arcs operate the same as with reciprocating engines. Rotorcraft use two synchronous tachometers.

Cylinder Head Temperature Indicator

During the engine test procedures, the cylinder head temperatures of various cylinders on the reciprocating engine are normally tested. Thermocouples are connected to several cylinders and, by a selector switch, any cylinder head temperature can be indicated on the indicators. When installed in the aircraft, there is sometimes only one thermocouple lead and indicator for each engine installed in an aircraft.

Cylinder head temperatures are indicated by a gauge connected to a thermocouple attached to the cylinder, that 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 inside the cylinder dome, exhaust valve, and piston is 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 are lower, conditions such as detonation are not indicated unless they occur in the cylinder that has the thermocouple attached.

The cylinder head temperature gauge range marking is similar to that of the manifold pressure and tachometer indicator. The cylinder head temperature gauge is a dual gauge that incorporates two separate temperature scales. *[Figure 10-39]* 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 gauge 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 minutes). The red line indicates maximum permissible temperature, 260 °C.

Torquemeter

Most torque systems use an oil pressure output from a torque valve to indicate actual engine power output at various power settings. The torquemeter indicates the amount of torque being produced at the propeller shaft. A helical gear moves back and forth as the torque on the propeller shaft varies. This gear, acting on a piston, positions a valve that meters the oil pressure proportionally to the torque being produced. A change in pressure from the valve that is connected to a transducer is then converted to an electrical signal and is transmitted to the flight deck. The torquemeter can read out in foot-pounds of torque, percent of horsepower, or horsepower. The earlier systems read out in psi, and the flight engineer converted this to the correct power setting. *[Figure 10-40]* Some systems use strain gauges to attach to the ring gear to provide an electrical signal directly to the readout.

Warning Systems

Many of the miscellaneous gauges and devices indicate only that a system is functioning or has failed to function. On some aircraft, a warning light illuminates when the fuel pressure or oil pressure is low.

Reciprocating Engine Operation

The operation of the powerplant is controlled from the flight deck. Some installations have numerous control handles and levers connected to the engine by rods, cables, bellcranks, pulleys, etc. In most cases, the control handles are conveniently mounted on quadrants in the flight deck. 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.

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. Manifold pressure, rpm, engine temperature, oil temperature, CAT, and the air-fuel ratio can be controlled by manipulating the flight deck 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 (rpm).
2. Manifold pressure.

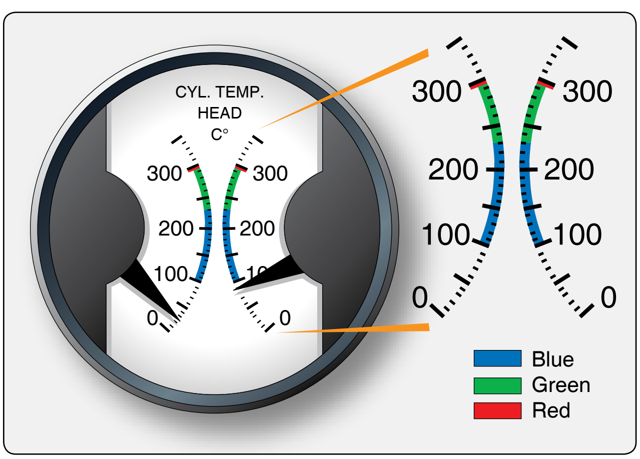


Figure 10-39. *Cylinder head temperature gauge.*

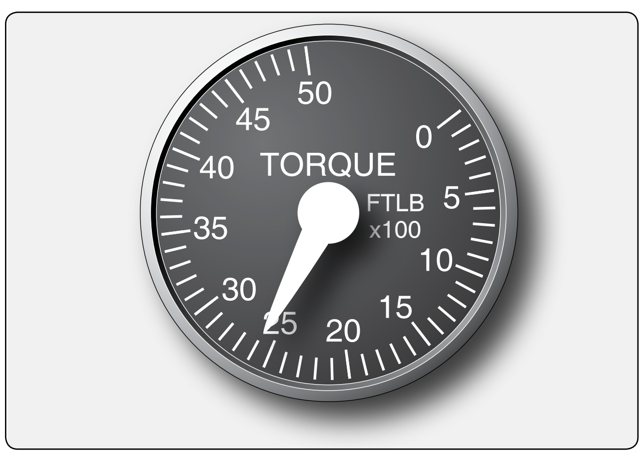


Figure 10-40. *Torquemeter readout.*

3. Cylinder head temperature.
4. CAT.
5. Oil temperature.
6. Oil pressure.
7. Fuel pressure.
8. Fuel-flow meter.
9. Air-fuel mixture setting.

The procedures, pressures, temperatures, and rpm 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 Starting

Before starting the engine, observe the manifold pressure gauge that should read approximate atmospheric (barometric) pressure when the engine is not running. At sea level, this is approximately 30 "Hg, and at fields above sea level, the atmospheric pressure is less, depending on the height above sea level. Also, observe all engine gauges for the correct reading for engine off settings.

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. Read more about typical procedures for starting reciprocating engines in the Aviation Maintenance Technician Handbook - General.

Pre-Oiling

Engines that have undergone overhaul or major maintenance can have air trapped in some of the oil passages that must be removed before the first start. This is done by pre-oiling the engine by cranking, with the spark plugs removed, the engine with the starter or by hand (turning) until oil pressure is indicated. A second method is to pump oil under pressure through the oil system using an external pump until oil comes out of the oil outlet of the engine.

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 10-41]* 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.

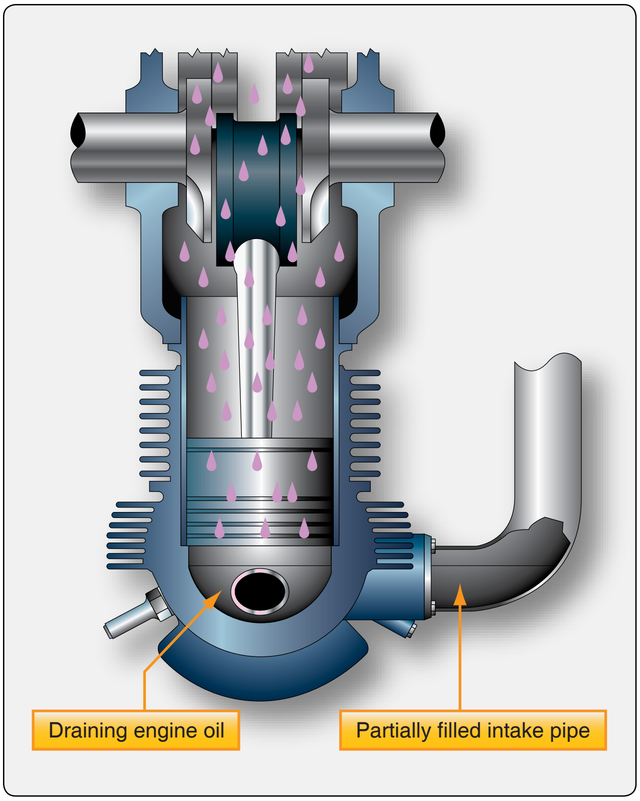


Figure 10-41. *Initial step in developing a hydraulic lock.*

To eliminate a lock, remove either the front or rear spark plug of the lower cylinders and pull the propeller through in the direction of rotation. The piston expels any liquid that may be present. If the hydraulic lock occurs as a result of over-priming prior to initial engine start, eliminate the lock in the same manner (i.e., remove one of the spark plugs from the cylinder and rotate the crankshaft through two turns). Never attempt to clear the hydraulic lock by pulling the propeller through in the direction opposite to normal rotation. This tends to inject the liquid from the cylinder into the intake pipe with the possibility of a complete or partial lock occurring on the subsequent start.

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 rpm. 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.

Some 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 very low. Consequently, start the warm-up of these engines at approximately 1,000 rpm and then move to the higher, more stable engine speed as soon as oil temperature reaches a warmer level.

During warm-up, watch the instruments associated with engine operation. This aids in making sure that all phases of engine operation are normal. For example, engine oil pressure should be indicated within 30 seconds after the start. Furthermore, if the oil pressure is not up to or above normal within 1 minute 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 rpm, 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 CAT 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 permits 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 rpm (low pitch) position, at approximately 1,000 rpm. 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 rpm 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. While in the single magneto position, failure to obtain any rpm drop, or failure of the engine to cut out while switching to off, indicates that one or both ground connections are faulty. This indicates a safety problem; the magnetos are not secured at shut down and may fire if the propeller is turned.

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 rpm or torque.

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 is an unsuitable condition disclosed. The magneto check can also fail to show shortcomings, since the allowable rpm 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 when an unsatisfactory condition is 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 procedure is outlined below:

1. Control position check.
2. Cowl flaps (if equipped)—open.
3. Mixture—rich.
4. Propeller—high rpm.
5. Carburetor heat—cold.
6. Check propeller according to propeller manufacturer's instruction.
7. Open throttle to the run-up rpm setting as per manufacturer's instructions (specified RPM and manifold pressure).
8. 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 rpm. 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 percent can be expected when operating on a single magneto. By comparing the rpm 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 rpm 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 rpm drop off between the left and right switch positions can indicate a difference in time between the left and right magnetos.

Sufficient time should be given to 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. Operation as long as 1 minute on a single ignition system is not excessive.

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

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

Fast rpm 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 rpm drop usually is caused by incorrect ignition timing or faulty valve adjustment. With late ignition timing, the charge is fired too late (in 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 rpm 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 rpm drop on the ignition check. Switch from “both” to “right” and return to “both.” Switch from “both” to “left” and return to “both.” Observe the rpm drop while operating on the right and left positions. The maximum drop should not exceed that specified by the engine manufacturer.

Fuel Pressure & Oil Pressure Check

Fuel pressure and oil pressure must be within the established tolerance (green arc) for the engine.

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 gauge 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 rpm 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 purpose 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 rpm and manifold pressure. The original calibration, or measurement of power, is made by means of a dynamometer in a test cell. During the ground check, power is measured with the propeller. With constant conditions of air density, the propeller, at any fixed-pitch position, always requires the same rpm 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, because the engine is static. Under these conditions, the manifold pressure for any specific engine, with the mixture control in 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 rpm. 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 at the same barometer and temperature readings, should require the same manifold pressure to within 1 "Hg. A higher than normal manifold pressure usually indicates a dead cylinder or late ignition timing. An excessively low manifold pressure for a particular rpm usually indicates that the ignition timing is early. Early ignition can cause detonation and loss of power at takeoff power settings.

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

1. Wind—any appreciable air movement (5 mph or more) changes the air load on the propeller blade when it is in the fixed-pitch position. A head wind increases the rpm obtainable with a given manifold pressure. A tail wind decreases the rpm.
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 rpm, 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 rpm results since the power is lowered without a compensating lowering of the propeller load.
4. Oil temperature—cold oil tends to hold down the rpm, since the higher viscosity results in increased friction horsepower losses.

Idle Speed & 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 rpm for minimum idling. With a properly adjusted idle mixture setting, it is possible to run the engine at idle rpm for long periods. Such a setting results in a minimum of plug fouling and exhaust smoking, and it pays 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 rpm. 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 rpm, but less than that recommended by the manufacturer (usually 20 rpm), 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-rpm rise after idle cutoff.

Engine Stopping

With each type of engine 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 prevents overheating of tightly baffled air-cooled engine during operation on the ground.

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

1. Cowl flaps and any other shutters or doors 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. Carburetor air-heater control is left in the cold position to prevent damage that may occur from backfire.
3. Constant speed propeller is usually stopped with the control set in the high pitch (decrease rpm) position to prevent exposure and corrosion of the pitch changing mechanism.

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

1. Idle the engine by setting the throttle for 800 to 1,000 rpm.

2. Move the mixture control to the idle cutoff position. 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.

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

Basic Engine Operating Principles

Combustion Process

Normal combustion occurs when the air-fuel 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 10-42]* The velocity of the flame travel is influenced by the type of fuel, the ratio of the air-fuel mixture, and the pressure and temperature of the fuel mixture. With normal combustion, the flame travel is about 100 feet/second. The temperature and pressure within the cylinder rises at a normal rate as the air-fuel mixture burns.

Detonation

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 ignite spontaneously and burn with explosive violence. This instantaneous and explosive burning of the air-fuel mixture or, more accurately, of the latter portion of the charge is called detonation.

Detonation is the spontaneous combustion of the unburned charge ahead of the flame fronts after ignition of the charge. *[Figure 10-43]* 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.

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, 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 air-fuel ratio. At high power output, combustion pressures and temperatures are higher than they are at low or medium power. Therefore, at high power, the air-fuel 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 does not detonate as readily as a lean mixture.

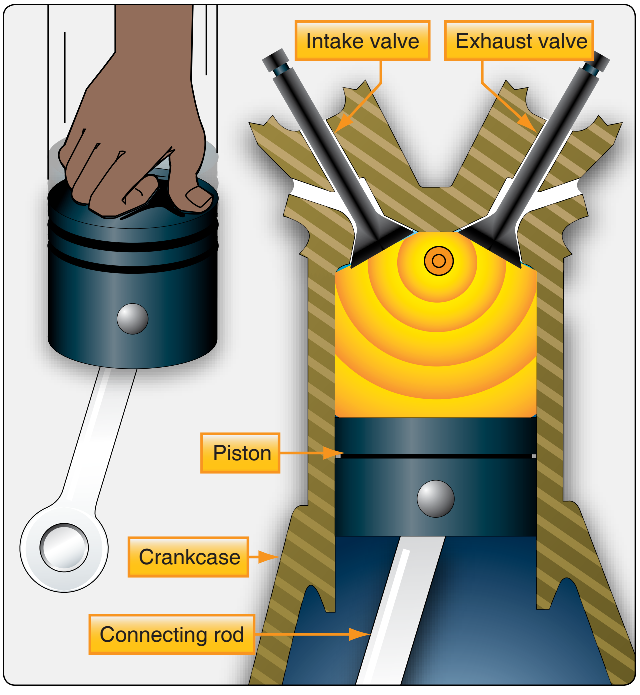


Figure 10-42. *Normal combustion within a cylinder.*

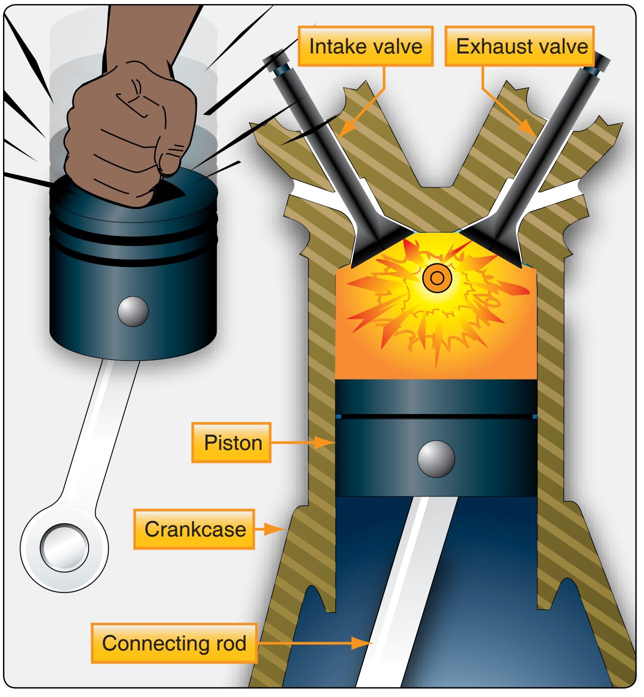


Figure 10-43. *Detonation within a cylinder.*

Unless detonation is heavy, there is no flight deck 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 flight 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, degree of 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 rpm and manifold pressure limits. Proper use of supercharger and fuel mixture, and maintenance of suitable cylinder head and carburetor-air-temperature (CAT) must be adhered to.

Pre-Ignition

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 that 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 flight deck by engine roughness, backfiring, and by a sudden increase in cylinder head temperature.

Any area within the combustion chamber that becomes incandescent serves as an igniter in advance of normal timed ignition and causes 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, that 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 that 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, reduce manifold pressure as much as possible to reduce 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.

Backfiring

When an air-fuel 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 does not burn at all or burns 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.

Incorrect ignition timing, or faulty ignition wires, can cause the cylinder to fire at the wrong time, allowing the cylinder to fire when the intake valve is open, which can cause backfiring. 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 that 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 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 air-fuel mixture usually corrects this problem.

Afterfiring

Afterfiring, sometimes called afterburning, often results when the air-fuel 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 that 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 air-fuel mixture.

Afterfiring can also be caused by cylinders that 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 that are firing intermittently can cause a similar effect. Again, the malfunction can be remedied only by discovering the real cause and correcting the defect. 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 operating correctly 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 is no loss of compression at these points. Third, and very important, the timing of the valves (opening and closing) must be such that highest efficiency is obtained when the engine is operating at its normal rated rpm. 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 air-fuel 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 air-fuel ratio and power is illustrated in *Figure 10-44*. 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.

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 rpm, the first curve might be run at this speed. Another curve might be run at 700 rpm, another at 800 rpm, and so on, in 100-rpm increments, up to takeoff rpm. 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 rich setting of the carburetor.

In establishing the detailed engine requirements regarding carburetor setting, the fact that the cylinder head temperature varies with air-fuel ratio must be considered. This variation is illustrated in the curve shown in *Figure 10-45*. 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 air-fuel 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 rpm, the power output of the engine is less with the best-economy setting (auto-lean) than with the best-power mixture.

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

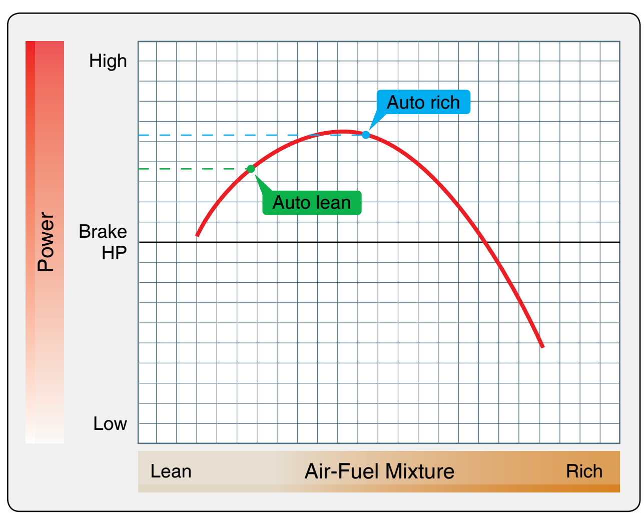


Figure 10-44. *Power versus air-fuel mixture curve.*

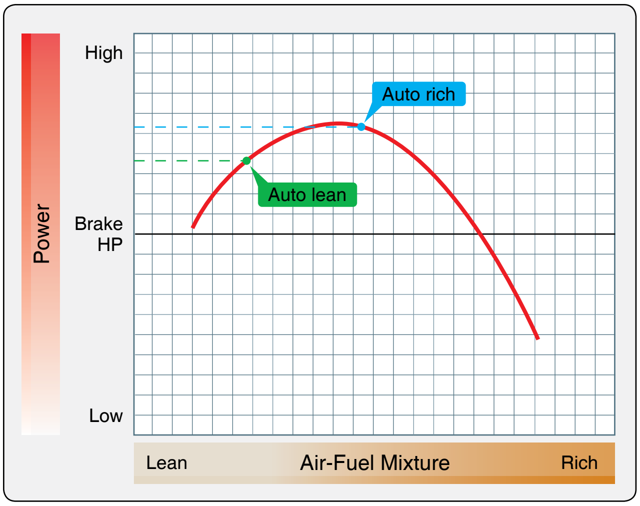


Figure 10-45. *Variation in head temperature with air-fuel mixture (cruise power).*

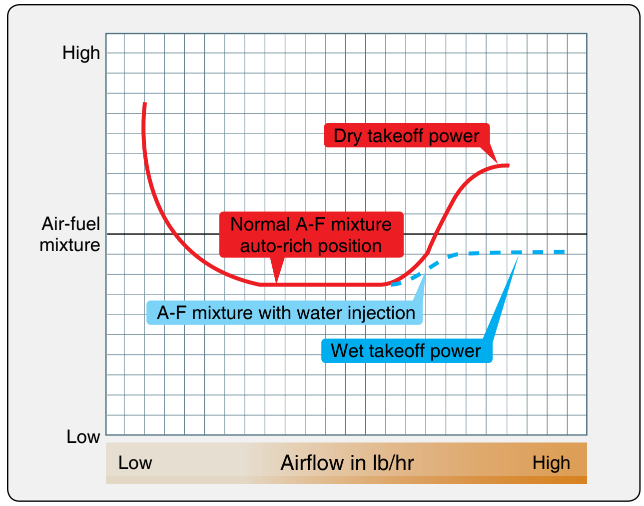


Figure 10-46. *Air-fuel curve for a water-injection engine.*

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 do not provide sufficient cooling. At this point, a secondary cooling method must be used. This secondary cooling is done by enriching the air-fuel 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.

Many older, large, high-powered radial engines were influenced by the cooling requirements on air-fuel mixture, by effects of water injection. *Figure 10-46* shows an air-fuel curve for a water-injection engine. The dotted portion of the curve shows how the air-fuel mixture is leaned out during water injection. This leaning is possible because water, rather than extra fuel, is used as a cylinder coolant. These types of systems are not used on modern aircraft.

This permits leaning out to approximately best-power mixture without danger of overheating or 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 air-fuel mixture curves take into account economy, power, engine cooling, idling characteristics, and all other factors that affect combustion.

Figure 10-47 shows a typical final curve for a float-type carburetor. Note that the air-fuel mixture at idle is the same in rich and in manual lean. 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 is 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.

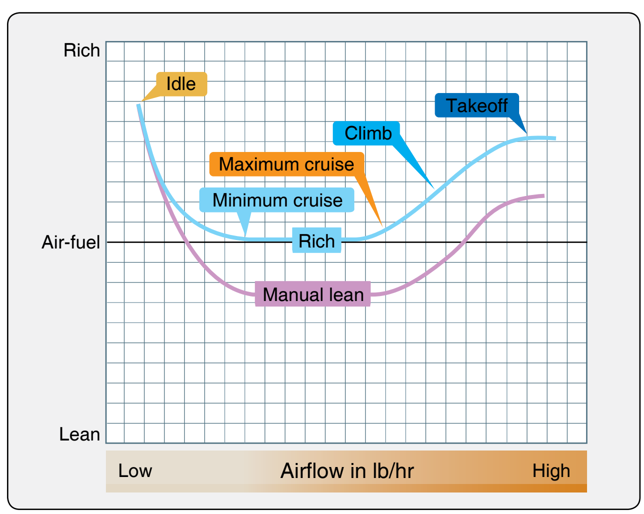


Figure 10-47. *Typical air-fuel mixture curve for a float-type carburetor.*

Therefore, any leaning out gives a mixture that is leaner than best power.

Idle Mixture

The idle mixture curve shows how the mixture changes when the idle mixture adjustment is changed. *[Figure 10-48]* 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 air-fuel mixture 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.

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, 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 that 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.

Induction Manifold

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

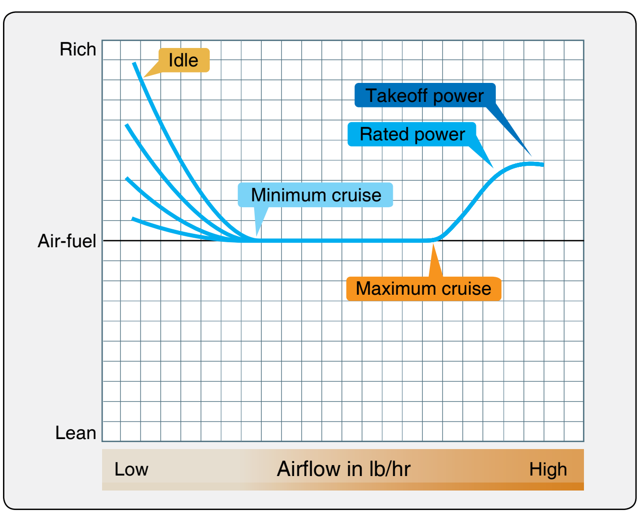


Figure 10-48. *Idle mixture curve.*

The induction manifold is an important item because of the effect it can have on the air-fuel mixture that 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 clings to the walls of the intake pipes. Obviously, this affects the effective air-fuel ratio of the mixture that 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 that 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 air-fuel 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 leans 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. Valve overlap is when the intake and exhaust valves are open at the same time. This takes advantage of the momentum of the entering and exiting gases to improve the efficiency of getting air-fuel in and exhaust gases out. *Figure 10-49* 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 "Hg. Barometric pressure (exhaust back pressure) is 29 "Hg. This gives a pressure acting in the direction indicated by the arrow of differential of 6 "Hg (3 psi).

During the valve overlap period, this pressure differential forces the air-fuel mixture across the combustion chamber toward the open exhaust. This flow of air-fuel mixture forces ahead of it the exhaust gases remaining in the cylinder, resulting in complete scavenging of the combustion chamber.

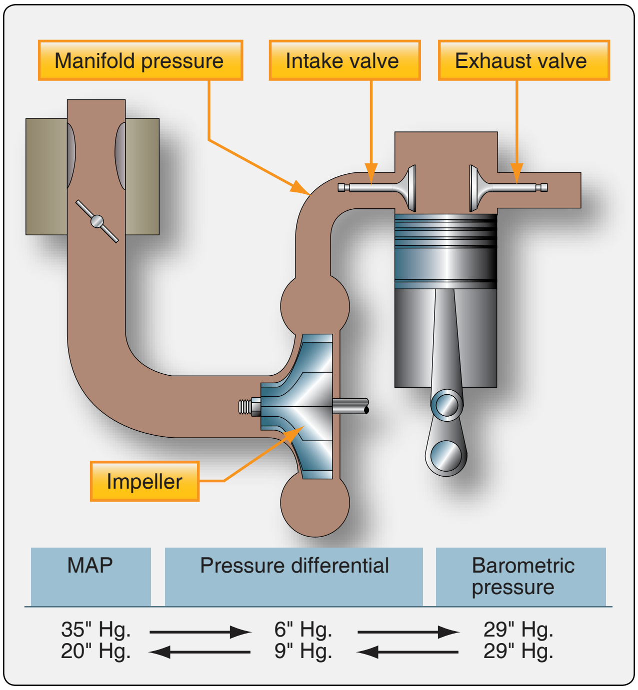


Figure 10-49. *Effect of valve overlap.*

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.

There is a pressure differential in the opposite direction of 9 "Hg (4.5 psi) when the manifold pressure is below atmospheric pressure, for example, 20 "Hg. These cause air or exhaust gases 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 air-fuel mixture. However, these exhaust gases are inert; they do not contain oxygen. Therefore, the air-fuel 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 air-fuel mixture is sufficient to cause concern. However, the effect of valve overlap becomes apparent when considering idle air-fuel mixtures. These mixtures must be enriched 20 to 30 percent when open stacks, instead of collector rings (radial engines) are used on the same engine. *[Figure 10-50]* 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.

Engine, airplane, and equipment manufacturers provide a powerplant installation that gives satisfactory performance. Cams are designed to give best valve operation and correct overlap. But valve operation is 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 is 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 do not open as wide or remain open as long as they should. This reduces the overlap period. At idling speed, it affects the air-fuel mixture, since a less-than-normal amount of air or exhaust gases is drawn back into the cylinder during the shortened overlap period. As a result, the idle mixture tends to be too rich.

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

When valve clearances are wrong, it is unlikely that they are all wrong in the same direction. Instead, there is too much clearance on some cylinders and too little on others. Naturally,

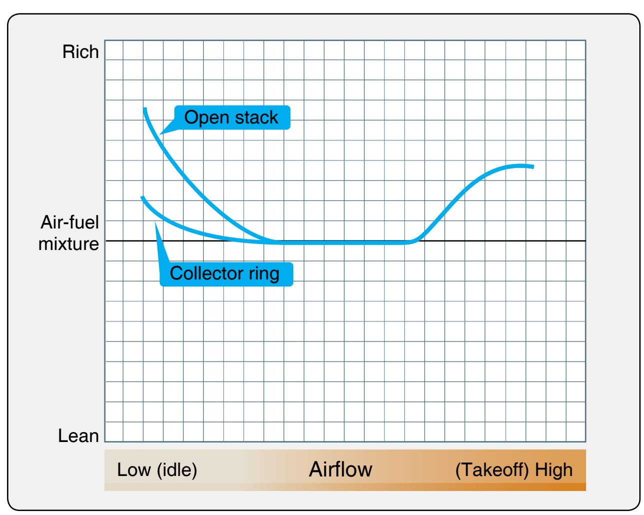


Figure 10-50. *Comparison of air-fuel mixture curves for open-stack and collector-ring installations.*

this gives a variation in valve overlap between cylinders. This results in a variation in air-fuel 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 air-fuel mixture between cylinders is illustrated in *Figure 10-51*. 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.

Valve clearance also effects volumetric efficiency. Any variations in air-fuel into, and exhaust gases out of, the cylinder affects the volumetric efficiency of the cylinder. With the use of hydraulic valve lifters that set the valve clearance automatically, engine operation has been greatly improved. Hydraulic lifters do have a limited range in which they can control the valve clearance, or they can become stuck in one position that can cause them to be a source of engine trouble. Normally engines equipped with hydraulic lifters require little to no maintenance.

Engine Troubleshooting

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

Figure 10-52 lists general conditions or troubles that 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.

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, indicate that part of the powerplant that is the basic cause of difficulty.

The cylinders of an engine, along with any type of supercharging, form an air pump. Furthermore, the power developed in the cylinders varies directly with the rate that air can be consumed by the engine. 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 gauge and the engine tachometer provide a measure of engine air consumption. Thus, for a given rpm, any change in power input is 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 rpm, blade angle, and air density. For a given angle and air

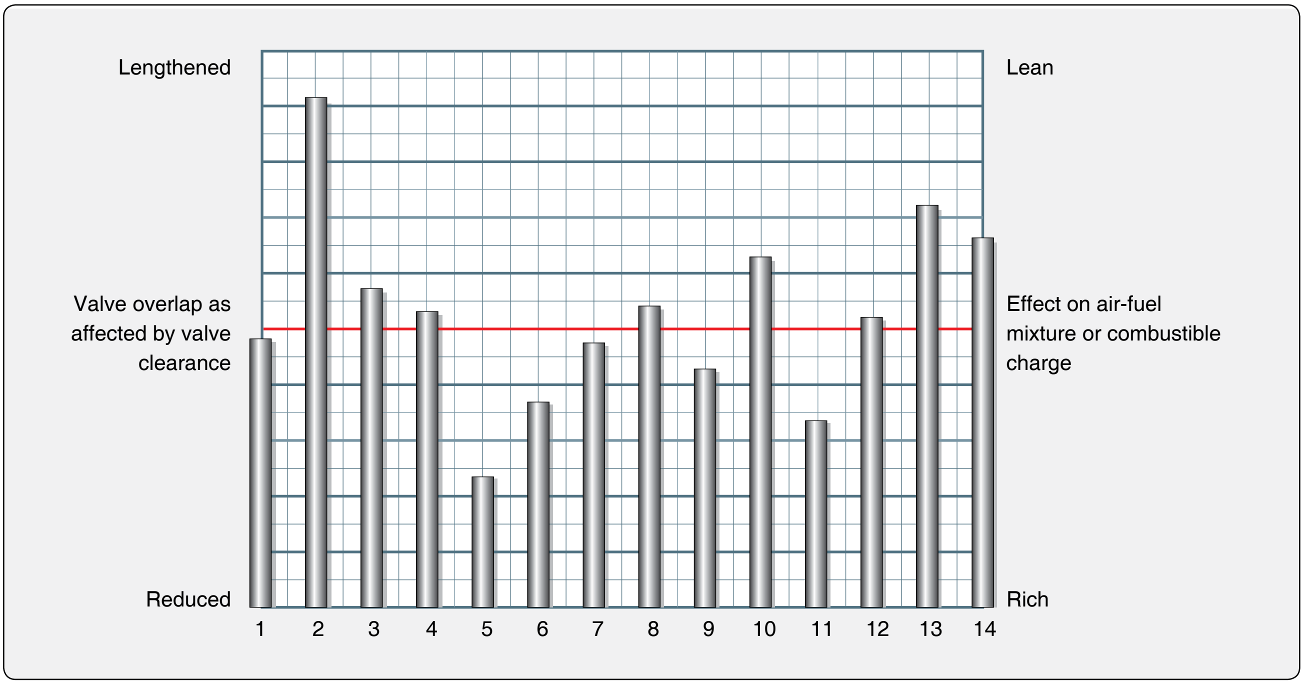


Figure 10-51. *Effect of variation in valve overlap on air-fuel mixture between cylinders.*

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.
	• 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 obtain correct idle.
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.
		• Check and replace or repair.

Figure 10-52. *Troubleshooting opposed engines.*

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 rpm. Because the rpm of the engine and the throttle opening directly control manifold pressure, the primary engine power controls are the throttle and the rpm 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 rpm.

With proper precautions, manifold pressure can be taken as a measure of power input, and rpm can be taken as a measure of power output. However, the following factors must be

Trouble	Probable causes	Remedy
Low power and engine running uneven.	• 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.
Low oil pressure.	• Insufficient oil.	• Check oil supply.
	• Dirty oil strainers.	• Remove and clean oil strainers.
	• Defective pressure gauge.	• Replace gauge.
	• 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 line or strainers.
	• Failing or failed bearings.	• Examine sump for metal particles and, if found, overhaul engine.
	• Defective thermostats.	• Replace thermostats.
	• Defective temperature gauge.	• Usually caused by weak or stuck rings.
	• Excessive blow-by.	• 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.

Figure 10-52. *Troubleshooting opposed engines (continued).*

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 rpm, regardless of power input or engine condition. This precaution means that the propeller control must be set to maximum or takeoff rpm, and the checks made at engine speeds below this setting.

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 rpm with the manifold pressure required to produce the same rpm at a time when the engine (or an identical powerplant) was known to be in top operating condition.

An example shows the practical application of this method of determining engine condition. With the propeller control set for takeoff rpm (full low blade angle), an engine may require 32 inches of manifold pressure to turn 2,200 rpm for the ignition check. On previous checks, this engine required only 30 inches of manifold pressure to turn 2,200 rpm 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 (rpm). There is a good chance that one cylinder has a malfunction.

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 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: fuel metering and 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 is 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 that causes individual cylinders to receive too small a charge or one too large, even though the mixture to the cylinders has the same air-fuel 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 are not 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 bhp unless some fault exists in the basic power section.

Valve Blow-By

Valve blow-by is indicated by a hissing or whistle when pulling the propeller through prior to starting the engine, when turning the engine with the starter, or when running and blow-by past the intake valve is audible through the carburetor.

Correct valve blow-by immediately to prevent valve failure and possible engine failure by taking the following steps:

1. Perform a cylinder compression test to locate the faulty cylinder.
2. Check the valve clearance on the affected cylinder. If the valve clearance is incorrect, the valve may be sticking in the valve guide. To release the sticking valve, place a fiber drift on the rocker arm immediately over the valve stem and strike the drift several times with a mallet. Sufficient hand pressure should be exerted on the fiber drift to remove any space between the rocker arm and the valve stem prior to hitting the drift.
3. If the valve is not sticking and the valve clearance is incorrect, adjust it as necessary.
4. Determine whether blow-by has been eliminated by again pulling the engine through by hand or turning it with the starter. If blow-by is still present, it may be necessary to replace the cylinder.

Cylinder Compression Tests

The cylinder compression test determines if the valves, piston rings, and pistons are adequately sealing the combustion chamber. If pressure leakage is excessive, the cylinder cannot develop its full power. The purpose of testing cylinder compression is to determine whether cylinder replacement is necessary. The detection and replacement of defective cylinders prevents a complete engine change because of cylinder failure. It is essential that cylinder compression tests be made periodically. Low compression, for the most part, can be traced to leaky valves.

Conditions that affect engine compression are:

1. Incorrect valve clearances.
2. Worn, scuffed, or damaged piston.
3. Excessive wear of piston rings and cylinder walls.
4. Burned or warped valves.
5. Carbon particles between the face and the seat of the valve or valves.
6. Early or late valve timing.

Perform a compression test as soon as possible after the engine is shut down so that piston rings, cylinder walls, and other parts are still freshly lubricated. However, it is not necessary to operate the engine prior to accomplishing compression tests during engine buildup or on individually replaced cylinders. In such cases, before making the test, spray a small quantity of lubricating oil into the cylinder(s), and turn the engine over several times to seal the piston and rings in the cylinder barrel.

Be sure that the ignition switch is in the OFF position so that there is no accidental firing of the engine. Remove necessary cowling and the most accessible spark plug from each cylinder. When removing the spark plugs, identify them to coincide with the cylinder. Close examination of the plugs aid in diagnosing problems within the cylinder. Review the maintenance records of the engine being tested. Records of previous compression checks help in determining progressive wear conditions and in establishing the necessary maintenance actions.

Differential Pressure Tester

The differential pressure tester checks the compression of aircraft engines by measuring the leakage through the cylinders. The design of this compression tester is such that minute valve leakages can be detected, making possible the replacement of cylinders where valve burning is starting. The operation of the compression tester is based on the principle that, for any given airflow through a fixed orifice, a constant pressure drop across the orifice results.

As the airflow and pressure changes, pressure varies accordingly in the same direction. If air is supplied under pressure to the cylinder with both intake and exhaust valves closed, the amount of air that leaks by the valves or piston rings indicates their condition; the perfect cylinder would have no leakage. The differential pressure tester requires the application of air pressure to the cylinder being tested with the piston at top-center compression stroke. *[Figure 10-53]*

Guidelines for performing a differential compression test are:

1. Perform the compression test as soon as possible after engine shutdown to provide uniform lubrication of cylinder walls and rings.
2. Remove the most accessible spark plug from the cylinder, or cylinders, and install a spark plug adapter in the spark plug insert.
3. Connect the compression tester assembly to a 100 to 150 psi compressed air supply. *[Figure 10-54]* With the shutoff valve on the compression tester closed,

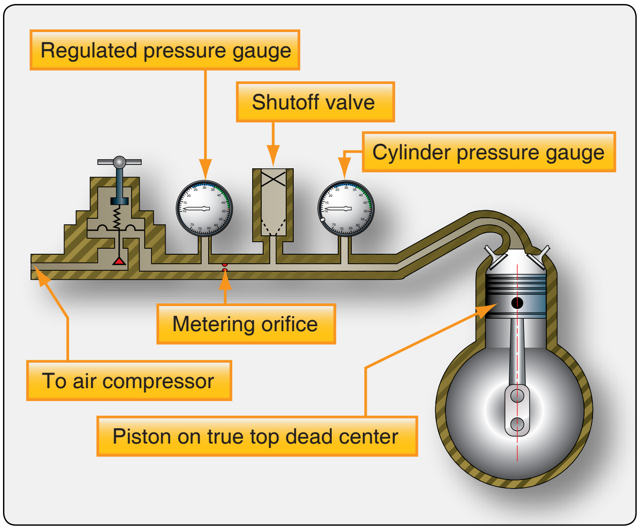


Figure 10-53. *Differential compression tester diagrams.*

adjust the regulator of the regulated pressure gauge compression tester to obtain 80 psi.

4. Open the shutoff valve and attach the air hose quick-connect fitting to the spark plug adapter. The shutoff valve, when open, automatically maintains a pressure in the cylinder of 15 to 20 psi when both the intake and exhaust valves are closed.
5. By hand, turn the engine over in the direction of rotation until the piston in the cylinder being tested comes up on the compression stroke against the 15 psi. Continue turning the propeller slowly in the direction of rotation until the piston reaches top dead center. Top dead center can be detected by a decrease in force required to move the propeller. If the engine is rotated past top dead center, the 15 to 20 psi tends to move the propeller in the direction of rotation. If this occurs, back the propeller up at least one blade prior to turning the propeller again in the direction of rotation. This backing up is necessary to eliminate the effect of backlash in the valve-operating mechanism and to keep the piston rings seated on the lower ring lands.

Figure 10-54. *Compression tester and adapter.*

6. Close the shutoff valve in the compression tester and re-check the regulated pressure to see that it is 80 psi with air flowing into the cylinder. If the regulated pressure is more or less than 80 psi, readjust the regulator in the test unit to obtain 80 psi. When closing the shutoff valve, make sure that the propeller path is clear of all objects. There is sufficient air pressure in the combustion chamber to rotate the propeller if the piston is not on top dead center.
7. With regulated pressure adjusted to 80 psi, if the cylinder pressure reading indicated on the cylinder pressure gauge is below the minimum specified for the engine being tested, move the propeller in the direction of rotation to seat the piston rings in the grooves. Check all the cylinders and record the readings.

If low compression is obtained on any cylinder, turn the engine through with the starter, or re-start, and run the engine to takeoff power and re-check the cylinder, or cylinders, having low compression.

If the low compression is not corrected, remove the rocker-box cover and check the valve clearance to determine if the difficulty is caused by inadequate valve clearance. If the low compression is not caused by inadequate valve clearance, place a fiber drift on the rocker arm immediately over the valve stem and tap the drift several times with a 1 to 2 pound hammer to dislodge any foreign material that may be lodged between the valve and valve seat.

After staking the valve in this manner, rotate the engine with the starter and re-check the compression. Do not make a compression check after staking a valve until the crankshaft has been rotated either with the starter or by hand to re-seat the valve in normal manner. The higher seating velocity obtained when staking the valve will indicate valve seating, even though valve seats are slightly egged or eccentric. This procedure should only be performed if approved by the manufacturer.

Cylinders having compression below the minimum specified should be further checked to determine whether leakage is past the exhaust valve, intake valve, or piston. Excessive leakage can be detected (during the compression check):

1. At the exhaust valve by listening for air leakage at the exhaust outlet;
2. At the intake valve by escaping air at the air intake; and
3. Past the piston rings by escaping air at the engine

breather outlets.

Next to valve blow-by, the most frequent cause of compression leakage is excessive leakage past the piston. This leakage may occur because of lack of oil. To check this possibility, apply engine oil into the cylinder and around the piston. Then, re-check the compression. If this procedure raises compression to or above the minimum required, continue the cylinder in service. If the cylinder pressure readings still do not meet the minimum requirement, replace the cylinder. When it is necessary to replace a cylinder as a result of low compression, record the cylinder number and the compression value of the newly installed cylinder on the compression check sheet.

Cylinder Replacement

Reciprocating engine cylinders are designed to operate for a specified time before normal wear requires their overhaul. If the engine is operated as recommended and proficient maintenance is performed, the cylinders normally last until the engine has reached its TBO. It is known from experience that materials fail, and engines are abused through incorrect operation; this has a serious effect on cylinder life. Another reason for premature cylinder change is poor maintenance. Therefore, exert special care to ensure that all the correct maintenance procedures are adhered to when working on the engine. Some of the reasons for cylinder replacement are:

1. Low compression.
2. High oil consumption in one or more cylinders.
3. Excessive valve guide clearance.
4. Loose intake pipe flanges.
5. Loose or defective spark plug inserts.
6. External damage, such as cracks.

The cylinder is always replaced as a complete assembly, which includes piston, rings, valves, and valve springs. Obtain the cylinder by ordering the cylinder assembly under the part number specified in the engine parts catalog. Parts, such as valve springs, rocker arms, and rocker box covers, may be replaced individually.

Normally, all the cylinders in an engine are similar, all are standard size or all a certain oversize, and all are steel bore or all are chrome-plated. The size of the cylinder is indicated by a color code around the barrel between the attaching flange and the lower barrel cooling fin. In some instances, air-cooled engines are equipped with chrome-plated cylinders. Chrome-plated cylinders are usually identified by a paint band around the barrel between the attaching flange and the lower barrel cooling fin. This color band is usually international orange.

When installing a chrome-plated cylinder, do not use chrome-plated piston rings. The matched assembly includes the correct piston rings. However, if a piston ring is broken during cylinder installation, check the cylinder marking to determine what ring, chrome-plated or otherwise, is correct for replacement. Similar precautions must be taken to be sure that the correct size rings are installed.

Correct procedures and care are important when replacing cylinders. Careless work or the use of incorrect tools can damage the replacement cylinder or its parts. Incorrect procedures in installing rocker-box covers may result in troublesome oil leaks. Improper torque on cylinder hold down nuts or cap-screws can easily result in a cylinder malfunction and subsequent engine failure.

Cylinder Removal

Since these instructions are meant to cover all air-cooled engines, they are of a very general nature. The applicable manufacturer's maintenance manual should be consulted for torque values and special precautions applying to a particular aircraft and engine. However, always practice neatness and cleanliness, and always protect openings so that nuts, washers, tools, and miscellaneous items do not enter the engine's internal sections.

Assuming that all obstructing cowling and brackets have been removed, first remove the intake pipe and exhaust pipes. Plug or cover openings in the intake or diffuser section. Then, remove cylinder deflectors and any attaching brackets that would obstruct cylinder removal. Loosen the spark plugs and remove the spark plug lead clamps. Do not remove the spark plugs until ready to pull the cylinder off. Remove the rocker box covers. First, remove the nuts and then tap the cover lightly with a rawhide mallet or plastic hammer. Never pry the cover off with a screwdriver or similar tool.

Loosen the pushrod packing gland nuts or hose clamps, top and bottom. Pushrods are removed by depressing the rocker arms with a special tool, or by removing the rocker arm. Before removing the pushrods, turn the crankshaft until the piston is at top dead center on the compression stroke. This relieves the pressure on both intake and exhaust rocker arms. It is also wise to back off the adjusting nut as far as possible, because this allows maximum clearance for pushrod removal when the rocker arms are depressed.

On some model engines, or if the engine is rotated, tappets and springs of lower cylinders can fall out. Provision must be made to catch them as the pushrod and housing are removed. After removing the pushrods, examine them for markings or mark them so that they may be replaced in the same location as they were before removal. The ball ends are usually worn to fit the sockets in which they have been operating. Furthermore, on some engines, pushrods are not all of the same length. A good procedure is to mark the pushrods near the valve tappet ends No. 1 IN, No. 1 EX, No. 2 IN, No. 2 EX., etc. On fuel injection engines, disconnect the fuel injection line and any line clamps that interfere with cylinder removal.

The next step in removing the cylinder is to cut the lock wire or remove the cotter pin, and pry off the locking device from the cylinder-attaching cap-screws or nuts. Remove all the screws or nuts except two located 180° apart. Use the wrench specified for this purpose in the special tools section of the applicable manual.

Finally, while supporting the cylinder, remove the two remaining nuts and gently pull the cylinder away from the crankcase. Two technicians working together during this step, as well as during the remaining procedure for cylinder replacement, helps prevent damage or dropping of the cylinder. After the cylinder skirt has cleared the crankcase, but before the piston protrudes from the skirt, provide some means (usually a shop cloth) for preventing pieces of broken rings from falling into the crankcase. After the piston has been removed, remove the cloths and carefully check that all pieces were prevented from falling into the crankcase.

Place a support on the cylinder mounting pad and secure it with two cap-screws or nuts. Then, remove the piston and ring assembly from the connecting rod. A pin pusher or puller tool can be used when varnish makes it hard to remove the pin. If the special tool is not available and a drift is used to remove the piston pin, the connecting rod should be supported so that it does not have to take the shock of the blows. If this is not done, the rod may be damaged.

After the removal of a cylinder and piston, the connecting rod must be supported to prevent damage to the rod and crankcase. This can be done by supporting each connecting rod with the removed cylinder base oil seal ring looped around the rod and cylinder base studs.

Using a wire brush, clean the studs or cap-screws and examine them for cracks, damaged threads, or any other visible defects. If one cap-screw is found loose or broken at the time of cylinder removal, all the cap-screws for the cylinder should be discarded, since the remaining cap-screws may have been seriously weakened. A cylinder hold down stud failure places the adjacent studs under a greater operating pressure, and they are likely to be stretched beyond their elastic limit. The engine manufacturer's instruction must be followed for the number of studs that have to be replaced after a stud failure. When removing a broken stud, take proper precautions to prevent metal chips from entering the engine crankcase section. In all cases, both faces of the washers and the seating faces of stud nuts or cap-screws must be cleaned and any roughness or burrs removed.

Cylinder Installation

See that all preservative oil accumulation on the cylinder and piston assembly is washed off with solvent and thoroughly dried with compressed air. Install the piston and ring assembly on the connecting rod. Be sure that the piston faces in the right direction. The piston number stamped on the bottom of the piston head should face toward the front of the engine. Lubricate the piston pin before inserting it. It should fit with a push fit. If a drift must be used, follow the same precaution that was taken during pin removal.

Oil the exterior of the piston assembly generously, forcing oil around the piston rings and in the space between the rings and grooves. Stagger the ring gaps around the piston and check to see that rings are in the correct grooves, and whether they are positioned correctly, as some are used as oil scrapers, others as pumper rings. The number, type, and arrangement of the compression and oil-control rings vary with the make and model of engine.

Perform any and all visual, structural, and dimensional inspection checks before installing the cylinder. Check the flange to see that the mating surface is smooth and clean. Coat the inside of the cylinder barrel generously with oil. Be sure that the cylinder oil-seal ring is in place and that only one seal ring is used.

Using a ring compressor, compress the rings to a diameter equal to that of the piston. With the piston at TDC, start the cylinder assembly down over the piston, making certain that the cylinder and piston plane remain the same. Ease the cylinder over the piston with a straight, even movement that moves the ring compressor as the cylinder slips on. Do not rock the cylinder while slipping it on the piston, since any rocking is apt to release a piston ring or a part of a ring from the ring compressor prior to the ring's entrance into the cylinder bore. A ring released in this manner expands and prevents the piston from entering the cylinder. Any attempt to force the cylinder onto the piston is apt to cause cracking or chipping of the ring or damage to the ring lands.

After the cylinder has slipped on the piston, so that all piston rings are in the cylinder bore, remove the ring compressor and the connecting rod guide. Then, slide the cylinder into place on the mounting pad. If cap-screws are used, rotate the cylinder to align the holes. While still supporting the cylinder, install two cap-screws or stud nuts 180° apart.

Install the remaining nuts or cap-screws and tighten them until they are snug. The hold down nuts, or cap-screws, must now be torqued to the value specified in the table of torque values in the engine manufacturer's service or overhaul manual. Apply the torque with a slow, steady motion until the prescribed value is reached. Hold the tension on the wrench for a sufficient length of time to ensure that the nut or cap-screw tightens no more at the prescribed torque value. In many cases, additional turning of the cap-screw, or nut, as much as one-quarter turn can be done by maintaining the prescribed torque on the nut for a short period of time. After the stud nuts, or cap-screws, have been torqued to the prescribed value, safety them in the manner recommended in the engine manufacturer's service manual.

Reinstall the push rods, push rod housings, rocker arms, barrel deflectors, intake pipes, ignition harness lead clamps and brackets, fuel injection line clamps and fuel injection nozzles (if removed), exhaust stack, cylinder head deflectors, and spark plugs. Remember that the push rods must be installed in their original locations and must not be turned end to end. Make sure that the push rod ball end seats properly in the tappet. If it rests on the edge or shoulder of the tappet during valve clearance adjustment and later drops into place, valve clearance is off.

Furthermore, rotating the crankshaft with the push rod resting on the edge of the tappet may bend the push rod. After installing the push rods and rocker arms, set the valve clearance. Before installing the rocker-box covers, lubricate the rocker arm bearings and valve stems. Check the rocker-box covers for flatness; re-surface them if necessary. After installing the gaskets and covers, tighten the rocker-box cover nuts to the specified torque. Always follow the recommended safety procedures.

Cold Cylinder Check

The cold cylinder check determines the operating characteristics of each cylinder of an air-cooled engine. The tendency for any cylinder, or cylinders, to be cold, or to be only slightly warm, indicates lack of combustion or incomplete combustion within the cylinder. This must be corrected if best operation and power conditions are to be obtained. The cold cylinder check is made with a cold cylinder indicator.

Engine difficulties that can be analyzed by use of the cold cylinder indicator are *[Figure 10-55]*:

1. Rough engine operation.
2. Excessive rpm drop during the ignition system check.
3. High manifold pressure for a given engine rpm during the ground check when the propeller is in the full low-pitch position.
4. Faulty mixture ratios caused by improper valve clearance.

In preparation for the cold cylinder check, head the aircraft into the wind to minimize irregular cooling of the individual cylinders and to ensure even propeller loading during engine operation.

Operate the engine on its roughest magneto at a speed between 1,200 and 1,600 rpm until the cylinder head temperature reading is stabilized. If engine roughness is encountered at more than one speed, or if there is an indication that a cylinder ceases operating at idle or higher speeds, run the engine at each of these speeds, and perform a cold cylinder check to pick out all the dead or intermittently operating cylinders. When low power output or engine vibration is encountered at speeds above 1,600 rpm when operating with the ignition switch on both, run the engine at the speed where the difficulty is encountered until the cylinder head temperatures have stabilized.

When cylinder head temperatures have reached the stabilized values, stop the engine by moving the mixture control to

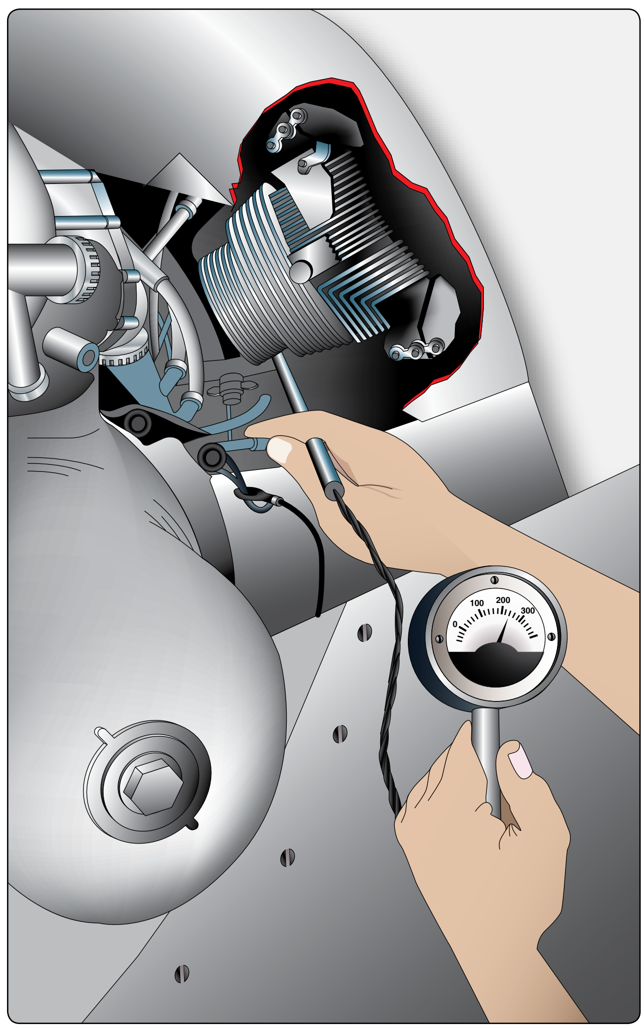


Figure 10-55. *Cold cylinder indicator.*

the idle cutoff or full lean position. When the engine ceases firing, turn off both ignition and master switches. Record the cylinder head temperature reading registered on the flight deck gauge. As soon as the propeller has ceased rotating, apply the instrument to each cylinder head, and record the relative temperature of each cylinder. Start with number one and proceed in numerical order around the engine, as rapidly as possible. To obtain comparative temperature values, a firm contact must be made at the same relative location on each cylinder. Note any outstandingly low (cold) values. Compare the temperature readings to determine which cylinders are dead (cold cylinders) or are operating intermittently.

Difficulties that may cause a cylinder to be inoperative (dead) when isolated to one magneto, either the right or left positions, are:

1. Defective spark plugs.
2. Incorrect valve clearances.
3. Leaking intake pipes.
4. Lack of compression.
5. Defective spark plug lead.
6. Defective fuel-injection nozzle.

Repeat the cold cylinder test for the other magneto positions on the ignition switch, if necessary. Cooling the engine between tests is unnecessary. The airflow created by the propeller, and the cooling effect of the incoming air-fuel mixture is sufficient to cool any cylinders that are functioning on one test and not functioning on the next.

In interpreting the results of a cold cylinder check, remember that the temperatures are relative. A cylinder temperature taken alone means little, but when compared with the temperatures of other cylinders on the same engine, it provides valuable diagnostic information. The readings shown in *Figure 10-56* illustrate this point. On this check, the cylinder head temperature gauge reading at the time the engine was shut down was 160 °C on both tests.

A review of these temperature readings reveals that, on the right magneto, cylinder number 3 runs cool and cylinders 5 and 6 run cold. This indicates that cylinder 3 is firing intermittently, and cylinders 5 and 6 are dead during engine operation on the plugs fired by the right magneto. Cylinders 4 and 6 are dead during operation on the plugs fired by the left magneto. Cylinder 6 is completely dead. An ignition system operational check would not disclose this dead cylinder, since the cylinder is inoperative on both right and left switch positions.

A dead cylinder can be detected during run-up, since an engine with a dead cylinder requires a higher than normal

Cylinder No.	Temperature readings	
	Right magneto	Left magneto
1	180	170
2	170	175
3	100	170
4	145	60
5	70	155
6	60	45

Figure 10-56. *Readings taken during a cold cylinder check.*

manifold pressure to produce any given rpm below the cut-in speed of the propeller governor. A dead cylinder could also be detected by comparing power input and power output with the aid of a torquemeter.

Defects within the ignition system that can cause a cylinder to go completely dead are:

1. Both spark plugs inoperative.
2. Both ignition leads grounded, leaking, or open.
3. A combination of inoperative spark plugs and defective ignition leads.
4. Faulty fuel-injection nozzles, incorrect valve clearances, and other defects outside the ignition system.

In interpreting the readings obtained on a cold cylinder check, the amount the engine cools during the check must be considered. To determine the extent to which this factor should be considered in evaluating the readings, re-check some of the first cylinders tested, and compare the final readings with those made at the start of the check. Another factor to be considered is the normal variation in temperature between cylinders and between rows. This variation results from those design features that affect the airflow past the cylinders.

Turbine Engine Maintenance

Turbine powerplant maintenance procedures vary widely according to the design and construction of the particular engine being serviced. The detailed procedures recommended by the engine manufacturer should be followed when performing inspections or maintenance. Maintenance information presented in this section is not intended to specify the exact manner in which maintenance operations are to be performed but is included to convey a general idea of the procedures involved. For inspection purposes, the turbine engine is divided into two main sections: the cold and hot.

Compressor Section

Maintenance of the compressor, or cold section, is one of concern because damage to blades can cause engine failure. Much of the damage to the blades arises from foreign matter being drawn into the turbine engine air intakes. The atmosphere near the ground is filled with tiny particles of dirt, oil, soot, and other foreign matter. A large volume of air is introduced into the compressor, and centrifugal force throws the dirt particles outward so that they build up to form a coating on the casing, the vanes, and the compressor blades. Accumulation of dirt on the compressor blades reduces the aerodynamic efficiency of the blades with resultant deterioration in engine performance. The efficiency of the blades is impaired by dirt deposits in a manner similar to that of an aircraft wing under icing conditions. Unsatisfactory acceleration and high exhaust gas temperature can result from foreign deposits on compressor components.

An end result of foreign particles, if allowed to accumulate in sufficient quantity, would be inefficiency. The condition can be remedied by periodic inspection, cleaning, and repair of compressor components.

Inspection & Cleaning

Minor damage to axial-flow engine compressor blades may be repaired if the damage can be removed without exceeding the allowable limits established by the manufacturer. Typical compressor blade repair limits are shown in *Figure 10-57*. Well-rounded damage to leading and trailing edges that is evident on the opposite side of the blade is usually acceptable without re-work, provided the damage is in the outer half of the blade only, and the indentation does not exceed values specified in the engine manufacturer's service and overhaul instruction manuals. When working on the inner half of the blade, damage must be treated with extreme caution. Repaired compressor blades are inspected by either magnetic particle or fluorescent penetrant inspection methods to ensure that all traces of the damage have been removed. All repairs must be well blended so that surfaces are smooth. *[Figure 10-58]* No cracks of any extent are tolerated in any area.

Whenever possible, stoning and local re-work of the blade should be performed parallel to the length of the blade. Re-work must be accomplished by hand, using stones, files, or emery cloth. Do not use a power tool to buff the entire area of the blade. The surface finish in the repaired area must be comparable to that of a new blade. On centrifugal flow engines, it is difficult to inspect the compressor inducers without first removing the air-inlet screen. After removing the screen, clean the compressor inducer and inspect it with a strong light. Check each vane for cracks by slowly turning the compressor. Look for cracks in the leading edges. A crack is usually cause for component rejection. The compressor inducers are normally the parts that are damaged by the impingement of foreign material during engine operation.

Compressor inducers are repaired by stoning out and blending the nicks and dents in the critical band (1½ to 2½ inches from the outside edge), if the depth of such nicks or dents does not exceed that specified in the engine manufacturer's service or overhaul instruction manuals. Repair nicks by stoning out material beyond the depth of damage to remove the resulting cold-worked metal. A generous radius must be applied at the edges of the blend. After blending the nick, it should be smoothed over with a crocus cloth. Pitting nicks or corrosion found on the sides of the inducer vanes are similarly removed by blending.

Causes of Blade Damage

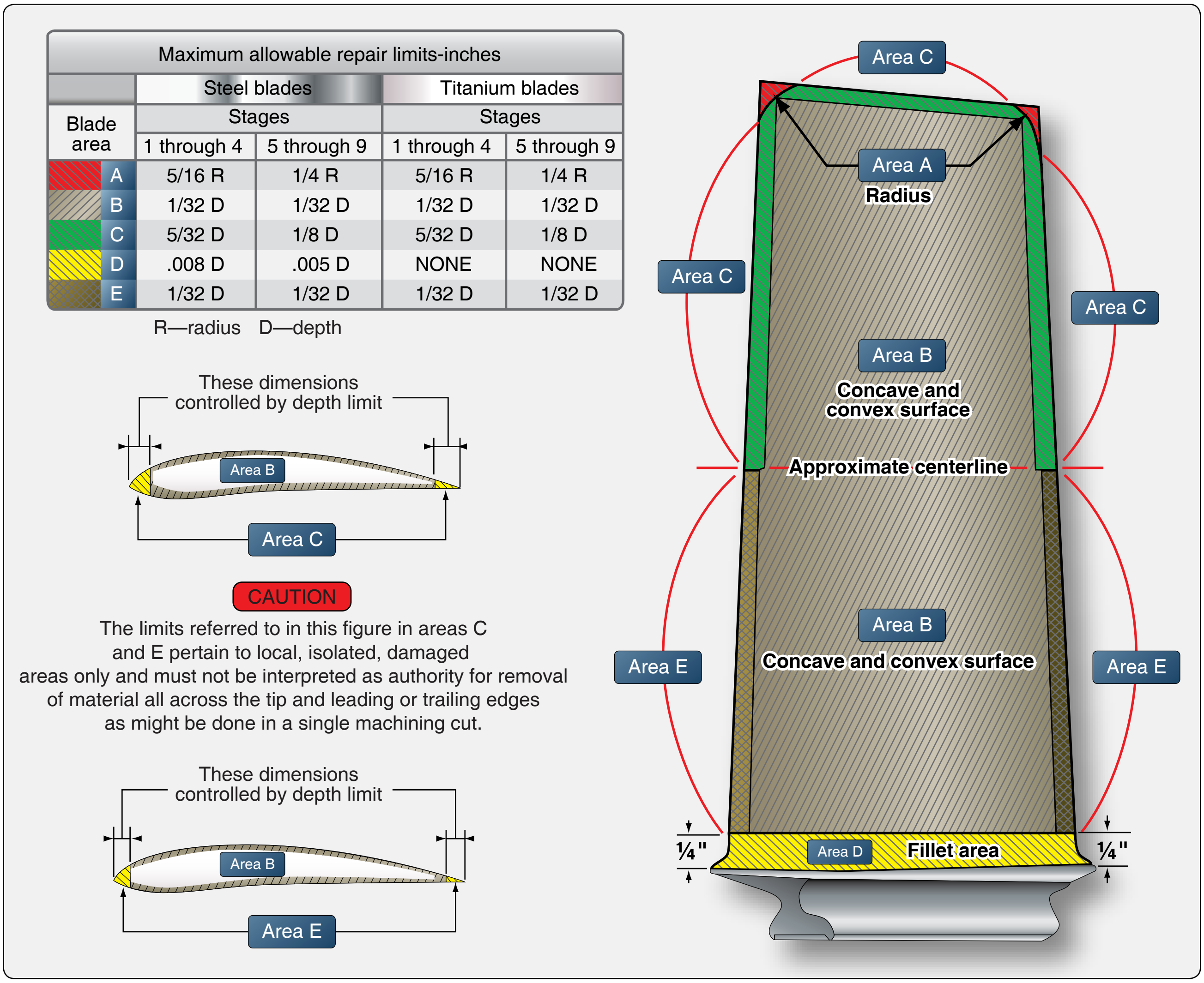
Loose objects often enter an engine either accidentally or through carelessness. Foreign object damage (FOD), such as pencils, tools, and flashlights, are often drawn into the engine and can cause damage to the fan blades. *[Figure 10-59]* Do not carry any objects in pockets when working around operational turbine engines.

A compressor rotor can be damaged beyond repair by tools that are left in the air intake, where they are drawn into the engine on subsequent starts. A simple solution to the problem is to check the tools against a tool checklist. Prior to starting a turbine engine, make a minute inspection of engine inlet ducts to assure that items, such as nuts, bolts, lock wire, or tools, were not left there after work had been performed.

Figure 10-60 shows some examples of blade damage to an axial-flow engine. The descriptions and possible causes of blade damage are given in *Figure 10-61*. Corrosion pitting is not considered serious on the compressor stator vanes of axial-flow engines if the pitting is within the allowed tolerance. Do not attempt to repair any vane by straightening, brazing, welding, or soldering. Crocus cloth, fine files, and stones are used to blend out damage by removing a minimum of material and leaving a surface finish comparable to that of a new part. The purpose of this blending is to minimize stresses that concentrate at dents, scratches, or cracks.

The inspection and repair of air intake guide vanes, swirl vanes, and screens on centrifugal-flow engines necessitates the use of a strong light. Inspect screen assemblies for breaks, rips, or holes. Screens may be tin-dipped to tighten the wire mesh, provided the wires are not worn too thin. If the frame strip or lugs have separated from the screen frames, re-brazing may be necessary.

Inspect the guide and swirl vanes for looseness. Inspect the outer edges of the guide vanes, paying particular attention to



Maximum allowable repair limits-inches				
	Steel blades		Titanium blades	
Blade area	Stages		Stages	
	1 through 4	5 through 9	1 through 4	5 through 9
A	5/16 R	1/4 R	5/16 R	1/4 R
B	1/32 D	1/32 D	1/32 D	1/32 D
C	5/32 D	1/8 D	5/32 D	1/8 D
D	.008 D	.005 D	NONE	NONE
E	1/32 D	1/32 D	1/32 D	1/32 D

R—radius D—depth

Figure 10-57. *Typical compressor blade repair limits.*

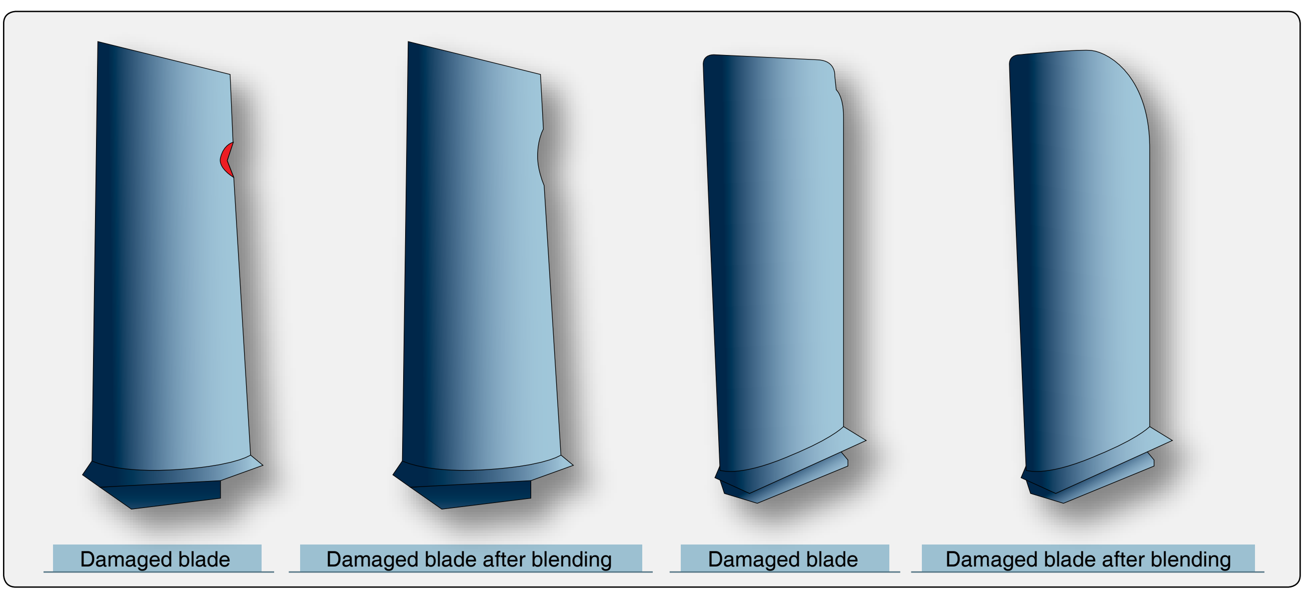


Figure 10-58. *Examples of repairs to damaged blades.*

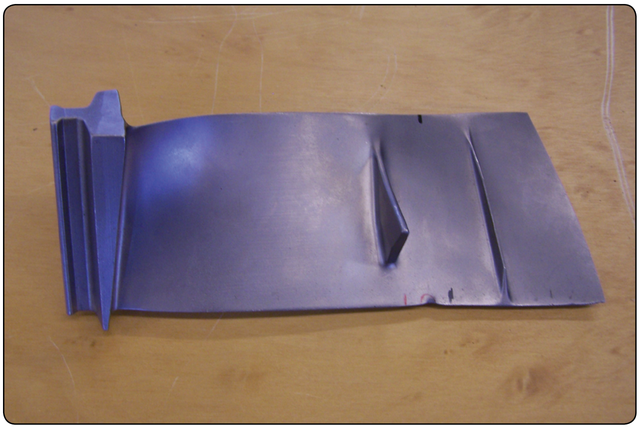


Figure 10-59. *Fan blade damage.*

the point of contact between the guides and swirl vanes for cracks and dents due to the impingement of foreign particles. Inspect the edges of the swirl vanes. Inspect the downstream edge of the guide vanes very closely, because cracks are generally more prevalent in this area. Cracks that branch or fork out so that a piece of metal could break free and fall into the compressor are cause for vane rejection.

Blending & Replacement

Because of the thin-sheet construction of hollow vanes, blending on the concave and convex surfaces, including the leading edge, is limited. Small, shallow dents are acceptable if the damage is of a rounded or gradual contour type and not a sharp or V-type, and if no cracking or tearing of vane material is evident in the damaged area.

Trailing edge damage may be blended, if one-third of the weld seam remains after repair. *[Figure 10-62]* Concave surfaces of rubber-filled vanes may have allowable cracks extending inward from the outer airfoil, provided there is no suggestion of pieces breaking away. Using a light and mirror, inspect each guide vane trailing edge and vane body for cracks or damage caused by foreign objects.

Any inspection and repair of turbine compressor section components require that the technician always use the specific manufacturer's current information for evaluation and limits of repairs.

Combustion Section Inspection

One of the controlling factors in the service life of the turbine engine is the inspection and cleaning of the hot section. Emphasis must be placed on the importance of careful inspection and repair of this section.

The following are general procedures for performing a hot section (turbine and combustion section) inspection. It is not intended to imply that these procedures are to be followed when performing repairs or inspections on turbine engines. However, the various practices are typical of those used on many turbine engines. Where a clearance or tolerance is shown, it is for illustrative purposes only. Always follow the instructions contained in the applicable manufacturer's maintenance and overhaul manuals.

The entire external combustion case should be inspected for evidence of hot spots, exhaust leaks, and distortions before the case is opened. After the combustion case has been opened, the combustion chambers can be inspected for localized overheating, cracks, or excessive wear. *[Figure 10-63]* Inspect the first stage turbine blades and nozzle guide vanes for cracks, warping, or FOD. Also inspect the combustion chamber outlet ducts and turbine nozzle for cracks and for evidence of FOD.

One of the most frequent discrepancies that are detected while inspecting the hot section of a turbine engine is cracking. These cracks may occur in many forms, and the only way to determine that they are within acceptable limits or if they are allowed at all, is to refer to the applicable engine manufacturer's service and overhaul manuals.

Cleaning the hot section is not usually necessary for a repair in the field, but in areas of high salt water or other chemicals a turbine rinse should be accomplished.

Engine parts can be degreased by using the emulsion-type cleaners or chlorinated solvents. The emulsion-type cleaners are safe for all metals, since they are neutral and noncorrosive. Cleaning parts by the chlorinated solvent method leaves the parts absolutely dry. If they are not to be subjected to further cleaning operations, they should be sprayed with a corrosion-preventive solution to protect them against rust or corrosion.

The hot section, which generally includes the combustion section and turbine sections, normally require inspections at regular intervals. The extent of disassembly of the engine to accomplish this inspection varies from different engine types. Most engines require that the combustion case be open for the inspection of the hot section. However, in performing this disassembly, numerous associated parts are readily accessible for inspection. The importance of properly supporting the engine and the parts being removed cannot be overstressed.

The alignment of components being removed and installed is also of the utmost importance. After all the inspections and repairs are made, the manufacturer's detailed assembly instructions should be followed. These instructions are important in efficient engine maintenance, and the ultimate life and performance of the engine. Extreme care must be

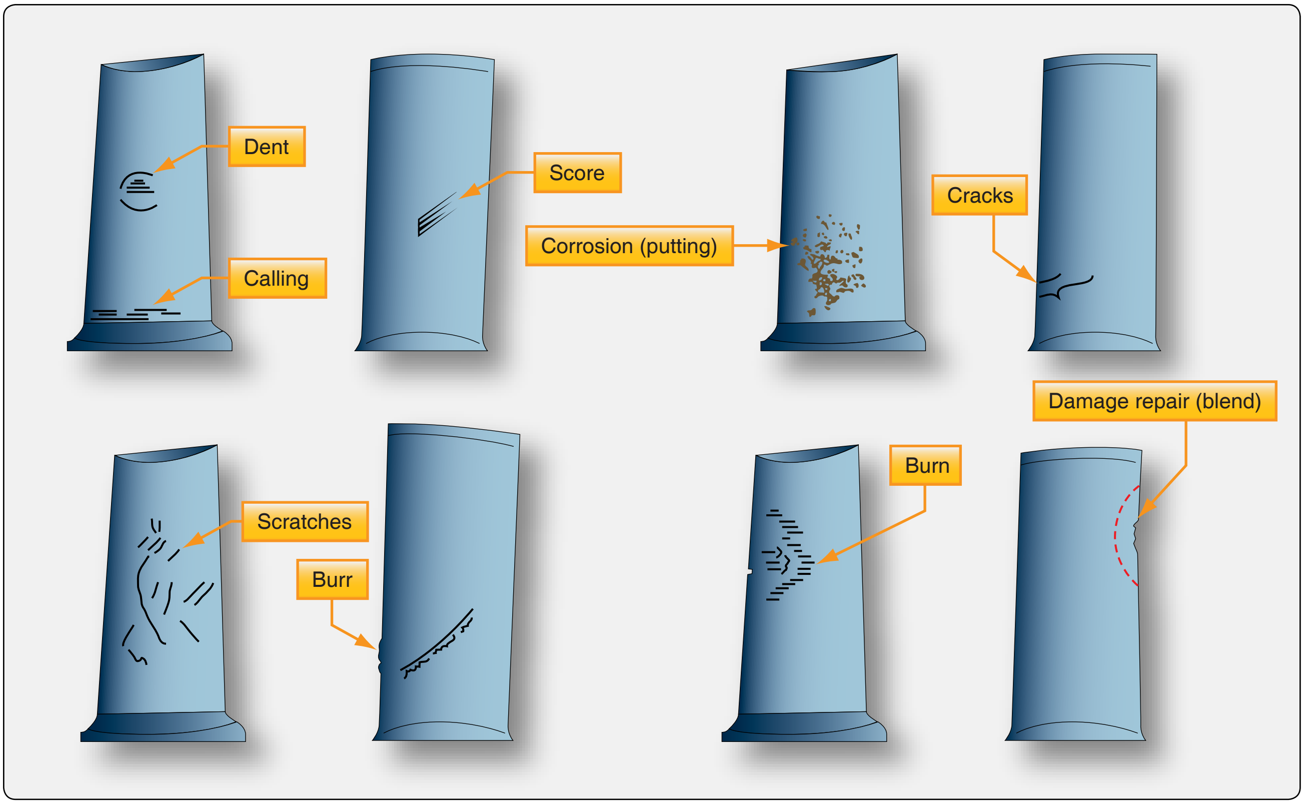


Figure 10-60. *Compressor blade damage.*

Term	Appearance	Usual Causes
• Blend	• Smooth repair of ragged edge or surface into the contour of surrounding area.	
• Bow	• Bent blade.	• Foreign objects.
• Burning	• Damage to surfaces evidenced by discoloration or, in severe cases, by flow of material.	• Excessive heat.
• Burr	• A ragged or turned out edge.	• Grinding or cutting operation.
• Corrosion (pits)	• Breakdown of the surface; pitted appearance.	• Corrosive agents—moisture, etc.
• Cracks	• A partial fracture (separation).	• Excessive stress due to shock, overloading, or faulty processing; defective materials; overheating.
• Dent	• Small, smoothly rounded hollow.	• Striking of a part with a dull object.
• Gall	• A transfer of metal from one surface to another.	• Severe rubbing.
• Gouging	• Displacement of material from a surface; a cutting or tearing effect.	• Presence of a comparatively large foreign body between moving parts.
• Growth	• Elongation of blade.	• Continued and/or excessive heat and centrifugal force.
• Pit	• (See corrosion).	
• Profile	• Contour of a blade or surface.	
• Score	• Deep scratches.	• Presence of chips between surfaces.
• Scratch	• Narrow shallow marks.	• Sand or fine foreign particles; careless handling.

Figure 10-61. *Blade maintenance terms.*

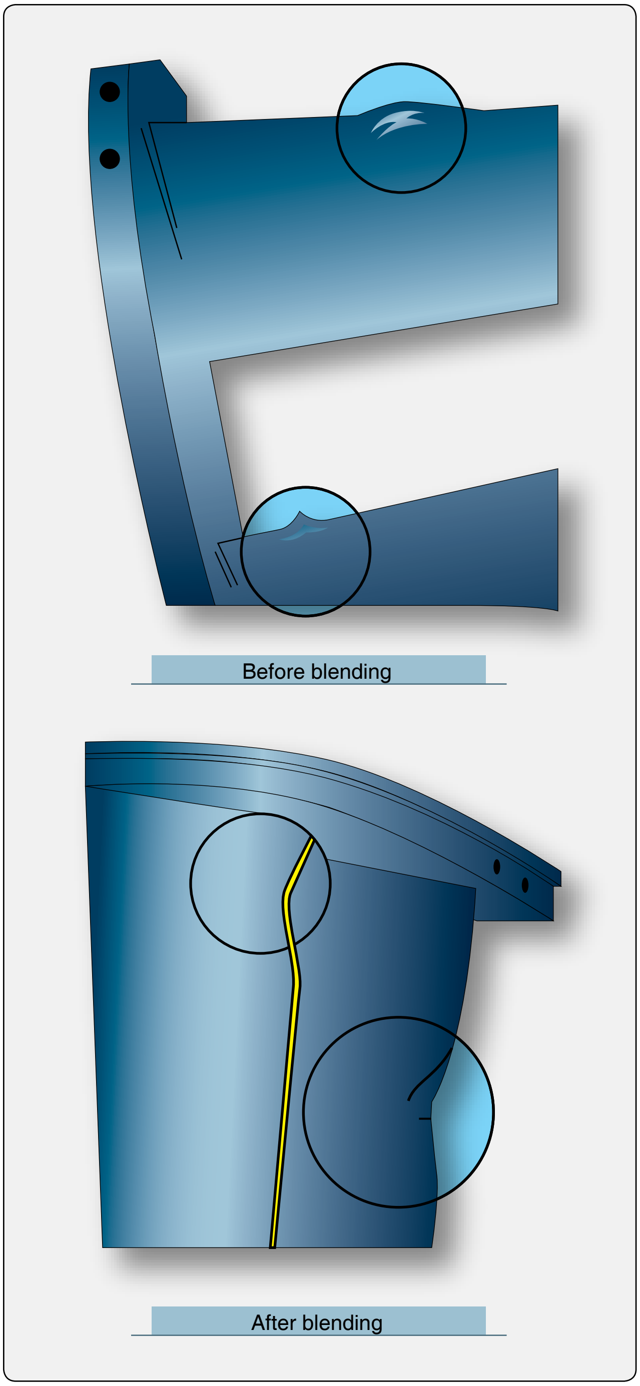


Figure 10-62. *Guide vane trailing edge damage.*

taken during assembly to prevent dirt, dust, cotter pins, lock wire, nuts, washers, or other foreign material from entering the engine.

Marking Materials for Combustion Section Parts

Certain materials may be used for temporary marking during assembly and disassembly. Always refer to manufacturer's information for marking parts. Layout dye (lightly applied), a felt tip marker, or chalk may be used to mark parts that are

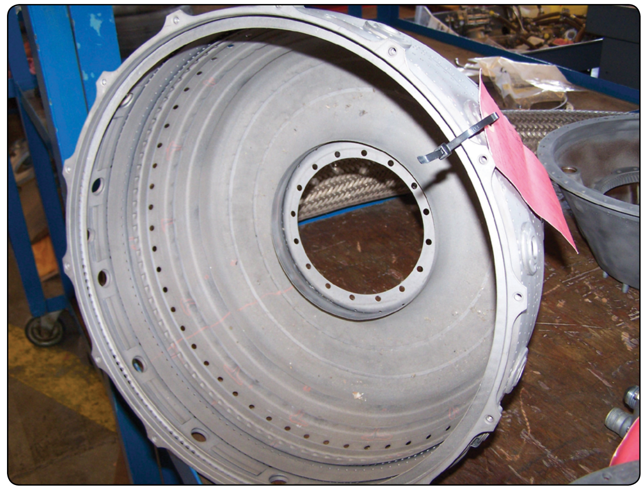


Figure 10-63. *Combustion case inspection.*

directly exposed to the engine's gas path, such as turbine blades and discs, turbine vanes, and combustion chamber liners. A wax marking pencil may be used for parts that are not directly exposed to the gas path. Do not use a wax marking pencil on a liner surface or a turbine rotor. The use of carbon alloy or metallic pencils is not recommended because of the possibility of causing intergranular corrosion attack, that could result in a reduction in material strength and cracking.

Inspection & Repair of Combustion Chambers

Inspect the combustion chambers and covers for cracks by using visible dye or fluorescent penetrant inspection method. Any cracks, nicks, or dents are usually cause for rejecting the component. Inspect the covers, noting particularly the area around the fuel drain bosses for any pits or corrosion. When repairing the combustion chamber liner, the procedures given in the appropriate engine manufacturer's overhaul instruction manual should be followed. If there is doubt that the liner is serviceable, it should be replaced.

Combustion chambers should be replaced or repaired if two cracks are progressing from a free edge so that their meeting is imminent and could allow a piece of metal that could cause turbine damage to break loose. Separate cracks in the baffle are acceptable. Cracks in the cone are rare but, at any location on this component, is cause for rejection of the liner. Cracks in the swirl vanes are cause for rejection of the liner. Loose swirl vanes may be repaired by silver brazing. Cracks in the front liner emanating from the air holes are acceptable, provided they do not exceed allowable limits. If such cracks fork or link with others, the liner must be repaired. If two cracks originating from the same air hole are diametrically opposite, the liner is acceptable. Radial cracks extending from the interconnector and spark igniter boss are acceptable, if they do not exceed allowable limits and if such cracks do not fork or link with others. Circumferential cracks around the boss pads should be repaired prior to re-use of the liner. Baffle cracks connecting more than two holes should be repaired.

After long periods of engine operation, the external surfaces of the combustion chamber liner location pads often show signs of fretting. This is acceptable, provided no resultant cracks or perforation of the metal is apparent. Any cover or chamber inadvertently dropped on a hard surface or mishandled should be thoroughly inspected for minute cracks that may elongate over a period of time and then open, creating a hazard.

Parts may be found where localized areas have been heated to an extent to buckle small portions of the chamber. Such parts are considered acceptable if the burning of the part has not progressed into an adjacent welded area, or to such an extent as to weaken the structure of the liner weldment. Buckling of the combustion chamber liner can be corrected by straightening the liner. Moderate buckling and associated cracks are acceptable in the row of cooling holes. More severe buckling that produces a pronounced shortening or tilting of the liner is cause for rejection. Upon completion of the repairs by welding, the liner should be restored as closely as possible to its original shape.

Fuel Nozzle & Support Assemblies

Clean all carbon deposits from the nozzles by washing with a cleaning fluid approved by the engine manufacturer and remove the softened deposits with a soft bristle brush. It is desirable to have filtered air passing through the nozzle during the cleaning operation to carry away deposits as they are loosened. Make sure all parts are clean. Dry the assemblies with clean, filtered air. Because the spray characteristics of the nozzle may become impaired, no attempt should be made to clean the nozzles by scraping with a hard implement or by rubbing with a wire brush. Inspect each component part of the fuel nozzle assembly for nicks and burrs. Many fuel nozzles can be checked by flowing fluid through the nozzle under pressure and closely checking the flow pattern coming for the nozzle.

Turbine Disc Inspection

The inspection for cracks is very important because cracks are not normally allowed. Crack detection, when dealing with the turbine disc and blades, is mostly visual, although structural inspection techniques can be used, such as penetrant methods and others to aid in the inspection. Cracks on the disc necessitate the rejection of the disc and replacement of the turbine rotor. Slight pitting caused by the impingement of foreign matter may be blended by stoning and polishing.

Turbine Blade Inspection

Turbine blades are usually inspected and cleaned in the same manner as compressor blades. However, because of the extreme heat under which the turbine blades operate, they are more susceptible to damage. Using a strong light and a magnifying glass, inspect the turbine blades for stress rupture cracks and deformation of the leading edge. *[Figures 10-64* and *10-65]*

Stress rupture cracks usually appear as minute hairline cracks on or across the leading or trailing edge at a right angle to the edge length. Visible cracks may range in length from one-sixteenth inch upward. Deformation, caused by over-temperature, may appear as waviness and/or areas of varying airfoil thickness along the leading edge. The leading edge must be straight and of uniform thickness along its entire length, except for areas repaired by blending. Do not confuse stress rupture cracks or deformation of the leading edge with foreign material impingement damage or with

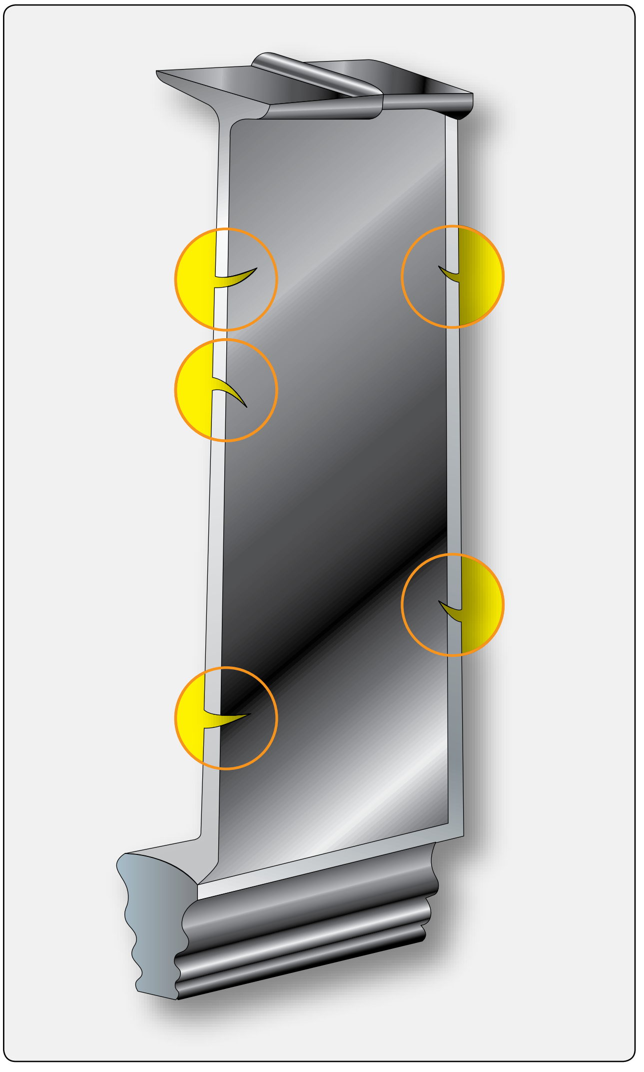


Figure 10-64. *Stress rupture cracks.*

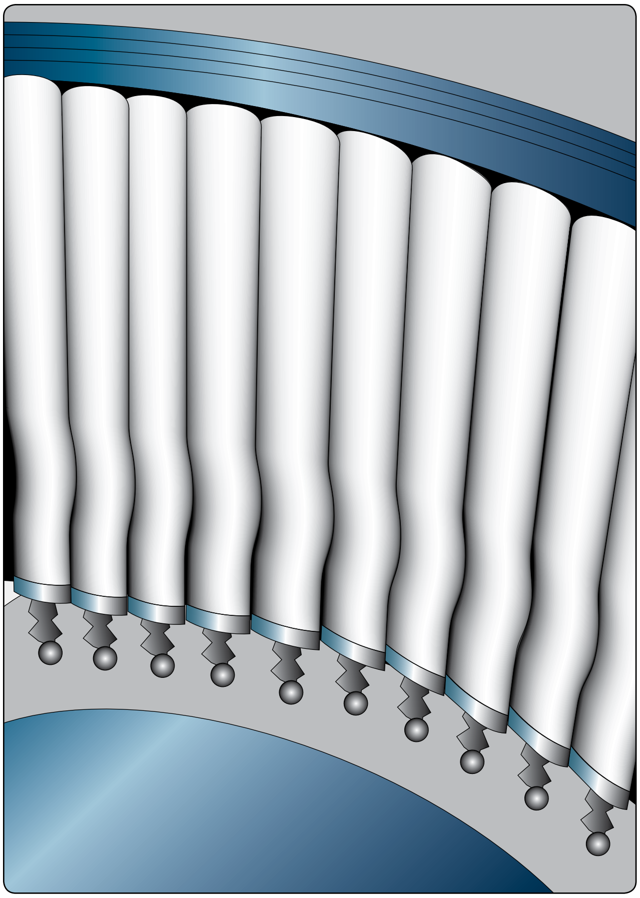


Figure 10-65. *Turbine blade waviness.*

blending repairs to the blade. When any stress rupture cracks or deformation of the leading edges of the first-stage turbine blades are found, an over-temperature condition must be suspected. Check the individual blades for stretch and the turbine disc for hardness and stretch. Blades removed for a detailed inspection or for a check of turbine disc stretch must be re-installed in the same slots from which they were removed. Number the blades prior to removal.

The turbine blade outer shroud should be inspected for air seal wear. If shroud wear is found, measure the thickness of the shroud at the worn area. Use a micrometer or another suitable and accurate measuring device that ensures a good reading in the bottom of the comparatively narrow wear groove. If the remaining radial thickness of the shroud is less than that specified, the stretched blade must be replaced. Typical blade inspection requirements are indicated in *Figure 10-66*. Blade tip curling within a one-half inch square area on the leading edge of the blade tip is usually acceptable if the curling is not sharp. Curling is acceptable on the trailing edge if it does not extend beyond the allowable area. Any sharp bends that may result in cracking or a piece breaking out of the turbine blade is cause for rejection, even though the curl may be within the allowable limits. Each turbine blade should be inspected for cracks.

Turbine Blade Replacement Procedure

Turbine blades are generally replaceable, subject to moment-weight limitations. These limitations are contained in the

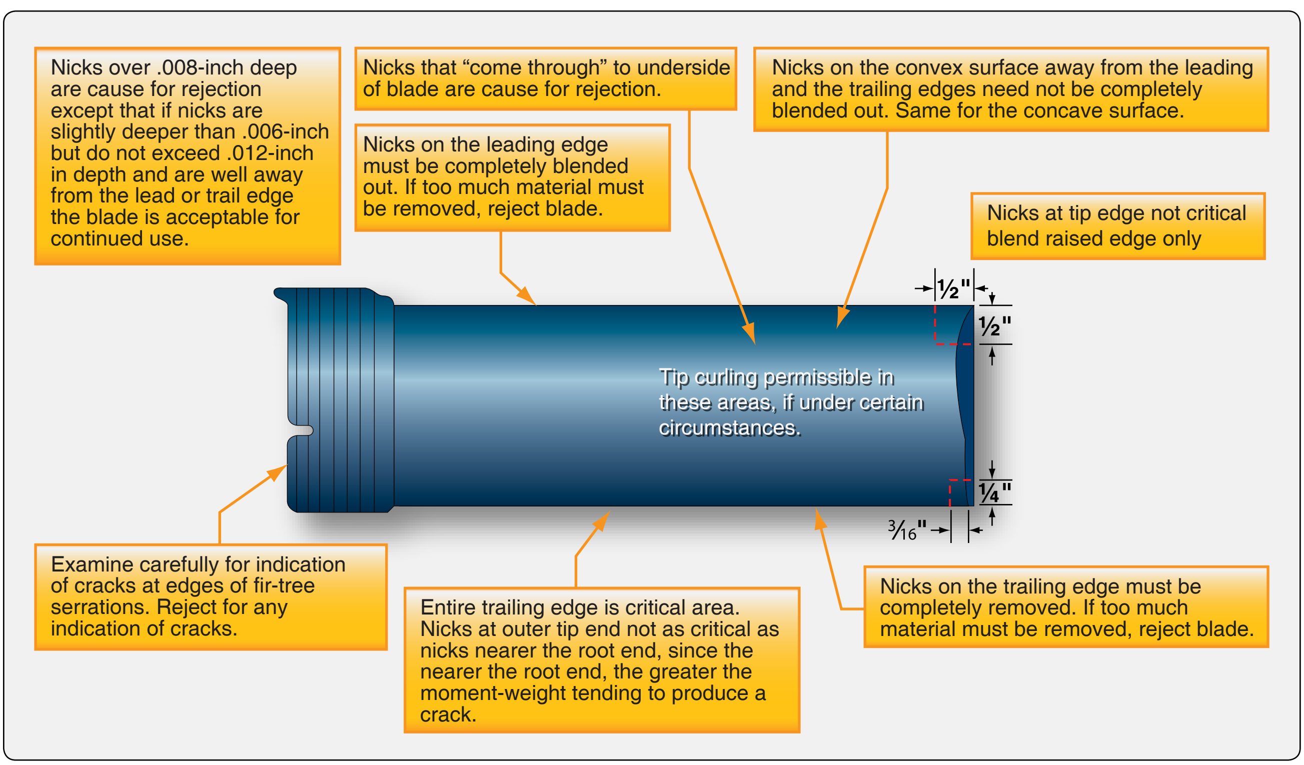


Figure 10-66. *Typical turbine blade inspection.*

engine manufacturer's applicable technical instructions. If visual inspection of the turbine assembly discloses several broken, cracked, or eroded blades, replacing the entire turbine assembly may be more economical than replacing the damaged blades. *[Figure 10-67]*

In the initial buildup of the turbine, a complete set of 54 blades made in coded pairs (two blades having the same code letters) is laid out on a bench in the order of diminishing moment-weight. The code letters, indicating the moment-weight balance in ounces, are marked on the rear face of the fir-tree section of the blade (viewing the blade as installed at final assembly of the engine). The pair of blades having the heaviest moment-weight is numbered 1 and 28; the next heaviest pair of blades is numbered 2 and 29; the third heaviest pair is numbered 3 and 30. This is continued until all the blades have been numbered. Mark a number 1 on the face of the hub on the turbine disc. The number 1 blade is then installed adjacent to the number 1 on the disc. *[Figure 10-68]*

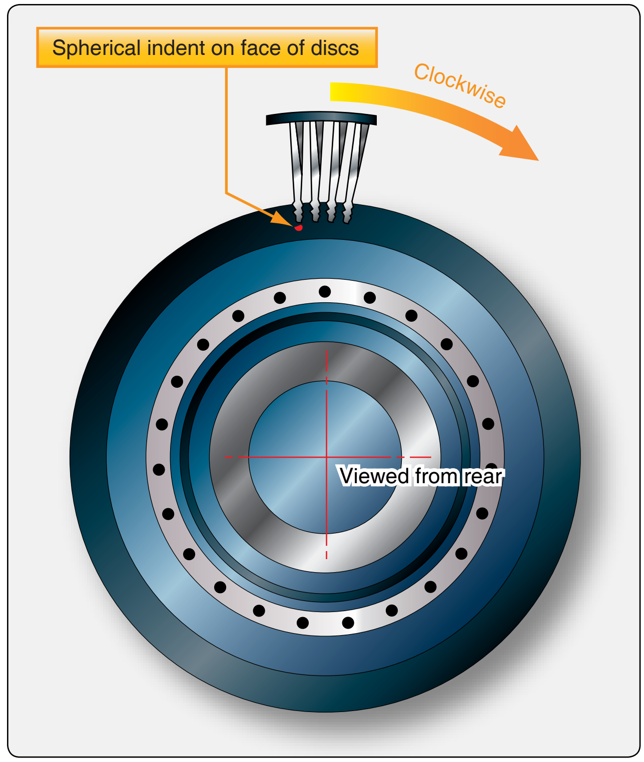


Figure 10-68. *Turbine blades.*

The remaining blades are then installed consecutively in a clockwise direction, viewed from the rear face of the turbine disc. If there are several pairs of blades having the same code letters, they are installed consecutively before going to the next code letters. If a blade requires replacement, the diametrically opposite blade must also be replaced. Computer programs generally determine the location for turbine blades for turbine wheels on modern engines.

Turbine Nozzle Inlet Guide Vane Inspection

After removing the required components, the first stage turbine blades and turbine nozzle vanes are accessible for inspection. The blade limits specified in the engine manufacturer's overhaul and service instruction manual should he adhered to. *Figure 10-69* shows where cracks usually occur on a turbine nozzle assembly. Slight nicks and dents are permissible if the depth of damage is within limits. Inspect the nozzle vanes for nicks or cracks. Small nicks are not cause for vane rejection, provided such nicks blend out smoothly.

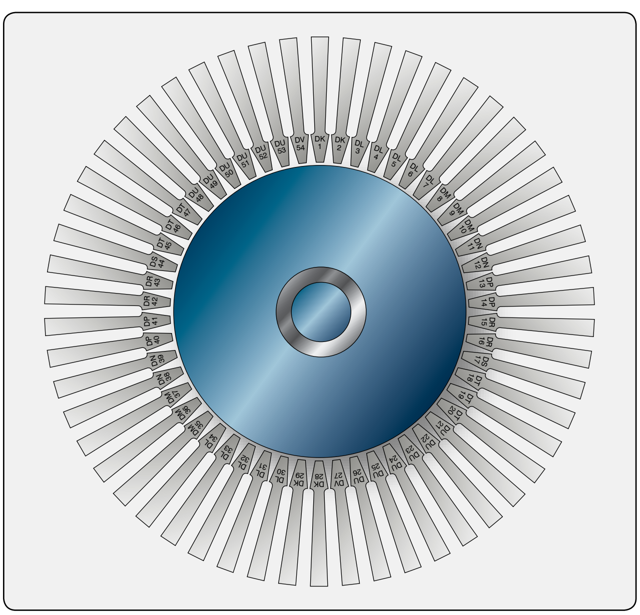


Figure 10-67. *Typical turbine rotor blade moment-weight distribution.*

Inspect the nozzle vane supports for defects caused by the impingement of foreign particles. Use a stone to blend any doubtful nicks to a smooth radius. Like turbine blades, it is possible to replace a maximum number of turbine nozzle vanes in some engines. If more than the maximum vanes are damaged, a new turbine nozzle vane assembly must be installed. With the tailpipe (exhaust nozzle) removed, the rear turbine stage can be inspected for any cracks or evidence of blade stretch. Additional nozzle stages can also be inspected with a strong light by looking through the rear-stage turbine.

Clearances

Checking the clearances is one of the procedures in the maintenance of the turbine section of a turbine engine. The manufacturer's service and overhaul manual gives the procedures and tolerances for checking the turbine. Turbine clearances being measured at various locations are shown in *Figures 10-70* and *10-71*. To obtain accurate readings, special tools provided by each manufacturer must be used

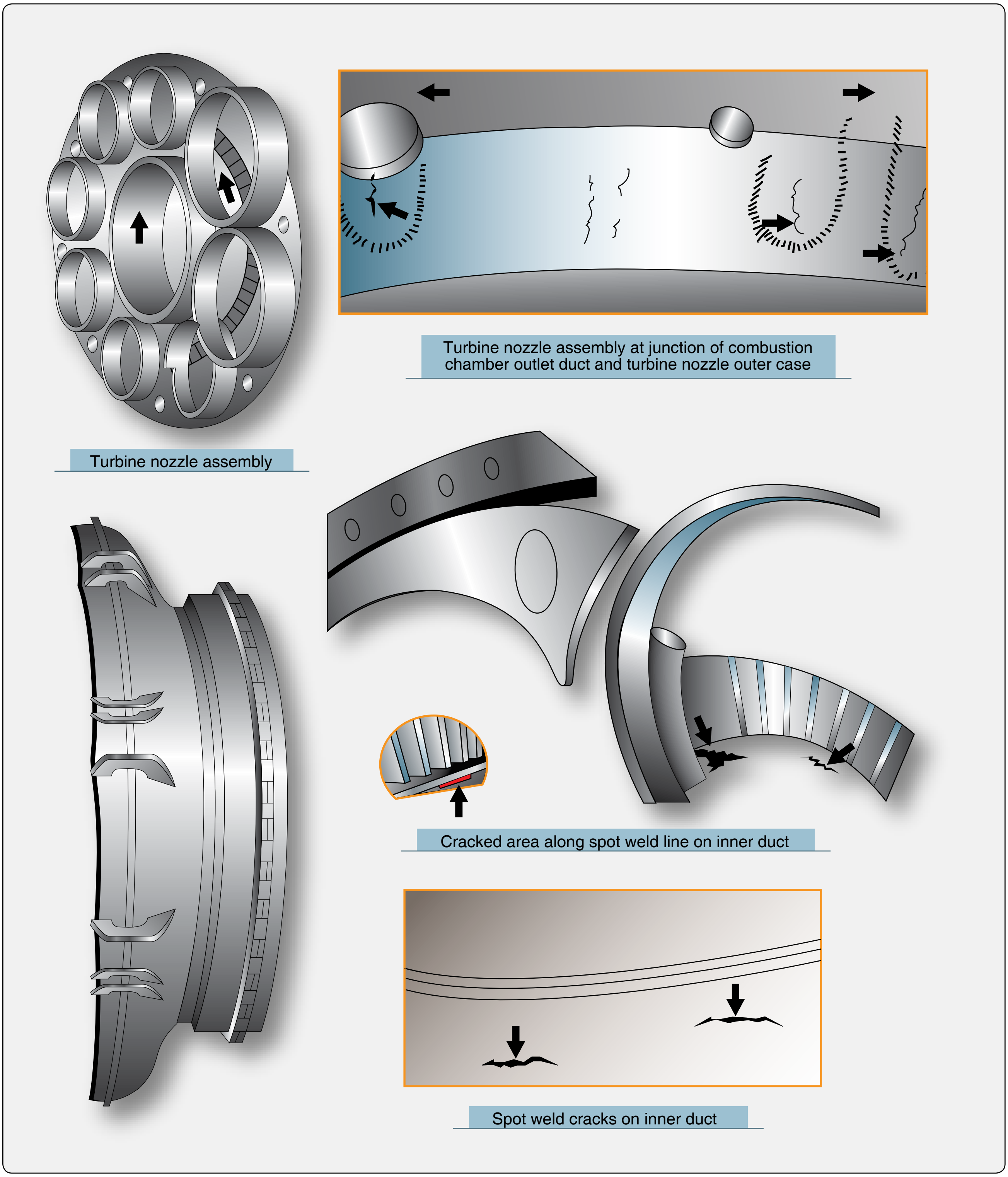


Figure 10-69. *Turbine nozzle assembly defects.*

as described in the service instructions for specific engines.

Exhaust Section

The exhaust section of the turbine engine is susceptible to heat cracking. This section must be thoroughly inspected along with the inspection the combustion section and turbine section of the engine. Inspect the exhaust cone and exhaust nozzle for cracks, warping, buckling, or hot spots. Hot spots on the tail cone are a good indication of a malfunctioning fuel nozzle or combustion chamber.

The inspection and repair procedures for the hot section of any one gas turbine engine share similarities to those of other gas turbine engines. One usual difference is the nomenclature applied to the various parts of the hot section by the different manufacturers. Other differences include the manner of disassembly, the tooling necessary, and the repair methods and limits.

Engine Ratings

The flat rating of a turbine engine is the thrust performance that is guaranteed by the manufacturer for a new engine under specific operating conditions, such as takeoff, maximum continuous climb, and cruise power settings. The turbine inlet temperature is proportional to the energy available to turn the turbine. This means that the hotter the gases are that are entering the turbine section of the engine, the more power is available to turn the turbine wheel. The exhaust temperature is proportional to the turbine inlet temperature. Regardless of how or where the exhaust temperature is taken on the engine for the flight deck reading, this temperature is proportional to the temperature of the exhaust gases entering the first stage of inlet guide vanes. A higher EGT corresponds to a larger amount of energy to the turbine so it can turn the compressor faster. This works fine until the temperature reaches a point when the turbine inlet guide vanes start to be damaged. EGT must be held constant or lowered as the result of a prolonged hot section life and, at the same time, provide the thrust to meet the certification requirements.

Before high bypass turbofan engines, some older types of engines used water injection to increase thrust for takeoff (wet). This is the maximum allowable thrust for takeoff. The rating is obtained by actuating the water-injection system and setting the computed wet thrust with the throttle, in terms of a predetermined turbine discharge pressure or engine pressure ratio for the prevailing ambient conditions. The rating is restricted to takeoff, is time-limited, and has an altitude limitation. Water injection is not used very much on turbine engines any more.

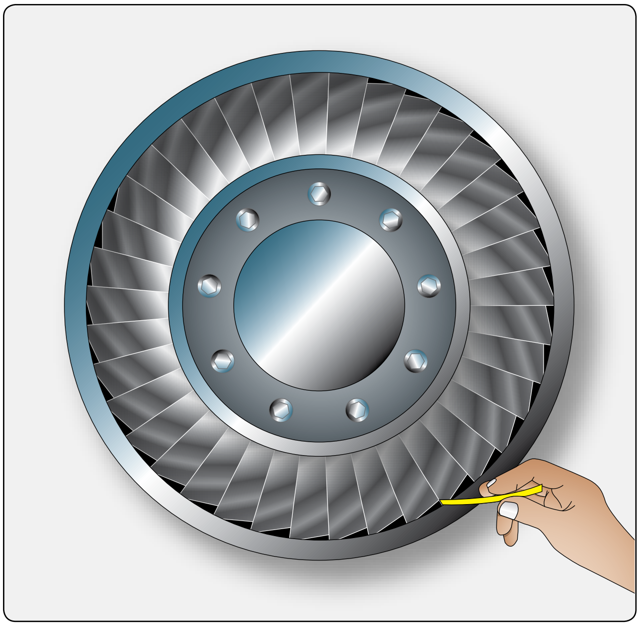


Figure 10-70. *Measuring the turbine blades to shroud (tip) clearances.*

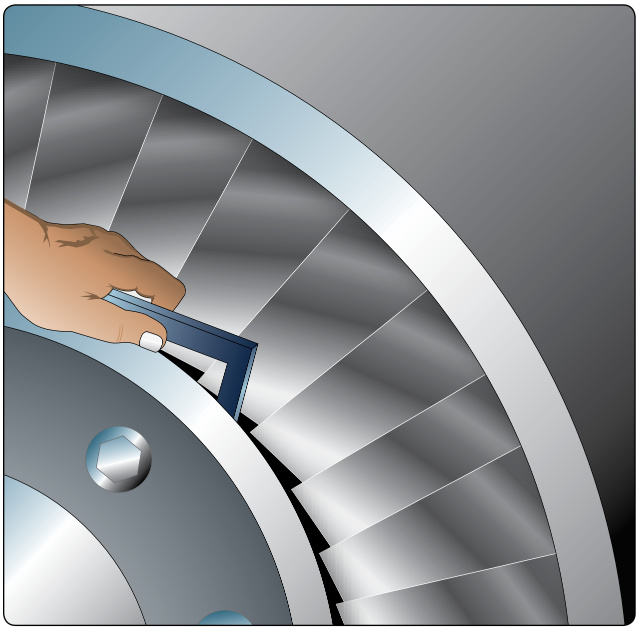


Figure 10-71. *Measuring turbine wheel to exhaust cone clearance.*

Turbine Engine Instruments

Engine Pressure Ratio Indicator

Engine pressure ratio (EPR) is an indication of the thrust being developed by a turbofan engine and is used to set power for takeoff on many types of aircraft. It is instrumented by total pressure pickups in the engine inlet (Pt2) and in the turbine exhaust (Pt7). The reading is displayed in the flight deck by the EPR gauge, which is used in making engine power settings. *[Figure 10-72]*

Torquemeter (Turboprop Engines)

Only 10 to 15 percent of the thrust produced by a turboprop engine is from propulsive force derived from the jet thrust exiting the exhaust. Engine pressure ratio is not used as an indicator of the power produced by a turboprop engine. Turboprops are usually fitted with a torquemeter that measures torque applied to a shaft turned by the gas generator and power turbines of the turbine engine. The torquemeter can be operated by engine oil pressure metered through a valve that is controlled by a helical ring gear that moves in response to the applied torque. *[Figure 10-73]* This gear moves against a piston that controls the opening of a valve, which controls the oil pressure flow. This action makes the oil pressure proportional to torque being applied at the propeller shaft. Generally, transducer is used to transfer the oil pressure into an electrical signal to be read by the flight deck instrument. The read out in the flight deck is normally in lb/ft of torque, or percent horsepower. The torquemeter is very important as it is used to set power settings. This instrument must be calibrated at intervals to assure its accuracy.

Tachometer

Gas turbine engine speeds are measured by the engines rpm, which are also the compressor/turbine combination rpm of each rotating spool. Most turbofan engines have two or more spools, compressor, and turbine sections that turn independently at different speeds. Tachometers are usually calibrated in percent rpm so that various types of engines can be operated on the same basis of comparison. *[Figure 10-73]* Also, turbine speeds are generally very high, and the large numbers of rpm would make it very confusing. Turbofan engines with two spools or separate shafts, high pressure and low pressure spools, are generally referred to as N1 and N2, with each having their own indicator. The main purpose of the tachometer is to be able to monitor rpm under normal conditions, during an engine start, and to indicate an overspeed condition, if one occurs.

Figure 10-72. *Engine pressure ratio indications.*

Exhaust Gas Temperature Indicator (EGT)

Exhaust gas temperature (EGT), turbine inlet temperature, (TIT), turbine gas temperature (TGT), interstage turbine temperature (ITT), and turbine outlet temperature (TOT) are all relative temperatures used to monitor the temperature of the exhaust gases entering the first stage turbine inlet guide vanes. Even though these temperatures are taken at different locations on the engine (each engine having one location), they are all relative to the temperature of the gases entering the first stage turbine inlet guide vanes.

Temperature is an engine operating limit and is used to monitor the mechanical integrity of the turbines, as well as to check engine operating conditions. Actually, the temperature of the gases entering the first stage turbine inlet guide vanes is the important consideration, since it is the most critical of all the engine variables. However, it is impractical to measure turbine inlet temperature in most engines, especially large engines. Consequently, temperature thermocouples are inserted at the turbine discharge, where the temperature provides a relative indication of that at the inlet. Although the temperature at this point is much lower than at the inlet, it provides surveillance over the engine's internal operating conditions. Several thermocouples are usually used, that are spaced at intervals around the perimeter of the engine exhaust duct near the turbine exit. The EGT indicator in the flight deck shows the average temperature measured by the individual thermocouples. *[Figure 10-73]*

Fuel-Flow Indicator

Fuel-flow instruments indicate the fuel flow in pounds per hour (lb/hr) from the engine fuel control. Fuel flow in turbine aircraft is measured in lb/hr instead of gallons, because the fuel weight is a major factor in the aerodynamics of large turbine aircraft. Fuel flow is of interest in monitoring fuel consumption and checking engine performance. *[Figure 10-73]*

Engine Oil Pressure Indicator

To guard against engine failure resulting from inadequate lubrication and cooling of the various engine parts, the oil supply to critical areas must be monitored. The oil pressure indicator usually shows the engine oil pump discharge pressure.

Engine Oil Temperature Indicator

The ability of the engine oil to lubricate and cool depends on the temperature of the oil, as well as the amount of

Figure 10-73. *Typical turbine engine instruments.*

oil supplied to the critical areas. An oil inlet temperature indicator frequently is provided to show the temperature of the oil as it enters the oil pressure pump. Oil inlet temperature is also an indication of proper operation of the engine oil cooler.

Turbine Engine Operation

The engine operating procedures presented here apply generally to turbofan, turboprop, turboshaft, and auxiliary power units (APU). The procedures, pressures, temperatures, and rpm that follow are intended primarily to serve as a guide. It should be understood that they do not have general application. The manufacturer's operating instructions should be consulted before attempting to start and operate any turbine engine.

A turbofan engine has only one power control lever. Adjusting the power lever, or throttle lever, sets up a thrust condition for which the fuel control meters fuel to the engine. Engines equipped with thrust reversers go into reverse thrust at throttle positions below idle. A separate fuel shutoff lever is usually provided on engines equipped with thrust reversers.

Prior to start, particular attention should be paid to the engine air inlet, the visual condition and free movement of the compressor and turbine assembly, and the parking ramp area fore and aft of the aircraft. The engine is started by using an external air power source, APU, or an already operating engine. Starter types and the engine starting cycle have been discussed previously. On multi-engine aircraft, the engines are usually started by an onboard APU that supplies the air pressure for a pneumatic starter on each engine. Air bled from the APU is used as a source of power for starting the engines.

During the start, it is necessary to monitor the tachometer, the oil pressure, and the exhaust gas temperature. The normal starting sequence is:

1. Rotate the compressor with the starter;
2. Turn the ignition on; and
3. Open the engine fuel valve, either by moving the throttle to idle or by moving a fuel shutoff lever or turning a switch.

Adherence to the procedure prescribed for a particular engine is necessary as a safety measure and to avoid a hot or hung start. A successful start is noted first by a rise in exhaust gas temperature. If the engine does not light up, meaning that fuel starts to burn inside of the engine within a prescribed period of time, or if the exhaust gas starting temperature limit is exceeded, a hot start, the starting procedure should be aborted. Hot starts are not common, but when they do occur, they can usually be stopped in time to avoid excessive temperature by observing the exhaust gas temperature constantly during the start. When necessary, the engine is cleared of trapped fuel or gases by continuing to rotate the compressor with the starter, but with the ignition and fuel turned off. If the engine did not light off during start after the allotted time, about 10 seconds although this time varies from engine to engine, the fuel must be shut off as the engine is being filled with unburned fuel. A hung start is when the engine lights off, but the engine will not accelerate to idle rpm.

Ground Operation Engine Fire

Move the fuel shutoff lever to the off position if an engine fire occurs, or if the fire warning light is illuminated during the starting cycle. Continue cranking or motoring the engine until the fire has been expelled from the engine. If the fire persists, CO_2 can be discharged into the inlet duct while it is being cranked. Do not discharge CO_2 directly into the engine exhaust, because it may damage the engine. If the fire cannot be extinguished, secure all switches and leave the aircraft. If the fire is on the ground under the engine overboard drain, discharge the CO_2 on the ground rather than on the engine. This also is true if the fire is at the tailpipe and the fuel is dripping to the ground and burning.

Engine Checks

Checking turbofan engines for proper operation consists primarily of simply reading the engine instruments and then comparing the observed values with those known to be correct for any given engine operating condition. After the engine has started, idle rpm has been attained, and the instrument readings have stabilized, the engine should be checked for satisfactory operation at idling speed. The oil pressure indicator, tachometer, and the exhaust gas temperature readings should be compared with the allowable ranges.

Checking Takeoff Thrust

Takeoff thrust is checked by adjusting the throttle to obtain a single, predicted reading on the engine pressure ratio indicator in the aircraft. The value for engine pressure ratio, which represents takeoff thrust for the prevailing ambient atmospheric conditions, is calculated from a takeoff thrust setting curve or, on newer aircraft, is a function of the onboard computer. This curve has been computed for static conditions. *[Figure 10-74]* Therefore, for all precise thrust checking, the aircraft should be stationary, and stable engine operation should be established. If it is needed for calculating thrust during an engine trim check, turbine discharge pressure (Pt7) is also shown on these curves. Appropriate manuals should be consulted for the charts for a specific make and model engine. Engine trimming procedure is also covered in Chapter 2, Engine Fuel & Fuel Metering Systems. The engine pressure ratio computed from the thrust setting curve represents thrust or a lower thrust call part power thrust used for testing. The aircraft throttle is advanced to obtain this predicted reading on the engine pressure ratio indicator, or the part power stop is engaged in the aircraft. If an engine develops the predicted thrust and if all the other engine instruments are reading within their proper ranges, engine operation is considered satisfactory. Full authority digital engine controls (FADEC) (computer controls) also have means of checking the engine with the results displayed on the flight deck.

Ambient Conditions

The sensitivity of gas turbine engines to compressor inlet air temperature and pressure necessitates that considerable care be taken to obtain correct values for the prevailing ambient air conditions when computing takeoff thrust. Some things to remember are:

1. The engine senses the air temperature and pressure at the compressor inlet. This is the actual air temperature just above the runway surface. When the aircraft is stationary, the pressure at the compressor inlet is the static field or true barometric pressure, and not the barometric pressure corrected to sea level that is normally reported by airport control towers as the altimeter setting. On FADEC engines, the computer reads this information and sends it to the engine controls.
2. Temperature sensed is the total air temperature (TAT) that is used by several onboard computers. The engine controls set the engine computers according to the TAT.
3. Relative humidity, which affects reciprocating engine power appreciably, has a negligible effect on turbine engine thrust, fuel flow, and rpm. Therefore, relative humidity is not usually considered when computing thrust for takeoff or determining fuel flow and rpm for routine operation.

Engine Shutdown

On turbine engines that have a thrust reverser, retarding the aircraft throttle to idle or power lever to OFF cuts the fuel supply to the engine and shuts down the engine. On engines equipped with thrust reversers, this is accomplished by means of a separate fuel shutoff lever or switch. When an engine has been operated at high power levels for extended periods of time, a cool down time should be allowed before shutting down. It is recommended the engine be operated at below a low power setting, preferably at idle for a period of 5 minutes to prevent possible seizure of the rotors. This applies, in particular, to prolonged operation at high rpm on the ground, such as during engine trimming. The turbine case and the turbine wheels operate at approximately the same temperature

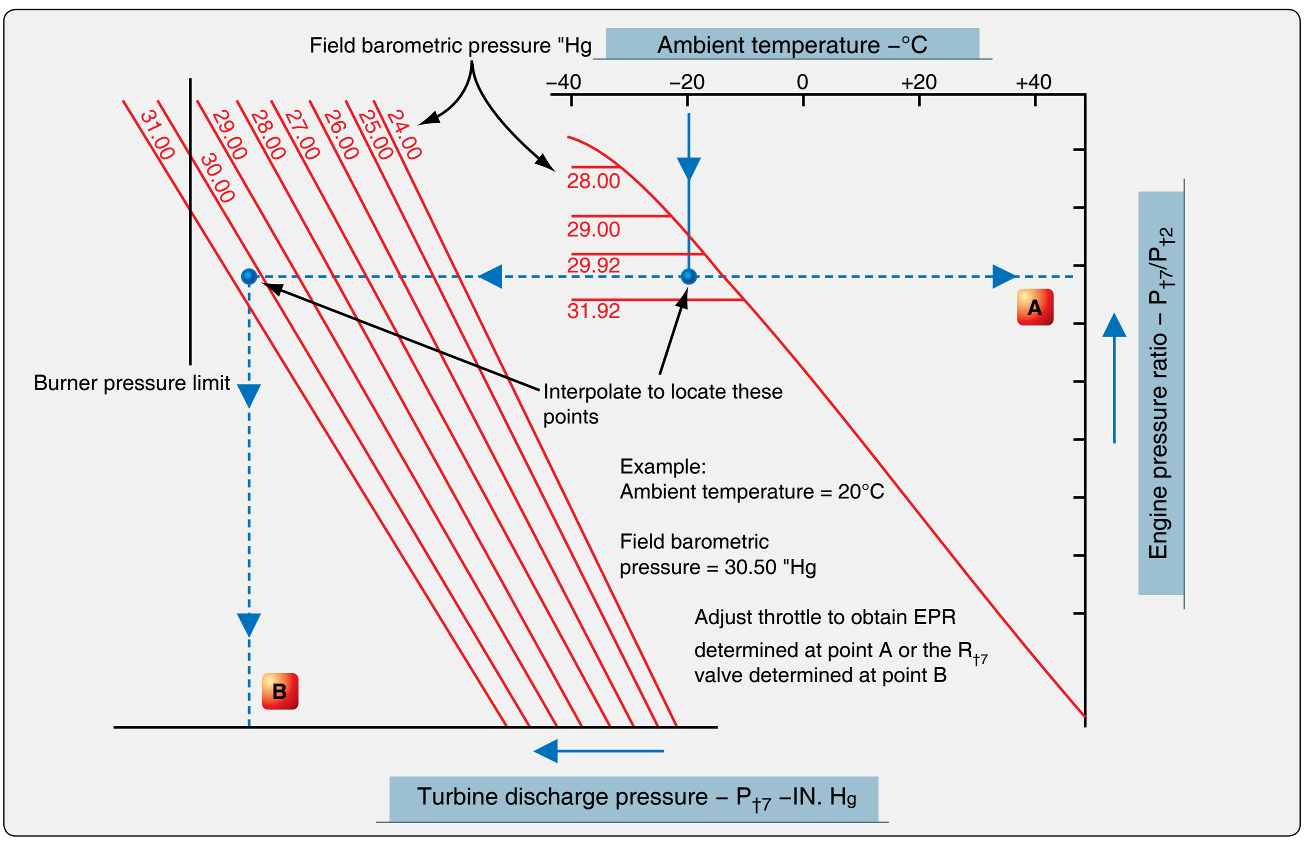


Figure 10-74. *Typical takeoff thrust setting curve for static conditions.*

when the engine is running. However, the turbine wheels are relatively massive, compared with the case, and are not cooled so readily. The turbine case is exposed to cooling air from both inside and outside the engine. Consequently, the case and the wheels lose their residual heat at different rates after the engine has been shut down. The case, cooling faster, tends to shrink upon the wheels, that are still rotating. Under extreme conditions, the turbine blades may squeal or seize; thus, a cooling period is required if the engine has been operating at prolonged high speed. Should the turbine wheels seize, no harm normally results, provided no attempt is made to turn the engine over until it has cooled sufficiently to free the wheels. In spite of this, every effort should be made to avoid seizure.

To ensure that fuel remains in the lines and that the engine-driven fuel pumps are not starved for fuel that lubricates the pumps, the aircraft fuel boost pump must be turned off after, not before, the throttle or the fuel shutoff lever is placed in the OFF position.

Generally, an engine should not be shut down by the fuel shutoff lever until after the aircraft throttle has been retarded to idle. Because the fuel shutoff valve is located on the fuel control discharge, a shutdown from high thrust settings results in high fuel pressures within the control that can harm the fuel system parts.

When an accurate reading of the oil level in the oil tank is needed following an engine shutdown, the engine should be operated and shut down with the oil check taking place within not more than 30 minutes after shutdown. Check the engine manuals for the specific procedure.

Troubleshooting Turbine Engines

Included in this section are typical guidelines for locating engine malfunctions on most turbine engines. Since it would be impractical to list all the malfunctions that could occur, only the most common malfunctions are covered. A thorough knowledge of the engine systems, applied with logical reasoning, solves most problems that may occur.

Figure 10-75 enumerates some malfunctions that may be encountered. Possible causes and suggested actions are given in the adjacent columns. The malfunctions presented herein are solely for the purpose of illustration and should not be construed to have general application. For exact information about a specific engine model, consult the applicable manufacturer's instructions.

Turboprop Operation

Turboprop engine operation is quite similar to that of a turbojet engine, except for the added feature of a propeller. The starting procedure and the various operational features are very much alike. The turboprop chiefly requires attention to engine operating limits, the throttle or power lever setting, and the torquemeter pressure gauge. Although torquemeters indicate only the power being supplied to the propeller and not the equivalent shaft horsepower, torquemeter pressure is approximately proportional to the total power output and, thus, is used as a measure of engine performance. The torquemeter pressure gauge reading during the takeoff engine check is an important value. It is usually necessary to compute the takeoff power in the same manner as is done for a turbojet engine. This computation is to determine the maximum allowable exhaust gas temperature and the torquemeter pressure that a normally functioning engine should produce for the outside, or ambient, air temperature and barometric pressure prevailing at the time.

Troubleshooting Procedures for Turboprop Engines

All test run-ups, inspections, and troubleshooting should be performed in accordance with the applicable engine manufacturer's instructions. In *Figure 10-76*, the troubleshooting procedure for the turboprop reduction gear, torquemeter, and power section are combined because of their inter-relationships. The table includes the principal troubles, together with their probable causes and remedies.

Turbine Engine Calibration & Testing

Some of the most important factors affecting turbine engine life are EGT, engine cycles (a cycle is generally a takeoff and landing) and engine speed. Excess EGT of a few degrees reduces turbine component life. Low EGT materially reduces turbine engine efficiency and thrust. So, to make the engine highly efficient, the exhaust temperatures need to be as high as possible, while maintaining an EGT operating temperature that does not damage the turbine section of the engine. If the engine is operated at excess exhaust temperatures, engine deterioration occurs. Since the EGT temperature is set by the EGT temperature gauge, it is imperative that it is accurate. Excessive engine speed can cause premature engine wear and, if extreme, can cause engine failure.

One older type of calibration test unit used to analyze the turbine engine is the jetcal analyzer. *[Figure 10-77]* A jetcal analyzer is a portable instrument made of aluminum, stainless steel, and plastic. The major components of the analyzer are the thermocouple, rpm, EGT indicator, resistance, and insulation check circuits, as well as the potentiometer, temperature regulators, meters, switches, and all the necessary cables, probes, and adapters for performing all tests.

Turbine Engine Analyzer Uses

Many different types of analyzers are used each with its own function, including onboard systems that use computers to

Indicated Malfunction	Probable Causes	Suggested Action
Engine has low rpm, exhaust gas temperature, and fuel flow when set to expected engine pressure ratio.	• Engine pressure ratio indication has high reading error.	• Check inlet pressure line from probe to transmitter for leaks. • Check engine pressure ratio transmitter and indicator for accuracy.
Engine has high rpm, exhaust gas temperature, and fuel flow when set to expect engine pressure ratio.	• Engine pressure ratio indication has low reading error due to: - Misaligned or cracked turbine discharge probe. - Leak in turbine discharge pressure line from probe to transmitter. - Inaccurate engine pressure ratio transmitter or indicator. - Carbon particles collected in turbine discharge pressure line or restrictor orifices.	• Check probe condition. • Pressure-test turbine discharge pressure line for leaks. • Check engine pressure ratio transmitter and indicator for accuracy.
Engine has high exhaust gas temperature, low rpm, and high fuel flow at all engine pressure ratio settings.	• Possible turbine damage and/or loss of turbine efficiency.	• Confirm indication of turbine damage by: - Checking engine coast-down for abnormal noise and reduced time. - Visually inspect turbine area with strong light.
Note: Engines with damage in turbine section may have tendency to hang up during starting.	• If only exhaust gas temperature is high, other parameters normal, the problem may be thermocouple leads or instrument.	• Re-calibrate exhaust gas temperature instrumentation.
Engine vibrates throughout rpm range, but indicated amplitude reduces as rpm is reduced.	• Turbine damage.	• Check turbine as outlined in preceding item.
Engine vibrates at high rpm and fuel flow when compared to constant engine pressure ratio.	• Damage in compressor section.	• Check compressor section for damage.
Engine vibrates throughout rpm range, but is more pronounced in cruise or idle rpm range.	• Engine-mounted accessory such as constant-speed drive, generator, hydraulic pump, etc.	• Check each component in turn.
No change in power setting parameters, but oil temperature high.	• Engine main bearings.	• Check scavenge oil filters and magnetic plugs.
Engine has higher than normal exhaust gas temperature during takeoff, climb, and cruise. Rpm and fuel flow higher than normal.	• Engine bleed-air valve malfunction. • Turbine discharge pressure probe or line to transmitter leaking.	• Check operation of bleed valve. • Check condition of probe and pressure line to transmitter.
Engine has high exhaust gas temperature at target engine pressure ratio for takeoff.	• Engine out of trim.	• Check engine with jetcal. Re-trim as desired.

Figure 10-75. *Troubleshooting turbojet engines.*

Indicated Malfunction	Probable Causes	Suggested Action
Engine rumbles during starting and at low power cruise conditions.	• Pressurizing and drain valve malfunction.	• Replace pressurizing and drain valves.
	• Cracked air duct.	• Repair or replace duct.
	• Fuel control malfunction.	• Replace fuel control.
Engine rpm hangs up during starting.	• Subzero ambient temperatures.	• If hang-up is due to low ambient temperature, engine usually can be started by turning on fuel booster pump or by positioning start lever to run earlier in the starting cycle.
	• Compressor section damage.	• Check compressor for damage.
	• Turbine section damage.	• Inspect turbine for damage.
High oil temperature.	• Scavenge pump failure.	• Check lubricating system and scavenge pumps.
	• Fuel heater malfunction.	• Replace fuel heater.
High oil consumption.	• Scavenge pump failure.	• Check scavenge pumps.
	• High sump pressure.	• Check sump pressure as outlined in manufacturer's maintenance manual.
	• Gearbox seal leakage.	• Check gearbox seal by pressurizing overboard vent.
Overboard oil loss.	• Can be caused by high airflow through the tank, foaming oil, or unusual amounts of oil returned to the tank through the vent system.	• Check oil for foaming. • Vacuum-check sumps. • Check scavenge pumps.

Figure 10-75. *Troubleshooting turbojet engines (continued).*

test aircraft systems. Depending upon the specific analyzer used, procedures vary somewhat, but the basic test are outlined here. Always refer to the specific instructions associated with the analyzer being used.

Most analyzers may be used to:

1. Functionally check the aircraft EGT system for error, without running the engine or disconnecting the wiring.
2. Check individual thermocouples before placement in a parallel harness.
3. Check each engine thermocouple in a parallel harness for continuity.
4. Check the thermocouples and parallel harness for accuracy.
5. Check the resistance of the EGT circuit.
6. Check the insulation of the EGT circuit for shorts to ground, or for shorts between leads.
7. Check EGT indicators , either in or out of the aircraft, for error.
8. Determine engine rpm accuracy during engine testing. Added to this is the checking and troubleshooting of the aircraft tachometer system.
9. Establish the proper relationship between the EGT and engine rpm during engine run-up.

Analyzer Safety Precautions

Observe the following safety precautions while operating the engine analyzer or other types of test equipment:

1. Never use a voltammeter to check the potentiometer for continuity. If a voltammeter is used, damage to the galvanometer and standard battery cell results.
2. Check the thermocouple harness before engine run-up. This must be done because the circuit must be correct before the thermocouples can be used for true EGT pickup.
3. For safety, ground the jetcal analyzer when using an AC power supply. Any electrical equipment operated on AC power and utilizing wire-wound coils, such as the probes with the jetcal analyzer, has an induced voltage on the case that can be discharged if the equipment is not grounded. This condition is not apparent during dry weather, but on damp days the operator can be shocked slightly. Therefore, for the operator's protection, the jetcal analyzer should be grounded using the pigtail lead in the power inlet cable.
4. Use heater probes designed for use on the engine

Trouble	Probable causes	Remedy
Power unit fails to turn over during attempted start.	• No air to starter.	• Check started air valve solenoid and air supply.
	• Propeller brake locked.	• Unlock brake by turning propeller by hand in direction of normal rotation.
Power unit fails to start.	• Starter speed low because of inadequate air supply to starter.	• Check starter air valve solenoid and air supply.
	• If fuel is not observed leaving the exhaust pipe during start, fuel selector valve may be inoperative because of low power supply or may be locked in "OFF."	• Check power supply or electrically operated valves. Replace valves if defective.
	• Fuel pump inoperative.	• Check pump for sheared drives or internal damage. Check for air leaks at outlet.
	• Aircraft fuel filter dirty.	• Clean filter and replace filtering elements if necessary.
	• Fuel control cutoff valve closed.	• Check electrical circuit to ensure that actuator is being energized. Replace actuator or control.
Engine fires, but will not accelerate to correct speed.	• Insufficient fuel supply to control unit.	• Check fuel system to ensure all valves are open and pumps are operative.
	• Fuel control main metering valve sticking.	• Flush system. Replace control.
	• Fuel control bypass valve sticking open.	• Flush system. Replace control.
	• Drain valve stuck open. Starting fuel enrichment pressure switch setting too high.	• Replace drain valve. Replace pressure switch.
Acceleration temperature too high during starting.	• Fuel control bypass valve sticking closed.	• Flush system. Replace control.
	• Fuel control acceleration cam incorrectly adjusted.	• Replace control.
	• Defective fuel nozzle.	• Replace nozzle with a known satisfactory unit.
	• Fuel control thermostat failure.	• Replace control.
Acceleration temperature during starting too low.	• Acceleration cam of fuel control incorrectly adjusted.	• Replace control.
Engine speed cycles after start.	• Unstable fuel control governor operation.	• Continue engine operation to allow control to condition itself.
Power unit oil pressure drops off severely.	• Oil supply low.	• Check oil supply and refill as necessary.
	• Oil pressure transmitter or indicator giving false indication.	• Check transmitter or indicator and repair or replace if necessary.
Oil leakage at accessory drive seals.	• Seal failure.	• Replace seal or seals.
Engine unable to reach maximum controlled speed of 100 percent.	• Faulty propeller governor.	• Replace propeller control assembly.
	• Faulty fuel control or air sensing tip.	• Replace faulty control. If dirty, use air pressure in reverse direction of normal flow through internal engine passage and sensing tip.
Vibration indication high.	• Vibration pickup or vibration meter malfunction.	• Calibrate vibration meter. • Start engine and increase power gradually. • Observe vibration indicator. If indications prove pickup to be at fault, replace it. If high vibration remains as originally observed, remove power unit for overhaul.

Figure 10-76. *Troubleshooting turboprop engines.*

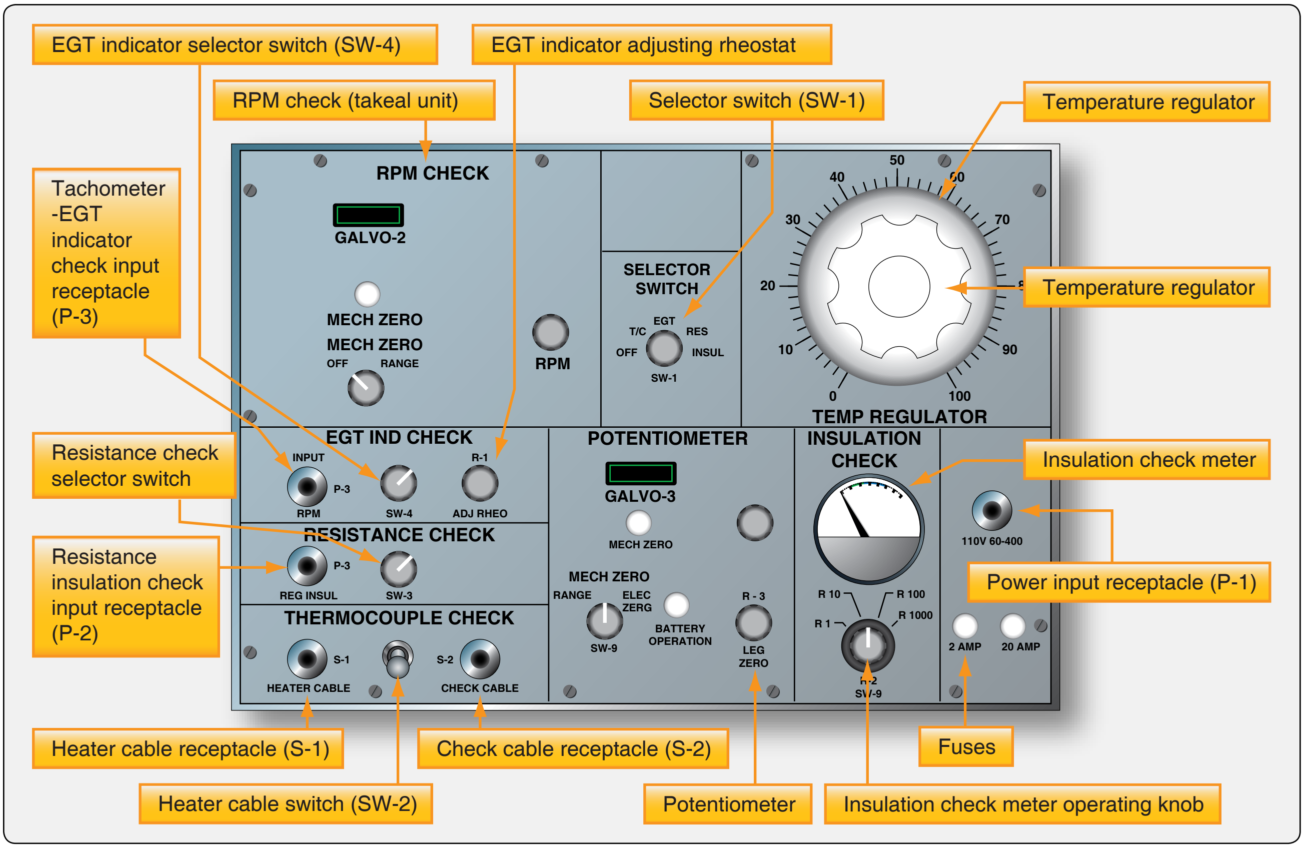


Figure 10-77. *Jetcal analyzer instrument compartment.*

thermocouples to be tested. Temperature gradients are very critical in the design of heater probes. Each type of aircraft thermocouple has its own specially designed probe. Never attempt to modify heater probes to test other types of thermocouples.

5. Do not leave heater probe assemblies in the exhaust nozzle during engine run-up.
6. Never allow the heater probes to go over 900 °C (1,652 °F). Exceeding these temperatures results in damage to the jetcal analyzer and heater probe assemblies.

Continuity Check of Aircraft EGT Circuit

To eliminate any error caused by one or more inoperative aircraft thermocouples, a continuity check is performed. The check is made by heating one heater probe to between 500 and 700 °C and placing the hot probe over each of the aircraft thermocouples, one at a time. The EGT indicator must show a temperature rise as each thermocouple is checked. When large numbers (eight or more) of thermocouples are used in the harness, it is difficult to see a rise on the aircraft instrument because of the electrical characteristics of a parallel circuit. Therefore, the temperature indication of the aircraft thermocouples is read on the potentiometer of the analyzer by using the check cable and necessary adapter.

Functional Check of Aircraft EGT Circuit

During the EGT system functional test and the thermocouple harness checks, the analyzer has a specific degree of accuracy at the test temperature, which is usually the maximum operating temperature of the turbine engine. *[Figure 10-78]* Each engine has its own maximum operating temperature, that can be found in applicable technical instructions.

The test is made by heating the engine thermocouples in the exhaust nozzle or turbine section to the engine test temperature. The heat is supplied by heater probes through the necessary cables. With the engine thermocouples hot, their temperature is registered on the aircraft EGT indicator. At the same time, the thermocouples embedded in the heater probes, which are completely isolated from the aircraft system, are picking up and registering the same temperature on the test analyzer.

The temperature registered on the aircraft EGT indicator should be within the specified tolerance of the aircraft system and the temperature reading on the temperature analyzer. When the temperature difference exceeds the allowable tolerance, troubleshoot the aircraft system.

Figure 10-78. *EGT analyzer.*

EGT Indicator Check

The EGT indicator is tested after being removed from the aircraft instrument panel and disconnected from the aircraft EGT circuit leads. Attach the instrument cable and EGT indicator adapter leads to the indicator terminals and place the indicator in its normal operating position. Adjust the analyzer switches to the proper settings. The indicator reading should correspond to the readings of the analyzer within the allowable limits of the EGT indicator.

Correction for ambient temperature is not required for this test, as both the EGT indicator and analyzer are temperature compensated. The temperature registered on the aircraft EGT indicator should be within the specified tolerance of the aircraft system and the temperature reading on the analyzer readout. When the temperature difference exceeds the allowable tolerance, troubleshoot the aircraft system.

Resistance & Insulation Check

The thermocouple harness continuity is checked while the EGT system is being checked functionally. The resistance of the thermocouple harness is held to very close tolerances, since a change in resistance changes the amount of current flow in the circuit. A change of resistance gives erroneous temperature readings. The resistance and insulation check circuits make it possible to analyze and isolate any error in the aircraft system. How the resistance and insulation circuits are used is discussed with troubleshooting procedures.

Tachometer Check

To read engine speed with an accuracy of ±0.1 percent during engine run, the frequency of the tachometer-generator (older style) is measured by the rpm check analyzer. The scale of the rpm check circuit is calibrated in percent rpm to correspond to the aircraft tachometer indicator, which also reads in percent rpm. The aircraft tachometer and the rpm check circuit are connected in parallel, and both are indicating during engine run-up. The rpm check circuit readings can be compared with the readings of the aircraft tachometer to determine the accuracy of the aircraft instrument.

Many newer engines use a magnetic pickup that counts passing gear teeth edges, which are seen electrically as pulses of electrical power as they pass by the pickup. *[Figure 10-79]* By counting the amount of pulses, the rpm of the shaft is obtained. This type of system requires little maintenance, other than setting the clearance between the gear teeth and the magnetic pickup.

Troubleshooting EGT System

An appropriate analyzer is used to test and troubleshoot the aircraft thermocouple system at the first indication of trouble, or during periodic maintenance checks.

The test circuits of the analyzer make it possible to isolate the troubles listed below. Following the list is a discussion of each trouble mentioned.

1. One or more inoperative thermocouples in engine parallel harness.
2. Engine thermocouples out of calibration.
3. EGT indicator error.
4. Resistance of circuit out of tolerance.
5. Shorts to ground.
6. Shorts between leads.

One or More Inoperative Thermocouples in Engine Parallel Harness

This error is found in the regular testing of aircraft thermocouples with a hot heater probe and is a broken lead wire in the parallel harness, or a short to ground in the harness. In the latter case, the current from the grounded thermocouple can leak off and never be shown on the indicator. However, this grounded condition can be found by using the insulation resistance check.

Engine Thermocouples Out of Calibration

When thermocouples are subjected for a period of time to oxidizing atmospheres, such as encountered in turbine engines, they drift appreciably from their original calibration. On engine parallel harnesses, when individual thermocouples can be removed, these thermocouples can be bench-checked, using one heater probe. The temperature reading obtained from the thermocouples should be within manufacturer's tolerances.

Figure 10-79. *Magnetic pickup and gear.*

EGT Circuit Error

This error is found by using the EGT and comparing the reading of the aircraft EGT indicator with the analyzer temperature reading. *[Figure 10-78]* The analyzer and aircraft temperature readings are then compared.

Resistance of Circuit Out of Tolerance

The engine thermocouple circuit resistance is a very important adjustment since a high-resistance condition gives a low indication on the aircraft EGT indicator. This condition is dangerous, because the engine is operating with excess temperature, but the high resistance makes the indicator read low. It is important to check and correct this condition.

Shorts to Ground/Shorts Between Leads

These errors are found by doing the insulation check using an ohmmeter. Resistance values from zero to 550,000 ohms can be read on the insulation check ohmmeter by selecting the proper range.

Troubleshooting Aircraft Tachometer System

A function of the rpm check is troubleshooting the aircraft tachometer system. The rpm check circuit in the analyzer is used to read engine speed during engine run-up with an accuracy of ±0.1 percent. The connections for the rpm check are the instrument cable and aircraft tachometer system lead to the tachometer indicator. After the connections have been made between the analyzer rpm check circuit and the aircraft tachometer circuit, the two circuits, now classed as one, are a parallel circuit. The engine is then run-up as prescribed in applicable technical instructions. Both systems can be read simultaneously.

If the difference between the readings of the aircraft tachometer indicator and the analyzer rpm check circuit exceeds the tolerance prescribed in applicable technical instructions, the engine must be stopped, and the trouble located and corrected.