A&P TEST READY

VOLUME 3

THE STUDY GUIDE

POWERPLANT

Reciprocating · Turbine · Engine Systems



FAA Aviation Mechanic Written Test

Complete ACS knowledge coverage · Worked examples · Glossary & Index

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Contents

Copyright and Credits **8**

How to Use This Book **9**

ACS Coverage Map 9

Chapter 1. Reciprocating Engines **18**

1.1 Internal Combustion Engine Principles 18
1.2 Types of Reciprocating Engines 20
1.3 The Four-Stroke Cycle and Valve Timing 22
1.4 Horizontally Opposed Engine Construction 27
1.5 Radial Engine Construction 30
1.6 Reciprocating Engine Performance 31
1.7 Reciprocating Engine Maintenance and Inspection 37
1.8 Ground Operation 41
1.9 Storage and Preservation 42
1.10 Diesel Engine Principles 44
1.11 Chapter Review 45

Chapter 2. Turbine Engines **48**

2.1 Turbine Engine Operating Principles 49
2.2 Types of Turbine Engines 53
2.3 Turbine Engine Construction 56
2.4 Turbine Engine Performance and Monitoring 61
2.5 Causes of Turbine Performance Loss 63
2.6 Bleed Air Systems 64
2.7 Turbine Troubleshooting, Maintenance and Inspection 64
2.8 Turbine Engine Adjustment and Testing 65
2.9 Procedures After Turbine Engine Installation 67
2.10 Turbine Engine Storage and Preservation 67
2.11 Auxiliary Power Units 68
2.12 Chapter Review 70

Chapter 3. Lubrication Systems **73**

3.1 Engine Oil: Types, Grades and Uses 74
3.2 Lubrication System Operation and Components 76

SAMPLE

3.3 Wet-Sump Systems 79
3.4 Dry-Sump Systems 80
3.5 Chip Detectors 82
3.6 Maintenance, Inspection, Servicing and Analysis 83
3.7 Excessive Oil Consumption 85
3.8 Chapter Review 87

Chapter 4. Ignition and Starting Systems 90
4.1 Ignition System Theory 90
4.2 Magneto Components and Operation 91
4.3 The Three Circuits of a Magneto 94
4.4 Shower of Sparks and Impulse Coupling 95
4.5 Spark Plug Theory 97
4.6 Magneto Timing and Harness Inspection 100
4.7 Solid-State and Digital Ignition 102
4.8 Turbine Engine Ignition Systems 103
4.9 Engine Starters 104
4.10 Chapter Review 106

Chapter 5. Engine Fuel and Fuel Metering Systems 109
5.1 Fuel/Air Ratio and Carburetor Theory 110
5.2 Float Carburetors 112
5.3 Pressure Carburetors 114
5.4 Continuous-Flow Fuel Injection 115
5.5 Engine Fuel System Operation and Components 118
5.6 Turbine Fuel Metering and Hydromechanical Controls 121
5.7 Digital Engine Control (FADEC) 122
5.8 Fuel Nozzles and Manifolds 123
5.9 Fuel System Inspection 124
5.10 Chapter Review 125

Chapter 6. Reciprocating Engine Induction and Cooling Systems 127
6.1 Induction System Theory and Components 127
6.2 Induction System Filtering 128
6.3 Induction System Icing 129
6.4 Carburetor Heaters 131
6.5 Superchargers 132
6.6 Turbochargers, Intercoolers and Controls 133

SAMPLE

6.7 Pressure Cowling and Airflow Control 136
6.8 Baffle and Seal Installation 137
6.9 Augmenter Cooling 138
6.10 Liquid Cooling Systems 139
6.11 Chapter Review 141

Chapter 7. Turbine Engine Air Systems 143
7.1 Turbine Engine Cooling Theory 143
7.2 Turbine Engine Cowling Airflow 143
7.3 Turbine Engine Internal Cooling 144
7.4 Turbine Engine Baffles and Seals 145
7.5 Insulation Blankets and Shrouds 146
7.6 Turbine Engine Induction Systems 146
7.7 Turbine Engine Bleed Air Systems 148
7.8 Turbine Engine Anti-Ice Systems 149
7.9 Chapter Review 151

Chapter 8. Engine Exhaust and Reverser Systems 153
8.1 Reciprocating Engine Exhaust Systems 153
8.2 Turbine Engine Exhaust Systems 155
8.3 Noise Suppression 156
8.4 Thrust Reversers 157
8.5 Chapter Review 160

Chapter 9. Engine Instrument Systems 162
9.1 Range Markings and Instrument Condition 162
9.2 Pressure Indication 164
9.3 Temperature Indication 166
9.4 Engine Speed Indication 168
9.5 Fuel Flow Indication 170
9.6 Torquemeters 170
9.7 Engine Pressure Ratio 172
9.8 Annunciator Systems 172
9.9 EICAS and ECAM 173
9.10 FADEC as an Indicating System 174
9.11 Chapter Review 175

Chapter 10. Engine Fire Protection Systems 177
10.1 Types of Fires and Engine Fire Zones 177

SAMPLE

10.2 Fire Detection System Operation 179
10.3 Fire Detection System Maintenance and Inspection 181
10.4 Fire Extinguishing Agents and Systems 182
10.5 Fire Extinguishing System Maintenance and Inspection 186
10.6 Chapter Review 187

Chapter 11. Engine Electrical Systems 189
11.1 Generators 189
11.2 Alternators 191
11.3 Starter-Generators 191
11.4 Voltage Regulators and Overvoltage and Overcurrent Protection 192
11.5 DC and AC Generation Systems 193
11.6 Constant-Speed Drives and Integrated Drive Generators 194
11.7 Paralleling Dual Generators 195
11.8 Finding the Correct Wire Size 195
11.9 Engine Wiring, Switches and Protective Devices 198
11.10 Chapter Review 199

Chapter 12. Engine Inspection 201
12.1 Inspection Requirements Under Parts 43 and 91 201
12.2 Life-Limited Parts 203
12.3 Special Inspections 204
12.4 FAA-Approved Data 204
12.5 SLs, SBs, ICAs, ADs and TCDSs 205
12.6 Maintenance Records (Part 43) 206
12.7 Inspecting, Checking and Servicing Engine Components 207
12.8 Engine Mounts 209
12.9 Chapter Review 210

Chapter 13. Propellers 212
13.1 Propeller Theory 213
13.2 Propeller Types and Blade Design 215
13.3 Pitch Control and Adjustment 216
13.4 Constant-Speed Propellers and Governors 217
13.5 Turbine Engine Propellers: Reverse and Beta 220
13.6 Servicing and Inspection 221
13.7 Removal and Installation 222
13.8 Propeller Type Certificate Data Sheet 223

SAMPLE

13.9 Propeller Synchronization 223
13.10 Propeller Ice Control 224
13.11 Chapter Review 224

Definitions and Abbreviations 226

Glossary 227

References 233

Index 234

SAMPLE

ACS code	Knowledge element	Section(s)
	Turbine engine exhaust system theory, components, operation, and inspection.	
AM.III.L.K3	Noise suppression theory, components, and operation (e.g., mufflers, hush kits, augmenter tubes).	8.3
AM.III.L.K4	Thrust reverser theory, components, and operation.	8.4
AM.III.M.K1	Propeller theory and operation.	13.1
AM.III.M.K2	Types of propellers and blade design.	13.2
AM.III.M.K3	Pitch control and adjustment.	13.3
AM.III.M.K4	Constant speed propeller and governor theory and operation.	13.4
AM.III.M.K5	Turbine engine propeller reverse/beta range operation.	13.5
AM.III.M.K6	Propeller servicing, maintenance, and inspection requirements.	13.6
AM.III.M.K7	Procedures for removal and installation of a propeller.	13.7
AM.III.M.K8	Propeller TCDS.	13.8
AM.III.M.K9	Propeller synchronization systems.	13.9
AM.III.M.K10	Propeller ice control systems.	13.10

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Chapter 1. Reciprocating Engines

CHAPTER OBJECTIVES

Learning objectives. After studying this chapter you should be able to:

1. Classify reciprocating engines by cylinder arrangement, cooling method and operating cycle.
2. Explain the four-stroke cycle, valve timing, lead, lag and valve overlap.
3. Name the internal parts of opposed and radial engines and state what each does.
4. Calculate displacement, compression ratio, horsepower (PLANK) and specific fuel consumption.
5. Describe the inspections, checks and ground-run procedures a technician performs, including the differential compression test.
6. Describe the storage and preservation categories and the materials used.
7. Compare spark-ignition and diesel (compression-ignition) aircraft engines.

ACS reference: AM.III.A (Reciprocating Engines). **Kit practice topic:** REC.

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The reciprocating engine is still the heart of general aviation. It turns the chemical energy of fuel into heat, the heat into gas pressure, and the pressure into rotation of a crankshaft. This chapter starts with the physics, builds up to the parts you will handle on the hangar floor, and finishes with the checks, ground runs and storage procedures that the written test asks about. Later chapters cover the systems that feed and support the engine: lubrication (Chapter 3), ignition (Chapter 4), fuel metering (Chapter 5) and induction and cooling (Chapter 6).

1.1 Internal Combustion Engine Principles

ACS: AM.III.A.K3

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Heat engines

Every aircraft engine is a **heat engine**: it converts heat energy into mechanical work. In an *internal combustion* engine the fuel burns inside the engine itself, and the hot gas acts directly on a moving part. In a reciprocating engine that part is a piston moving back and forth in a cylinder; in a turbine engine (Chapter 2) it is a set of rotating blades.

Three gas laws explain what happens inside the cylinder:

- **Boyle's law.** At constant temperature, the volume of a gas varies inversely with its pressure. Squeezing the charge on the compression stroke raises its pressure.
- **Charles' law.** At constant pressure, volume varies directly with absolute temperature. Heating the gas makes it try to expand.
- **The general gas law** combines them: $\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$. When the mixture burns at almost constant volume near top center, its temperature, and therefore its pressure, rises sharply. That pressure pushes the piston down.

Energy conversion and efficiency

Only part of the fuel's heat becomes useful work. The rest leaves through the exhaust, the cooling air and the oil. **Thermal efficiency** is the ratio of work done to the heat energy in the fuel burned. A typical aircraft piston engine has a thermal efficiency of roughly 25 to 30 percent. Raising the compression ratio raises thermal efficiency, which is why compression ratio is limited mainly by the fuel's resistance to detonation.

Operating cycles

An engine *cycle* is the series of events that repeats for each power impulse. Aircraft engines have used four cycles:

Table 1-1. Engine operating cycles.

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Cycle	How it works	Aviation use
Four-stroke (Otto)	Intake, compression, power, exhaust; 2 crank revolutions per cycle	Almost all certificated piston engines
Two-stroke	Intake and exhaust overlap the end of the power stroke; 1 revolution per cycle	Ultralights, some light-sport and UAV engines
Rotary (Wankel)	A triangular rotor in an epitrochoid housing	Few; some experimental and UAV
Diesel (compression ignition)	Air only is compressed; fuel ignites from heat of compression	Growing use with Jet-A (Section 1.10)

1.2 Types of Reciprocating Engines

ACS: AM.III.A.K1

Reciprocating engines are classified by how the cylinders are arranged around the crankshaft (Figure 1-1), how they are cooled (air or liquid), and how they are aspirated (normally aspirated, supercharged or turbocharged).

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Reciprocating engine cylinder arrangements FAA-H-8083-32B Ch. 1

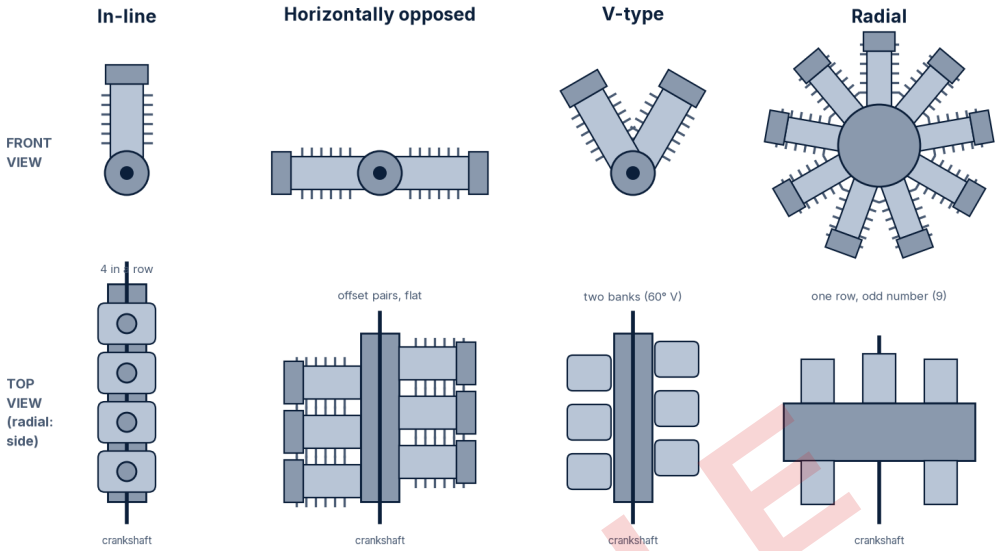


Figure 1-1. Cylinder arrangements. Horizontally opposed engines dominate light aircraft because they are flat, smooth and easy to cowl. Radials put every cylinder in the cooling airflow. In-line and V engines have a small frontal area.

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- **In-line.** Cylinders in one row along the crankshaft. Usually an even number. Small frontal area, but long and heavy for the power, and the rear cylinders are hard to air-cool. Many in-line aircraft engines were *inverted* (cylinders below the crankshaft) for better visibility over the nose.
- **V-type.** Two in-line banks set at an angle, usually 60° or 90°, sharing one crankshaft. Most were liquid-cooled (for example, the Merlin).
- **Horizontally opposed.** Two banks of cylinders 180° apart, flat on each side of the crankcase. Four- and six-cylinder versions power most of today's piston fleet. The arrangement is compact, well balanced and has a low profile.
- **Radial.** One or more rows of cylinders arranged around a central crankcase like spokes. Each row has an *odd* number of cylinders so that a firing order of every other cylinder gives evenly spaced power impulses. Multi-row radials have two (or more) rows with the rear cylinders staggered behind the gaps of the front row.

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Rule. A single-row radial always has an odd number of cylinders. That is what lets it fire alternate cylinders (1-3-5-7-9-2-4-6-8) with a power impulse every 80° of crankshaft rotation in a nine-cylinder engine (720° ÷ 9).

1.3 The Four-Stroke Cycle and Valve Timing

ACS: AM.III.A.K2

Five events, four strokes

A **stroke** is one movement of the piston from **top dead center** (TDC) to **bottom dead center** (BDC) or back. The four-stroke cycle contains five events (intake, compression, ignition, power and exhaust) in four strokes and two complete crankshaft revolutions (Figure 1-2).

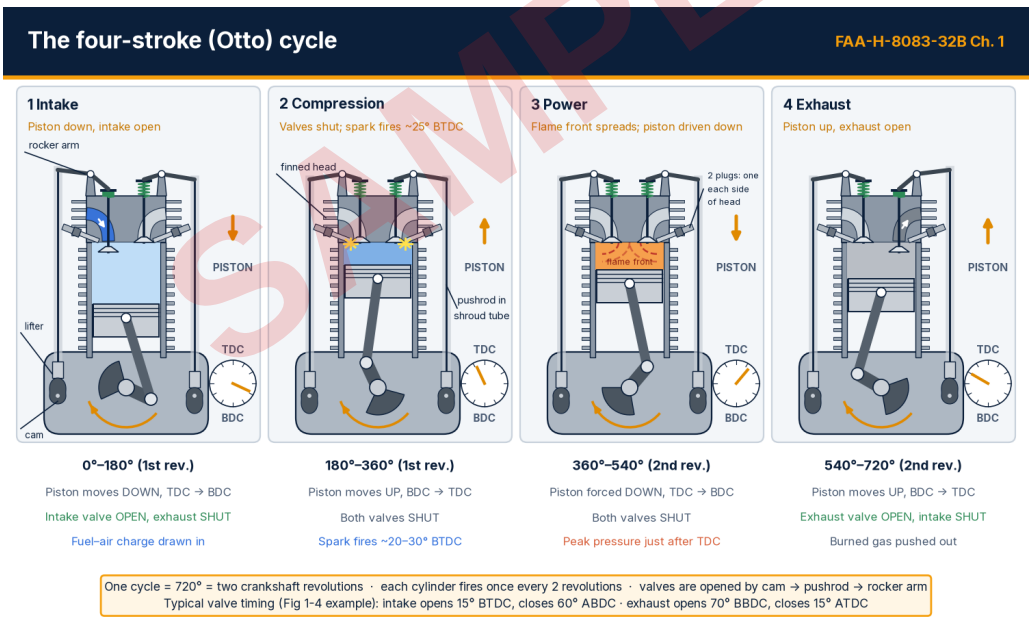


Figure 1-2. The four strokes, drawn with the crank, rod and piston to scale. Each cylinder fires once every two revolutions (720°).

1. **Intake.** The piston moves down with the intake valve open. Atmospheric (or manifold) pressure pushes the fuel–air charge into the cylinder.

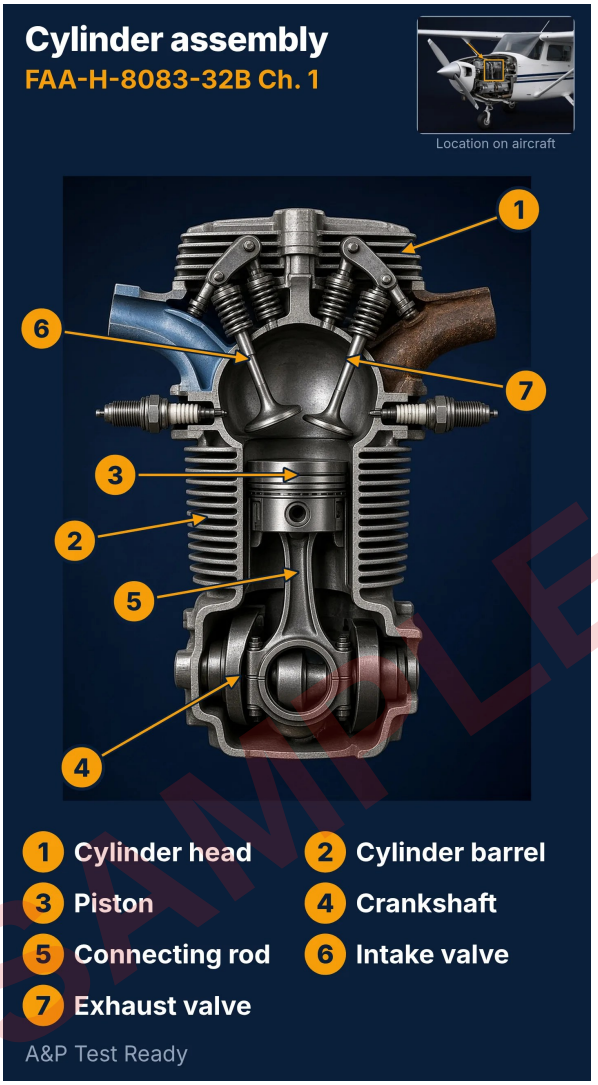
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2. **Compression.** Both valves close and the piston moves up, compressing the charge to a fraction of its volume.
3. **Ignition and power.** The spark plugs fire *before* TDC, typically 20° to 30° BTDC on many engines, so that the flame front has time to build peak pressure just after TDC. The expanding gas drives the piston down. This is the only stroke that delivers work.
4. **Exhaust.** The exhaust valve opens and the rising piston pushes the burned gas out.

The kit's cylinder illustration (Figure 1-3) shows the parts that make this happen.

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Figure 1-3. A cylinder assembly cutaway from the A&P Test Ready Powerplant kit: head, barrel, piston, connecting rod, crankshaft and the intake and exhaust valves.

Valve timing: lead, lag and overlap

If valves opened and closed exactly at TDC and BDC, the engine would breathe poorly. Gases have mass, so they take time to start and stop moving. Valves therefore open early (*lead*) and close late (*lag*), as shown in Figure 1-4.

- **Valve lead**: opening a valve before the piston reaches dead center. The exhaust valve opens well before BDC on the power stroke (typically 60° to 70°), giving up a little expansion to get the exhaust moving.
- **Valve lag**: closing a valve after dead center. The intake valve closes well after BDC (often 50° to 60°), so the inertia of the incoming charge keeps filling the cylinder even as the piston starts up.
- **Valve overlap**: the period around TDC at the end of exhaust and start of intake when *both* valves are open. The outgoing exhaust draws in fresh charge and scavenges the cylinder.

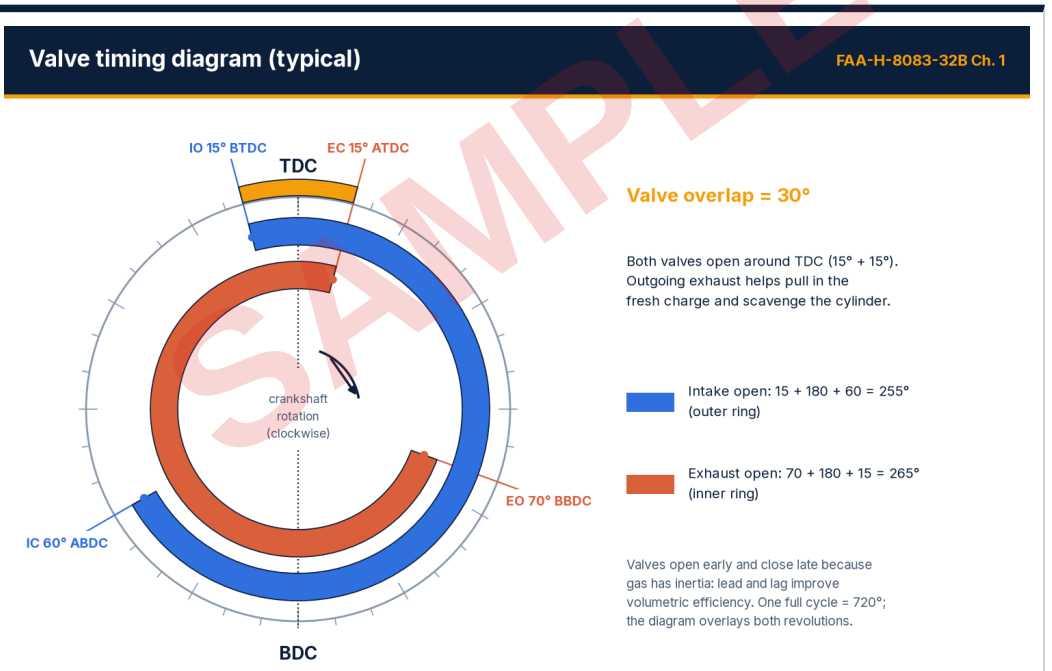


Figure 1-4. A typical valve timing diagram using example values (actual timing varies by engine; always use the manufacturer's data). The intake valve opens 15° BTDC and closes 60° ABDC; the exhaust valve opens 70° BBDC and closes 15° ATDC. Overlap is 30°.

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WORKED EXAMPLE

Worked Example 1-1. Valve overlap and duration. An engine's timing is: intake opens 20° BTDC, intake closes 55° ABDC, exhaust opens 65° BBDC, exhaust closes 12° ATDC. Find the overlap and how many degrees each valve stays open.

Overlap = IO before TDC + EC after TDC
= 20° + 12°
= 32°

Intake duration = 20° + 180° + 55°
= 255°

Exhaust duration = 65° + 180° + 12°
= 257°

Overlap is **32°**; the intake is open **255°** and the exhaust **257°** of crankshaft travel.

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The valve operating mechanism

Valves are opened by a *cam* and closed by springs (Figure 1-5). In an opposed engine one camshaft, gear-driven from the crankshaft at **one-half crankshaft speed**, operates every valve through a lifter (tappet), pushrod and rocker arm. Most modern opposed engines use **hydraulic lifters**, which fill with engine oil and take up all clearance so the valve train runs at zero lash.

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Valve operating mechanism (one cylinder, section) FAA-H-8083-32B Ch. 1

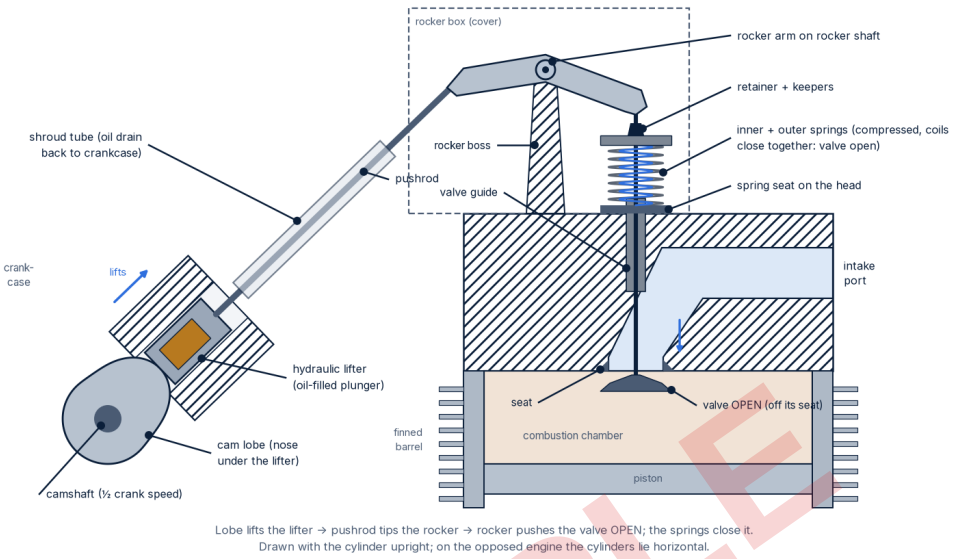


Figure 1-5. The valve operating mechanism: cam lobe, lifter, pushrod, rocker arm, valve springs and valve.

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Two or three concentric valve springs wound in opposite directions are used on each valve. They prevent *valve float* and surge, and if one spring breaks the others still close the valve.

> **Rule.** The camshaft (or cam ring drive) turns at half crankshaft speed in an opposed engine because each valve opens once per cycle, which is two crankshaft revolutions.

1.4 Horizontally Opposed Engine Construction

ACS: AM.III.A.K4

Crankcase

The crankcase is the engine's backbone. It supports the crankshaft and camshaft, carries the cylinders, contains the oil and forms the mounting points. Opposed-

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engine cases are two aluminum-alloy castings split vertically on the centerline and held together with through-bolts and studs. Cases must not be "mixed and matched"; the halves are machined as a set.

Crankshaft

The **crankshaft** turns the reciprocating motion of the pistons into rotation. Its parts are the *main journals* (which ride in the main bearings), the *crankpins* (rod journals), and the *crank cheeks* (webs) that join them. Crankpins are often hollow; they lighten the shaft, carry oil, and act as *sludge chambers* that collect heavy contaminants by centrifugal force.

Every power impulse twists the crankshaft. To keep these torsional vibrations from building up at certain RPMs, many engines carry **dynamic dampers**: pendulum-type counterweights loosely pinned to the crank cheek. They swing opposite to the vibration and absorb it. Static counterweights, by contrast, simply balance the mass of the throws.

Connecting rods

Rods link piston and crankpin. Opposed engines use *plain* rods with a split big end and a bearing insert. The piston end holds a bronze bushing for the piston pin.

Pistons and rings

Pistons are forged or cast aluminum alloy. They carry:

- **Compression rings** at the top, which seal combustion pressure.
- **Oil control rings** in the middle groove, which regulate the oil film on the cylinder wall; oil drains back through holes in the ring groove.
- **Oil scraper (wiper) ring** at the bottom of the skirt on some pistons, which moves oil toward or away from the rings depending on how it is installed.

The **piston pin** (wrist pin) is usually *full-floating*: it is free to turn in both the rod bushing and the piston bosses, and aluminum or bronze end plugs keep it from scoring the cylinder wall.

Cylinders

A cylinder is a steel barrel screwed and shrunk into an aluminum head. The barrel is often **choke bored**: its bore is slightly smaller at the top than at the bot-

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tom. In operation the head end runs hotter and expands more, so at operating temperature the bore becomes nearly straight. Barrel walls are hardened by *nitriding* or plated with *chrome* (porous chrome holds oil). Never use chrome-plated rings in a chrome barrel.

The head contains the combustion chamber, the spark plug bushings (two per cylinder in certificated engines, for dual ignition), valve guides, and hardened valve seats. Fins on the head and barrel give the cooling area (Chapter 6).

Valves

The intake valve has a flat or tulip head. The exhaust valve runs much hotter, so it often has a hollow stem partly filled with *metallic sodium*. The sodium melts and sloshes, carrying heat from the head to the stem and guide. Valve faces are often coated with *Stellite*, a hard alloy, and ground at 30° or 45°. Sodium-filled valves must never be cut open or discarded in household waste, because sodium reacts violently with water.

Bearings

Table 1-2. Bearings and the loads they carry.

Bearing type	Load it carries	Typical use
Plain (sleeve) insert	Radial loads	Main bearings, connecting rods, cam
Ball	Radial and thrust	Propeller thrust bearing in radials, accessories
Roller	Heavy radial loads; tapered rollers also take thrust	Radial-engine main bearings, turbine engines

EXAM TRAP

- *Choke bore direction.* The bore is **smaller at the top** (head end) when cold, not larger.
- *Camshaft speed.* Half crankshaft speed, not double.
- *Dynamic dampers* reduce **torsional vibration**, not static imbalance.
- *Sodium valves* are **exhaust** valves.

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1.5 Radial Engine Construction

ACS: AM.III.A.K5

A radial engine's crankshaft has one throw per row. All the pistons in a row drive that throw through a single **master rod**, with the other cylinders' **articulating rods** (link rods) pinned to the master rod's flange by *knuckle pins*. The master rod's cylinder is usually cylinder number 1.

Valves are opened by a *cam ring* (cam plate) concentric with the crankshaft, not a camshaft. The cam ring speed depends on how many lobes it has:

$$\text{Cam ring speed} = \frac{1}{2 \times \text{number of lobes}} \times \text{crankshaft speed}$$

A nine-cylinder engine with a four-lobe ring turns it at $\frac{1}{8}$ **crankshaft speed, opposite** crankshaft rotation. A five-lobe ring turns at $\frac{1}{10}$ **crankshaft speed in the same direction**.

Radials are numbered clockwise as viewed from the rear (the anti-propeller end), with number 1 at the top. A *propeller reduction gear* and a *ball thrust bearing* in the nose section carry propeller loads. The *diffuser section* behind the crankcase holds the supercharger impeller on most large radials.

SAMPLE

Firing orders to memorize — Numbering is set by the manufacturer

Lycoming 4-cyl opposed	1-3-2-4
Continental 6-cyl opposed	1-6-3-2-5-4
9-cyl radial	1-3-5-7-9-2-4-6-8
14-cyl twin-row radial	+9, −5 rule: 1-10-5-14-9-4-13-8-3-12-7-2-11-6
18-cyl twin-row radial	+11, −7 rule: 1-12-5-16-9-2-13-6-17-10-3-14-7-18-11-4-15-8

Figure 1-6. Firing orders that appear on the test. Odd-numbered cylinders fire first in a single-row radial. Twin-row radials use a "plus-minus" rule: add 9 and subtract 5 for a 14-cylinder; add 11 and subtract 7 for an 18-cylinder.

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Hydraulic lock

When a radial engine sits, oil drains past the rings of the lower cylinders and into the lower intake pipes (Figure 1-7). If the engine is started with liquid in a combustion chamber, the piston cannot compress it, and a connecting rod bends or a cylinder cracks. Before starting a radial that has been sitting, pull the propeller through by hand (with the ignition off) at least two complete revolutions. If you feel the prop lock up, **do not force it**. Remove a spark plug from the lower cylinders and drain the oil.

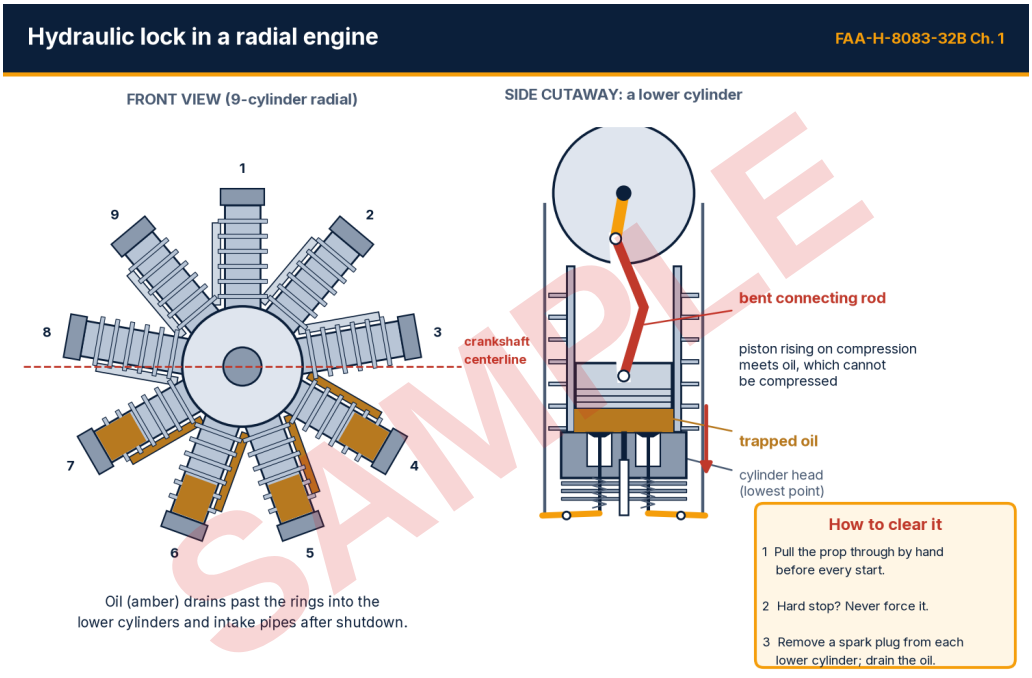


Figure 1-7. Hydraulic lock. Oil collects in the cylinders below the crankshaft centerline.

1.6 Reciprocating Engine Performance

ACS: AM.III.A.K7

Work, power and horsepower

Work is force times distance (foot-pounds). *Power* is work per unit time. One **horsepower** is 33,000 foot-pounds per minute (550 ft-lb per second), or 746 watts.

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Displacement

Piston displacement is the volume a piston sweeps in one stroke. Total displacement is that volume times the number of cylinders:

$$\text{Displacement} = \text{piston area} \times \text{stroke} \times \text{number of cylinders}$$
$$\text{Piston area} = 0.7854 \times \text{bore}^2$$

WORKED EXAMPLE

Worked Example 1-2. Displacement of a four-cylinder engine. Bore 5.125 in, stroke 4.375 in, four cylinders.

$$\text{Area} = 0.7854 \times 5.125^2$$
$$= 0.7854 \times 26.27 = 20.63 \text{ in}^2$$
$$\text{Per cylinder} = 20.63 \times 4.375 = 90.25 \text{ in}^3$$
$$\text{Total} = 90.25 \times 4 = 361 \text{ in}^3$$

Total displacement is **361 in³**, which is why this engine is called a "360."

SAMPLE

Compression ratio

The **compression ratio** is the total cylinder volume with the piston at BDC divided by the volume with the piston at TDC (the clearance volume), as in Figure 1-8. Higher compression gives more power and better fuel economy but raises the risk of detonation.

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Compression ratio FAA-H-8083-32B Ch. 1

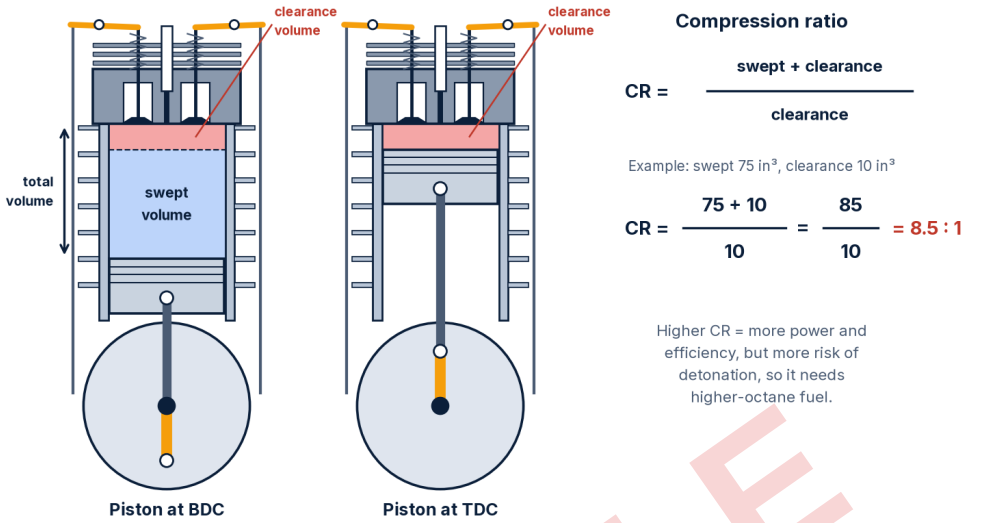


Figure 1-8. Compression ratio drawn to scale for 8.5 : 1.

SAMPLE

WORKED EXAMPLE

Worked Example 1-3. Finding compression ratio. A cylinder has a swept volume of 90 in³ and a clearance volume of 12 in³.

$$\text{Total volume at BDC} = 90 + 12 = 102 \text{ in}^3$$

$$\text{CR} = \frac{102}{12} = 8.5 : 1$$

The compression ratio is **8.5 : 1**.

Trap: dividing swept volume by clearance volume ($\frac{90}{12} = 7.5$) gives the wrong answer. Always add the clearance volume first.

Indicated, brake and friction horsepower

- **Indicated horsepower** (IHP) is the power the burning gas delivers to the pistons. It is found with the PLANK formula (Figure 1-9).
- **Brake horsepower** (BHP) is the power actually delivered at the propeller shaft. It is measured with a dynamometer (historically a *prony brake*).

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- *Friction horsepower* (FHP) is the power used up by internal friction and by driving accessories. BHP = IHP − FHP (Figure 1-10).

The PLANK formula: indicated horsepower

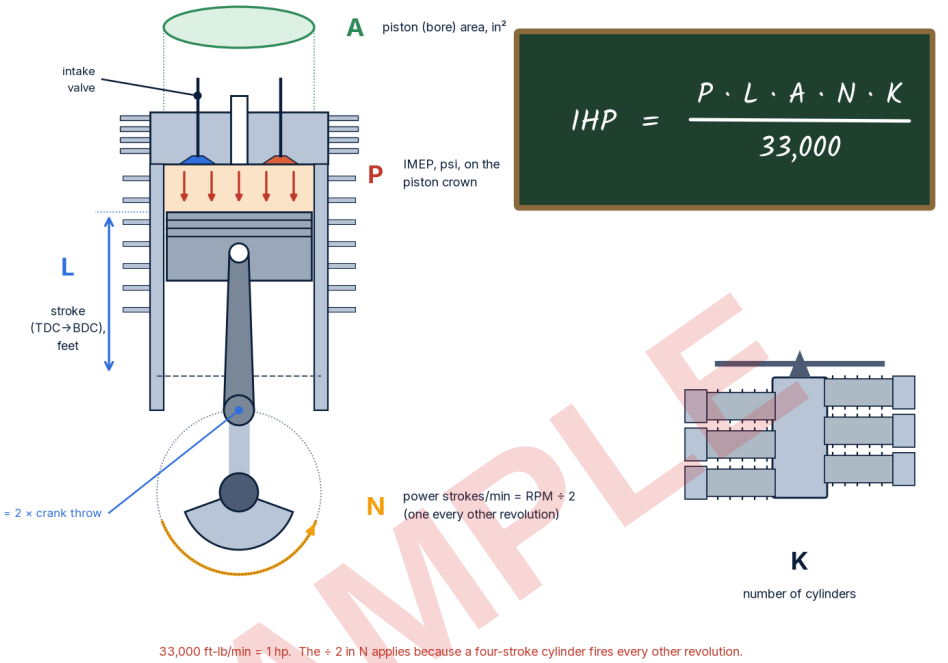


Figure 1-9. The PLANK formula. N is the number of power strokes per minute for one cylinder, which is RPM ÷ 2 in a four-stroke engine.

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WORKED EXAMPLE

Worked Example 1-4. Indicated horsepower with PLANK. A six-cylinder engine has an IMEP of 165 psi, a stroke of 4.0 in, a bore of 5.25 in, and runs at 2,400 RPM.

List each PLANK value first:

$$P = 165 \text{ psi}$$

$$L = \frac{4.0}{12} = \frac{1}{3} \text{ ft}$$

$$A = 0.7854 \times 5.25^2 = 21.65 \text{ in}^2$$

$$N = \frac{2{,}400}{2} = 1{,}200$$

$$K = 6$$

Then put them in the formula and work it one step at a time:

$$\text{IHP} = \frac{P \times L \times A \times N \times K}{33{,}000}$$

$$= \frac{165 \times \frac{1}{3} \times 21.65 \times 1{,}200 \times 6}{33{,}000}$$

$$= \frac{8{,}573{,}400}{33{,}000}$$

$$\approx 260 \text{ hp}$$

Indicated horsepower is about **260 hp**. The numerator, one step at a time:

$$165 \times \frac{1}{3} = 55$$

$$55 \times 21.65 = 1{,}190.75$$

$$1{,}190.75 \times 1{,}200 = 1{,}428{,}900$$

$$1{,}428{,}900 \times 6 = 8{,}573{,}400$$

$$\frac{8{,}573{,}400}{33{,}000} = 259.8 \text{ hp}$$

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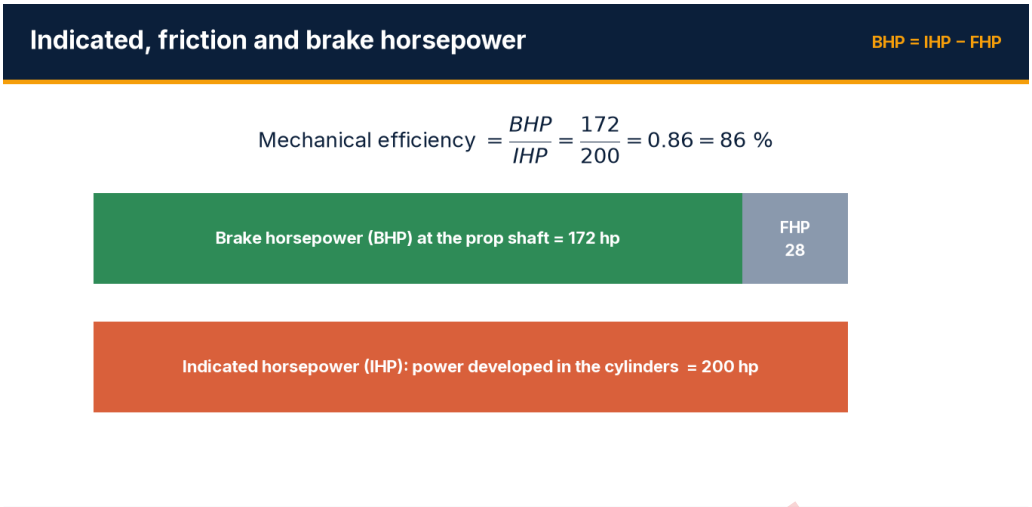


Figure 1-10. Brake horsepower is what is left of indicated horsepower after friction. In this example the mechanical efficiency is 86 percent.

Mean effective pressure and efficiencies

Brake mean effective pressure (BMEP) is the average pressure that, acting on the pistons through each power stroke, would produce the measured brake horsepower. It is a good indicator of how hard an engine is working; high BMEP at low RPM (lugging) stresses an engine.

- *Mechanical efficiency* = BHP ÷ IHP (often 85 to 90 percent).
- **Volumetric efficiency** is the ratio of the charge actually drawn into the cylinder to the piston displacement, corrected to standard conditions. A normally aspirated engine is always below 100 percent; it falls with high RPM, hot induction air, high altitude and restrictive intakes. Supercharging can push it above 100 percent.
- *Thermal efficiency* was covered in Section 1.1.

Specific fuel consumption

Specific fuel consumption (SFC) is the fuel burned per hour for each horsepower: lb/hp/hr. A good piston engine runs around 0.40 to 0.50 lb/hp/hr in cruise.

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WORKED EXAMPLE

Worked Example 1-5. Specific fuel consumption. An engine producing 180 BHP burns 13 gal/hr of 100LL (6 lb/gal).

$$\text{Fuel flow} = 13 \times 6 = 78 \text{ lb/hr}$$

$$\text{SFC} = \frac{78}{180} = 0.43 \text{ lb/hp/hr}$$

SFC is **0.43 lb/hp/hr**.

Factors that affect power

- **Density of the air.** Power falls with altitude, high temperature and high humidity (water vapor displaces oxygen). *Density altitude* combines these effects.
- **Mixture.** See Chapter 5 for best-power and best-economy mixtures.
- **Detonation** is the explosive, uncontrolled burning of the end-gas after normal ignition. It causes sharp pressure spikes, high cylinder head temperature, and can hole a piston. It is caused by too-low fuel grade, too-lean mixture, high manifold pressure at low RPM, and high induction air temperature.
- **Preignition** is ignition of the charge *before* the spark, from a glowing carbon deposit, a hot valve or an overheated spark plug electrode.

EXAM TRAP

- *Detonation vs. preignition.* Detonation happens **after** the spark (end-gas explodes); preignition happens **before** the spark (hot spot).
- *BHP vs. IHP.* BHP is always **less** than IHP.
- *Humidity* **decreases** engine power, even though humid air feels "heavy."

1.7 Reciprocating Engine Maintenance and Inspection

ACS: AM.III.A.K8

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Overhaul terms

- **Time between overhaul (TBO)** is the manufacturer's recommended operating time before overhaul. For Part 91 operators it is a recommendation, not a mandatory limit.
- A **top overhaul** rebuilds the parts above the crankcase (cylinders, pistons, valves, rings) without splitting the case.
- A **major overhaul** completely disassembles, inspects, repairs and reassembles the engine to approved limits. Parts may be within *service limits* (serviceable) or *new limits* (rebuilt only by the manufacturer, which is what allows a zero-time logbook under 14 CFR 91.421).

The differential compression test

The **differential compression test** checks how well each cylinder holds pressure. The kit illustration (Figure 1-11) shows the tester.

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Figure 1-11. The differential compression tester from the kit: regulated air source, two gauges and a calibrated restricting orifice between them.

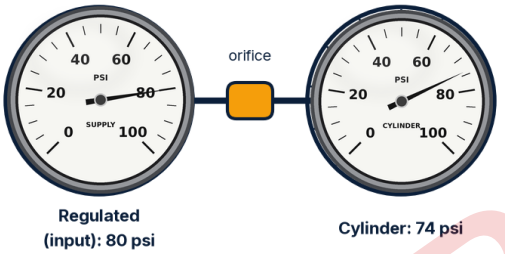
Procedure.

1. Run the engine to operating temperature if possible, so the rings and valves are at working clearances.
2. Remove one spark plug from each cylinder (the most accessible one).
3. Rotate the engine until the piston of the cylinder being tested is coming up on the compression stroke; install the adapter.

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4. Apply a small amount of regulated air, then bring the piston to **TDC** carefully. Hold the propeller firmly; air pressure can swing the prop violently if the piston is off TDC.
5. Set the regulated pressure to **80 psi** and read the cylinder gauge.
6. Compare the leakage with the engine manufacturer's limit, or with the *master orifice* reading of that tester (Continental's method).
7. Listen for the source of any leak (Figure 1-12).

Reading a differential compression test — Piston at TDC on compression stroke; 80 psi regulated



Regulated (input): 80 psi

Cylinder: 74 psi

Leakage = 80 − 74 = 6 psi.
Compare the reading with the master orifice limit for the engine.

Air at exhaust stack → exhaust valve
Air at carb/intake → intake valve
Air at breather/oil filler → rings

Figure 1-12. Reading the test. The difference between the two gauges is the leakage. Where the air escapes tells you which part is leaking.

SAMPLE

WORKED EXAMPLE

Worked Example 1-6. Interpreting a low reading. Cylinder 3 reads 52/80. Air hisses from the oil filler opening.

Leakage is 80 − 52 = 28 psi, likely beyond limits. Air at the breather or oil filler means leakage past the **piston rings**. Before condemning the cylinder, run the engine and retest; a ring that is not seated or a bit of carbon on a valve seat can give a false low reading. If air were heard at the exhaust stack, the **exhaust valve** would be suspect.

Other checks

- **Valve clearance.** On engines with solid lifters (and when checking hydraulic lifters "dry"), clearance is measured with a feeler gauge between rocker and valve stem. In a *radial engine*, clearance grows as the

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engine warms, so cold clearance is set smaller than the running (hot) clearance.

- **Cylinder hold-down nuts** are torqued in the sequence and to the value in the overhaul manual, using the recommended lubricant on the threads.
- **Borescope inspection** looks into the cylinder through a spark plug hole for burned exhaust valves, scoring, corrosion and cracks.
- **Ring gap and side clearance** are measured on overhaul. Ring gaps are staggered on installation so they do not line up.
- **Metal in the oil filter** (Chapter 3) is often the first sign of internal failure.
- **Cylinder removal.** Bring the piston to TDC on compression (both valves closed) before removing the cylinder, and support the piston and rod as the barrel comes off so the rod does not strike the crankcase.

1.8 Ground Operation

ACS: AM.III.A.K9

Before starting

Position the aircraft into the wind, chock it, clear the propeller arc, have a fire extinguisher (CO_2 or dry chemical) at hand, and know the hand signals. Never stand in or walk through the propeller arc; treat every propeller as live, because a broken P-lead (Chapter 4) leaves a magneto "hot" even with the switch off.

Starting and fire during start

If an induction fire starts during cranking (usually from over-priming), **keep cranking**. The engine will usually start and suck the fire through. If it does not start, keep cranking, shut off fuel, and use the extinguisher if the fire continues. Never pour water on a fuel fire.

Hand propping

Hand propping requires a qualified person at the controls, brakes set or the aircraft chocked, and the propeller swung with the palms flat on the blade and the body moving *away* from the arc.

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Run-up checks

Table 1-3. Typical run-up checks. Always use the aircraft manufacturer's procedure and numbers.

Check	What you look for
Oil pressure	Indicating within about 30 seconds of start (60 s in cold weather), or shut down
Magneto check	RPM drop on each magneto within the manufacturer's limit (commonly about 125–175 RPM) and within about 50 RPM of each other
Idle mixture check	Pull mixture to idle cutoff slowly at idle; a small RPM rise (roughly 25–50 RPM, per the manufacturer) shows correct idle mixture
Carburetor heat	A drop in RPM when heat is applied; no drop may mean the heat valve is not working
Propeller	Cycle a constant-speed prop to exercise the governor (Chapter 13)

> **Rule.** A *no-drop* magneto check is not good news. It usually means a magneto is not grounding (open P-lead), so that magneto will fire even with the switch off.

1.9 Storage and Preservation

ACS: AM.III.A.K6

Engines that sit corrode inside. Combustion by-products (acids and water) settle on cylinder walls, cam lobes and lifters. Preservation keeps moisture and oxygen away from these surfaces.

Table 1-4. Storage categories.

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Category (typical manufacturer guidance)	Period	Main actions
Flyable storage	Up to about 30 days	Pull the prop through by hand periodically; fly at least 1 hour every 30 days or follow the manufacturer
Temporary storage	Up to about 90 days	Corrosion-preventive oil in the sump, spray cylinders through plug holes, install dehydrator plugs, seal openings
Indefinite storage	Longer	Same as temporary plus thorough coating, desiccant bags in intake and exhaust, periodic inspection; engine may be crated

Materials

- **Corrosion-preventive compound** is a heavy oil mixture (often to MIL-C-6529) that coats internal surfaces. It is sprayed into the cylinders through the spark plug holes with the crankshaft in a fixed position.
- **Dehydrator plugs** screw into the spark plug holes. They contain silica gel treated with cobalt chloride: **blue means dry; pink or lavender means moisture has been absorbed** and the plugs need to be replaced or dried.
- **Desiccant bags** in the intake and exhaust openings absorb moisture in a sealed engine. Remember them on depreservation: a forgotten bag in an intake can be ingested.
- **Never ground-run an engine** just to “circulate the oil.” A short run that does not reach operating temperature leaves more water in the engine than it removes.

Returning an engine to service

Remove desiccant and dehydrator plugs, drain the preservative oil and refill with fresh oil, clean the plugs, turn the engine by hand to check for hydraulic lock and free rotation, and inspect per the manufacturer before the first run.

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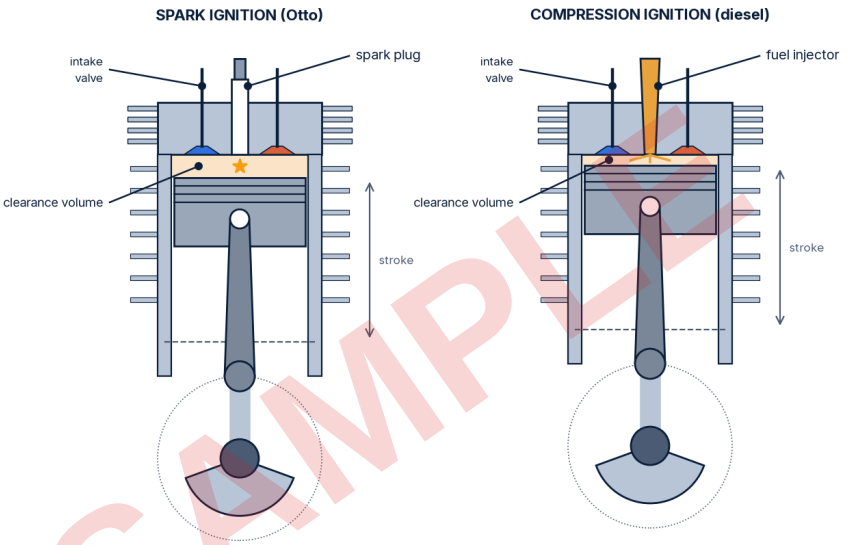
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1.10 Diesel Engine Principles

ACS: AM.III.A.K10

A **diesel engine** compresses air alone, to a much higher ratio than a spark-ignition engine, and then sprays fuel into the hot air. The fuel ignites from the heat of compression; there are no spark plugs or magnetos (Figure 1-13).

Spark ignition vs compression ignition (diesel) — Cylinders at TDC; clearance volume drawn to scale



	Spark ignition	Compression ignition
Air intake	Fuel-air mixture	Air only
Ignition	Spark plug	Heat of compression
Compression ratio	≈ 7–9 : 1 (drawn 8:1)	≈ 14–22 : 1 (drawn 16:1)
Fuel	Avgas (100LL)	Jet-A / diesel
Power control	Throttle limits air	Fuel quantity only

Figure 1-13. Spark ignition and compression ignition compared.

Aviation diesels run on Jet-A or diesel, which is cheaper and more available worldwide than 100LL and does not contain lead. Most are liquid-cooled, turbocharged and controlled by a FADEC (Chapters 5 and 9), which typically gives single-lever power control: the pilot sets a power demand and the computer meters fuel and sets propeller pitch. Because there is no throttle restricting airflow, power is controlled by the quantity of fuel injected. *Glow plugs* may be used to

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help cold starts. Diesels have better specific fuel consumption than spark-ignition engines but tend to be heavier for their power.

1.11 Chapter Review

KEY NUMBERS

Key numbers and rules

Item	Value
1 horsepower	33,000 ft-lb/min = 550 ft-lb/s = 746 W
Crank revolutions per four-stroke cycle	2 (720°)
Camshaft speed (opposed)	½ crankshaft speed
4-lobe cam ring (9-cyl radial)	⅛ crank speed, opposite direction
5-lobe cam ring (9-cyl radial)	$\frac{1}{10}$ crank speed, same direction
Lycoming 4-cyl firing order	1-3-2-4
Continental 6-cyl firing order	1-6-3-2-5-4
Differential compression test	80 psi, piston at TDC on compression
Piston area	0.7854 × bore²
Dehydrator plug colors	Blue = dry, pink = wet

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Summary. A reciprocating engine converts heat to work using the four-stroke cycle. Valves open early and close late to use the inertia of the gases, and valve overlap scavenges the cylinder. Opposed engines use a split crankcase, a single camshaft and plain bearings; radials use master and articulating rods, a cam ring and an odd number of cylinders per row. Performance is measured as displacement, compression ratio, indicated and brake horsepower, BMEP, volumetric efficiency and SFC. The differential compression test, valve clearance checks and borescope inspections find internal wear. Ground runs need preflight safety, correct fire procedure and careful magneto checks. Stored engines must be preserved against corrosion. Diesel aircraft engines use compression ignition and Jet-A.

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