

AUTOMOTIVE ENGINES

Eighth Edition

Diagnosis, Repair, and Rebuilding

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TIM GILLES



AUTOMOTIVE ENGINES

Diagnosis, Repair, and Rebuilding

EIGHTH EDITION

TIM GILLES

Professor Emeritus
Santa Barbara City College
Santa Barbara, CA



Australia • Brazil • Mexico • Singapore • United Kingdom • United States

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***Automotive Engines: Diagnosis,
Repair, and Rebuilding, 8th edition***

Tim Gilles

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Senior Director, Development:
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Senior Content Developer: Mary Clyne

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Jennifer Ann Baker

Associate Marketing Manager:
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Senior Art Director: Jack Pendleton

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DEDICATION

The completion of this book was made possible with the help of a great many individuals. *Automotive Engines* is dedicated to them and especially to my parents for the inspiration, and to my wife, Joy, and children, Jody and Terri, without whose help the book would not have been completed. Special appreciation is due to my wife, Joy, who has managed the organization of the art package, spending countless hours developing and organizing all the spreadsheets, captions, photos, and sketches, making certain they are in their correct locations—a substantial task.

This book is also dedicated to four important mentors: Lloyd Corliss, my first automotive teacher, who shared his love of engines and whose integrity and example inspired me to become an automotive teacher; Roger Aylesworth, who became a big brother to me while I worked in his automotive business and who shared, by example, his attitude that, with knowledge, a good mechanic can fix just about anything; and Bob Barkhouse, another big brother and good friend. Bob is a retired automotive teacher and the author of a very fine best-selling textbook on the upper end of engines. His example is one of generosity. He has been a big help and an inspiration to me and countless other teachers. My good friend and mentor, Joe Schuit, began helping the engine-rebuilding students at Santa Barbara City College shortly after he retired from his automotive machine shop business. Joe was an inventor with a gifted mind for automotive engines and an enthusiasm that was contagious. He always had something new and valuable to share from his vast library of knowledge and experience.

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Preface

ABOUT THIS BOOK

It is often said that engines never change. Although large changes are not the norm, the internal combustion engine (ICE) is constantly evolving. When the first edition of this text was being written in 1980, futurists were questioning whether the four-stroke cycle engine would still be around in 20 years. The long history of this well-proven engine has shown continuous small refinements, and ICEs still power most of today's vehicles. Compared with the engines that powered the muscle cars of 1980, today's engines are more refined, lighter, and offer improved performance and durability.

Automotive Engines, Eighth Edition, provides the reader with the comprehensive knowledge needed to repair and rebuild these automotive engines. The most complete book of its kind, it takes a generic, rather than product-specific, approach. The text provides all of the need-to-know information in an easy-to-understand format. Much effort has gone into organizing this book to make it easily readable, like a story. To facilitate learning, all items related to a given topic are included within a single chapter. Appropriate for entry-level as well as more experienced technicians and machinists, this text also provides opportunities for the reader to develop critical diagnostic and problem-solving skills.

Organization of This Edition

This text is divided into five sections and is designed so that the student can begin working in the shop right away. Section 1 covers engine construction, disassembly, inspection, and parts ordering. Diagnosis techniques, both before and after disassembly, are covered in detail. Also included are repair procedures that can be performed while the engine is still in the vehicle. Tools and equipment procedures, as well as safety issues, are covered throughout. Section 2 deals with the valvetrain, cylinder head repair, camshafts, and cam drives. Section 3 discusses the cylinder block assembly with a focus on lower-end repair

procedures. The lubrication and cooling systems are also covered. Section 4 deals with final reassembly and starting the engine. Gaskets and miscellaneous repair procedures are covered in this section as well. Section 5 covers engine power and performance, including intake and exhaust systems, turbochargers and superchargers, varying valve timing, and measuring power and torque.

New to This Edition

This eighth edition of *Automotive Engines* has been updated and refined to reflect changes in the marketplace. The seventh edition was produced in a four-color design for the first time with many new and updated photos and illustrations. This has been a tremendous improvement. An emphasis on photos and art anticipates the needs of those with different learning styles and encourages student interest in reading the related text. New color photos and illustrations have been added to this eighth edition to continue improving this project.

The design and engineering of the internal combustion engine is continuing to evolve, with enhancement of high-performance sport compact cars and vehicle restoration accounting for a substantial part of the industry.

Here is a listing of some of the highlights:

- The updated high-performance Section 5 includes three chapters with updated information on engine breathing, including intake and exhaust manifolds, turbocharging, supercharging, high-performance camshafts, and variable valve timing.
- Up-to-date information on cooling and lubrication systems is included in this edition of the text. Engines last far longer than they did 25 years ago. Maintenance is important to vehicle owners; cooling system failures that result in serious engine damage must be avoided.
- Metric micrometer reading has been expanded in Chapter 6.

- New or updated case histories highlight real-world situations, providing more critical thinking practices.
- Vintage Engines additions help put newer technologies in historical perspective by offering interesting facts about older technologies while separating them from the core text, along with accompanying photographs.

Use of the Text

A goal of *Automotive Engines* is to fill the needs of many, merging commonplace and vintage content with the latest high-tech information. Some schools have smaller engine course offerings, whereas others have large programs with classes of long enough duration to complete the entire text. Some instructors assign certain chapters, leaving others to be covered in an introductory course. Others use some of the chapters in a prerequisite introductory engines course, saving others for an advanced engine-rebuilding course. For instance, Chapter 9 covers all of the camshaft-related items that would be needed for an entry-level automotive apprentice, whereas the Engine Power and Performance Chapters, 17, 18, and 19, consist of more advanced technical material for aspiring engine machinists and high-performance specialists.

There are many new and updated photos of engine disassembly and reassembly on newer vehicles. Students need to learn to diagnose an engine during disassembly so they can assess its suitability for repair prior to spending a lot of money and wasting a lot of time. Analyzing unusual wear or part failure will also help them correct problems so they do not recur.

The camshaft chapter emphasizes timing belt service, including cam lobe position identification, so you can be sure you are doing the right thing. This is something all good technicians should know, but many do not.

This book is used in schools that teach NATEF A-1 (Engine Repair). Coverage emphasizes procedures that would be performed in a typical automotive facility that does engine repairs. The book is also used in schools that teach in-depth engine machining processes. One of my challenges as an author is to present machining tips in a way that will benefit all students who study the book. Instructions on the use of a particular machine are avoided; they are available in video form or in the online pdf manual for the machine.

The primary aim of the text is to provide a student with adequate preparation for entry-level employment with emphasis on the ASE A1 Engines area, including ASE test preparation.

To the Student

Restoration and improvement is a very popular automotive technology area and you should be prepared to capitalize on that interest. Most cities and towns have residents who can afford to spend money on their cars and light trucks. You will need a good understanding of performance and vintage material to be successful in this field. Additionally, you need a good grounding in the broad area covering four-stroke cycle engine basics if you are to be successful as an engine diagnostician. During engine diagnosis and disassembly, the text gives an emphasis to analyzing worn and damaged parts. The aim is to improve your diagnostic ability and develop a method of approaching things in an inquisitive manner. Get into the habit of asking yourself, “What caused this to happen?” You will want to take measures so it does not happen again. This can be applied to more advanced topics as you further your automotive studies.

You will also find that learning about automotive internal combustion engines will prepare you for work in the heavy-duty market. Working on heavy trucks or on marine engines is not that much different than working on cars. The principles are the same.

Features of the Text

Learning the theory, diagnosis, and repair procedures for today's complex engines can be challenging. To guide readers through this material, a series of features are included that will ease the teaching and learning processes.

Objectives

Each chapter begins with a list of objectives. The objectives state the expected outcome that will result from completing a thorough study of the contents of the chapter.

58 SECTION 1 Engine Construction, Diagnosis, Disassembly, and Inspection

Leaking V-Type Intake Manifold Gasket

Intake manifold vacuum can draw oil into the intake ports from the lifter-valley area under some intake manifolds (FIGURE 3.8). This is a tough problem to find. A smoke test is a good way of finding an intake test for internal air leaks before the engine is disassembled. These procedures are covered later in this chapter. When removing an intake manifold, always visually inspect for the possibility of previous intake gasket leakage.

V-type engines equipped with an exhaust gas recirculation (EGR) valve on the intake manifold often experience oil-fouling of the spark plugs that are closest to the EGR valve. This is caused when the intake manifold warps or the manifold gasket fails. Replace the gasket with one designed for high-temperature applications.

Crankcase Pressure

Normally, there is a slight vacuum in the crankcase. One possible reason for excessive oil leakage is a positive crankcase ventilation (PCV) valve that is plugged. This can cause pressure to build up in the crankcase at low rpm. Crankcase pressure can result in increased internal oil consumption, too.

EXP NOTE
The operation of the PCV valve is covered in detail in Chapter 13.

To see if the PCV valve is working properly:

- Pinch the line that leads to it, or cover the end of the PCV valve with your thumb.
- With computer idle speed adjust disabled, if the PCV valve is good, idle speed should drop.

Blocking the flow of air to the PCV valve enriches the air-fuel mixture.

REMEMBER:
A leaner air-fuel mixture means a higher idle speed.

SHOP TIP
Here is another simple test to see if there are any leaks in the crankcase:

- Remove the hose from the valve cover to the air cleaner (at the air cleaner side).
- With the engine idling, put your thumb over the end and wait for a couple of seconds. If the crankcase ventilation system is working correctly, vacuum should be felt in the hose.

Be sure to check for a restricted filter or a kink in the breather line from the valve cover to the air cleaner. This can result in oil leakage caused by crankcase pressure.

Vintage Engines
If oil is leaking from the breather hole of a mechanical fuel pump, be sure to inspect for excessive crankcase pressure.

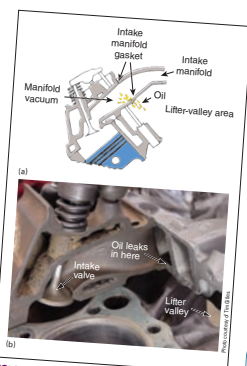


FIGURE 3.8 Oil can be drawn into the intake manifold past a faulty manifold gasket.

CHAPTER 1 Engine Operation

CONTENTS

Simple Engine	Front-Wheel Drive	Engine Cooling
Four-Stroke Engine Operation	Engine Classifications	Spark and Compression Ignition
Cylinder Arrangement	Combustion Chamber Designs	Putting It All Together
Valvetrain	Direction of Crankshaft Rotation	High-Performance Engine
Cylinder Block	Firing Order	Trivia

OBJECTIVES

Upon completion of this chapter, you should be able to:

- Explain the principles of internal combustion engine operation.
- Identify internal combustion engine parts by name.
- Explain various engine classifications and systems.

INTRODUCTION

Most of today's automobiles and light trucks are powered by a spark-ignited four-stroke reciprocating engine. The first engine of this type was built in 1876 by Nicolaus Otto in Germany. Thus, it was named the Otto-cycle engine. Compared to previous internal combustion engine designs using the same amount of fuel, Otto's four-stroke engine weighed less, ran much faster, and required less cylinder displacement to produce the same horsepower. A few years later, this engine design powered a motorcycle and then a horseless carriage. Other engine designs in limited use in modern autos include the rotary (Wankel), two-stroke, and compression ignition (diesel) engines.

In a spark-ignited internal combustion engine, a precise mixture of air and fuel is compressed in a cylinder. The fuel must be of a type that vaporizes easily (such as gasoline, methanol, or ethanol) or a flammable gas (such as propane or natural gas). When the compressed air-fuel mixture is burned, it pushes a piston down in a cylinder. This action turns a crankshaft, which powers the car (FIGURE 1.1).

Vintage Engines
Although Nicolaus Otto has been credited with the invention of the four-stroke internal combustion engine in 1876, the French inventor Alphonse Beau de Rochas developed the concept 14 years earlier in 1862. He applied for a patent but did not pay the required taxes so the French government did not validate his patent.

2

Shop Tips

Found throughout the chapters, these tips cover things commonly performed by experienced technicians.

Safety Notes and Cautions

Safety is a major concern in any automotive shop, so safety notes and cautions are listed throughout to focus the reader's attention on important safety information.

Vintage Engines

These text boxes place newer technologies in historical perspective by offering interesting facts about older technologies while separating them from the core text. Vintage figures are also included within the boxes.

Case Histories

These true stories describe automotive situations encountered by the author and others. They provide the reader with insight into the critical thinking skills necessary to diagnose automotive engine problems.

Key Terms

Each chapter ends with a list of the terms that were introduced in the chapter. These terms are highlighted in the text upon first use.

98 SECTION 10 Engine Construction, Diagnosis, Disassembly, and Inspection

Vintage Engines

MANUFACTURER SERVICE MANUALS AND MICROFICHE

Until computers eventually made them obsolete, manufacturer service manuals were published each year for each make of vehicle. These were designed for use by the technicians in a dealership and cover for one year and model of vehicle. Every service operation was listed in detail. In the days of a simple car and truck, when do-it-yourself was a popular service option, many new vehicle owners would purchase a dealer service manual to go with their vehicle. These are still available from some aftermarket publishers.

Another casualty of the computer revolution is microfilm. Although it is still available from some service literature providers, it has largely been replaced by computers and has become uncommon. Microfilm is a small plastic film card that is magnified by a microfiche reader. Many of these machines had copying capability so a hard copy of the information could be carried to the service bay.

Another character and the year of the vehicle is the eighth character (FIGURE 4.3). Check the manufacturer's service manual for the meaning of each character for that make of car.

Engine Identification

If the engine is out of the vehicle, the VIN code might not be available. Some manufacturers use tags or stickers attached at various places such as the valve cover or oil pan. Do not lose the tag.

Blocks often have a serial number stamped into them. FIGURE 4.4 shows several examples of serial number locations. The service manual gives the location of the code for a particular engine.

Under-Hood Label

Vehicles produced since 1972 are equipped with under-hood emission control label (FIGURE 4.5). This label gives useful information to the technician.

FIGURE 4.3 Each digit of the VIN stands for a specific meaning.

- 1—World Manufacturing Identifier
- 2—Restraint System Type
- 3—Country of Origin
- 4—Line, Series, Body Type
- 5—Engine Type
- 6—Check Digit
- 7—Model Year
- 8—Plant
- 9—Product

FIGURE 4.4 Engine serial number locations.

FIGURE 4.5 An under-hood emission label.

266 SECTION 11 The Breathing System

Valve Clearance Adjustment

On OHC heads with bucket adjusters, the valve clearance can be adjusted using special tools so the adjustment discs or pads, can be removed and replaced as needed. One tool fits on the outside edges of two buckets. Prying the tool against the camshaft pressure while the other tool reaches around the camshaft and lifts the disc from the bucket (FIGURE 6.116). A rubber-tipped blowgun can be used, as shown in FIGURE 6.117, to release the disc from trapped oil that tends to hold it against the bucket. Chapter 16 describes the procedure for adjusting valve lash on engines with an adjustment provision on the rocker arm or cam follower. Be sure to readjust the valve lash after they have seated, when the engine has been run at operating temperature.

FIGURE 6.117 A rubber-tipped blowgun can be used to remove a lash pad adjusting disc from its bucket.

KEY TERMS

carbon-manganese steel	low-carbon steel	solvent test
induction hardened	medium-carbon steel	valve lash
integral seats	protrud surface	valve spring inserts
interference angle	runout	

STUDY QUESTIONS

- List three tests made on valve springs.
 - Intake
 - Exhaust
- VSI shims are available in 0.015", 0.030", and 0.060" sizes. True or false?
- Which valve would most often have a hardened tip?
 - Intake
 - Exhaust
- What is the name of the part of the valve that becomes too thin when excessive metal is ground from the valve face?
- By what process are integral seats usually hardened?
 - 30°
 - 60°
- List three sources of valve seating pressure.
 - Repairs to what part of the head must be completed prior to refitting the seats?
 - What are the names of the three valve seat angles?
 - 30°
 - 45°
 - 60°
 - To correctly position the valve seat about 1/32" from the outer edge of a 45° valve face, which angle would you grind?
 - 30°
 - 60°

31 CHAPTER 7 Engine Shop Safety

CASE HISTORY

A technician was removing an engine from a Volkswagen. When the fuel hose was disconnected, gasoline dripped on the floor. The technician accidentally dropped his spark light before the gasoline spill was cleaned up. The bulb in the shop light caused the gasoline to catch fire. The resulting fire destroyed the business. For safety, always use a light that is enclosed in a tube. (see figure below.)

SAFETY NOTES

- Gasoline should be stored in an approved safety container and never in a glass jar.
- Never use gasoline to clean filters or parts. Standard solvent has a higher flash point than gasoline so it is safe to use. A flash point is the lowest temperature where a liquid produces ignitable vapors at a certain pressure. Gasoline has a flash point of approximately -45°F (-43°C). This means that liquid gasoline produces ignitable vapors at almost any temperature you will ever encounter. Diesel fuel is safer than gasoline. The flash point of diesel fuel is 125°F (52°C), which is one of the reasons why diesel engines are popular in boats and ships.
- Cigarette smoking or talking to someone while working around gasoline can be dangerous. People become how dangerous it can be.
- Do not attempt to sip gasoline with your mouth. Accidental breathing of gasoline into the lungs can be fatal.

NOTE

The ground cable is the one bolted to the engine block. Do not assume the ground is the negative cable. On some older vehicles the positive cable is ground.

Fuel Fires

Gasoline is a major cause of automotive fires. Liquid gasoline is not what catches fire. Rather, it is the vapors that are so dangerous. Gasoline vapors are heavier than air, so they can collect in low places in the shop. They can be ignited by a spark from a light switch, the most electrical wires that have been accidentally crossed, or a dropped shop light.

Two kinds of shop lights are acceptable. One has a fluorescent bulb enclosed in a plastic tube. The other uses a special spark-proof incandescent bulb.

Electrical Fires

Electrical fires are prevented by disconnecting the battery before working on the electrical system or other electrical components, such as the starter or alternator. Disconnect the battery ground cable first (FIGURE 2.14). This prevents the possibility of a spark occurring when a wrench completes a circuit between a "hot" cable and the ground cable. The battery must be disconnected as fast as possible so the fire can be put out. Another advantage to removing the ground cable is that an electric cooling fan cannot accidentally turn on while working near it.

FIGURE 2.13 An approved flammable storage cabinet.

FIGURE 2.14 Disconnecting the battery ground cable first.

Notes

Throughout the text, notes are included to call attention to need-to-know information.

ASE-Style Review Questions

Each appropriate chapter concludes with ten ASE-style review questions to help the reader prepare for the ASE Certification Exam.

Study Questions

At the end of each chapter, there are 15 study questions of varying types. The questions provide an opportunity for reinforcement and review of key concepts presented in the chapter.

Instructor Resources

An Instructor Companion Website is available to instructors at login.cengage.com and includes the following components: an electronic Instructor's Guide with answers to all end-of-chapter questions, Word files of all end-of-chapter questions, Cengage Testing, Powered by Conero(R), with hundreds of questions for quizzes or exams, chapter presentations in PowerPoint

266 SECTION II The Breathing System

Valve Clearance Adjustment
 On OHC heads with bucket adjusters, the valve clearance can be adjusted using special tools so the adjustment discs, or buckets, can be removed and replaced as needed. One tool fits on the outside edges of two buckets. Prying the tool against the camshaft holds the two buckets down against spring pressure while the other tool reaches around the camshaft and lifts the disc from the bucket (FIGURE 8-116). A rubber-tipped blowgun can be used, as shown in FIGURE 8-117, to release the disc from trapped oil that tends to hold it against the bucket. Chapter 16 describes the procedure for adjusting valve lash on engines with an adjustment provision on the rocker arm or cam follower. Be sure to readjust the valves after they have seated, when the engine has been run at operating temperature.




FIGURE 8-117 A rubber-tipped blowgun can be used to remove a lash pad adjusting disc from its bucket.

KEY TERMS

carbon-manganese steel	low-carbon steel
induction hardened	medium-carbon steel
integral seats	prond surface
interference angle	runout
	solvent test
	valve lash
	valve spring inserts

STUDY QUESTIONS

- List three tests made on valve springs.
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- VSI shims are available in 0.015", 0.030", and 0.060" sizes. True or false?
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 - 30°
 - 60°

CHAPTER 10 Cylinder Block: Inspection and Service 337

NOTE
 Select a tool 1/16" smaller than the inside diameter of the core plug. A driving tool that is too small can distort the plug, causing it to leak; one that is too tight will get stuck in the plug when the plug is driven into the block. The core plug shown in FIGURE 10-57 was installed incorrectly by pounding on its outer sealing lip.



FIGURE 10-54 Putting sealer on the core opening prior to core plug installation.



FIGURE 10-55 Drive in the core plug. Be sure to use a brass hammer to avoid damaging the tool.



FIGURE 10-56 Install the core plug until its lips are past the chamfer in the block.



FIGURE 10-57 This core plug was installed incorrectly by pounding on its outer sealing lip.



FIGURE 10-58 These core plugs are the same diameter but have different depths.



FIGURE 10-59 Installing an expansion plug.

for each chapter of the text, an Image Gallery with hundreds of illustrations to support in-class presentations, a NATEF AST/MAST correlation grid connecting the chapter content with the most current A1 task list, and electronic job sheets to guide students through common engine diagnosis and repair procedures.

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MindTap for Automotive Engines: Diagnosis, Repair, and Rebuilding, 8th Edition

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About the Author

Tim Gilles has authored and coauthored several textbooks. He recently retired from the Automotive Technology Department at Santa Barbara City College, after having been a teacher for 38 years. He holds a Master of Arts degree in Occupational Education from Chicago State University and a Bachelor of Arts degree in Industrial Arts from California State University, Long Beach. He has held the industry certifications of ASE Master Engine Machinist and ASE Master Automotive Technician.

Tim has been active in professional associations for many years, serving as president and board member

of the California Automotive Teachers (CAT) and as a board member and election committee chair of the North American Council of Automotive Teachers (NACAT). He has been a frequent seminar presenter at association conferences. Tim was a longtime member of the California Community College Chancellor's Trade and Industry Advisory Committee. He has been active in industry associations and groups, including AERA, ARC, ASCCA, and IATN, and served several terms as education representative on the board of the Santa Barbara Chapter of the Independent Automotive Professionals Association (IAPA).

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The National Institute for Automotive Service Excellence (ASE) certifies automotive technicians in eight specialty areas of automotive and light truck repair. The engine repair certification test is A1. Tests are given on the Internet at proctored centers during eight months of the year. For more information, check the following URL: <http://www.ase.com/Tests/ASE-Certification-Tests/Certification-Testing.aspx>.

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AERA Engine Rebuilding and Machining Certificate Program

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David R. Christen
Instructor
University of Northwestern Ohio
Lima, OH

Jonathan Couch
Owner: Couch's Automotive Racing Services
Competition
Engine Builder/Automotive Educator
Klein Forest High School
Houston, TX

Gerard Egan
Associate Professor/Department Head
Wake Tech Community College
Raleigh, NC

Vincent LaVerdi
Instructor
Alfred State College
Wellsville, NY

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Instructor, College of Applied Technologies
University of Northwestern Ohio
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David Christen
University of Northwestern Ohio
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Earl Comer
University of Northwestern Ohio
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Pennsylvania College of Technology
Williamsport, PA

Dimitri Elgin
D. Elgin Cams
Redwood City, CA

Gary Engberg
Northeast Metro Technical College
White Bear Lake, MN

Paul Gagnon
Central Maine Community College
Auburn, ME

Dave Hagen
AERA Engine Builders Association
Crystal Lake, IL

John Kraemer
Western Iowa Tech Community College
Sioux City, IA

Norman Laws
Professor Emeritus
Chicago State University

Larry Leavitt
Pennsylvania College of Technology
Williamsport, PA

Tim LeVan
University of Northwestern Ohio
Lima, OH

Wilmer Martin
Automotive Training Center

Gary McDaniel
Metropolitan Community College–Longview
Lee’s Summit, MO

J. C. Mitchell
Gaston College

Joseph Moore
Southern Maine Community College
South Portland, ME

Ted Nicoll
Central Missouri State University

Jason Norris
Pasadena City College
Pasadena, CA

Jerry Norris
Southeast Community College
Milford, NE

Joe Polich
President Production Engine Rebuilders Association

Fred Raadsheer
British Columbia Institute of Technology
Vancouver, BC

Richard Rackow
Moraine Valley Community College
Palos Hills, IL

Robert D. Raduechel
Modesto Junior College
Modesto, CA

Butch Reilly
Spokane Community College
Spokane, WA

Chuck Rockwood
Ventura College
Ventura, CA

Charles Romack
Southern Illinois University

Jerry Rosenquist
Fel-Pro/Federal-Mogul

Raymond K. Scow Sr
Truckee Meadows Community College

Gary Semerdjian
Santa Barbara City College
Santa Barbara, CA

Jason Spohr
Pasadena City College
Pasadena, CA

Bill J. Steen
Yuba College
Marysville, CA

Forrest J. Stewardson
Mayo Technical College

Don Sykora
Morton College
Cicero, IL

John Thorp
Illinois Central College
Peoria, IL

Christopher VanStavoren
Pennsylvania College of Technology
Williamsport, PA

Walter Varella
Trident Technical College
North Charleston, SC

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University of Northwestern Ohio
Lima, OH

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SECTION 1

Engine Construction, Diagnosis, Disassembly, and Inspection

OVERVIEW

Automotive Engines is a book about the diagnosis, repair, and rebuilding of engines in modern automobiles and light trucks. Section 1, comprising the first six chapters, introduces the reader to the internal combustion engine. Chapter 1 provides a brief overview of engine construction and operation. Safety and shop equipment are covered next in Chapter 2. Chapter 3 deals with engine problem diagnosis that can be performed before engine repair while the engine is still running. The chapter has been designed so that it can be used as a reference while studying the rest of the text. Problems are listed alphabetically throughout the index at the back of the book. Chapter 4 covers engine removal, disassembly, inspection, and diagnosis of internal engine parts wear. Also covered are in-chassis repairs—those that can be done on an engine without removing it from the vehicle. The final two chapters in this section deal with engine cleaning and measuring after disassembly.

CHAPTER 1

Engine Operation

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Simple Engine

Four Stroke Engine
Operation

Cylinder Arrangement

Valvetrain

Cylinder Block

Front-Wheel Drive

Engine Classifications

Combustion Chamber Designs

Direction of Crankshaft
Rotation

Firing Order

Engine Cooling

Spark and Compression
Ignition

Putting It All Together

High-Performance Engine
Trivia

OBJECTIVES

Upon completion of this chapter, you should be able to:

- Explain the principles of internal combustion engine operation.
- Identify internal combustion engine parts by name.
- Explain various engine classifications and systems.

INTRODUCTION

Most of today's automobiles and light trucks are powered by a spark-ignited four-stroke reciprocating engine. The first engine of this type was built in 1876 by Nicolaus Otto in Germany. Thus, it was named the Otto-cycle engine. Compared to previous internal combustion engine designs using the same amount of fuel, Otto's four-stroke engine weighed less, ran much faster, and required less cylinder displacement to produce the same horsepower. A few years later, this engine design powered a motorcycle and then a horseless carriage. Other engine designs in limited use in modern autos include the rotary (Wankel), two-stroke, and compression ignition (diesel) engines.

In a spark-ignited internal combustion engine, a precise mixture of air and fuel is compressed in a cylinder. The fuel must be of a type that vaporizes easily (such as gasoline, methanol, or ethanol) or a flammable gas (such as propane or natural gas). When the compressed air-fuel mixture is burned, it pushes a piston down in a cylinder. This action turns a crankshaft, which powers the car (**FIGURE 1.1**).

SIMPLE ENGINE

A simple reciprocating engine has a cylinder, a piston, a connecting rod, and a crankshaft. The cylinder can be compared to a cannon and the round piston can be compared to a cannonball. The end of the cylinder is sealed with a cylinder head. The piston, which is sealed to the cylinder wall by piston rings, is connected to the crankshaft by a connecting rod and a piston pin (also called a wrist pin).

This arrangement allows the piston to return to the top of the cylinder, making continuous

Vintage Engines



Although Nicolaus Otto has been credited with the invention of the four-stroke internal combustion engine in 1876, the French inventor Alphonse Beau de Rochas developed the concept 14 years earlier in 1862. He applied for a patent but did not pay the required taxes so the French government did not validate his patent.

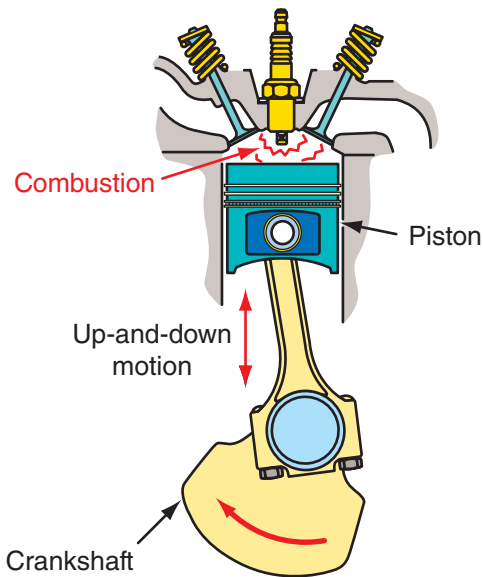


FIGURE 1.1 A piston forces a crankshaft to turn.

rotary motion of the crankshaft possible. Because of the powerful impulses on the piston as the fuel is burned in the cylinder, a heavy flywheel is bolted to the rear of the crankshaft (**FIGURE 1.2**). The weight of the flywheel blends the power impulses together into one continuous motion of the crankshaft.

The cylinder head has one combustion chamber for each cylinder (**FIGURE 1.3**). An intake valve port allows a mixture of air and fuel to flow into the cylinder, and an exhaust valve port allows the burned gases to flow out. Each port is sealed off by a poppet-style valve. The head is sealed to the cylinder block with a head gasket (**FIGURE 1.4**). The opening of the valves is controlled by the camshaft (**FIGURE 1.5**).

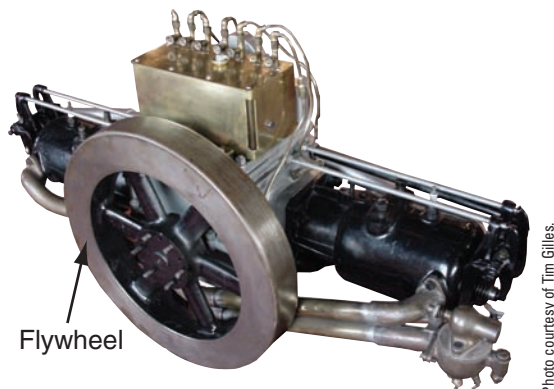


FIGURE 1.2 A flywheel is installed at the end of the crankshaft. This is a Buick opposed engine from the early 1900s.

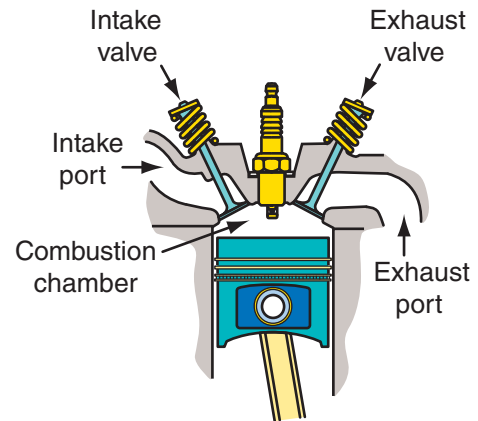


FIGURE 1.3 Valves seal off the valve ports.

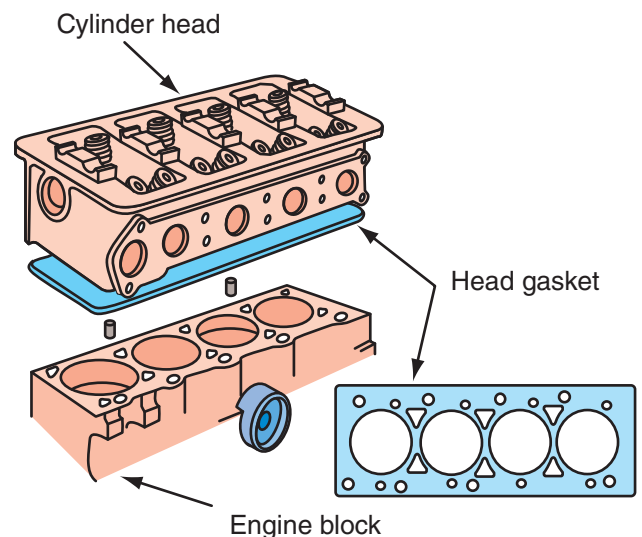


FIGURE 1.4 A head gasket seals the head to the block.

FOUR-STROKE ENGINE OPERATION

A stroke is the movement of the piston from **TDC** (top dead center) to **BDC** (bottom dead center), or from BDC to TDC. There are four strokes in one four-stroke cycle of the engine. They are called the intake stroke, compression stroke, power stroke, and exhaust stroke.

- Intake Stroke.** Gasoline will not burn unless it is mixed with the correct amount of air. It is very explosive when 1 part is mixed with about 15 parts of air. Shortly before the piston reaches TDC, the intake valve begins to open. As the crankshaft turns, it pulls the rod and piston down in the

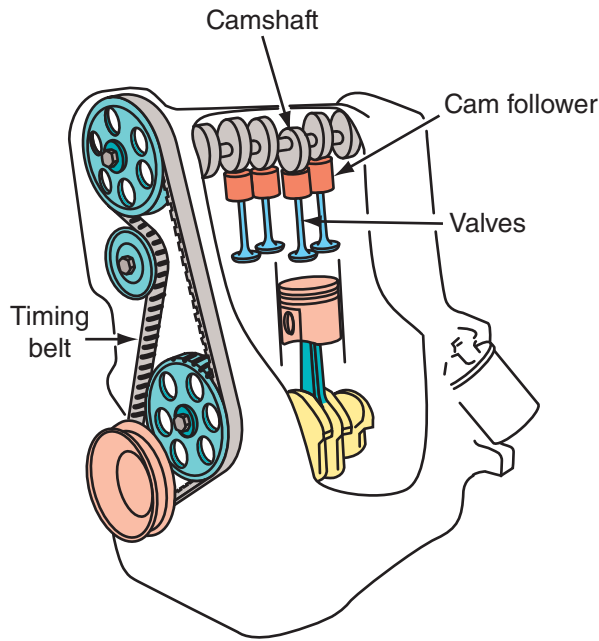


FIGURE 1.5 The opening of the valves is controlled by the camshaft.

cylinder toward BDC (**FIGURE 1.6**). This action creates a low-pressure void that is filled by atmospheric air pressure and fuel through the open intake valve. About 10,000 gallons of air is drawn in for every 1 gallon of fuel supplied by the fuel system. The ideal mixture (called stoichiometric) for the combined purposes of engine performance, emission control, and fuel economy is about 14.7:1 (at sea level).

Older vehicles had carburetors and newer vehicles manufactured since the mid-1980s have fuel injection systems with computer controls. The computer monitors the oxygen content in the vehicle's exhaust and then adjusts the fuel supply to provide the correct amount of fuel and air for each intake stroke.

As the crankshaft continues to turn, the piston begins to move back up in the cylinder and the intake valve closes.

- **Compression Stroke.** The piston moves up in the cylinder, compressing the air-fuel mixture (**FIGURE 1.7**). If you light a puddle of gasoline on fire in open air, it does not produce power. If it is confined in a cylinder, however, usable power can be produced. Compressing the mixture of air and fuel into a smaller area makes it easier to burn. The compression stroke begins at BDC after the intake stroke is completed. As the piston

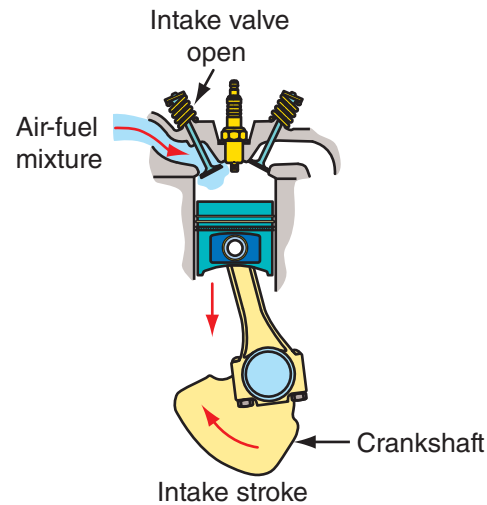


FIGURE 1.6 The air-fuel mixture is drawn into the cylinder.

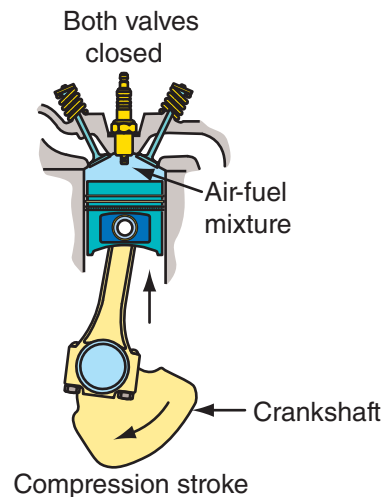


FIGURE 1.7 The air-fuel mixture is compressed as the piston moves up in the cylinder.

moves toward TDC, both of the valves are closed as the mixture is compressed to about $\frac{1}{8}$ of the volume it occupied when the piston was at BDC. In this case, the **compression ratio** is said to be 8:1 (**FIGURE 1.8**). If the mixture is compressed to $\frac{1}{12}$ its original volume, the compression ratio is then 12:1.

- **Power Stroke.** As the piston approaches TDC on its compression stroke, the compressed air-fuel mixture becomes very explosive (**FIGURE 1.9**). When the ignition system generates a spark at the spark plug, the fuel ignites. The air-fuel mixture burns,

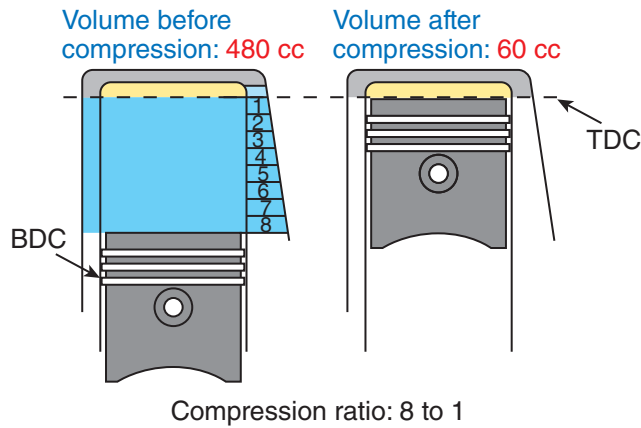


FIGURE 1.8 Compression ratio is a comparison of the volume of the air space above the piston at BDC and at TDC. In this example the compression ratio is 8:1.

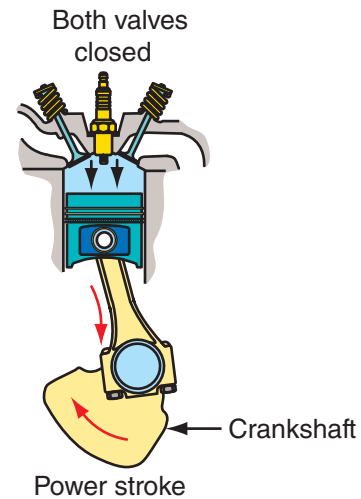


FIGURE 1.10 The air-fuel mixture ignites, pushing the piston down.

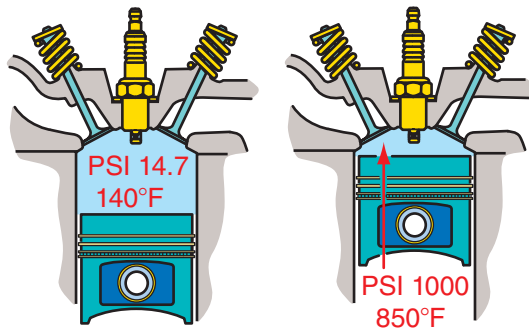


FIGURE 1.9 The air-fuel mixture heats up as it is compressed.

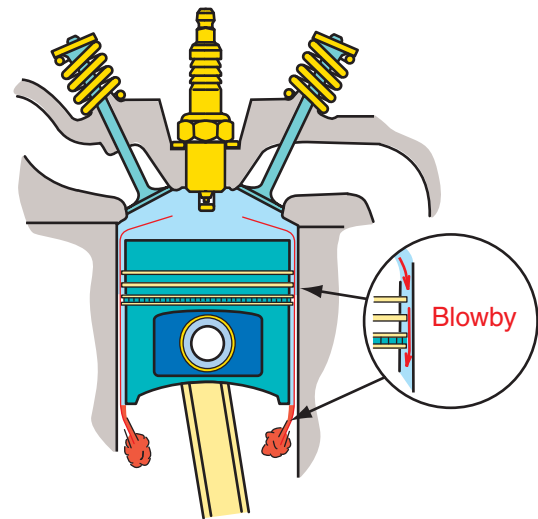


FIGURE 1.11 Blowby into the crankcase is leakage of gases past the piston rings. It starts in the combustion chamber in gasoline and diesel engines.

but it must not explode. As the mixture burns, it expands, forcing the piston to move down in the cylinder until it reaches BDC (**FIGURE 1.10**). The action of the piston turns the crankshaft to power the car. The power stroke is sometimes called the expansion stroke.

Some leakage of gases past the rings occurs during the power stroke. This leakage, called **blowby**, causes pressure in the crankcase (**FIGURE 1.11**). Blowby starts in the combustion chamber in both gasoline and diesel engines.

- **Exhaust Stroke.** As the piston nears BDC on the power stroke, the exhaust valve opens, allowing the spent gases to escape. Because the burning gases are still expanding, they are forced out through the open exhaust valve. As the crankshaft continues to turn past BDC, the piston moves up in the cylinder, helping to push the remaining exhaust gases out through the open

exhaust valve (**FIGURE 1.12**). A few degrees after the piston passes TDC, the exhaust valve closes. The entire four-stroke cycle repeats itself, starting again as the piston moves down on the intake stroke.

The four-stroke cycle is considerably more complicated than this simple explanation. When the engine is running, the timing of the opening and closing of the valves actually determines when each stroke effectively begins. Valve timing is discussed in much greater detail in Chapter 9.

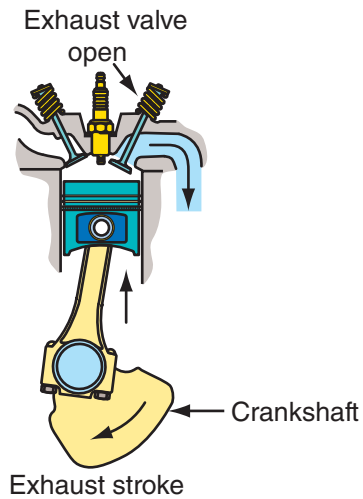


FIGURE 1.12 The exhaust valve opens and exhaust gases escape as the piston comes up.

CYLINDER ARRANGEMENT

Automobile and light truck engines have three, four, five, six, eight, or more cylinders. Cylinders are arranged in one of three ways: in-line, in a “V” arrangement, or opposed to each other (**FIGURE 1.13**). In-line six-cylinder and V6 engines are shown in **FIGURE 1.14**.

The V arrangement is popular with designers when an engine has more than four cylinders because this design can be considerably shorter in length.

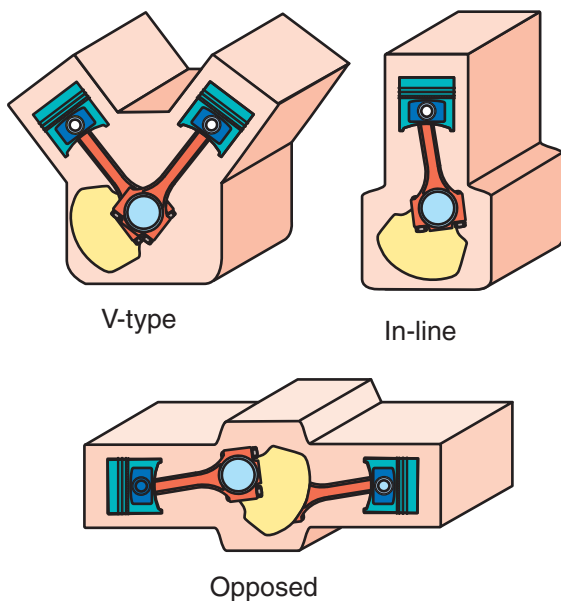


FIGURE 1.13 Cylinder arrangements.

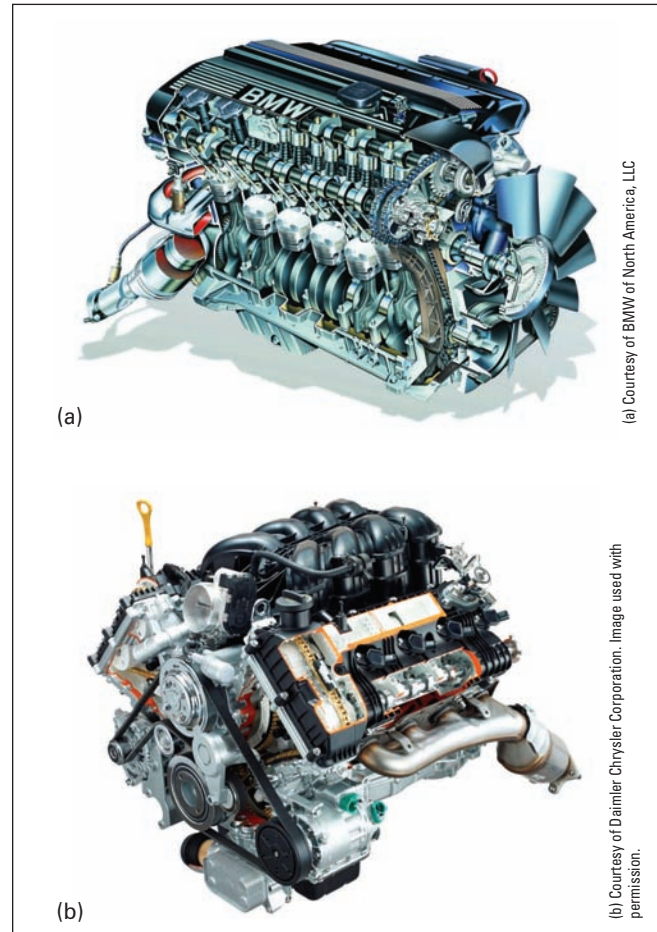
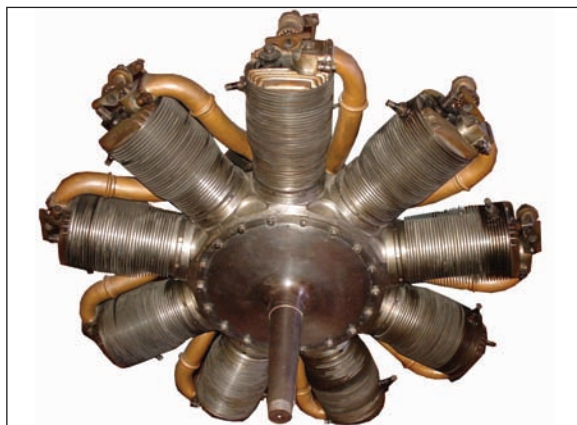


FIGURE 1.14 (a) Section view of an in-line six-cylinder engine. (b) Section view of a V8 engine.

Vintage Engines



In the first half of the 20th Century, before the jet age, airplane engines had cylinders arranged in a radial arrangement. (see figure below.)



A radial engine from a vintage airplane.

Photo courtesy of Tim Gilles.

A completely assembled V-type engine typically weighs less than an in-line engine with the same number of cylinders.

V-type engines have connecting rods from two cylinders on opposite sides of the engine that share one crankpin (see Chapter 11). This allows the engine block to have fewer supports for the crankshaft main bearings. An in-line six-cylinder engine might have seven main bearings; a V6 block is shorter and will typically have only four main bearings. A V8 block will usually have five main bearings.

VALVETRAIN

One complete four-stroke cycle requires the crankshaft to rotate two times. Two 360° crankshaft revolutions means the crankshaft travels a total of 720° to complete one cycle. During these two revolutions, each cylinder's intake and exhaust valves open once. The valves are opened by the camshaft, commonly called the "cam," which is considered the "heart" of the engine. The cam has lobes that are off-center and push against the valvetrain parts, causing the valves to open at precise times (FIGURE 1.15).

The camshaft controls the rate at which the engine breathes. Its design can be for best operation at maximum power and high speed, or for fuel economy and best low-speed operation. A production engine is an engine produced at the factory. Production engines are a compromise between these two concerns, and this is the reason many late-model vehicles use variable valve timing. Chapter 19 deals with different "cam grinds" and variable valve timing in detail.

Camshafts can be located either in the block (see FIGURE 1.15a) or in an overhead cam cylinder head (see FIGURE 1.15b). One or more camshafts are driven via crankshaft rotation using one of several combinations, including gears or sprockets and chains or belts. The crank must turn twice for every one turn of the cam, so there are half as many teeth on the crank drive as there are on the cam drive (FIGURE 1.16).

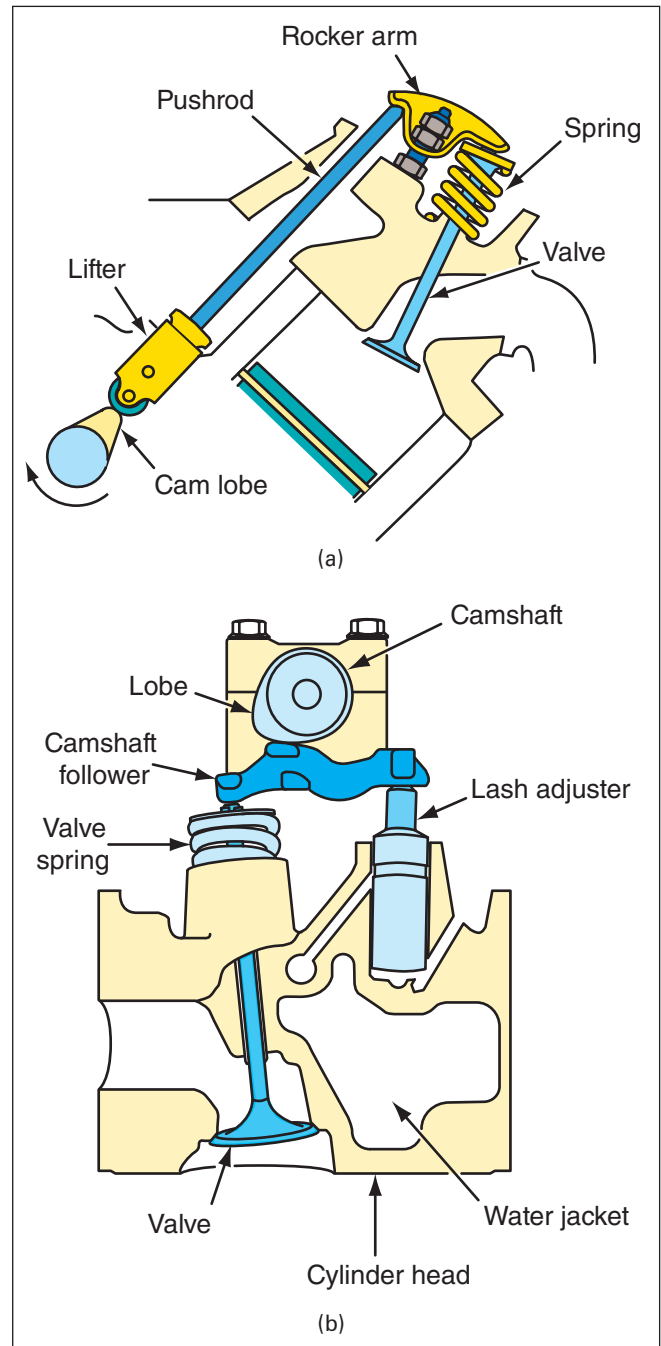


FIGURE 1.15 A cam lobe forces the valve open. (a) The cam-in-block design uses pushrods to open valves. (b) In the overhead cam design, the camshaft is located in the cylinder head.

Vintage Engines

A V-type engine uses a carburetor more efficiently than an in-line engine. This is because the intake manifold runner lengths are more equal (see Chapter 17).



CYLINDER BLOCK

The cylinder block is an intricate casting that includes oil galleries as well as jackets for coolant, which are commonly called *water jackets*. Cylinder blocks are made of cast iron or aluminum, cast into a mold. Many engine blocks today are made of aluminum with iron

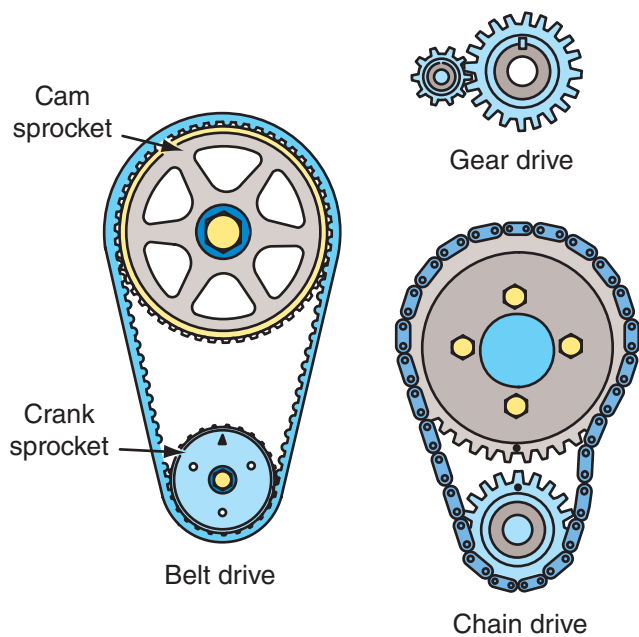


FIGURE 1.16 There are half as many teeth on the crank drive as there are on the cam drive.

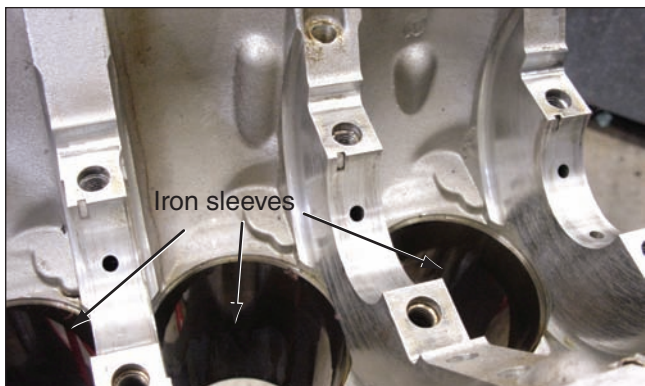


FIGURE 1.17 An aluminum block with cast iron sleeves.

cylinder bore liners called sleeves (**FIGURE 1.17**). This allows for the weight savings provided by aluminum, coupled with the durability and trueness of cast iron in the cylinder bore area. Some aluminum blocks do not have iron sleeves because aluminum cylinder wall surfaces can be made very hard.

There are different casting processes for engine parts, including sand and foam.

Sand Casting

The sand casting process uses a zircon sand mold made up of several sections, called cores (**FIGURE 1.18**). The mold is suspended in a container, or core box, with a

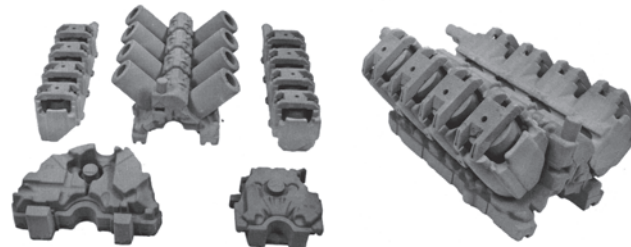


FIGURE 1.18 Sand casting cores.

liner that will provide the shape for the outside surface of the engine block. The mold is supported at several points around the outside of the core box; the supports will leave core holes in the finished block. Glue binders and a hardener hold the grains of sand together. They are mixed with the sand and blown into an iron master mold. Next a gas is injected to cure the sand into a hard core mold.

Most of today's blocks are made of aluminum alloy. When iron liners are used in aluminum blocks, they are inserted into the cylinder block core. They are heated before the pour to help them bond to the molten aluminum. Oil gallery areas of the core are coated with talcum powder to prevent sand from sticking to the aluminum during the pour. Otherwise, the sand might contaminate engine lubricating oil.

Molten aluminum is poured into the mold at 1,500°F. The mold cavity is filled from the bottom to prevent oxidation when the molten aluminum contacts air. If the mold was filled from the top, aluminum oxide would contaminate the pour. Following the pour, the aluminum casting is placed for a few hours in an oven for heat treating to strengthen the block. This process also bakes the binder that holds the sand mold together, loosening the sand. Then a robot rotates and vibrates the casting to expel the loose sand. The casting is rough machined before sending it to another plant that does the finish machining and assembly.

Lost Foam Casting

In another casting process, *lost foam casting (LFC)*, a foam mold pattern, is “lost” or burned up as it is replaced by molten metal during the pour. General Motors first experimented with LFC in 1982 and since then has refined the process for use in casting blocks, heads, and crankshafts. GM's now-defunct Saturn line used this process since its beginning in 1990 and GM has been routinely casting aluminum heads and blocks in its other divisions using LFC since 1999. With conventional sand casting, oil galleries must be

machined in the block casting. With LFC, the oil galleries and coolant passages can be cast into the part. Foam also provides a more accurate casting compared to sand casting. The completed casting is smoother in appearance and there are no parting lines. The mold is often made in pieces, which are fastened together using hot-melt glue to make up the finished model. These more intricate castings are possible because the pattern does not need to be removed as was the case with sand castings.

The LFC pattern is made of expendable polystyrene beads, otherwise known as Styrofoam. Patterns are made by injecting the beads into a die and then superheating them with steam to bond them together and form the finished mold. The foam pattern is coated with a refractory coating, which smoothes the surface of the pattern. Gates and risers are attached to the pattern to allow for the pouring and venting of the molten metal. Unlike the conventional sand casting process, which uses binders to hold the sand together, LFC uses dry, unbonded sand that is poured around and into the internal passages in the pattern. The sand is vibrated and compacted to thoroughly fill the voids around the pattern. During the pour, the molten metal replaces the pattern as it vaporizes. When the finished casting has cooled and become solid, the unbonded sand is dumped out. It can be reused, unlike conventional casting sand, which requires disposal.

A typical passenger car engine today uses a cast aluminum cylinder block with cast iron cylinder sleeves. The sleeves are ground to size on the outside diameter (O.D.), chilled, and pressed into machined holes in the aluminum block. This allows the iron liners to dissipate heat into the aluminum casting and water jackets. The inside diameter (I.D.) of the cast iron sleeves is bored and honed to approximately 1.5 mm thick when finished, providing an excellent wear surface for the piston rings.

Core Plugs and Gussets

Gussets to add strength are cast in strategic positions on the block. Core holes in the block and head(s) are closed off with core plugs (**FIGURE 1.19**). Core plugs are usually made of steel or brass, although rubber and copper expandable plugs are available, too. Brass core plugs are superior because they do not rust. Brass plugs are not used in new cars because of their extra cost and because new engines are filled with coolant, which prevents rust. Core plugs are sometimes referred to as expansion plugs, welsh plugs, freeze plugs, or soft plugs.

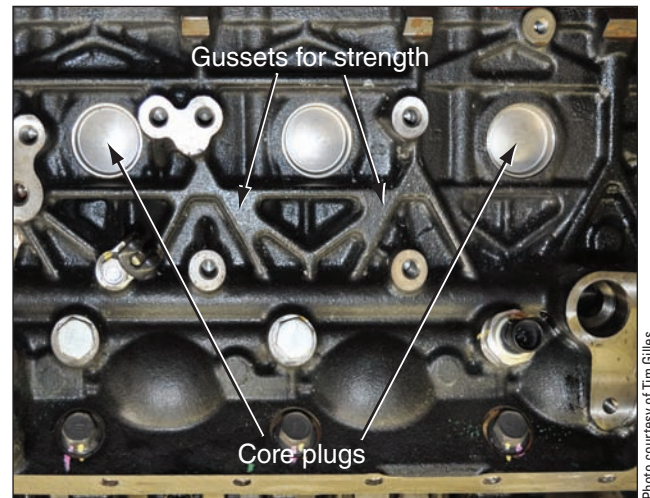


FIGURE 1.19 Core plugs.

V-Type Cylinder Banks

On V-type blocks, cylinders are cast in two rows called left and right banks.



NOTE

The location of the left and right banks is determined when viewing from the transmission end of the engine.

V8 blocks are cast with the cylinder banks separated by a 90° angle. V6 blocks have either 60° or 90° between banks. There are also unusual engine designs, such as Volkswagen's V6, which has 15° between banks.

There are *big block* and *small block* engine designs. Smaller, lighter blocks are more popular in passenger cars because of their fuel efficiency. Some intake manifolds cover the area between the heads known as the *valley* (**FIGURE 1.20**), whereas others use covers and a separate intake plenum.

A complete block assembly with the entire valvetrain (cylinder heads and related parts) included is called a *long block*.

Short Block and Long Block

The cylinder block assembly (without the heads installed) is called a *short block*. The short block includes the crankshaft, piston and rod assembly, and all bearings. On pushrod engines, the camshaft, timing sprockets, and timing chain are also part of the short block (**FIGURE 1.21**).