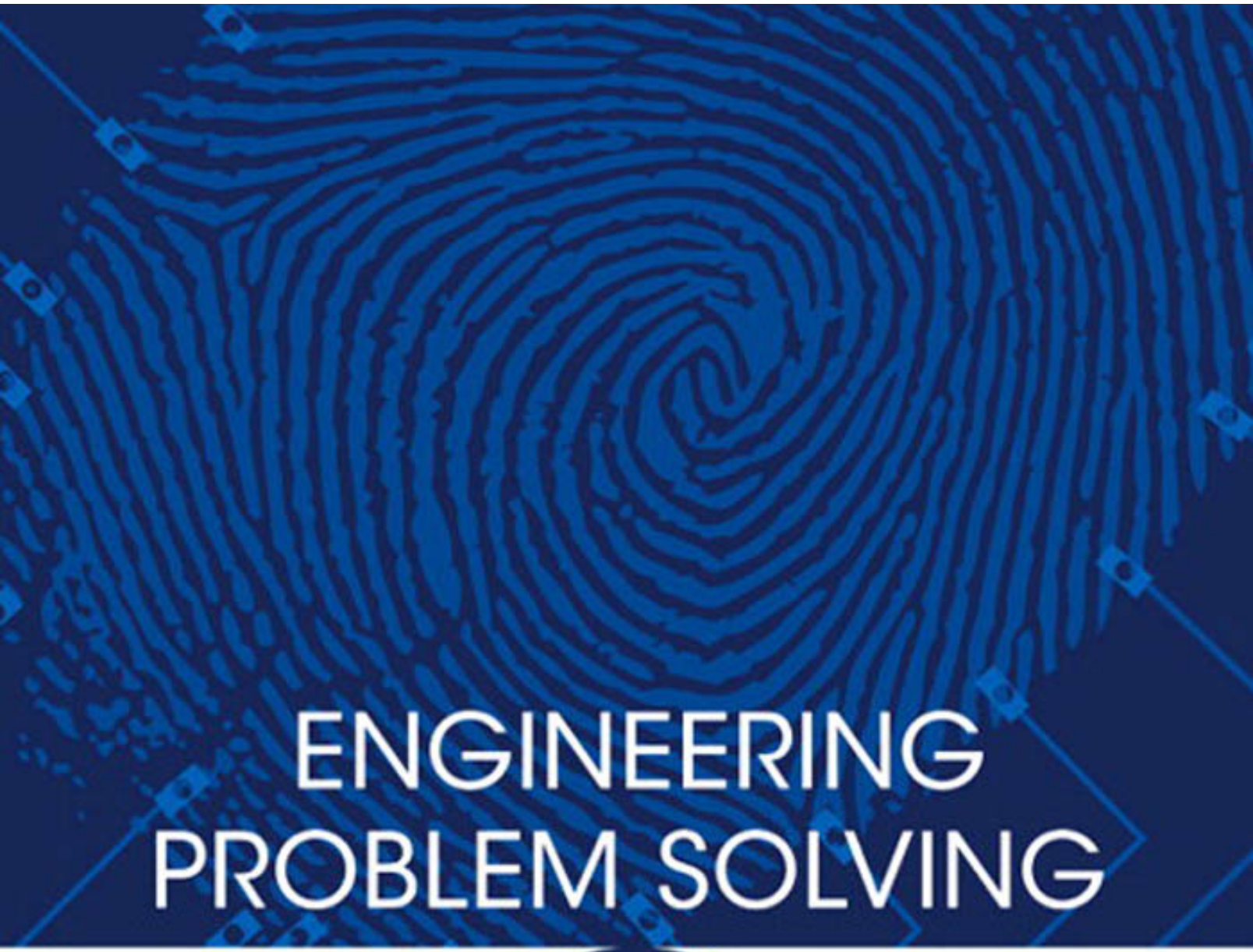

# ENGINEERING PROBLEM SOLVING WITH C

FOURTH EDITION

DELORES M. ETTER

# COMMON C FUNCTIONS

Elementary Math Functions *(Text page 66)*

```
ceil(x)     exp(x)      fabs(x)     floor(x)
log(x)      log10(x)    pow(x,y)    sqrt(x)
```

Trigonometric Functions *(Text page 67)*

```
acos(x)     asin(x)     atan(x)     atan2(y,x)
cos(x)      sin(x)      tan(x)
```

Character Functions *(Text page 71)*

```
isalnum(c)    isalpha(c)    iscntrl(c)
isdigit(c)    isgraph(c)    islower(c)
isprint(c)    ispunct(c)    isspace(c)
isupper(c)    isxdigit(c)   tolower(c)
toupper(c)
```

Character String Functions *(Text pages 309-310)*

```
strcat(s,t)      strchr(s,c)      strcmp(s,t)
strcpy(s,t)      strcspn(s,t)     strlen(s)
strncat(s,t,n)   strcmp(s,t,n)    strncpy(s,t,n)
strpbrk(s,t)     strrchr(s,c)     strspn(s,t)
strstr(s,t)
```

## OPERATOR PRECEDENCE

| Precedence | Operation | Associativity | Text pages |
|---|---|---|---|
| 1 | `( ) [ ]` | innermost first | pages 45, 47, 208 |
| 2 | `++ -- + - ! (type) & *` | unary, right to left | pages 45, 46, 49, 56, 286 |
| 3 | `* / %` | left to right | page 45 |
| 4 | `+ -` | left to right | page 45 |
| 5 | `< <= > >=` | left to right | page 92 |
| 6 | `== !=` | left to right | page 92 |
| 7 | `&&` | left to right | page 93 |
| 8 | `\|\|` | left to right | page 93 |
| 9 | `?:` | right to left | page 98 |
| 10 | `= += -= *= /= %=` | right to left | page 50 |
| 11 | `,` | left to right | page 96 |

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# ENGINEERING PROBLEM SOLVING WITH C

## FOURTH EDITION

Delores M. Etter
Department of Electrical Engineering
*Southern Methodist University*
*Dallas, TX*

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*In memory of my dearest Mother,*
*Muerladene Janice Van Camp*

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# PREFACE

Engineers use computers to solve a variety of problems ranging from the evaluation of a simple function to solving a system of nonlinear equations. Thus, **C has become the language of choice for many engineers and scientists**, not only because it has powerful commands and data structures, but also because it can easily be used for system-level operations. Since C is a language that a new engineer is likely to encounter in a job, it is a good choice for an introduction to computing for engineers. Therefore, this text was written to introduce engineering problem solving with the following **objectives**:

- to develop a **consistent methodology for solving engineering problems**;
- to present the **fundamental capabilities of C**, the language of choice for many practicing engineers and scientists; and
- to illustrate the problem-solving process with C through a variety of **interesting engineering examples and applications**.

To accomplish these objectives, **Chapter 1 presents a five-step process** that is used consistently in the rest of the text for solving engineering problems. **Chapters 2 through 7 present the fundamental capabilities of C** for solving engineering problems. **Chapter 8 is an introduction to object-oriented programming using C++**. Object-oriented programming is gaining popularity in many fields of engineering and science, and is likely to be seen in the workplace. Throughout all these chapters, we present a large number of examples from many different engineering and scientific disciplines. The solutions to these examples are developed using the five-step process and ANSI C (and ANSI C++ in Chapter 8), which are the standards developed by the American National Standards Institute.

## Changes to the Fourth Edition

- The new theme for this edition is Crime Scene Investigation (CSI). Learning about the technology behind crime scene investigation is not only very interesting, but it provides a number of problems for which we can develop C program solutions.
- Section 1.2 has been rewritten to include discussion on current topics such as cloud computing and kernels.
- A new four-color insert has been added to define an important area of crime scene investigation—biometrics. Biometrics is a term used to describe the physical or behavioral characteristics that can be used to identify a person. The insert includes discussion on fingerprints, face recognition, iris recognition, DNA, and speech recognition.
- Each chapter begins with a photo and a related discussion on a technology used in crime scene investigation. Then, within each chapter after Chapter 1, an associated application section has been added so that in addition to learning all the key features of C, you will also learn about forensic anthropology, face recognition and surveillance video, iris recognition, speech analysis and speech recognition, DNA analysis, fingerprint recognition, and hand recognition. In these application sections, we develop a C solution to a problem related to the crime scene technology.

- New Modify! problems have been added to each new application.
- The material in Chapter 8 on C++ has been updated to reflect the new C++ standards.

## Prerequisites

No prior experience with the computer is assumed. The **mathematical prerequisites are college algebra and trigonometry**. Of course, the initial material can be covered much faster if the student has used other computer languages or software tools.

## Course Structure

The material in these chapters was selected to provide the basis for a **one-term course in engineering computing**. These chapters contain the essential topics of mathematical computing, character data, control structures, functions, arrays, pointers, and structures. Students with a background in another computer language should be able to complete this material in less than a semester. A minimal course that provides only an introduction to C can be designed using the nonoptional sections of the text. (Optional sections are indicated in the table of contents.) There are three ways to use the text, along with the recommended chapter sections:

- **Introduction to C**. Many freshman courses introduce the student to several computer tools in addition to a language. For these courses, we recommend covering **the nonoptional sections of Chapters 1 through 5**. This material introduces students to the fundamental capabilities of C, and they will be able to write substantial programs using mathematical computations, character data, control structures, functions, and arrays.
- **Problem solving with C**. In a semester course devoted specifically to teaching students to **master the C language**, we recommend covering **all non-optional sections of Chapters 1 through 7**. This material covers all the fundamental concepts of the C language, including mathematical computations, character data, control structures, functions, arrays, pointers, and structures.
- **Problem solving with C and numerical techniques**. A number of sections included in the text cover common numerical techniques, such as linear interpolation, linear modeling, finding roots of polynomials, and solutions to simultaneous equations. Including these along with the sections on the C language provides a strong combination for students who may need to use numerical techniques in their course work. This coverage would include **all sections of Chapters 1 through 7**.

Many students may be interested in reading about some of the additional **object-oriented features found in C++**. We recommend that students cover all non-optional sections of Chapters 1 through 7 before reading **Chapter 8**.

## Problem-Solving Methodology

The emphasis on engineering and scientific problem solving is an integral part of the text. Chapter 1 introduces **a five-step process** for solving engineering problems using the computer. This five-step problem-solving process was developed by the author of this text early in her academic career, and it has been successfully used by the many thousands of students who

were in her classes or used one of her textbooks. This successful process has also been adopted by a number of other authors. The five steps are:

1. **State the problem clearly.**
2. **Describe the input and output information.**
3. **Work a simple example by hand.**
4. **Develop an algorithm and convert it to a computer program.**
5. **Test the solution with a variety of data.**

To reinforce the development of problem-solving skills, each of these five steps is clearly identified each time that a complete engineering problem is solved. In addition, **top-down design and stepwise refinement are presented with the use of decomposition outlines, pseudocode, and flowcharts**.

## Engineering and Scientific Applications

Throughout the text, emphasis is placed on incorporating real-world engineering and scientific examples and problems. Some examples to illustrate this **wide variety of engineering applications are**

- salinity of sea water
- velocity computation
- amino acid molecular weights
- wind tunnels
- ocean wave interactions
- ozone measurements
- sounding rocket trajectory
- suture packaging
- timber regrowth
- critical path analysis
- weather balloons
- iceberg tracking
- instrumentation reliability
- system stability
- component reliability
- flight simulator wind speeds
- hurricane categories
- molecular weights
- speech signal analysis
- terrain navigation
- electrical circuit analysis

- power plant data
- cryptography
- temperature distribution
- El Niño–Southern Oscillation
- seismic event detection
- tsunami analysis
- surface wind directions

In addition, each chapter begins with a discussion of some aspect of the **new theme**. Later in the chapter, we solve **a problem that relates to the introductory discussion on the technology behind crime scene investigation**. These problems address the following applications:

- forensic anthropology
- face recognition and surveillance video
- iris recognition
- speech analysis
- DNA analysis
- fingerprint recognition
- hand recognition

## ANSI C

The statements presented and all programs developed use the **C standards** developed by the American National Standards Institute. By using ANSI C, students learn to write **portable code** that can be transferred from one computer system to another.

## Software Engineering Concepts

Engineers and scientists are expected to develop and implement **user-friendly and reusable computer solutions**. Learning software engineering techniques is crucial to successfully developing these computer solutions. **Readability and documentation** are stressed in the development of programs. Additional topics that relate to software engineering issues are discussed throughout the text and include issues such as **software life cycle, portability, maintenance, modularity, recursion, abstraction, reusability, structured programming, validation, and verification**.

## Four Types of Problems

Learning any new skill requires practice at several different levels of difficulty. Four types of exercises are used throughout the text to develop problem-solving skills. The first set of exercises is **Practice! problems**. These are short-answer questions that **relate to the section of the material just presented**. Most sections are immediately followed by a set of Practice! problems so that students can determine whether they are ready to continue to the next section. Complete solutions to all the Practice! problems are included at the end of the text.

The **Modify! problems** are designed to provide **hands-on experience with the programs developed in the Problem Solving Applied sections**. In these sections, we develop a

complete C program using the five-step process. The Modify! problems ask students to run the program with different sets of data to test their understanding of how the program works and of the relationships among the engineering variables. These exercises also ask the students to make simple modifications to the program and then run the program to test their changes. Selected solutions to some of the Modify! problems are included at the end of the text.

Each chapter ends with two sets of problems. The **Short-Answer problems** include **true/false problems, multiple choice problems, matching problems, syntax problems, fill-in-the-blank problems, memory snapshot problems, program output problems, and program segment analysis problems**. Complete solutions to all the Short-Answer problems are included at the end of the text.

The final set of problems in each chapter (except for Chapter 1) are **Programming problems**. These are **new problems that relate to a variety of engineering applications**. The level of difficulty ranges from very straightforward to longer project assignments. Each problem requires that the students develop a complete C program or function. Selected solutions to the programming problems are included at the end of the text. Complete solutions to the programming problems are available for instructors.

## Study and Programming Aids


**Margin notes** are used to help the reader not only identify the important concepts, but also to easily locate specific topics. In addition, margin notes are used to identify programming style guidelines and debugging information. **Style guidelines** show students how to write C programs that incorporate good software discipline; **debugging notes** help students recognize common errors so that they can avoid them. The programming style notes are indicated with a margin note, and the debugging notes are indicated with a bug icon. Each Chapter Summary contains a summary of the style notes and debugging notes, plus a list of the **Key Terms** from the chapter and a **C Statement Summary** of the new statements to make the book easier to use as a reference. The combined list of these key terms, along with their definitions, is included in a **Glossary** at the end of the text. In addition, the **inside of the front cover contains common functions and the precedence table; the inside of the back cover contains examples of most of the C statements**.

## Optional Numerical Techniques

**Numerical techniques** that are commonly used in solving engineering problems are also discussed in the text, and they include **interpolation, linear modeling (regression), root finding, and the solution to simultaneous equations**. The concept of a matrix is also introduced and then illustrated using a number of examples. All of these topics are presented **assuming only a trigonometry and college algebra background**.

## MATLAB and Visualization

The **visualization** of the information related to a problem and its solution is a **critical component in understanding and developing the intuition necessary to be a creative engineer**. Therefore, we have included a number of plots of data throughout the text to illustrate the relationships of the information needed to solve specific problems. All the plots were

generated **using MATLAB, a powerful environment for numerical computations, data analysis, and visualization**. We have also included an appendix that shows how to generate a simple plot from data that have been stored in a text file; this text file could be generated with a word processor or it could be generated by a C program.

## Appendices

To further enhance reference use, the appendices include a number of important topics. Appendix A contains a discussion of the components in the **ANSI C Standard Library**. Appendix B presents the **ASCII character codes**. Appendix C shows how to use **MATLAB to plot data** from ASCII files; this allows students to generate ASCII files with their C programs and to plot the values using MATLAB.

## Nontechnical Skills

The engineer of the twenty-first century needs many skills and capabilities in addition to the technical ones learned in an engineering program. In Chapter 1, we present a brief discussion on some of these nontechnical skills that are so important to engineers. Specifically, we discuss developing **both oral and written communications skills**, understanding the **design/process/manufacture path** that takes an idea and leads to a product, working in **interdisciplinary teams**, understanding the **world marketplace**, the importance of **synthesis as well as analysis**, and the importance of **ethics and other societal concerns** in engineering solutions. While this text is devoted primarily to teaching problem-solving skills and the C language, we have attempted to tie these other nontechnical topics into many of the problems and discussions in the text.

## Additional Resources

All instructor and student resources can be accessed at www.pearsonhighered.com/etter. Here, students can access student data files for the book, and instructors can register for the password-protected Instructor's Resource Center. The IRC contains complete solutions to all of the Programming Projects found at the end of each chapter, and a complete set of PowerPoint lecture slides.

## Acknowledgments

A number of people have made significant contributions to this text. Students are always the best judge of "what works" and "what doesn't work." I appreciate the feedback from students who had never used the computer when they started this text, to undergraduates who already knew another language, and to graduate students who wanted to use C to do their research analysis. The comments and suggestions from these students greatly improved the text.

A constructive, but critical, review is extremely important in improving a text. The many reviewers who provided this critical guidance included Murali Narayanan (Kansas State University), Kyle Squires (Arizona State University), Amelia Regan (University of California at Irvine), Hyeong-Ah Choi (George Washington University), George Friedman (University of Illinois, Champaign), D. Dandapani (University of Colorado, Colorado Springs), Karl Mathias (Auburn University), William Koffke (Villanova University), Paul Heinemann

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*Delores M. Etter*
*Department of Electrical Engineering*
*Southern Methodist University*
*Dallas, TX*

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# CONTENTS



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# ENGINEERING APPLICATIONS

## Genetic Engineering



## Manufacturing Engineering



## Mechanical Engineering



## Ocean Engineering

# ENGINEERING PROBLEM SOLVING WITH C

# CHAPTER ONE


## *Crime Scene Investigation*

We are all familiar with the investigation of crime scenes, from movies, books, and TV shows. However, you may not be aware of the technology behind many aspects of crime scene investigation. Learning about this technology is not only very interesting, but it also provides a theme that we will use throughout the text as we are learning about the C language. Starting with Chapter 2, we present in each chapter an aspect of crime scene investigation and explain more about the technology behind it. We then present a problem related to that aspect of crime scene investigation and solve the problem using a C language program. Additional information related to crime scene investigation is included in the four-page color insert that defines biometrics and gives a number of examples of how biometrics and related technology are used to identify a person.

# ENGINEERING PROBLEM SOLVING

## CHAPTER OUTLINE



## OBJECTIVES

***In this chapter, we introduce you to***

- recent outstanding engineering achievements,
- the changing engineering environment and the nontechnical skills needed to successfully adapt to this environment,
- computer systems, in terms of both hardware and software, and
- a five-step problem-solving technique that we will use throughout the text.

## 1.1 Engineering in the 21st Century

Engineers solve real-world problems using scientific principles from disciplines that include computer science, mathematics, physics, biology, and chemistry. It is this variety of subjects, and the challenge of real problems, that makes engineering so interesting and so rewarding. In this section, we present some of the outstanding engineering achievements of recent years. We also consider some of the nontechnical skills and capabilities needed by the engineers of the twenty-first century.

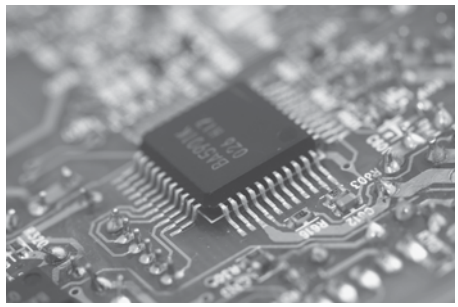
### Recent Engineering Achievements

10 engineering achievements

Since the development of the computer in the late 1950s, a number of significant engineering achievements have occurred. In 1989, the National Academy of Engineering selected the **10 engineering achievements** that it considered to be the most important accomplishments during the previous 25 years. These achievements illustrate the multidisciplinary nature of engineering and demonstrate how engineering has improved our lives and expanded the possibilities for the future while providing a wide variety of interesting and challenging careers. We now briefly discuss these 10 achievements.

Microprocessor

The development of the **microprocessor**, a tiny computer smaller than a postage stamp, is one of the top engineering achievements of the last 25 years. Microprocessors are used in electronic equipment, household appliances, toys, and games, as well as in automobiles, aircraft, and space shuttles, because they provide powerful yet inexpensive computing capabilities. Microprocessors also provide the computing power inside calculators and smart phones.



**MICROPROCESSOR**

Moon landing

Several of the top 10 achievements relate to the exploration of space. The **moon landing** was probably the most complex and ambitious engineering project ever attempted. Major breakthroughs were required in the design of the Apollo spacecraft, the lunar lander, and the three-stage Saturn V rocket. Even the design of the spacesuit was a major engineering project that resulted in a system that included a three-piece suit and backpack, which together weighed 190 pounds. The computer played a key role not only in the design of the various systems, but also in the communications required during an individual moon flight. A single flight required the coordination of over 450 people in the launch control center and over 7000 others on nine ships, in 54 aircraft, and at stations located around the earth.

**MOON LANDING**

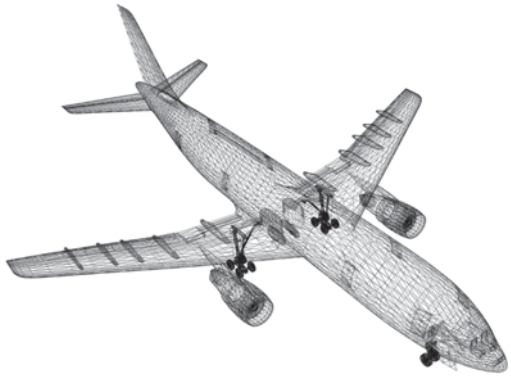
Application satellites

The space program also provided much of the impetus for the development of **application satellites** that are used to provide weather information, relay communication signals, map uncharted terrain, and provide environmental updates on the composition of the atmosphere. The Global Positioning System (GPS) is a constellation of 24 satellites that broadcasts position, velocity, and time information worldwide. GPS receivers measure the time it takes for signals to travel from the GPS satellite to the receiver. Using information received from four satellites, a microprocessor in the receiver can determine very precise measurements of the receiver's location; its accuracy varies from a few meters to centimeters, depending on the computation techniques used.

SATELLITE

Computer-aided design and manufacturing

Another of the top engineering achievements recognizes the contributions of **computer-aided design and manufacturing** (CAD/CAM). CAD/CAM has generated a new industrial revolution by increasing the speed and efficiency of many types of manufacturing processes. CAD allows the design to be done using the computer, which then produces the final schematics, parts lists, and computer simulation results. CAM uses design results to control machinery or industrial robots to manufacture, assemble, and move components.



COMPUTER-AIDED DESIGN

Jumbo jet

The **jumbo jet** originated from the U.S. Air Force C-5A cargo plane that began operational flights in 1969. Much of the success of the jumbo jets can be attributed to the high-bypass fanjet that allows them to fly farther with less fuel and with less noise than previous jet engines. The core of the engine operates like a pure turbojet, in which compressor blades pull air into the engine's combustion chamber. The hot expanding gas thrusts the engine forward, and at the same time spins a turbine that drives the compressor and the large fan on the front of the engine. The spinning fan provides the bulk of the engine's thrust.

**JUMBO JET**

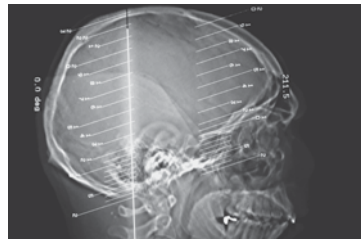
Advanced composite materials

The aircraft industry was also the first industry to develop and use **advanced composite materials** that consist of materials that can be bonded together in such a way that one material reinforces the fibers of the other material. Advanced composite materials were developed to provide lighter, stronger, and more temperature-resistant materials for aircraft and spacecraft. New markets for composites now exist in sporting goods. For example, downhill snow skis use layers of woven Kevlar fibers to increase their strength and reduce weight, and golf club shafts of graphite and epoxy are stronger and lighter than the steel in conventional shafts. Composite materials are also used in the design of prosthetics for artificial limbs.

Computerized axial tomography

The areas of medicine, bioengineering, and computer science were teamed for the development of the CAT (**computerized axial tomography**) scanner machine. This instrument can generate three-dimensional images or two-dimensional slices of an object using X rays that are generated from different angles around the object. Each X ray measures a density from its angle, and complicated computer algorithms combine the information from all the X rays to reconstruct a clear image of the inside of the object. CAT scans are routinely used to identify tumors, blood clots, and brain abnormalities.

ADVANCED COMPOSITE MATERIALS



CAT SCAN

Genetic engineering

**Genetic engineering**, combining the work of geneticists and engineers, has resulted in many new products, ranging from insulin, to growth hormones, to infection-resistant vegetables. A genetically engineered product is produced by splicing a gene that produces a valuable substance from one organism into another organism that will multiply itself and the foreign gene along with it. The first commercial genetically engineered product was human insulin, which appeared under the trade name Humulin. Current work is investigating the use of genetically altered microbes to clean up toxic waste and to degrade pesticides.