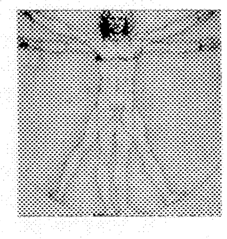
Chapter 4



COMPUTERS IN ENGINEERING DESIGN AND MANUFACTURING

LEARNING OBJECTIVES

Upon completion of this chapter you will be able to:

1. Recognize the significance of computer-integrated manufacturing (CIM) in modern production.
2. Define CAD/CAM hardware and software as well as their respective configurations and capabilities.
3. Understand the role hardware plays in CAD/CAM, CIM, and computer-aided engineering (CAE).
4. Demonstrate an understanding of how data is stored on magnetic disk, magnetic tape, and CD's and in the computer itself.
5. Identify the components of a CAD workstation and their functions.
6. Develop a broad understanding of applications software.
7. Demonstrate knowledge of computer numerical control (CNC) part programming and of robotic integration into the manufacturing production process.

4.1 INTRODUCTION

Anyone wishing to enter industry as an engineer or a designer must be familiar with how profoundly the computer is altering the factory floor and the engineering office (Fig. 4.1). **Computer-aided engineering (CAE), computer-aided manufacturing (CAM),** and **computer-aided design and drafting (CAD)** are collectively called **computer-integrated manufacturing (CIM).** CIM refers to the integration of all phases of production, from design to manufacturing, via the computer. The term **CAD/CAM** refers to the use of computers to integrate the design and production process to improve productivity. CAM includes **computer numerical control (CNC)** machining (Fig. 4.2) and the integration of robotics into manufacturing and production.

In the 1990s, the role of CAM in a CAD/CAM environment will continue to increase, especially as an integrator in helping firms achieve the benefits of computer-integrated manufacturing. The CIM concept encompasses many manufacturing, computer-based automation applications. CIM can be thought of as a closed-loop feedback system whose primary inputs are product requirements and whose primary outputs are finished products. CIM is comprised of a combination of software and hardware for product design, production planning/control, and manufacturing processes.

CAD/CAM is the primary CIM integrator for computer-based applications in manufacturing. CAD/CAM's integration ability rests on a foundation of common engineering and manufacturing information. This allows engineering to define a part model (Fig. 4.3) and manufacturing to use that same definition to produce the product.

Product design simplification and other factory simplifications, such as **just-in-time (JIT)** programs, are normally completed before large-scale integration is introduced in a company. JIT programs are developed to bring the correct

FIGURE 4.1 Design and Engineering Office

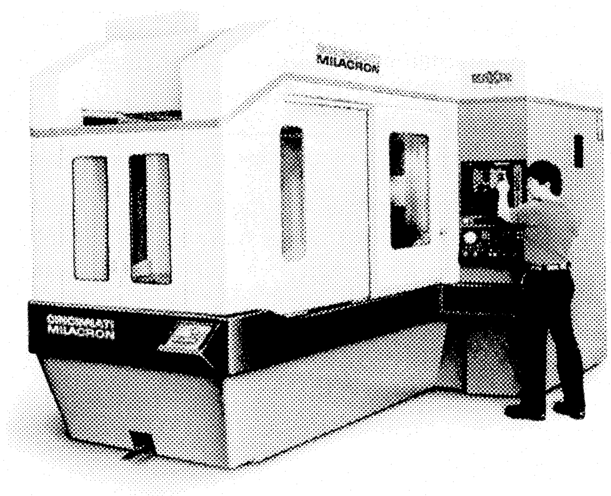


FIGURE 4.2 CNC Machining Center

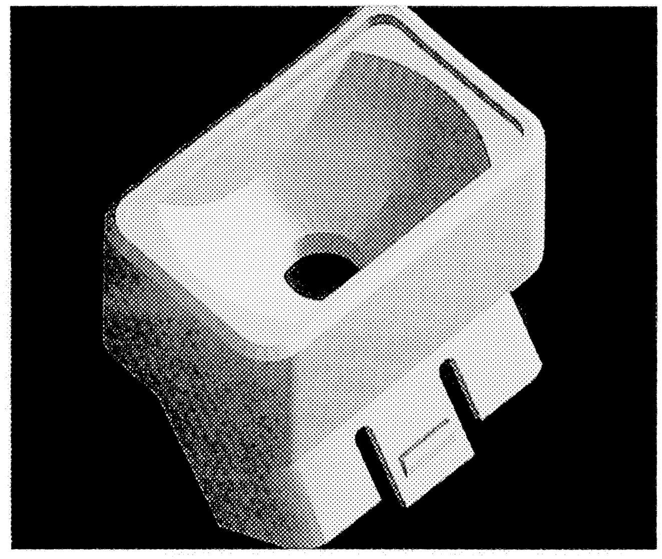


FIGURE 4.3 3D Part Design

The method of design determines how well the design fits into a CIM environment. CAD easily flows into CAM; but once the factory is dependent on CAD input, it will be less able to accept manual designs.

CIM also encompasses flexible manufacturing processes and procedures. Flexible manufacturing depends on parts commonality programs, which strive to minimize the number of part types and maximize commonality throughout the product line. If a factory (Fig. 4.4) is to be flexible, every manufacturing workstation must be able to work on a wide range of products. This is possible only when the parts are common enough so as always to be available where needed. Standardization of design features is also required for flexible manufacturing. Different parts will be traveling along the same materials handling systems and will be built by the part or material to the appropriate place at the required time. This eliminates excessive and costly warehousing of material and parts and streamlines the production and materials/parts handling process. JIT programs depend on parts standardization: The fewer the part variations and types of parts, the simpler the flow of material and parts within the factory. JIT programs therefore reduce the **work-in-progress (WIP)** inventory. This is why **design for manufacturability (DFM)** is usually the first step when initiating a CIM program. DFM simplifies designs, reduces the number of part types, and thus streamlines the flow of parts in a factory.

FIGURE 4.4 Computerized Advanced Electronic Assembly and Inspection Stations

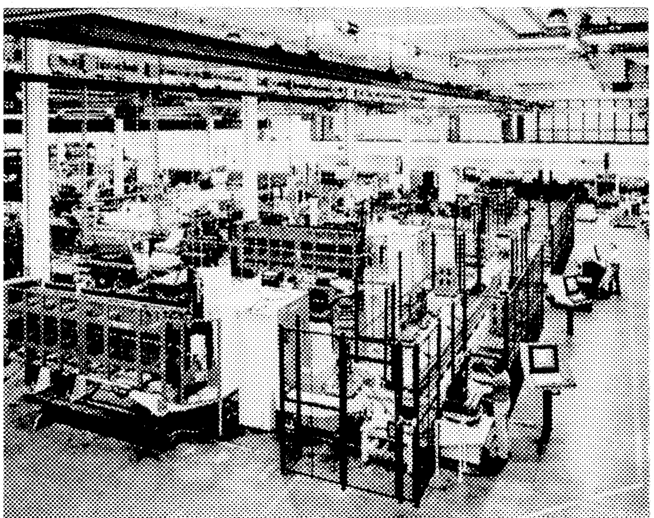


FIGURE 4.5 Flexible Manufacturing System

same tools and equipment. Figure 4.5 shows a factory employing a flexible manufacturing system for production. In it, a number of manufacturing workstations are linked by a *materials handling system that moves the part from station to station, where one or more machining or processing operations are performed.*

Design for manufacturability, just-in-time programs, flexible manufacturing, and other automation concepts are driven by the original CAD input. Automation using CIM places constraints on the design based on DFM principles. Because the trend is toward more sophisticated factories, good DFM practices will be required by the designer and should be understood by engineers. The extensive use and integration of the computer in the design and manufacturing process will continue to increase throughout your career in industry.

4.2 CAD TECHNOLOGY

Engineers and designers create their designs electronically with a CAD system, view the designs on a display (Fig. 4.6), make quick and easy revisions, and then command the system to draw the design on a plotter. The completed parts [Figs. 4.6(a) and (b)] can be combined in an assembly [Fig. 4.6(c)] and displayed as shaded models [Fig. 4.6(d)]. Interactive graphics means the ability to perform graphics operations directly on the computer with immediate feedback. You need not be a computer programmer or typist to use a CAD system effectively. However, good typing skills do improve command input. Built-in programming knowledge of some CAD programs using EDIT and AutoLISP is also helpful.

The CAD operator also has constant access to processors and storage units that provide all the capabilities of a calculator and all the reference information of a library: Data is supplied for both trigonometric and geometric construction. Symbols, patterns, drawing segments, minidrawings, and even complete drawings can be stored and reused. You can electronically erase selected portions, shrink or enlarge a part's geometry, copy and edit portions of existing parts, and mirror, copy, and rotate complete parts or selected geometry. To accomplish this, a combination of hardware and software is required.

Hardware includes tablets, display devices, keyboards, input devices, processors, data storage components, plotters, printers, and all the other physical parts of a complete system. The hardware itself does nothing unless directed to do so by a set of instructions.

Software includes the sets of instructions that control the hardware. Software is usually provided by the CAD manufacturer and is already stored on the computer or available on disks, ready for use.

The input, processing, output, and storage hardware elements are interconnected via cables or telecommunications. Interactive CAD is either a stand-alone system or a processor with remote input/output units attached, such as on a PC-based CAD system (Fig. 4.7). System configuration and component terminology vary among CAD manufacturers.

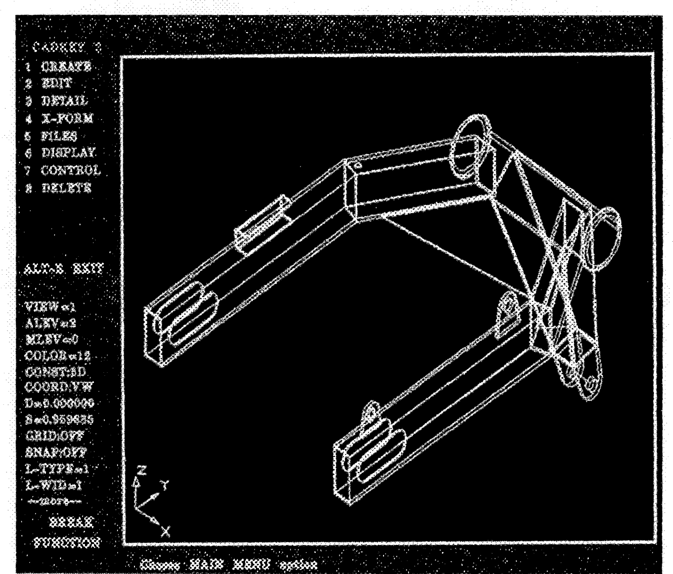
An operator of a CAD system must be able to understand the system's hardware configuration and its software capabilities. The following is essential in order to understand and use a CAD system effectively in engineering design:

1. Knowledge of drafting standards and procedures
2. Specific engineering discipline conventions
3. Actual industrial applications
4. Software language for a particular CAD system package

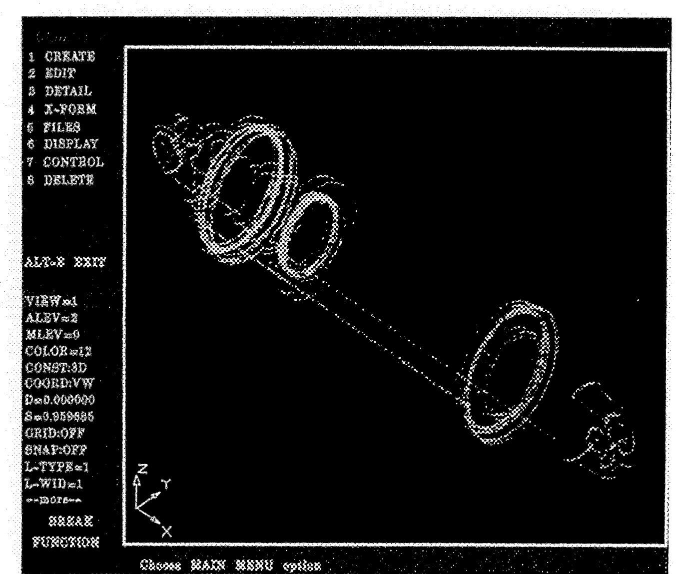
Software programs are available for all areas of engineering and design. Most systems can be mastered with training, but the specifics of the design area (piping, architecture, electronics, mechanical, structural, etc.) must be learned through a combination of education and experience.

The heart of any CAD system is the design **terminal** or **workstation** (Figs. 4.7 and 4.8). Here, the engineer/designer interacts with the system to develop a part design in detail, monitoring the work constantly on a display screen. By issuing commands to the system and responding to messages from the system, you create a design by manipulating, modifying, and refining it. Once the design is final, a command to the system will make a hard copy or guide computer-controlled machine tools in manufacturing and testing the part. *Hard copy* can be any level of graphics, from a simple check copy to a full-scale ink plot of the drawing on vellum paper. The PC-based system in Figure 4.7 is linked to a pen plotter for outputting drawings.

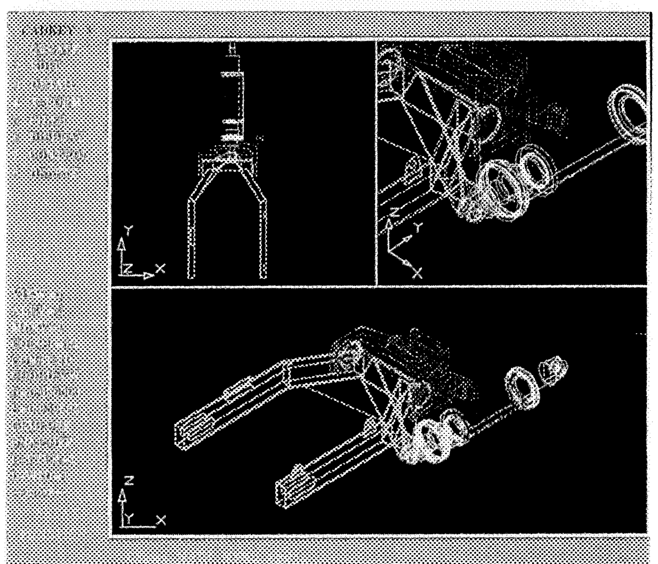
As a design is developed, the software accumulates and stores product-related data—identifying the precise location, dimensions, descriptive text, and other properties of every element that helps define the new part. Using the design data, the system can perform complex engineering analyses, generate special lists and reports, and detect and flag (note/indicate) design flaws before the part is manufactured.



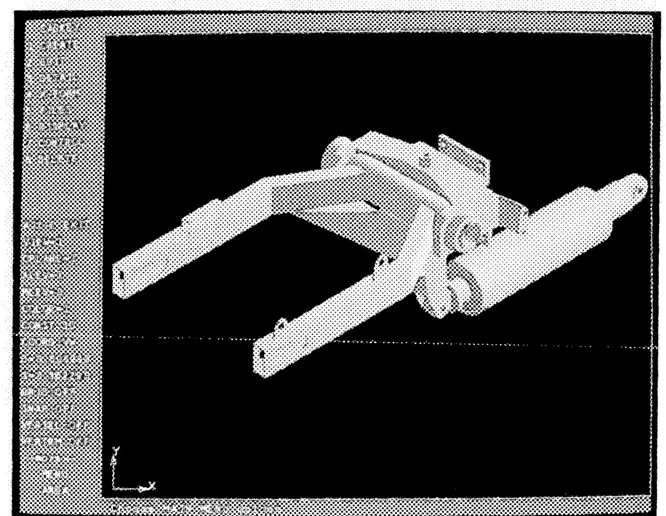
(a) 3D part design (wireframe)



(b) Wireframe model of subpart



(c) Wireframe assembly



(d) Shaded assembly

FIGURE 4.6 Part Design and Assemblies

4.3 HARDWARE AND SOFTWARE

CAD systems vary in size, capability, and cost. Engineering firms select the computers and software based on their needs and funds available to buy them. The range is from personal computers (PCs) to large mainframes. Some companies need the systems for drafting and design. Others use the systems for CAD/CAM, analysis, fabrication, and testing.

The stand-alone personal computers (Fig. 4.7) have an integral **central processing unit (CPU).** The CPU for the CAD system in Figure 4.7 is housed in a separate floor cabinet. The CPU is the brain; it figures out what the software directions are telling it to do. Inside the brain is a section for **read-only memory (ROM).** ROM cannot be changed or edited easily. There is also a **random-access memory (RAM)** section where the data gets changed and edited. The CPU, ROM, and RAM are on the inside. On the outside are the various devices for putting data into the CPU. The monitor looks like a TV screen. The function keys on the keyboard (F1, F2, etc.) are shorthand versions of commands. The keyboard is another way to input commands—by typing.

A **digitizer** is a table or tablet with pictures, words, or icons of items from which to choose.

RAM is also considered volatile because it can remember the data stored in it only as long as power is applied. Once the power has been removed, the memory promptly forgets, and the next time power is applied it must be taught all over

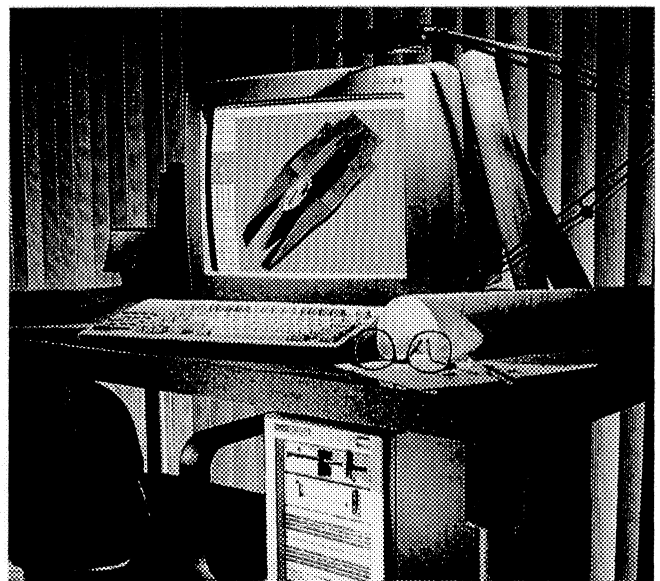


FIGURE 4.7 Engineering Workstation with Tower CPU Located Under the Table Surface

FIGURE 4.8 Drafting Station, Including CAD System and Plotter

again. This is like having a series of lights, each controlled by a button. When you press down any combination of buttons, the corresponding lights come on; when you release the buttons, the lights go off. All data is stored in the RAM as a series of 1's and 0's called **bits.** This is again like the light bulbs, where a 1 is on and a 0 is off. Eight bits make up a **byte,** which is the smallest unit for describing a letter or number. The amount of memory in a computer is measured in bytes. Sixty-four megabytes (Mbytes) represent 64 × 1,024,000 bytes, or 65,536,000 letters, or about 100,000 typewritten pages. An **M** (meaning "mega" or "million") is shorthand for 1,024,000. The typical PC CAD system requires 16 Mbytes or more of RAM.

ROM is like RAM, but the data is not lost when the power is turned off. ROM has many uses. ROM is small compared to RAM. ROM contains hardware configuration data and basic instructions about where the CPU looks for startup data. After the power is turned on, the computer must be given a detailed instruction, that is, where to get the incoming data (from which peripheral device). It must then be fed specific information, that is, what to do with the incoming data (what kind of calculation or other process). These instructions are in the ROM and are never erased.

On a **networked system,** several people can work simultaneously on different parts (making a drawing or model of a project), each providing information from his or her own terminal (Fig. 4.1). It is not uncommon to have eight or more people working on different aspects of the project, each on a different phase of development—such as design, engineering analysis, drafting, or manufacturing—for a single product or for many different products all tied together by the network.

The most common type of CAD system is PC-based. Macintosh, Intel 486 PCs, Pentiums, or clones now compete with workstation-based or terminal systems (Fig. 4.7). AutoCAD, CADKEY, VersaCAD, and Personal Designer software packages are PC-based systems typically found in schools and throughout industry. ProENGINEER is available for high-end PCs.

4.3.1 Operation

A typical CAD system makes possible simple yet powerful interaction between you and the computer. Just by pointing an electronic pen, a puck, or a mouse to a premarked, touch-sensitive drawing tablet or by picking an option from a pull-down menu, you can give the system drafting commands, such as **DRAW** or **ERASE**. You can create, modify, and refine the design interactively, viewing the emerging work on a graphics display. With a single stroke of the pen or keyboard input, you can move, magnify, mirror, rotate, copy, stretch, or otherwise manipulate the entire design or any portion of it.

The system lets you know, by a message on the screen, if there is a procedural error. Via the keyboard, electronic pen, and drawing tablet, you can ask the system to retrieve automatically any previously completed drawing needed for reference, as well as the standard design symbols expected to be used. Symbols and completed designs are all stored in the computer's data bank (memory or database), where they are instantly available. The online library speeds up the design process by eliminating unnecessary redrafting of commonly used components and subassemblies.

4.3.2 Documentation

As a part is designed on the system, its physical dimensions are defined, along with the attributes of its various components. This data, filed in the computer's memory, can later serve many other nongraphical needs. For example, the

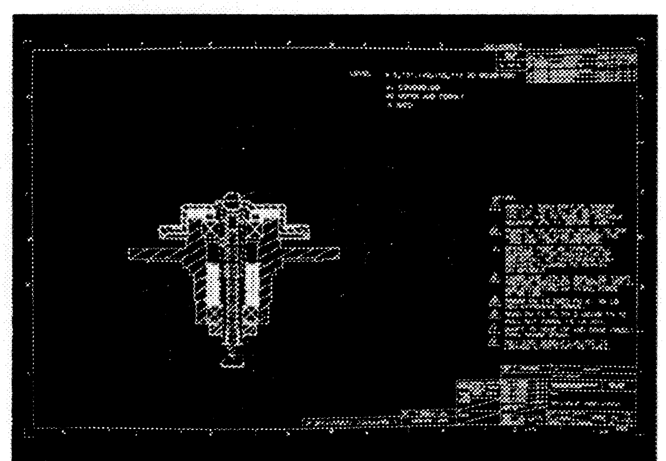


FIGURE 4.9 Engineering Documentation Is Important to Production

materials part-number data can help generate bills of materials (Fig. 4.9) for production control.

The CAD database can be used directly by CNC machine tools and equipment for quality control and product testing. Other computer programs can help engineers check for interferences or tolerances, generate models for engineering analyses, and calculate areas, volumes, and weights for the product under development. All these nongraphic capabilities are automatic by-products of the CAD/CAM design process.

4.3.3 Memory/Storage

On mainframe computers and minicomputers, data may be stored in four ways:

- Magnetic disks (which are configured like stacked long-playing records but have much more storage capacity) contain data in a form quickly accessible to the system.
- Magnetic tapes (resembling reel-to-reel audiotapes) are used for semiactive storage.
- CDs are now available that have read and write capabilities.
- The computer itself has a storage capacity, although data is seldom stored there for extended periods.

System commands, utility instructions, and computational procedures are usually stored on disks. Seldom-used reference data is typically stored on magnetic tape. On PC-based systems, storage is accomplished with internal or external hard drives, WORM optical disks, tape drives, or on 3.5 in. or 5.25 in. floppy disks. Figure 4.10 shows a variety of PC disk drives and hard drives.

Symbol libraries, drawing segments, whole drawings, design models, and submodels complete with text are stored on magnetic tape (if inactive or waiting for scheduled revisions) or on disks (if needed for reference at an adjoining workstation or another CAD system). A completed drawing is placed on a portion of disk storage where it can be found rapidly by the system.

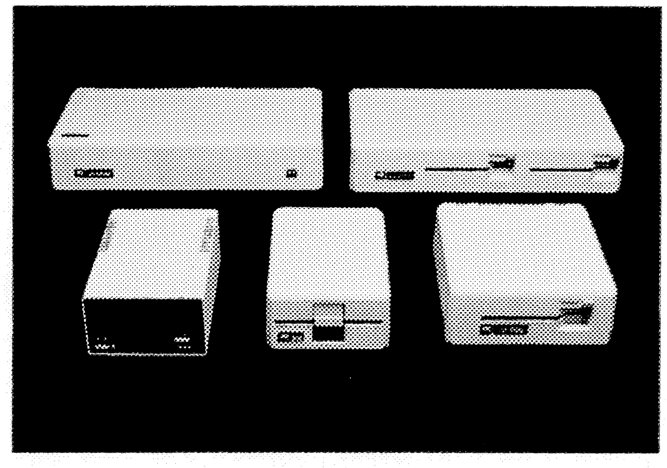


FIGURE 4.10 Floppy and Hard Disk Drives

4.3.4 CAD Workstations

The **engineering and CAD workstation** (Fig. 4.11) may include a digitizer (which converts graphics to digits) and a monitor with alphanumeric keyboard. This is the control center for active work input. If a mouse is used, the system may not have a digitizer tablet.

The digitizer is wired so that the location of each place on its surface can be sent electronically to the processor by pushing the input button on the crosshair device to indicate a particular point. In the processor, all information is in digits (0 or 1); the digitizer changes graphics (lines and points) to digits. The processor then uses its calculating power to change the lines as the designer or engineer indicates and then reproduces them on the monitor. A typical interactive CAD workstation serves several functions:

- Interface to the host computer, either a large mainframe or local minicomputer
- Digital descriptions of a drawing, possibly stored locally
- Generation of a steady image on the display through its own local memory or by other means

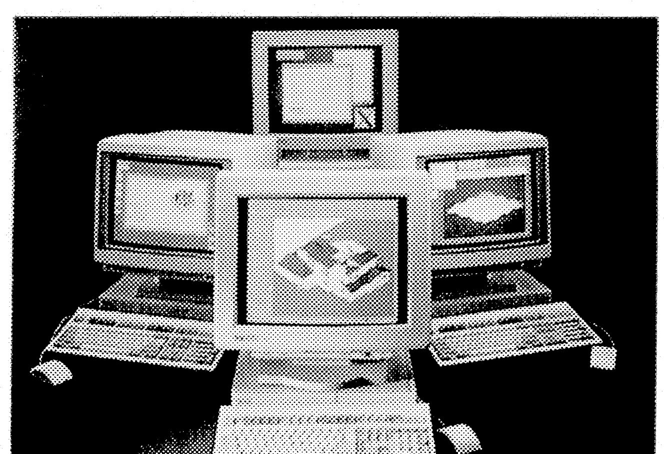


FIGURE 4.11 Engineering Workstations

- Translation of computer instructions into operating functions and routing of commands for the various function generators
- Operator input devices for communicating with the computer: data tablets, mouse, light pen, digitizer table, cursor controls, or function keys

To carry out these functions, some form of display and an alphanumeric keyboard must be available.

4.3.5 Display Devices

All CAD systems use some kind of display device (monitor). There may be two screens, one alphanumeric (letters and numbers), the other graphic (pictures) (Fig. 4.11). This image can be produced by a number of available devices. One such device is the **cathode ray tube (CRT),** which is similar to a television, oscilloscope, or radar. CRTs are available in many sizes and configurations and with various capabilities.

FIGURE 4.12 CAD System Using a Keyboard and a Separate Function Box

4.4 INPUT DEVICES

Input devices enable you to communicate with a computer without the need to learn programming. Through these devices you can pick a function, enter text and numerical data, insert and manipulate geometry, modify the graphics, and even detail the finished part. All CAD systems have at least one operator input device. Many systems have several such devices, each for a different function. Alphanumeric keyboards, function boxes, electronic pens, light pens, trackballs, mice, joysticks, graphics tablets, and digitizing tables are used with CAD systems.

4.4.1 Keyboards and Function Boxes

In addition to the pen, mouse, or puck, you can communicate with the system through a **keyboard.** Using a combination of numbers and simple phrases, you can type **X, Y, Z** coordinates, enter text for drawing annotation, and initiate graphics processing commands. Several kinds of alphanumeric keyboards are commonly employed with CAD/CAM graphics terminals. The conventional typewriter-like alphanumeric keyboard allows you to enter commands, symbols, and text, as well as to request information. One of the most important functions of the keyboard is annotation, the process of inserting text (words and numbers) on a drawing.

The keyboard can enter messages consisting of letters, numbers, mathematical computations, and other symbols into computer storage. As the message or text is composed, it is displayed on the screen for verification or editing before the content is entered into the computer's main storage. The keyboard also can control the screen location of a movable cursor symbol (dash, blinking box, small cross, full-screen cross, or other marker) that is displayed where the next character will be entered. Keyboards may also include special graphics buttons called function keys.

In many cases, the CAD terminal is equipped with a separate box containing program-controlled push buttons (called a **function box** or **button box**). The function box can be integrated into the main keyboard or housed separately, as in Figure 4.12. The number of function keys varies from about 8 to 80. The function identified with each button is generally under computer control and can be changed as the program progresses or when a new application program is activated on the system. In some systems, the buttons can be labeled with an overlay, and the overlay can be changed with each application program. The use of function keys is easily mastered and their meanings quickly memorized. In other applications, the buttons are simply numbered and the function of each button is included in a user-selectable **menu.**

4.4.2 Graphics Tablet and Digitizing

One common input device is the **graphics tablet.** Graphics tablets and tables are electronic units that consist of a rectangular grid of horizontal and vertical lines integrated into a flat drafting-tablelike surface. Generators within the tablet pulse the lines, producing discrete code signals in response to an electronic pen, a puck, or a mouse device moved by the designer. The computer determines the location of the pointing device by decoding the signal. This decoded information is displayed on the CRT as **X** and **Y** coordinates. A line or spot (cursor symbol) corresponding to the input device position appears on the screen.

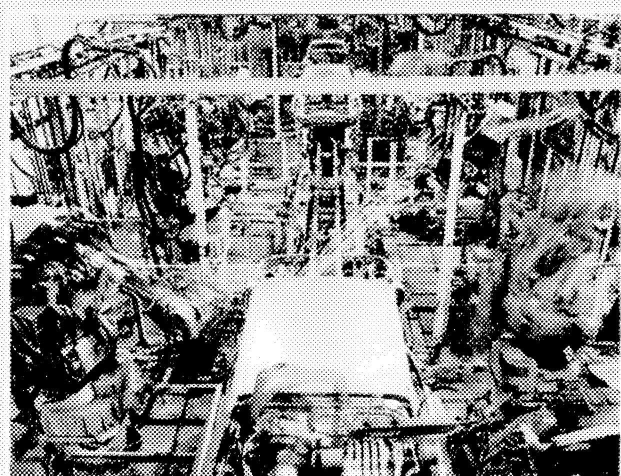
Most data tablets allow some separation between the pen and the tablet surface. That is, the pen need not be in contact with the tablet surface. Therefore, a paper drawing or other sheet can be placed on the data tablet, enabling you

Focus On . . .

COMPUTER-INTEGRATED MANUFACTURING

Computer-integrated manufacturing (CIM) is a system in which all the functions needed in design, purchasing, manufacturing, inventory, and marketing of products are networked together. The computer information database is shared by everyone, eliminating duplication of information. The software that controls such a system must be refined and perfected, but many companies already have the key components of such a system in place.

One of the major components of CIM is the flexible manufacturing system (FMS), in which computer numerically controlled (CNC) machines are used with robots and part



Manufacturing cells.

transfer vehicles to move a part from raw stock, through all machining steps and assembly, until it becomes a finished part. A software base controls the entire sequence.

The four major components of FMS are CNC machines, the coordinate measuring machines (CMM), robots, and part and tool transfer vehicles. This system can run unattended if it is supported properly. Worn tools are not a problem because of the online monitoring system. Inspection is completed with the CMM. Electronic gaging probes measure the features of the part, and the computer compares the results with the limits stored in the database.

Robots load and unload materials and parts to the manufacturing cell. The tool and material transfer vehicles shuttle workpieces and tool magazines from inventory and to specific machines. These vehicles can be automatic guided vehicles (AGVs) or wire-guided, air cushion, or hardware-guided vehicles.

AGVs are not connected to hardware, and rely on onboard sensors and programs to establish their paths. A wire buried in the factory floor defines the path of travel for wire-guided vehicles. The air cushion vehicle glides on an air cushion and is guided by external hardware. Unfortunately, any debris on the floor will stop the air cushion vehicle. The hardware-guided vehicle runs on a track or rail. It is very reliable, but hardly flexible.

The American manufacturing industry has taken a hard look at what must be done to compete with ambitious programs under way in Japan and in Europe. Executives from a review program concluded that we need to make our factories "agile," link them together by computers, and collaborate.

CIM will certainly play the key role as industry strives to eliminate paperwork, eliminate duplication of effort, reduce development-to-product cycle time, and improve quality and customer satisfaction. Much development is still needed before we have a true CIM environment.

to translate drawing coordinates into digital form. This process is called **digitizing.** This digitizing feature is very important in many computer-aided design and data analysis applications. Digitizers are devices that convert coordinate information into numeric form readable by a digital computer. Some CAD systems use a sheet overlay to develop unique menus for program control.

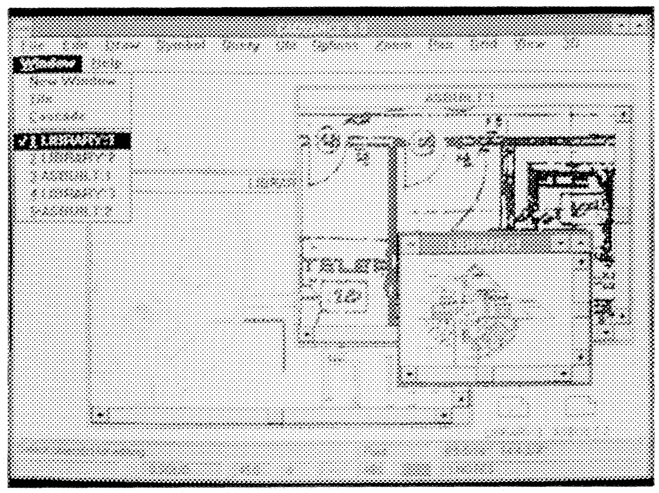
Some CAD systems now run with Windows-based software, as shown in Figure 4.13. These systems are normally equipped with a mouse-type input device for quick and simple selection of the Windows options.

A tablet without menu options is simply a **data tablet.** This type of graphics tablet has a surface area that corresponds to the display area of the CRT. By moving a hand-held puck with input buttons, you can position the display cursor symbol on the CRT. Instead of a tablet menu, a **display menu** appears on the CRT (Fig. 4.14). Menu commands are entered by positioning the symbol cursor over the desired menu function displayed on the screen and pressing an input button.

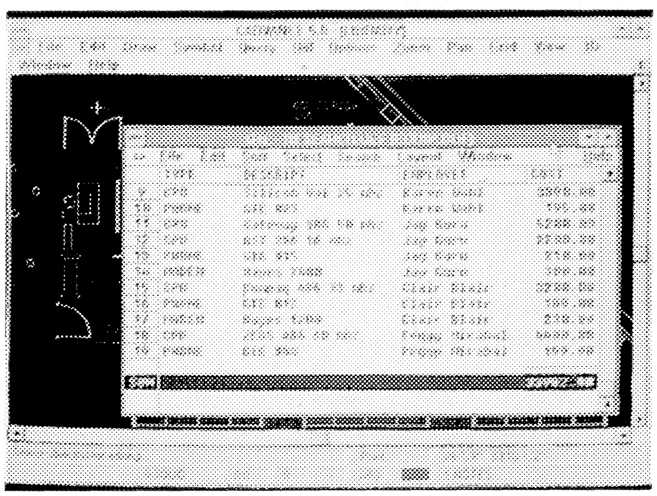
Digitizing tables are used by some companies to input 2D sketches into the system directly (Fig. 4.15). Flow diagrams, block diagrams, schematic diagrams, logic diagrams for electronics, and piping diagrams for piping design lend themselves to direct digitizing.

4.4.3 Light Pen and Electronic Pen

The **light pen** is a pen-shaped electrophoto-optical device that allows you to identify a particular element directly on the display screen or to select a particular function from the



(a) Assessing part libraries via Windows



(b) Equipment list for office (displayed with Windows)

FIGURE 4.13 CADVANCE CAD System Using Windows-Based Software

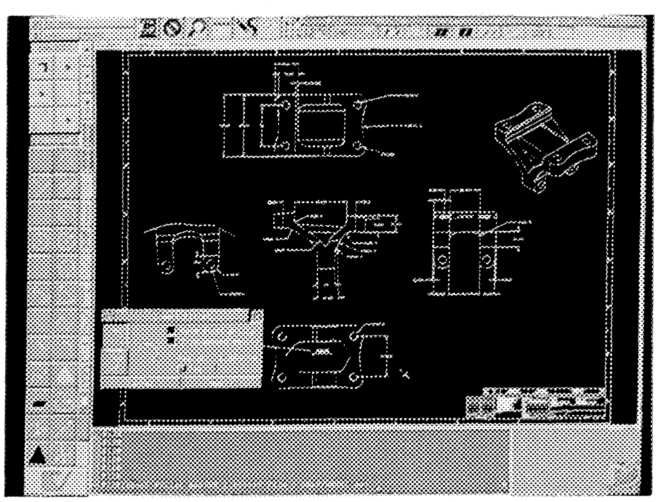


FIGURE 4.14 Screen Menu

FIGURE 4.15 Large Digitizing Table Being Used to Input a Sketch

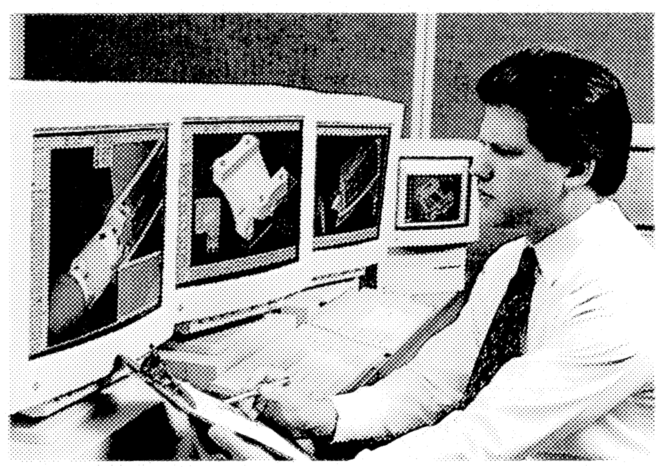


FIGURE 4.16 CAD System Using a Pen

menu. An **electronic pen** (Fig. 4.16) is restricted to coordinating input or menu selections and cannot be used to draw on the display device. A light pen, however, can be used to draw on the CRT display surface. Few systems today employ a light pen. Most CAD stations input information via electronic pen, puck, or mouse (using a screen menu).

4.4.4 Pointing Devices

Besides pens, various special **cursor controls** are available for CAD systems, including the trackball, the joystick, and the mouse. Figure 4.17 shows a variety of pointing devices available for CAD systems, including roller ball and mouse types. Each of these data entry devices can be used by the engineer to enter coordinates manually in specific **X, Y,** and **Z** registers. The trackball mechanically couples a control element to both the X and Y generators so that a single motion can drive both transducers simultaneously (operating like a mouse). The trackball uses a rolling ball to drive the transducers. The **joystick** is similar to the trackball except that it is moved by a small, batlike handle.

Most PC-based CAD systems can be operated with a **mouse** as their primary means of input (Fig. 4.18). A mouse

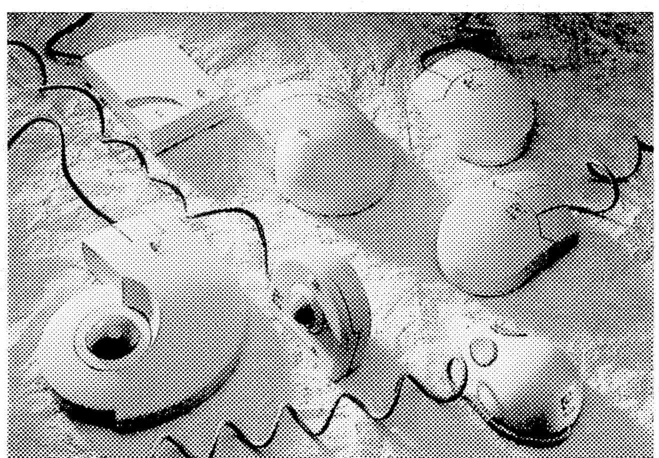
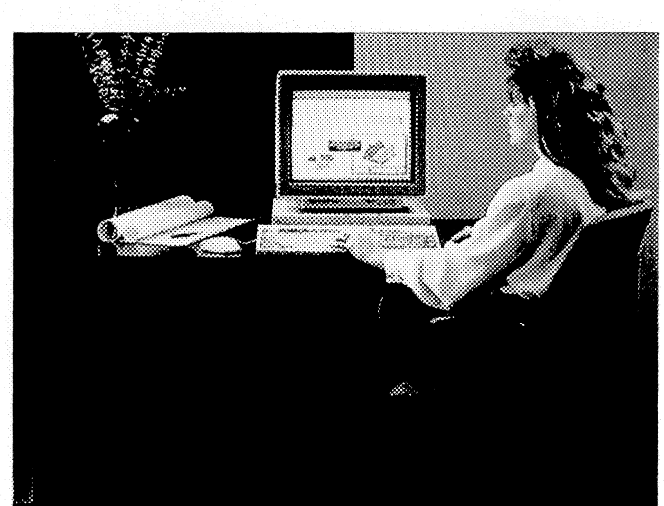
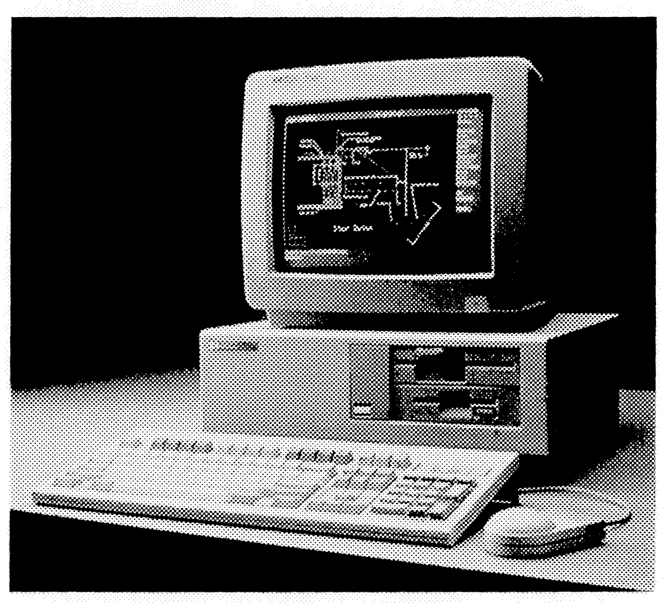


FIGURE 4.17 Pointing Devices



(a)



(b)

FIGURE 4.18 CAD Systems That Use a Mouse as the Only Input Device

is moved along a flat surface (a pad or table); its movement controls the position of the screen cursor. Buttons on the mouse allow you to input the screen menu selections and to pick locations on the screen.

4.4.5 Menus

A **menu** template overlay for a digitizer is an input device consisting of command squares on a digitizing surface (such as a tablet or table) or on the screen. A menu eliminates the need for the keyboard for entering graphical or common command data. A menu tablet allows the selection of the most commonly used tasks for a particular design field. General drawing menus are available for constructing simple to complex graphics. New menus can be changed or created as required.

To utilize a menu (Fig. 4.19), you simply place the pointing device over the desired command and press the cursor button or the function key. Most systems have commands that allow frequently changed parameter options (such as letter heights and slant) to be displayed on the alphanumeric screen for operator inspection or modification.

The menu shows the commonly used symbols and commands. Since not all symbols can be placed on a menu, a typical system is capable of creating and holding a large **drafting library.** A library contains all the needed symbols, drawings, or figures for a particular engineering field: nuts, bolts, screws, electrical symbols, welding symbols, or component outlines. It is basically an unlimited template. The drafting library can be added to or subtracted from as necessary. An engineer typically collects and customizes figures or symbols from the drafting library, creates any special figures that will be needed repeatedly, and assembles them into special menus. Some companies supply drawings on disk and even 3D models of their products to serve as templates for a library of parts.

Although the number of figures may be limited because of size and space, the number of menus is unlimited. The

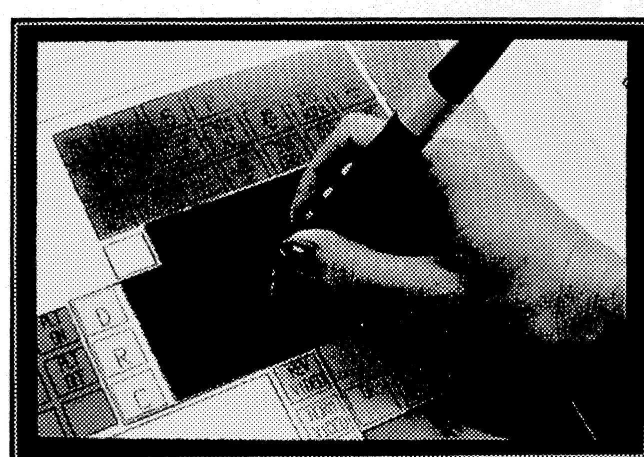


FIGURE 4.19 Tablet and Pen

typical menu item is inserted with a minimum of keystrokes. Each symbol can be inserted at any angle or scale. The symbol or figure can be as simple as an electronic diagram symbol or as complex as a complete printed circuit board. Once the menu symbol or figure is created, it can be stored and used any number of times in other drawings.

4.5 OUTPUT/HARDCOPY DEVICES

Output from CAD systems comes in many forms. The most common is a drawing just like the one created on a drafting board. This drawing, which is a copy of what is on the screen, is created by a plotter (Fig. 4.20). Output can also be a copy of what is on the screen, called a **hard copy.** A hard copy normally comes from a printer or plotter attached directly to the workstation. A drawing not only can be obtained from a plotter, but can also be drawn on microfilm. This is called **computer output microfilm (COM).**

Hard-copy and output devices include printers, plotters, and photocopy equipment. Printers provide the user with alphanumeric readouts and material lists. The plotter allows you to produce ink drawings on paper, vellum, or drafting film in a multitude of colors. Some plotters are limited by the size of the plotting surface. Although they are limited to standard paper widths, others can plot drawings of any length. Pen plotters can use ballpoint pens, felt-tip pens, liquid ink pens, or pencils. Check copies are normally run with inexpensive ballpoint pens. Original high-quality drawings are plotted with India ink and liquid ink pens. When plotting a drawing, you have a number of options: to scale the drawing, rotate it, select the colors to plot, or even substitute different line widths. Not all pen plotters have these options. Various plotters are available, including drum plotters, flatbed plotters, electrostatic plotters, digitizer plotters, and laser plotters.

FIGURE 4.20 3D Models. Three-dimensional models from a computer screen can be easily coverted back to two dimensions to make hard-copy displays.

4.5.1 Plotters

In a CAD system, plotters and displays complement each other. A display is capable of presenting a picture rapidly so that you can react to it, perhaps making changes interactively. A **plotter,** on the other hand, can make large, highly accurate drawings, but more slowly (Fig. 4.21). Displays are used to make the initial decisions, while plotters make the record copies.

The accuracy of plotted output can be considerably higher than the apparent accuracy and quality of the image on the display. A computer defines all graphics as coordinate points. Therefore, all graphics on a CAD system are made of straight-line elements. The closer the points of a curve are spaced, the better a system's **resolution.** *Resolution is the smallest spacing between points on a graphic device at which the points can be detected as distinct.* The degree of resolution influences the quality of the drawing plot, since curves appear as a series of straight lines if the resolution is poor.

4.5.2 Pen Plotters

Typical CAD systems use an electromechanical **pen plotter** to plot data and make engineering drawings. Two basic kinds of pen plotters are in current use. The earliest and perhaps most widely used type is the **drum plotter** (Fig. 4.21). Plotting paper is wrapped around the drum, and the drum is rotated by a digital stepping motor. The rotation provides one deflection axis, while the pen, mounted on a gantry across the drum, provides the other deflection axis. The only other basic control, besides **X** and **Y** deflection, is

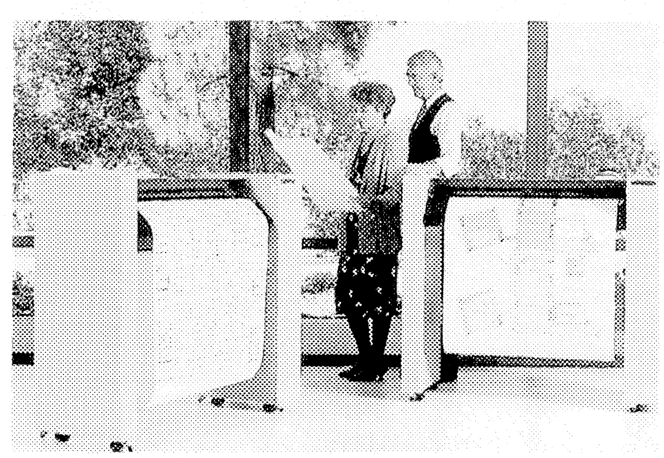


FIGURE 4.21 Drum Plotters

the control to move the pen up and down. Drum plotters are available in sizes that range from $8\frac{1}{2}$ in. to more than 42 in. wide. They make plots quickly and of unlimited length. The smaller drum plotters make lines in incremental steps, approximately .005–.01 in. apart, with plotting rates of around 5 in. per second. A typical drum plotter uses either ballpoint, felt-tip, or ink pens.

As the name suggests, a **flatbed plotter** has a flat, horizontal drawing surface, with the paper lying flat, suitable for highly accurate, top-quality drawings. On most flatbed plotters, the pens move and the paper remains stationary. Flatbed plotters were introduced to satisfy the need for high-quality images and large drawing sizes. Now plotters ranging from about $8\frac{1}{2} \times 11$ in. to as much as 4 ft wide × 12 ft long are available.

4.5.3 Electrostatic Plotters

In the past, **electrostatic plotters** were used primarily for quick-look capability. However, electrostatic plotters are now of such high quality that they are selected as one of the primary output devices for CAD/CAM systems.

While it takes seconds (or even fractions of a second) to display an image on the CRT, the time required to plot that same drawing on a precision plotter may be several minutes. Plotting twenty to thirty times faster than pen plotters, electrostatic plotters can plot a square foot of data in a few seconds.

All electrostatic plotters (Fig. 4.22) share a similar operating principle: Voltage is applied to an array of densely spaced writing nibs embedded in a stationary writing head. The nibs selectively create minute electrostatic dots on the paper as the paper passes over the writing head. The paper is then exposed to liquid toner to produce a visible, permanent image.

The electrostatic plotter retains the advantage of the drum plotter that drawings can be of unlimited length. Electrostatic plotters are available up to 6 ft in width. A further advantage is that the electrostatic plotter can be used very effectively as a high-speed line printer (up to 1200 lines per minute).

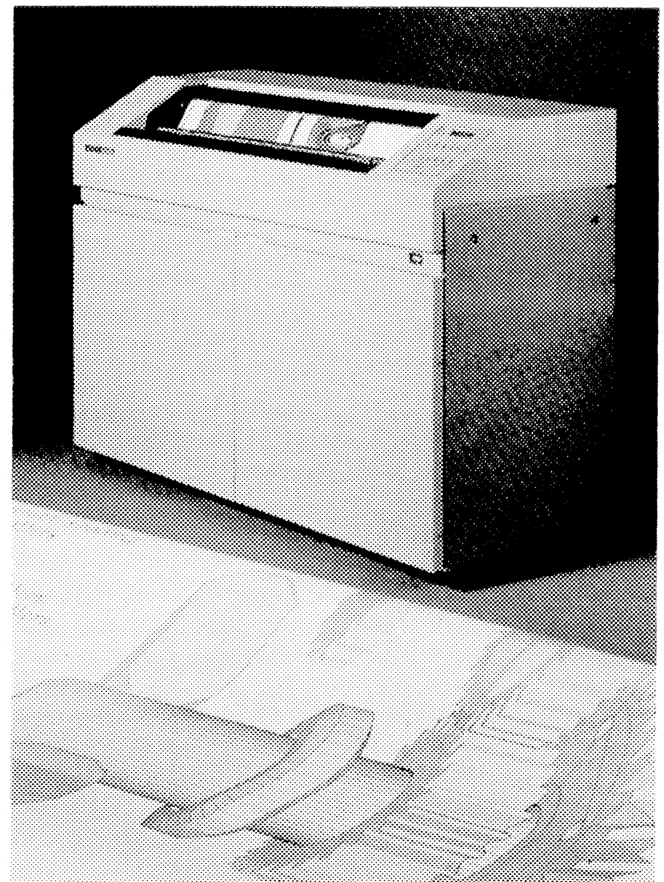


FIGURE 4.22 Electrostatic Plotter

4.5.4 Photoplotter

Photoplotters, the most accurate type of plotter, are chosen where extreme accuracy takes precedence over the cost of the unit. Printed circuit board art masters are normally created with this type of plotter. A light beam is used to "plot" the drawing on light-sensitive film.

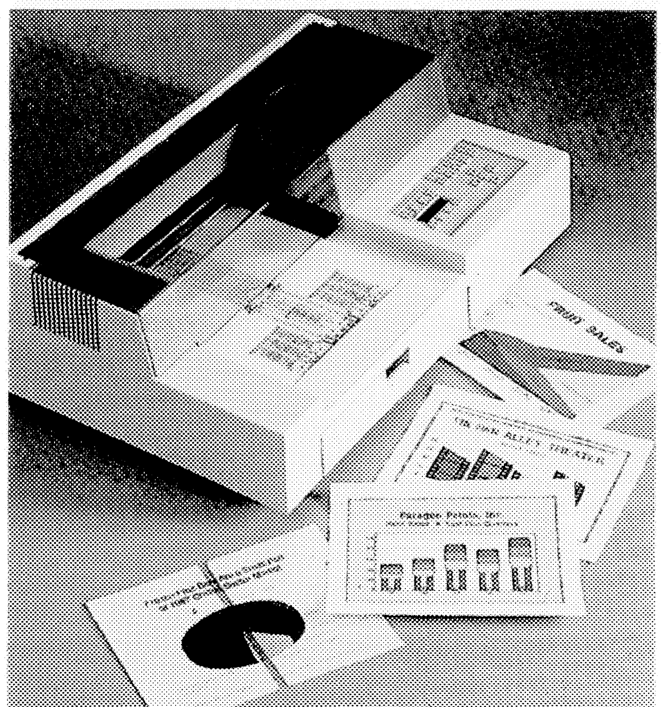
4.5.5 Scanners

Scanners can produce high-quality reproductions of photographs, line drawings, or technical illustrations (Fig. 4.23). This technology is employed in desktop publishing, and to produce and merge graphics with word processing for technical reports, technical and service manuals, and various other output.

FIGURE 4.23 Scanner

4.5.6 Printers

A **printer** is a computer-operated typewriter providing the user with hard copy of alphanumeric data. Printers are used as a quick screen dump for reviewing graphics and for producing parts lists and other nongraphic output. Many types of printers are available. The quality of typeface and the speed of printing are two of the most important features of a printer. **Letter-quality printers** are slower and do not plot any type of graphics. Although the quality of the typeface is poor, **dot matrix printers** are extremely fast and plot limited-quality graphics. **Ink-jet printers** [Fig. 4.24(a)] and **laser printers** [Fig. 4.24(b)] are also available for high-quality printing needs as well as high-quality graphics. Printers acting as hard-copy devices with CAD systems must be able to process graphics.



(a) HP Ink-Jet

(b) HP Laserjet 4

FIGURE 4.24 Printers

4.6 CAD/CAM SOFTWARE

Software is the programmed instructions that tell the processor what to do. Programming that is built into the microchips (integrated circuits) and printed circuit boards of the computer is called **firmware.**

Many CAD systems come from the manufacturer preprogrammed. Knowledge of programming is not needed to use a CAD system; you just turn it on and the system is ready for use. Software orders the computer to direct the flow of input data either into working storage or to the disk for instant recall. Software also helps the computer retrieve input data for processing.

4.6.1 Applications Software

A typical CAD **application software** package does not require the designer or engineer to be a computer programmer. CAD systems are designed to free designers from the time-consuming task of programming so that they can concentrate on the design capabilities of the system. On the other hand, any person using an application program must be familiar with the standards and the conventions in that technical field. It is very important for the young engineer to understand that, no matter what the level of sophistication, the hardware and the software are only there to aid the user in design and drafting tasks. As an engineer or designer, you must know about the application and what procedures are applicable to that area. Excellent software packages have been developed for civil and mapping engineering, structural engineering, architectural engineering, piping engineering, mechanical engineering, electronics, technical illustration, and a variety of other areas. The use of CAD in these technical areas has enhanced design and streamlined engineering. But the designer or engineer must still know all of the particulars of the application area. CAD as a tool is cost-effective only in the hands of a knowledgeable, well-educated user.

Generally, the manufacturer of the CAD/CAM system supplies programs for basic-level creation of 2D and 3D drawings. Additional programs may be supplied by the manufacturer to do engineering analysis or help the designers learn special system functions. A typical drawing software package allows the designer to construct all the traditional drafting graphics using standard conventions and practices. The difference lies in the automated capabilities imbedded in the system and the availability of specific applications programs.

Some CAD vendors offer a general CAD software package for constructing symbols, menus, standards, and conventions for any engineering area. This type of software allows other vendors of applications programs to write software for a technical area such as printed circuit board (PCB) design and architecture, using the generic software as the base. Other CAD systems are totally dedicated to one or just a limited number of applications, for example, integrated circuit design, PCB design, or mechanical drafting.

An excellent exercise would be to investigate what other areas of industry and business utilize CAD capabilities. For instance, chemists are using CAD to create new drugs (this field is actually called computer-aided drug design). The 1985 Indy race winner drove a car that was designed on a CAD system. Once you start to look into the present-day uses of CAD, the future possibilities seem unlimited.

4.6.2 Electronic Applications

One of the most important applications for CAD is **integrated circuit** and **printed circuit board (PCB)** design and documentation. All integrated circuit design is done on a computer. CAD increases productivity by automating and integrating the key steps in the design and production of integrated circuits and PCBs. The typical PCB program (Fig. 4.25) uses automatic and manual editing modes to design the entire board, from the drawing of the schematic to the final manufacturing and testing stages (Figs. 4.26 and 4.27). Schematics, text, and board geometry are entered interactively into the system. Automatic assignment, placement, and routing routines are used to complete the design of the board. A variety of PCB sizes and types can be designed. Manual input can override the automatic routines.

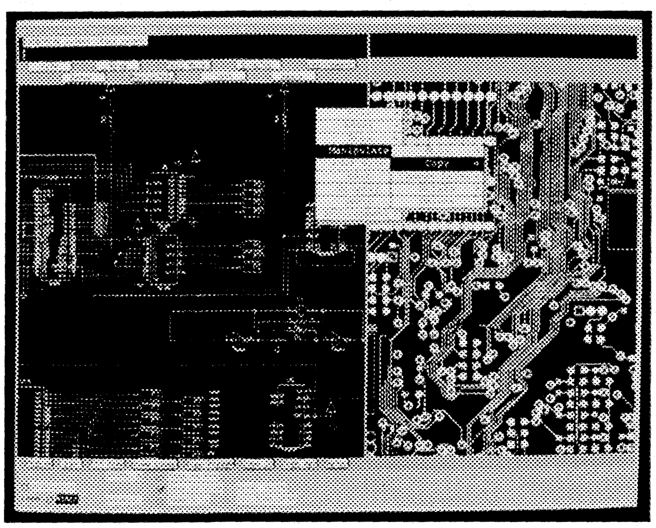


FIGURE 4.25 Printed Circuit Board (PCB) Design

FIGURE 4.26 PCB Design on an Engineering Workstation

The automatic routing of PCBs is complemented by software to place components on the board automatically. Because of the increasing density of boards and complexity of circuits, this is an important feature for development. The CAD system also provides control tapes for numerically controlled drilling and insertion machines for use during the production and manufacturing of circuit boards.

For the development department, there are special problems both in design and in preparing the necessary documentation for manufacturing. Designing the printed board entails overcoming spatial restrictions and layout constraints. Designing the equipment housing requires consideration of cooling arrangements, protection against shocks and vibrations, provision of easy access for servicing, and, at the same time, satisfaction of styling requirements. This is called electronic packaging design.

CAD systems can automate and integrate the key steps in the design, documentation, and design-rules-checking of wiring diagrams. It reduces the time and expense required to capture, check, update, and extract design information. This capability is applied to many types of diagrams: logic, schematic, wire harness, and interconnection.

4.6.3 Architecture and Construction Applications

Applications are available for building designs on a CAD system, including **architectural design** (Fig. 4.28 a, b, and c). You can design the structure, display and detail the appropriate views, and use color shading to show how the

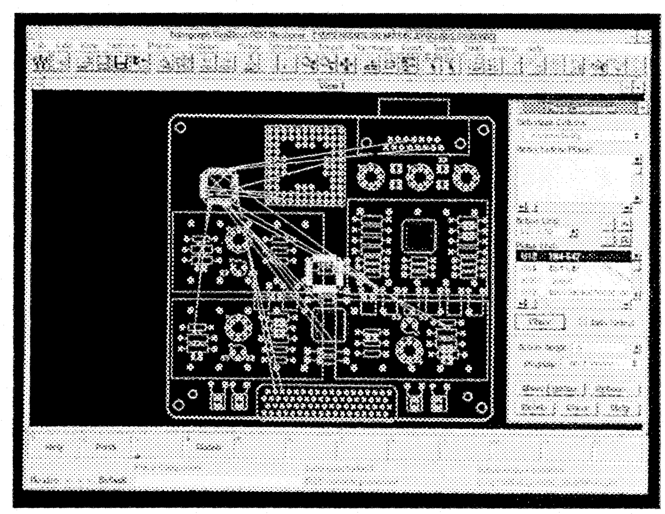
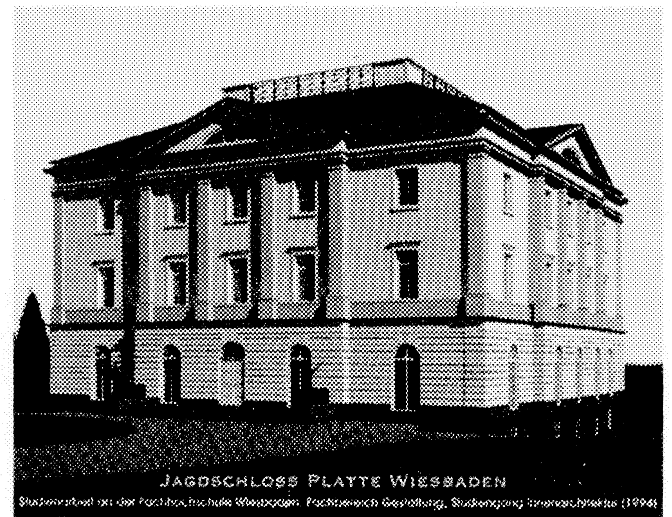
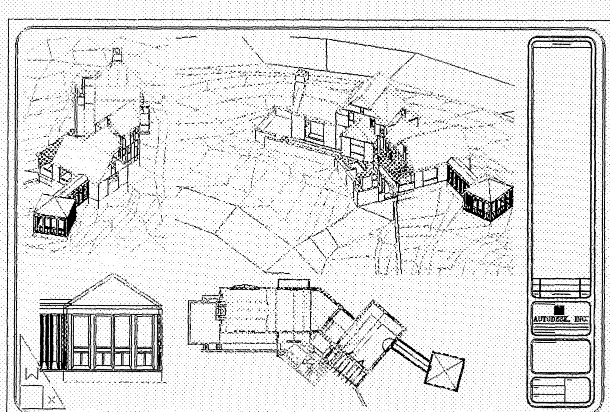


FIGURE 4.27 PCB Design and Editing



(a) Architectural design using AutoCAD

(b) Shaded model



(c) Wireframe model

FIGURE 4.28 Architectural Design

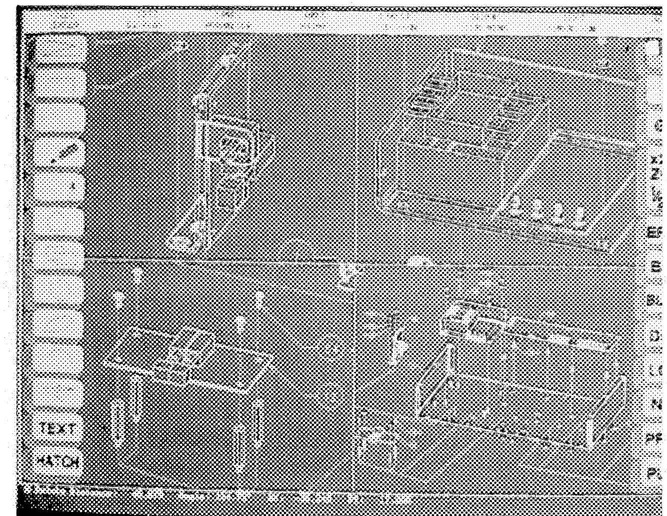


FIGURE 4.29 Electronic Packaging Design

building would appear realistically. This eliminates the need to model the building physically or do a rendering.

Electronic packaging design (Fig. 4.29), space planning, duct work, electrical layout, and plumbing can also be completed. The system allows the integration of such disciplines and permits you to develop several design alternatives for a particular project, including possible landscaping schemes.

4.6.4 Structural Design and Engineering Applications

Structural design, layout, and detailing are important applications for which CAD has been used effectively in the building industry to improve design and decrease drafting time (Fig. 4.30). The designer inputs the structural grid,

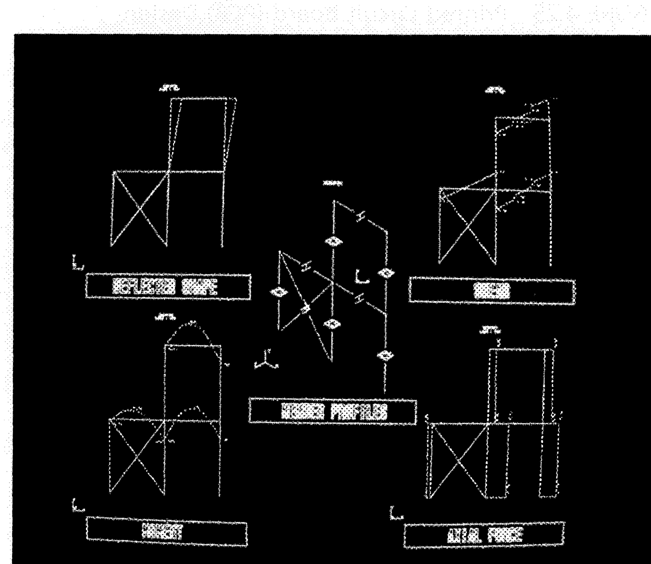
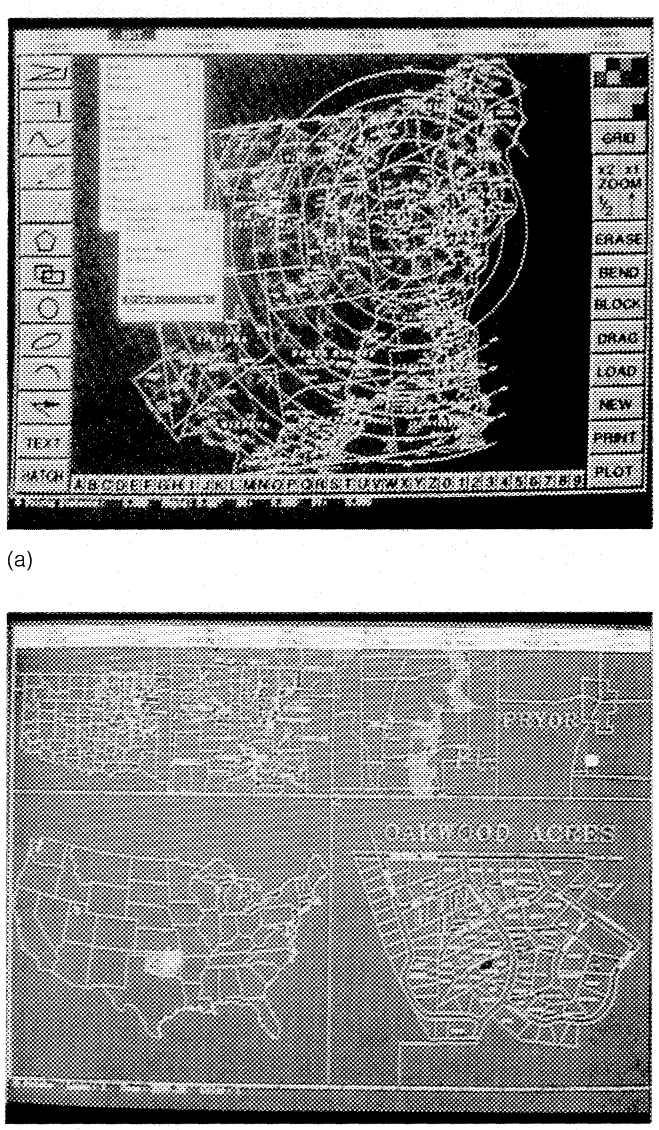


FIGURE 4.30 Structural Steel Design and Drafting

geometry, and member properties. The member profiles can then be graphically checked before analysis begins. After the structural analysis is performed, the results can be displayed using moment, sheer, axial force, and deflected shape diagrams. Color and layering capabilities help in analysis and in differentiating between structural element types and sizes.

4.6.5 Civil Engineering and Mapping Applications

Civil engineering and **mapping** [Fig. 4.31(a)] features include site selection, site preparation, digital terrain modeling, earth work calculations, and contour mapping. Other mapping capabilities allow utility companies and municipalities to plan distribution networks and to manage accurately assets widely distributed throughout large geographic areas [Fig. 4.31(b)].



(a)

(b)

FIGURE 4.31 Mapping Layout with DesignCAD

The CAD system provides a tool for analysis and design coupled with actual cost estimates. You can automatically design and estimate costs of a runoff water collection system by selecting the minimum pipe sizes required and the minimum pipe slope, calculating flow line and elevation data, and segregating the quantities into bid item costs for the specified layout and flow input to each manhole. This design tool allows the engineer to process several layouts and system modifications, including full cost estimates, in less time than would be spent to design one layout conventionally without cost estimates.

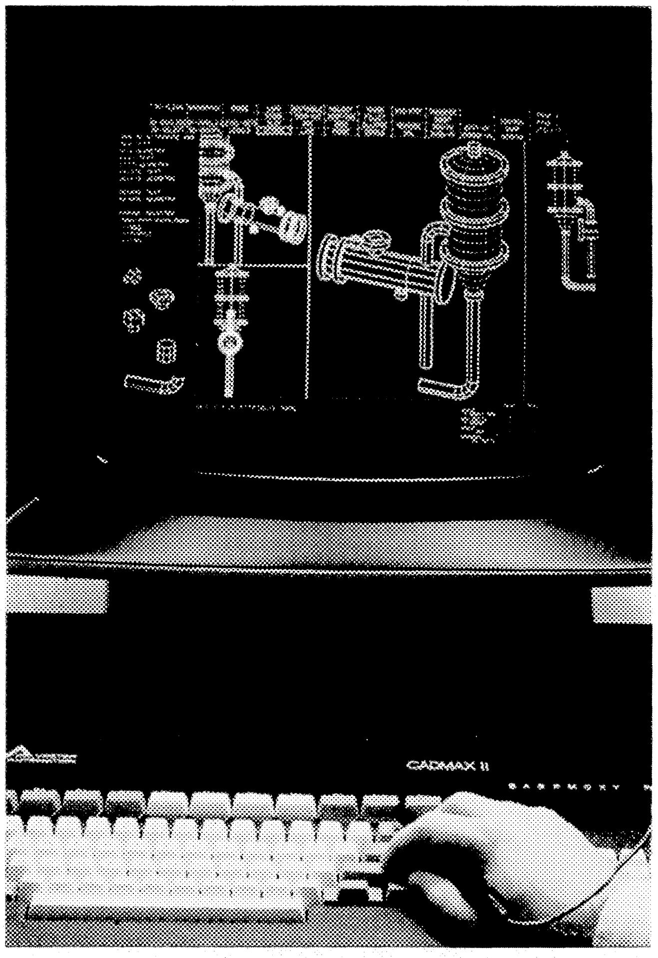
4.6.6 Piping and Plant Design

Plant design CAD programs permit the extraction of a wide range of drawings and reports directly from the stored information, including flow diagrams, isometrics, spools, pipe fabrication, pipe supports, plan, elevation, and section drawings, solid views, from–to lists, bills of materials, and formatted lists. With a 3D CAD system, designs for process and power plants can be created as a true 3D model on the system [Fig. 4.32(a)]. The 3D model facilitates revisions, graphics manipulations, and analysis, such as piping interference checks. These checks pinpoint interferences between plant components early in the design cycle. The 3D model provides hidden line removal to enhance the visual representation of the model [Fig. 4.32(b)]. The designer can recognize and rectify potential plant problems early in the design phase, eliminating costly and time-consuming construction delays.

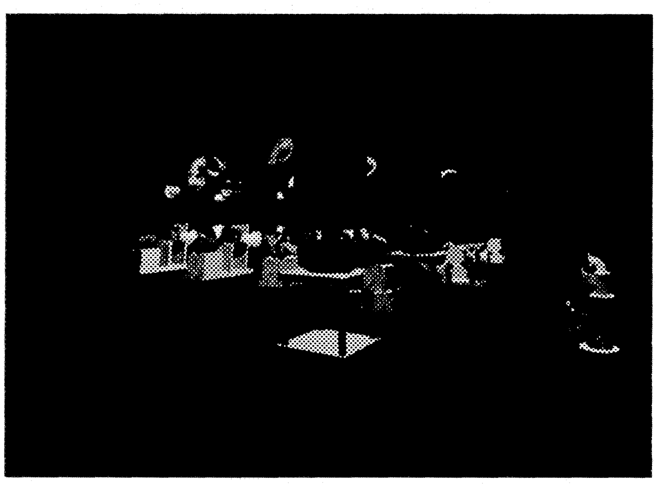
4.6.7 Mechanical Design Applications

A majority of CAD software packages have mechanical design and detailing capabilities. Besides 3D modeling of mechanical parts, mechanical software packages have many drafting and detailing capabilities to add dimensional information, notes, and labels to your drawings. You can also manipulate your drawings of the model for aesthetic reasons or for visual clarification (Fig. 4.33). These manipulation features include choosing a variety of line fonts (patterns), erasing hidden lines, defining any type or number of views, inserting dual dimensions, defining ANSI, JIS, or ISO standards, sectioning, and crosshatching. One of the most important tasks handled by a CAD system is the updating of existing mechanical designs and drawings, since this can be accomplished quickly and easily compared to manual methods.

Mechanical design includes a wide variety of products and machinery. Aerospace design is one of the most important uses of mechanical CAD, and many of the software packages employed in mechanical design were developed by aerospace companies such as Lockheed and McDonnell Douglas. McDonnell Douglas Unigraphics software running on HP 9000 computers is used in the design and manufac-



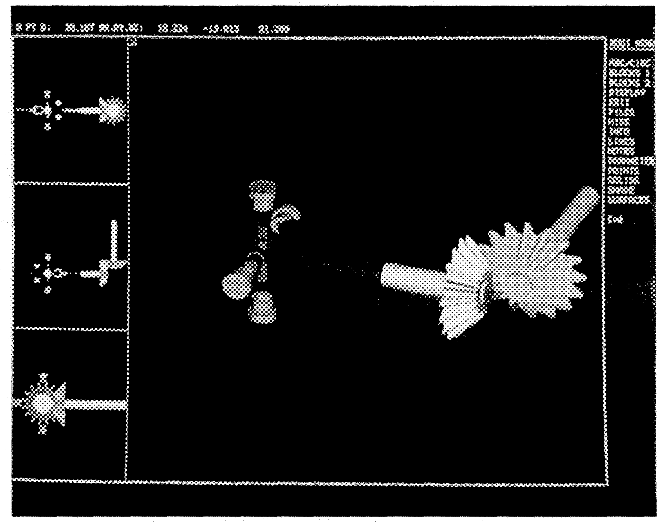
(a) Piping design (wireframe)



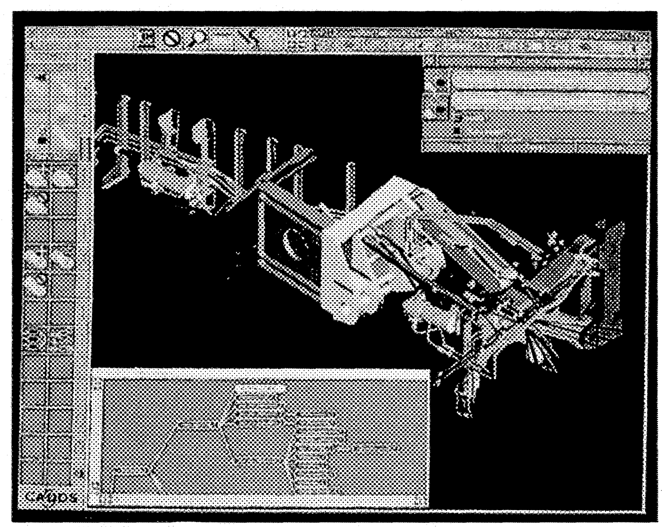
(b) Piping design using 3D CAD (surface model with shading)

FIGURE 4.32 3D Piping Design

ture of the NOTAR helicopter shown in Figure 4.34(a). McDonnell Douglas Helicopter Company uses DFM principles in the development of turbine parts [Fig. 4.34(b)].



(a) Helical Gear Design

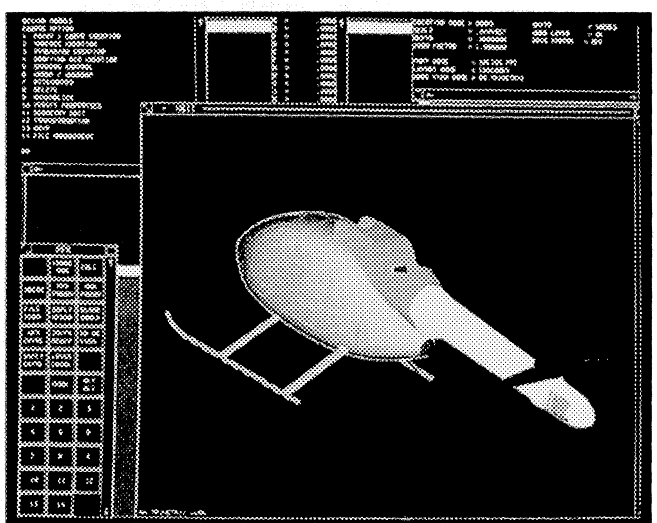


(b) Electrical Routing

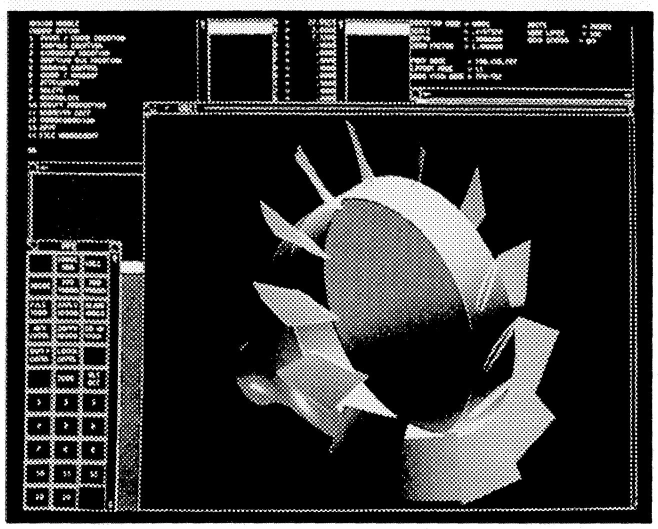
FIGURE 4.33 3D Solid Modeling

4.6.8 Product Design and Development

CAD systems provide a means to explore any number of design ideas for new products, such as the motorcycle in Figure 4.35(a) or the aerospace design in Figure 4.35(b). Since exploring design alternatives with CAD systems is much faster than with manual methods, more exploration is possible in the same amount of time. These designs are eventually refined into one finished model. Figure 4.36 shows a phone design created with CADAM software. The phone is shown as a solid model, with the arm and hand of the user modeled to enable study of the product in relationship to the person using it. The use of color and shading along with 3D models of the proposed product aids in rendering and illustrating the product for consumer display.

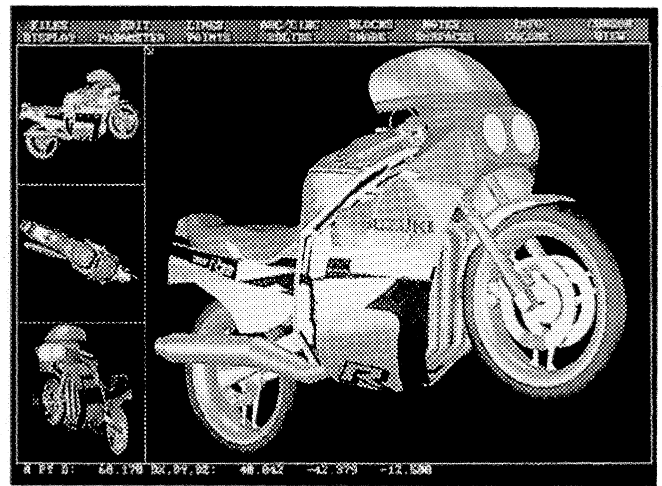


(a) Helicopter design

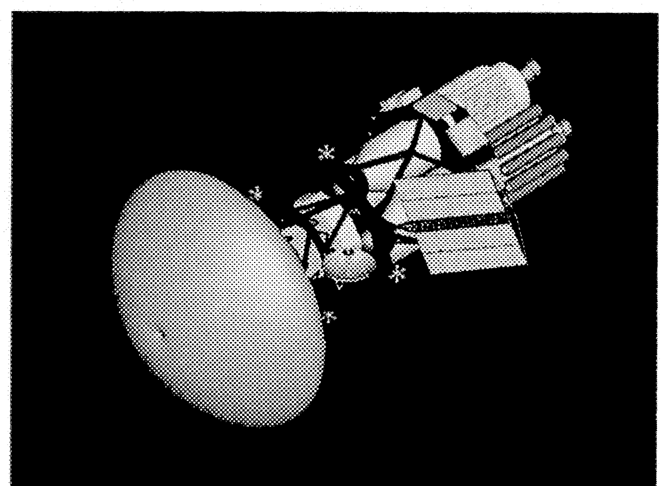


(b) Turbine design

FIGURE 4.34 3D Modeling



(a) Motorcycle



(b) Aerospace

FIGURE 4.35 Product Design Using 3D CAD

4.6.9 Technical Illustration

Technical illustration can be done with a 2D or 3D system. The fact that the original 3D model database can be used to generate the illustration instead of redrawing the part is an advantage of the 3D system (Fig. 4.37). The generation of sales literature is also expedited with CAD, especially when the different departments within a company can all share a common 3D model database.

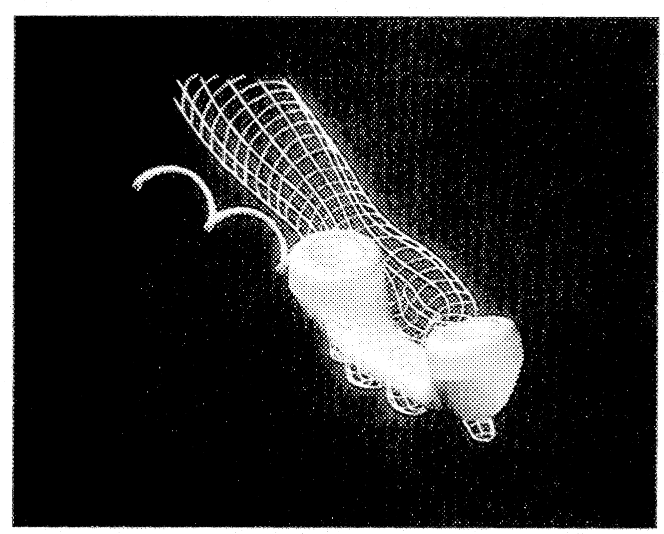
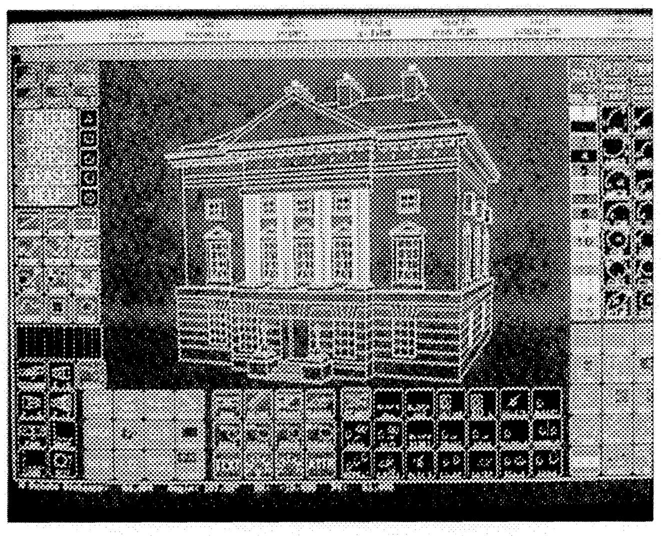


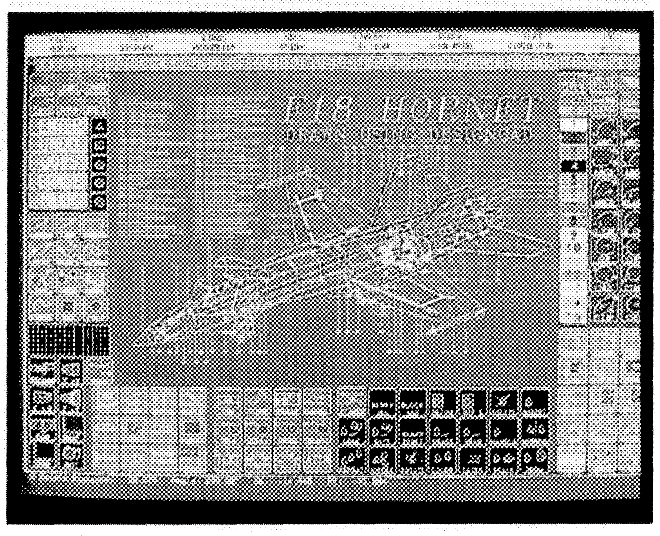
FIGURE 4.36 Product Design and Display

4.6.10 FEM and FEA Applications

To design an optimal structure or to determine the cause of failure in service, design engineers commonly use computerized design and analysis methods. CAD/CAM systems may have a **finite-element modeling and meshing (FEM)** pack-

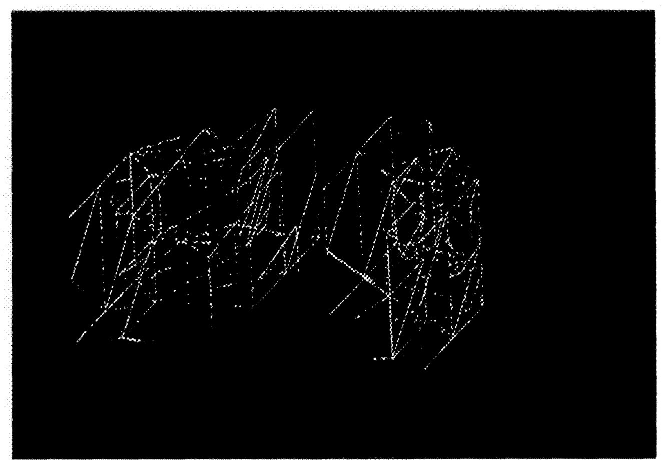


(a) Building illustration

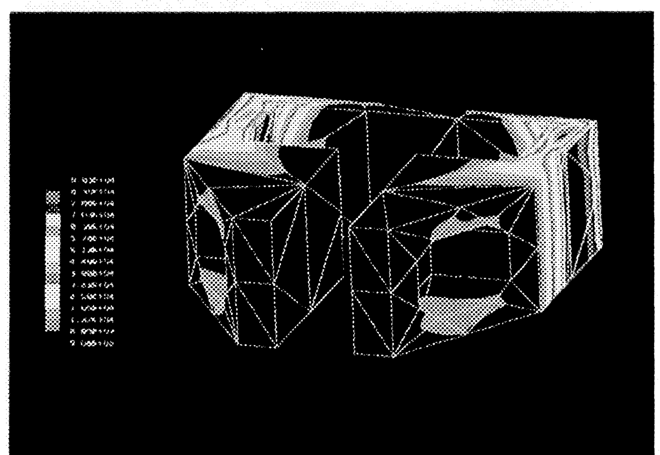


(b) Aircraft illustration

FIGURE 4.37 Technical Illustration Using DesignCAD



(a) FEM



(b) FEA

FIGURE 4.38 Engineering Analysis

age that allows you to create the model, prepare it for analysis, and then graphically display the results.

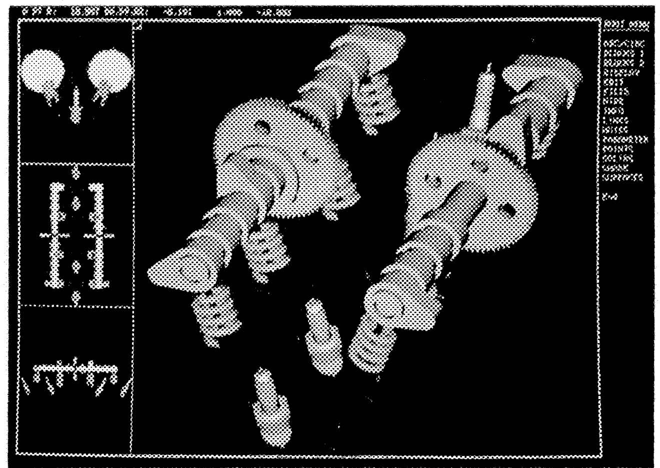
Finite-element modeling and meshing [Fig. 4.38(a)] involves subdividing a structure into a network of simple elements that have easily definable characteristics. A mesh, which is comprised of associative grid points (nodes) and elements, is generated. Then you interactively define material properties, boundary conditions, and loads (such as forces/moments, pressures, and displacements) applied to the structure.

Most CAD systems significantly aid the design engineer in design detailing and in the verification of the functionality and mechanical resistance of complex parts by employing **finite-element analysis (FEA)** methods interfaced to the 3D model of the structure. FEA methods may be set up to calculate thermal stresses [Fig. 4.38(b)] in addition to loads or to model the behavior of the construction material in its elastic or elastoplastic domain.

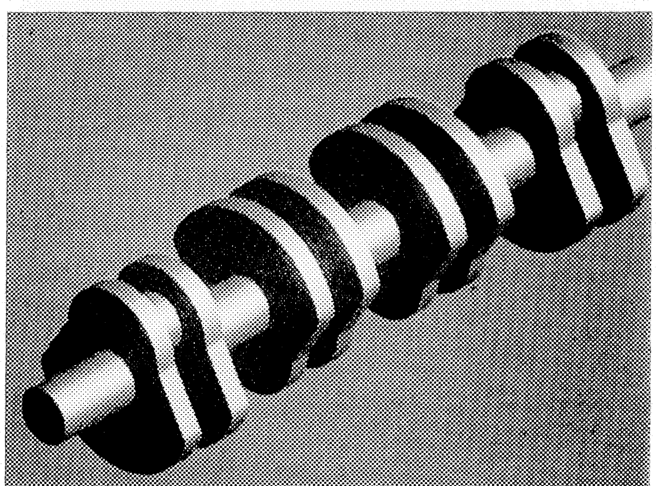
4.6.11 Computer-Aided Manufacturing Applications

CAD helps to create or modify a design. **CAM** manages and controls the operations of a manufacturing facility. The integration of computer-aided design and computer-aided manufacturing eliminates duplication of effort by the engineering and manufacturing or production departments. An engineering model (Fig. 4.39) created on a graphics terminal simultaneously defines the source geometry (points, lines, planes, etc.) that otherwise must be manually derived from the drawing before the product is manufactured.

In an optimal CAD/CAM integrated system the production process is computerized, from the original graphics input to the manufacture of the part on a numerically controlled machine. Shop production drawings may at times be entirely eliminated with this process. By producing the source geometry directly from the engineering data, the programmer can extract accurate geometric data, replicating the definition of the part to be manufactured (Fig. 4.40).

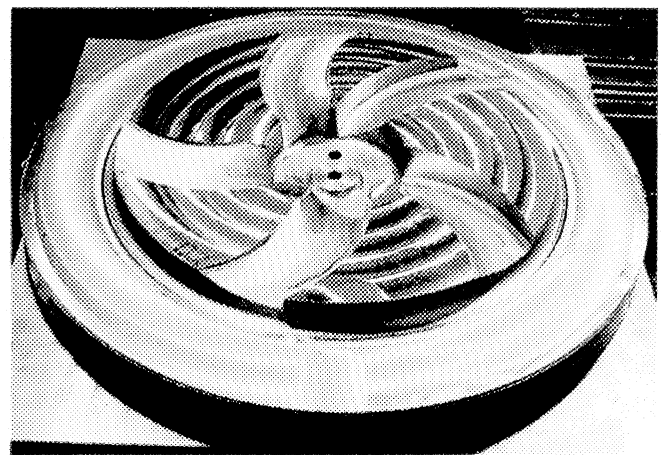


(a) Cam shaft assembly

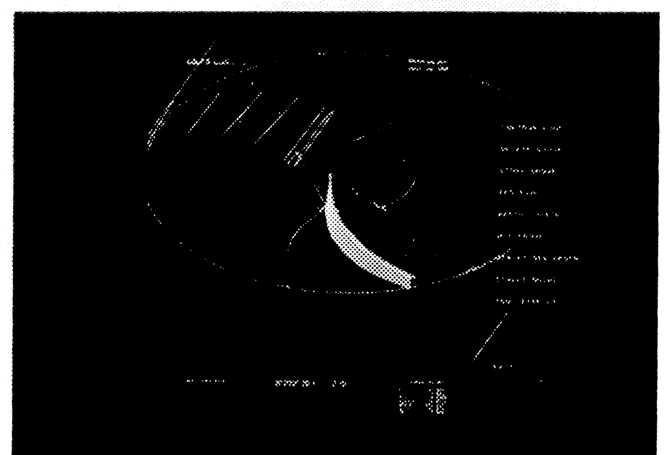


(b) 3D design of a crank shaft

FIGURE 4.39 3D Design of Cams



(a) Mold



(b) Cutter Paths

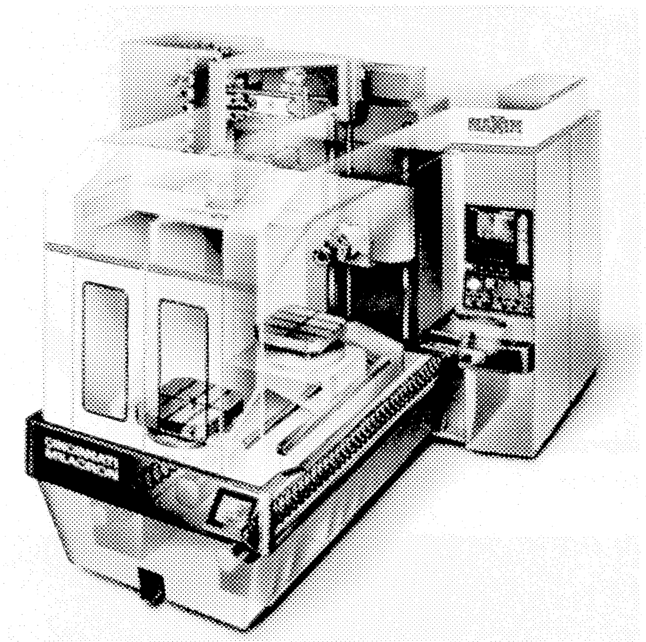
FIGURE 4.40 3D Mold Design

CAM speeds the manufacturing process by using the same common information initially created in the design and drafting cycle. This information, representing the part (or model) design, is also used by the manufacturing group. The system serves all applications, promotes standardization to enhance management control, accumulates (rather than randomly collecting) manufacturing information, and reduces redundancy and errors.

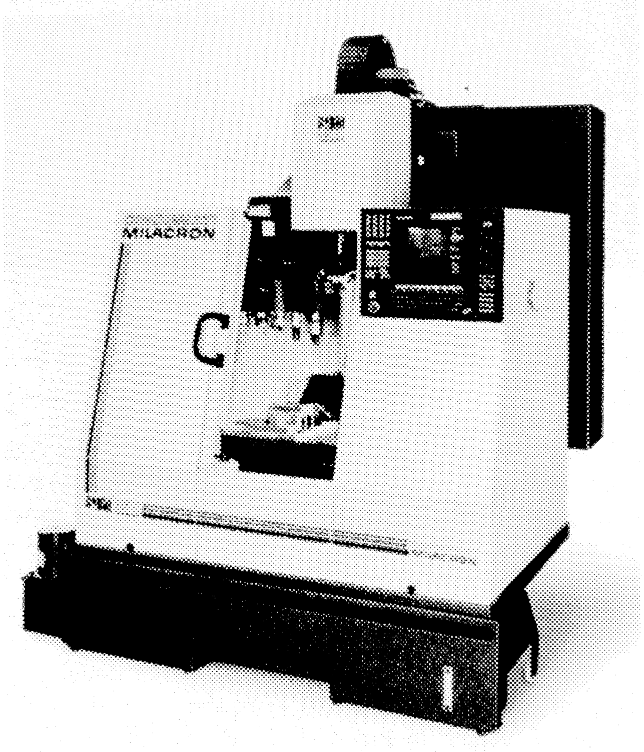
4.6.12 Computer Numerical Control Part Programming

Since the geometry of the part is defined in the CAD/CAM system, there is no need to go through the process of extracting the part geometry from the drawings. The geometry is already given, precisely as specified. Since the designer is provided with visual verification of every step in the process, the graphic display and interactive nature of the system eliminate the need to envision the cutter path. Many CAD/CAM systems provide this graphical approach to computer numerical control (CNC). CNC involves generating tool paths and producing machine control data for a variety of machining operations (Fig. 4.40). CNC machines (Fig. 4.41) perform their machining operations automatically by using the instructions contained on punched tape or derived directly from the engineering database by the computers. Figure 4.41(a) shows an example of a horizontal CNC machining center, and Figure 4.41(b) shows a vertical CNC machining center. In Figure 4.42, an example of a CNC turning center is provided. Each of these machines uses the CAD-generated engineering database for programming the part machining requirements.

The programmer (Fig. 4.42) defines cutting tools, creates a tool library, and retrieves these tools later to create tool path information. Because CAM packages support most cutting tool configurations, programmers can describe most types of generally used cutting tools. The system also prompts the user to define machining characteristics, such as retract and clearance plane, cutting depth, feed rate (rate of travel), and spindle speed (rate of spindle rotation). The



a) Horizontal CNC machining center



b) Vertical CNC machining center

FIGURE 4.41 **Computer Numerical Control Machining**

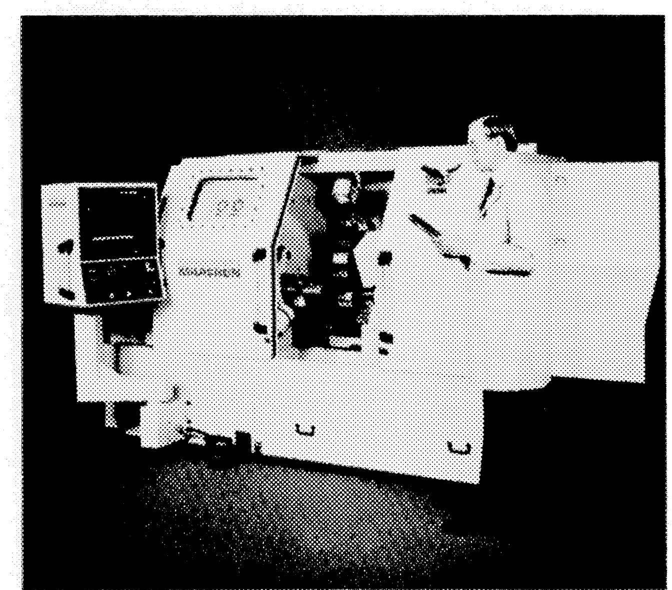


FIGURE 4.42 **CNC Turning Center**

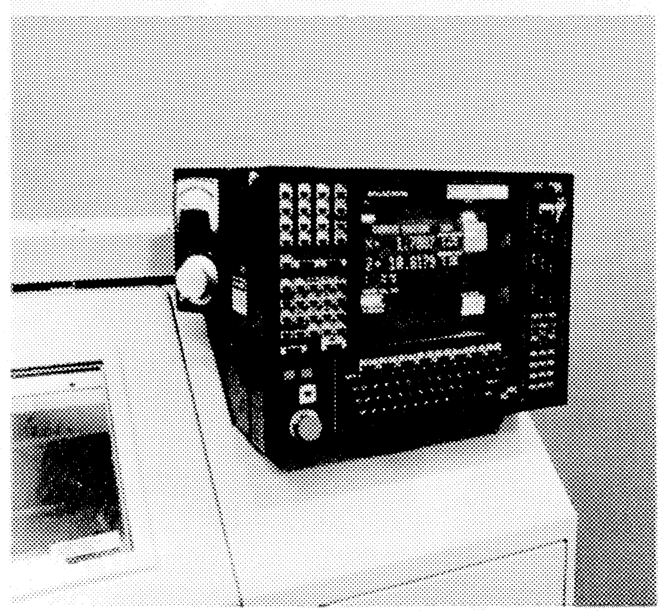


FIGURE 4.43 **CNC Control Panel**

cutter position (**X** and **Z** positions in Fig. 4.43) and all other machining information are displayed on the CNC control center while the machining is in progress.

4.6.13 Robotic Applications and CAD

Robotics is the integration of computer-controlled robots into the manufacturing production process. Industrial robots are used to move, manipulate, position, weld, and machine. Robots are controlled by a microprocessor and are normally composed of a separate, stand-alone computer station, the robot mechanism itself, and an electrical hydraulic power unit (Fig. 4.44).

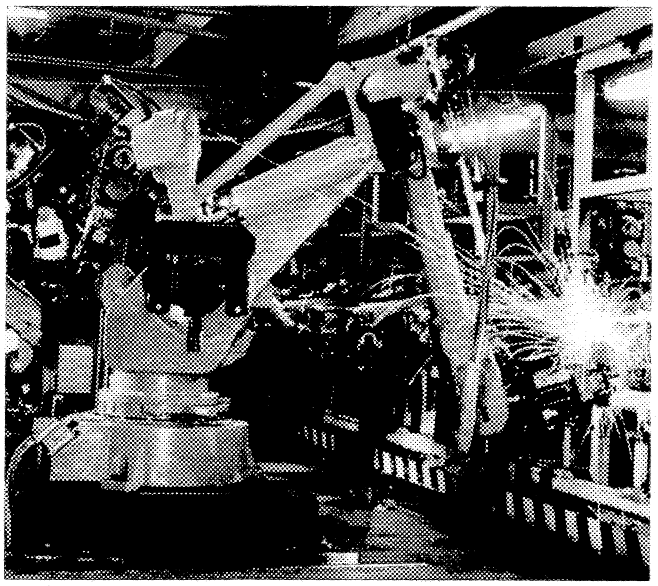


FIGURE 4.44 **Industrial Robot**

A robot is a reprogrammable, multifunction manipulator designed to move material, parts, tools, or specialized devices through variable, programmed motions for the performance of a variety of tasks. This definition can be expanded to include the control and synchronization of the equipment with which the robot works. This capability can eliminate the need for humans to work in an environment that may be hazardous.

The integration of CAD/CAM and robotics results in increased productivity for robotic implementation activities. The **robotic workcell** contains all the physical equipment needed to create a functioning robot application. In addition to the robot, a workcell can have special fixturing, other automated machines (CNC machines, coordinate measuring machines, or visual inspection equipment), materials handling devices, part-presentation equipment, and robot grippers.

The equipment in the workcell must be arranged so that the robot work envelope includes all required device areas. CAD/CAM is perfect for designing the equipment layout (Fig. 4.45). Libraries of workcell components can be stored on the CAD/CAM system and recalled when needed. For example, a robot library could contain commercial robots along with their work envelopes. Robot movement can be programmed, displayed, and checked directly on the CAD system (Fig. 4.46).

Robotics represents a stage in the engineering, design, drafting, manufacturing, and production sequence. As can be seen, the computer and its related technology play an essential part in the present and future of industrial design. From the days of T-squares and wooden pencils, the technology of engineering design techniques has been continually evolving, making the process of product design and manufacturing increasingly more creative and streamlined.

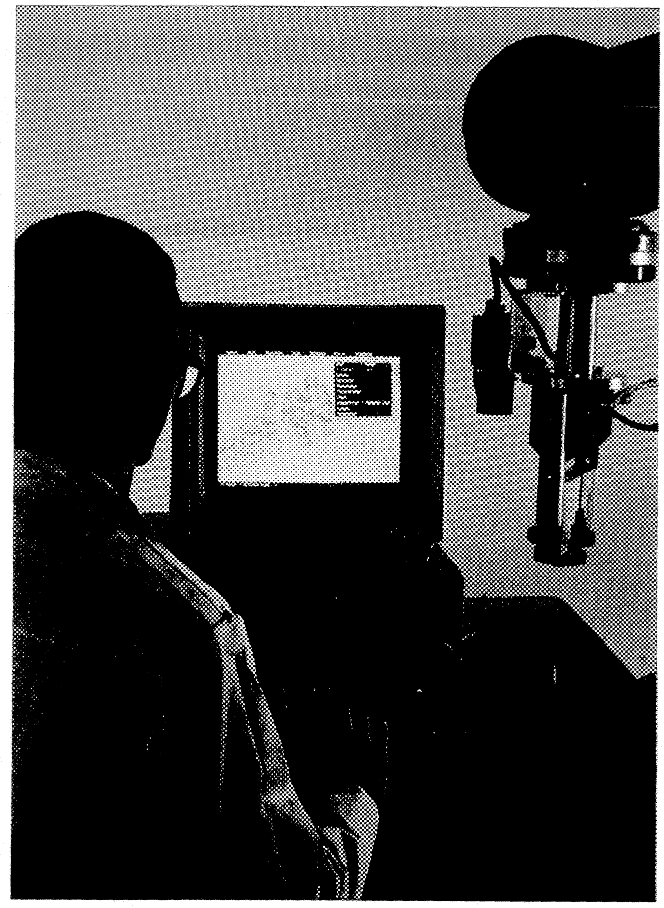


FIGURE 4.45 **On-Screen Robot Programming (Off-Line Programming)**

The need for manual methods of drafting and drawing will never be totally replaced. But the use of computer-assisted methods will continue to influence the type, quality, and pace of industry.

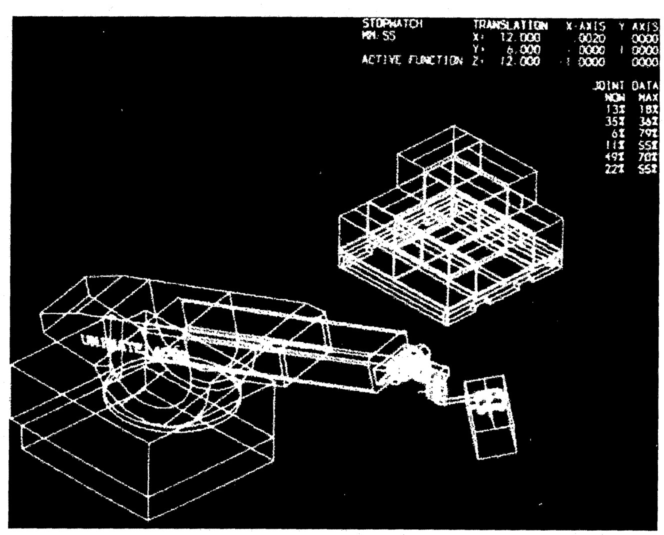


FIGURE 4.46 **Robotic Workcell Design**

QUIZ

True or False

1. Hardware includes instructions to do specific CAD commands to manipulate the display.
2. CAD systems require the operator to have programming ability.
3. The CPU of a CAD system performs all data manipulation required to construct, calculate, process, and store a drawing or engineering design.
4. Interactive CAD means that the system requires little or no input from the operator.
5. Resolution is the smallest spacing between points on a graphics display at which the points can be detected as distinct.
6. Robots can be viewed and controlled directly on a CAD/CAM system.
7. Electrostatic plotters are the most accurate hard-copy device.
8. Systems software allows the user to complete drawings in specific engineering fields, such as piping and electronics.

Fill in the Blanks

9. ___________, ___________, ___________, and ___________ are four applications areas of CAD software.
10. Industrial ___________ are used to move, manipulate, position, weld, and assemble items in the manufacturing cycle.
11. A design workstation normally includes a ___________, ___________, ___________, ___________, and a ___________.
12. Electrostatic ___________, ___________, ___________, and printers are hard-copy devices.
13. The CPU is shared by a number of ___________ on a ___________ CAD system.
14. The ___________ is the movable screen "marker," usually a blinking box, crosshair, or other symbol.
15. Keyboards, ___________ boxes, ___________ balls, ___________ sticks, ___________, and ___________ tables are all types of operator input devices.
16. A ___________ is an input device consisting of command spaces on a digitizing surface such as a data tablet, digitizing tablet, or digitizing table.

Answer the Following

17. Name six typical input devices.
18. Name five typical output devices.
19. What are function keyboards, and how do they differ from terminal keyboards?
20. What is the difference between a printer and a plotter? What are the capabilities of both pieces of equipment?
21. Name three types of plotters, and explain their uses.
22. What is applications software? Name five types.
23. What is the difference between a display menu (online menu) and a tablet menu?
24. Define "CIM" and explain how it relates to the total design-through-manufacturing cycle.