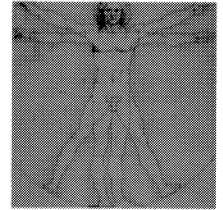


THE DESIGN PROCESS

Chapter 3



LEARNING OBJECTIVES

Upon completion of this chapter you will be able to:

1. Understand the role of the engineer in the design process.
2. Interpret the criteria for product and manufacturing engineering that result in design for manufacturability.
3. Analyze and utilize the stages involved in the design process while recognizing their flexibility.
4. Develop an understanding of critical-path scheduling and just-in-time production concepts.
5. Integrate CAD applications into the design process.
6. Understand the role that solid modeling and CAD play in the efficient design of a manufactured product.

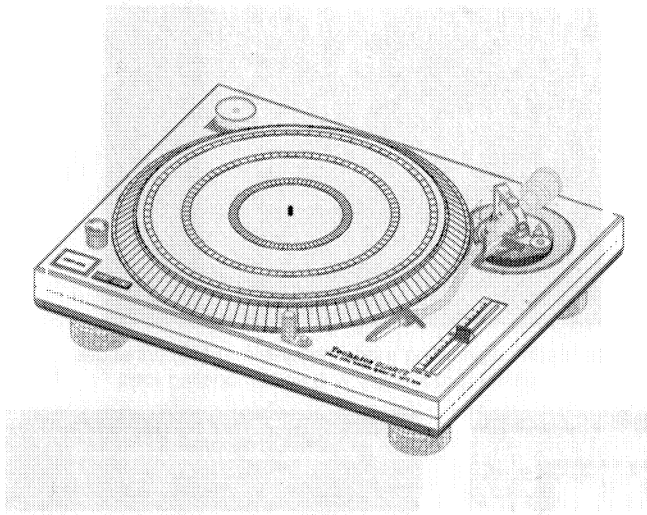
3.1 INTRODUCTION

The design process is an organized interactive engineering activity that results in a well defined concept and a specific plan to turn that concept into reality. The design process is a logical and planned sequence by which an individual or a team can develop a solution to a specific problem. The stages in the design process described here are not intended to be rules or procedures that are appropriate for all design situations; consider them a guide to the design process.

Though the end product is specified in the form of drawings, computer images, sketches, and engineering specifications, designing involves more than simply putting a drawing together and having the part made in the shop. Designing is an interactive process with planned steps and checkpoints. Every design involves solving a particular problem, analyzing what is needed to do the job, and planning the series of steps and activities that will transform the concept into a concrete object. Each design involves making choices in materials, instrumentation, manufacturing processes, and fabrication personnel. Finally, every design should have the input of a team, each member of which can offer advice, assistance, guidance, constructive critiques, and support.

With the advent of **design for manufacturability (DFM)**, the design process now incorporates procedures and considerations formerly left only to manufacturing. Throughout this chapter, you will be introduced to a variety of DFM concepts and ideas that will show the design process to be a fluid and dynamic way to integrate manufacturability into the design. With DFM, manufacturing is considered at the beginning of the design process. Since as much as 70% of the manufacturing cost of a part is fixed during design, DFM is an important concept. For more information, see *Design for Manufacturability* by David M. Anderson (CIM Press, Lafayette, CA).

Few people understand the complexity of a particular product or the amount of effort required to bring a product to market. Figure 3.1 presents an example of a complex



(a) Design of assembly using 3D wireframe modeling



(b) Same assembly shown with AutoShade

FIGURE 3.1 Design Via a Solid Modeler

assembly designed on a solid modeling system. The complexity of a typical system design, such as a nuclear power plant, a petrochemical facility, or an industrial building, is more obvious. But even in these types of projects, the general public does not fathom the complexity of and the time devoted to the design process.

A typical consumer product, such as a household appliance or a hand tool, can appear deceptively simple. In reality, however, the design concerns engineering requirements, and manufacturing procedures are extremely complicated and time-consuming. Obviously all products are the result of many hours of intense work. Product description and development include design, drafting, analysis, and manufacturing (Fig. 3.2). If the part design is generated on a CAD system (Fig. 3.3), it can be used in all subsequent stages of the design through manufacturing sequence (Fig. 3.4).

It is impossible to describe how to design every item. It has been said that you cannot teach engineering design, but

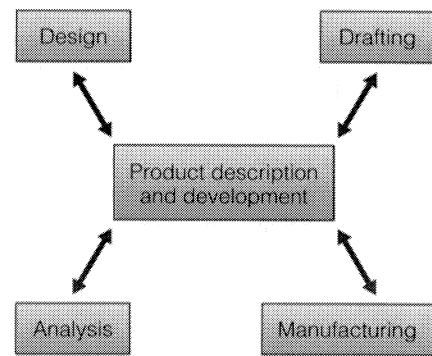


FIGURE 3.2 Product Description and Development

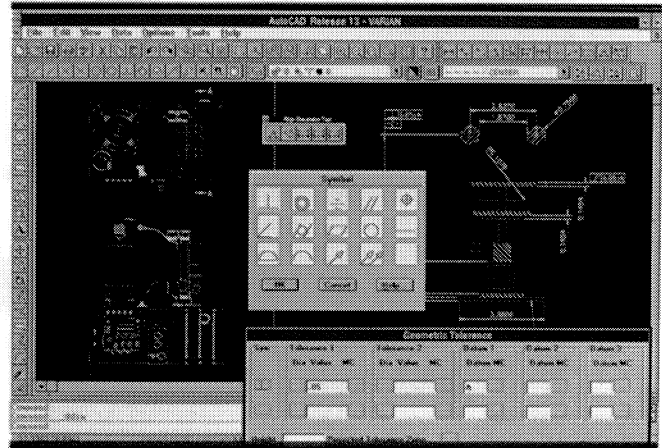


FIGURE 3.3 Using CAD in the Design Process

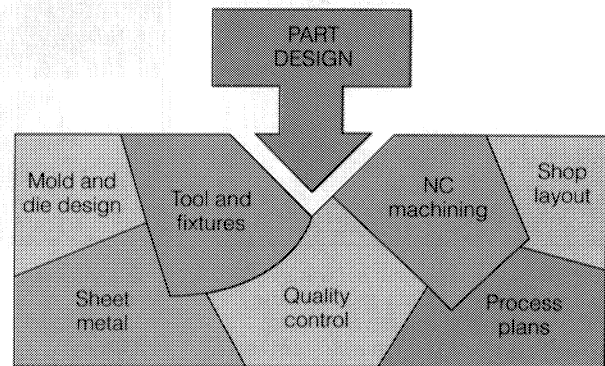


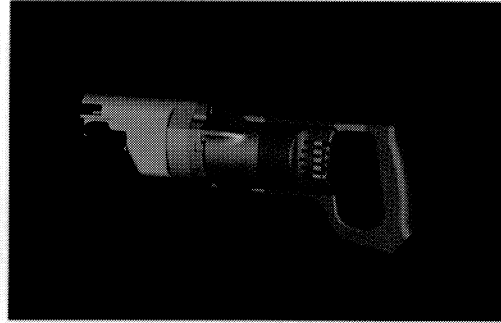
FIGURE 3.4 Part Design Using CAD

a thorough presentation of design concepts leading to the understanding of the conceptualization process involved in design and mastery of the stages involved in the design process will lay a solid foundation for anyone aspiring to become a design engineer. Specific design parameters for a product or system are mastered on the job through the accumulation of experience.

The two main divisions of engineering design are systems design and product design. Although systems design is an important field, a majority of this text is devoted to product and mechanical design techniques. Therefore, this chapter is primarily a detailed analysis of the design process as it relates to product development and mechanical design.

3.2 OVERVIEW OF THE DESIGN PROCESS

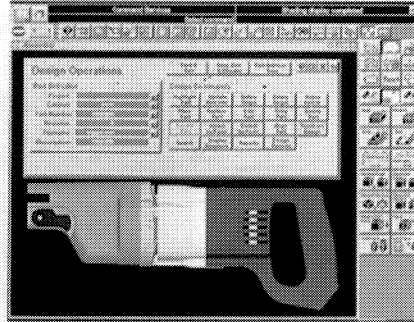
The design process begins when a customer expresses a need for a product. Working with the customer, you define the project and formulate its requirements. Figure 3.5 shows the design analysis and manufacture of a commercial product—a saw—on a CAD/CAE/AM/AF system (Intergraph). Many steps are required to design and manufacture a complicated product such as the saw shown in the figure.



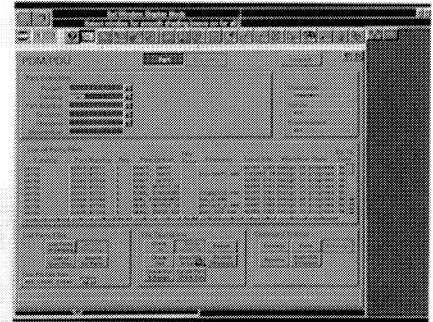
(a) Intergraph engineering modeling system (EMS) enhances mechanical design productivity with solid modeling tools



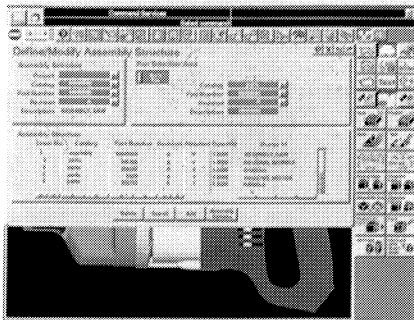
(b) EMS data management software produces bills of material and automatically generates single-level parts lists for drawings



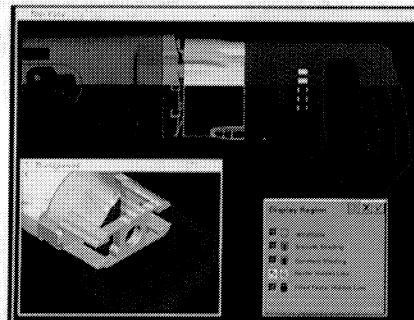
(c) EMS forms make it easy to select parts and add them to an assembly; a design engineer can choose either top-down or bottom-up design



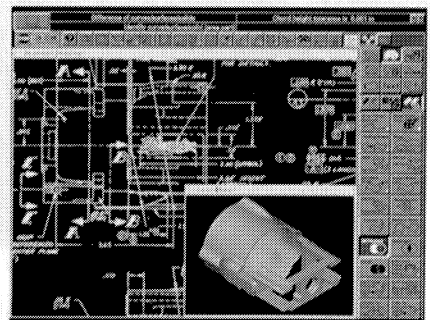
(d) EMS data management system simplifies file management with component check-in and check-out, file location tracking, archiving, retrieval, and security



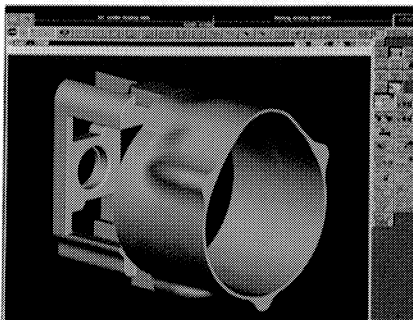
(e) EMS data management software provides a single product structure and central controls that link development teams with a shared information resource



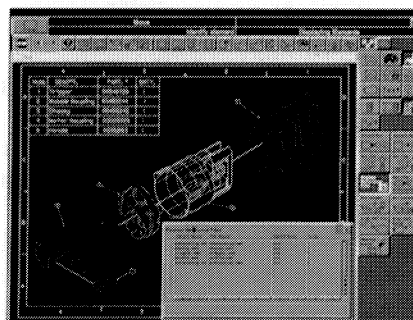
(f) Sharing data with engineering design: Intergraph industrial design products couple product styling with engineering processes



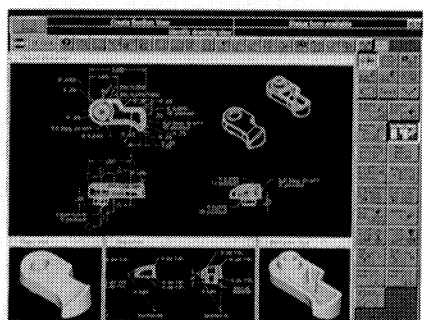
(g) With Intergraph's EMS, existing drawings are electronically scanned and can be used for reference or modified for new uses



(h) The master model supplies Intergraph's full suite of downstream applications with complete data, eliminating translation and re-creation

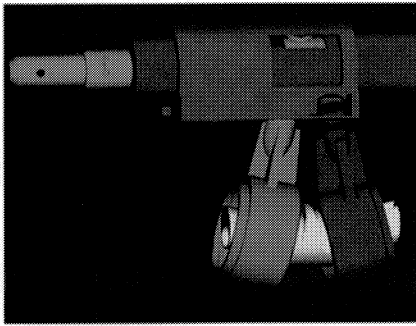


(i) Using Intergraph read-only design files ensure parts' mating and enable designers to share information while designing different parts of an assembly

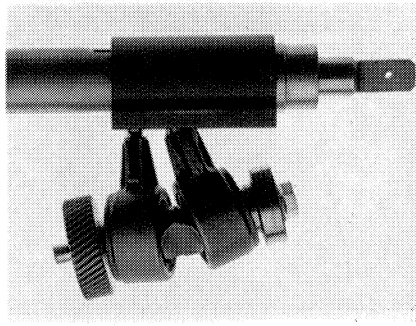


(j) For detailing in Intergraph, the design software includes dimensions and creates section views, which are automatically updated to incorporate model modifications

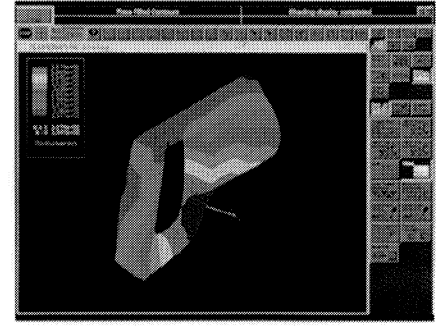
FIGURE 3.5 Design Example—a Saw



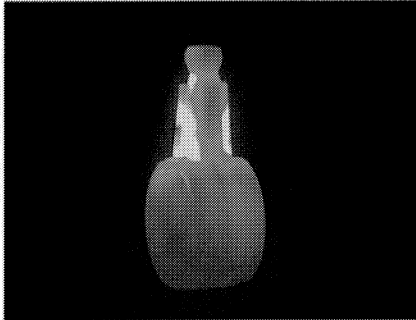
(k) Shaded models in EMS show the relationship and relative motion of mating parts and assemblies



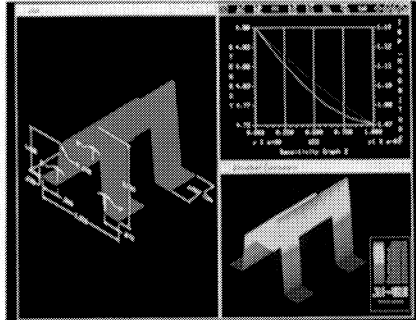
(l) Machined assembly showing actual part geometry and motion



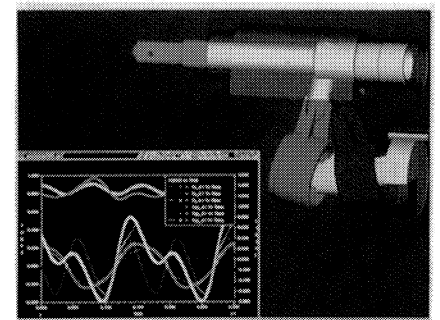
(m) EMS plastics injection analysis software analyzes the effects of time, temperature and pressure on the flow of molten plastic



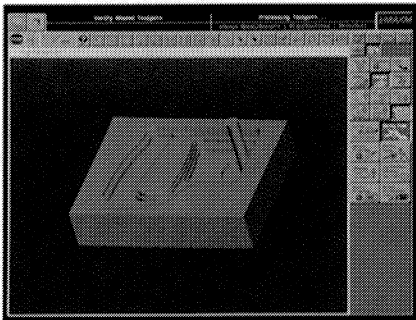
(n) Intergraph finite element analysis software enables engineers to perform structural analysis of complex components



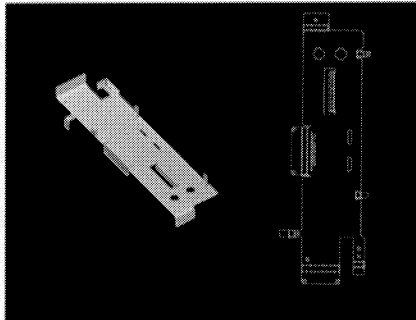
(o) Based on user-defined variables, constraints, and goals, closed-loop design optimization software evaluates design variations to determine the best solution in EMS



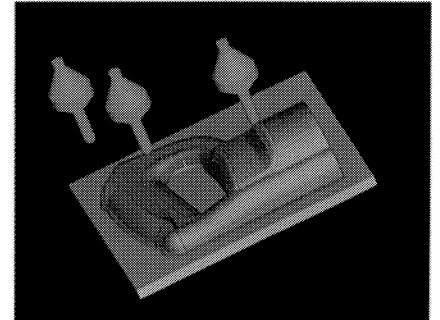
(p) Mechanical systems analysis software in EMS helps study mechanism performance including interference and the way forces change during operation



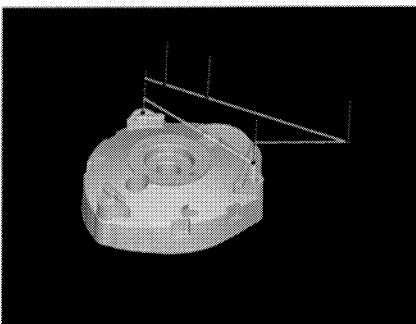
(q) Three-axis milling in roughing mode maximizes machining efficiency and prepares a part for finishing in EMS. Animated simulation helps verify machining processes



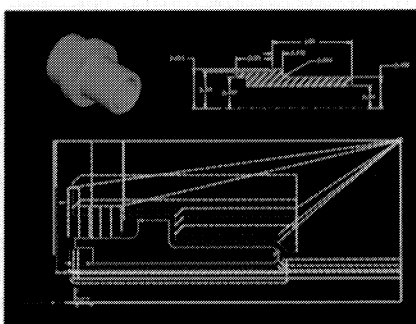
(r) Reducing design-to-manufacture turnaround time, flat-pattern development software develops flat patterns for a variety of 3D shapes in EMS



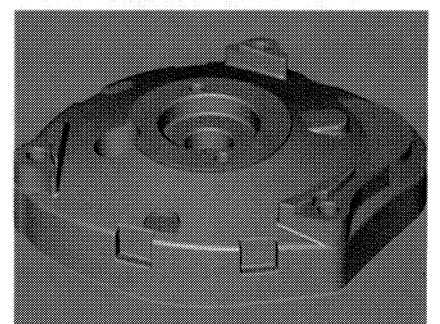
(s) Directly linked with design data, Intergraph manufacturing software generates and verifies milling toolpaths



(t) Integrating design manufacturing and quality control. Intergraph Coordinate Measuring Machine (CMM) software accesses design files directly for measuring free form and geometric features

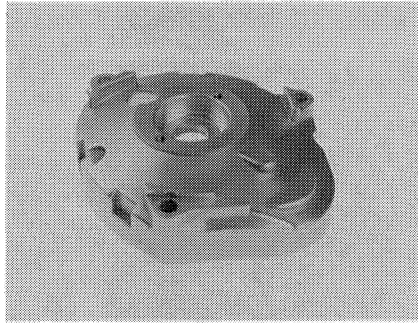


(u) Intergraph's lathe option creates turning, grooving and threading toolpaths according to model geometry

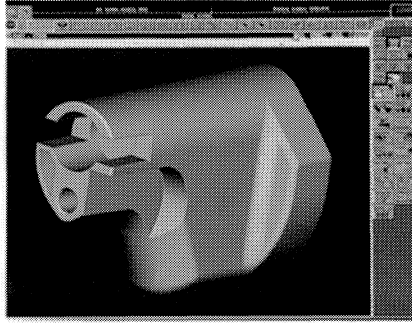


(v) Shaded solid model in EMS shows detail of part design

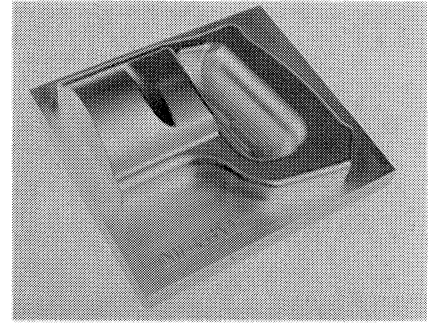
FIGURE 3.5 Design Example—a Saw—Continued



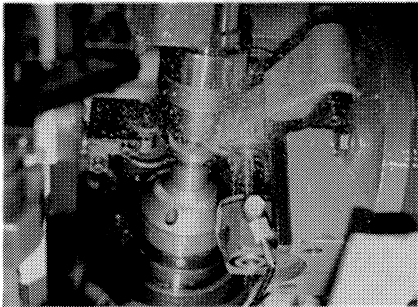
(w) Using Intergraph's EMS shading of solid models makes part creation and visualization easier



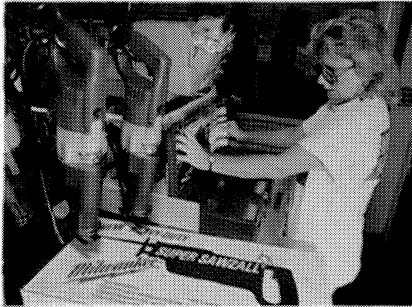
(x) Complex components are easier to visualize using a shaded solid model in Intergraph's EMS



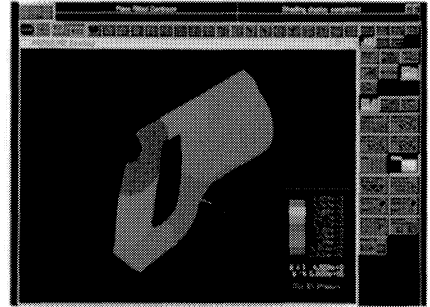
(y) CNC toolpaths are created in EMS to speed the production of rough cut molds and components



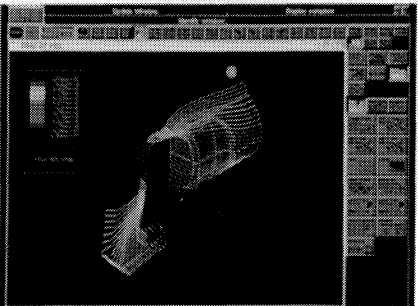
(z) Machining operations are made easier using one 3D design database



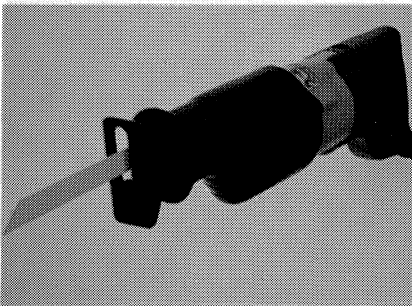
(aa) Inspection quality control and packaging are simplified by using one 3D solid model design database for the entire assembly



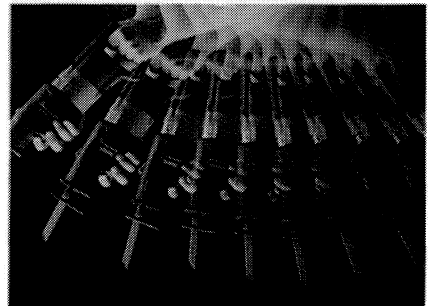
(bb) Finite element modeling and plastics injection molding analysis are part of the EMS system. Shaded contours show stress or temperature distributions



(cc) Finite element modeling and plastics injection molding analysis can also be shown in EMS with iso lines



(dd) Product design is integrated in Intergraph's EMS software



(ee) Part designed via EMS shown in use

FIGURE 3.5 Design Example—a Saw—Continued

The design process to complete such a product and bring it to market involves a series of steps. Though in most cases the design steps are unique to each product, there are general steps and guidelines by which every project can develop and produce a product.

For simplicity, the design process has been separated into eight individual stages (Fig. 3.6). This is not to be taken as a set of hard-and-fast steps or rules. The actual design process is more flexible and is not as linear as described here. *Design for manufacturability* requires the eight stages to be considered not separately but as an integrated whole in which each stage is constantly being considered within every other stage. Many of the eight stages presented here are performed simultaneously by the design/manufacturing

team. The stages do not always flow in a straight line from 1 through 8. Sometimes there are different stages or more or fewer stages. Remember, these are theoretical divisions of tasks. Manufacturing always comes after the engineering and analysis, but *manufacturing decisions and capabilities are integrated into the preliminary design and engineering stage*.

The flow diagram of Figure 3.6 shows various stages in the design process. The general flow is from top to bottom as the arrows beneath each box indicate. The flow lines and arrows on the left and the right sides of the illustration flow from the bottom up. On the left side for instance we see that consulting the marketing and sales division influences problem identification (1), evaluation (3), and the design choice (5). On the right side of the figure we see that

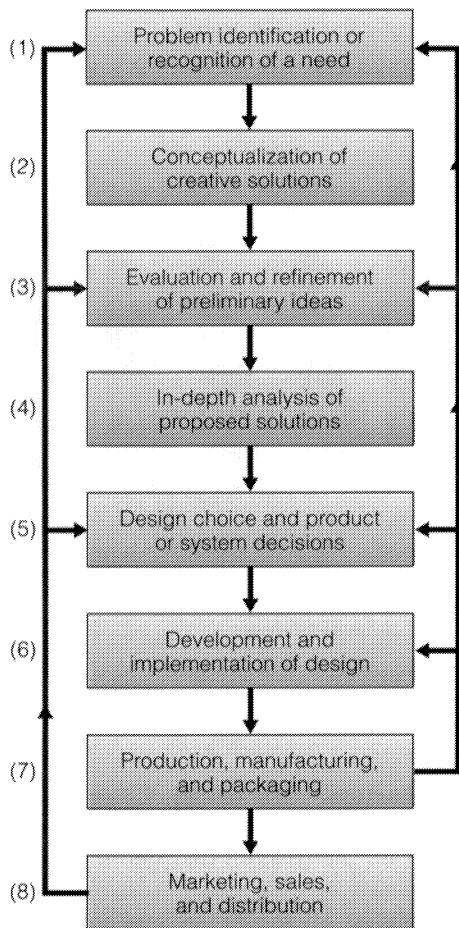


FIGURE 3.6 Stages in the Design Process

manufacturing (7) affects almost every other stage in the process. The rest of this chapter will take each stage in sequence and indicate the specific influencing factors and tasks associated with it.

3.3 PROBLEM IDENTIFICATION OR RECOGNITION OF NEEDS

The design process starts with the **identification** of a problem (Fig. 3.7) an observed need or a potential new idea for a product or system. Problem identification or recognition of need is the starting point of all design efforts. The identification or recognition stage requires the designer or design team to be thoroughly acquainted with the problem or need. You should attempt to answer the following at this stage of the project:

- Who needs it?
- What is needed?
- Where is it needed?
- When is it needed?
- Why is it needed?
- How many are needed?

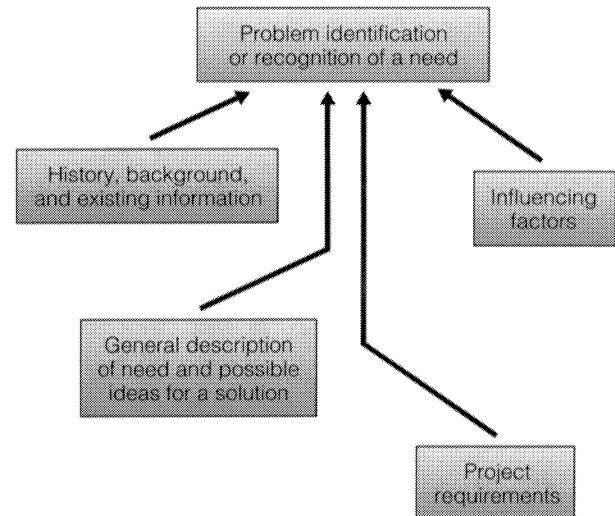


FIGURE 3.7 Stage 1 in the Design Process

History Background and Existing Information The **background** of the project is presented to the design team by a concerned party—the company management, an outside client, or a company inventor who has a new idea. The marketing department may be asked to do a survey on the potential for a particular product. For example, suppose a computer company that has a well-received product line servicing the private sector with personal computers wishes to enter the engineering workstation market. Surveys may be needed to determine the total sales of computers in that sector and create a forecast for the future. The marketing and research department will probably create a series of charts and graphs to present their findings visually. The company's management, along with the design team, then discusses the potential for their firm to enter—and be successful in—this market. Figure 3.8(a) presents a graphical analysis of the market forecast shown in Figure 3.8(b).

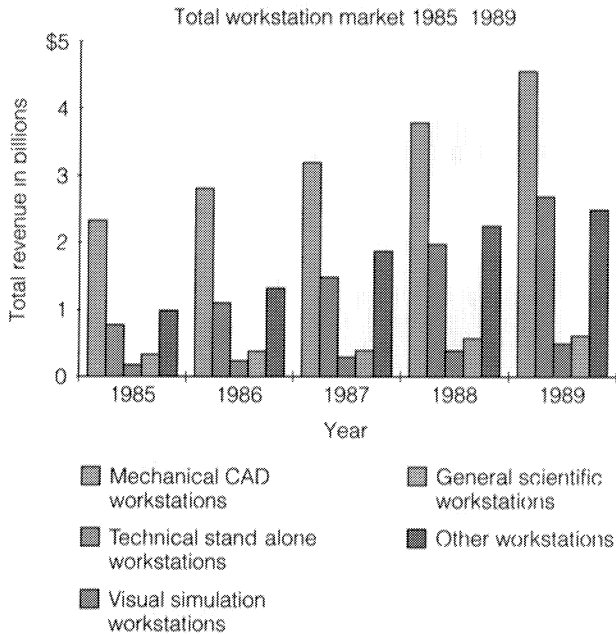
A number of questions can be asked at this stage of the process:

- What exists now?
- How was the problem faced in the past?
- Is this a new problem?

The answers to these questions may be incomplete at this stage; in fact, they may create more questions.

General Description of Needs and Possible Ideas for Solutions The **general description** of and possible solutions to the problem flow from a series of meetings conducted with the design team. Let us say a company that has been manufacturing small residential plumbing valves and medium-sized industrial valves has an opportunity to bid on a large job requiring pipeline-sized valves (Fig. 3.9). The new product line will affect the manufacturing equipment, facility space, manpower requirements, shipping and storage areas of the firm. The size of the valve alone may necessitate a total retooling of the facility. The job may also

(a) Graph depicting workstation market data



(b) Market forecast data in graph form

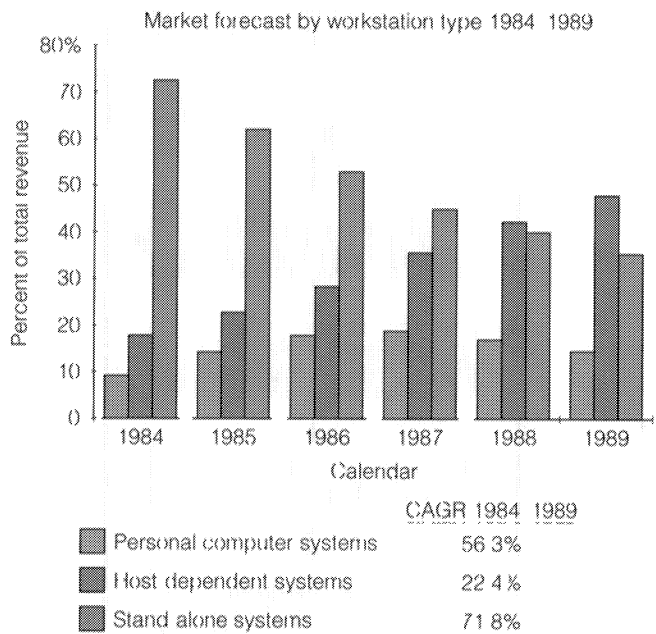
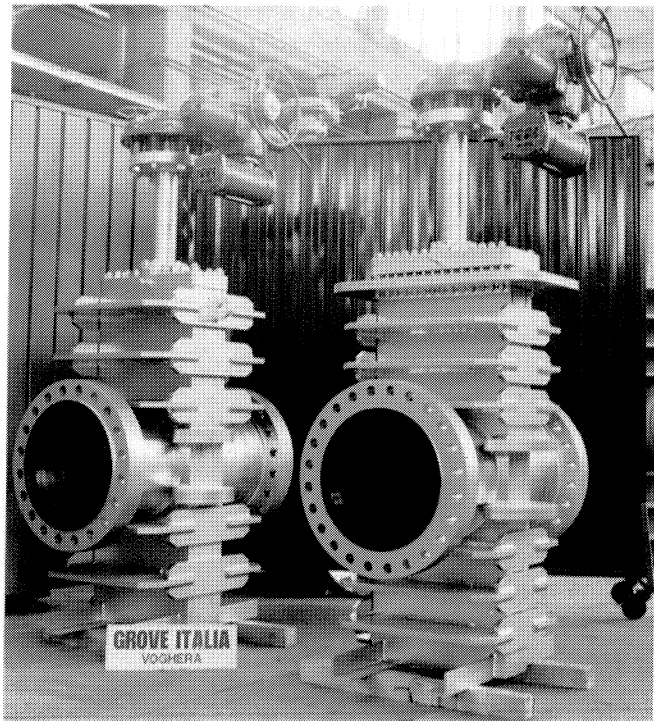


FIGURE 3 8 Example of a Market Analysis

be a one time opportunity and have little continued sales after the project is complete. The economics of the project is of primary concern. How will it affect existing product lines? Is it worth the risk? Will the company turn a profit for its effort? Will the company be able to sustain a continued presence in this market after the project is complete?

Influencing Factors The design of a product or system does not happen in a vacuum. All products and systems have an effect on the users of the product or system and possibly on society in general. The cost of a project determines its feasibility. All factors that may influence the total cost and the economic feasibility of the design must be considered before the project is initiated.



Environmental constraints and concerns may be important for many product designs. Systems design is influenced by the environmental constraints and effects imposed on it by the government and special interest groups. The design of a power plant, chemical facility, hydroelectric plant, bridge, housing complex, or building, to name a few, is defined by the acceptable effect it has on the environment. An environmental impact report may be needed before much of the design effort is begun. The valve of Figure 3 9 is on the TransAlaska pipeline (Fig. 3 10). Environmental impact reports were a major part of the design effort and were used to convince the public that the pipeline was feasible and safe. The actual conditions under which the pipeline and valves operate stretched the limits of pipeline technology.

FIGURE 3 9 48 in Gate Valve for TransAlaska Pipeline

The economics of a particular solution must be understood at an early part of this stage. Can the product or system make money? Is the existing budget adequate? Will the project involve new markets, or will the product be replacing an existing one? When economics is concerned, input from all other departments is important. The marketing and manufacturing departments have considerable input that must be integrated into the total economic analysis of the project if it is to be successful.

Project Requirements Basic parameters can be identified at this stage. All ideas and suggestions should be recorded as



FIGURE 3.10 Gate Valve Being Installed on the TransAlaska Pipeline

notes and rough sketches. The project's size, shape, color, material, and general configuration can be discussed. No decisions should be made at this point. Requirements dictated by a client or purchaser of the product or system must be added to the list of known influencing factors and project requirements. If a project must be a certain color or weight, this must be understood at the earliest stage of the process. If the product is to be produced efficiently, design for manufacturability must be integrated into the project from the outset.

3.4 CONCEPTUALIZATION OF CREATIVE SOLUTIONS

Before the design process goes any further, **creative possibilities** for a solution to the design problem should purposely be investigated. Knowing background information and the research on pertinent data helps the designer see clearly the range of possible answers to the design problem.

This second stage (Fig. 3.11) includes researching every available source of information about the project. Each of the design elements listed in Stage 1 is now analyzed thoroughly. The influencing factors, general parameters, and project requirements are used to investigate possible solutions. Even at this stage, attempt should not be made to find a complete final solution. Data from outside sources is integrated into the design process during this stage. Former solutions to the same or a similar problem can be discussed and expanded on now.

Although the past experience and education of a designer are extremely important for the success of a project, proper research on all existing information on the subject is no less important. Since the research process helps build a professional database that can be tapped for other projects, a new

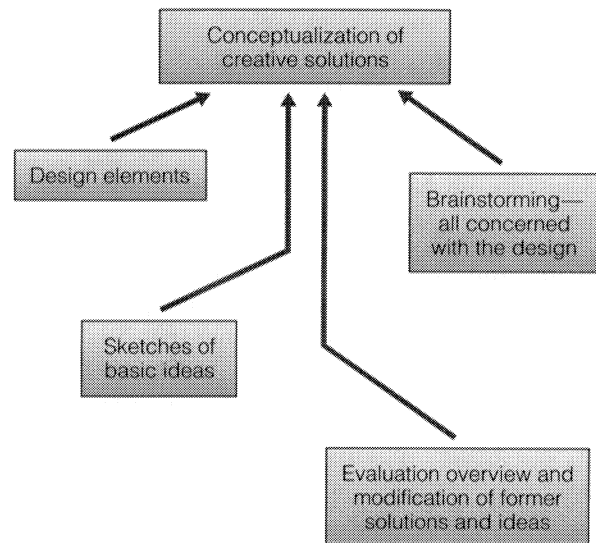


FIGURE 3.11 Stage 2 in the Design Process

or inexperienced designer benefits from any existing information. Oddly enough, it is not the lack of background sources but the overabundance of information that is a problem. The design engineer must differentiate between what is useful and important and what is unessential. The following list provides some sources for acquiring information on a design problem.

- Textbooks
- Periodicals—technical magazines
- Library search
- Engineering standards
- Technical reports
- Published papers presented at conferences
- Manufacturing specifications
- Catalogs of parts
- Patents
- Handbooks
- Previous designs in the company
- Coworkers—other designers and engineers

Design Elements The **elements of design** must be identified by the design engineer early in this stage of the project. The identification and classification of design elements helps to clarify and divide important or vital elements from minor or nonvital concerns. A creative choice for a design solution must flow from a deep understanding of the design elements related to the project. Listing the design elements helps clear up any misconceptions regarding the project. The following is a list of steps that will help identify the design elements.

- 1 Define the *basic design problems* relevant to the solution.
- 2 Define the *secondary design problems* that are not the designer's concern but that still need to be solved.
- 3 Identify *perceived problems* that are not really important. This alleviates false concerns.
- 4 Identify *obstructions* to the design, i.e., significant ob-

stacles to the design solution that must be avoided or circumvented

- 5 Find and discuss all *hidden difficulties*. These are obstructions to the solution that are not clearly seen or understood
- 6 Scrutinize any *hindrances* to the design that are really not important enough to justify much time

Sketches and Layouts of Basic Ideas Although a few rough sketches may have been made during Stage 1, more developed sketches and pictorial layouts (Fig. 3.12) now can help define any preliminary ideas better. All notes and preliminary sketches should be kept on file. Nothing created at this stage should be destroyed. Sketches and layouts help refine the design. They also define physical aspects of the problem and help spin off creative or new solutions. All those concerned with the project should bring the notes and sketches developed to this point to the next meeting, where a short brainstorming session may introduce creative solutions to the problem.

Brainstorming A brainstorming session would be appropriate at this time. **Brainstorming** is a group problem-solving technique that elicits a spontaneous contribution of ideas from all members of the group. No idea is rejected at this point, and all members of the group are considered equal. Ideas are not explored in depth at this time. All suggestions are recorded to be used later to develop certain ideas. The acceptance of the project or design choice is a long way off at this stage of the project. Creative solutions are given as much merit as practical or obvious solutions.

Many aspects of the design background must be understood *before* the brainstorming session so that it does not become a useless exercise. Brainstorming may help find a unique or unthought-of set of possibilities. Multiple products or variations of one product or solution should be thoroughly investigated before the next stage.

Review and Modification After the brainstorming session, all notes, sketches, surveys, marketing analysis, and

research data should be reviewed. Any ideas that show no merit are filed at this point. The basic thrust of the design effort starts to take shape. Many possible answers to the problem are still considered, but a basic or general idea of the direction of the project will be sought so as not to linger at this stage.

3.5 EVALUATION AND REFINEMENT OF IDEAS

The **evaluation** of possible solutions and their **refinement** into an end product (Fig. 3.13) is done at Stage 3. Refinement of a design is more restrictive at this point. More than one solution is still pursued, but the basic parameters of the project have been used to control the breadth of the design effort. An analysis of the project includes graphical analysis via descriptive geometry, statics, and vector analysis. Human factors engineering is also an aspect of this analysis.

Creative Choices and Alternative Size and Shape Before a formal proposal is formulated, a number of possibilities for the project should be sketched and evaluated to determine size and shape. The basic parameters determined here help define the engineering and scientific analysis needed and what must be understood before the final decision on design choice is made.

The size and shape of the design will narrow the choice of materials. Specific design requirements, elements, and parameters are now solidified into a complete description of the problem and the thrust of a solution.

Comparative Analysis of Design Possibilities To be successful, the analysis of a problem must include both its requirements and its limitations in order. The restraints and limitations of a design problem help define the boundaries of the solution. Any analysis of the data gathered to this time must include the possibility of a compromise solution to the

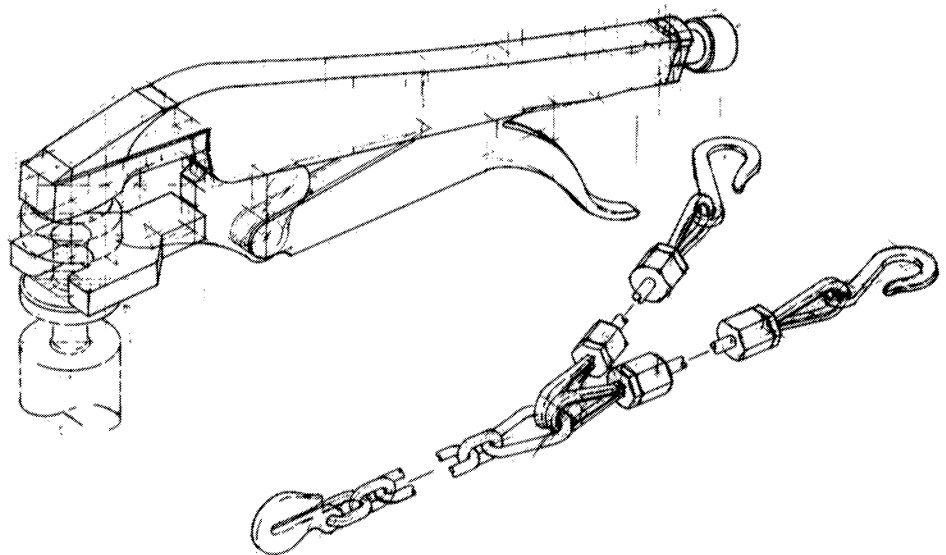


FIGURE 3.12 Pictorial Layout

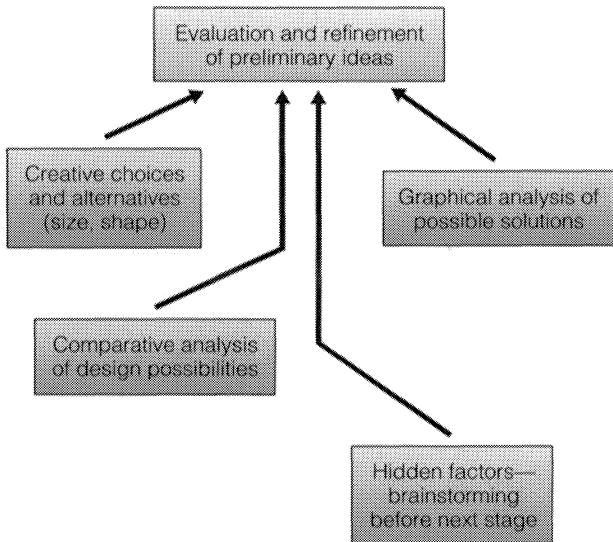


FIGURE 3 13 Stage 3 in the Design Process

problem. From this analysis a decision must be made to proceed with any graphical analysis that may be needed to define the project better.

Graphical Analysis of Possible Solutions Engineering analysis includes the use of graphics to define a number of possible solutions and analyze them using descriptive geometry, vector analysis, layout drawings, and 3D modeling with a CAD system. Figure 3 14 is an example of the use of descriptive geometry to find a clearance between a pipeline and a fixed point in space. Piping systems, as in Figure 3 15, are one part of a complete plant. The interferences between pipelines and other systems (e.g., electrical, heating/cooling) and the structure require a detailed analysis. Sketches and

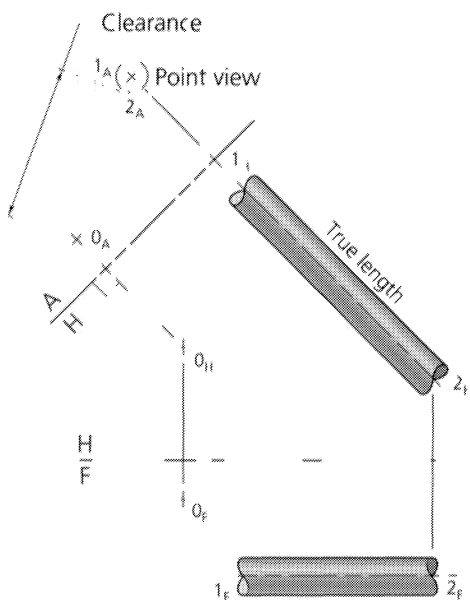


FIGURE 3 14 Descriptive Geometry Problem Solving for the Shortest Distance Between a Pipe and a Fixed Point

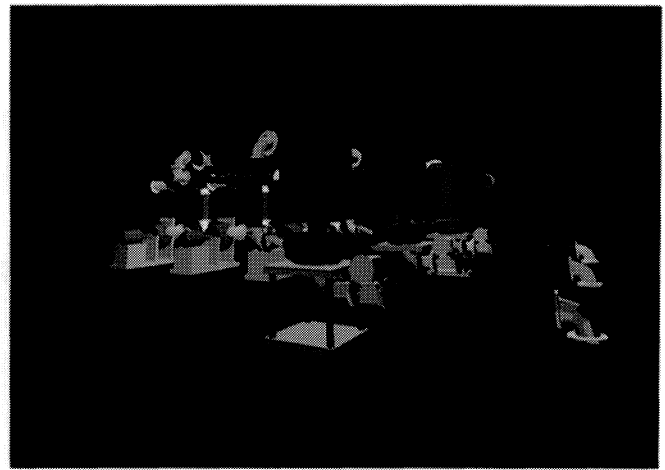


FIGURE 3 15 Shaded Image of Piping and Equipment

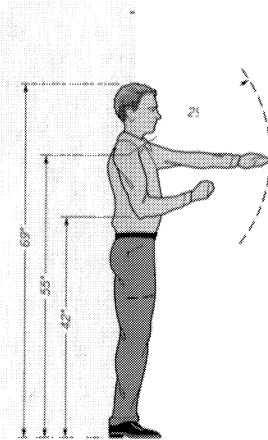
descriptive geometry drawings are created with instruments or on a computer to scale. A selection of the best possible solutions is rendered for **graphic analysis**.

Human Engineering and Graphical Analysis Product design includes consideration of human engineering requirements. Human engineering involves analyzing how people are affected by performing specific tasks and the man-machine interface. The first concern is normally referred to as ergonomics and the second as human factors. Both are important to the successful design of a product or a system.

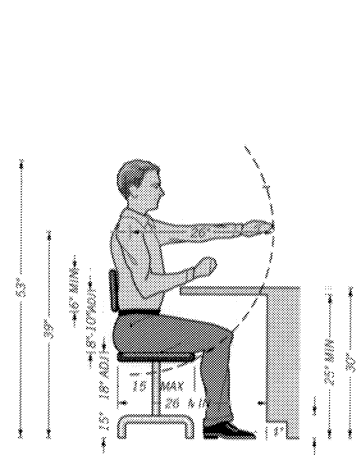
Ergonomics is concerned primarily with the study of physiological responses to physically demanding work, environmental stress caused by temperature, noise, and lighting; motor skills for assembly and visual monitoring tasks. *Human factors* is the modeling of the human body in a work-related setting. Human factors data is useful in the design of a factory workstation in order to provide a comfortable environment and thereby increase work output and decrease job stress. As an example, three views of a man at work are shown in Figure 3 16. The seating and standing heights of a typical male, the comfortable reaching distance from both positions, and the maximum and minimum working area are defined graphically. Industrial design requires the study of body dimensions and movements. Simple products, such as hand tools, to complex system products, such as automobiles, require extensive use of human factors and ergonomic studies and recommendations.

Human engineering also considers a person's behavior within a work environment. The interaction of workers with their tools, equipment, or workstation is the focus of human engineering design. Strength capabilities relative to the equipment and workplace design are also essential factors in a sound and functional design. Much of the human engineering design research has come from the space program. The space program spawned the first intensive study of human physiology of man in the healthy state. Many of the tasks associated with space travel required intensive study of adverse environments to create appropriate designs for equipment and living. The restrictive work environment of a

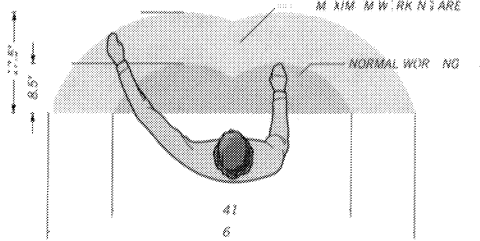
ELEVATION VIEW — STANDING



ELEVATION VIEW SEATED



PLAN VIEW



NOTES

- 1 SOURCE, HUMAN FACTORS IN ENGINEERING DESIGN, E. J. MCCORMICK, 3RD EDITION, MCGRAW HILL
- 2 POPULATION SOURCE, NATIONAL HEALTH SURVEY (SP-5) PUBLICATION 1000, SERIES 11-N-7-B, LINE 1985
- 3 IN GENERAL, DESIGN WORK STATIONS TO ACCOMMODATE 95TH PERCENTILE MALE WITH LEFT HANDED REACH FOR A 5TH PERCENTILE FEMALE

TECHNOLOGY GROUP STAFF ENGINEERING			
50TH PERCENTILE MALE			
HUMAN FACTORS DATA			
DE NA	LE NA	ELEKTRONIK IN: BEAVERTON (R)	
SCALE 1/2"	1"		
M. J. GONZALES		APPROVED	
DATE 31 OCT 81			

FIGURE 3 16 Male Human Factors Data

spaceship required designs incorporating the findings of research on human factors and ergonomics

The human factors dummy in Figure 3 17 was used to design an ejection seat for an airplane. The dummy attired in a pressurization suit is fitted into an ejection seat for engineering tests. Notice the foot clamps, arm guards, and stabilizing fins on the seat. The seat was designed by engineers to have a stable supersonic ejection with maximum projection for the pilot.

The design of products and systems used and operated by people incorporates human factors analysis as an important part of the research and analysis stage of the project. Typically, the operation of a system or product must incorporate the following objectives:

- 1 Minimize the possibility of injury caused by improper use of the product or system. Designs must incorporate safety features that make normal usage error free. Avoiding injury to others adjacent to the user of the product is also important, as is anticipating misuse of the product.
- 2 The design should be as efficient as possible. Limiting user fatigue and stress due to repetition is essential to proper design.
- 3 Systems or products should be designed with physical attractiveness, operational ease, and error-free operation in mind. These factors contribute to overall user satisfaction and to the desire to purchase and maintain the unit.
- 4 The product or system should be designed with a positive, efficient, and functional user interface.



FIGURE 3 17 Human Factors Dummy

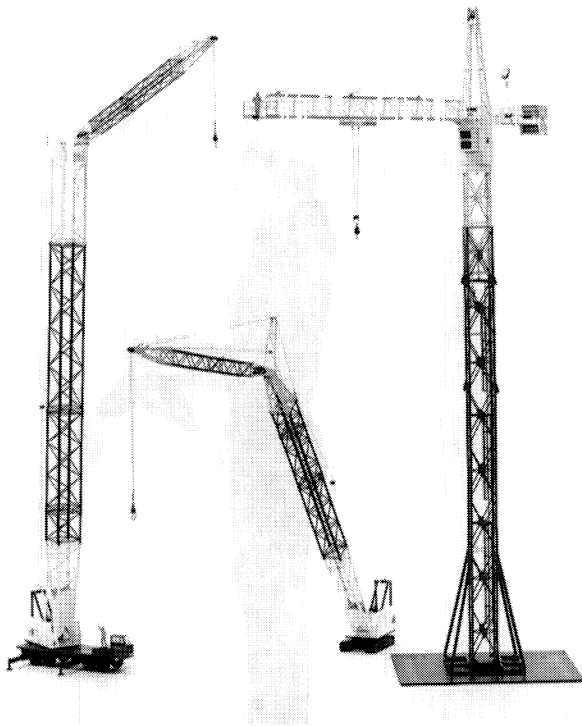


FIGURE 3 18 Model of a Crane

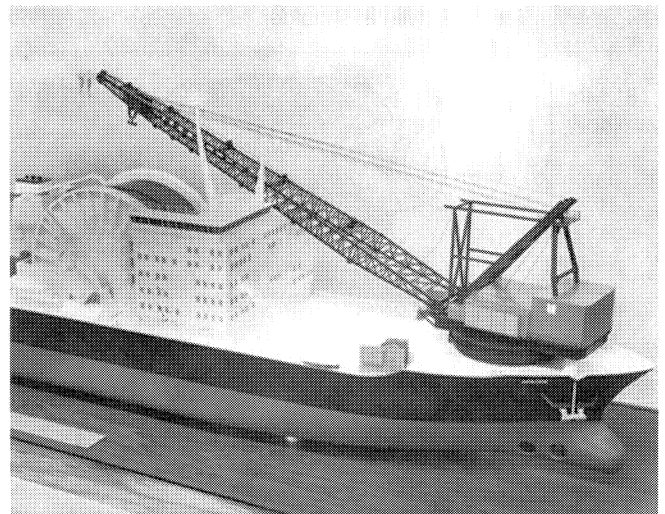


FIGURE 3 19 Model of a Pipe Laying Ship

the end of their useful life. The end of a product's useful life must come with subtle and safe warnings.

The designing of controls for crane operation is an example of a system that requires the study and analysis of human engineering. The cranes in Figures 3 18 and 3 19 are operated by a center-post joystick. The design of such a control starts with the establishment of the physical movements required by the operator and of the variations in a typical operator's body dimensions. Figure 3 20 shows a set of sketches that helped establish the maximum movements.

5 Products and systems must be designed to prevent catastrophic failure and must fail in a relatively safe mode at

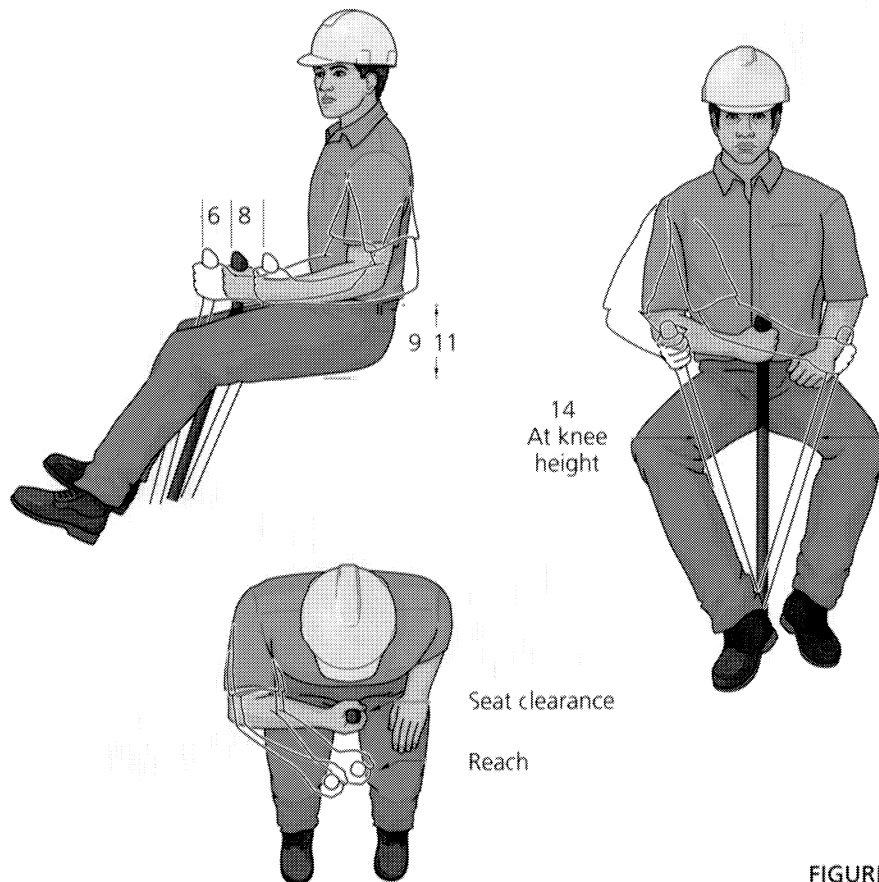
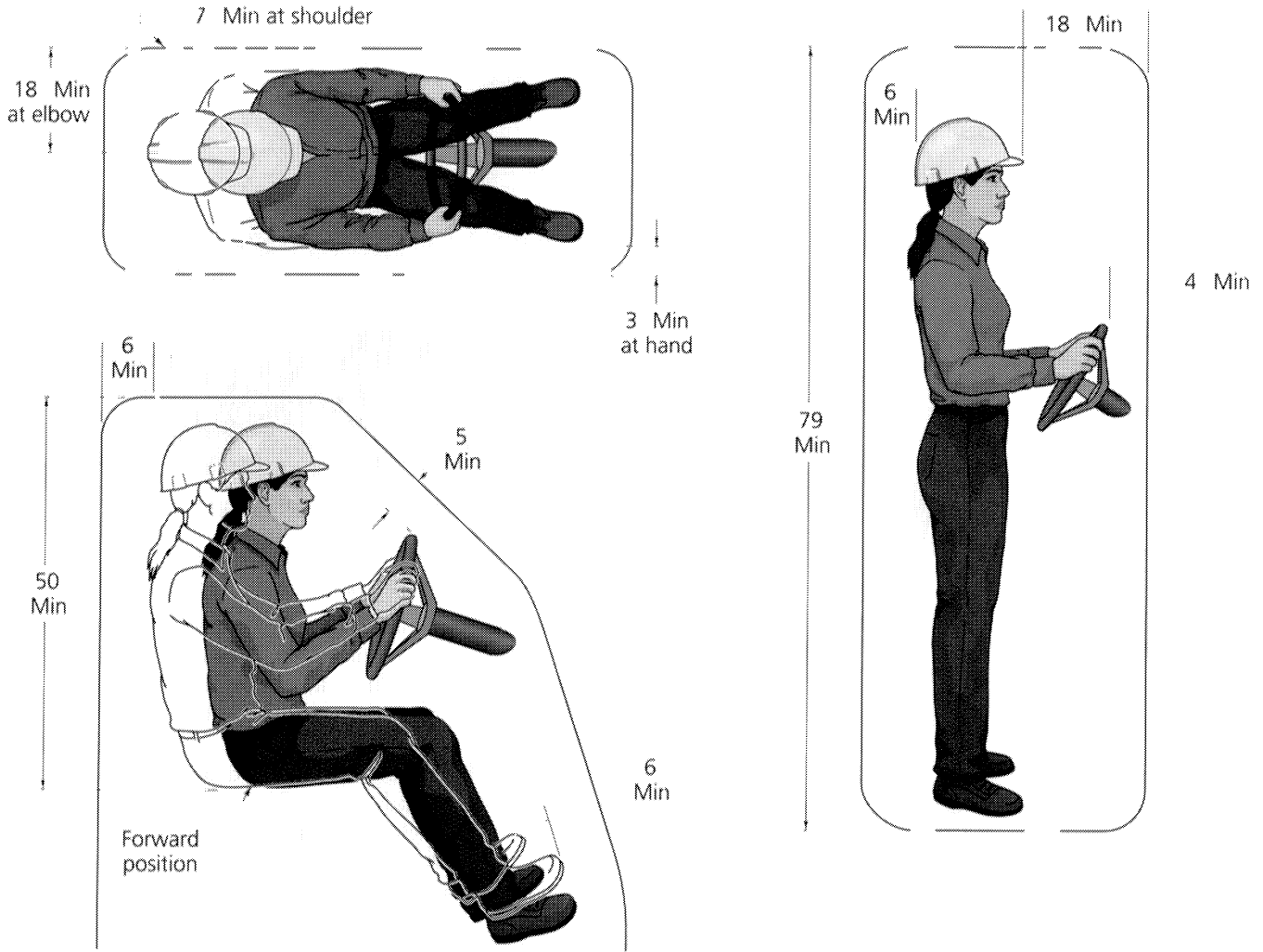


FIGURE 3 20 Control Stick Movement Studies



(a) Sitting
 (b) Standing
FIGURE 3 21 Human Factors Study of a Cab Design

required for proper operation. Reach, seat clearance, stick height, lateral movement, and arm height are graphically described in this illustration. The given dimensions are rough estimates of the design requirements that were refined in a later step.

Descriptive geometry methods were used to solve graphically for potential interferences and to verify the degrees of freedom of movement of the control stick. If someone was supposed to be able to drive the operator's cab, then the human factors and ergonomic studies would include design of a space envelope [Figs 3 21(a) and (b)]. The cab is designed for optimal, comfortable operation and safety during movement over rough surfaces. The determination of whether the operator was to stand or to sit would also have to be made at this stage of the design.

Product Design and Human Factors The mechanical factors, anthropometric (human dimensions) and anatomical considerations (body and limb rotational and movement characteristics), ergonomic factors, and the work environ-

ment must also be considered in the design of consumer products. Hand tools require the study and utilization of these principles. The tools must be designed to be strong, functional, easy to carry, safe to operate, easy to store, compact, insulated from electrical shock, and slip resistant.

The design of the long nose pliers in Figure 3 22 required

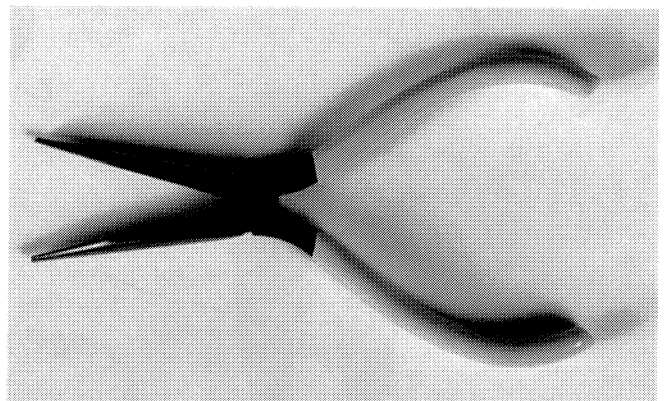


FIGURE 3 22 Needle Nose Pliers

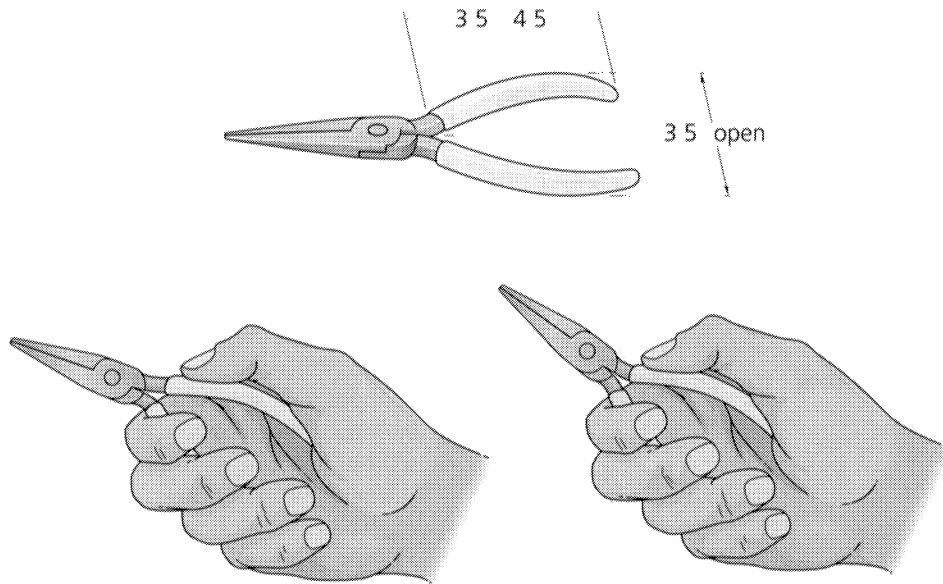


FIGURE 3.23 Design Studies of Pliers Handles

the designer to align the center of gravity with the grasping hand so that the user does not have to overcome rotational movement or torque of the tool. The tool handle is oriented so the user's wrist remains in the most comfortable and natural position while applying force. The sketches in Figure 3.23 show variations in designs for handle orientation. The handle must be long enough to accommodate the average hand so that the user's grip includes all fingers and provides proper leverage during operation. And yet the maximum handle spread must not be so great that a small hand could not fully open the tool's jaws during operation.

Hidden Factors What possible factors may have been overlooked in the design? Are there any aspects of the design that are suspect? If these and other such pertinent questions are not satisfactorily answered, the design team should go back to the beginning of the design process and review each step. The design proposal cannot be accepted without the consensus of the total team and all departments in the company. Solutions to any problems must be solved here, not later when they could prove costly.

A variety of pertinent questions should be honestly and openly discussed at this point in the project.

- What could go wrong?
- Will the product work?
- Will it sell?
- Will the company lose money?

Often at this juncture the business managers will determine that although the product will sell, the company cannot with its current assets produce the item. A startup company may then be formed with the design team becoming the core of a new company. The impact of potential failure is minimized while success produces a diversification of assets.

3.6 IN-DEPTH ANALYSIS OF PROPOSED SOLUTIONS

The **analysis and evaluation** (Fig. 3.24) of possible design solutions is normally done through a thorough investigation of the data that pertains to it. The use of graphs, charts, and diagrams can greatly improve this analysis and help in communicating the data to others involved in the project. Data can be categorized into three types: **survey data** gathered by the marketing department evaluating a design's possible acceptance by the public; **design data** gathered by analyzing the performance characteristics of the test model; and **comparison data** used to balance two or more design

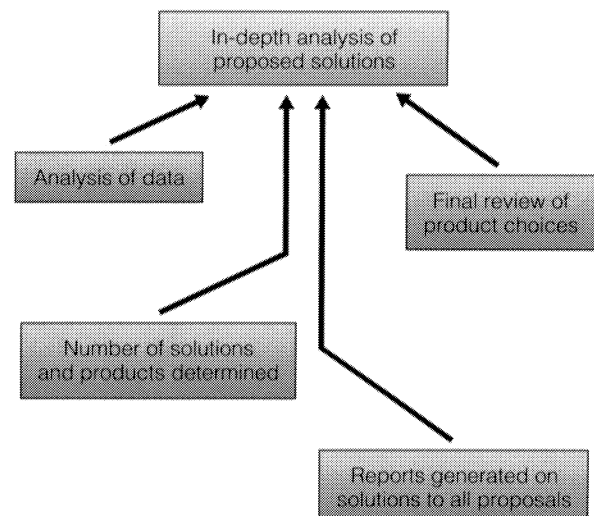


FIGURE 3.24 Stage 4 in the Design Process

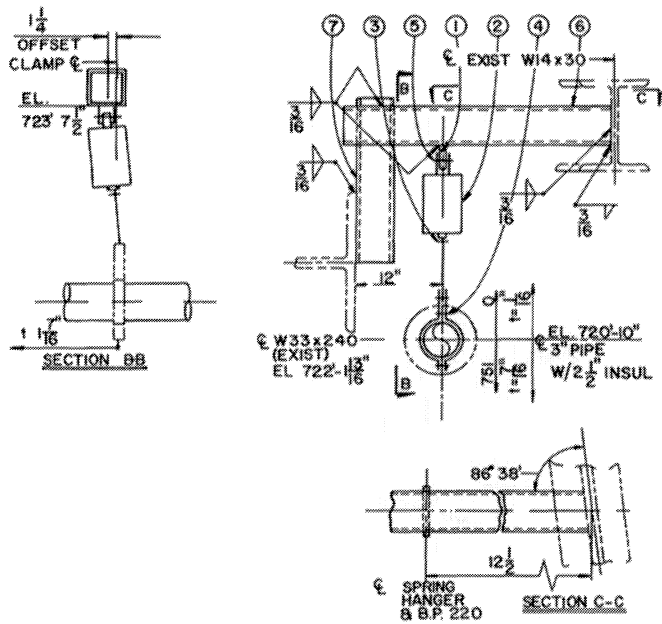


FIGURE 3 25 Spring Hanger Used in Pipe Support Design

solutions against each other based on material manufacturability or exclusive design features

Data presented graphically can also help a designer determine the adequacy of a design based on environmental conditions or the reaction of the materials to stresses created during operation As an example consider piping systems A typical piping system is designed to operate under specific temperatures A steam line or a chemical process line may have a high operating temperature The designer must create a piping system that not only transfers the line contents from one place to another but also is flexible enough to handle expansion and contraction of the system during operation Pipe supports must handle the full weight of the system and at the same time allow for restricted movement of the line caused by thermal expansion or earthquakes

The pipe support shown in Figure 3 25 incorporates a spring hanger in its design Spring hangers can adjust the load of the pipe and allow for limited safe movement The graph in Figure 3 26 was used in the design of the pipe support The thermal expansion of a pipe for a steam line at various temperatures is graphed Six separate materials have been plotted The expansion characteristics of the pipeline being designed are determined so as to meet the operating conditions

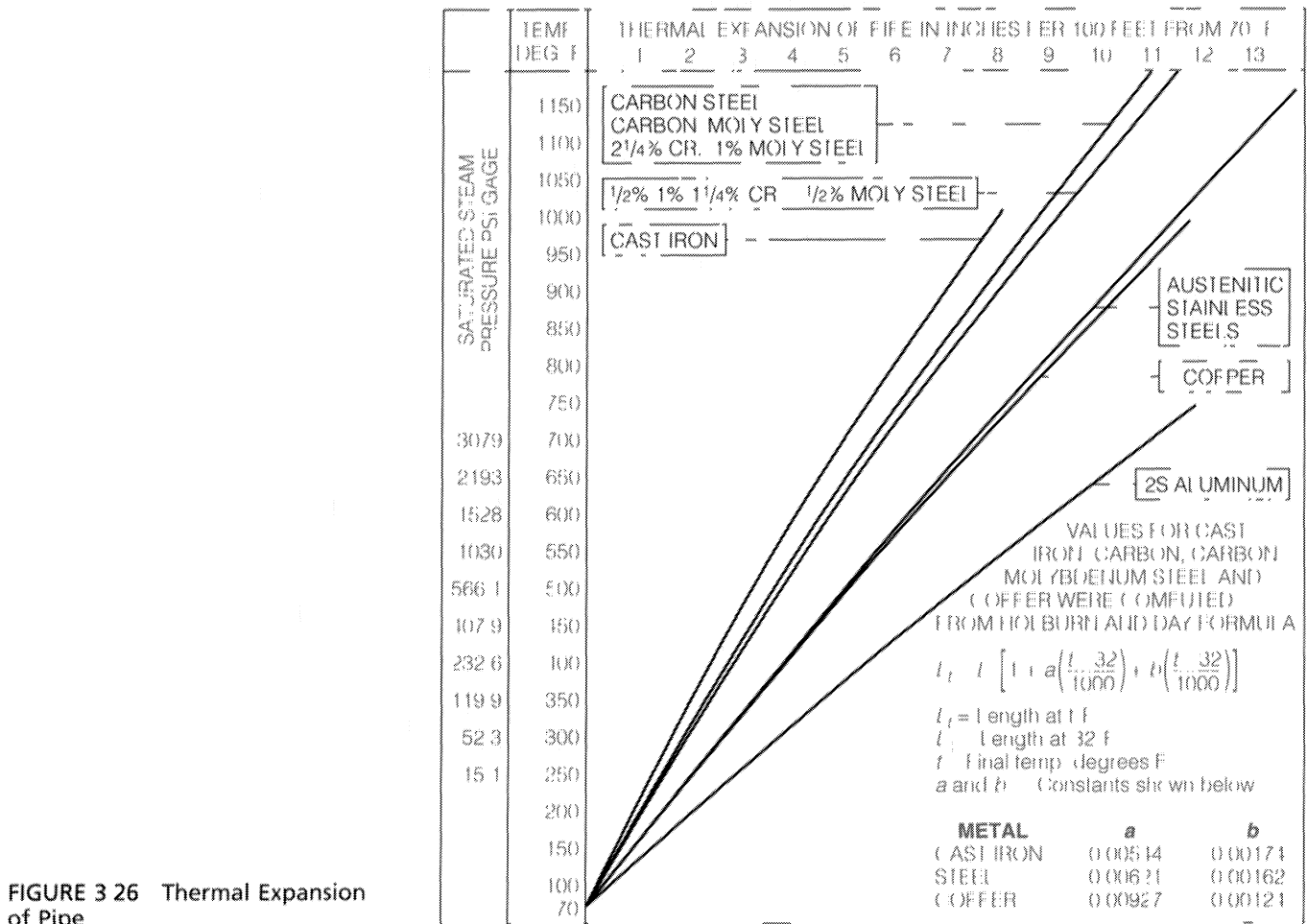


FIGURE 3 26 Thermal Expansion of Pipe

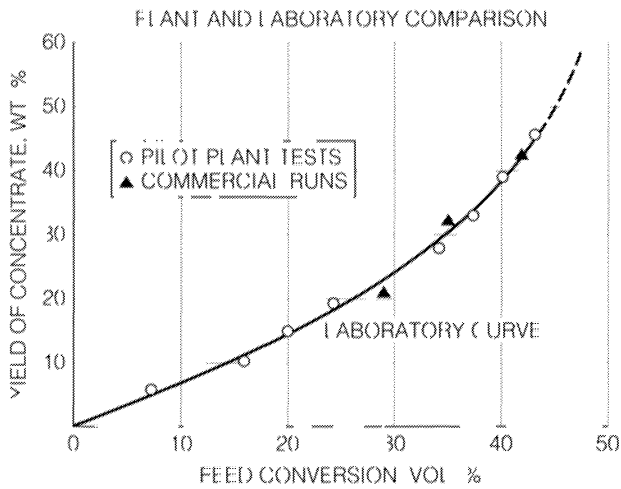


FIGURE 3 27 Graph Layout for Publications

Analysis of Data Marketing data is useful in identifying features and capabilities desired by the public. Marketing data will at times drive the project design. The performance characteristics of a possible design solution are determined by analyzing the data generated from hardware testing. The use of graphs and charts is an integral part of this process.

Graphs and Charts Throughout this text information about the fundamentals of drafting and design is displayed in **graphs**, **charts**, and **diagrams**. Most technical graphs are plotted on preprinted grid paper. All graphs must contain

the following information: axes or scale lines, major divisions, a brief title, designators on axes, units, one or more curves, and captions or notes (Fig. 3 27). Sometimes, in addition to this information, plotting symbols (data representation points) are required. A graph should be able to stand alone—that is, be easily understood without extensive explanation. Figures 3 28 and 3 29 show some of the do's and don'ts associated with creating a graph.

The importance of drawing clear, easily understood graphs should not be overlooked. Much of the information needed to do a design is shown in graphical form. This information includes characteristic performance curves of devices, stress input response curves of devices and entire systems, relationships of one quantity to another, wave forms, thermal expansion of items, and project schedules.

Graphical data is sometimes represented by noncircular curves, as in Figure 3 29. Graph lines are plotted on a given grid pattern on rectangular coordinate paper, representing two variables. When a CAD system is used for the graph, spline or smooth curves are used to connect the data points. The horizontal coordinate on a graph is usually plotted as the independent variable, and the dependent variable is plotted vertically. The horizontal or **X** axis is called the **abscissa**, and the vertical or **Y** axis, the **ordinate**. The origin of the data may be located at one of a number of different places on the graph, such as the lower left corner of the graph with 0, 0, as in Figure 3 29, or the center, as in Figure 3 30.

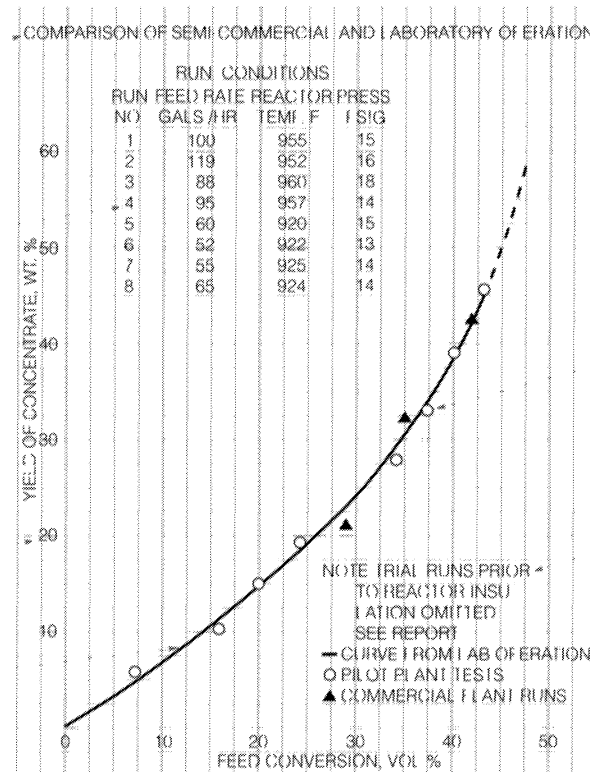
Figure 3 31 shows lines and symbols on a graph. Clear, accurate graphs and charts are essential for communicating

In slides, avoid long titles that show outside of graph border. In publications, the title should appear as a caption following the figure number.

On it supporting data tables, equations, or other nonessential details.

Show all scale numbers and titles outside grid border.

Used double weight ruling to emphasize curve.



Use a horizontal rectangle when feasible.

Use only open grid paper. Commercial fine line papers are unsatisfactory.

Use template or transfer lettering symbols.

On it explanatory details they detract from the main emphasis of the illustration.

Where feasible omit legends or symbol keys and instead use curve or data point labels (call outs).

FIGURE 3 28 Example of Poor Illustration of Graph

Original copy 100 x 150 mm work area done in no. 120 capitals or equivalent (for exceptions using typewritten lettering)

Vertical capitals preferred when possible

Title reads up from bottom

Copy proportion (2/3) fits standard slide masks and common projection screen shapes

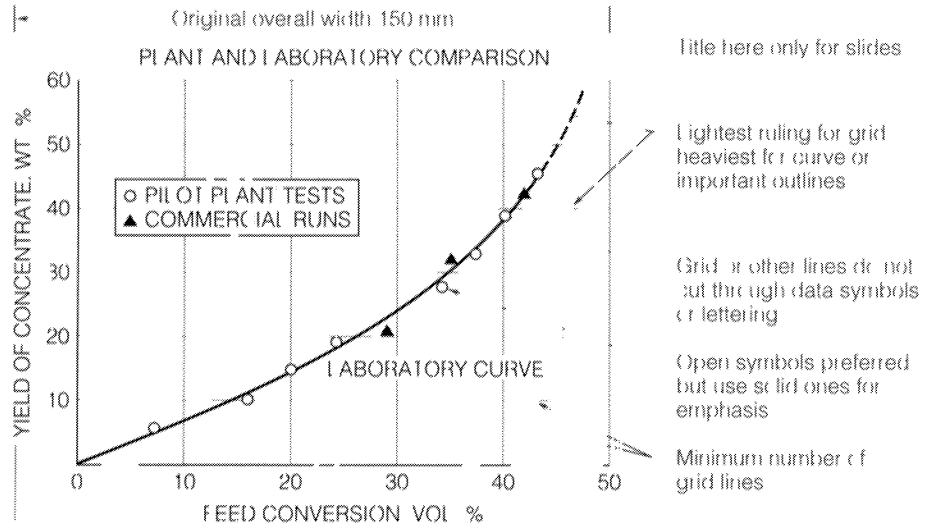


FIGURE 3 29 Example of a Good Illustration of a Graph

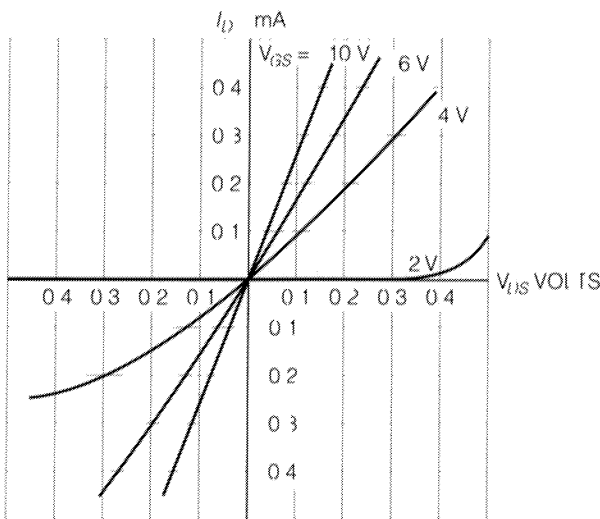


FIGURE 3 30 Voltage Versus Current Characteristics for an FET

data in this stage of the design process. At present, almost all graphs and charts are generated with the help of a computer (Fig. 3 32).

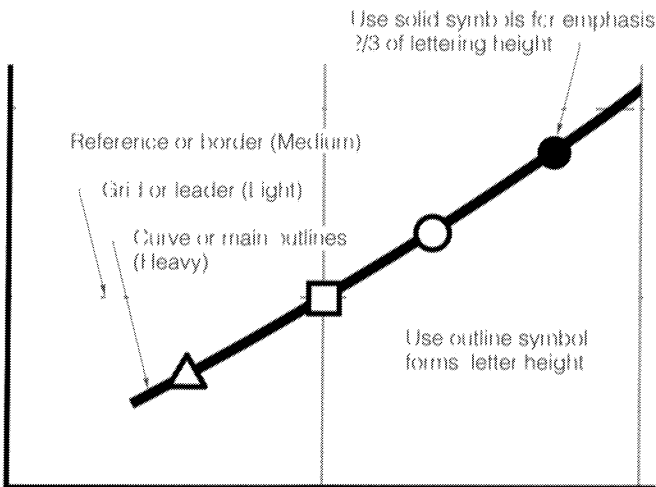
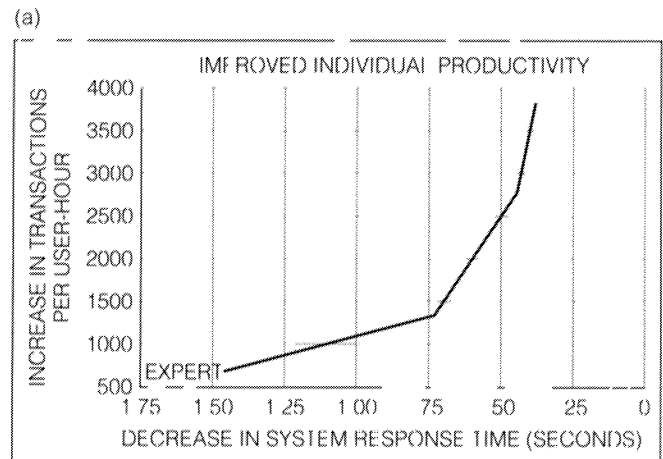


FIGURE 3 31 Lines and Symbols on Graphs

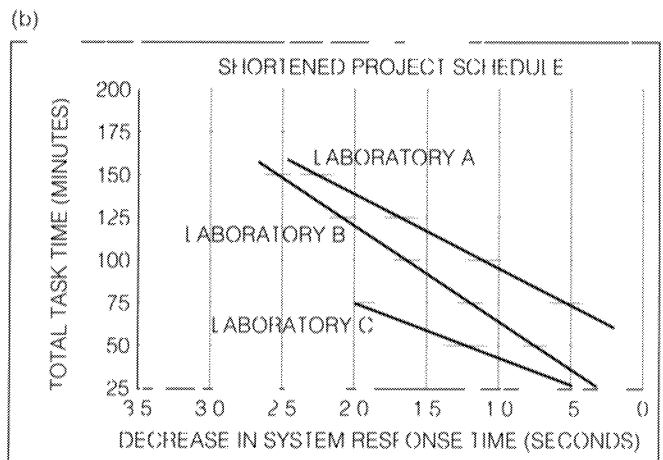


FIGURE 3 32 Computer Generated Graphs

Number of Solutions and Products Determined The process of creating a new design always gives rise to more than one solution. Often the different solutions involve trade-offs between cost, reliability, and time. Manufacturability concepts and procedures help ensure a design that is functional, cost-effective, and timely. If the design process has given birth to more than one solution or product, then it should be determined whether or not the project needs to be separated into different proposals. Each possible solution may produce a valid, marketable item. A record of each design possibility should be kept, including all sketches, written descriptions, and other data. It is appropriate to investigate more than one solution at a time. If a team is working on a project, it may need to be divided into subunits, with each subunit investigating different solutions. A variety of different designs should be created and developed to a point where they are sufficiently defined. They should then be evaluated and compared during the next stage of the project. Duplication by competing teams should be minimized by the sharing of data and resources.

The model of a hovercraft in Figure 3.33 is one of many design solutions being investigated by a ship building company. The surface effect ship, in Figure 3.34 is a more detailed design alternative. The Coast Guard hovercraft shown in Figure 3.35 is a full-scale test prototype. The design of simple products or complex systems (like the hovercraft) requires a complete analysis of design alternatives and a comparison of performance capabilities before production.

Reports Generated on Solutions to All Proposals. Technical reports containing design data on each possible solution must be generated at this point in the process. All pertinent factors, both positive and negative, must be clearly defined before the project is developed further. The design team does not want to enter the decision stage of the project

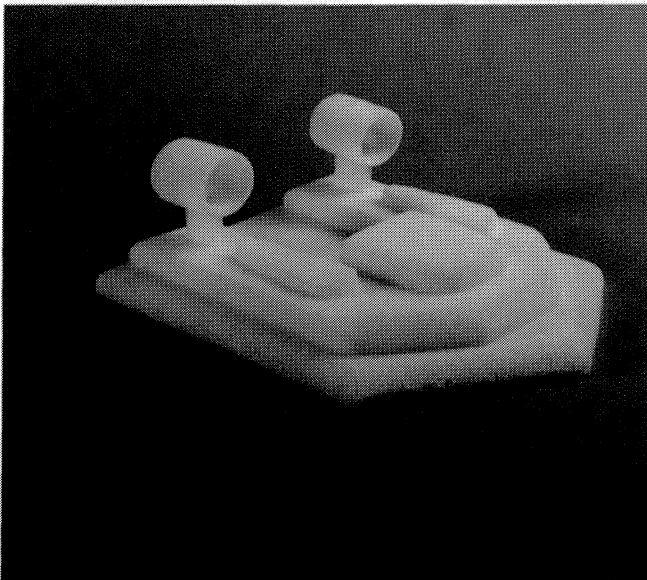


FIGURE 3.33 Model of a Hovercraft Produced by Carving Art Foam

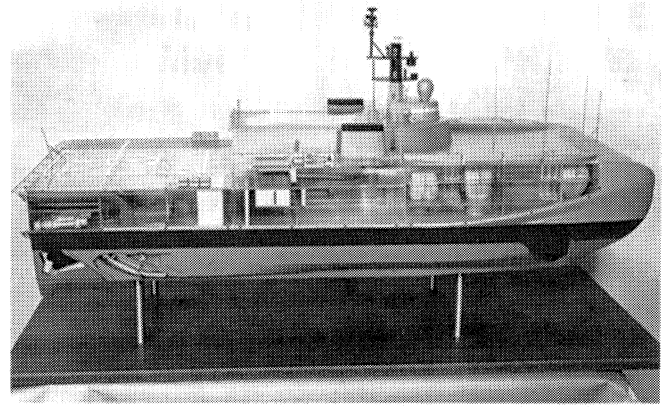


FIGURE 3.34 Surface Effect Ship Model

will be prepared or with incomplete findings. Management will not pursue a project that is poorly defined. Properly presented projects need complete graphic descriptions and well-written reports.

Final Review of Product Choices The design department must evaluate each of the possible solutions before submitting their findings and suggestions to the management during Stage 5. Two or more design solutions should be prepared by the design team. During a team meeting, each of the designs should be compared. The merits of each design solution should be presented clearly, as should any drawbacks to the design. Each of the features incorporated into the design should be compared to those of other possible solutions. A list should be prepared ranking the relative importance of each feature.

Materials, manufacturing, and facility requirements should be discussed at this meeting to balance each solution's effectiveness against others, based on cost and company capabilities. At this point, select the best designs and prepare for the next stage of the project.



FIGURE 3.35 Coast Guard Hovercraft Test Model

3.7 DESIGN CHOICE AND PRODUCT OR SYSTEM DECISIONS

After all the data have been gathered on the design problem and the remaining possible solutions have been clearly defined, the fifth and last stage in the decision process is addressed (Fig. 3.36). Management has the final say on which project design solution to pursue. The designers, engineers, and other company personnel involved in the project present their findings and design choices to management for a decision. The choice depends on many variables. A project may even be abandoned at this point or more than one product or solution may be accepted.

The development and design of supersonic aircraft required extensive research leading to new and unconventionally shaped wings to offset the effects of the abrupt and erratic changes in air flows encountered at the speed of sound. One of the solutions was the swept back wing shown in Figure 3.37 being prepared for experiments. Resembling the tip of an arrow, this wing is more efficient because of the sharp reduction in the drag created by the formation of shock waves at and near the speed of sound. Earlier designs for wings were also modeled and tested in a wind tunnel to determine their in-flight characteristics. Each of these was eventually incorporated into modern military and commercial aircraft. The sharp wing style was also tested in a full size mockup shown in a wind tunnel experiment in Figure 3.38. The eventual prototype aircraft shown in Figure 3.39 was the world's largest experimental aircraft. The B70 project was never produced because of cost, materials, research, government decisions, and improvements in the accuracy of IC BMs which made the aircraft obsolete. The development work was later used in the design of the Concorde supersonic transport. The Stealth bomber (Fig. 3.40) involved technology and research devel-

oped for previous aircraft but also incorporated special high tech materials and design concepts to enable it to fly undetected by conventional radar.

At present, a revival of interest in supersonic transport is occurring. The years of research and development that seemed for naught may eventually bring an efficient well designed product to the market—a supersonic aircraft for commercial passengers.

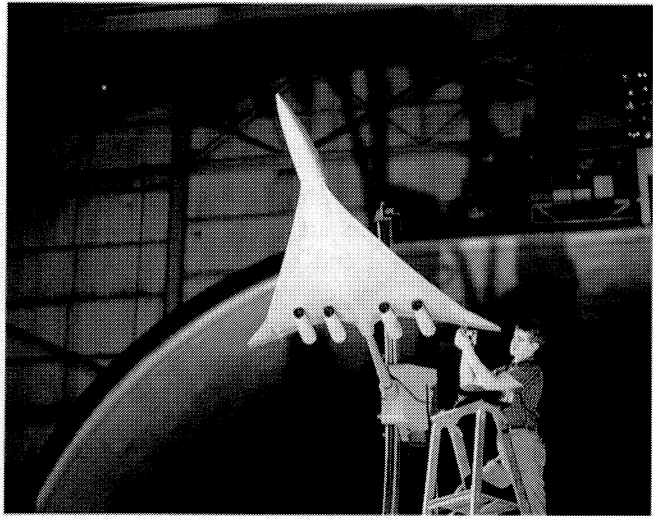


FIGURE 3.37 Model Being Prepared for Research and Development of Air Flows and Wing



FIGURE 3.38 Aircraft Model Being Prepared for Wind Tunnel Studies

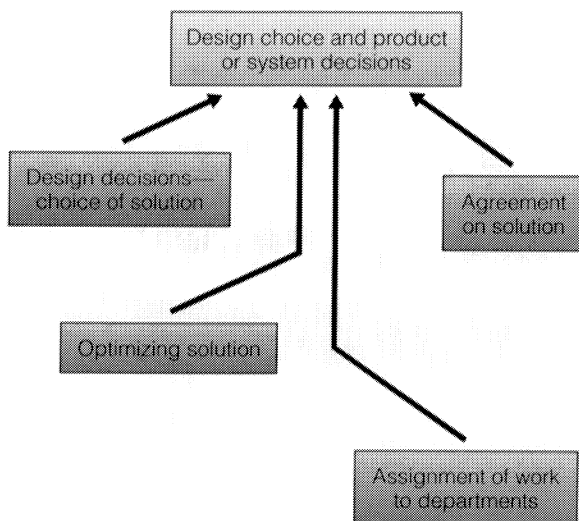


FIGURE 3.36 Stage 5 in the Design Process

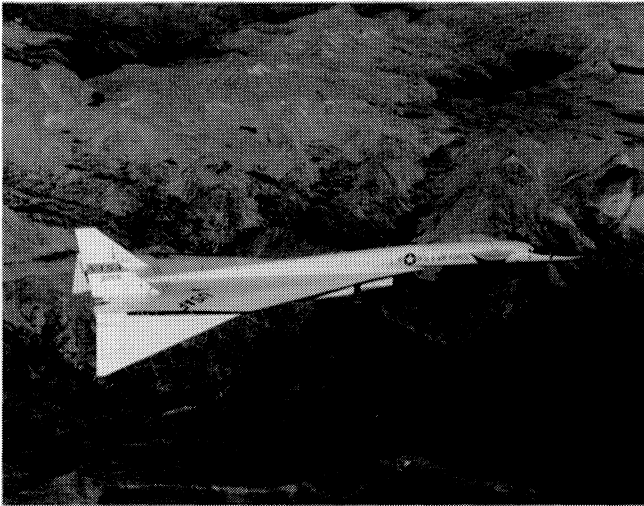
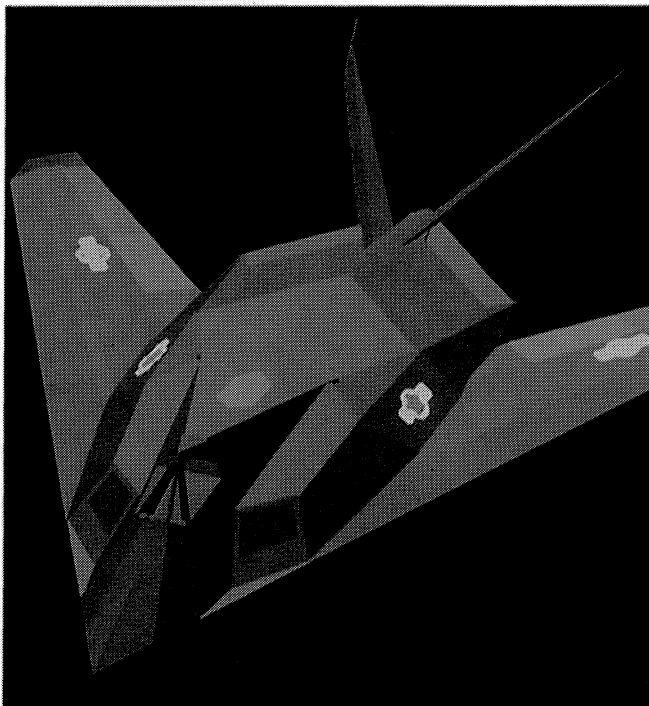


FIGURE 3 39 World's Largest Experimental Test Aircraft

Over the last twenty years new materials such as composites have been developed. A new generation of materials will fly with the X 30 an experimental plane that will pioneer hypersonic travel in the late 1990s. To withstand the environmental impact of travel at 17 000 mph (Mach 2.5) and an orbit near that of the present day space shuttle carbon composite materials coated with ceramics will be used.

Sometimes a design concept exceeds the known capabilities of science and technology. In this case the development of the design may have to wait for the technology to catch up with the concept. History has many examples of designs that were developed before they could be effectively safely and profitably brought to market. The former Soviet Union's 2000 mph transport and the French-English Concorde jet



may have been premature efforts considering design flaws and cost of operation.

Design Decisions A complete technical report on each solution must be submitted at this juncture by the design group. The report consists of a design proposal and a timetable for completion of the project. All pertinent data regarding the design solutions must accompany the proposal including cost analysis, time studies, capital requirements (personnel, equipment, and facility), design layouts, and other materials that may help in the decision process.

The management decision team, which includes members from the design, manufacturing, and marketing departments, evaluates the merits of each solution submitted by the design department. The evaluations of competing designs consider the following:

Design Comparison

- Capability to satisfy the original statement of the design intent and project definition
- Cost, manufacturability, and reliability
- Design requirements for precision (which will affect cost), operating efficiency/flexibility, maintenance projections, and environmental impact
- Material and manufacturing processes
- Effect of configuration and complexity on manufacturing costs

After each of these is satisfactorily investigated, the management team can decide on the design choice or choices. The design team then proceeds to the next stage: optimizing the selected design.

Optimizing Solution The design team further develops and refines the selected design. The selection of materials

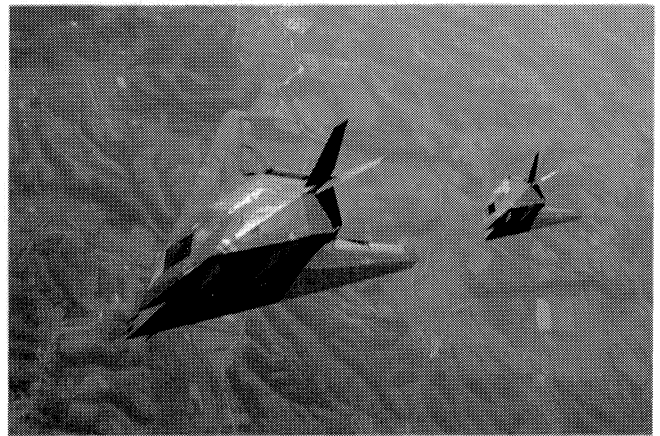


FIGURE 3 40 Stealth Bomber on Computer Screen (left) and in Flight (above)

processes, and other design requirements can be further refined at this stage. Each feature and capability of the design should be analyzed and evaluated. Any changes should be made at this point so that during Stage 6 (development and implementation) there are no drastic changes in the design that hinder its completion. Any new desirable features or capabilities should be evaluated. A list of concerns and considerations should include the following:

Design Refinements

- Should any new or desired features be added at this time?
- Should the effective life of the design be extended or decreased?
- Are there any aspects of the design's appearance that need to be changed or defined better?
- Based on the design's potential configuration and operating conditions, what materials should be considered acceptable?
- Is the design manufacturable?
- What are the basic cost parameters for the design?
- Can the design be more flexible and interchangeable without cost increases?
- What are the tolerance requirements?
- Have the stress factors and alignment problems that may be encountered been determined?
- Has the need for study models, prototypes, and test models for motion, stress, or other design studies been established?

Agreement on Solution After the choice of solutions is determined, it is important that all of the concerns of each department be addressed. A consensus must be reached on the acceptability of the solution. There should be complete agreement as to the direction and choice of management's decision. Reservations by one or more of the departments in the company about the product's feasibility are addressed and eliminated at this time so as not to undermine the design's success. All basic features and design requirements are now solidified into an accepted solution.

Assignment of Work. The project work schedule is determined after the final design is chosen and the **project launch** is given the go-ahead by management. Several methods of project scheduling are used in industry. One method is the **Project Evaluation and Review Technique (PERT)**, for coordinating the many activities associated with a successful design project. All departments must be coordinated efficiently to move the project from design through production smoothly and error free.

The success of the project depends on this coordination. At the project launch, each department is given specific work assignments and time requirements. The **critical path method** of scheduling project work assignments is used in conjunction with PERT to control the project. The critical path method was used in the design and manufacturing of the trackball input device to be discussed in Section 3.11. Design Project Example

3.8 DEVELOPMENT AND IMPLEMENTATION OF DESIGN

The development and implementation stage of the design process includes the drawing, modeling, testing, analysis, and refinement of the design (Fig. 3.41). The actual documentation of the project can be done manually or on a CAD system.

Physical models are used for design and testing (Fig. 3.42). Actual full-scale prototypes, developed from design drawings, are used to test for strength and design flaws. The rotor mount test in Figure 3.43 focused on that portion of the prototype design. Other models are used for testing different aspects of the design.

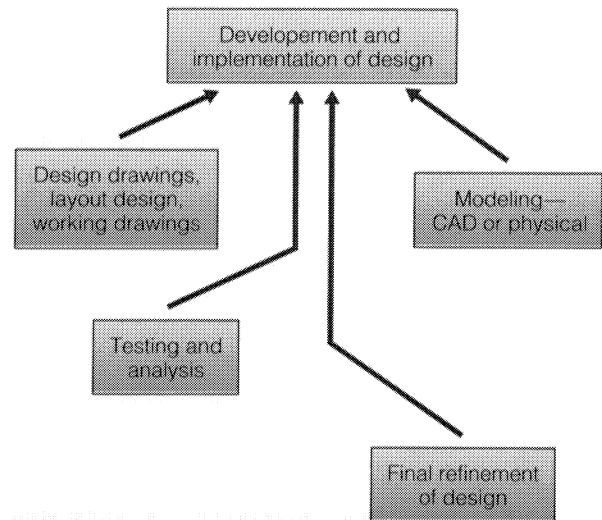


FIGURE 3.41 Stage 6 in the Design Process

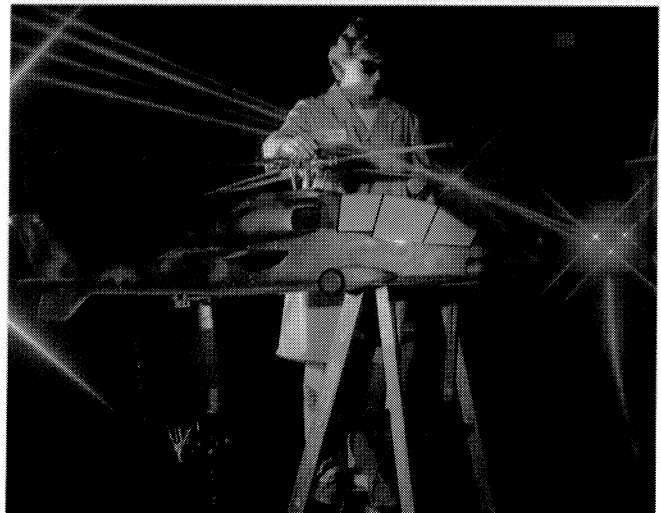


FIGURE 3.42 Test Being Prepared for the Scale Model of a Helicopter

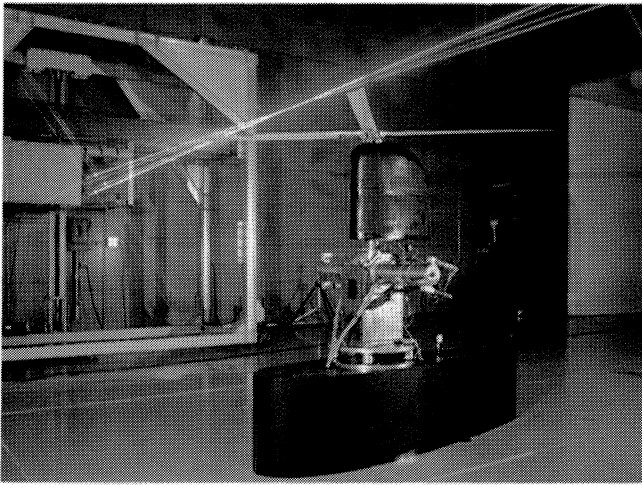


FIGURE 3.43 Rotor Test

The design and development of a project takes many forms while it weaves through a series of trials and errors testing and refinement. The space shuttle started as a design concept and proposal. The pictorial rendering in Figure 3.44 is quite unlike the final vehicle. The original designs were drawn, modeled, tested, and refined many times before design completion.

Stage 6 in the design process is the heart of all design efforts. It is when most of the work is done and the project brought to fruition. All previous steps must have been accomplished effectively for this step to be successful. If the system or product was not properly identified, the research was not conducted correctly, alternative solutions were not developed and analyzed, the analysis of all data was inadequate, and all departments involved in the project were not incorporated in the first five stages, the development and implementation of the design might not come to successful conclusion. The sixth stage starts with the creation of design drawings, either manually or with a CAD system.

Design Layout and Working Drawings At this step in the design process, it is important for all preliminary work to be complete and for the design to have been accepted. No major changes in the design should be implemented at this point. The acceptance of the project by all parties is essential.

A majority of this text is devoted to this stage of the design process. Manual or CAD-generated technical drawings or models are the primary means of communicating design and manufacturing information at this time. Drawings are also required before the construction of physical models, test prototype, mock-ups, presentation process, system, or product.

Similar designs and previous work are useful guides for product improvement design work. The designer must be familiar with existing documents. There are many situations where the redesign of an existing item or relitting of an existing system necessitates the use of older drawings that have been completed under previous standards. Most design work rarely involves original design work from concept to

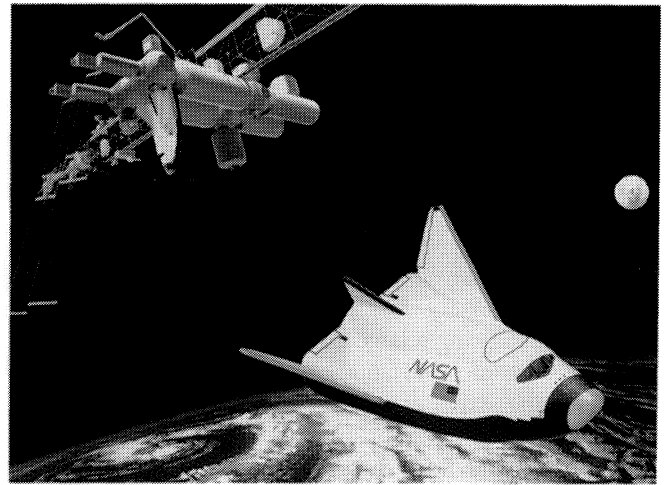


FIGURE 3.44 Space Shuttle Design

production but is instead a continual evolution of an existing product. Each member of a design team works only on a small portion of the total effort.

Physical Models Models are used throughout the industry as scaled representations of systems, design, and for refinement and testing of product designs. A **systems model** shows an installation, components, structure, and instrumentation. A model provides a better understanding of any installation and can be used as a tool for design and checking. Product models are employed in many stages of the design process to establish scale, appearance, and function of a product. Scale models of tractor-trailer designs are shown in Figure 3.45.

The designer can request a model at almost any stage of the design process. The type of models requested depends on the product or system and the availability of modeling facilities. Outside vendors are, at times, called on to complete a model. Regardless of who does the modeling or where, the designer will be an important part of its creation.

Engineering systems models are a design tool that can eliminate unnecessary problems, bad design, inefficient

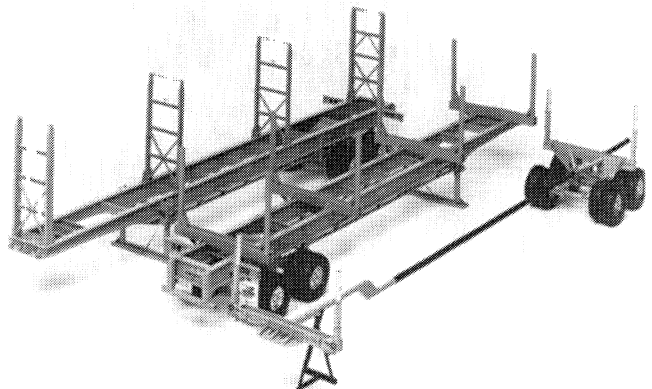


FIGURE 3.45 Tractor Trailer Design Models

planning, and other expensive, time loss situations. They are used throughout the petrochemical nuclear and conventional power-generation industries. They are also encountered in food and beverage processing pulp and paper manufacture, pharmaceutical processing, and other fields of systems design. Product design uses models throughout the design process, including research and development.

When working with a three-dimensional model (Fig. 3 46) the designer can visualize the design sequences and operations necessary for the project. This may not be possible when using a large assortment of drawings.

Models are most advantageous as a working tool, from the beginning stages of a project through the entire design phase. The beginning or preliminary models may look nothing like the final design model. Many intermediate stages may be needed to provide the 3D information for solving problems that may be encountered.

A **mock up model** is a full size replica of a proposed design used primarily to refine the appearance of the product its size configuration color and artistic considerations. This type of model is not often involved in movement or operation design.

Product models are found more often in mechanical engineering fields to help design various parts of machinery or other mechanical devices such as components that must be manufactured. In some cases such models are built to a scale larger than that of the project itself.

Prototype models are basically similar to product models but are sometimes working simulations of the product. In the case of an airplane the company might build an

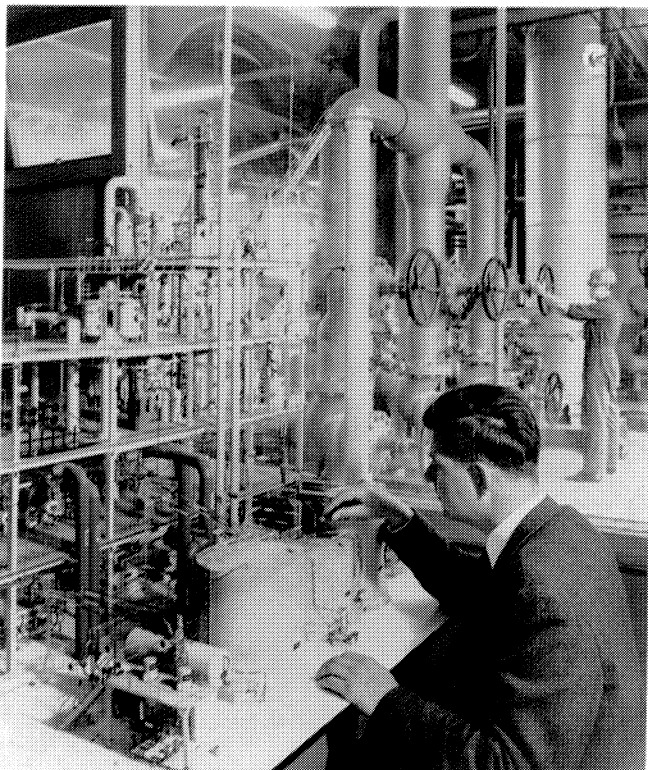


FIGURE 3 46 Working with a 3D Plant Model

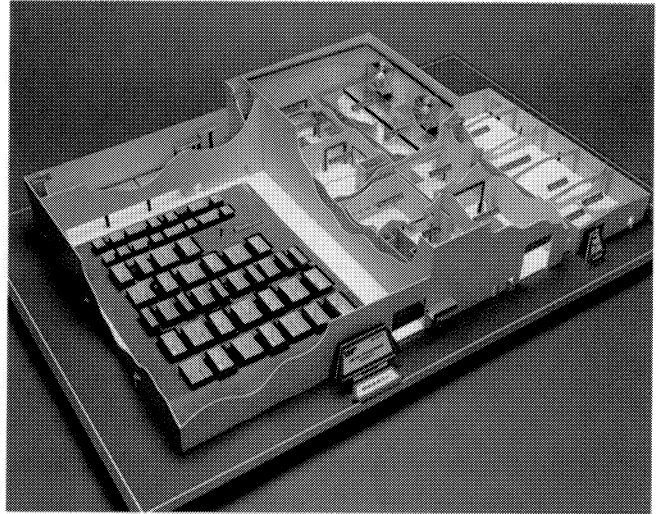


FIGURE 3 47 Scale Model of Metals and Spray Painting Facility

actual full scale prototype to gain knowledge of its aerodynamic characteristics and also to estimate public acceptance and sales. Some prototype models are mock ups of the eventual product. Three dimensional prototypes are sometimes required in the design of mechanisms to test their performance and capabilities. A prototype will often be close to the same configuration as the finished product. Therefore the prototype model is used in the project design stage after much of the design data has already been determined and the choice of designs made. Prototypes are tested under typical operating conditions of the proposed product.

Presentation models such as the one in Figure 3 47 are created to display a project building product or design to the general public or for sales.

CAD Modeling Modeling with a 3D CAD system allows the designer to create multiple options for a design. A CAD model can be altered much easier than a layout on paper or a physical model. The CAD model can be used in every phase of the design decision process.

Three dimensional modeling capabilities are grouped into four basic categories: 3D wireframe models, 3D surface models, hybrids of these first two types, and solid models.

Wireframe Models As the name signifies a wireframe model is one in which the part geometry is represented by interconnected edges (Fig. 3 48). These edges may be lines, arcs, or splines. Most CAD systems with 2D drafting capabilities can create 2D wireframe models for 2D numerical control or to generate drawings. Three dimensional systems however provide better modeling capability than the 2D systems.

Three dimensional wireframe models (Fig. 3 49) have the same basic elements as the 2D model but add the Z coordinates. Visualization is much better with the 3D wireframe model than with the 2D wireframe model and it is easier to use.

Surface Models Three dimensional surface models are con-

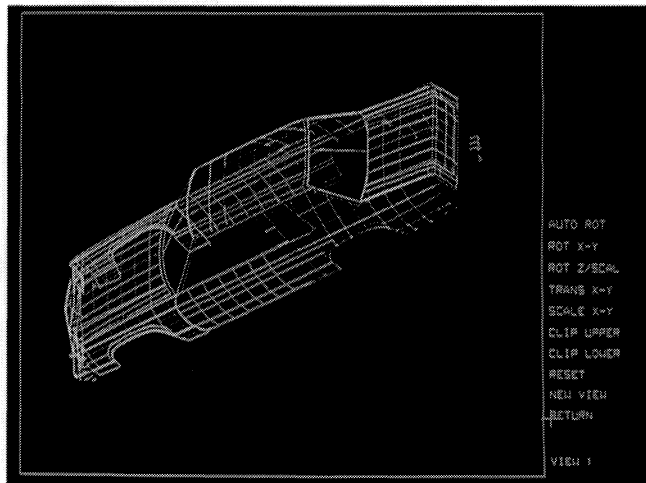


FIGURE 3.48 Wireframe Model of a Car

constructed by stretching a transparent membrane over the wireframe model. These membranes then become the faces of the model. The faces may be simple surfaces such as planes, cylinders, and spheres, or more complex surfaces such as ruled surfaces, extrusions, rotations of spline curves, and sculpted surfaces.

Three-dimensional surface models (Fig. 3.50) can represent shapes that are difficult to construct with wireframes, for example, styled surfaces such as the outer skins of automobiles and function surfaces such as turbine blades and gears.

Hybrid Models. Most 3D modeling systems on the market are a combination of wireframe and surface modeling. The addition of the surfaces eliminates some of the deficiencies of the wireframe model. Specifically, the model can be unambiguous and complete.

Solid Models. The major requirement of a solid modeler is that it be able to construct an unambiguous representation

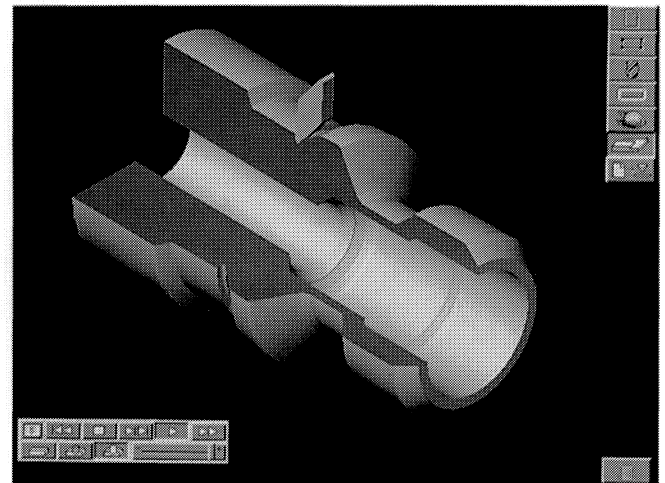


FIGURE 3.50 3D CAD Geometry Creation with Virtual Gibbs Features

of parts or assemblies (Fig. 3.51). Constructive solid geometry (CSG), boundary representation (b-rep), and parametric modeling are the three popular methods for creating a solid model.

A solid design model (Fig. 3.50) forms the master representation of a part, instead of the engineering drawing. The main output of a design office is a solid model of the part, together with all the associated information contained on the engineering drawing. Engineering drawings are a secondary function when this system is used. In particular, the drawings, if required, are generated from the model. The combination of a solid model and the necessary tolerance and associated technical data is called the product model. Functions downstream of the design office take the product model as their primary input.

Physical Models from a CAD Database. Conceptual models are an important part of the product design process.

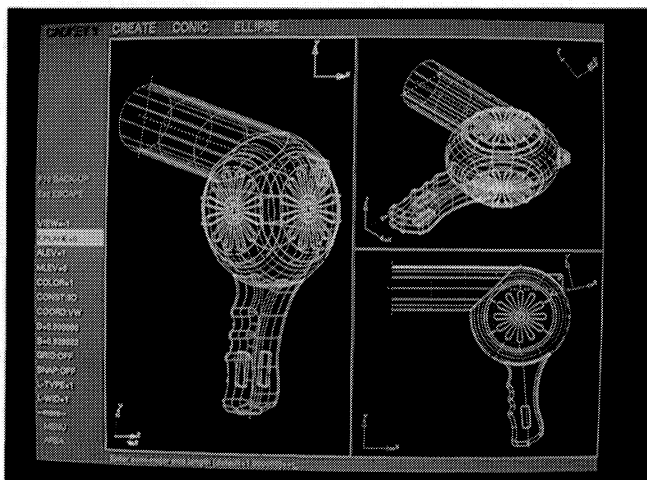


FIGURE 3.49 3D Wireframe Design Model of a Hairdryer

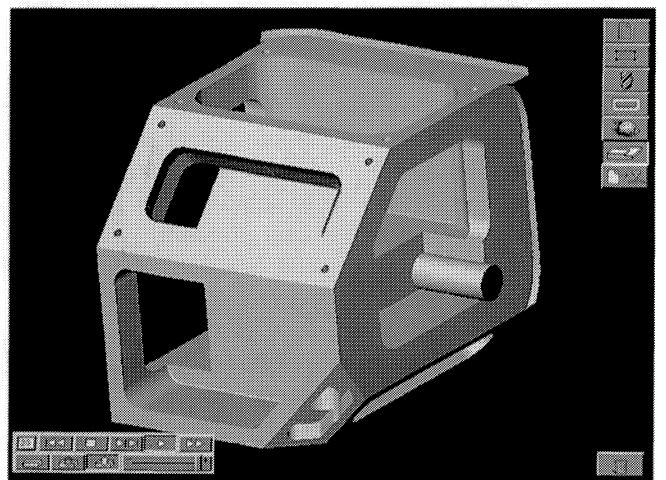


FIGURE 3.51 3D Real Time Cut Part Rendering with Virtual Gibbs System

Industrial designers and packaging engineers get a computer representation of their idea via CAD/CAM/CAE. Sometimes, however, seeing the part on a 2D high-resolution graphic screen or even on the stereoscopic monitors that project a 3D view, is not enough. The soft touch of the physical model can bring a design to life—sometimes revealing unanticipated problems. By quickly forming 3D conceptual models from design ideas, engineers can evaluate a design, demonstrate its feasibility and sell the concept.

Building conceptual models, prototypes, and patterns for castings are necessary steps in product design—but expensive and time consuming, often accounting for over half of the design effort. **Rapid prototyping (RP)** is currently changing the way products are designed and brought to market. The ability to create plastic model parts (Fig. 3.52) in a matter of hours without tooling, using the same CAD database created while designing the part on the CAD system, is revolutionizing design. CAD/CAM/CAE software,

chemistry, laser, and optical scanning technologies have been combined to form this unique process. Rapid prototyping, which creates 3D plastic parts from CAD/CAM/CAE data in a matter of hours, is producing parts for the automotive, aerospace, computer, medical, consumer, and electronic components industries. Applications of this technology include conceptual designs, prototypes, testing models, and casting master patterns.

Conventional model making proves to be time consuming and expensive. Typically, a design engineer creates a 3D model on a mechanical CAD system or on a drafting table. Then paper drawings are plotted and passed to a model maker, who interprets them to create a prototype. Traditional methods include creating models from wood, clay, or a block of solid material, which is sculpted, cut, or machined.

Stereolithography, one of the most common rapid prototyping methods in industry today, is used to make conceptual models, plastic prototypes, soft tooling for silicone and sand molds, and patterns for metal castings (Fig. 3.52). Models created with stereolithography help to visualize designs, to verify engineering changes, and to check form, fit, and function.

Stereolithography Process A 3D model database produced on a CAD format is sliced into a stack of thin layers using the stereolithography software. The layers are then redrawn on the surface of a vat of liquid photopolymer by a computer-controlled ultraviolet laser projector. Via a stereolithography apparatus (SLA), solid or surface data (from a CAD database) are sliced by software into very thin cross sections. A laser then generates a small, intense spot of ultraviolet (UV) light that is moved across the top of a vat of liquid photopolymer by a computer-controlled optical scanning system. The laser changes the liquid photopolymer to a solid wherever it touches, as it prints precisely each cross section. A vertical elevator system lowers the newly formed layer, while a recoating and leveling system establishes the next layer's thickness. Successive cross sections, each of

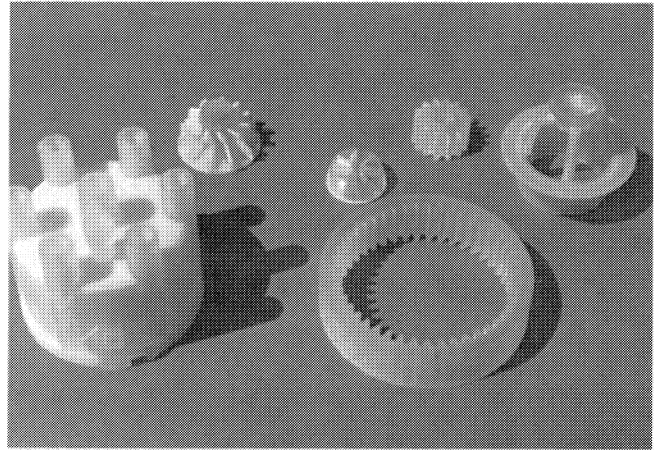


FIGURE 3.52 Parts Produced via Stereolithography

which adheres to the one below it, are built one on top of another to form the part, from the bottom up. After the last layer is made, the part is removed from the SLA and given a high-intensity flood of UV light to complete the polymerization process. The part can then be finished by sanding, sandblasting, painting, or dyeing.

Testing and Analysis One of the primary responsibilities of the designer is to create a design that will withstand the stresses under which the product, part, or system is to function. If the design is to be operated safely, the proper strength becomes the designer's major concern. The size and configuration of a structural member, the ability of the part to withstand loads without breaking, deforming, or fracturing, the safe design of rotating machinery, the shielding of radical temperatures in operation of a system, and the stress produced by the application of external stress during operation are all in the domain of the designer. After the product or system is designed, it must undergo testing and analysis. Lab testing for strength of materials and finite element analysis using a CAD system (Fig. 3.53) are both used throughout industry to determine the adequacy of the design.

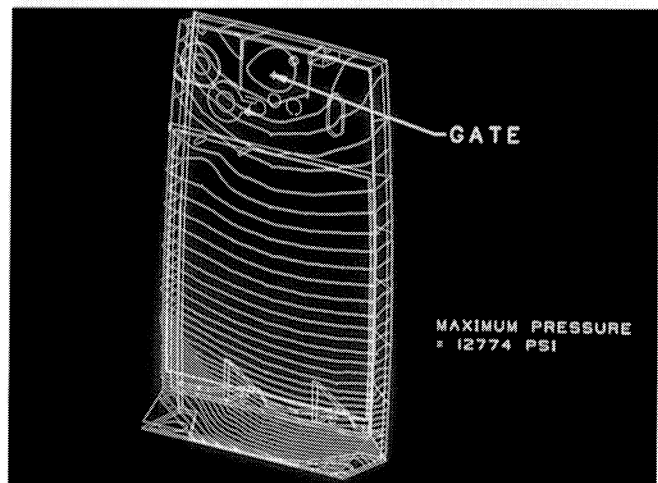


FIGURE 3.53 Wireframe Model of a Mold Part During Analysis

Focus On . . .

STEREOLITHOGRAPHY IN THE DESIGN PROCESS

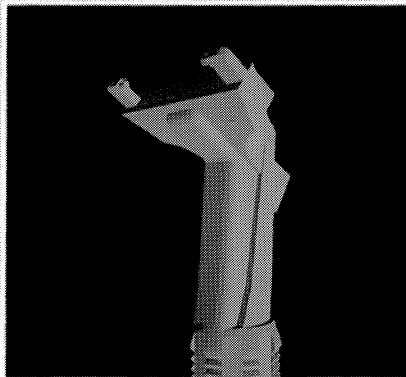
Stereolithography was invented in 1984, was patented in 1986, and became commercially available in early 1988. In 1989 only one commercial product was available. Today more than a dozen models are available from at least six manufacturers. In that brief time, stereolithography has moved from being primarily a visualization tool to a product by which several design iterations can be made and some limited tooling and prototype parts (see figure) can be produced. For example, stereolithography parts can be used in place of wax models for patterns in investment casting.

Stereolithography can produce a solid object from a CAD model (surface or solid) (see figure) quickly and efficiently by directing ultraviolet laser radiation onto a liquid photopolymer. The photopolymer hardens when exposed to this laser beam. Each pass produces a hard polymer down to a certain depth. The platform on which the exposed polymer sits is lowered after each pass, sending the hardened polymer under the surface of the liquid bath. The part is built up layer by layer. The designer can hold and examine a real object at any stage in

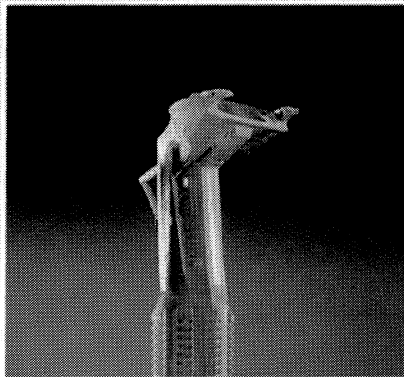
the design process. Changes in the CAD file can be quickly translated into a new solid object. The cost of each prototype (see figure) is significantly lower than when produced by more traditional methods, so that design iterations are quicker. More radical designs can be considered as well.

The first stereolithography systems produced parts that were fragile and brittle. Today the parts are stronger and tougher. Initial systems had a part accuracy that was poor and could exceed 0.050 in. New resins and changes in the software have reduced part error to 0.010 in. or less. Most errors are within 0.005 in. After a part is produced, it must be cleaned and postcured. Liquid resin that clings to the part is wiped off, and the part is placed in a solvent cleaning system. Postcuring finishes the polymerization process and increases the part's strength. Small parts are cured in an hour or two, but large parts may require up to 10 hours. To become functional models, prototypes may be polished, painted, or spray-metal coated.

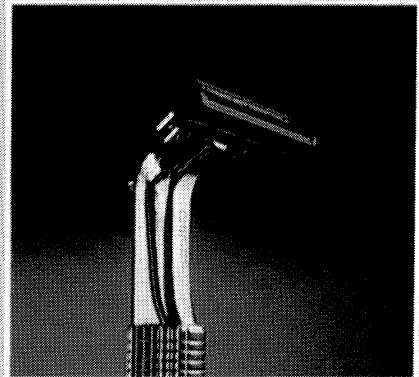
Many successful commercial companies (see figure) today use rapid prototyping stereolithography systems to evaluate a design and reduce the time to market for commercial products. For example, Motorola has built over 8000 models to date at about one-tenth the cost of conventional prototypes and saved over \$2 million. Delivery time for a part at Motorola is only 18–20 hours. Automatic generation of tooling is the next challenge for stereolithography systems.



Solid model of shaver.



Stereolithography prototype model.



Final part.



Shaving with the product.

Finite Element Method To design an optimal structure or to determine the cause of failure after manufacture design engineers commonly employ computerized design and analysis methods. One such method which is supported by the CAD system is the **finite-element method** (FEM, sometimes finite-element analysis, FEA). The finite-element method is an engineering tool that mathematically simulates the behavior of a part. Via FEM, the designer can determine the amount and location of stress in a design, without building a test prototype.

A typical finite element modeling program allows the designer/engineer to create the model, prepare it for analysis and then graphically display the results. As an integral part of a CAD system, the FEM program takes full advantage of all graphics and dynamics features. It also uses part information (since the part design information already exists) thus reducing the likelihood of errors and speeding the entire analysis cycle. Finite-element analysis starts with finite element modeling.

Finite element analysis is the second part of the finite element method. It is generally a mainframe computer program that analyzes the information from the text file to determine the amount and location of stress. Mass properties including weight, volume and center of gravity can also be calculated (Fig. 3.54).

Once the analysis is performed, numerical results are returned to the CAD system and the finite element analysis

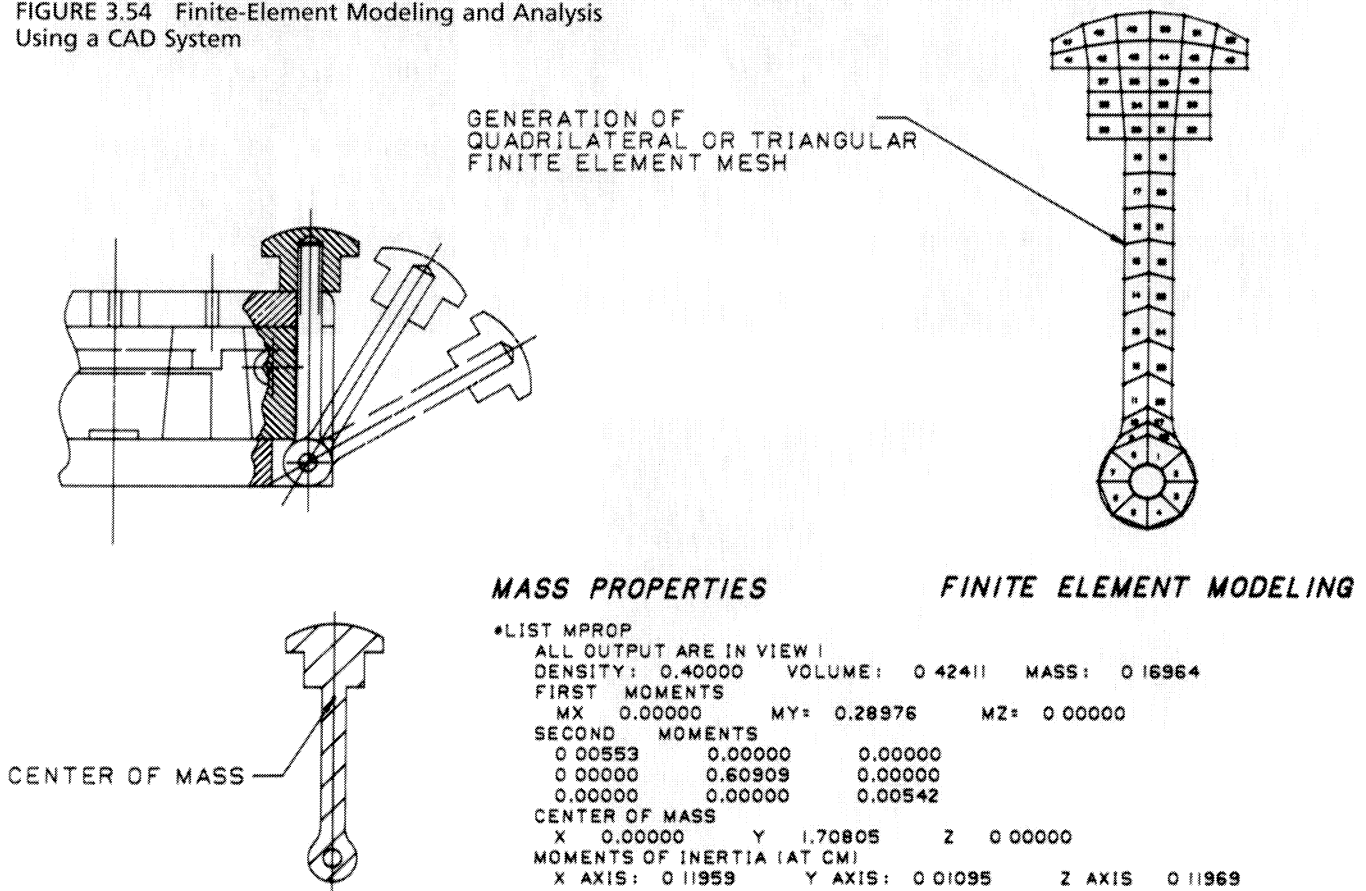
postprocessing phase begins. This involves reviewing the analysis results, determining problem areas, and modifying the design.

Final Refinement of Design The finalization of a design will begin at this point in the design sequence. After the basic design decisions have established an acceptable product and it has been drawn, modeled, and tested, the final design refinements are made. Any alterations and refinements in this stage require many hours of manual drawing changes or alteration of the design database on a CAD system.

When complete, the final design is evaluated for potential new technology innovation and patent possibilities. A patent can be granted for a process or a unique invention or discovery. A patent is granted only to an individual, not to a company. The patent law states: "Any person who invents or discovers any new and useful process, machine, manufacture, composition of matter, or any new or useful improvement thereto, may obtain a patent." A patent is established with a written description of the invention or process, normally accompanied by drawings.

Patent drawings—on standard patent drawing sheets—must be included as one portion of a patent application. Figure 3.55 shows a patent drawing. Inking is required, and shading is normally used to show the invention realistically. The patent drawing will be the last drawing created for a

FIGURE 3.54 Finite-Element Modeling and Analysis Using a CAD System



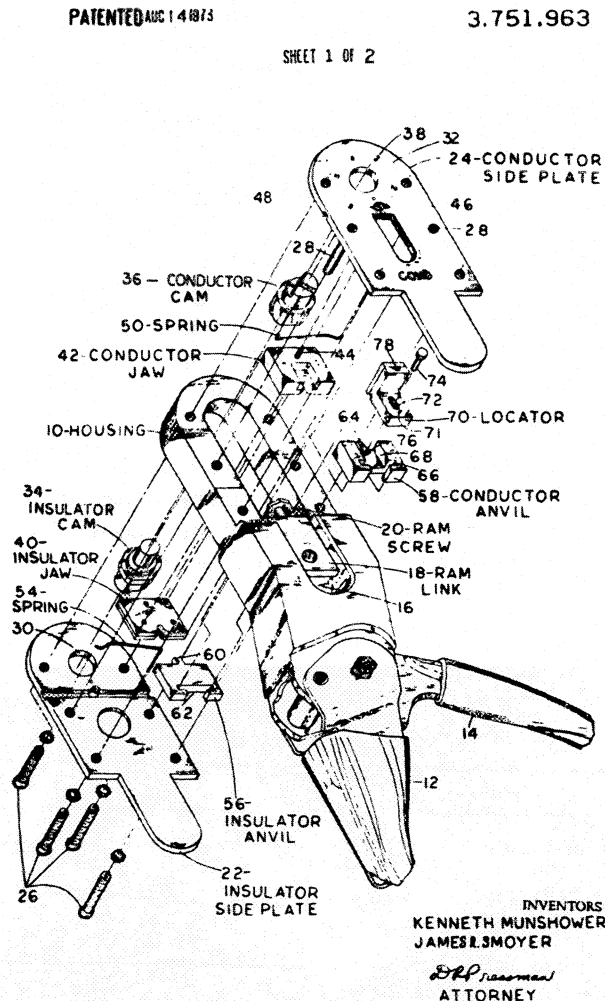


FIGURE 3.55 Patent Drawing

design project. (Once a product is designed, other drawings may be required for tooling and production.) A patent drawing should be very general and present concepts only, not specific size, shape, or material details, in order to prevent theft of the idea. The patent secures to the inventor exclusive production rights for up to fourteen years.

3.9 PRODUCTION, MANUFACTURING, AND PACKAGING

At this point in the design processes, Stage 7 (Fig. 3.56), the design must be presented to all interested, involved, and essential parties. The presentation will involve the designers, engineers, and other company personnel. The configuration of the design is presented in drawings, renderings, and possibly a prototype or presentation model. All aspects of the design are discussed at this meeting. The limitations, restraints, and capabilities of the design, as well as the new or improved features, problems in the product design pro-

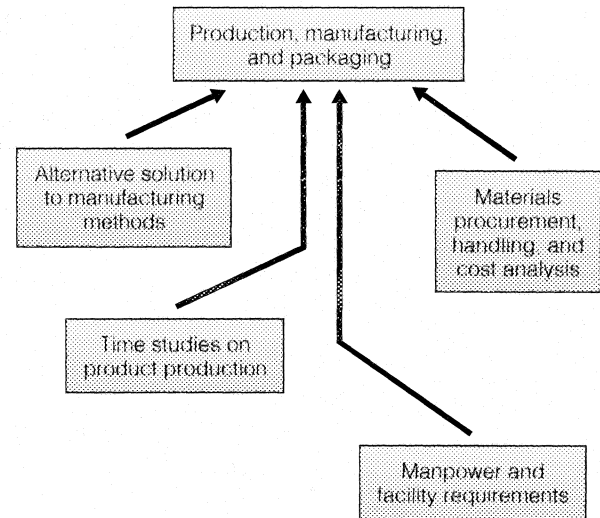


FIGURE 3.56 Stage 7 in the Design Process

cess, and validation of all research, scientific, and engineering aspects of the project, must be available so questions can be answered, decisions defended, and the appropriateness of the developed design demonstrated. Graphs, charts, notes, sketches, models (of rejected design alternatives), and design calculations used to establish the solution may all be needed at this meeting. The production department will require much of this information to establish manufacturing requirements and a production schedule.

Detail drawings of each aspect of the product, assemblies, and any other graphic documentation are complete at this stage. Remember, this is not the first time these parties have been consulted about the design. There has been continuous communication throughout the design process, and, although this is the seventh step in a formal explanation of the design process, the flow of information has been back and forth between these steps throughout the process.

Manufacturing Considerations in Design. The design of a particular part or product usually determines the material and the manufacturing process. Failure to understand the limits and possibilities of the material and the manufacturing options will doom the project from the start. Design for manufacturability is therefore essential to the success of a product. The stress, vibration, environmental operating conditions, tolerance requirements, and surface finish are determined during previous stages in the design process. Therefore, by the time the material selection and the manufacturing methods are selected, they are almost defined by default. The decisions by the designers at this stage are merely refinements. An overview of possible materials and processes to be used must include an understanding of the capabilities and limitations of each one. The engineer must be familiar with these capabilities and limitations in order to select the proper material and the manufacturing method.

Of course, the selection of materials in Stage 5 determines many of the methods used in manufacturing the part or

product. Comprehensive solid modeling packages incorporate many features to help the engineer understand and model the manufacturing process. The steps shown in Figure 3.57 illustrate how solid models can assist the engineer design the CNC manufacturing sequence. The part itself helps determine the material and, therefore, the manufacturing methods. Each of the following factors is critical to the manufacturability of a particular material and must be considered during this design stage:

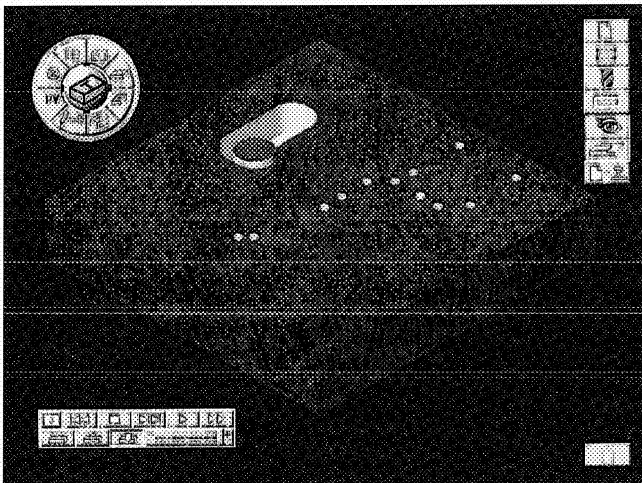
- ☒ **Size** limitation
- ☒ **Configuration**
- ☒ **Thermal** characteristics
- ☒ **Tolerance** requirements
- ☒ **Hardness**
- ☒ **Weight** limits
- ☒ Required ultimate **strength**
- ☒ **Elasticity**
- ☒ Surface **texture**—roughness
- ☒ **Precision**

A variety of manufacturing processes is available. The choice of a process is determined by the part's material and

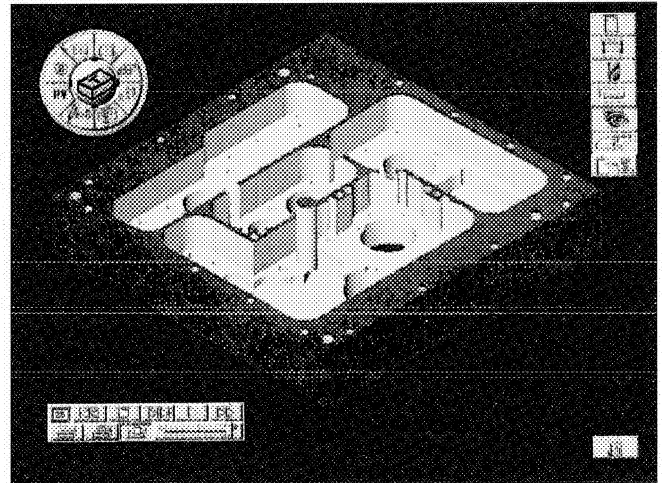
whether or not the process will create an acceptable part. Regardless of the process or the material, the designer should design to maximize efficiency and cost-effectiveness. The following processes are used in manufacturing and will be covered in more detail in Chapter 14:

- ☒ Machining
 - drilling
 - boring
 - milling
 - planing
 - reaming
 - broaching
 - turning
- ☒ Welding
- ☒ Casting
- ☒ Forging
- ☒ Forming
- ☒ Stamping
- ☒ Extruding
- ☒ Bending

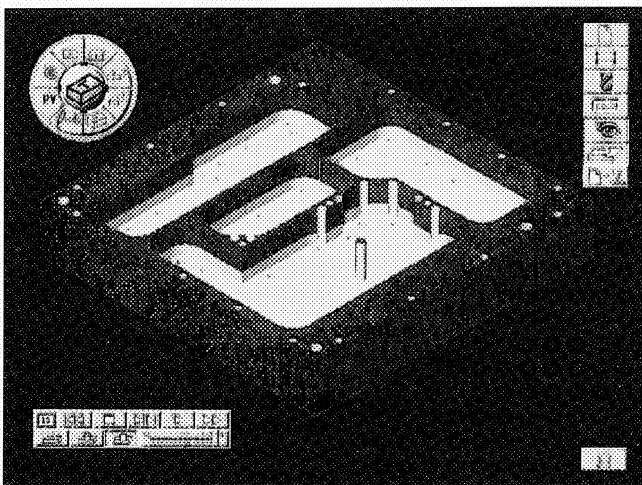
Assembly of the part is partially determined by material selection. The estimated maximum number of parts and the minimum run also affect selection of the process. Since a simple part is easier to create and assemble, the part's



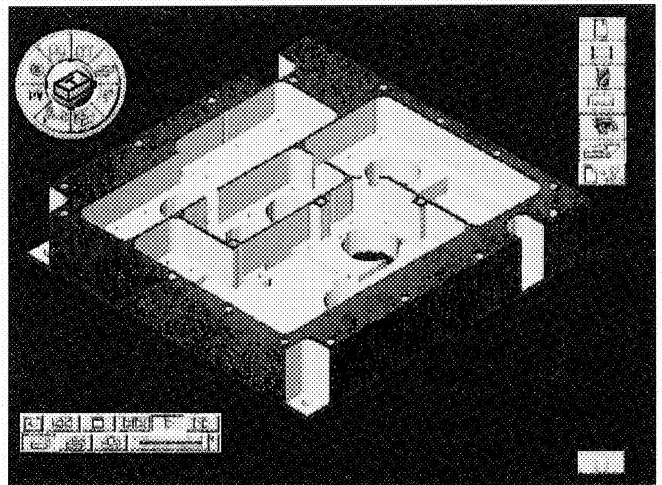
(a) 3D cut part rendering shows a preview of the part as it is machined



(c) Yellow highlights any number of individual operations for maximum contrast and visibility



(b) Red flags any noncutting surface of the tool that hits the material



(d) Viewing the part as a rendered image at the computer makes it easy to detect errors and reduce wasted machine time and scrap

FIGURE 3.57 Using Solid Modeling and CNC Machining to Produce a Part

complexity influences selection as well. Manufacturing assembly processes include:

- ⊠ Brazing
- ⊠ Riveting
- ⊠ Bolting
- ⊠ Welding
- ⊠ Gluing

The following is a partial list of concerns and suggestions for the designer. If these conditions are met, the chance of designing a successful, manufacturable part is greatly increased.

1. Design for standard machines and processes.
2. Design within the cost-effective limits of available and effective manufacturing procedures.
3. Design to limit the number of manufacturing processes.
4. Design to permit efficient production in acceptable quantities and within time requirements.
5. Design for the most cost-effective process that will deliver a product meeting the design parameters.
6. Design for ease of assembly

Although the preceding discussion centers on the designer's responsibilities and the design requirements, it should be understood that the actual selection of manufacturing processes should be made by the manufacturing engineer in conjunction with the product designer.

Alternate Solutions to Manufacturing Methods. *Automated manufacturing* is the design of a product or part so that it can be readily manufactured, fabricated, assembled, handled, tested, quality controlled, packaged, stored, and shipped using automated methods. Since much of today's manufacturing involves robot and automated assembly systems, the part itself should be designed to facilitate these methods. A typical engineer has always been concerned with materials and manufacturing methods, including fabrication and assembly. Increased productivity requirements, brought on by foreign competition and concern for profitability, have made automated manufacturing methods essential to the survival of a company. Ever-increasing overhead, labor, and material costs have driven industry's desire to automate. An understanding of the new methods of robotic production and automated manufacturing methods requires the knowledge of their capabilities as well as their shortcomings. Figure 3.58 shows the influences of automation on the design process.

As a new concept, material, or process becomes known, you can begin to compile a list that will help in the design process of a particular project. Material considerations, processes, automated technology, and other factors can be listed to help create the optimum design. If design rules and autofactoring tips are to be up to date and useful, they will be in a constant state of flux. As data for a project becomes known, you should incorporate it into the design rule list for a project. Automated manufacturing design often includes designing for simplicity. Remember, the more complex a part, the more difficult it is to autofactor; a simple part will require less manipulation by a robot. Thus, keeping the

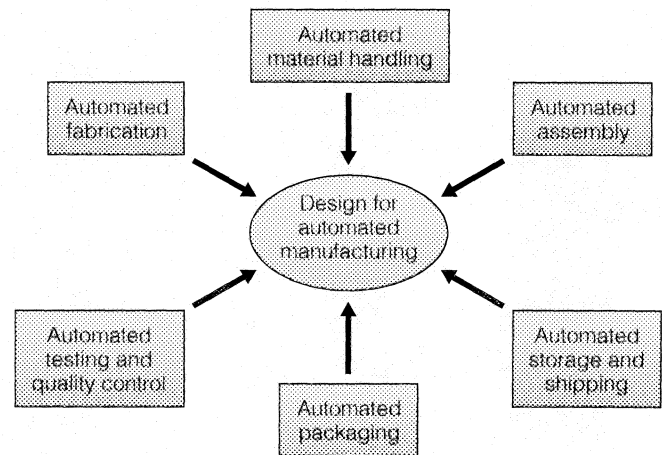


FIGURE 3.58 Design for Automated Manufacturing

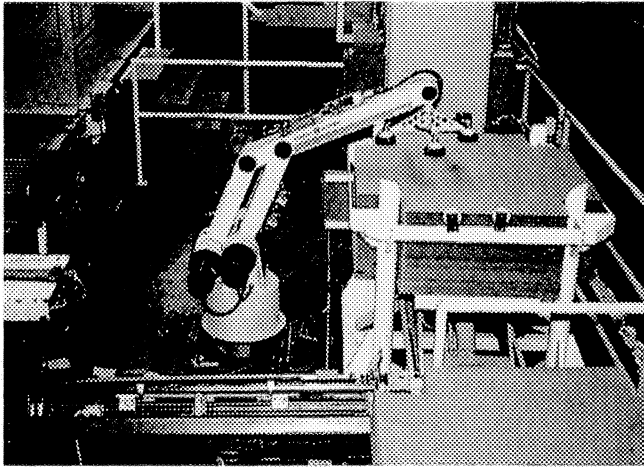
robot's movements short and efficient will decrease production time. The design of the part will influence the robot's required movements [Fig. 3.59(a)].

Designing for elimination of obstructions is another consideration [Fig. 3.59(b)]. Automated assembly and the incorporation of robots in the manufacturing process requires that obstructions be kept to a minimum so that the robotic arm and end-effector can move freely during material handling [Fig. 3.59(c)], part positioning [Fig. 3.59(d)], and part removal.

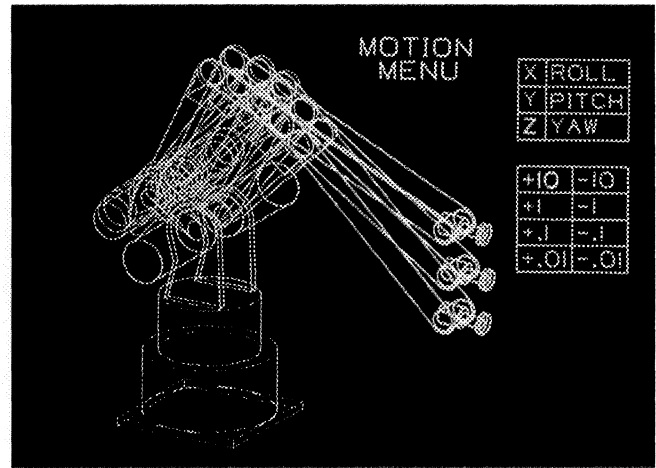
Designing with automated manufacturing in mind takes more initial design time, but you will be rewarded with a more efficient, cost-effective, and better product. The following checklist can maximize the results of your design effort.

1. Incorporate every design aid available to reduce manufacturing costs, without adversely influencing the product's essential features.
2. Understand the basic capabilities and limitations of your in-house production and outside vendors' capabilities pertaining to the part's manufacturing and materials.
3. Determine the manufacturing methods—whether manual production, automated production, or a combination of the two—early in the design process so as to maximize the successful creation of the product.
4. Use a design review process that maximizes the effect of any design rules created in the design process. Be willing to review the results and redefine. Keep an open mind about the material, the process, and the automated manufacturing methods.
5. Keep up to date on new and developing automated processes, machinery, time-and-production studies, advanced materials, and technology.

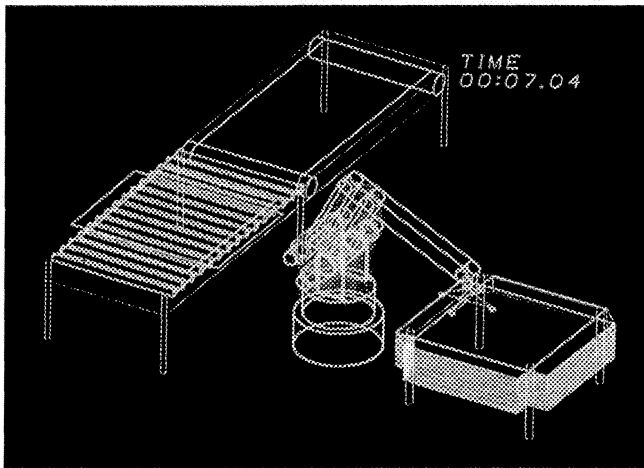
Time Studies on Product Production. Studies are required of all processes needed to produce a part. The rate of production has a direct effect on the profitability of a product. **Time studies** are conducted to optimize a product's manufacturing cycle. Material handling, production



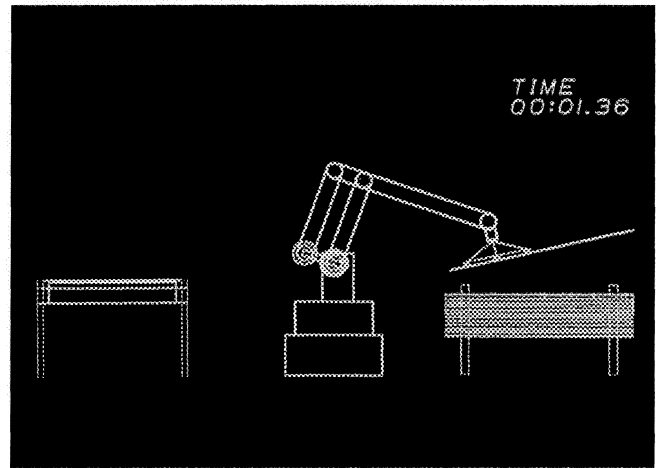
(a) The workcell can be designed for welding, assembly, machine loading, and other manufacturing operations. The robot is performing material-handling operations.



(c) Using the motion menu feature, workcell designers can analyze and simulate robot motion. The screen view shows the superimposed robot images.



(b) During robot simulation, workcell cycle time is displayed on the screen. Throughout the simulation, the software allows the operator to check workcell design elements—interferences, motion of the robot, end-effector, interaction of workcell components.



(d) The robotic workcell was designed via simulation software. The conveyor (*left*), indexing pallet (*right*), and robot (*center*) are drawn with the robot library.

FIGURE 3.59 Robots

elapsed time (manufacturing and assembly), and part removal (and transportation) are all in this study. Time analysis affects the determination of manufacturing methods, assembly fastening choice, and, sometimes, the material itself.

Materials Procurement, Handling, and Cost Analysis. The **availability** of a material or standard part will influence its selection as much as will design requirements. **Material procurement** and handling are an essential part of the total design effort. If the specified standard part is temporarily out of stock or not available, a product can be delayed in the manufacturing stage.

The designer must be aware of the material cost, as well as its availability. The increased cost of substituting one material for another at the manufacturing stage can completely destroy the product's profitability. The introduction of **just-in-time** manufacturing, where the traditional ware-

ing of large amounts of materials and standard parts is limited by efficient management of the procurement of the materials and parts and their arrival at the manufacturing station exactly when needed in the assembly or production process, requires extensive coordination of all departments. The manufacturing facility must be able to procure, store, and handle the material and standard parts if the production run is to be trouble free.

Manpower and Facility Requirements. Often, a company's facility and workforce will determine when and where the part or product should be made and assembled. The design process includes decisions based on available space, machinery, and trained personnel. One pressing problem in many industries is the lack of an educated, trainable workforce. The implementation of automated methods has been influenced by this lack of high-quality personnel, as well as by foreign competition. The use of robots in the manufac-

turing stage will also affect personnel, facility, and equipment considerations.

Robots and Manufacturing. Robots (Fig. 3.59) are increasingly used for efficient, safe, cost-effective manufacturing processes, including material and finished-product handling and storage, as well as the actual processes involved in the production of the item. CAD robotics packages are a computer-aided design and manufacturing (CAD/CAM) tool for robotic simulation and robot workcell design. Much of all robotics workcell design is simulated remotely on a CAD system before it is used on the factory floor.

A robot workcell consists of the robot itself, robot end-effectors (hands), part orienters, the part being operated on, fixtures, and the surrounding equipment with which the robot interacts. By means of a robot-simulator package, automation engineers can consult libraries of robots and equipment to design a workcell and simulate actual robot motion within the cell. From the simulation, an engineer can accurately determine the workcell cycle time and check for interferences in the motion of the robot with other workcell components.

Industrial Packaging. The field of packaging design includes design of boxes to hold consumer items such as perfume, electronic products, food products, and general household items. It also includes industrial packaging for mechanical and electronic designs (sheet metal enclosures). The artistic design of boxes for consumer items is considered under Stage 8. Here, the discussion is confined to sheet metal enclosures required for mechanical and electronic systems.

A typical sheet metal design can be created, in 3D, on a CAD system (Fig. 3.60). The 3D model sheet metal designs can be automatically unfolded in a flat pattern development (Fig. 3.61).

The enclosure for any mechanical or electronic system considers the many factors that influence other areas of design. Space requirements, safety, function, operation, service, and environmental conditions are all determining factors. Most of these requirements are known early in the design process so as to provide sufficient leeway in the packaging when this step is reached.

3.10 MARKETING, SALES, AND DISTRIBUTION

Marketing, sales, and distribution (Stage 8 in the design process) are an essential aspect of the total design effort (Fig. 3.62). The product or system may never exist without a thorough economic analysis. The cost of advertising, marketing, packaging, shipping, and distribution greatly affects the cost to bring the product to market. The input of the sales and marketing department, the packaging department, and the shipping and storage facility makes the important

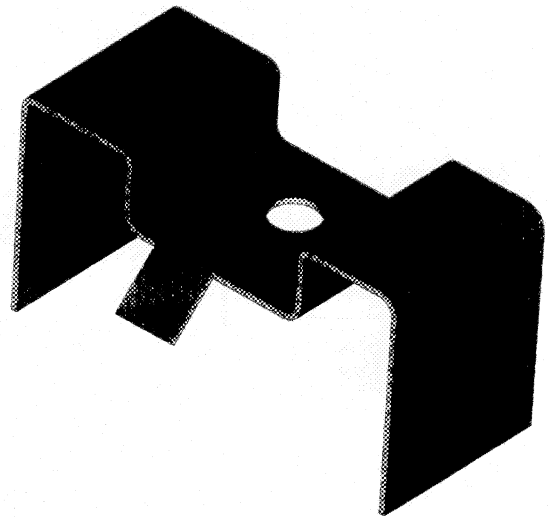


FIGURE 3.60 Example of Sheet Metal Used in Industrial Packaging

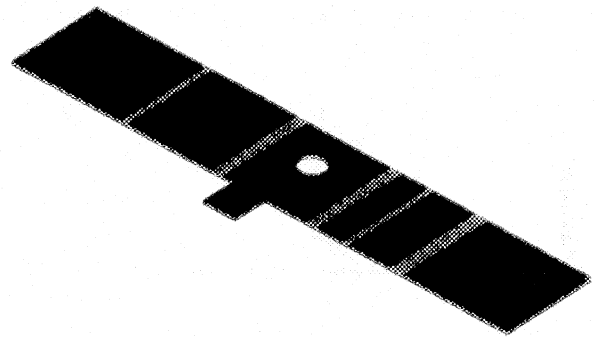


FIGURE 3.61 Sheet Metal Flat Pattern Development Using 3D CAD

connection to the real world of business and affects profit margin. Many products that have been brought to market without a proper understanding of the business aspects of the design process are doomed to fail—even good products.

Advertising, Budgets, and Marketing Direction. The marketing department may participate in preliminary project work. Marketing is responsible for an accurate product survey before the product is designed. A poor design decision with respect to customer needs would leave the marketing department with the job of selling an unusable or undesirable product. Sometimes an advertising campaign can create a need for a product in the minds of the public or sell an inferior product. In general, marketing will help determine many product function requirements before the final design is accepted. Surveys that help determine the need, size, color, shape, feel, and acceptable cost can be completed well before the engineers and designers are through with their work. The rough preliminary ideas of an

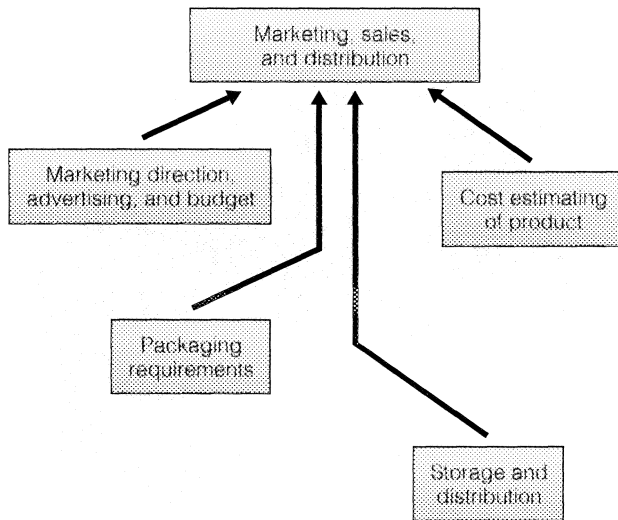


FIGURE 3.62 Stage 8 in the Design Process

inventor/engineer/designer may be refined and altered by the input of the marketing department.

Cost Estimating of Product. The **cost analysis** of the product includes the expenses generated by the engineering, design, manufacturing, sales, and shipping departments. Each department must submit a detailed cost estimate for the man-hours, materials, and overhead cost for each stage of the design development process in which it is involved. Design costs include modeling and drafting; sales costs include advertising and marketing; packaging costs include art design and box design. Since manufacturing cost includes personnel, equipment, facility, and material considerations, it may be the largest single cost item of the product.

Product **cost estimation** affects many of the other departments' decisions. The choice of materials, the choice of manufacturing methods (such as fastening), the choice of packaging materials and art design, and the level and extent of sales and advertising are all influenced by the item's cost and profit margin. Cost estimating includes how long it takes to generate an acceptable return and how many items must be sold before the product is considered an economic success.

Packaging Requirements. The design of a product does not end with the product itself. Without proper presentation, the product may fail to achieve the required sales to be successful. **Packaging** is almost as important as the product, especially in the world of mass marketing and international sales.

Packaging also includes new concepts of green-packaging (environmental packaging)—using biodegradable packaging and eliminating overpackaging. Too much packaging creates unnecessary amounts of waste when the product is used.

A simple box may not be so simple. As a matter of fact, it can be rather complex. Size must be considered, along with shape, printed text, color, art, and competition from other

boxes. Most packaging for consumer products must be designed for appearance as well as function.

Although packaging is normally part of Stage 7, most of the design input about appearance comes from the advertising and marketing departments. The actual design of the dies and patterns is the domain of the manufacturing group. The marketing department, in conjunction with the packaging designers assigned to the manufacturing department, must agree on a box design that is functional, attractive, and producible, within cost restraints.

Designing a box with a specific purpose can be even more complex—French fry boxes have unusual shapes and curves; deodorant boxes use die cuts to display the product inside; and medicine boxes are designed to be tamper resistant. Technology is minimizing complications while providing greater control, particularly over prototyping, through CAD/CAM.

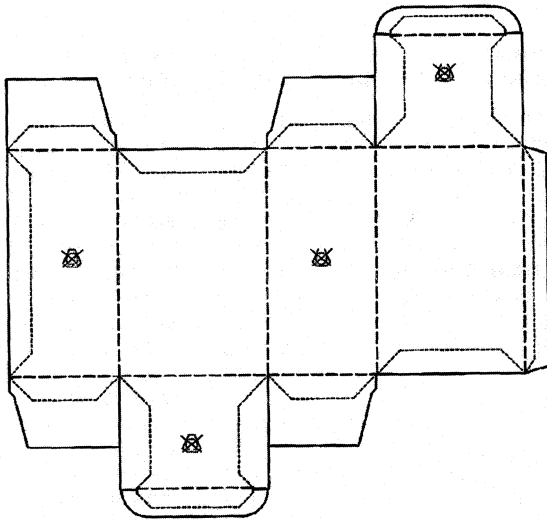
Software programs have been designed specifically for the packaging industry. Software is available that offers a library of parametric designs for creating standard box configurations. The designer simply provides appropriate dimensions to any box design (for example, the standard reverse tuck—a common design with simple end flaps connected to the front of one side of the box and the back of the other side to tuck it closed), and the CAD program automatically draws the required shape.

CAM programs can send instructions to devices such as a plotter. This machine cuts out the box and makes creases at the folds of the prototype, saving hours of tedious work. Instructions can also be sent to a laser that cuts a plywood die to hold the steel rules used to cut multiple boxes once the final design is determined.

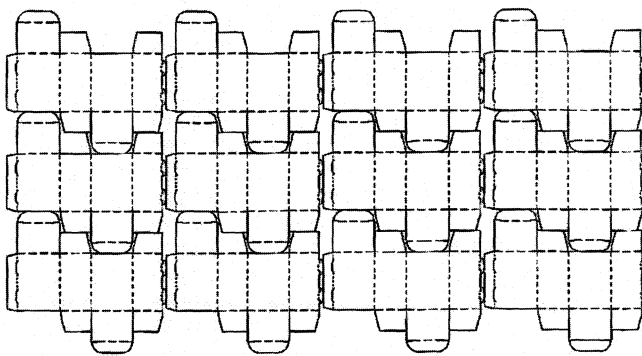
Once the individual box design is complete [Fig. 3.63(a)], copies are nested together [Fig. 3.63(b)], mirroring and duplicating the images and interlocking them like jigsaw puzzle pieces to produce as many boxes as possible from a single sheet of cardboard. The software performs automatic bridging, a technique in which gaps are left during the process of cutting the plywood so that it doesn't fall apart. The die manufacturer then inserts steel blades into the plywood, bridging the gaps with blades so that the boxes will fall out like shapes from a cookie cutter.

One potential for CAD/CAM packaging lies with large food and pharmaceutical companies that want more direct control over the prototyping phase for the hundreds of packages fabricated for their products. By combining packaging software with devices such as a PLANTAGRAM, in which a shelf environment is recreated, designers can see how the box will look against the competition. The decision can then be finalized before the die is cast.

While the ability to connect CAD box design to CAM machining has been available for some time, the concept of integrating the process with packaging graphics is a new idea that offers major advantages. The capability to prepare the entire design [Fig. 3.63(c)], including the structure, graphics, and machine codes, on a single computer not only



(a) Die design using Ovation CAD/CAM



(b) Nested design layout



(c) Package graphics

FIGURE 3.63 Packaging Design Example

speeds and simplifies the prototyping phase, it also eliminates expensive mistakes.

Shipping and Distribution. **Just-in-time (JIT)** manufacturing is a process in which the component parts of a system design arrive at the assembly line station at the time of installation. This requires careful control of materials, equipment, and fabrication processes and subassembly transportation to the site at the appropriate time. **Field fabrication** of system parts also depends on the timely arrival of appropriate materials. The planners of any project have most of the responsibility for this stage of the project. The designers and the procurement department must be in constant communication at almost every stage to prevent shortfalls or overstocking of supplies. It is the coordination between all involved departments that makes a project meet both time constraints and cost estimates.

Shipping and distribution of a product includes storing and warehousing the product. Many times, a consumer product's timely arrival on the market greatly affects its sales. If the greatest sales opportunity occurs in the three months before Christmas, what would happen if the product showed up on store shelves on December 28?

The shipping department must be aware of the product's size and weight and any other factors that would influence the method of shipment. Is the product fragile? Is it bulky? Will it be affected by heat or cold? Is it perishable? Does it need any special considerations, such as refrigeration? If the product is to be stored at the facility, will there be enough warehouse space? Should the warehouse be automated to handle the product with robotic systems? How many of the product should be available at any one time? These are all questions that must be asked early in the design process and solved by the time this last stage is reached.

The quantity of items to be handled and stored is also an important consideration. Design for stacking whenever possible. If the product is to be shipped to the general public, contracting with outside shipping sources must also be done. Other concerns at this stage include: Will the product be shipped overseas? If so, are there any packaging, duty, tariff, or handling factors that must be considered? As we can see, designing for storing, stacking, and shipping goes far beyond just how to move the product from the manufacturing and packaging facility to the trucking dock.

Illustrations for Presentation, Sales, Advertising, and Catalogs. Pictorial illustrations are used in this stage of the design process to present the product, system, or concept to a nontechnical or purchasing audience. Renderings of products and concepts provide a realistic illustration of the proposed item. Renderings and models help introduce a product, concept, or system design to the general public or an interested potential customer. Using the 3D CAD database, an illustrator can now create a pictorial illustration without redrawing the assembly or part.

3.11 DESIGN PROJECT EXAMPLE

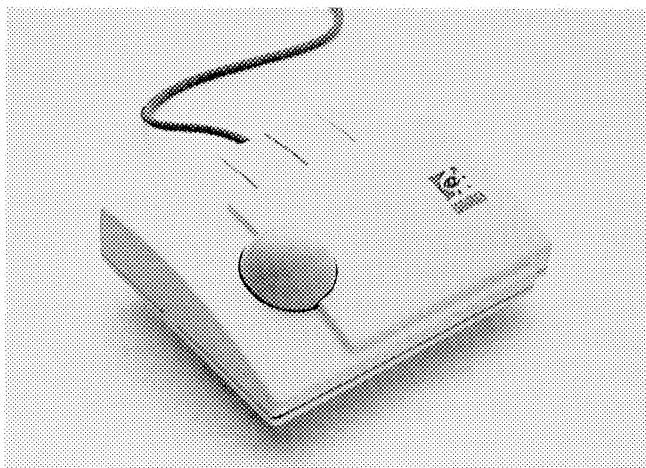
The device shown in Figure 3.64(a) is an example of a well-designed consumer product created on a CAD system. Logitech manufactures a variety of mouse devices for computers. You may even have one of their products in your school on your CAD system. Over the years the designers at Logitech became aware of some of the shortcomings of the traditional mouse. Since the ball is on the bottom of a typical mouse, the user must move the device across a flat surface. This meant that the mouse must always rest on a clean, flat pad or other acceptable surface. The position of the mouse, either on the right or the left of the computer, is dependent on whether the user is right-handed or left-handed. If the surface is not flat and clean, the mouse is susceptible to skipping. The user always has to have the device lying flat.

The new device solved many of these problems. The ball was moved to the top of the device to be rotated by the user's hand, not by contact between the ball and a flat surface. The user was now free to hold the input device in her or his hands. Of course, since it could be operated by either hand without a flat area, the device did not have to be on the right or left side of the computer. Logitech called this product Trackman.

The **critical-path method** of scheduling is documented in Figure 3.64(b). Here, a computer program was used to keep track of the critical and noncritical tasks in the design sequence. The major headings are:

- ⊗ Product management
- ⊗ Mechanical design
- ⊗ Software development
- ⊗ Software quality assurance (QA)
- ⊗ Publications
- ⊗ Product engineering
- ⊗ Test engineering
- ⊗ Materials
- ⊗ Manufacturing

Each of the major headings is subdivided into specific tasks. The duration of each task is estimated and noted as its *Duration Time*. The *Resource* of each task was the specific



(a) Trackman roller ball mouse

FIGURE 3.64 Trackman Mouse

Heading Task Resource	Dur	Schd Start	Schd Finish	Status
TRACKMAN.PJ	148	03-27-89	10-24-89	
PRODUCT MGMT	51	05-01-89	07-14-89	In Prog.
Rel Wood Model	0	05-01-89	05-01-89	Comp./Crit.
Rel Prototype	0	05-26-89	05-26-89	Comp./Crit.
Rel SalesForecast	0	06-01-89	06-01-89	Comp./Crit.
Rel IntiShipInfo	0	07-14-89	07-14-89	Scheduled
MECHANICAL DSGN	140	03-27-89	10-12-89	In Prog.
Rel Case Drawing	0	05-17-89	05-17-89	Comp./Crit.
Rel PWApartsList	0	06-21-89	06-21-89	Comp./Crit.
SubmitPC Bartwork	0	06-13-89	06-13-89	Comp./Crit.
Rel PCB Layout	0	06-26-89	06-26-89	Comp./Crit.
Tooling	69	03-27-89	07-07-89	Comp./Crit.
Tooling Support	69	03-27-89	07-07-89	Comp./Crit.
Josef	69	03-27-89	07-07-89	Critical
Rec CaseisArtcl	0	07-07-89	07-07-89	Comp./Crit.
Rel Proto to Pkg	0	07-13-89	07-13-89	Comp./Crit.
Debug Parts	1w	07-10-89	07-14-89	In Prog.
Josef	1w	07-10-89	07-14-89	
Make 60 PCB's	13	06-27-89	07-17-89	In Prog./Crit.
Rec PWA Components	0	07-14-89	07-14-89	Scheduled
Rec 60 PWAs	0	07-27-89	07-27-89	Schd./Crit.
Build DVT1 Units	1w	07-28-89	08-03-89	Schd./Crit.
Rel DVT1 Units	0	08-03-89	08-03-89	Schd./Crit.
Run DVT1 Test	2w	08-04-89	08-17-89	Schd./Crit.
Josef	2w	08-04-89	08-17-89	Critical
Run DVT2 Test	1w	08-18-89	08-24-89	Scheduled
Josef	1w	08-18-89	08-24-89	
Texture Tool	1w	08-25-89	08-31-89	Scheduled
Make PVT units	3	09-01-89	09-06-89	Scheduled
Evaluate PVT	2w	09-22-89	10-05-89	Schd./Crit.
Mftr M-P Units	1w	10-06-89	10-12-89	Schd./Crit.
SOFTWARE DEVELOP	94	05-01-89	09-13-89	In Prog.
Rel Prelim Spec	0	05-05-89	05-05-89	Comp./Crit.
Rel Final Spec	0	07-14-89	07-14-89	Scheduled
Driver	56	05-01-89	07-20-89	In Prog.
Trackball Driver	1w	05-01-89	05-05-89	Comp./Crit.
Joe	1w	05-01-89	05-05-89	Critical
Control Panel	4w	05-01-89	06-29-89	Comp./Crit.
Bang	4w	05-01-89	06-29-89	Critical
Dual Mode-Driver	2w	06-15-89	07-06-89	Comp./Crit.
Joe	2w	06-15-89	07-06-89	Critical
WORD Fix	16	06-19-89	07-14-89	In Prog.
Mark	16	06-19-89	07-14-89	
ADI Driver	1w	07-14-89	07-20-89	Scheduled
Mark	1w	07-14-89	07-20-89	
Rel for Alpha	0	07-14-89	07-14-89	Scheduled
Alpha Test	8	07-14-89	07-25-89	Scheduled
Rel for Beta	0	07-25-89	07-25-89	Scheduled
Beta Evaluation	4w	08-09-89	09-06-89	Scheduled
Rel for Final	0	09-13-89	09-13-89	Scheduled
SOFTWARE QA	54	07-07-89	09-22-89	In Prog.
Alpha Phase	12	07-07-89	07-25-89	In Prog.
Rec A-Materials	4	07-07-89	07-14-89	In Prog.
Rec Alpha Manual	0	07-07-89	07-07-89	Comp./Crit.
Rec Mouse Units	0	07-14-89	07-14-89	Scheduled
Rec Alpha SW	0	07-14-89	07-14-89	Scheduled
Run Alpha Test	8	07-14-89	07-25-89	Scheduled
Luis	8	07-14-89	07-25-89	
Manual FdbackDue	0	07-17-89	07-17-89	Scheduled
Beta Phase	30	07-25-89	09-06-89	Scheduled
Rec B-Materials	7	07-25-89	08-03-89	Scheduled
Rec Beta SW	0	07-25-89	07-25-89	Scheduled
Rec Beta Manuals	0	07-27-89	07-27-89	Scheduled

(b) Critical-path schedule for Trackman roller ball mouse

Heading	Schd	Schd	Status	
Task Resource	Dur	Start	Finish	
Reca Beta HW	0	08-03-89	08-03-89	Scheduled
Run Beta Test	23	08-04-89	09-06-89	Scheduled
Luis	23	08-04-89	09-06-89	
Mail Materials	3	08-04-89	08-08-89	Scheduled
Angie	3	08-04-89	08-08-89	
Beta Evaluation	4w	08-09-89	09-06-89	Scheduled
Final Phase	7	09-13-89	09-22-89	Scheduled
Rec Final SW	0	09-13-89	09-13-89	Scheduled
Run Final Tests	1w	09-14-89	09-20-89	Scheduled
Ref Master Disks	0	09-20-89	09-22-89	Scheduled
Write SWQA Reprt	2	09-21-89	09-22-89	Scheduled
PUBLICATIONS	103	05-05-89	10-03-89	In Prog.
Rec Prelim Spec	0	05-05-89	05-05-89	Comp./Crit.
Rec Final Spec	0	07-14-89	07-14-89	Scheduled
Getting Started	77	05-17-89	09-06-89	In Prog.
Alpha Phase	49	05-17-89	07-27-89	In Prog.
Write Alpha	7w	05-17-89	07-07-89	Comp./Crit.
Bob G.	7w	05-17-89	07-07-89	Critical
Release Alpha	0	07-07-89	07-07-89	Comp./Crit.
AlphaFeedbackDue	0	07-17-89	07-17-89	Scheduled
Correct Alpha	8	07-18-89	07-27-89	Scheduled
Rob G.	8	07-18-89	07-27-89	
Beta Phase	28	07-27-89	09-06-89	Scheduled
Release Beta	0	07-27-89	07-27-89	Scheduled
Beta FeedbackDue	0	08-03-89	08-03-89	Scheduled
Correct Beta	2w	08-04-89	08-17-89	Scheduled
Bob G.	2w	08-04-89	08-17-89	
Beta Test	4w	08-09-89	09-06-89	Scheduled
Final Phase	7	08-17-89	08-28-89	Scheduled
Ref Final Doc	0	08-17-89	08-17-89	Scheduled
Final Review	2	08-18-89	08-21-89	Scheduled
Correct Final	1w	08-22-89	08-28-89	Scheduled
Bob G.	1w	08-22-89	08-28-89	
Blueline #1	1w	08-29-89	09-05-89	Scheduled
Blueline #2	1w	09-06-89	09-12-89	Scheduled
Print Manuals	3w	09-13-89	10-03-89	Scheduled
PRODUCT ENG'G	114	05-02-89	10-12-89	In Prog.
Rec PCB Artwork	0	07-14-89	07-14-89	Scheduled
Rec TrackManUnit	0	08-04-89	08-04-89	Scheduled
Rec Master Disks	0	09-20-89	09-20-89	Scheduled
Rec SWQA Report	0	09-22-89	09-22-89	Scheduled
Rec HWTestReprts	0	10-09-89	10-09-89	Scheduled
Rec Blueline #2	0	09-12-89	09-12-89	Scheduled
BOM	78	06-21-89	10-12-89	In Prog.
Rec PrePartslst	0	06-21-89	06-21-89	Comp./Crit.
Prepare Pre BOM	2	06-22-89	06-23-89	Comp./Crit.
Issue Prelim BOM	0	06-28-89	06-28-89	Comp./Crit.
ECO Final BOM	0	10-12-89	10-12-89	Scheduled
HWQA Testing	7	08-04-89	08-14-89	Scheduled
Run HWQA Test	1w	08-04-89	08-10-89	Scheduled
Write HWQA Reprt	2	08-11-89	08-14-89	Scheduled
Safety Tests	42	08-04	10-03-89	Scheduled
FCC Test	2	08-04-89	08-07-89	Scheduled
Rec FCC Approval	0	08-07-89	08-07-89	Scheduled
UL Test	6w	08-04-89	09-15-89	Scheduled
Rec UI Approval	0	09-15-89	09-15-89	Scheduled
Rec FCC Letter	0	10-03-89	10-03-89	Scheduled
Packaging	89	05-02-89	09-07-89	In Prog.
Rec Wood Model	0	05-02-89	05-02-89	Comp./Crit.
Rec Drawings: MD	0	05-18-89	05-18-89	Comp./Crit.

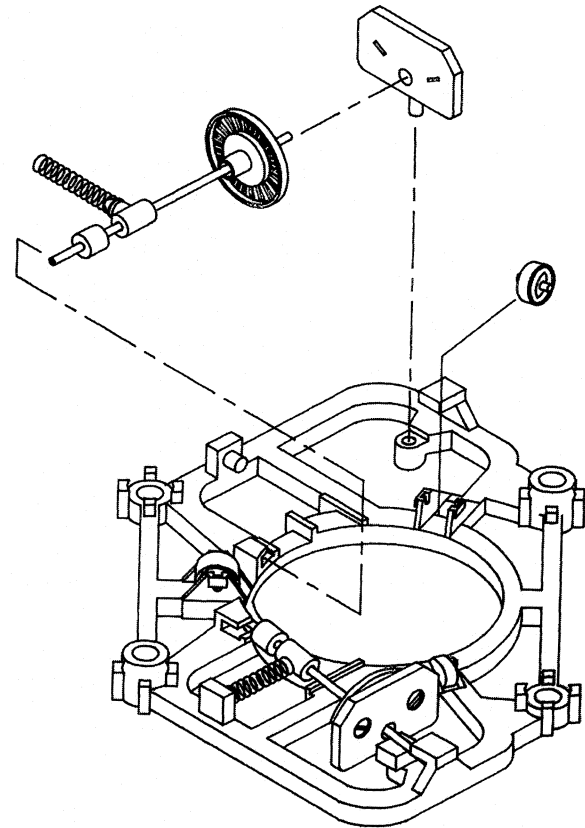
Heading	Schd	Schd	Status	
Task Resource	Dur	Start	Finish	
Tray	66	05-26-89	08-30-89	In Prog.
Rec.TrckballProto	0	05-26-89	05-26-89	Comp./Crit.
Make Proto	2w	05-26-89	06-14-89	Comp./Crit.
Drwgs				
Build Tooling	4w	07-17-89	08-11-89	Scheduled
Rec Hand	0	08-11-89	08-11-89	Scheduled
Samples				
Approve Samples	1w	08-14-89	08-18-89	Scheduled
Finalize Drwgs	3	08-21-89	08-23-89	Scheduled
Manufacture Tray	1w	08-24-89	08-30-89	Scheduled
Carton	62	06-09-89	09-07-89	In Prog.
Define Packaging	2w	06-09-89	06-15-89	Comp./Crit.
Rec Hand Sample	0	07-13-89	07-13-89	Comp./Crit.
Sample Approved	0	07-14-89	07-14-89	Scheduled
Draw	1	07-14-89	07-14-89	Scheduled
PackageSpec				
Make Die Vinyl	3	07-17-89	07-19-89	Scheduled
Ref Die Vinyl	0	07-19-89	07-19-89	Scheduled
Rec 1st Articles	0	08-11-89	08-11-89	Scheduled
Approve 1stArtcl	3	08-14-89	08-16-89	Scheduled
Artwork	20	07-19-89	08-16-89	Scheduled
Rec Die Vinyl	0	07-19-89	07-19-89	Scheduled
Design Artwork	20	07-20-89	08-16-89	Scheduled
Beth	20	07-20-89	08-16-89	
Rel Films	0	08-16-89	08-16-89	Scheduled
Die---	10	07-27-89	08-09-89	Scheduled
PURCHASING				
Select Vendor	1w	07-27-89	08-02-89	Scheduled
Carol B.	1w	07-27-89	08-02-89	
Make Die	1w	08-08-89	08-09-89	Scheduled
Carol B.	1w	08-03-89	08-09-89	
Mtr Carton	3w	08-17-89	09-07-89	Scheduled
ECO	40	08-17-89	10-12-89	Scheduled
Process PWA ECO	2	08-18-89	08-21-89	Schd./Crit.
Approve PWA ECO	1	08-22-89	08-22-89	Schd./Crit.
Process Pkg ECO	2	08-17-89	08-18-89	Scheduled
Approve Pkg ECO	1	08-21-89	08-21-89	Scheduled
Process SW ECO	2	09-25-89	09-26-89	Scheduled
Approve SW ECO	1	09-27-89	09-27-89	Scheduled
Process FinalECO	2	10-10-89	10-11-89	Scheduled
Approve FinalECO	1	10-12-89	10-12-89	Scheduled
TEST ENGINEERING	99	05-18-89	10-09-89	In Prog.
Case Evaluation	5	08-17-89	08-24-89	Scheduled
Rec Plastics	0	08-17-89	08-17-89	Scheduled
Eval Plastics	1w	08-18-89	08-24-89	Scheduled
PCB Evaluation	2	07-17-89	07-19-89	Scheduled
Rec PCB	0	07-17-89	07-17-89	Scheduled
Evaluate PCB	2	07-18-89	07-19-89	Scheduled
Product Testers	73	05-18-89	08-31-89	In Prog.
Develop Plan	7	05-18-89	07-14-89	In Prog.
Bus BON Test	35	07-14-89	08-31-89	Scheduled
Rec PCB Layout	0	07-14-89	07-14-89	Scheduled
Layout & Design	4w	07-14-89	08-10-89	Scheduled
Build Fixture	3w	08-11-89	08-31-89	Scheduled
Bus Test Ready	0	08-31-89	08-31-89	Scheduled
Serial BON Test	35	07-14-89	08-31-89	Scheduled
Rec PCB Layout	0	07-14-89	07-14-89	Scheduled
Layout & Design	4w	07-14-89	08-10-89	Scheduled
Build Fixture	3w	08-11-89	08-31-89	Scheduled
Serial TestReady	0	08-31-89	08-31-89	Scheduled

(b) Critical-path schedule for Trackman roller ball mouse—Continues

FIGURE 3.64 Trackman Mouse—Continues

Heading	Task Resource	Dur	Schd Start	Schd Finish	Status
Final Test		35	07-14-89	08-31-89	Scheduled
	Rec Case Drawing	0	07-14-89	07-14-89	Scheduled
	Layout & Design	4w	07-14-89	08-10-89	Scheduled
	Build Fixture	3w	08-11-89	08-31-89	Scheduled
	Final Test Ready	0	08-31-89	08-31-89	Scheduled
PVT—Trackball		12	09-22-89	10-09-89	Scheduled
	PVT Build	1w	09-22-89	09-28-89	Scheduled
	PVT Evaluation	1w	09-29-89	10-05-89	Scheduled
	Give PWA Approval	0	10-05-89	10-05-89	Scheduled
	Write PVT Report	2	10-06-89	10-09-89	Scheduled
MATERIALS		59	07-14-89	10-05-89	Scheduled
	Rel MP50	0	07-14-89	07-14-89	Scheduled
	Rel PWA Schedule	0	07-20-89	07-20-89	Scheduled
	Rel SW DupeSchd	0	07-27-89	07-27-89	Scheduled
SW Duplication		5	09-27-89	10-04-89	Scheduled
	Rec SW ECO Aprvl	0	09-27-89	09-27-89	Scheduled
	Duplicate Disks	1w	09-28-89	10-04-89	Scheduled
PWA Builds		31	08-22-89	10-05-89	Scheduled
PWA PreProd		21	08-22-89	09-21-89	Schd./Crit.
	PWA ECO Approval	0	08-22-89	08-22-89	Schd./Crit.
	PCB Artwork → Mfr	0	08-22-89	08-22-89	Schd./Crit.
	Make 300Barebrds	2w	08-23-89	09-06-89	Schd./Crit.
	QC Bareboards	2	09-07-89	09-08-89	Schd./Crit.
	Kit 300 PWAs	1	09-11-89	09-11-89	Schd./Crit.
	Make PWAs	6	09-12-89	09-19-89	Schd./Crit.
	QC PWAs	2	09-20-89	09-21-89	Schd./Crit.
PWA MassProd		31	08-22-89	10-05-89	Scheduled
	PWA ECO Approval	0	08-22-89	08-22-89	Scheduled
	Make Bareboards 2	4w	08-23-89	09-20-89	Scheduled
	Rec Bareboards 2	0	09-20-89	09-20-89	Scheduled
	QC Bareboards	2	09-21-89	09-22-89	Scheduled
	Kit PWAs 2	1	09-25-89	09-25-89	Scheduled
	Make PWAs 2	6	09-26-89	10-03-89	Scheduled
	QC PWAs 2	2	10-04-89	10-05-89	Scheduled
Intl. Shipping		40	07-14-89	09-08-89	Scheduled
	Rec IntlShipInfo	0	07-14-89	07-14-89	Scheduled
	Prepare Applctn	2w	07-14-89	07-27-89	Scheduled
	License Approval	6w	07-28-89	09-08-89	Scheduled
	Rec Approval	0	09-08-89	09-08-89	Scheduled
MANUFACTURING		47	08-18-89	10-24-89	Schd./Crit.
	Rel AssemblyPlan	0	08-18-89	08-18-89	Scheduled
Preproduction		24	08-31-89	10-05-89	Scheduled
	Rec Test Equip	0	08-31-89	08-31-89	Scheduled
	Rec Cases	0	09-08-89	09-08-89	Scheduled
	Rec PWAs #1	0	09-21-89	09-21-89	Schd./Crit.
	Run PreProductn	2w	09-22-89	10-05-89	Schd./Crit.
	PreProductn Done	0	10-05-89	10-05-89	Scheduled
Mass-Production		33	09-07-89	10-24-89	Schd./Crit.
	Final ECO Approval	0	10-12-89	10-12-89	Scheduled
	Rec Packaging	0	09-07-89	09-07-89	Scheduled
	Rec SW Diskettes	0	10-04-89	10-04-89	Scheduled
	Rec PWAs #2	0	10-05-89	10-05-89	Scheduled
	Rec Final Manual	0	10-03-89	10-03-89	Scheduled
	Rec Cases	0	10-12-89	10-12-89	Schd./Crit.
	Run MassProductn	1w	10-16-89	10-20-89	Schd./Crit.
	Inspect FinalPkg	2	10-23-89	10-24-89	Schd./Crit.
	MassProductnDone	0	10-24-89	10-24-89	Schd./Crit.
PRODUCT AVAIL:		0	10-24-89	10-24-89	Schd./Crit.

(b) Critical-path schedule for Trackman roller ball mouse—Continued



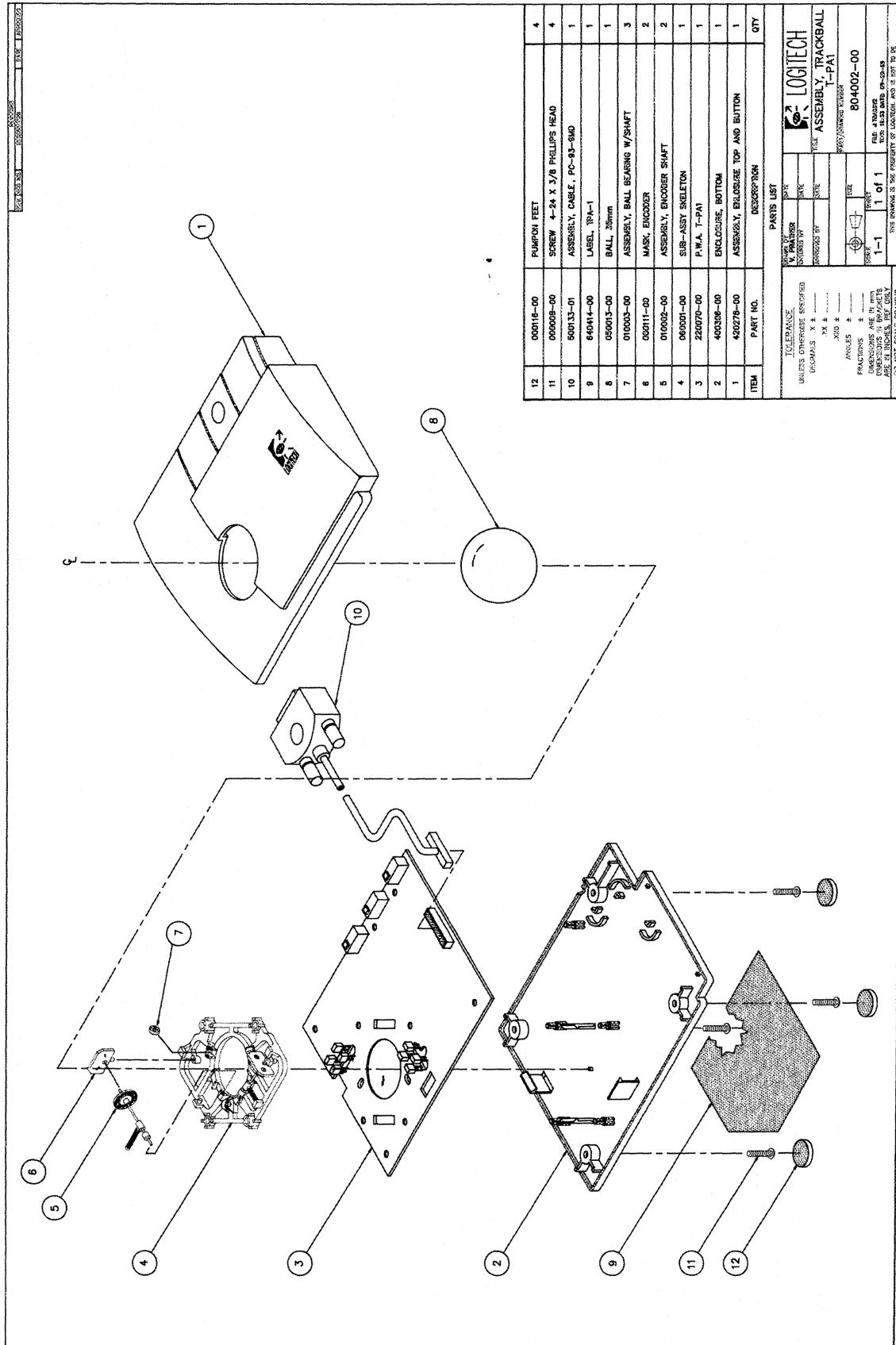
(c) Trackball subassembly

FIGURE 3.64 Trackman Mouse—Continued

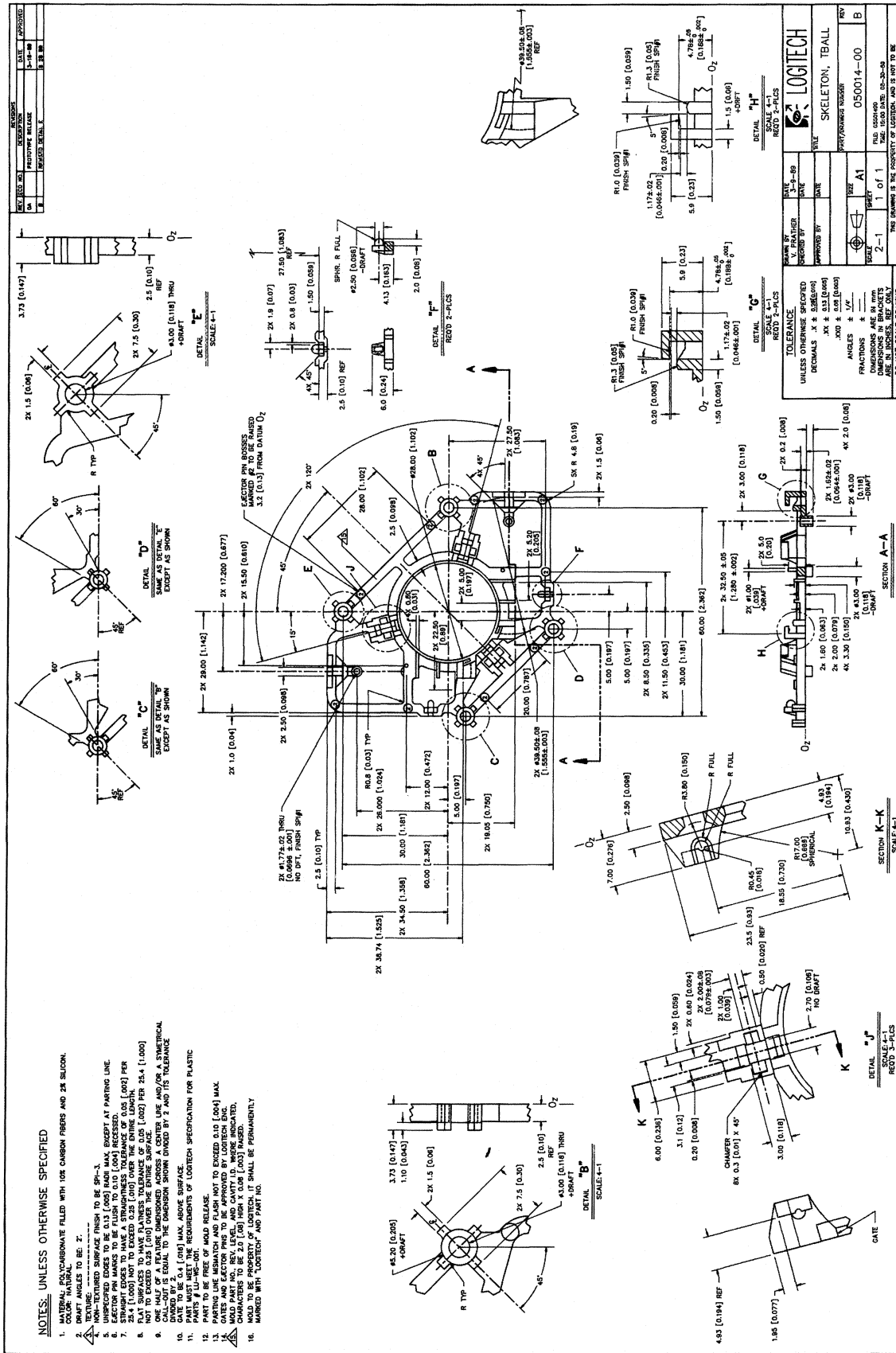
employee assigned to oversee and complete the task by the scheduled date. The *Scheduled Start* and *Scheduled Finish* dates were also noted on this list. Last, the *Status* was tracked for each task. *In Progress*, *Scheduled*, and *Completed* notations are shown, as well as whether or not this was a critical task. For the product to be on the market before Christmas, all tasks had to be completed by 10-24-89. The critical-path method of scheduling project tasks throughout the design-through-manufacturing process is used in many companies.

Figure 3.64(c) is an enlargement of the subassembly skeleton (part 4). Figure 3.64(d) shows the assembly of Trackman. Figure 3.64(e) is the detail of the Tball skeleton, which is part of the subassembly (part 4). Figure 3.64(f) is the detail of the top enclosure (part 1). Figure 3.64(g) is the detail of the bottom enclosure (part 2), and Figure 3.64(h) is the detail of the button plate. Trackman was designed completely on an AutoCAD system and is an excellent example of the critical-path method of scheduling project activities and using CAD in the design process.

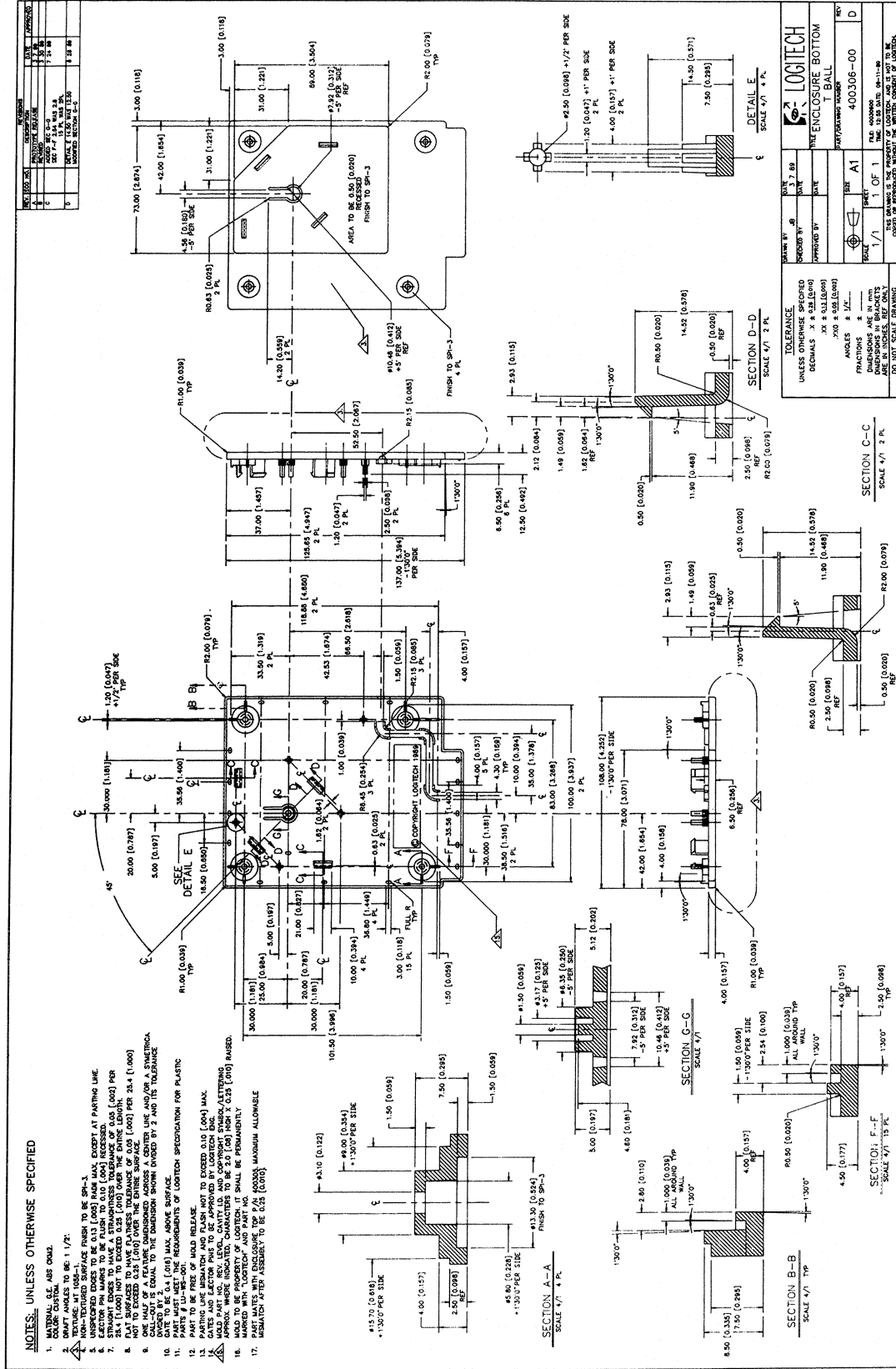
FIGURE 3.64 Trackman Mouse—Continued



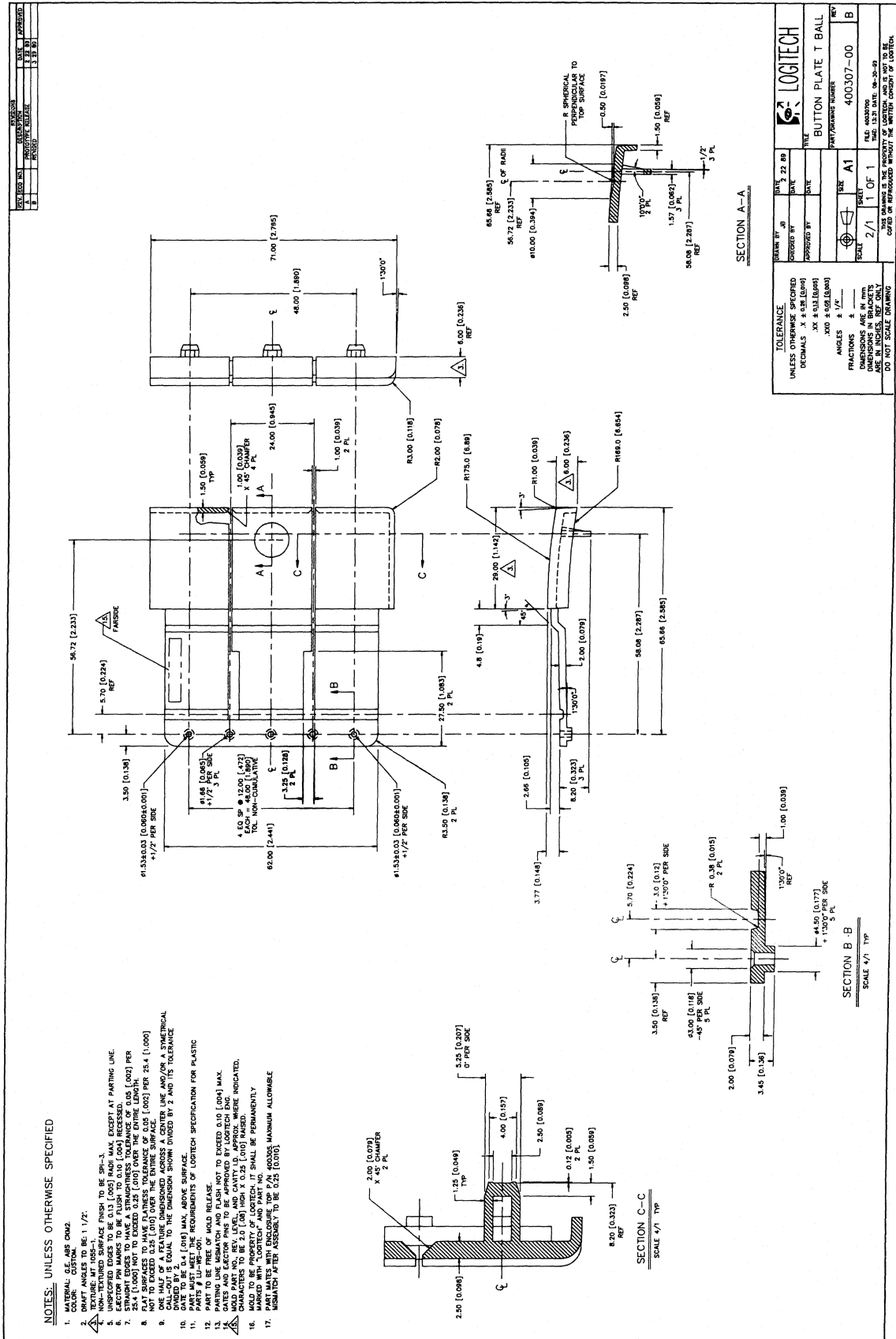
(d) Trackball assembly
 FIGURE 3.64 Trackman Mouse—Continues



(e) Detail of skeleton, Trackball
FIGURE 3.64 Trackman Mouse—Continued



(g) Bottom enclosure of Trackball
 FIGURE 3.64 Trackman Mouse—Continued



(h) Button plate for Trackball

FIGURE 3.64 Trackman Mouse—Continued

3.12 DESIGN PROCESS SUMMARY

The design process summary is included here as a guide and is hardly definitive. Table 3.1 gives a product design checklist. Use it as a guide only, because not all parts apply to all designs. It is recommended that any projects completed from this text use the checklist as a guide during the design process.

Design Process Summary

1. *Identification*: Defining the design objective
 - a. Make a list of known facts and existing information.
 - b. Ask the following questions: What? Why? Where? Whom? How? When?
2. *Conceptualization*: Brainstorming, creative solutions
 - a. How many ways can it be solved?
 - b. Thought starters, make a list of values.
3. *Evaluation*: Application, functional requirements, synthesis
 - a. What makes the design good—economy, simplicity, reliability, durability, usefulness, attractiveness, manufacturability, easy to promote in sales, easy to service?
 - b. What are the alternatives to the design?
4. *Decision*: Design optimization
 - a. What materials should be used?
 - b. Should the parts be interchangeable?
 - c. Should we use standard parts?
 - d. Is it an economical manufacturing process?
 - e. How easy is it to operate?
5. *Development*: Implementation of design
 - a. Create working drawings and details.
 - b. Model the part—CAD, physical, types, number of models.

TABLE 3.1 Product Design Checklist

A. Customer Requirements	Comment	Yes	No
1. Functionality <ol style="list-style-type: none"> a. Does the product meet customer requirements? b. Does it deliver the required performance? c. Does it satisfy emergency conditions? d. Have the important functions of the overall system and subsystems been agreed on? e. Is there a consensus between customers and designers? 			
2. Safety Provisions <ol style="list-style-type: none"> a. Were provisions made for both intended use and foreseeable misuse? b. Was the product analyzed for hazards? c. Are there interlocks and safety devices? d. Does it meet applicable DOE and MF safety standards? e. Are complete safety instructions provided? f. Are warning, hazard, and severity signs properly identified? g. Have all possible radiation, toxicity, or corrosivity problems been considered? h. Was the product subjected to overstress tests? i. Has Hazards Control reviewed the design? j. Are there any high-voltage, high-pressure, or high-explosive sources? k. Are there other stored-energy sources? 			
3. Operation and Maintenance Provisions Requested by Customer <ol style="list-style-type: none"> a. Does the product come with clear and concise instructions? b. Is it simple to operate? c. Are the controls operable and understandable? d. Does the product accommodate differing physical characteristics of operators? e. Is it easily maintained? f. Will spare parts be available? g. Can product be misused? h. Are operating or maintenance manuals needed? i. Are controls foolproof, so a hazardous condition cannot be inadvertently created? 			
4. Cost and Schedule Requirements <ol style="list-style-type: none"> a. What is the basic cost to design and produce the product? b. What will the cost be over the total life of the product? c. What will spare parts cost? d. What are the major cost items and drivers? e. Could cost savings be realized with alternate designs? f. Are costs reasonable and realistic? g. Has a detailed schedule been determined for the design release or for long lead-term items? 			

- c. Check the design.
- d. Testing and analysis—modeling, debugging
- e. Improve and redesign for aesthetic or functional refinements.
- 6. *Production*: Manufacturing, packaging, handling the product
 - a. Facility needs
 - b. Personnel requirements
 - c. Materials and processes for manufacturing
 - d. Packaging design
 - e. Material handling and product handling
- 7. *Marketing*: Sales and distribution
 - a. Staff training
 - b. Servicing the product
 - c. Low maintenance costs, customer acceptance
 - d. Sales strategy on how to present
 - e. Product and main features
 - f. Distribution of the product: Who? How?

TABLE 3.1 Product Design Checklist—Continued

A. Customer Requirements—Continued	Comment	Yes	No
5. Potential Environmental Effects on Product Performance and Reliability <ul style="list-style-type: none"> a. Could the product be affected by any of the following extremes at the customer's place of business? <ul style="list-style-type: none"> i. Voltage surges? ii. Service water hardness? iii. Pressure? iv. Temperature? v. External vibration? vi. External shock? vii. Ambient temperature? viii. Humidity? ix. Magnetic or electrical fields? x. Ambient sound? xi. Weather? b. Will operation be affected if the product is contaminated by foreign materials (sand, grit, oil, lint, dirt, etc.)? c. Will it be affected by corrosive ambients (salt, humid air, sea water, acids, cooling fluids, etc.)? d. Can radio interference affect operation? e. Can radiation affect the product? f. Can supplementary products (detergents, bleaches, oils, grease, solvents, lubricants, etc.) affect the product? g. How would an earthquake affect the product? 			
6. Potential Product Effect on Customer's Personnel and Environment <ul style="list-style-type: none"> a. Does the product have a pleasant appearance? Is it compatible with its surroundings? b. Is it noisy? c. Does it give off objectionable odors? d. Will it affect the temperature of the area it is used in? Will it affect other equipment? e. Does it vibrate? f. Does it produce objectionable light? g. Does it emit radiation? h. Does the exhaust give off noxious fumes? i. Will waste materials require special disposal? Have provisions been made for their handling, storage, and shipping? 			
7. Reliability and Performance Provisions <ul style="list-style-type: none"> a. Is the estimated reliability adequate? b. Was the reliability estimating method valid? c. Could performance deteriorate with wear or environmental change? d. Are the controls stable? e. What were the design provisions for minimizing likely failures? f. Have the methods of calibration and determining the performance been verified? g. Have emergency shutdown provision been provided for? h. Have provisions been made for power or water supply failures? i. Are there provisions for periodic inspection and in-service nondestructive evaluation? 			

Continued

TABLE 3.1 Product Design Checklist—Continued

B. Good Design Practices			
<p>1. Parts Breakdown</p> <ul style="list-style-type: none"> a. Can several parts be combined into one? b. Can cost savings be realized by breaking a complex part into smaller, simpler, or less costly components? c. Is the Bill of Materials structure logical? d. Will the Bill of Materials suit the needs of manufacturing personnel? e. Is the drawing numbering system logical? <p>2. Safety Practices</p> <ul style="list-style-type: none"> a. Does the product conform to the Design Safety Standards Manual? b. Is it free of sharp edges, burrs, or corners? c. Are the safety factors reasonable and defensible? d. Is a Safety Note needed? Has it been prepared according to the DSS? e. Is an Operational Safety Procedure needed? f. Has a failure modes and effects analysis been performed? g. Was a fault-tree analysis performed? h. Were all likely hazards identified and eliminated? <p>3. Assembly and Installation</p> <ul style="list-style-type: none"> a. Can any part be assembled incorrectly? b. Is the assembly sequence simple and logical? c. Is there space for tooling access, insertion, etc.? d. Can likely repairs be diagnosed without disassembly? e. Are special tools needed for assembly and installation? f. Are common fasteners used? g. Will corrosion be readily apparent? If not, can the design be changed to ensure visibility? h. Will the method of inspection really validate the correctness of the assembly or installation work? i. Are written assembly or installation procedures required? <p>4. Parts and Components</p> <ul style="list-style-type: none"> a. Does the design make use of proven standardized parts (fasteners, washers, clips, connectors, snap rings, etc)? b. Are the raw materials specified in standard sizes, types, or forms (e.g., standard plate or sheet metal thicknesses, rod sizes, composition)? c. Are standard parts or raw materials readily available in the shop where the design will be fabricated? d. Were the components proven by use in an earlier, related design? <p>5. Design Selection</p> <ul style="list-style-type: none"> a. Was the design scope properly defined? b. Were the selection criteria properly balanced and valid? c. Did the criteria respect customer requirements? d. Were alternate designs, concepts, or processes identified and documented? <p>6. Measurements and Control</p> <ul style="list-style-type: none"> a. What needs to be measured, recorded, monitored, or alarmed? Why? b. What alternate sensors can be considered? c. What functions are to be controlled? Why? How? d. What provisions were made for instrumentation recalibration? e. How should data be recorded? f. Have requirements for resolution, repetition, and accuracy of measurements been determined? g. What should be automated? Why? How? h. How and when should instruments or controls be tested? i. How can you tell when controls are working properly? <p>7. Nondestructive Evaluation</p> <ul style="list-style-type: none"> a. Are nondestructive evaluation inspections required? b. Are appropriate techniques and equipment available? c. If not, can the design be modified? d. If not, can new NDE equipment or techniques be developed? 			
C. Minimizing Costs			
<p>1. Has an engineering analysis been performed to investigate</p> <ul style="list-style-type: none"> a. The use of alternate, less expensive materials? b. Redesigning to reduce initial costs? 			

TABLE 3.1 Product Design Checklist—Continued

<p style="text-align: center;">C. Minimizing Costs—Continued</p> <ul style="list-style-type: none"> c. The cost of maintenance, repairs, or operation? 2. How reliable is the cost estimate? 3. Is a service warranty provided by the manufacturer? <ul style="list-style-type: none"> a. Is the manufacturer's reputation for service good? b. How quickly will service be provided? 4. Have manufacturing and production costs been optimized? <ul style="list-style-type: none"> a. To utilize existing processes, equipment, and facilities? b. To minimize tooling costs? c. To make the most use of standard parts? d. To utilize more efficient new processes, equipment, and facilities? e. To minimize inspection and testing? 5. Can an alternate component be procured with a substantially better warranty? 			
<p style="text-align: center;">D. Improving Reliability</p> <ul style="list-style-type: none"> 1. Are the maximum stresses within limits through the full range of travel, load, voltage, etc.? 2. Are the safety factors used reasonable? 3. Is the design as simple as possible? 4. Were failure modes or critical elements analyzed? 5. Did you make optimum use of standard, proven components and subassemblies? 6. Was the reliability data of similar devices considered? 7. Were design integrity tests successfully completed (life, safety, simulated stress environments, etc.)? 8. Are drawings clear and unambiguous? 9. Is the equipment available when needed? 10. Were steps taken to minimize electrolysis, corrosion, dirt, etc.? 			
<p style="text-align: center;">E. Manufacturability and Production</p> <ul style="list-style-type: none"> 1. Does the design use existing equipment for fabrication, finishing, assembly, inspection, calibration, testing, packaging, etc.? 2. If not, are new processes, equipment, and facilities more effective? 3. Does the design avoid hazardous operations? 4. Are tool and piece costs optimized? 5. Does the design use existing acceptable tooling where possible? 6. Does it permit maximum standardization? 7. Are the tolerances and surface finishes specified consistent with acceptable processes and equipment? 8. Does the design correct or avoid known manufacturing problems? 9. Are the operations requiring special skills, new equipment, or special attention minimized? 10. Are critical dimensions or parameters to be controlled during procurement and manufacturing clearly identified? 11. Do the materials specified conform to standards? 12. Are specifications clearly and completely described on drawings? 13. Could inspection be accomplished easier and cheaper by changing the design? 			
<p style="text-align: center;">F. Shipping and Storage Requirements</p> <ul style="list-style-type: none"> 1. Will the product be transported with standard packaging? 2. Is additional special packing material required? 3. Will the package withstand applicable transportation tests for <ul style="list-style-type: none"> a. Shock? b. Vibration? c. Temperature extremes? d. Humidity extremes? e. Handling equipment? f. Sand and dust? 4. Have you considered the available transport and storage equipment? 5. Has the shape and size of packaged product been optimized for rail and truck transportation? 			

Continued

TABLE 3.1 Product Design Checklist—Continued

F. Shipping and Storage Requirements—Continued			
6. Are clear instructions for handling and lifting provided on the outside of the package? 7. How will used packaging material be disposed of? 8. How will moveable parts be secured during transport?			
G. Maintenance and Serviceability			
1. Are there any potential safety hazards during installation, repair, disassembly, or maintenance? 2. Is special test or service equipment needed? If so, have provisions been made to procure it? 3. Can the product be satisfactorily installed quickly? 4. Are items requiring frequent maintenance easily accessible? 5. Are new or nonstandard items minimized? 6. Are servicing instructions clear? Are they adequate? Are they the result of a fault-tree analysis or failure mode and effects analysis? 7. How will performance be verified after repair? 8. Are periodic nondestructive inspections required?			
H. Applicable Laws and Agency Requirements			
1. Does the product comply with applicable laws and agency requirements such as a. Local ordinances? b. State or federal laws? c. Environmental Protection Agency laws and guidelines? d. Department of Energy (DOE) guidelines? e. Department of Transportation (DOT) rules for shipping? f. Others? 2. Does the product comply with applicable agency standards or guidelines such as: a. Underwriter's Laboratory (UL)? b. American Gas Association? c. Military specifications? d. Environmental Protection Agency (EPA)? e. Occupational Safety and Health Act (OSHA)? f. Consumer Product Safety Act? g. American National Standards Institute (ANSI)? h. American Society of Mechanical Engineers (ASME)? i. National Electronics Manufacturers Association (NEMA)? j. Institute of Electrical and Electronics Engineers (IEEE)? k. American Welding Society? l. DOE or others? 3. Are permits required for installation or operation, e.g., for venting gas or hazardous material?			
I. Patent and Classification Requirements			
1. Has a search been conducted to learn of recent related patents? 2. For patent protection, have any inventions been promptly disclosed? 3. Is any portion of the design, analysis, or documentation classified? Has an authorized classifier reviewed the preliminary and final designs? 4. Have steps been taken to safeguard the classified information? Are all personnel working on classified portions aware of the rules regarding the handling, dissemination, and disposal of classified information?			
J. Human Factors			
1. Are controls and displays well organized? 2. Are controls conveniently located for efficient operation? 3. Can monitoring or diagnostic devices be easily and accurately read? 4. Are instructions clear, legible, and complete? 5. Can all operations be performed safely without danger to the user or the product? 6. Have the physiological and psychological characteristics (age, education, size, strength, or handicap) of the user been considered? 7. Can maintenance be performed easily? 8. Have the human factors of similar devices been analyzed?			

Continued

TABLE 3.1 Product Design Checklist

A. Customer Requirements	Comment	Yes	No
1. Functionality a. Does the product meet customer requirements? b. Does it deliver the required performance? c. Does it satisfy emergency conditions? d. Have the important functions of the overall system and subsystems been agreed on? e. Is there a consensus between customers and designers? 2. Safety Provisions a. Were provisions made for both intended use and foreseeable misuse? b. Was the product analyzed for hazards? c. Are there interlocks and safety devices? d. Does it meet applicable DOE and ME safety standards? e. Are complete safety instructions provided? f. Are warning, hazard, and severity signs properly identified? g. Have all possible radiation, toxicity, or corrosivity problems been considered? h. Was the product subjected to overstress tests? i. Has Hazards Control reviewed the design? j. Are there any high-voltage, high-pressure, or high-explosive sources? k. Are there other stored-energy sources? 3. Operation and Maintenance Provisions Requested by Customer a. Does the product come with clear and concise instructions? b. Is it simple to operate? c. Are the controls operable and understandable? d. Does the product accommodate differing physical characteristics of operators? e. Is it easily maintained? f. Will spare parts be available?			

QUIZ

True or False

1. The design process is a series of eight rules that should be followed exactly.
2. All designs developed by a company's design team eventually get manufactured or produced.
3. Human engineering is the study of people and how they engineer/design projects in industry.
4. Human factors play an important role in all product design.
5. It is not important to have a brainstorming session during product design.
6. Ergonomics considers how humans interact with their work environment.
7. Automation is never considered during design of the manufacturing process.
8. In DFM, manufacturing is considered right from the start of the design sequence.

Fill in the Blanks

9. _____ design uses standard components arranged in a unique configuration.
10. _____ is the first stage of the design process.
11. _____ design and _____ design are the two main divisions of design projects.
12. The effects of motion, heat, _____, and environment are some of a designer's concerns.

13. Machinability, castability, _____, _____, and _____ environment are all factors in the selection of the material for a product.
14. Stereolithography is one of the most common _____ methods used in industry today.
15. Human factors is the modeling of the _____ in a work-related setting.
16. _____-_____ manufacturing is a process in which the component parts of a system design arrive at the assembly line station at the time of installation.

Answer the Following

17. Describe the use of models in the design process.
18. How are graphs and charts used in the design process?
19. What is human engineering, and how do human factors and ergonomics influence design?
20. What is DFM, and how does it affect the design process?
21. List six sources of information available to the designer.
22. What is critical-path scheduling?
23. Name and describe each of the stages of the design process.
24. What is stereolithography? How is it used in the design process?