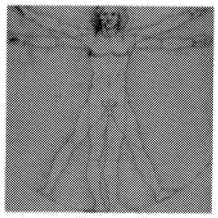
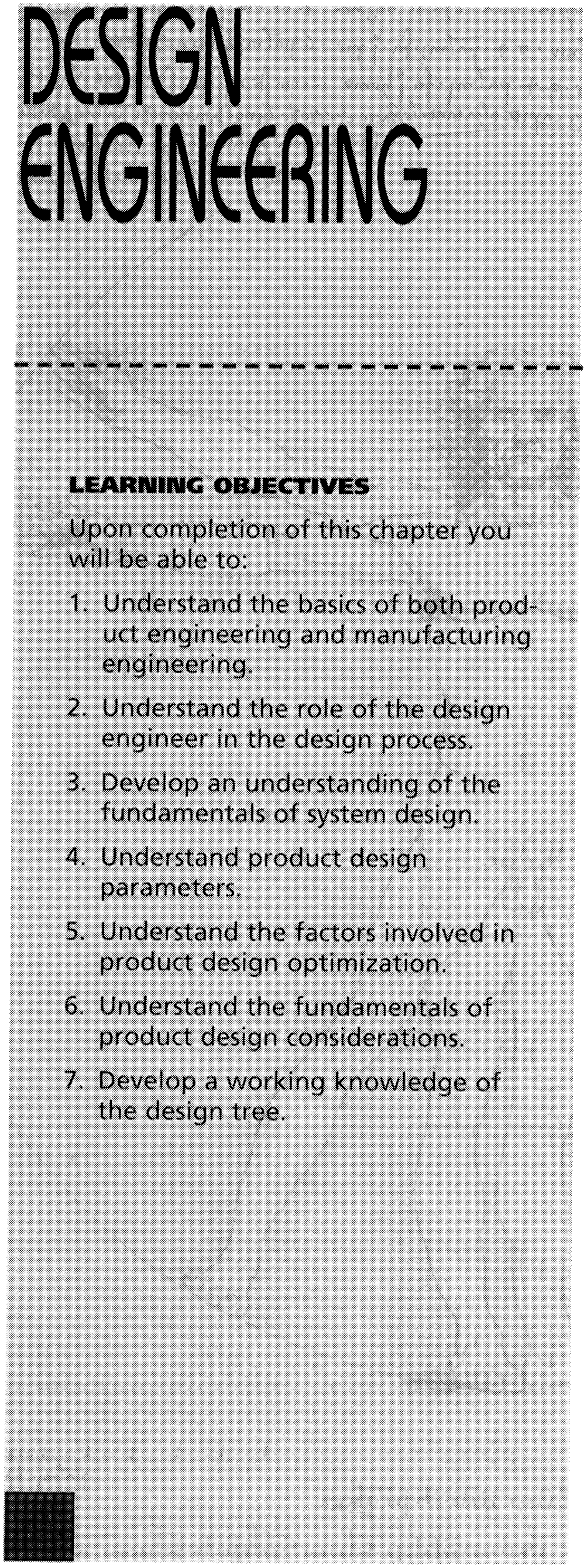
DESIGN ENGINEERING

Chapter 2





LEARNING OBJECTIVES

Upon completion of this chapter you will be able to:

1. Understand the basics of both product engineering and manufacturing engineering.
2. Understand the role of the design engineer in the design process.
3. Develop an understanding of the fundamentals of system design.
4. Understand product design parameters.
5. Understand the factors involved in product design optimization.
6. Understand the fundamentals of product design considerations.
7. Develop a working knowledge of the design tree.

2.1 INTRODUCTION

Engineering design encompasses both **product engineering** and **manufacturing engineering**. Product and manufacturing engineering include a wide range of activities, from the creative description of the item to its production. To design and produce a product efficiently the **manufacturability** of the part must be built into the design from the beginning. In **design for manufacturability (DFM)** the manufacturability of an item is considered from the very beginning of the project. (DFM is covered in more detail in Chapter 3.) Quality of the product must be built into the part, not inspected out during the production process. Service of the part should be easy, effective, and efficient. The materials used during the production of the part should be recyclable and remanufacturable. Product engineering and the manufacturing engineering of a successful project integrates many activities:

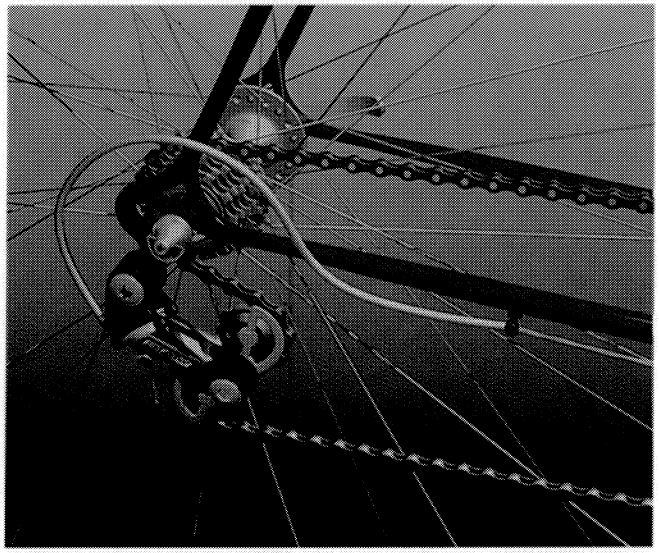
Product Engineering

Product description
Specifications
Models
  Test
  Prototype
  Fit and function
  Presentation
Analysis
  Stress/strain
  Fatigue/corrosion
  Movement/kinematics
  Load—forces/dynamics
  Heat—energy/thermodynamics
Layout and detail drawings
Redesign

Manufacturing Engineering

Production method
Costs
Quantity
Tooling
  Dies
  Tools
  Jigs and fixtures
  Inspection gages
Robot workcells
Material management and movement
Ordering
Production planning
Manpower requirements
Testing
Inspection
Quality control
Distribution
  Packaging
  Shipping
  Storing/stacking
Facility management

(a) Bicycle design



(b) Rear wheel of bicycle

FIGURE 2.1 Bicycle

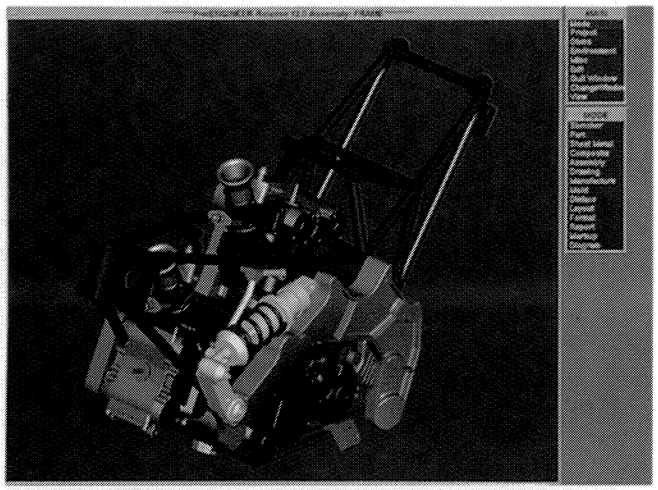


FIGURE 2.2 Motorcycle Engine

The end result of the design activity is the most useful and economic product or system. To achieve success, the engineer/designer must consider multiple factors and make decisions based on compromises. Seldom is a design everything the engineer wanted when the project began. A successful design is one that is functional and manufacturable and that serves the needs of the customer. The product must also come to market at the appropriate time. A product too late to market is usually a failure. As competition increases worldwide, time to market becomes critical.

Designs are functional when they satisfy a need and are available to the customer (Fig. 2.1) in some form or quantity that is cost effective to produce and use and is profitable for the company. Before a design is accepted, such as that of a motorcycle engine (Fig. 2.2), it must be tested and researched thoroughly. After the development and testing of a product or mechanical design, the design data are released to the factory for production.

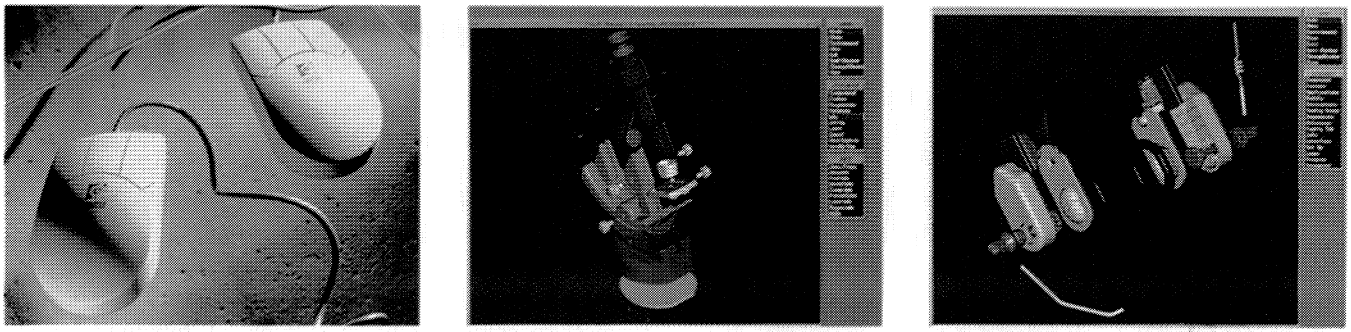
2.2 THE DESIGN ENGINEER AND DESIGNING

Designers use their education and experience to invent new products, create new systems, or take existing products or systems and add innovations. The design process involves creativity and the ability to discover new solutions to existing problems or to invent new products to fill a need. Being a designer has less to do with natural talent than with cultivating an eye for detail, accumulating knowledge from education, and gathering experience from designing.

Designing is an intellectual activity that has no hard and fast rules. Most good designers develop their expertise through experience. The best designers keep their minds open to new concepts and learn from co-workers, journals, magazines, and past failures. They are well informed; they choose the best features from several approaches for their designs. When they approach a new problem, they study existing related designs to try and understand the rationale behind their creation.

Since the item being designed or invented often does not exist before the process starts, product design (Fig. 2.3) demands more creativity. Product design involves the creation of commercially profitable, useful, or desirable items and devices. Mechanical design includes a wide range of industrial products (Fig. 2.4) and tools used in manufacturing (jigs and fixtures, dies, molds). The systems designer is a problem solver and innovator. He or she combines existing standard parts in a unique functional manner to satisfy a need or industrial requirement.

During the design process, the designer uses many different types of documents and consults a variety of



(a) Mouseman, right hand and left hand designs (b) Microscope (c) Headset

FIGURE 2.3 Product Design

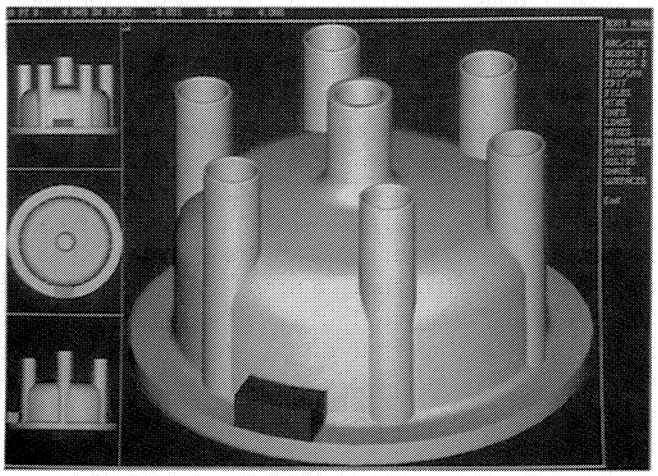


FIGURE 2.4 Design of a Distributor Cap

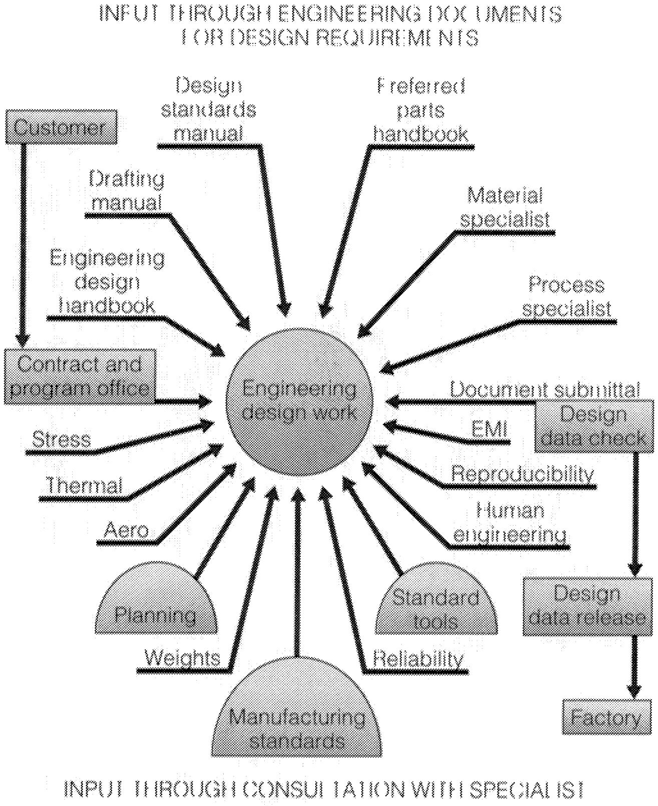


FIGURE 2.5 Engineering Design Flow Diagram

specialists (Fig. 2.5). Customers communicate their needs through the contract and program office, which in turn releases the job to the engineering team. During the design process the engineer has many responsibilities, including:

- Geometric arrangement of the components or design configuration
- Effects of motion, forces, shear, and environment
- Human capabilities, limitations, and requirements (human factors)
- Manufacturing and production processes
- Material selection

To understand a design situation (Fig. 2.6) and bring the problem to a successful conclusion, the engineer needs basic creative instincts, an inquisitive mind, and the ability to communicate verbally (in written form) and graphically. Successful design engineer traits include the following:

- Intuition
- Good communication skills: written, oral, graphic
- Open mind to problem solving
- Inquisitive mind
- Understanding of fundamental design principles
- Ability to integrate and balance several ideas and solutions
- Ability to do self evaluation
- Concentration skills
- Visualization skills
- Ability to think and communicate in 3D
- Mathematical skills

Cultivating successful designer traits can be done by 2D sketching, 3D visualization techniques, and the scrutiny of existing mechanical items and products. Developing creative mental skills, encouraging an investigative mind, practicing

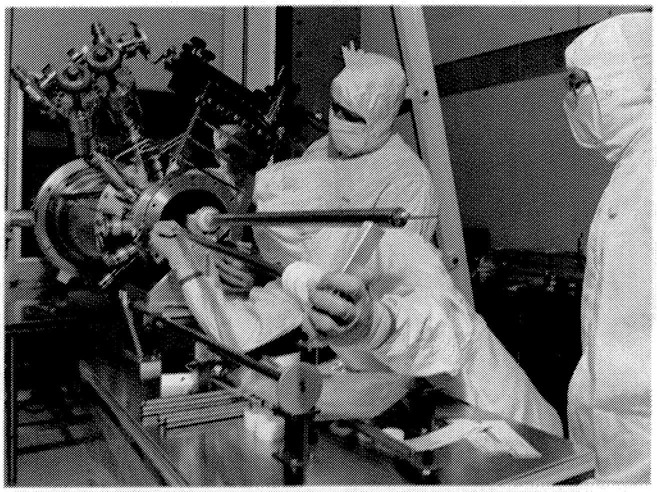


FIGURE 2.6 Electronics Alignment Assembly in a Clean Room

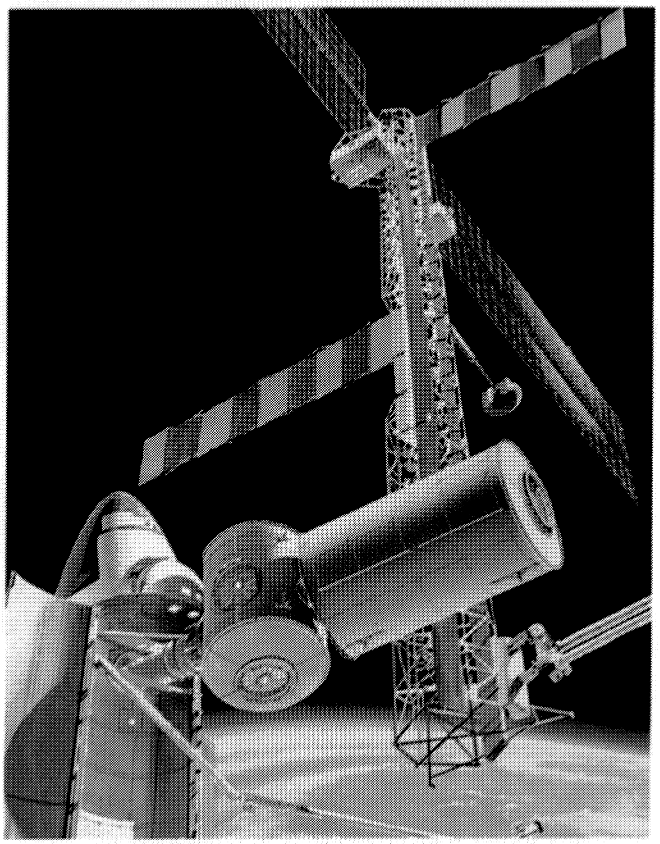


FIGURE 2.7 Space Station Illustration—Structure and Solar Panels

written and oral descriptions of designs and specific organizational skills are also essential.

The space program (Fig. 2.7) is an excellent example of where engineers had to create new designs for exploration in entirely unique environments. Space exploration required engineers who were not captive to preconceived notions or a limited vision, or who were afraid to push the frontiers of knowledge.

2.3 SYSTEMS DESIGN

Systems design and engineering involve a variety of engineering disciplines that use standard parts in an assembled configuration to accomplish a task. Systems design revolves around the use of standardized parts that can be assembled in unique ways to solve particular problems or meet specialized needs. Each system is a combination of parts designed to fit into a specialized environment. Many systems are themselves combinations of systems. A building, for example, is not just a structural and architectural system; the typical building has a structural system to support it, a plumbing and piping system to provide water and remove waste, a gas system for heating, an electronics system for communications and security, an electrical system for power and lighting, a heating distribution system, a mechanical system for moving people and materials, and a ventilation and air conditioning system for controlling the temperature and air filtration of the structure. The larger the building, the more complex the systems.

Power generation systems, construction/structural systems, mass transportation systems (public and military), and electronic systems, including computers, are all system designs. The nuclear plant in Figure 2.8 is an example of a combination of structural, mechanical, and electronic sys-

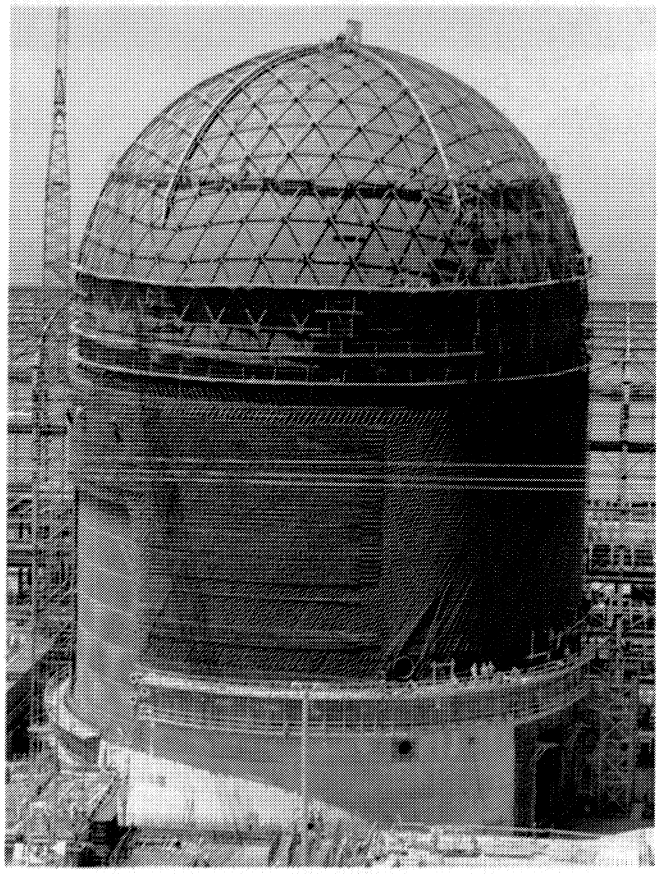


FIGURE 2.8 Nuclear Plant Containment Area

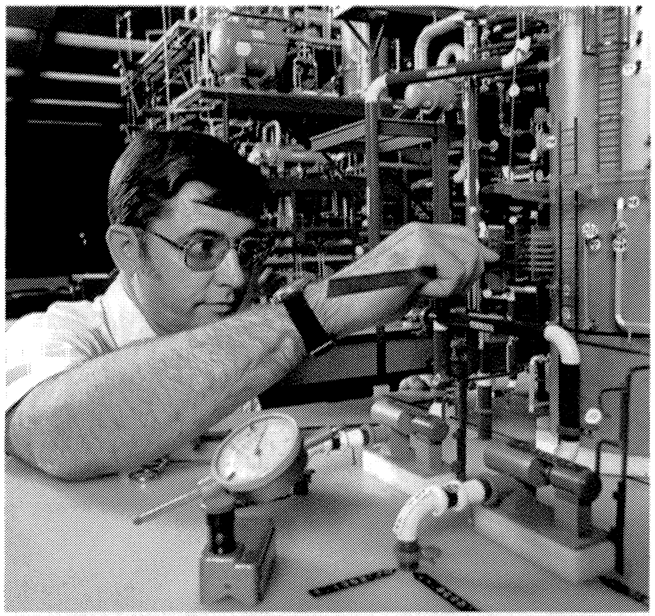


FIGURE 2.9 Petrochemical Plant Model

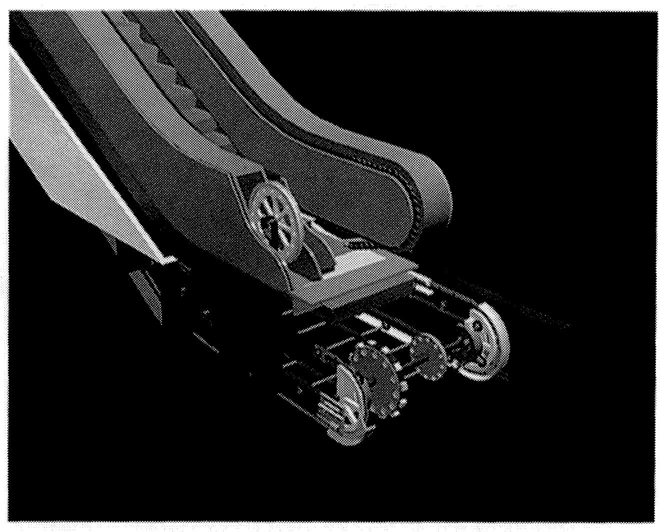


FIGURE 2.11 Escalator Design

tems. The petrochemical plant model shown in Figure 2.9 is an example of a system for producing consumable energy products. A refinery is composed of electrical, heating and ventilation, structural, mechanical, electronic, instrumentation, and piping systems—all integrated into a complex facility.

2.4 PRODUCT AND INDUSTRIAL DESIGN

Product design is accomplished by an industrial designer working in conjunction with the engineering, manufacturing and marketing departments to develop and create a useful and profitable product. Products are mass produced for consumer, educational, or industrial markets. Figure 2.10 shows an example of an industrial product whose function is far more important than its visual appeal: the oscilloscope, which is sold to industry, military, and educational markets. The escalator shown in Figure 2.11 is an example of a solid model design for the commercial market. The gas generator in Figure 2.12 is the kind of product that has both individual consumer and industrial markets. Since its design is functional and mechanical in nature, we could say that it is more of an industrial product. The pointing device used for computer input [Fig. 2.3(a)] is an example of a consumer product.

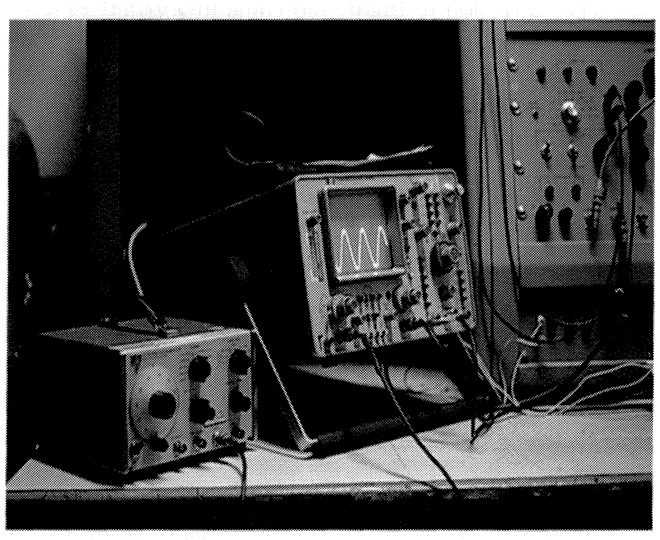


FIGURE 2.10 Oscilloscope

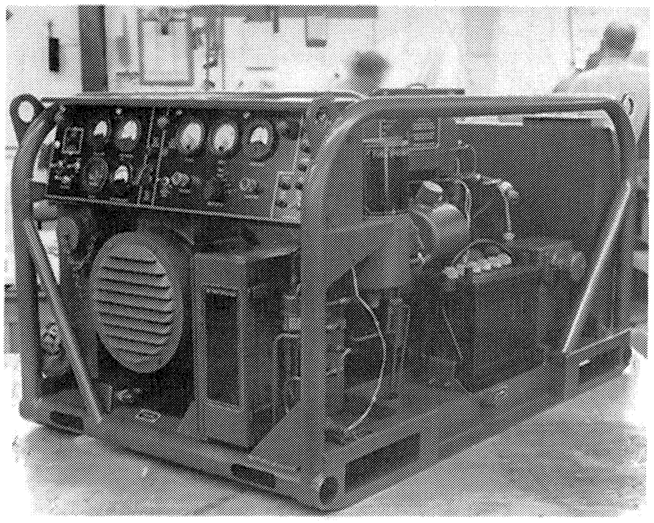


FIGURE 2.12 10 kW Gas Generator Mockup

2.5 PRODUCT DESIGN PARAMETERS

All design decisions must be made after careful consideration of the factors (design parameters) influencing the product. Product design parameters (Fig. 2.13) determine manufacturing and production methods and include the following:

- Weight
- Texture
- Material
- Color
- Symmetry
- Repetition
- Size
- Balance

Each design parameter affects the other parameters. For instance, the weight of the product is influenced by its material and size; the color will be influenced by the material; the material influences the texture or surface quality. Since the texture of a product may in some cases be more important than other factors, the surface feel or texture requirements, in return, affect the material choice. The weight and size of a product affect its ease of use.

The shape of a product should be considered with regard to its symmetry, proportion, repetition, and balance. Geometric proportions that are pleasing to the eye and appear balanced can give a repetitive shape to the part. Automotive design is a good illustration of this point. As shown in Figure 2.14, curves, lines, and contours all influence the balance and symmetry of a product. Remember, the best-selling product is not always the best product. An extremely reliable, completely functional, long-lasting product will not necessarily sell if it is also poorly proportioned and unappealing in color and shape. All of the listed factors are interdependent. A good designer determines the proper mix, based on their relative importance to the project.

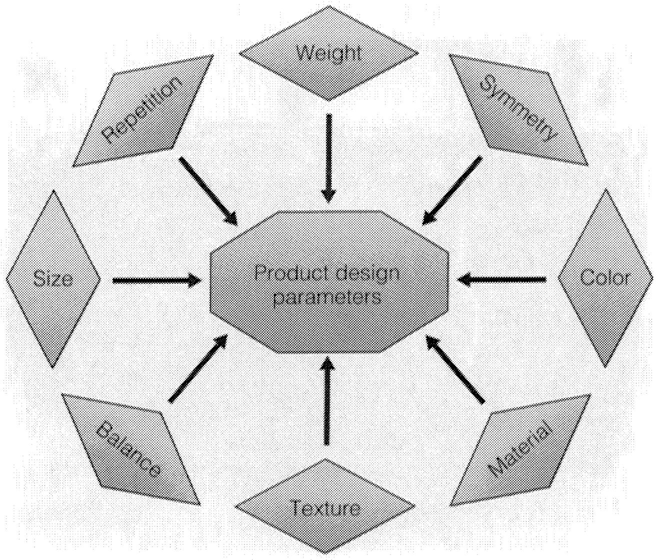


FIGURE 2.13 Product Design Parameters

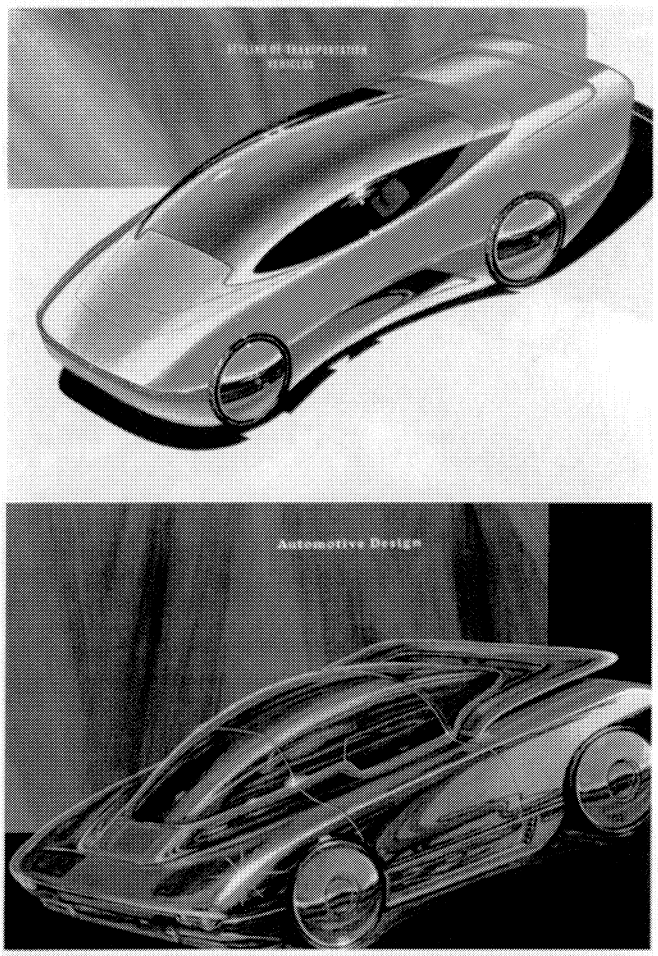


FIGURE 2.14 Two Examples of Geometric Proportion in Automotive Design

The forceps in Figure 2.15 are an example of a small product. Though normally considered a medical instrument, this clamping device can be found in industrial workplaces and in the home. This product must be strong, lightweight, balanced, corrosion resistant, and come in a variety of sizes and shapes. Since the main surgical requirement is that it be sterilizable, its color is not important. The material itself dictates most of its characteristics. Stainless steel satisfies the design requirements.

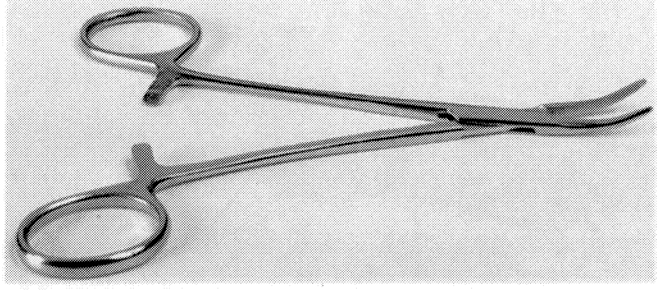


FIGURE 2.15 Forceps

2.6 DESIGN CONSIDERATIONS

Design considerations require proper and timely decisions by engineers. A careful and systematic overview of a product's design considerations will lead to a successful final product.

The calipers in Figure 2.16 are an example of a product that was designed for a very specific function. Calipers are used by designers, engineers, machinists, and others involved in the manufacturing process. Calipers must be accurate, lightweight, sturdy, simple to use, easy to handle, unbreakable within limits, have an extremely long life, and not be affected by the environment. Inaccurate, corrodible, or breakable calipers would not sell. Obviously, the function of this product is the foremost concern—it must measure something accurately. This functional consideration determines the material choice: nonmetals would be inappropriate since they would not allow for the accuracy required of the finished product. Appearance is not a major consideration. The requirement for corrosion resistance limits the material choices, as will the strength considerations.

Design considerations include the following:

- **Function**
- **Constraints**
- **Materials**
- **Appearance**
- **Environmental effect on product and product on environment**
- **Product life**
- **Reliability**
- **Safety requirements**
- **Standardization and interchangeability of components**
- **Maintenance and service requirements**
- **Costs**

Function The actual functions of a product must be defined early in the design process. Unnecessary functions or extra features (sometimes called "bells and whistles") should be eliminated if they do not substantially increase the value or salability of the product. The designer must determine whether the product could serve more than the original function described by the customer. Could the product be less complicated? Could it serve more than one purpose?

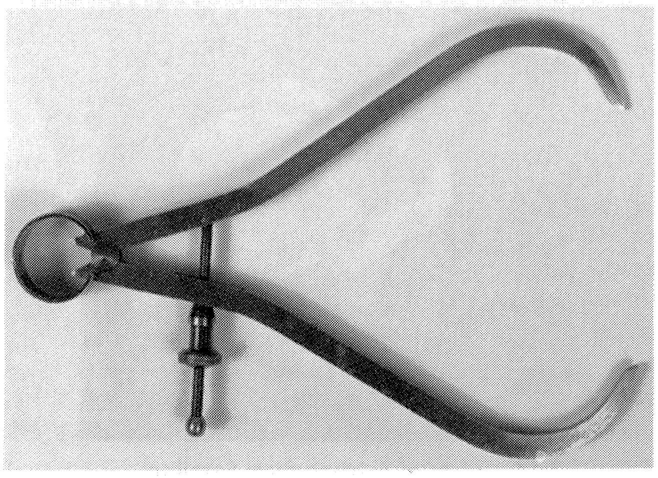


FIGURE 2.16 Calipers

The function of a product will always be its primary consideration. If the product does not function properly, then it is not marketable. The function of a product will be influenced by its complexity. A basic rule is to *minimize the complexity of a design*. The simpler a product, the easier and cheaper it is to manufacture. Strength requirements will be influenced by the product's function. Reducing rotational stress, bending, and other complex movements is the goal. The designer considers these factors when designing for strength. Interference between moving parts is also an aspect of function. The function of a product determines the movements and how many individual parts are required. *Attempt to minimize the number of parts in a design.*

Constraints *Design for simplicity* within the constraints. What are the **constraints** of the project? Are the size, weight, and volume of the product adequate? Could they be reduced to create a better design? The projected cost of the product is also a constraint. A "widget" that performs 24 different functions but costs five times more than the consumer will pay is not a well-designed product. Size, weight, and volume will be influenced by handling, shipping, and marketing considerations.

The size of a product will also be influenced by who uses the item. A child's hand is smaller than an adult's, and in most cases a woman's hand will be smaller than a man's. If the item is gender determined (used by only one sex), then marketing research defines many of the constraints.

Materials The **material** used for the design is determined by a multitude of factors. In fact, much of the success of a design might be determined by the material choice. The following is a partial list of material properties that are considered during the design process:

Strength A measure of a material's capacity to resist different types of forces.

Elasticity The stiffness of a material and its capacity to resist deflection under load; stress is related to strain by the **elastic constant**.

Ductility The ability of a metal to deform before fracturing.

Fatigue When a material fails after many repeated load cycles.

Bearing characteristics The suitability of a material to be used as an element resting on another part and in motion.

Hardness and brittleness The opposite of ductility, a characteristic of a material to resist penetration.

Damping The ability of a material to dissipate energy caused by vibration.

Temperature range The effective range within which the material properties will be suitable

Toughness The ability of a material to absorb energy before fracturing

Resilience or elasticity The ability of a material to store energy when deforming permanently

Wearing The ability of a material to withstand rubbing motion (frictional loads) causing removal of material

Corrosion The ability of a material to resist deterioration caused by a reaction to environmental conditions

Toxicity The possibility of producing a poisonous effect material safety data sheets (MSDS) are now required documentation for products

Machinability The relative ability of a material to be machined

Forgeability The ability of a material to be forged

Formability The ability of a material to be formed

Castability The ability of a material to be cast

Weldability The ease with which a material can be welded

Many times the function of the item determines the material in other cases there is more leeway in the material choice The material that best suits the design and manufacturing requirements is sometimes a compromise **Availability** is also a factor in material selection An exotic material may be the best choice but if it is hard to procure another material may be better for adequate production runs

Appearance Appearance is one of the most important considerations in consumer product design and usually the least important for industrial product design The look feel, shape (symmetry modernness roundness smoothness) and eye appeal of a product have to be considered early in the design phase Sometimes for the successful marketing of a product the function and other characteristics will be less important than the appearance

Environment The effect of the product on the environment is now more important than at any other time in history Industrial history is full of examples of how profit took precedence over protection of the environment In most places an environmental impact report is mandatory for large systems design

The effects of the environment on the product are also a concern for the designer as with the tractor in Figure 2 17 The effects of temperature variations during operation must be considered in the design phase of a product Dust and dirt must be excluded from many products to ensure proper operation Vibration also affects the operation and life of a product and therefore must be limited by dampening devices and other methods The moisture level in an operating environment will be a concern for many products excess moisture can cause corrosion Designing any product starts with an understanding of when how by whom and where the product is to be used

FIGURE 2 17 Case Tractor

The oscilloscope (Fig 2 10) was designed to be carried The electronics inside must be shielded properly by the packaging Heat must be allowed to escape from the package Therefore vents are provided in the sheet metal on the sides of the package The ruggedness of the product will obviously influence its reliability life and what effects the environment has on its operation

The space shuttle was designed to withstand heat that reaches thousands of degrees while it leaves and reenters the atmosphere The shuttle tiles had to be made of ceramics that could handle this type of repeated environmental assault Most of the shuttle's components were designed to operate in a dust free environment Therefore the manufacturing and assembly stages of production for its components were done in clean rooms

The space telescope in Figure 2 18 must be cooled to eliminate its own heat radiation which could interfere with

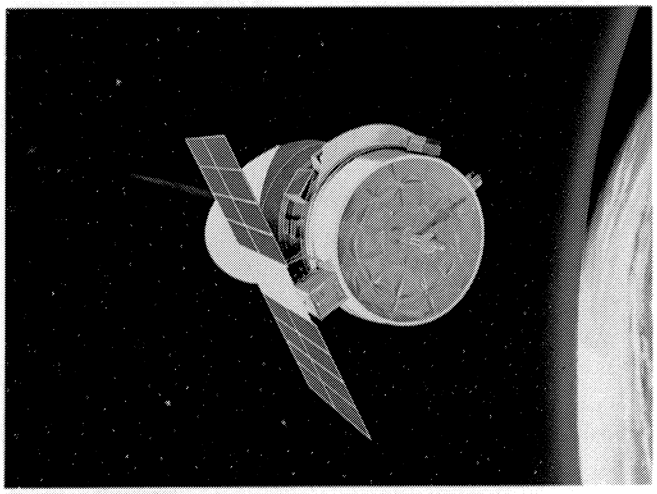


FIGURE 2 18 Infrared Astronomical Satellite infrared reception from the stars. The telescope and its associated measuring equipment were designed to be cooled to 4°F above absolute zero. Environmental considerations are one of the most demanding aspects of this design.

Product Life The **operation life** of a product is its time of operation before it fails. The **shelf life** of a product is the period of time it can be in storage and still operate correctly. The designer can influence the life of a product by choice of material, features, manufacturing methods, and assembly methods. Often it is the intention of the designer to have the product wear out at a given life length.

An industrial product's life may be longer and provide for easier replacement of worn parts. The tractor in Figure 2.17 is an example of a product designed to be maintained over a long period of use.

The Viking lander (Fig. 2.19) had to have an extremely long life in order to operate effectively in a hostile environment. Service, replacement, and maintenance were not considered in this design because the lander could not be reached to perform those functions. The original parts had to have extremely long operational lifetimes and had to operate error free for an extended period while undergoing extensive environmental attack: temperature variation, dust, and solar radiation. In other words, it had to be extremely reliable.

Reliability The reliability of a product is influenced by its number of moving parts, its complexity, and its sensitivity to the environment. **Reliability** is a product's ability to function properly during each operation. Reliability affects both the life and the cost of the product. An unreliable product will not enjoy continued sales. Each product is designed to have adequate reliability to last the average expected life. The higher the quality of the components in a product, the longer its life and the higher its reliability. However, it is not cost-effective to design something whose components are more reliable than the item itself. Parts designed for the military and for space exploration must have the highest reliability.

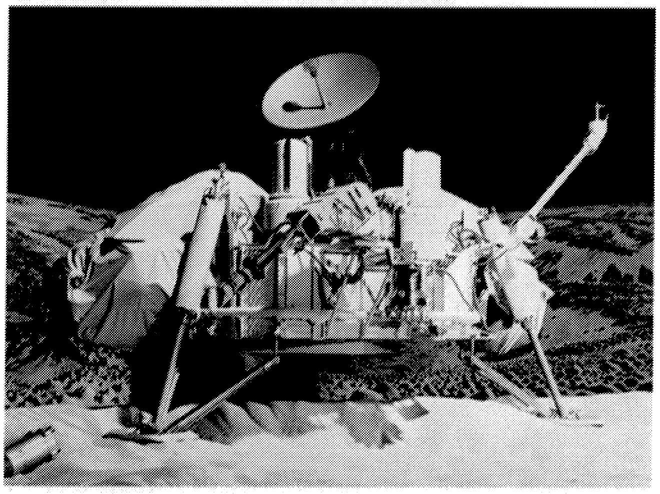


FIGURE 2.19 Viking Lander

Safety Safety involves the correct performance of a product. Some sensitive or dangerous products have fail-safe designs so as to prevent any injury or harm to the environment. **Fail safe** means that a product incorporates features for automatically counteracting the effect of an anticipated possible source of breakdown. Products can be dangerous when they do not perform correctly, when they are operated incorrectly, or when they are performing correctly but with insufficient protection for the operator. Each of these three considerations influences the design. The first and last are the easiest to prevent. Protective shields, housings, and guards can be incorporated into the design. The product can be rigorously tested for safe operation and incorporation of any safety features.

Standardization and Interchangeability By using standard, off-the-shelf items, the cost of the product can be reduced. Systems design is, in reality, the assembly of standard components in unique configurations that accomplish a specific task, such as producing power or creating a chemical. Products also benefit from the incorporation of standard parts in their design. The use of standard parts and previously designed parts is an important factor in DFM, thereby saving time and cost.

The ability of a unit to use similar parts or have different components that can be substituted is called interchangeability. The product is designed so that different sizes of fasteners or other standard components can be used. This will reduce the production costs and eliminate possible shortage problems and delays in production.

Maintenance *Design for simplicity* in disassembly and maintenance. Some, if not most, products are now designed as throwaways. Design with recycling in mind whenever the product is to be a throwaway.

Products that require repair, service, and maintenance are designed to be disassembled at specific intervals of operation or stages of wear; therefore, design for disassembly. Providing clearance for tools and hands during maintenance and repair is a consideration for many industrial products. As an example, the valve in Figure 2.20 is designed to allow for the removal of the handwheel, stem, bonnet, and disk to replace the composition ring. This service can be accomplished without cutting or disassembling the pipeline.

Costs The number of parts produced could influence the cost of a product. In general, the greater the quantity manufactured, the lower the overall unit cost of the product. If you had to purchase each part separately, the average automobile would cost about 100 times more than it does now, as most of us have experienced when we needed a repair on our car. Most consumer products can be made much more cheaply by producing large quantities. Industry

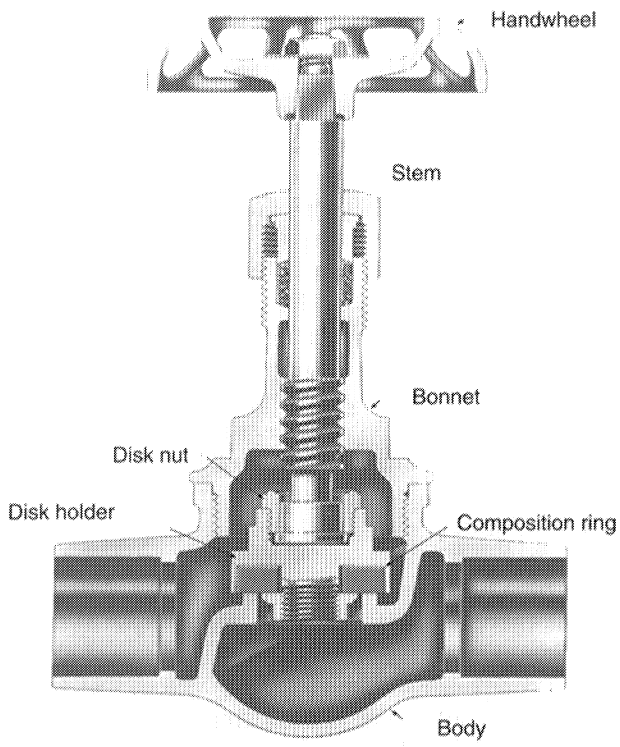


FIGURE 2.20 Composition Disk Globe Valve

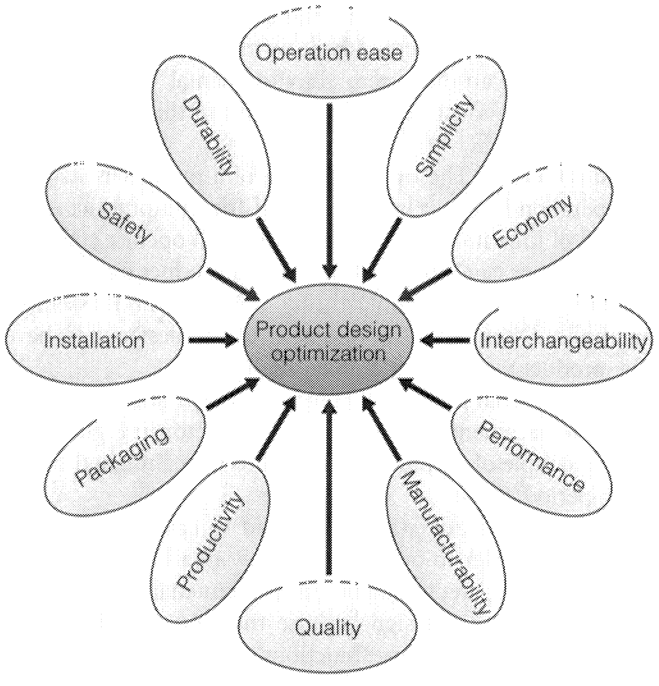


FIGURE 2.21 Product Design Optimization

has realized that they must hold down costs and at the same time increase quality. The designer can be an important factor in this equation. Materials, manufacturing methods, equipment, and labor all affect the cost of a product.

The design, production, and marketing costs of a product must be estimated early in the design process to bring the product to market and make a fair return on the investment. Designing in quality instead of inspecting out problems will ensure a greater profit and a better product.

2.7 PRODUCT DESIGN OPTIMIZATION

The optimum product is created when all factors are properly analyzed and balanced. Figure 2.21 shows the twelve major influences that, when properly considered, will yield a superior product. This process is called product optimization. Each of the twelve factors affects the success of the product. A good designer factors in each to develop an optimum product.

The pipe insulation covers shown in Figure 2.22 were designed according to many of these factors. Durability, quality, economy, performance, simplicity, installation ease, interchangeability, safety, and manufacturability were all considered in the design and production of the covers. Although the insulation of a pipeline (Fig. 2.23) that uses covers does not require the aesthetic considerations required of consumer products, it does demand proper industrial considerations that will affect design and production.

FIGURE 2.22 Zestron Pipe Insulation Covers

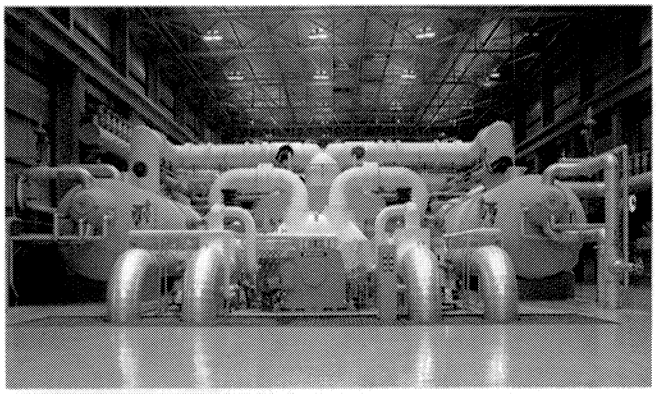


FIGURE 2.23 Pipe Insulation

2.8 THE DESIGN TREE

The design tree (Fig. 2.24) is useful in analyzing a particular project. The design tree can serve to illustrate the decision process during the crucial initial design or redesign phase of a project. Although the physical configuration, materials, manufacturing methods, assembly procedures, and equipment costs may be altered and balanced between selections, stages occur during the design of a new product in which equal function, quality, and performance levels can be obtained. The goal is to maximize the product's advantages while maintaining the critical specifications.

The design tree starts with the trunk (product idea). The two main branches are the material selection and the physical configuration. The left limb in the illustration depicts the material choices and splits at metal and nonmetal. Many questions must be answered at this juncture. If metal is chosen, what grades and types should be considered? If nonmetal is considered the best choice, the same questions are asked. The physical shape of the product will be determined by taking the right branch and selecting its size, shape, and features. The branching process can continue to include possible modifications and enhancements. The design tree can also help to see where a particular option or feature may actually threaten the product's integrity.

2.9 DESIGN EXAMPLE

Engineers and designers are pushed to the very edge of engineering design technology when designing visionary vehicles and experiments for the space program. **Gravity Probe B** (Figs. 2.25 and 2.26), an experiment first conceived over 30 years ago, is an example of how engineers, futurists, and designers have sought to use new technology to search for proof for Einstein's theory of relativity. Designers, engineers, and scientists have invented new technologies and given many demonstrations of new devices to work toward the launch of Gravity Probe B.

In 1959—only two years into the space age—three scientists at Stanford University conceived the idea of searching for proof of Einstein's theory of relativity in the only environment possible for the experiment—space. An adventuresome idea such as this is, of course, often the starting point

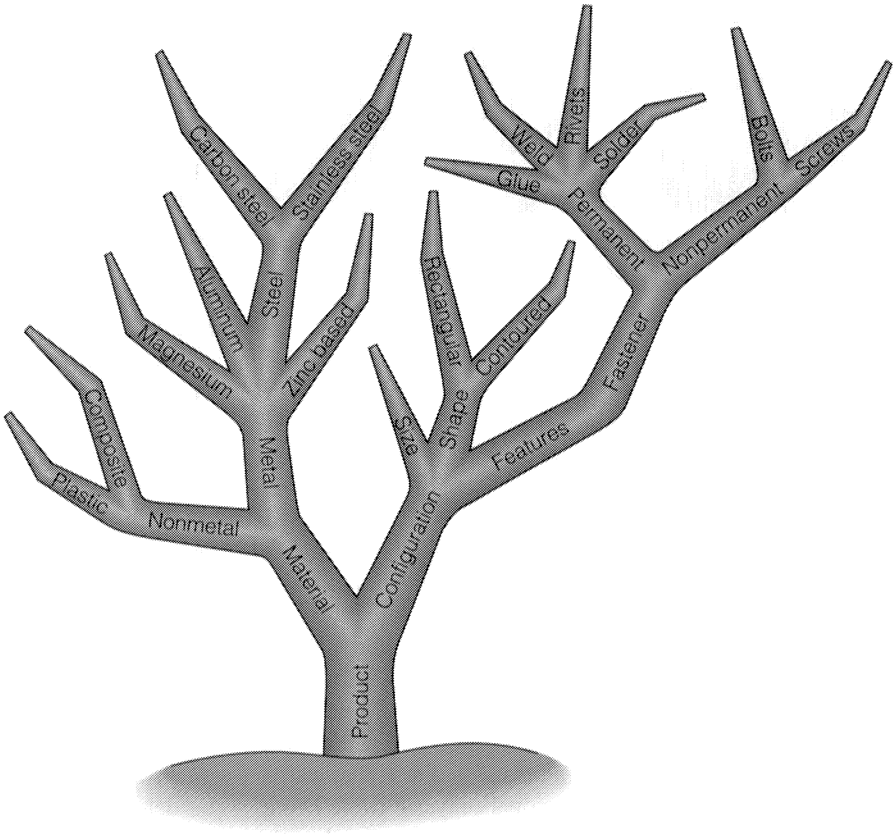


FIGURE 2.24 The Design Tree

FIGURE 2.25 Overview of the Design of Gravity Probe B

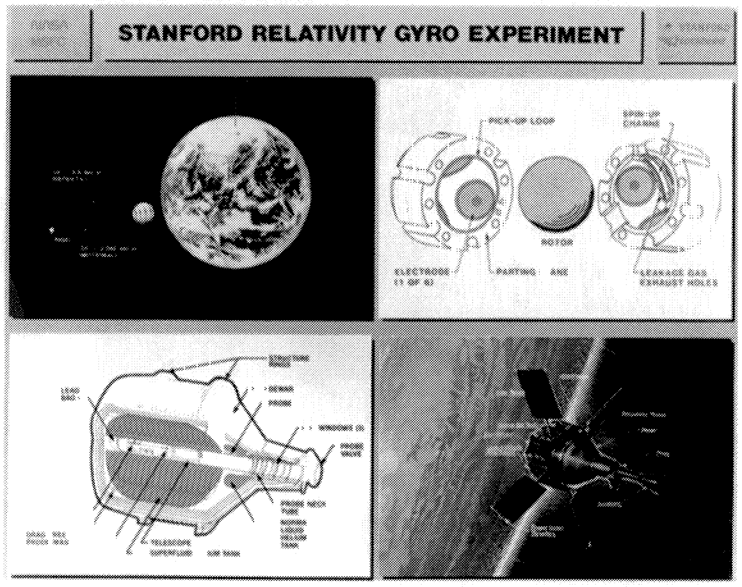


FIGURE 2.26 Electronic Test of Gravity Probe B to Be Flown in the Open Chamber of the Space Shuttle

for many great engineering designs. In the 1960s, research for the project was funded, but NASA clearly saw the success of the project as improbable. The designers had to invent four near-perfect gyroscopes to measure a very tiny effect in space, equivalent to looking for something the size of a human hair from ten miles away. However, by 1989 the designers had overcome so many obstacles that Gravity Probe B was widely recognized as one of the most important fundamental physics experiments ever to be undertaken.

Newton claimed that gravity is a force that is transmitted instantaneously—even over great distances. Einstein disagreed and worked out his theories of special relativity by which nothing can travel faster than the speed of light. Einstein proposed in 1916 that gravity is not a force, but a field that warps space and time in his four-dimensional universe (time being the fourth dimension). Newton said that the planets orbit the sun because a gravitational force holds them in orbit. Einstein said that each planet really travels in a straight line, but its path is elliptical because it is moving in curved space. Of course, most modern theories on the cosmos rely on Einstein's theories. Parts of Einstein's theories, however, remain largely untested. Therefore, not everyone is convinced that Einstein was *completely* right. No one has ever observed gravitational radiation, for example.

A phenomenon known as "frame dragging" is also predicted by Einstein's theory of general relativity. It is this effect that Gravity Probe B is designed to measure (Fig. 2.27). By that theory, a large object, such as Earth, drags space-time with it as it spins. The Stanford researchers' idea was to line up gyroscopes on a distant star and then see if Earth's rotation would drag space and time around with it; this would alter the spin of the gyroscopes (gyros). If Newton is right, the gyros will stay lined up on the star forever; if Einstein is right, the gyros' spin should change slightly over a period of time. However, the instruments will have to measure a tiny angle of 42 milliarc seconds a year to find the effect. If the Earth is really dragging space around it as it rotates, the axis of the gyro will swivel at a rate of one full turn in 25 million years.

The design of the experiment itself calls for four near-perfect gyros that can function in near zero gravity at near zero temperatures in a near perfect vacuum in near zero magnetic fields. The gyros will be near perfect spheres of quartz about the size of tennis balls (each sphere being round to a millionth of an inch). Vibrations during the experiment could ruin the experiment. Each sphere is coated with a thin film of superconducting material, allowing the gyros to be suspended in a magnetic field. To make the design challenge more complex, the position would be fixed on a star 300,000 light years away! The small signal that will be detected must be transmitted by satellite error free and immune from outside errors of all sorts.

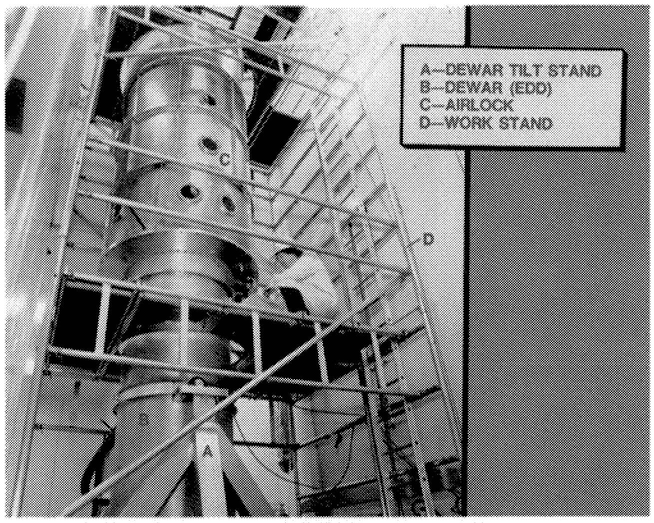


FIGURE 2.27 Airlock and Dewar Stand Vacuum Testing of Electronics for Gravity Probe B

The design team eventually found a way to produce the world's roundest gyroscopes, a drag free satellite, a refrigerated capsule to hold helium in place and cool it for two years, and a method for detecting the small change in spin with superconductor technology. Special clean rooms were designed just for the project (Fig. 2.28), as were special rooms for assembly and storage of the project. In order for the rotor ball in the gyroscope to be a superconductive, the engineers have developed a dewar, a large vacuum bottle like container that will provide the near absolute zero temperatures needed for the gyroscope. New composite materials were employed for the assemblies. Each piece or assembly that was developed had to be meticulously cleaned (Fig. 2.29) and tested in vacuum containers (Fig. 2.30) and cold chambers (Fig. 2.31) developed especially for the project. Electronic testing of some of the probe equipment will be sent up in the space shuttle in approximately 1996 (Fig. 2.32). The 3 ton payload drag free satellite is scheduled to be launched in 1999 on a Delta rocket. The satellite has been now renamed the Relativity Mission. Gravity Probe A in June 1976 was a suborbital flight of an atomic clock to test the equivalence of gravitational and inertial mass.

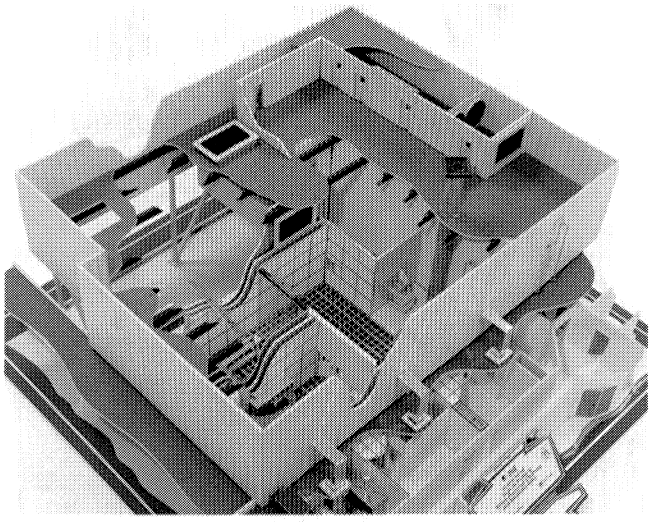


FIGURE 2.28 Scale Model of a Precision Clean Room Used to Assemble Probe Parts

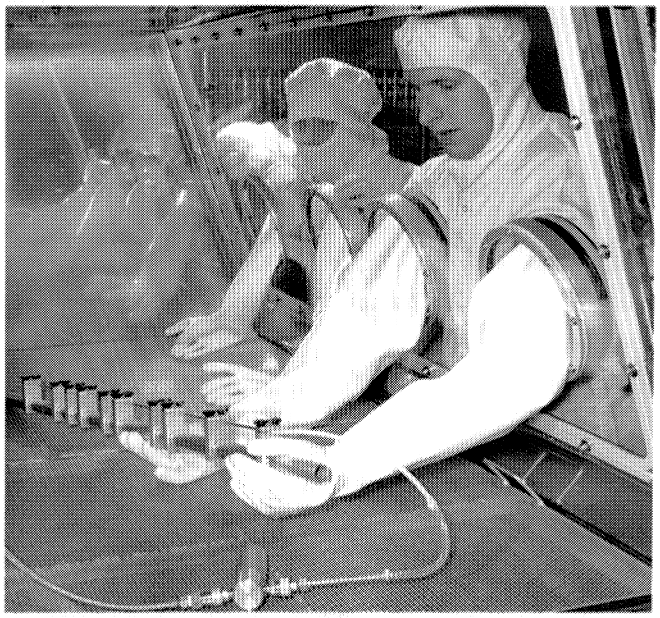


FIGURE 2.29 Precision Cleaning of Flexible Bellows Tubes for Electronic Controls

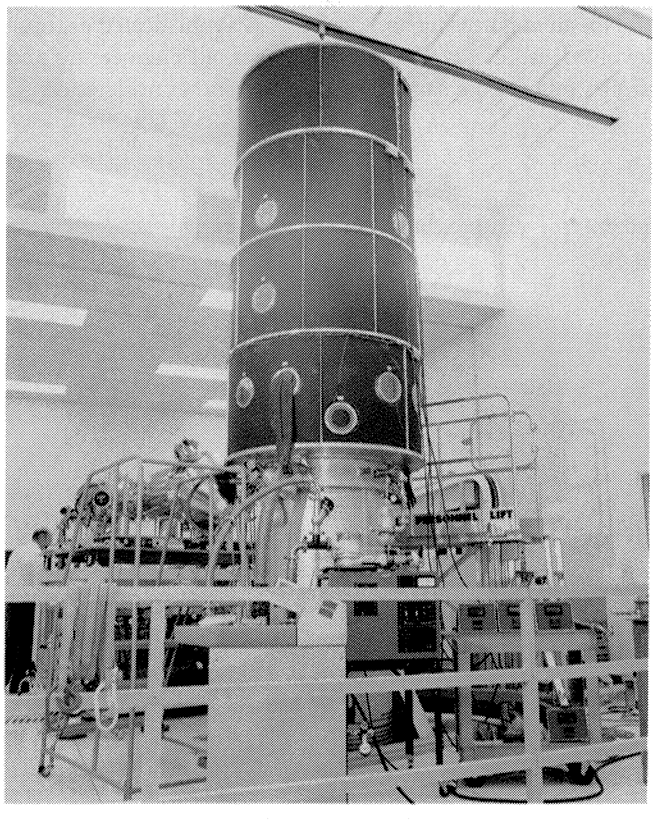


FIGURE 2.30 Airlock Chamber for Testing Electronics and Composites

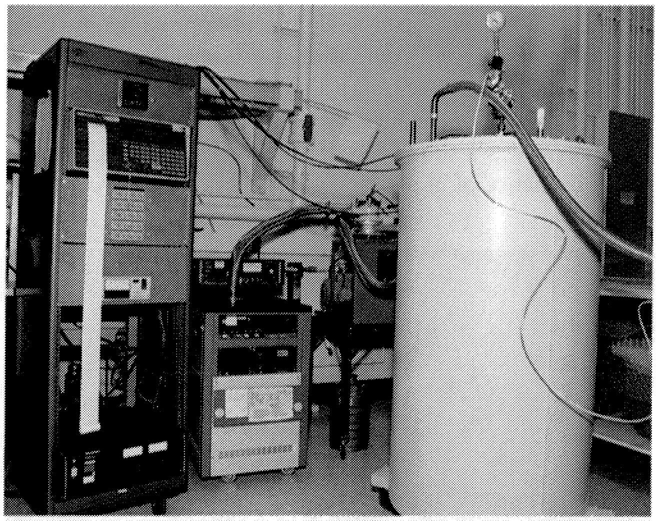


FIGURE 2 31 Cold Chamber for Testing Probe Segments

As with all design components and test facilities began as ideas that were first sketched to communicate ideas (Fig 2 33) and to understand placement of components and sizes Preliminary plans (Fig 2 34) and manufacturing assembly plans (Fig. 2.35) were developed before the components or facilities could be manufactured (Fig. 2.36) For most components of Gravity Probe B and the associated test facilities every idea was new and untried. Design iterations were many. Test followed test New concepts and new theories were developed Each design concept pushed the limits of known applications

Not all engineering and design is as sophisticated as those involved in Gravity Probe B. However all engineering and design follows the same methodology and considerations

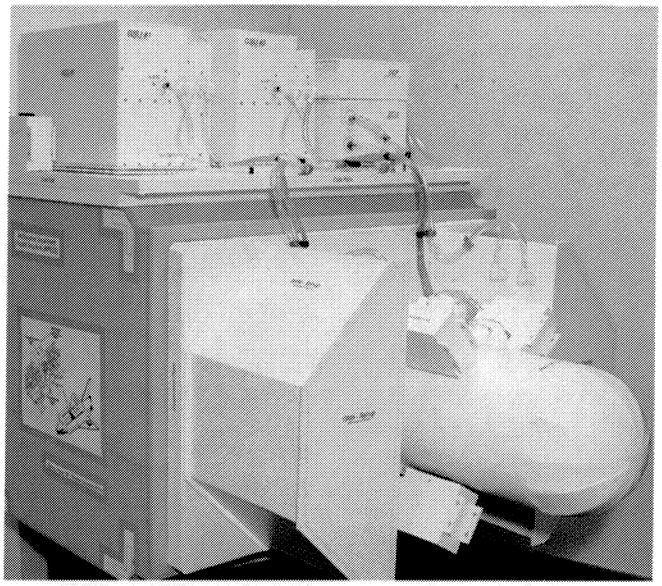


FIGURE 2.32 Scale Model of Electronic Testing of the Probe to Be Sent Up in the Space Shuttle

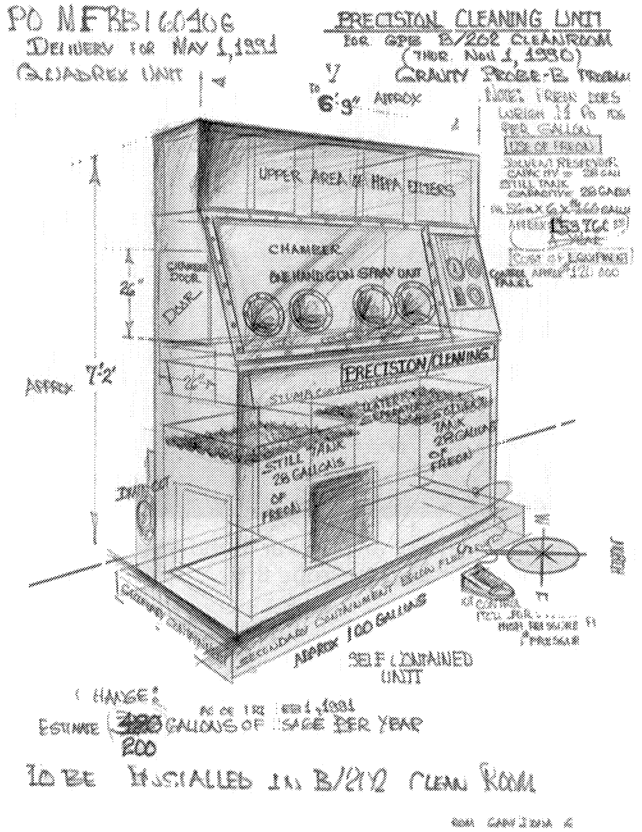


FIGURE 2 33 Sketch of a Precision Cleaning Apparatus

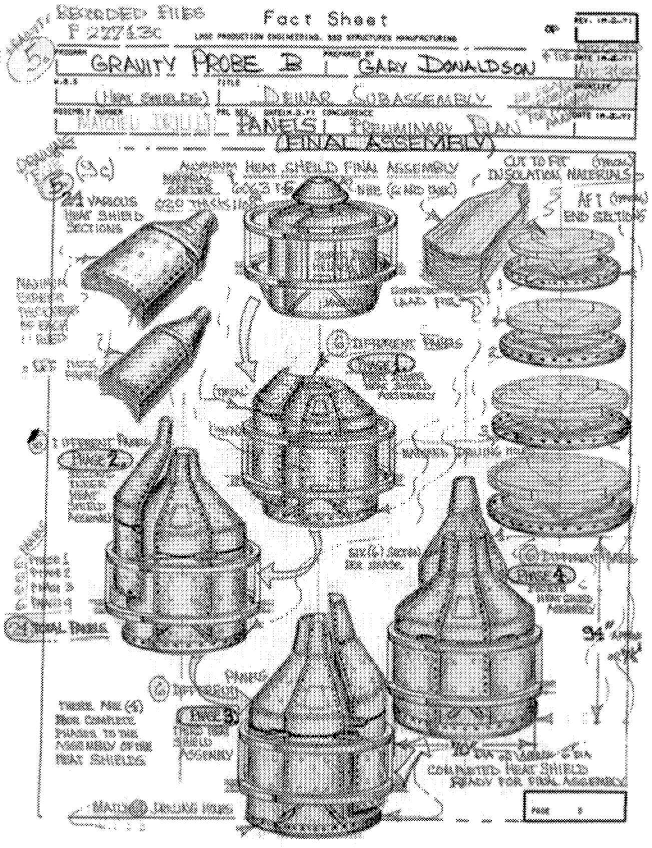
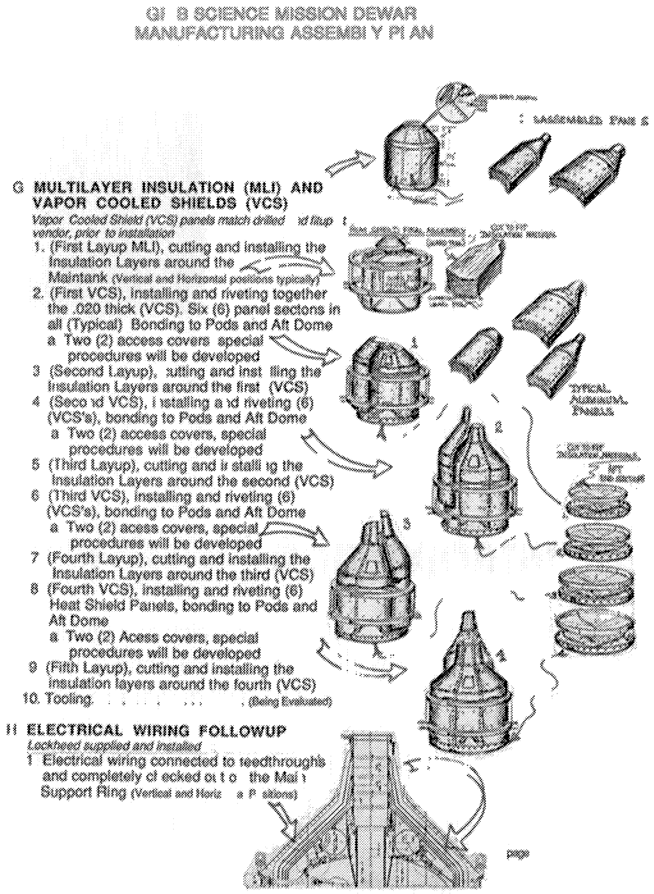


FIGURE 2 34 Plans for the Heat Shields of the Dewar



G MULTILAYER INSULATION (MLI) AND VAPOR COOLED SHIELDS (VCS)

Vapor Cooled Shield (VCS) panels match drilled and fitup at vendor, prior to installation

1. (First Layup MLI), cutting and installing the Insulation Layers around the Maintank (Vertical and Horizontal positions typically)
2. (First VCS), installing and riveting together the .020 thick (VCS). Six (6) panel sectons in all (Typical) Bonding to Pods and Aft Dome
   a Two (2) access covers special procedures will be developed
3. (Second Layup), cutting and installing the Insulation Layers around the first (VCS)
4. (Second VCS), installing and riveting (6) (VCS's), bonding to Pods and Aft Dome
   a Two (2) access covers, special procedures will be developed
5. (Third Layup), cutting and installing the Insulation Layers around the second (VCS)
6. (Third VCS), installing and riveting (6) (VCS's), bonding to Pods and Aft Dome
   a Two (2) acess covers, special procedures will be developed
7. (Fourth Layup), cutting and installing the Insulation Layers around the third (VCS)
8. (Fourth VCS), installing and riveting (6) Heat Shield Panels, bonding to Pods and Aft Dome
   a Two (2) Acess covers, special procedures will be developed
9. (Fifth Layup), cutting and installing the insulation layers around the fourth (VCS)
10. Tooling. (Being Evaluated)

H ELECTRICAL WIRING FOLLOWUP

Lockheed supplied and installed

1. Electrical wiring connected to feedthroughs and completely checked out to the Main Support Ring (Vertical and Horizontal Positions)

FIGURE 2 35 **Partial Manufacturing Assembly Plan for the Dewar**

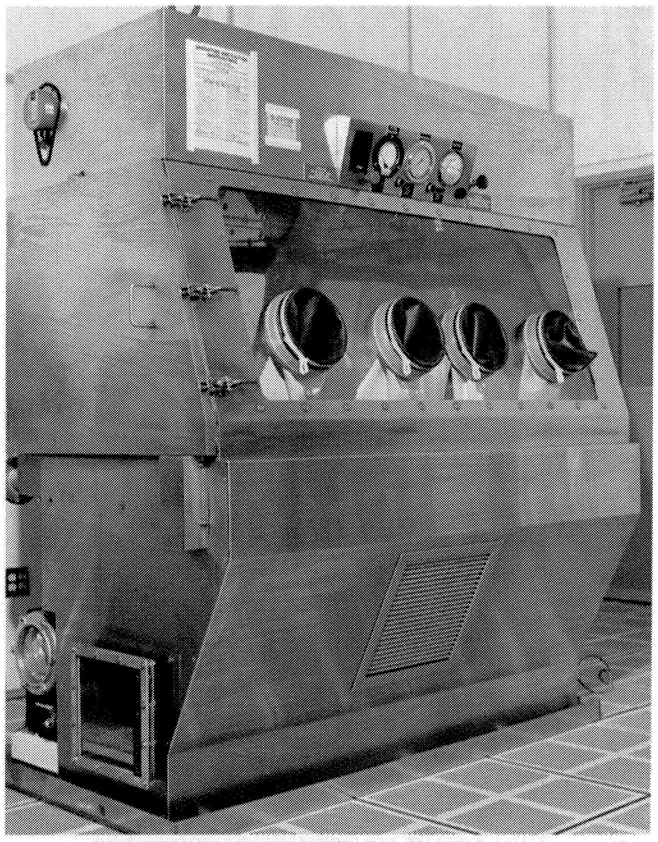


FIGURE 2 36 **Precision Cleaning Unit**

QUIZ

True or False

1. Product design is usually completed without considering how to manufacture the product
2. Systems engineering is relatively unimportant
3. Function is the most determining factor in design
4. Recyclability is not considered when the product is designed to be a throwaway
5. Project cost and profit margin are two of the most important factors in any design
6. Reliability is the length of time a product will operate properly
7. Weight is never important when designing a product for the industrial sector
8. Off the shelf' refers to a mechanical item that is too large for shelf storage

Fill in the Blanks

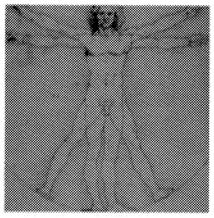
9. The can be used to illustrate the decision process during design or redesign
10. The shape of a product should be considered with regard to its symmetry, and
11. Durability life quality economy, and simplicity are all factors in product
12. The can be used to describe and determine the material and configuration requirements of a design
13. Products that must be disassembled after specific hours of operation must be
14. The product is created when all factors are properly analyzed and balanced
15. Design parameters include weight size color and
16. is an experiment designed to help prove Einstein's theory of relativity

Answer the Following

17. Compare systems design with product design Describe both and explain their differences
18. Name ten factors that influence design at the onset of a project
19. Describe the components involved in product engineering
20. Describe the components involved in manufacturing engineering
21. Describe concepts involved in the design tree
22. Describe the role of constraints and function in the design process
23. Explain in detail the concept of *design for manufacturability*
24. Explain the purpose of the Gravity Probe B experiment

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.

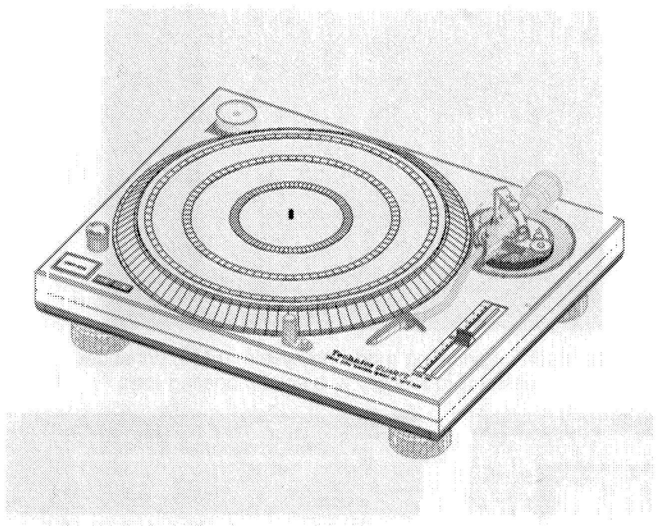
3.1 INTRODUCTION

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

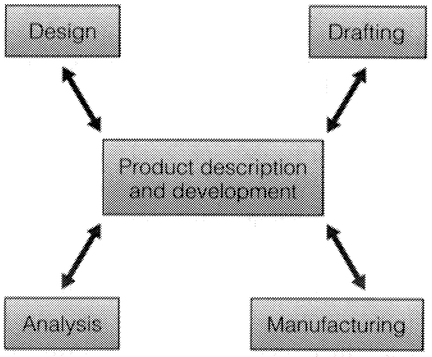


FIGURE 3.2 Product Description and Development

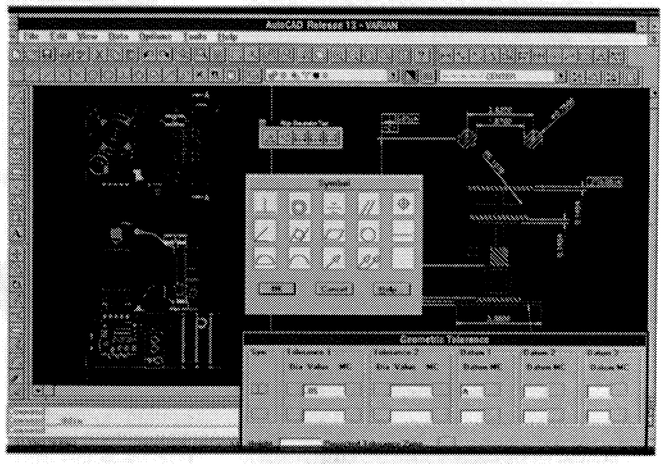


FIGURE 3.3 Using CAD in the Design Process

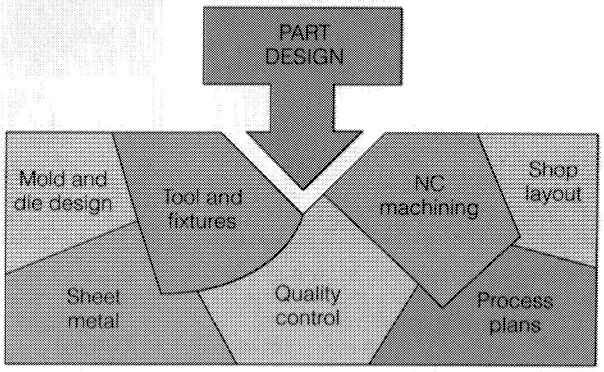


FIGURE 3.4 Part Design Using CAD

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.

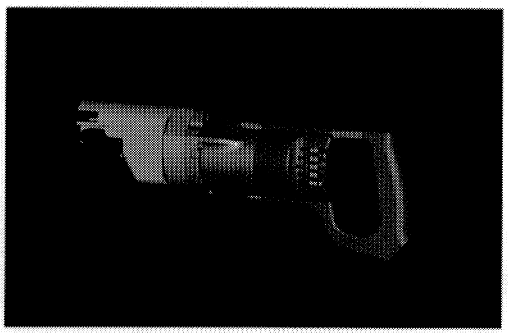
A typical consumer product, such as a household appliance or a hand tool, can appear deceptively simple. In reality, however, the design concerns, engineering requirements, and manufacturing procedures are extremely complicated and time-consuming. Obviously, all products are the result of many hours 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).

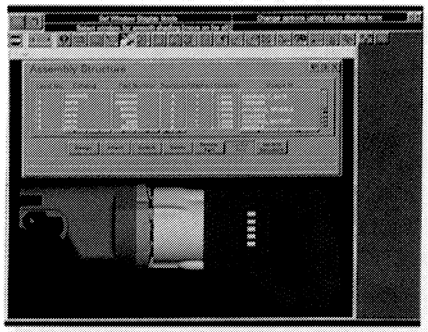
It is impossible to describe how to design every item. It has been said that you cannot teach engineering design, but a thorough presentation of design concepts leading to the understanding of the conceptualization process involved in design and mastery of the stages involved in the design process will 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.

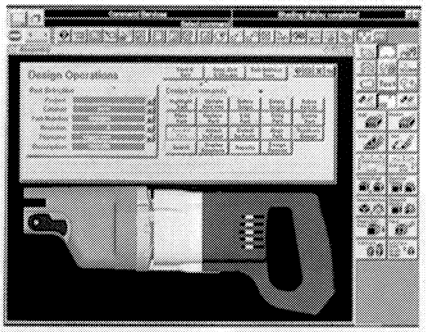
The two main divisions of engineering design are systems design and product design. Although systems design is an important field, a majority of this text is devoted to product and mechanical design techniques. Therefore, this chapter is primarily a detailed analysis of the design process as it relates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

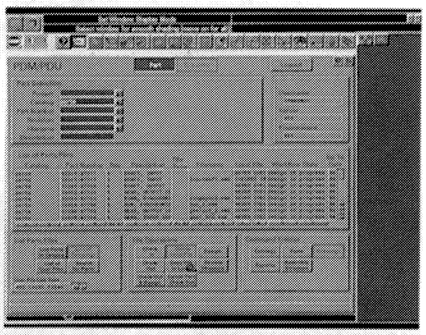
3.2 OVERVIEW OF THE DESIGN PROCESS

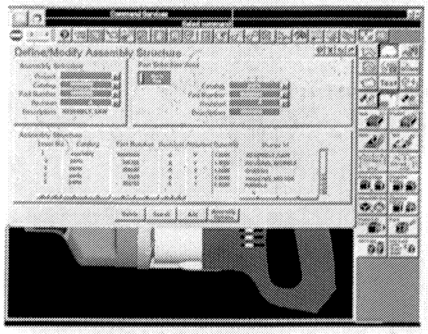
The **design process** begins when a customer expresses a need for a product Working with the customer you define the project and formulate its requirements Figure 3 5 shows the design analysis and manufacture of a commercial product -a saw—on a CAD/CAM/CAE system (Intergraph) Many steps are required to design and manufacture a complicated product such as the saw shown in the figure

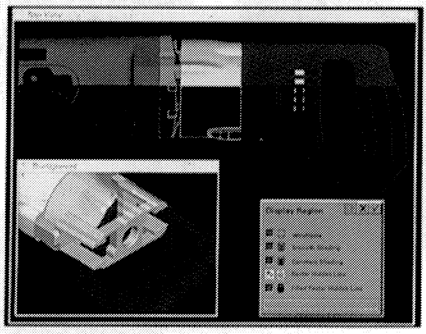

(a) Intergraph engineering modeling system (EMS) enhances mechanical design productivity with solid modeling tools

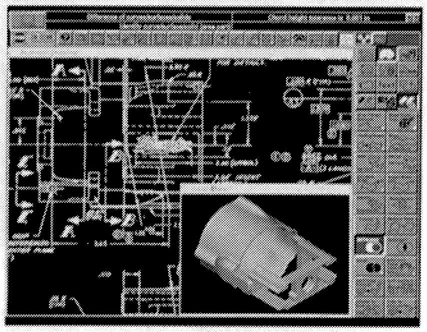

(b) EMS data management software produces bills of material and automatically generates single-level parts lists for drawings

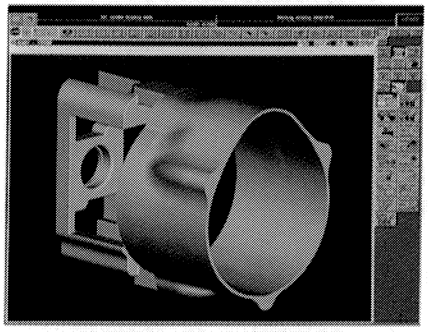

(c) EMS forms make it easy to select parts and add them to an assembly; a design engineer can choose either top-down or bottom-up design

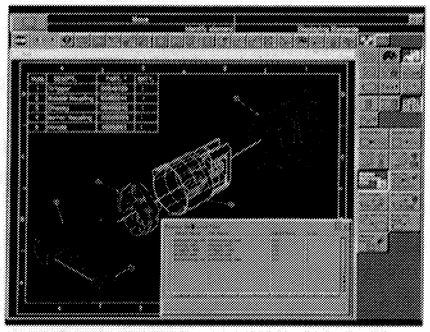

(d) EMS data management system simplifies file management with component check-in and check-out, file location tracking, archiving, retrieval, and security


(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 Intergraphs 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

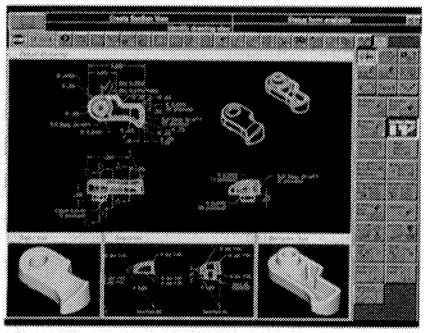
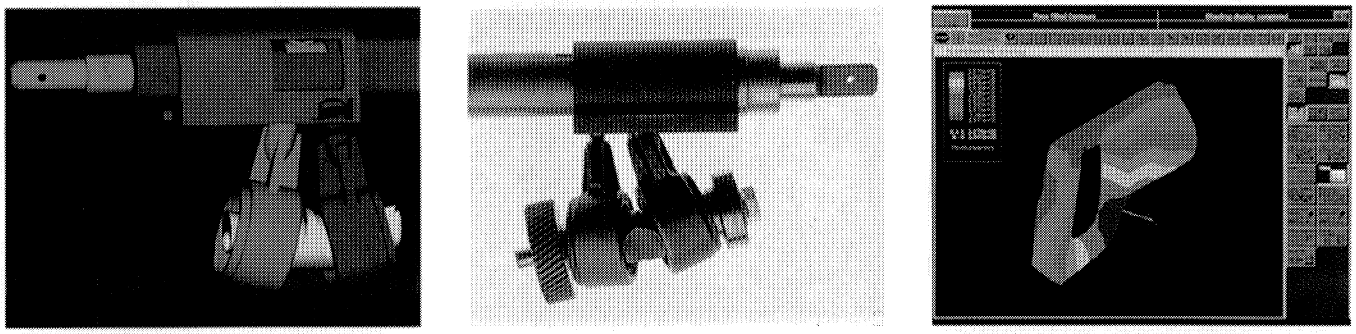

(j) For detailing in Intergraph the design software includes dimensions and creates section views, which are automatically updated to incorporate model modifications

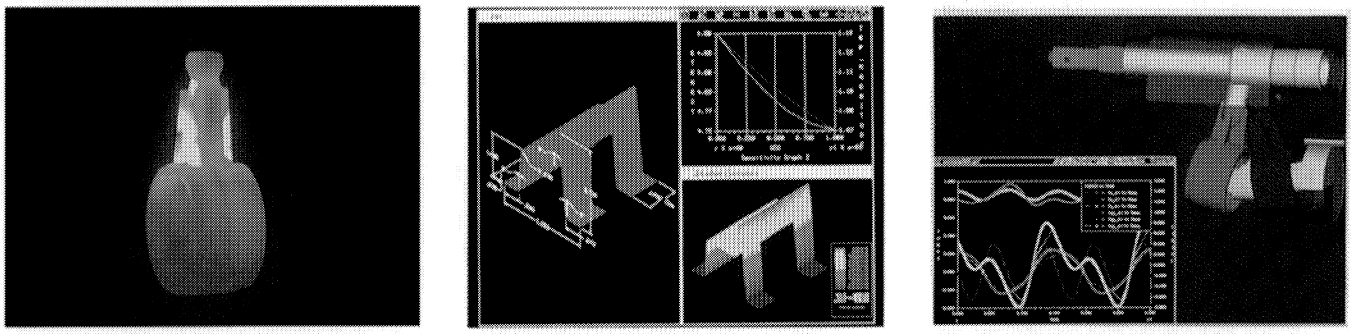
FIGURE 3 5 Design Example—a Saw



(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

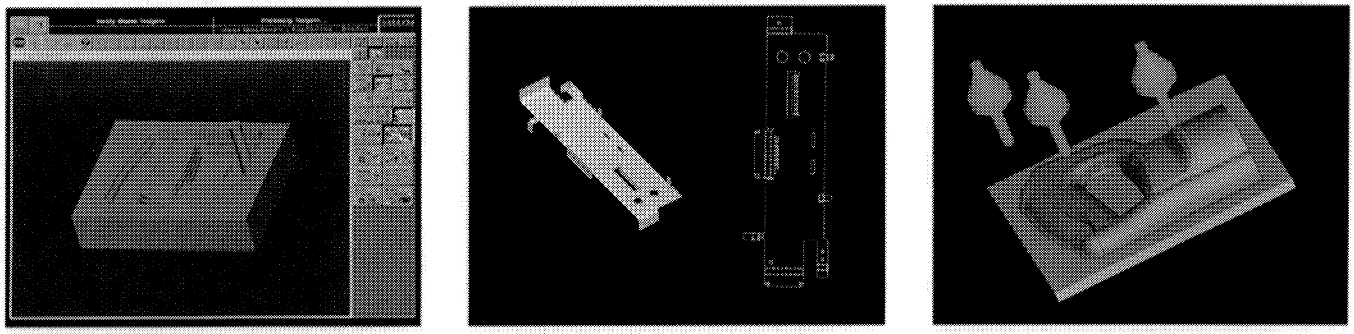
(m) EMS plastics injection analysis software analyzes the effects of time, temperature and pressure on the flow of molten plastic



(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

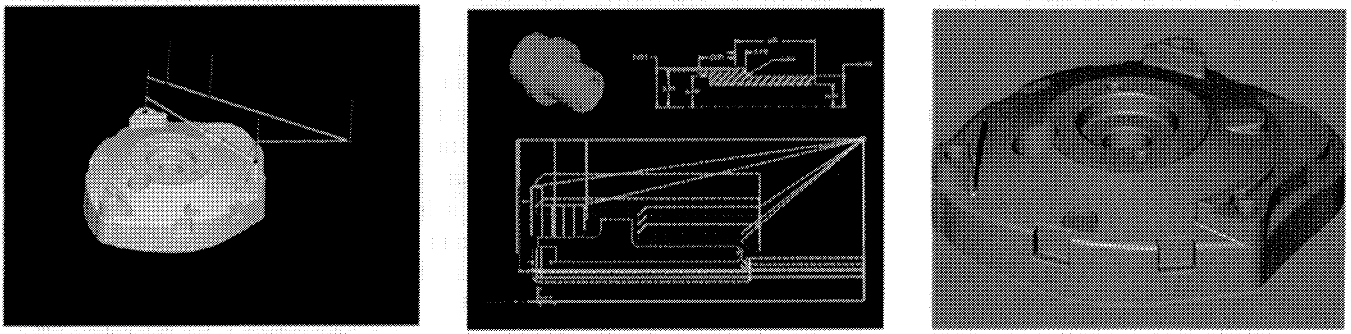
(p) Mechanical systems analysis software in EMS helps study mechanism performance including interference and the way forces change during operation



(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

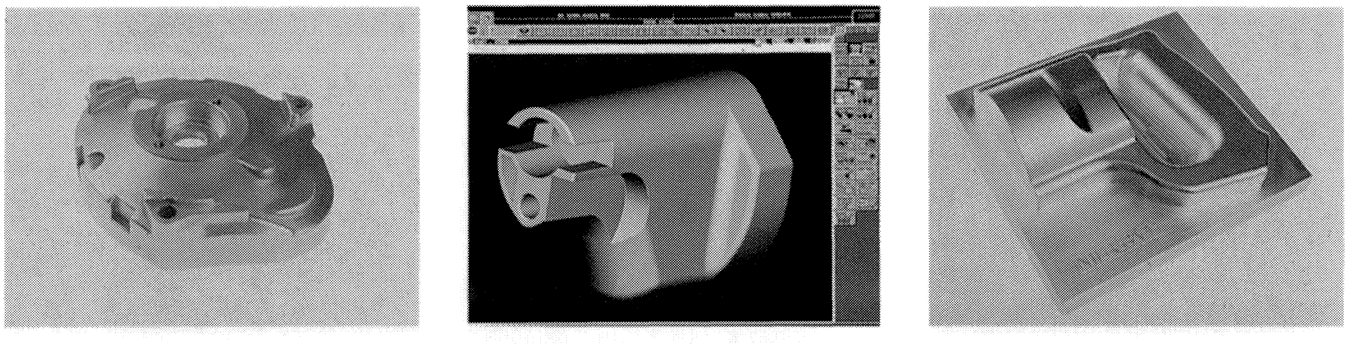


(t) Integrating design manufacturing and quality control Intergraph Coordinate Measuring Machine (CMM) software accesses design files directly for measuring free form and geometric features

(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

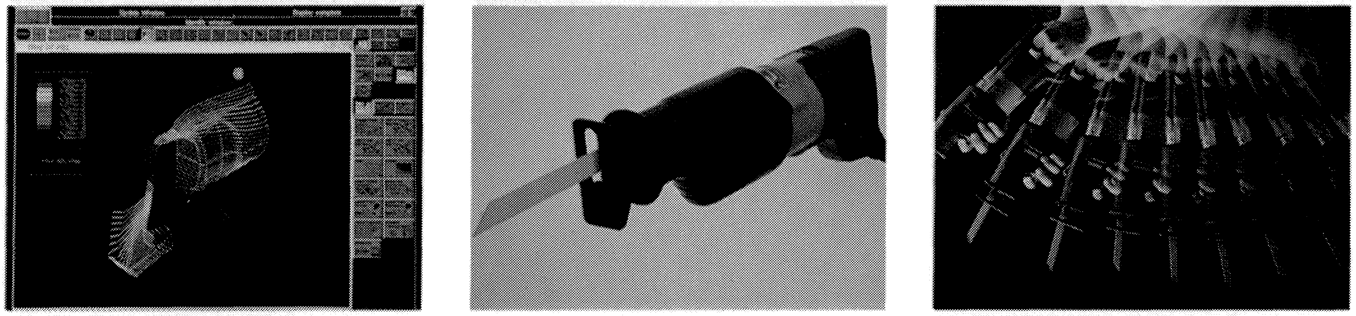
(x) Complex components are easier to visualize using a shaded solid model in Intergraph's EMS

(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

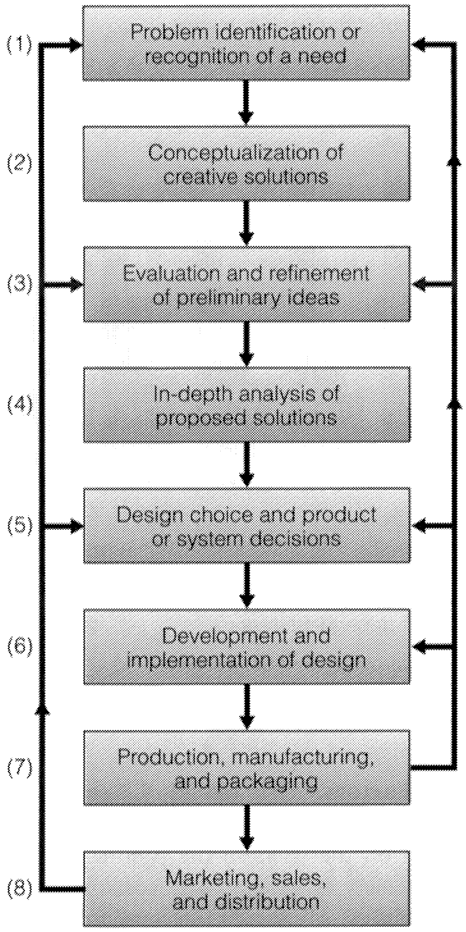


FIGURE 3.6 Stages in the Design Process

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?

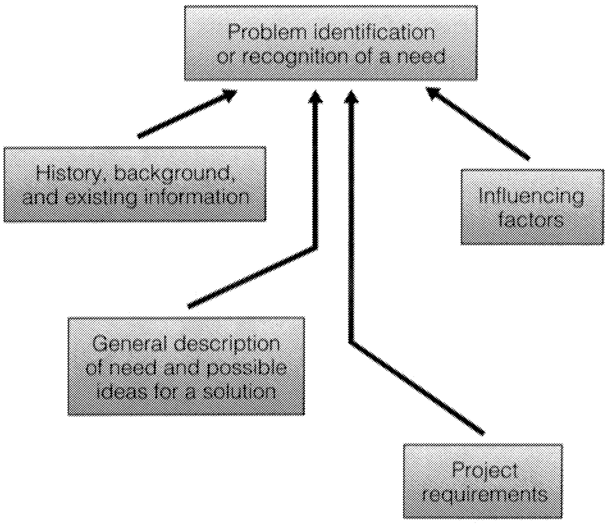


FIGURE 3.7 Stage 1 in the Design Process

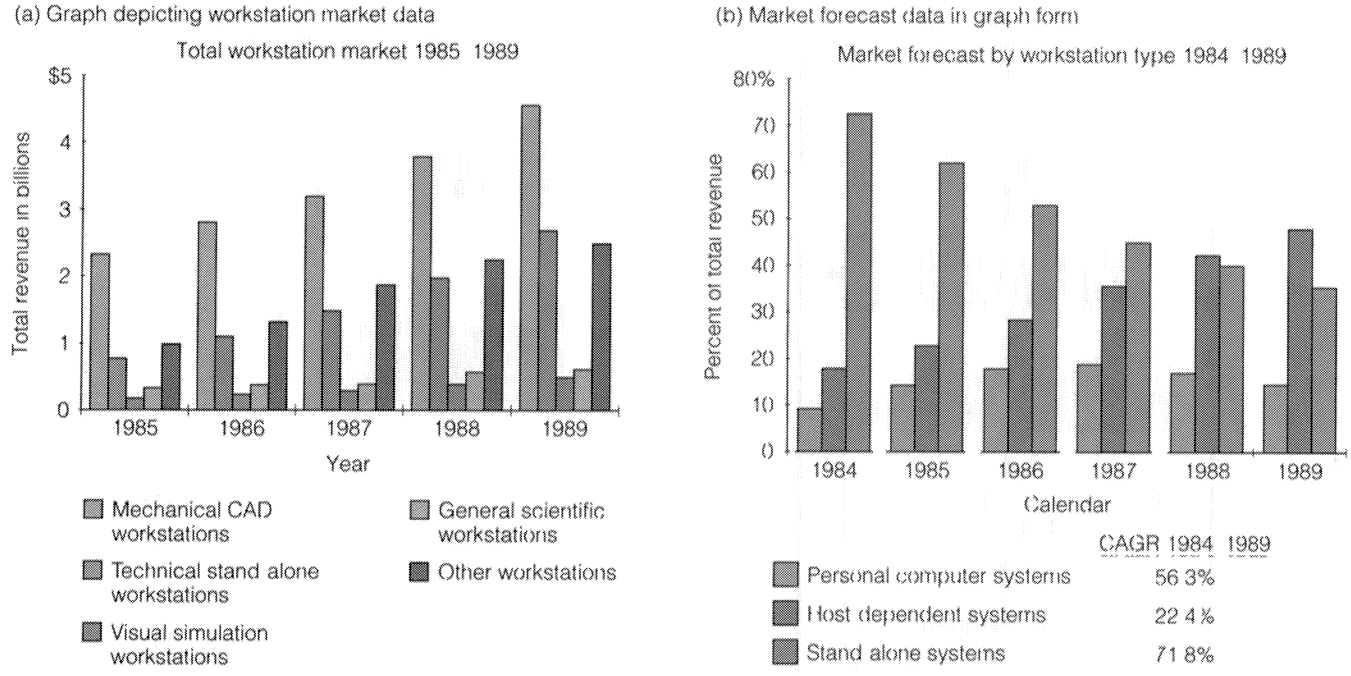
History, Background, and Existing Information The **background** of the project is presented to the design team by a concerned party: the company management, an outside client, or a company inventor who has a new idea. The marketing department may be asked to do a survey on the potential for a particular 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?

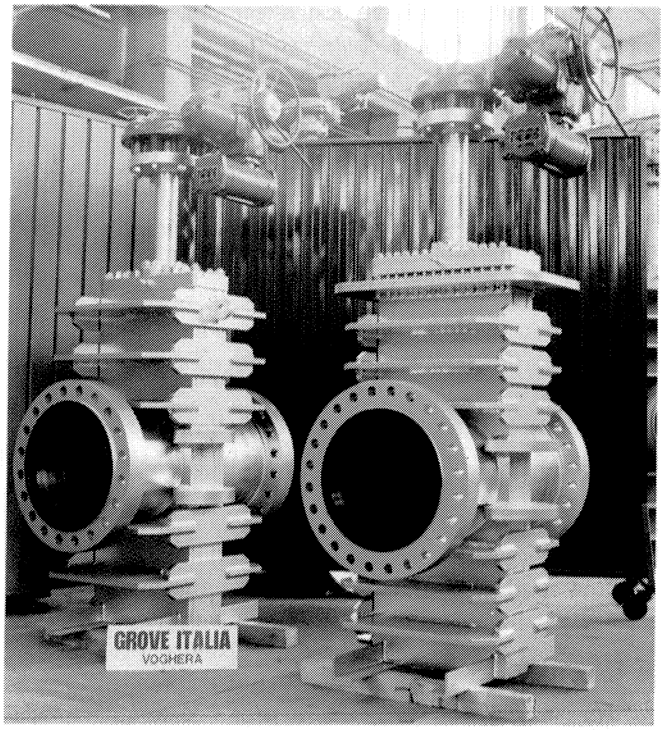


FIGURE 3.9 **48 in. Gate Valve for TransAlaska Pipeline**

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.

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

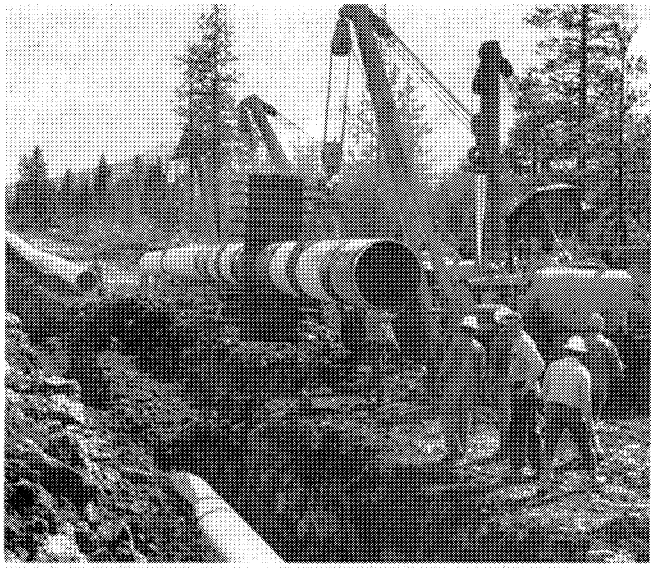


FIGURE 3.10 Gate Valve Being Installed on the TransAlaska Pipeline

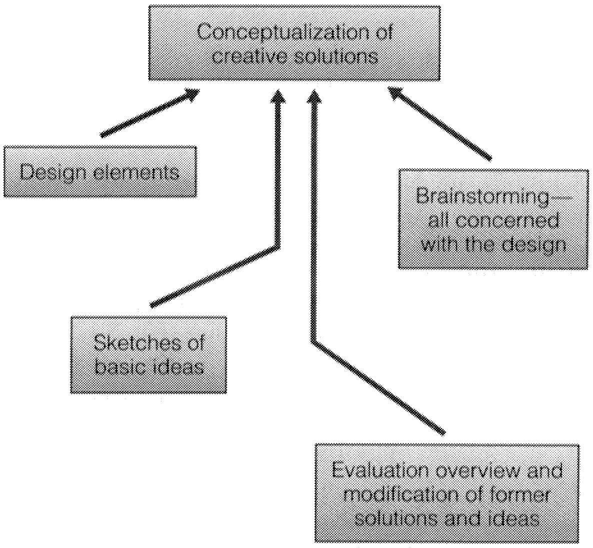


FIGURE 3.11 Stage 2 in the Design Process

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 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
- Co-workers—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

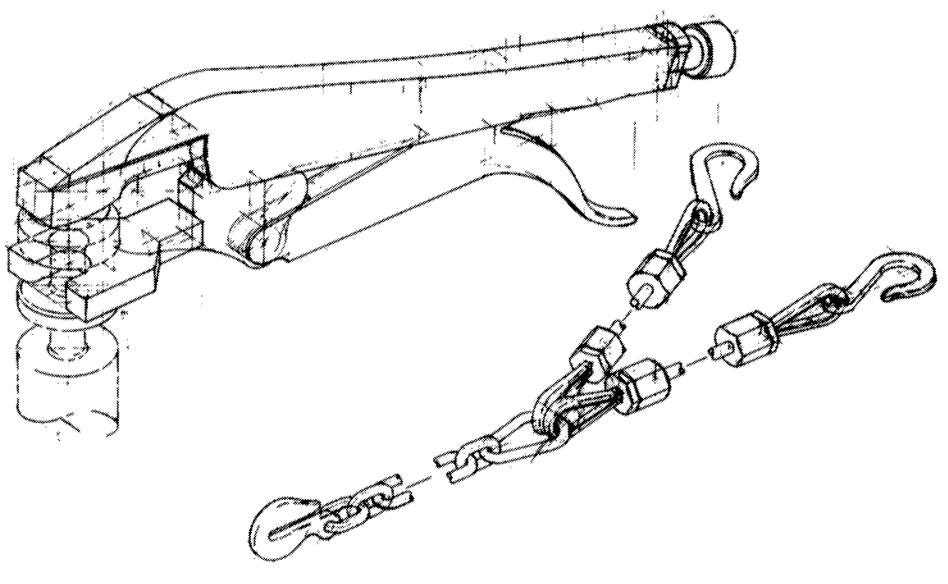


FIGURE 3 12 Pictorial Layout

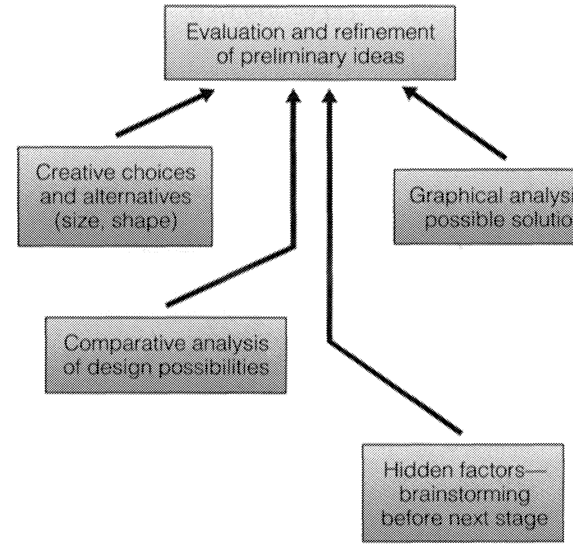


FIGURE 3.13 Stage 3 in the Design Process

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 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**.

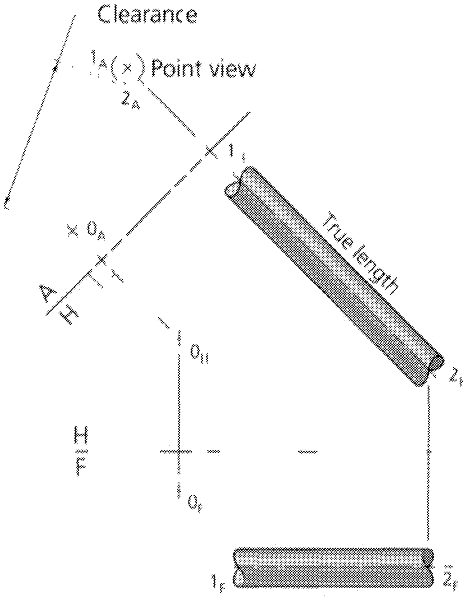


FIGURE 3.14 Descriptive Geometry Problem Solving for the Shortest Distance Between a Pipe and a Fixed Point

FIGURE 3.15 Shaded Image of Piping and Equipment

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

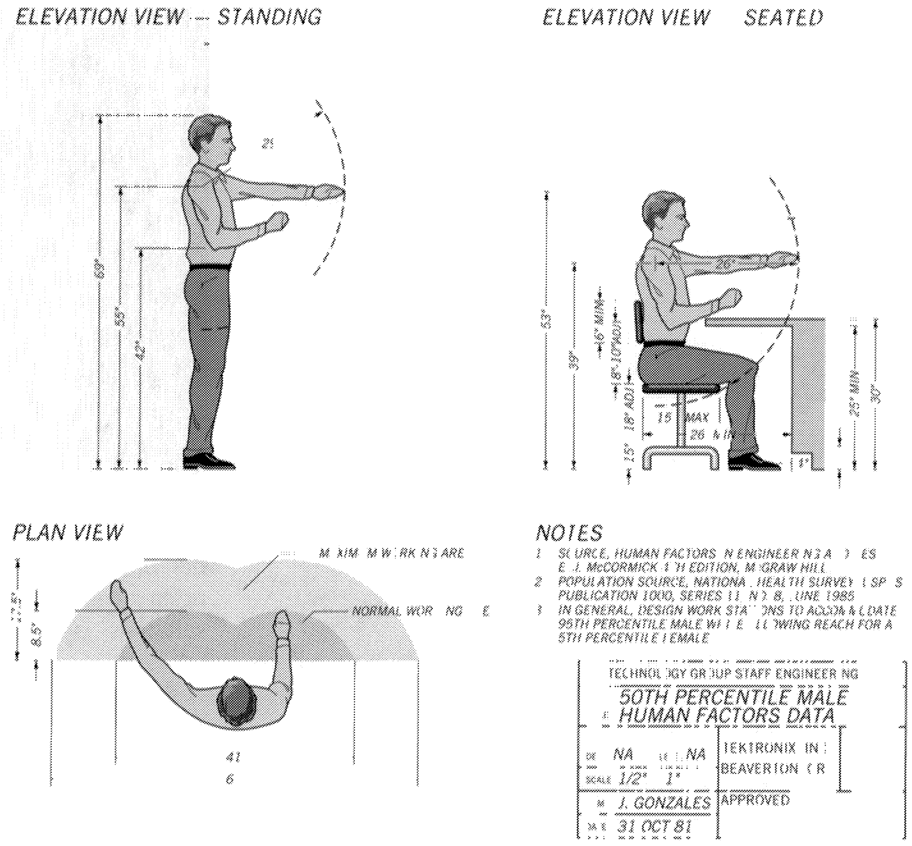


FIGURE 3 16 Male Human Factors Data

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

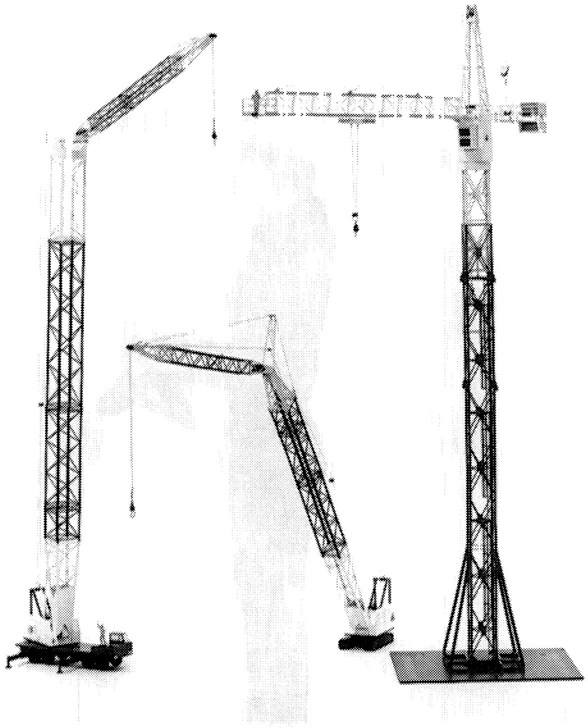


FIGURE 3 18 Model of a Crane

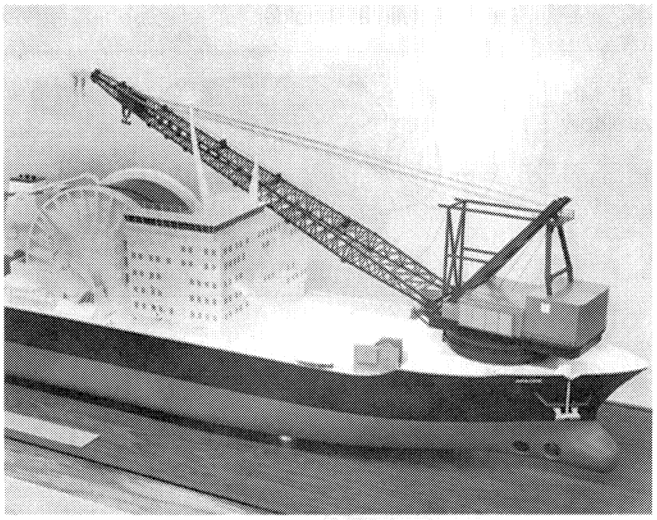


FIGURE 3 19 Model of a Pipe Laying Ship

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

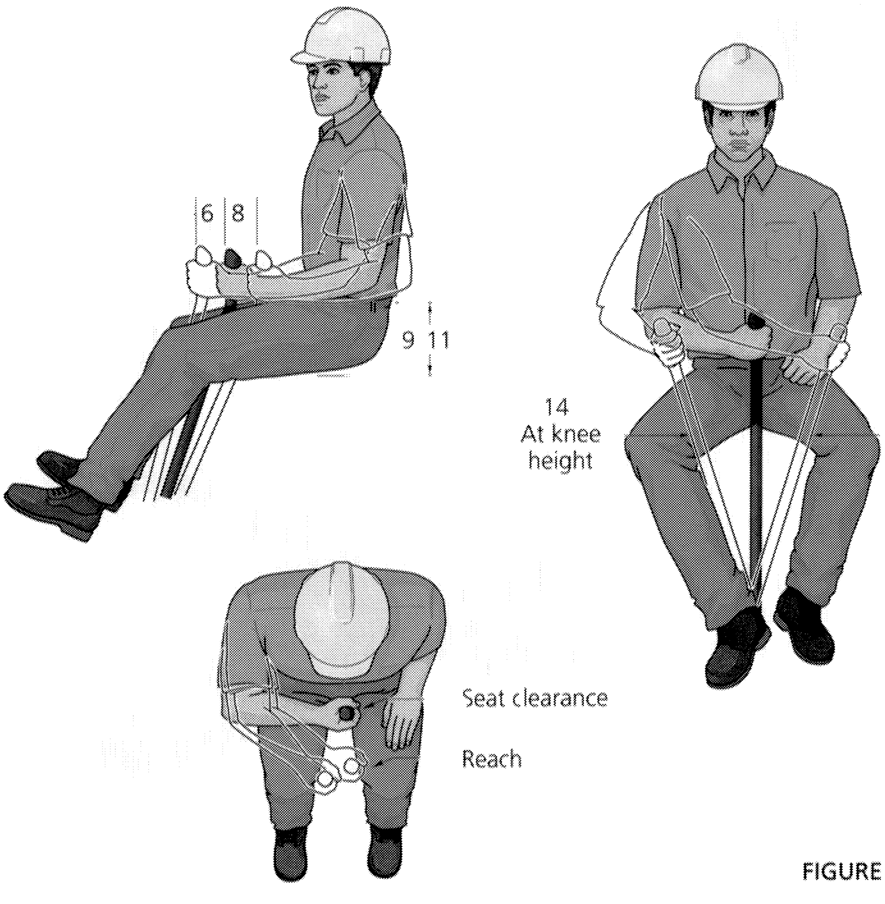
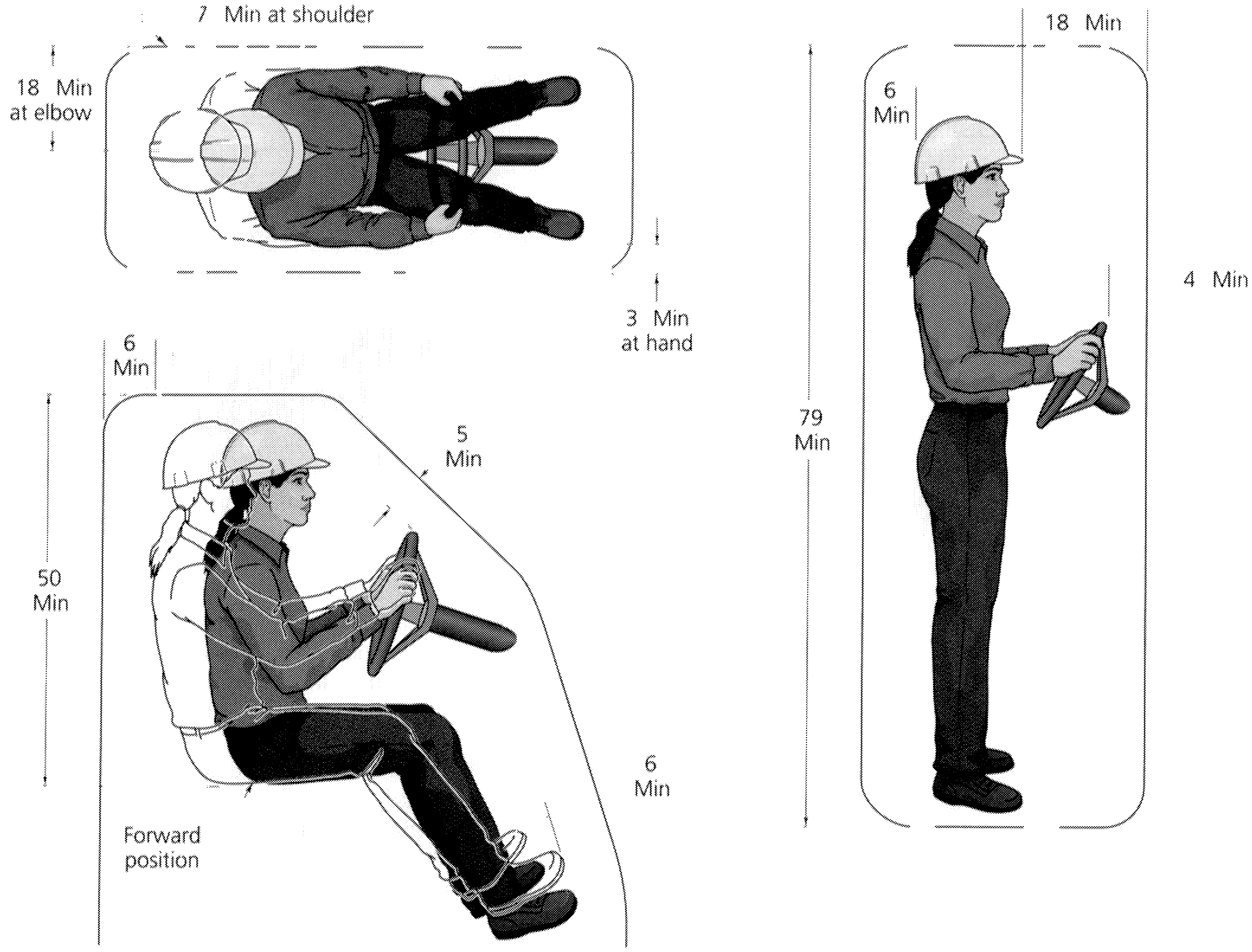


FIGURE 3 20 Control Stick Movement Studies



(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 environment 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

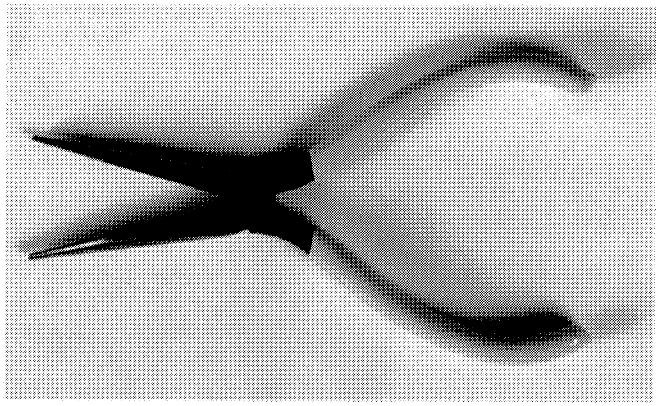


FIGURE 3.22 Needle Nose Pliers

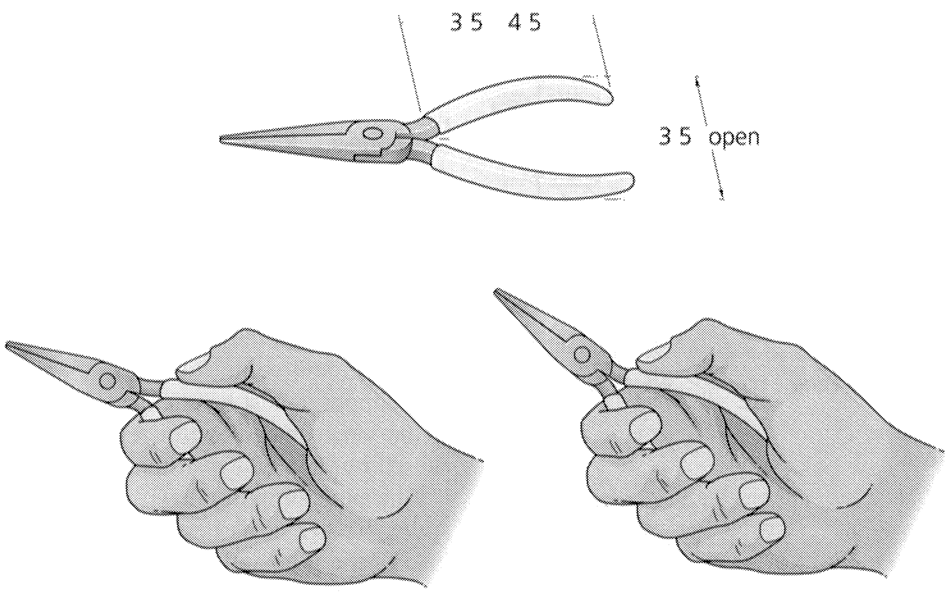


FIGURE 3.23 Design Studies of Pliers Handles

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

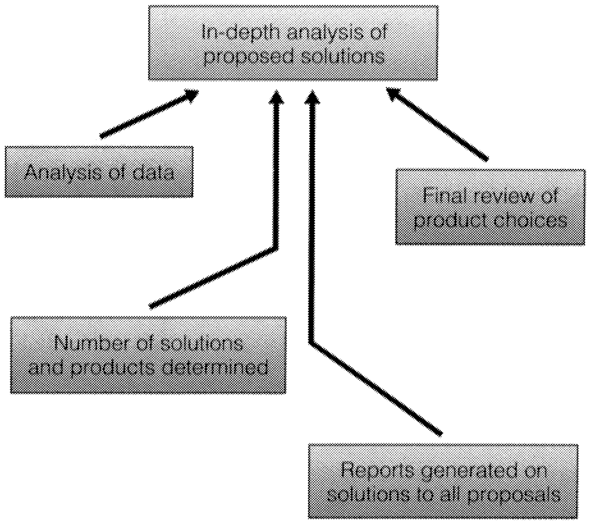


FIGURE 3.24 Stage 4 in the Design Process

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.

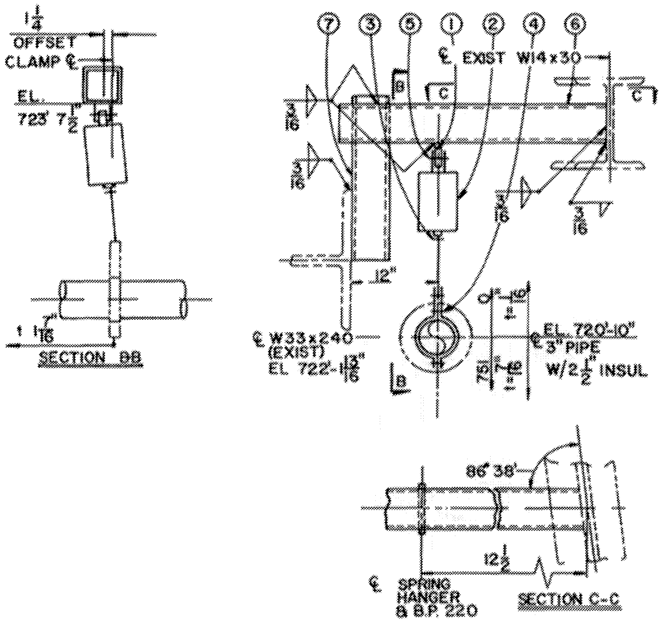


FIGURE 3.25 Spring Hanger Used in Pipe Support Design

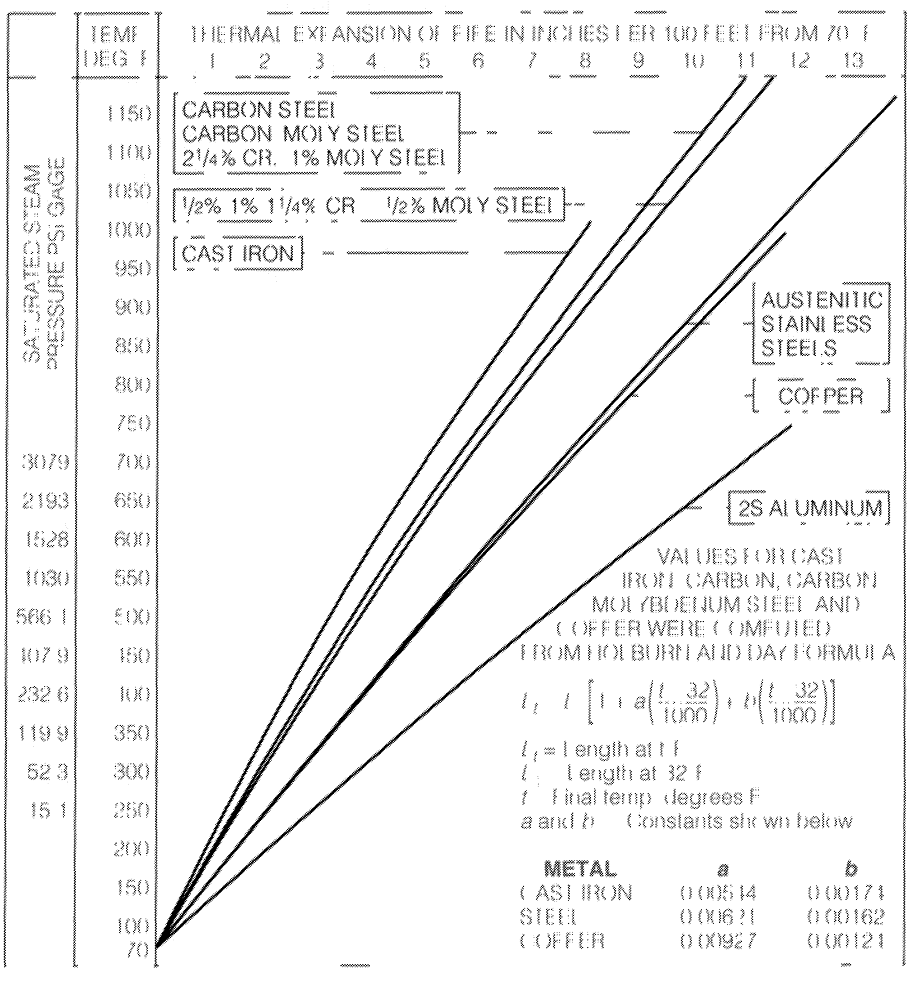


FIGURE 3.26 Thermal Expansion of Pipe

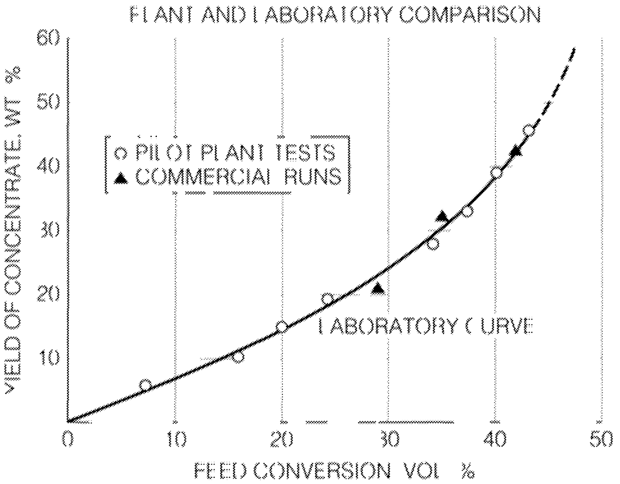


FIGURE 3.27 Graph Layout for Publications

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, waveforms, 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.

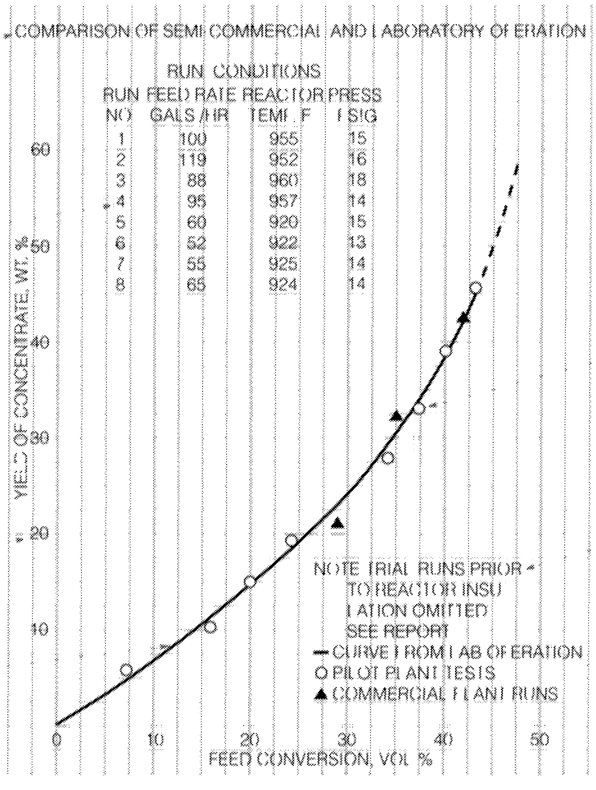
Figure 3.31 shows lines and symbols on a graph. Clear, accurate graphs and charts are essential for communicating

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

Omit supporting data tables, equations, or other nonessential details.

Show all scale numbers and titles outside grid border.

Used double weight ruling to emphasize curve.



RUN NO.	FEED RATE GALS/HR	REACTOR TEMP. F	PRESS. PSIG
1	100	955	15
2	119	952	16
3	88	960	18
4	95	957	14
5	60	920	15
6	52	922	13
7	55	925	14
8	65	924	14

Use a horizontal rectangle when feasible.

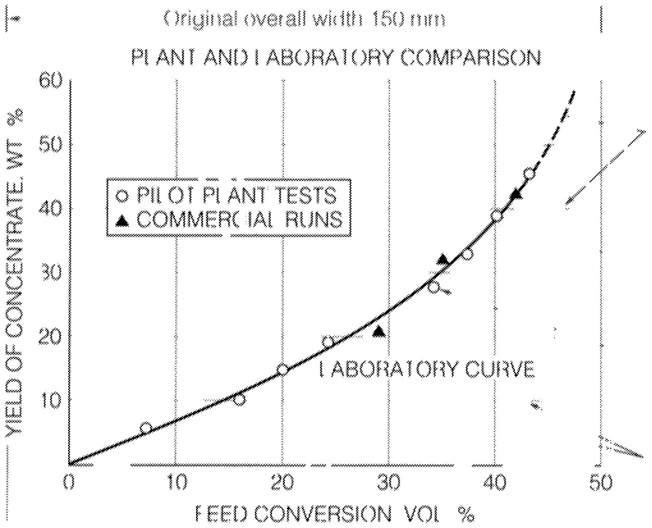
Use only open grid paper. Commercial fine line papers are unsatisfactory.

Use template or transfer lettering symbols.

Omit 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 (callouts).

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

Title here only for slides

Lightest ruling for grid, heaviest for curve or important outlines

Grid or other lines do not cut through data symbols or lettering

Open symbols preferred but use solid ones for emphasis

Minimum number of grid lines

FIGURE 3.29 Example of a Good Illustration of a Graph

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).

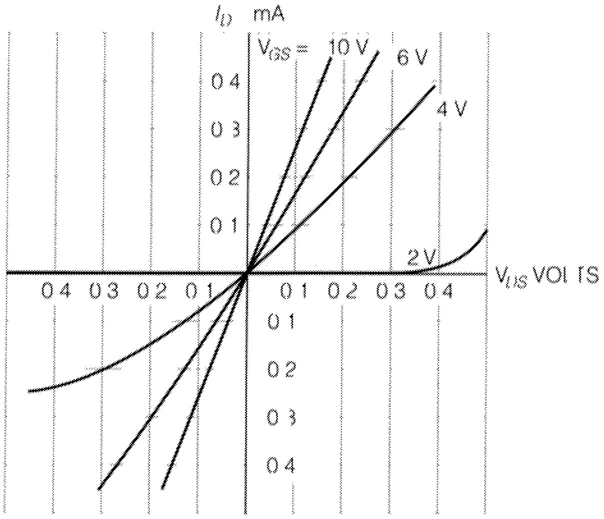
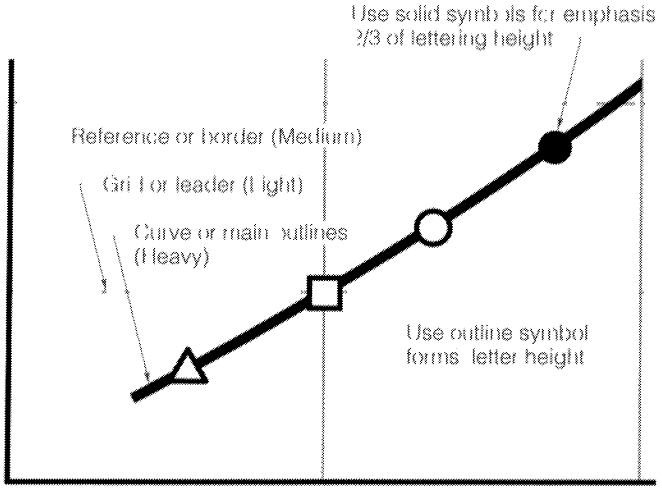


FIGURE 3.30 Voltage Versus Current Characteristics for an FET



Use solid symbols for emphasis 2/3 of lettering height

Reference or border (Medium)

Grid or leader (Light)

Curve or main outlines (Heavy)

Use outline symbol forms letter height

FIGURE 3.31 Lines and Symbols on Graphs

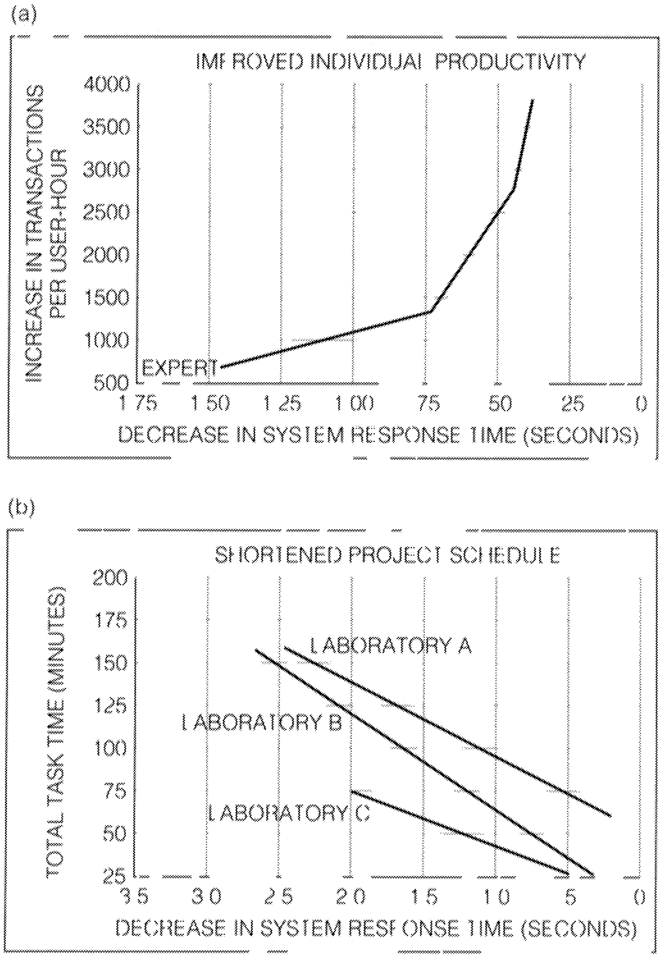


FIGURE 3.32 Computer Generated Graphs

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 ill 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

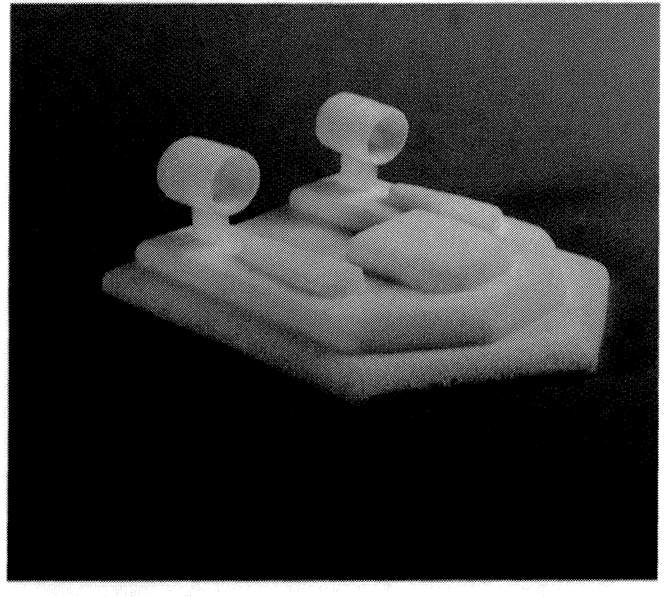


FIGURE 3.33 Model of a Hovercraft Produced by Carving Art Foam

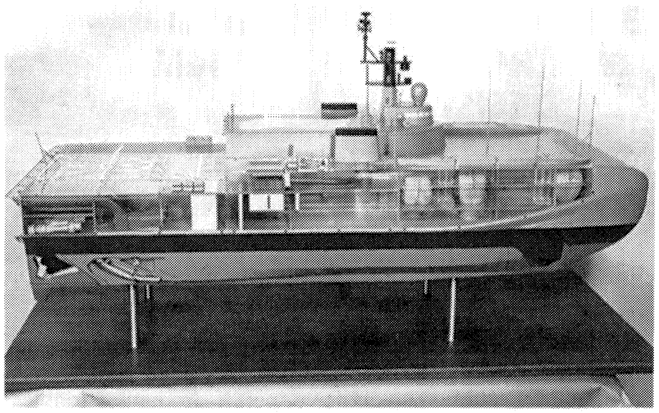


FIGURE 3 34 Surface Effect Ship Model

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 ICBMs, which made the aircraft obsolete. The development work was later used in the design of the Concord supersonic transport. The Stealth bomber (Fig. 3.40) involved technology and research developed 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.

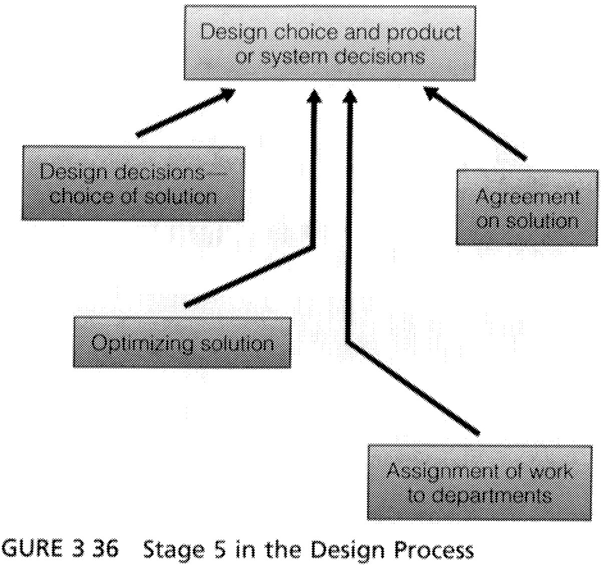


FIGURE 3.36 Stage 5 in the Design Process

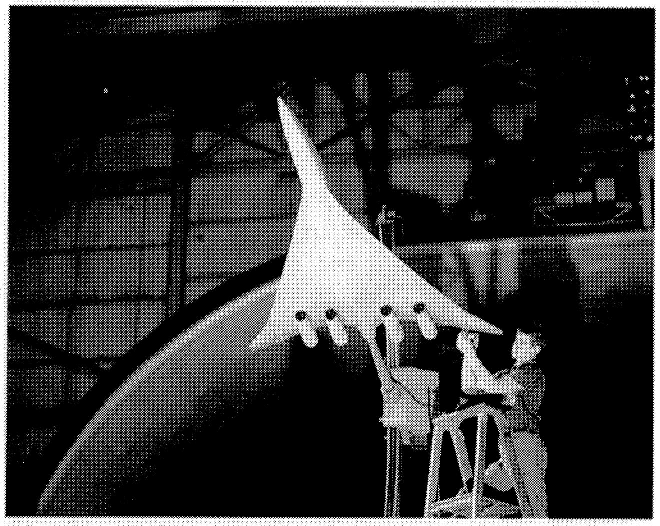


FIGURE 3.37 Model Being Prepared for Research and Development of Air Flows and Wing

FIGURE 3.38 Aircraft Model Being Prepared for Wind Tunnel Studies

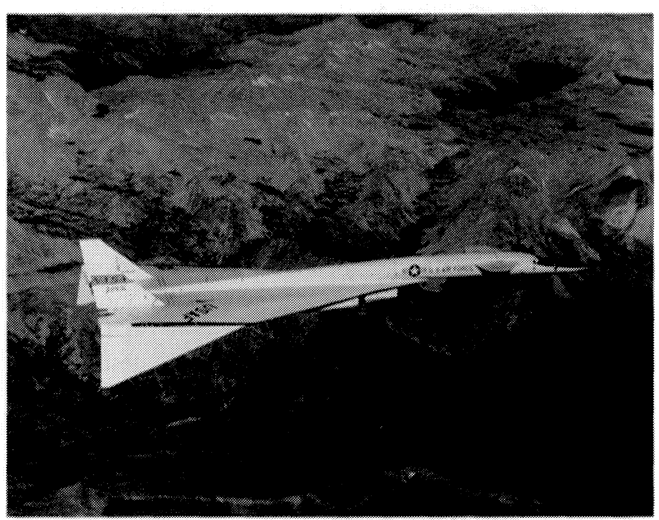


FIGURE 3 39 World's Largest Experimental Test Aircraft

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

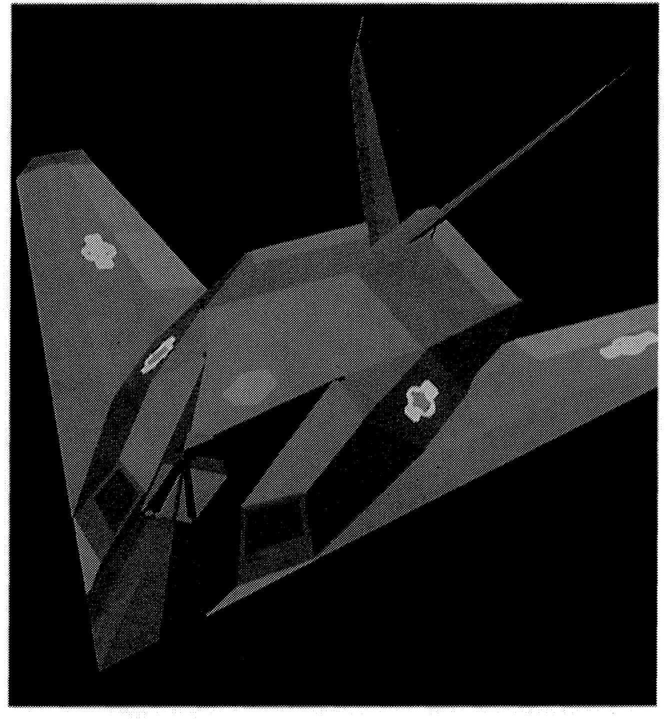


FIGURE 3 40 Stealth Bomber on Computer Screen (left) and in Flight (above) processes, and other design requirements can be further refined at this stage. Each feature and capability of the design should be analyzed and evaluated. Any changes should be made at this point so that during Stage 6 (development 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.

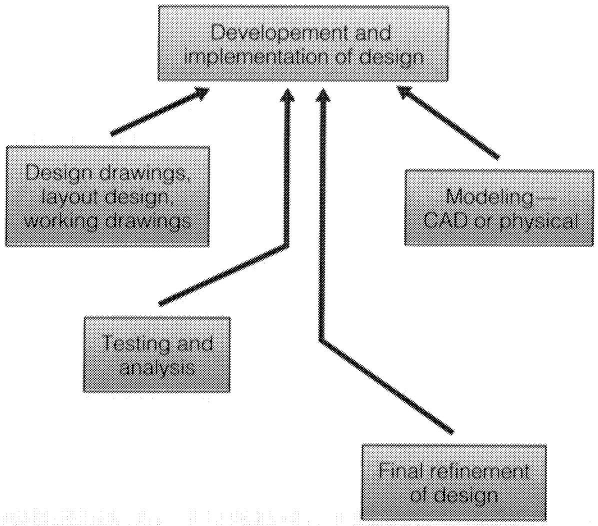


FIGURE 3.41 Stage 6 in the Design Process

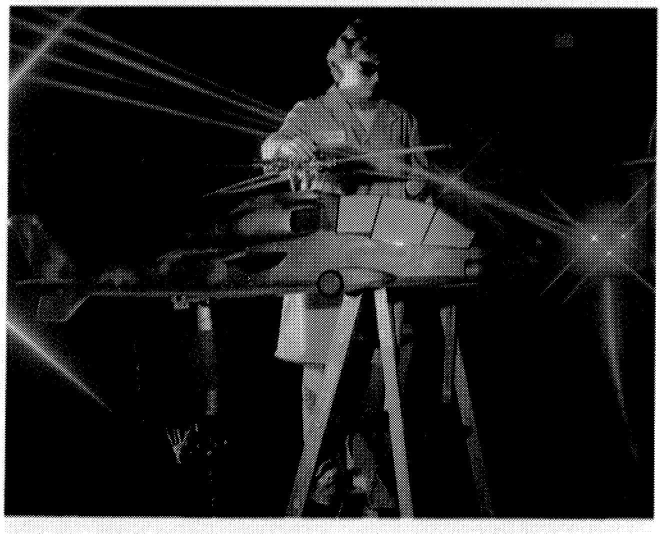


FIGURE 3.42 Test Being Prepared for the Scale Model of a Helicopter

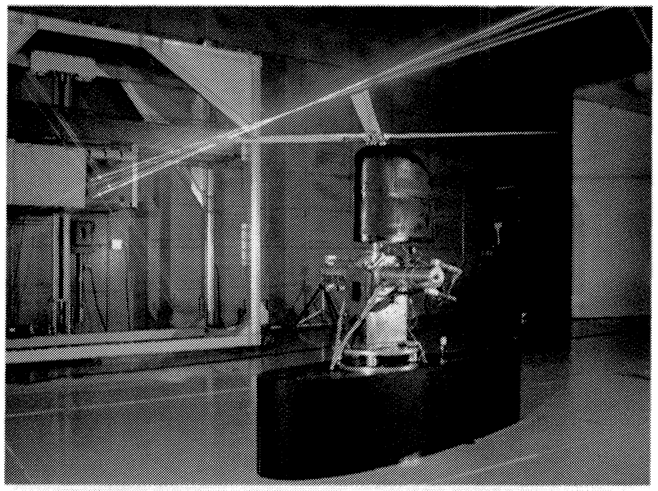


FIGURE 3.43 Rotor Test

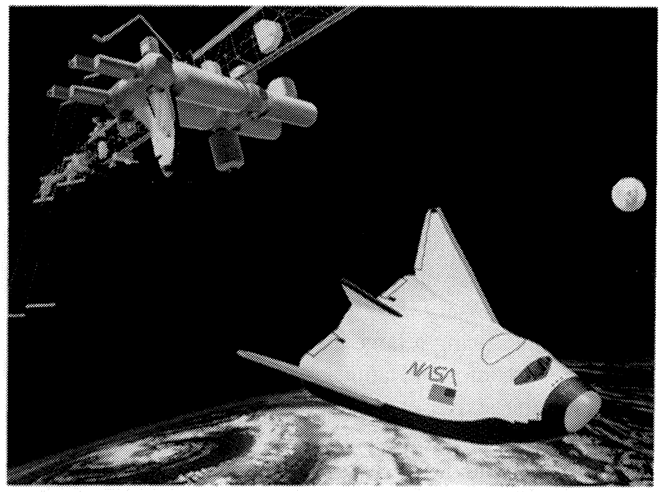


FIGURE 3.44 Space Shuttle Design

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 refitting 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 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

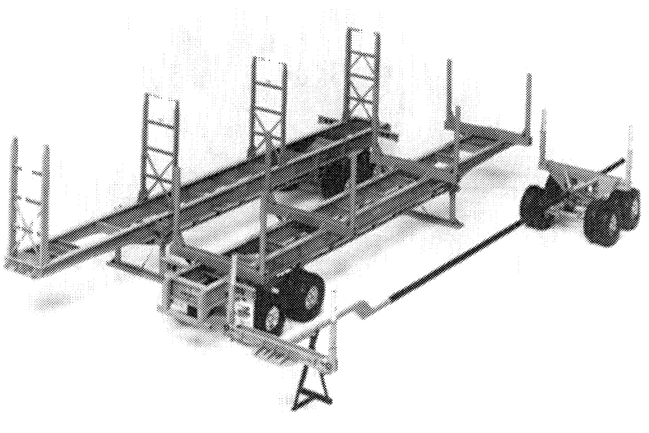


FIGURE 3.45 Tractor Trailer Design Models

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 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.

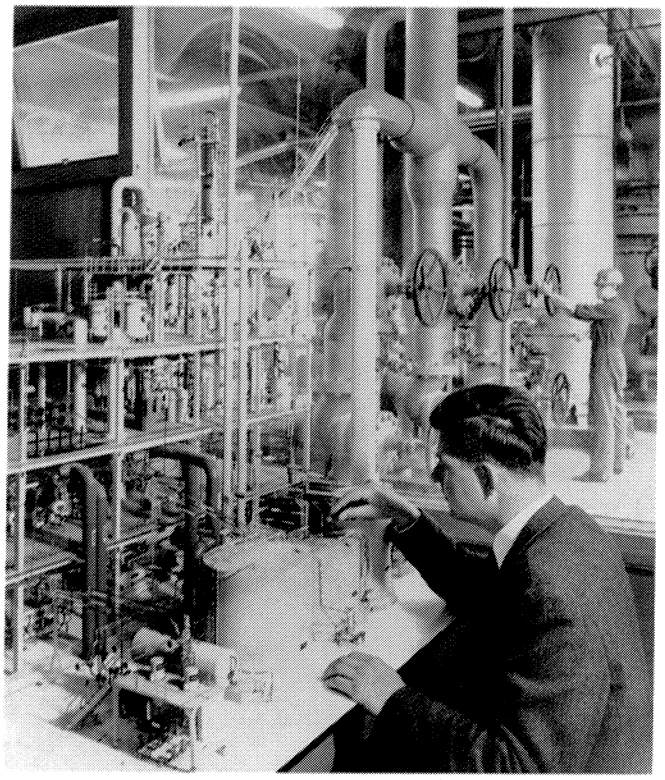


FIGURE 3.46 Working with a 3D Plant Model

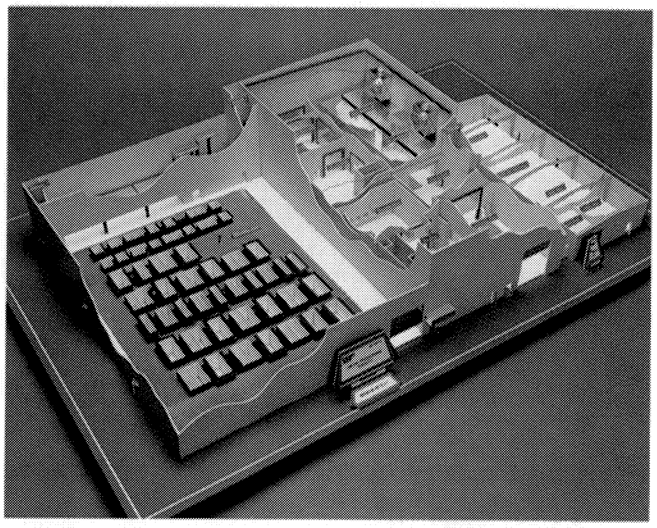


FIGURE 3.47 Scale Model of Metals and Spray Painting Facility

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

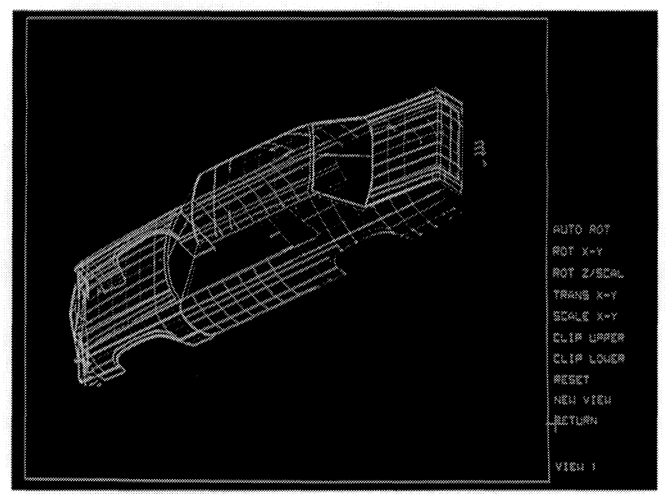


FIGURE 3.48 Wireframe Model of a Car

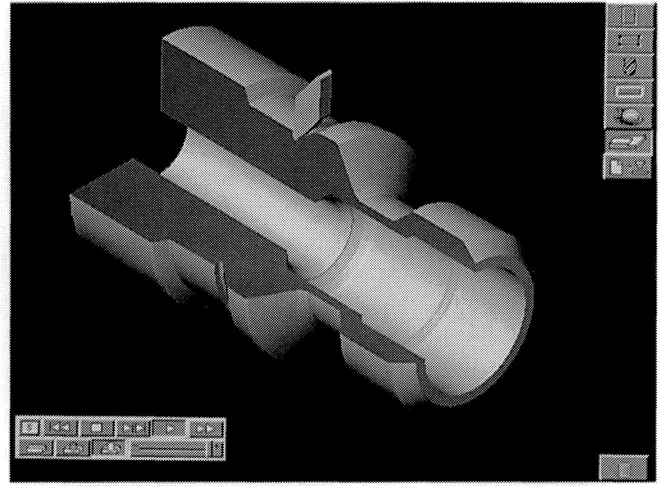


FIGURE 3.50 3D CAD Geometry Creation with Virtual Gibbs Features

structed 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 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

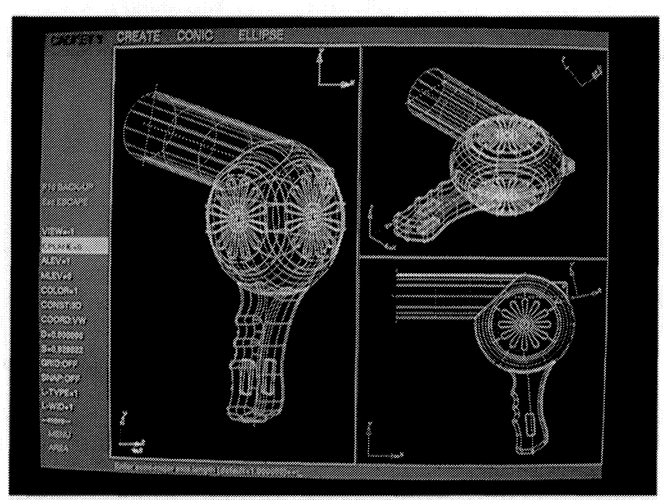


FIGURE 3.49 3D Wireframe Design Model of a Hairdryer

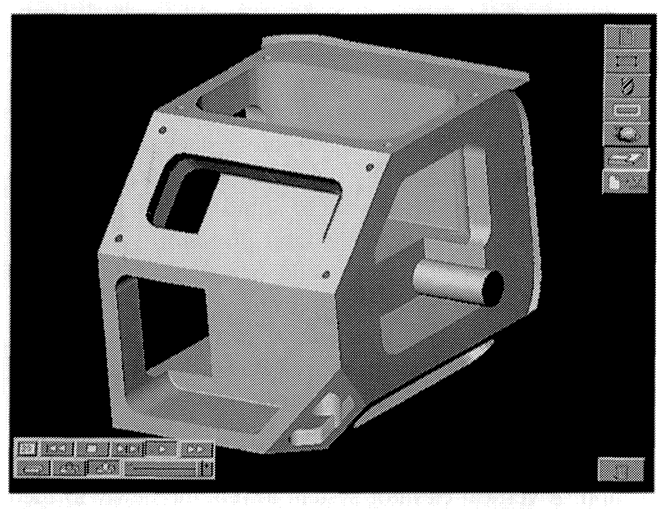


FIGURE 3.51 3D Real Time Cut Part Rendering with Virtual Gibbs System

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 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, sand blasting, painting, or dying.

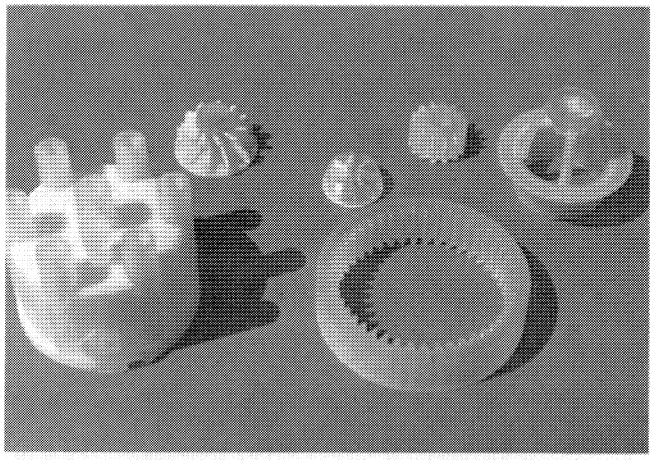


FIGURE 3.52 Parts Produced via Stereolithography

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.

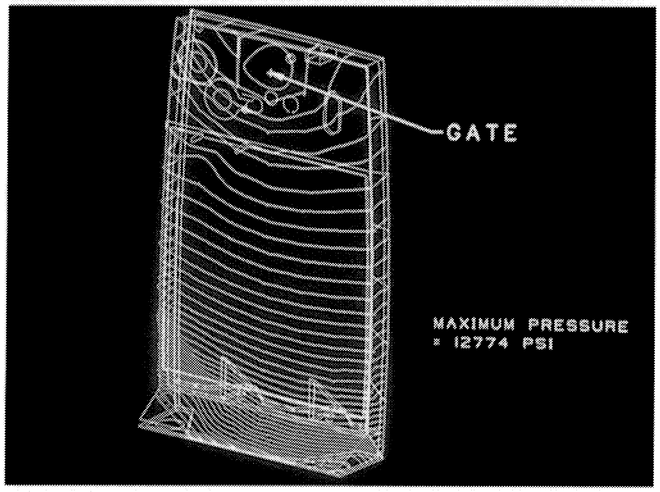


FIGURE 3.53 Wireframe Model of a Mold Part During Analysis

Focus On . . .

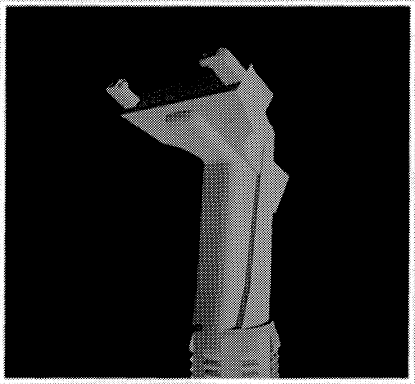
STEREOLITHOGRAPHY IN THE DESIGN PROCESS

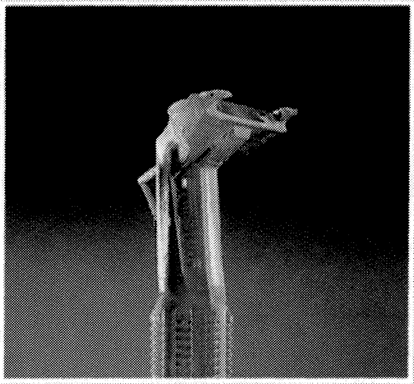
Stereolithography was invented in 1984, was patented in 1986, and became commercially available in early 1988. In 1989 only one commercial product was available. Today more than a dozen models are available from at least six manufacturers. In that brief time, stereolithography has moved from being primarily 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.

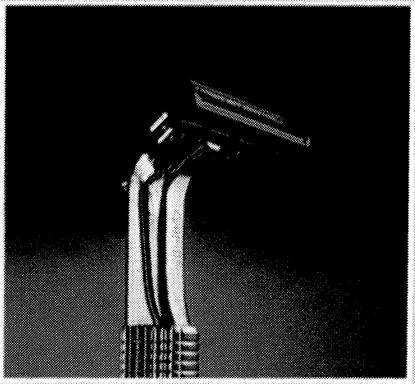
Stereolithography can produce a solid object from a CAD model (surface or solid) (see figure) quickly and efficiently by directing ultraviolet laser radiation onto a liquid photopolymer. The photopolymer hardens when exposed to this laser beam. Each pass produces a hard polymer down to a certain depth. 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).

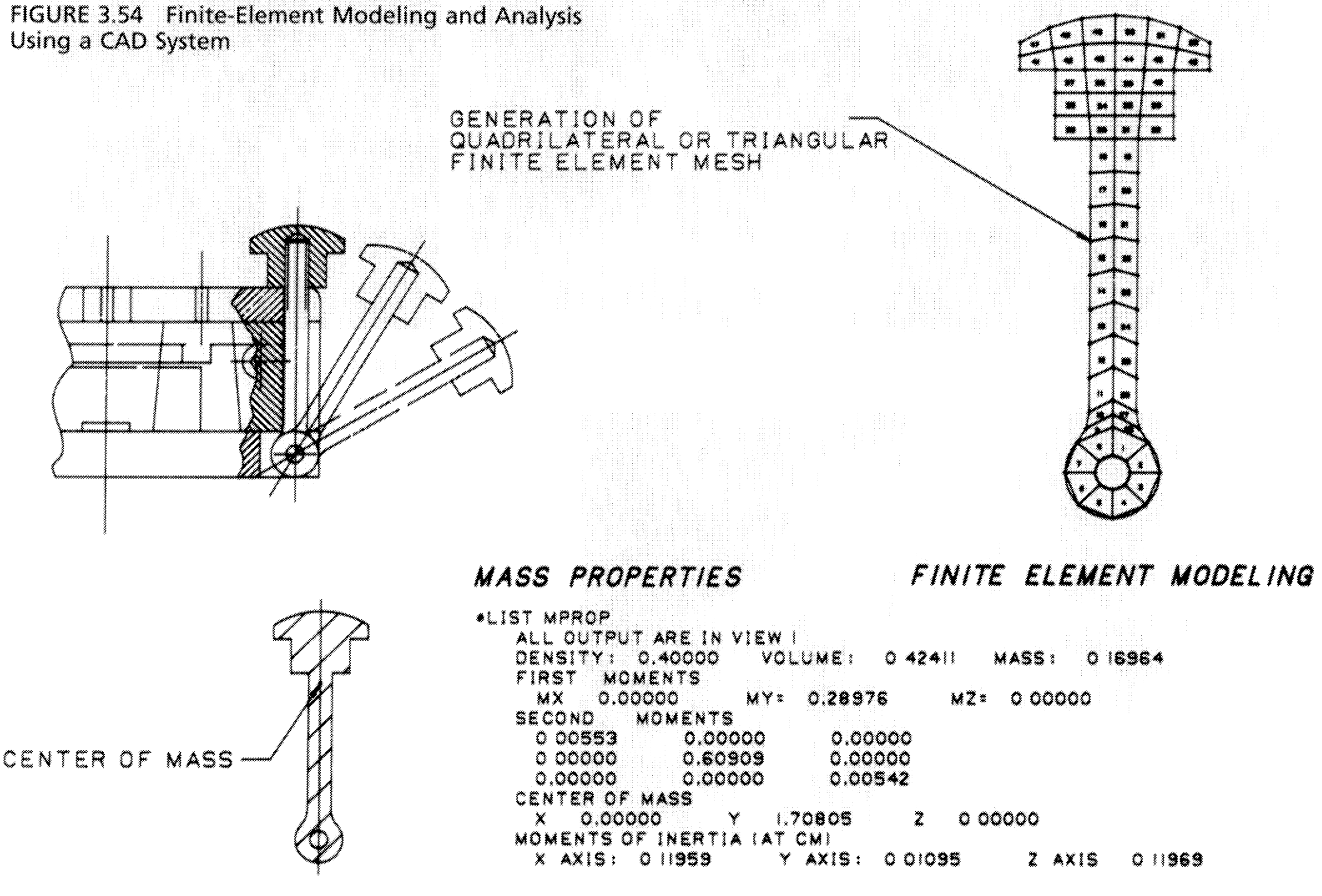
Once the analysis is performed, numerical results are returned to the CAD system and the finite element analysis postprocessing phase begins. This involves reviewing the analysis results, determining problem areas, and modifying the design.

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



```
*LIST MPROP
   ALL OUTPUT ARE IN VIEW 1
   DENSITY:  0.40000    VOLUME:   0.42411    MASS:   0.16964
   FIRST   MOMENTS
     MX    0.00000        MY=  0.28976       MZ=  0.00000
   SECOND    MOMENTS
     0.00553       0.00000       0.00000
     0.00000       0.60909       0.00000
     0.00000       0.00000       0.00542
   CENTER OF MASS
     X   0.00000       Y   1.70805       Z   0.00000
   MOMENTS OF INERTIA (AT CM)
     X AXIS:  0.11959       Y AXIS:  0.01095       Z AXIS   0.11969
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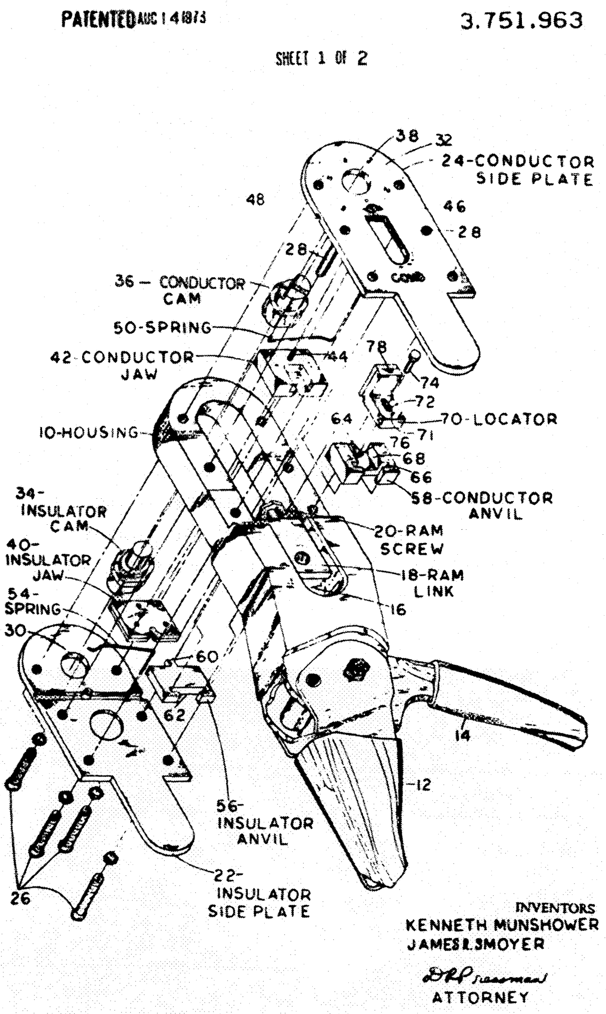


FIGURE 3.55 Patent Drawing

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 process, 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.

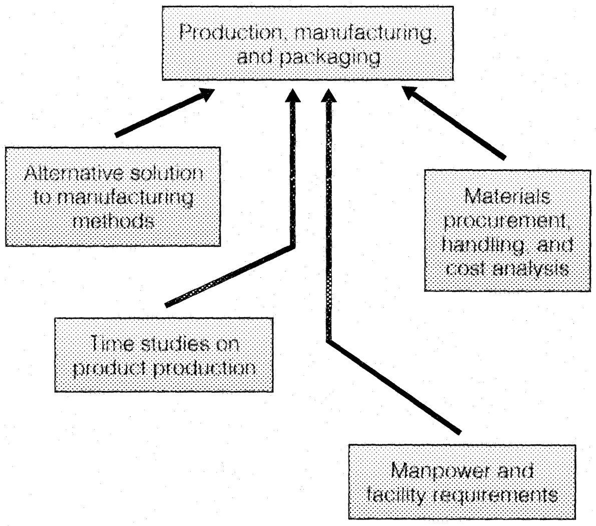


FIGURE 3.56 Stage 7 in the Design Process

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.

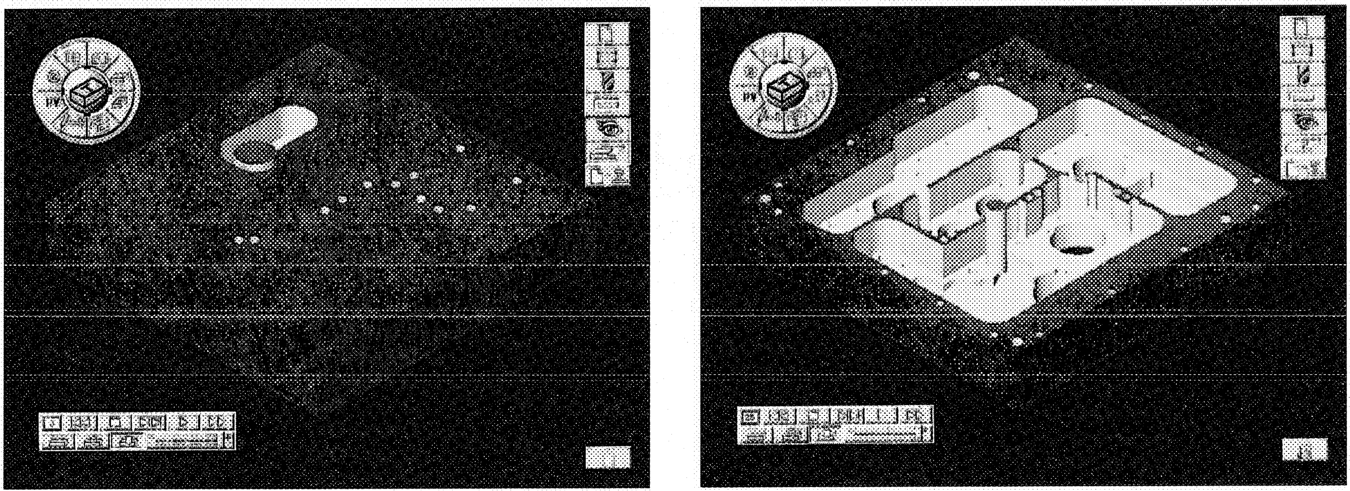
Of course, the selection of materials in Stage 5 determines many of the methods used in manufacturing the part or product. Comprehensive solid modeling packages incorporate many features to help the engineer understand and model the manufacturing process. The steps shown in Figure 3.57 illustrate how 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:

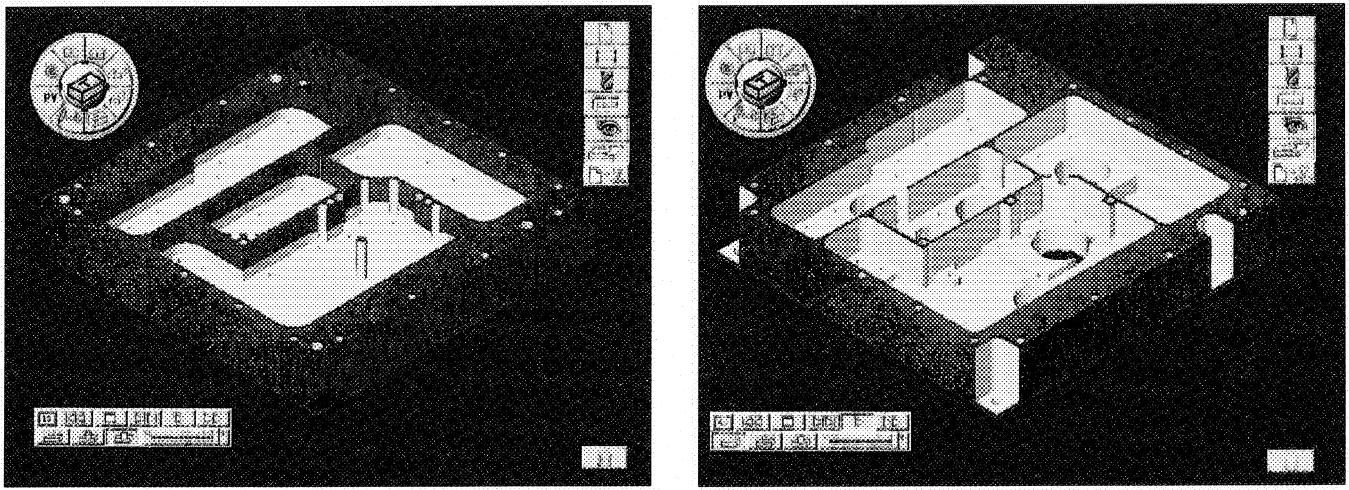
- Machining
    drilling
    boring
    milling
    planing
    reaming
    broaching
    turning
- Welding
- Casting
- Forging
- Forming
- Stamping
- Extruding
- Bending

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 autofacturing 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 autofacture; a simple part will require less manipulation by a robot. Thus, keeping the 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)].

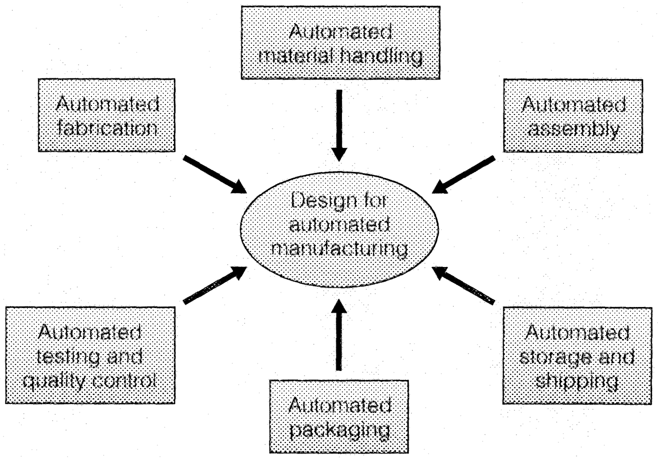


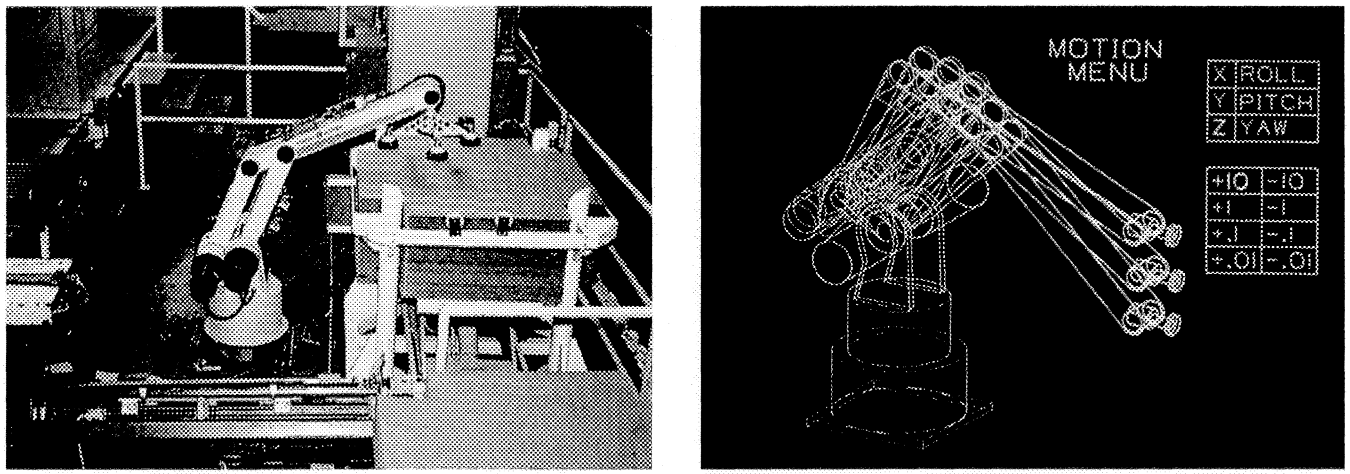
FIGURE 3.58 Design for Automated Manufacturing

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.

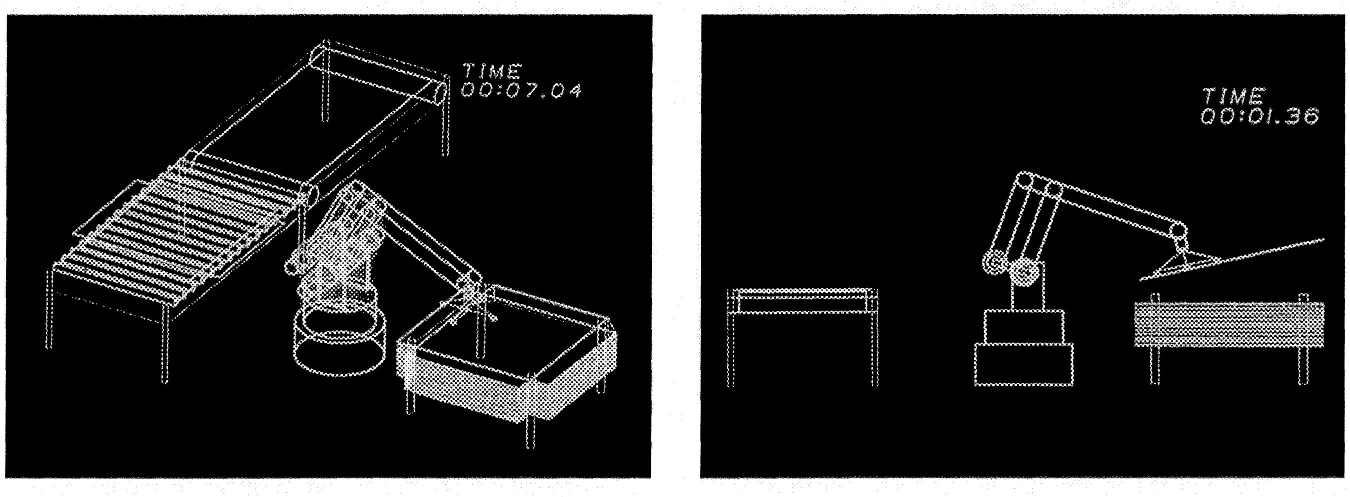
1. Incorporate every design aid available to reduce manufacturing costs, without adversely influencing the product's essential features.
2. Understand the basic capabilities and limitations of your in-house production and outside vendors' capabilities pertaining to the part's manufacturing and materials.
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 warehousing 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 manufacturing 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 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.

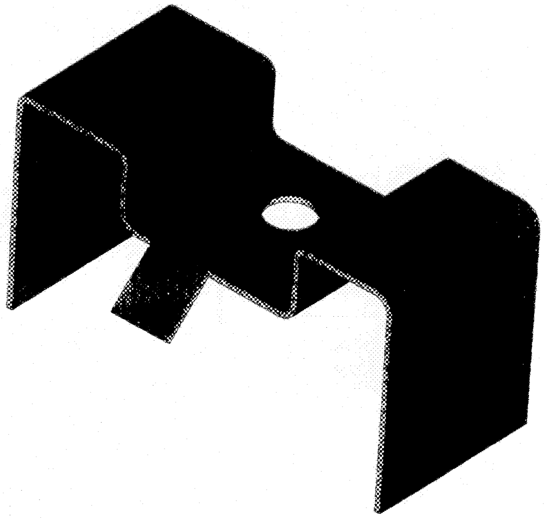


FIGURE 3.60 **Example of Sheet Metal Used in Industrial Packaging**

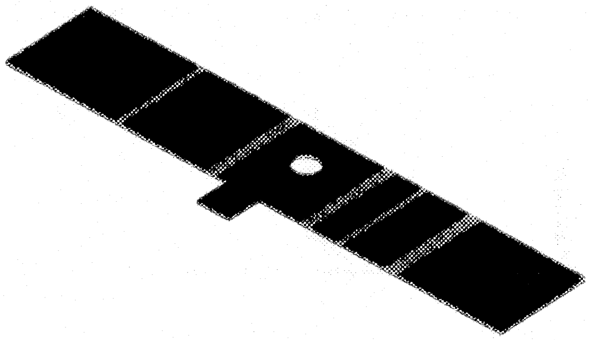


FIGURE 3.61 **Sheet Metal Flat Pattern Development Using 3D CAD**

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

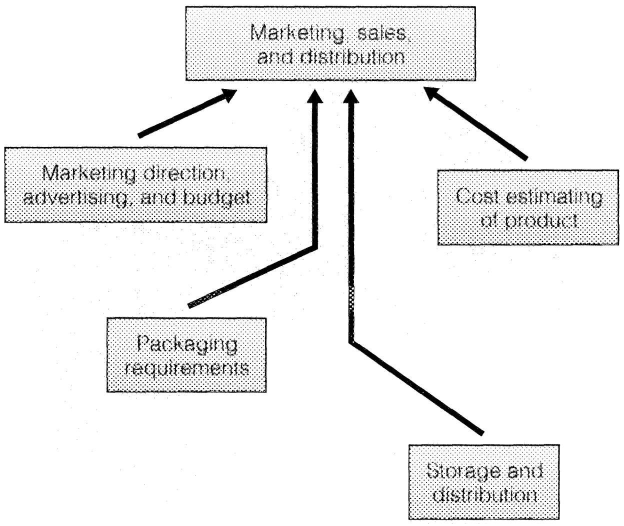


FIGURE 3.62 Stage 8 in the Design Process

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.

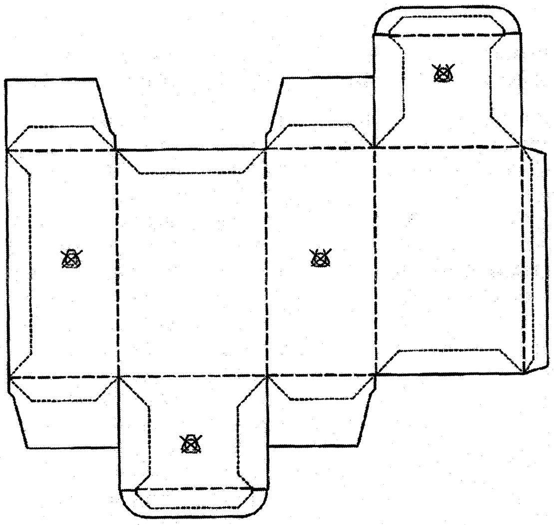
Software programs have been designed specifically for the packaging industry. Software is available that offers a library of parametric designs for creating standard box configurations. The designer simply provides appropriate dimensions to any box design (for example, the standard reverse tuck—a common 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.

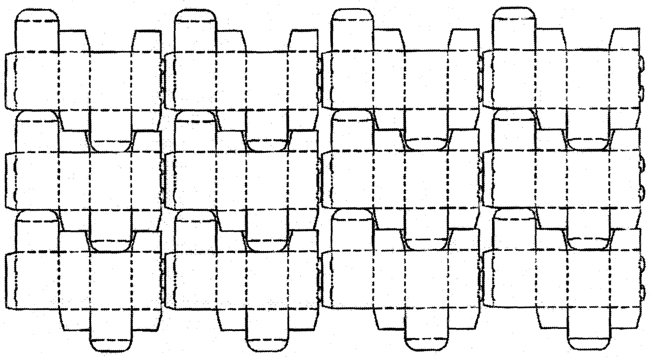
Once the individual box design is complete [Fig. 3.63(a)], copies are nested together [Fig. 3.63(b)], mirroring and duplicating the images and interlocking them like jigsaw puzzle pieces to produce as many boxes as possible from a single sheet of cardboard. The software performs automatic bridging, a 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.

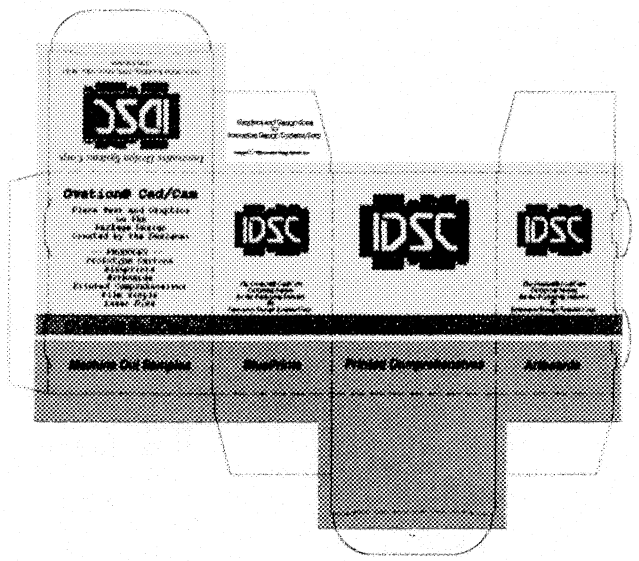
While the ability to connect CAD box design to CAM machining has been available for some time, the concept of integrating the process with packaging graphics is a new idea that offers major advantages. The capability to prepare the entire design [Fig. 3.63(c)], including the structure, graphics, and 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

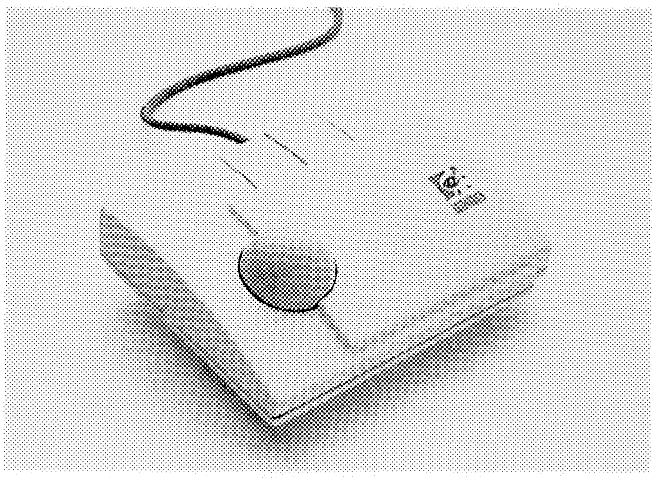
The device shown in Figure 3.64(a) is an example of a well-designed consumer product created on a CAD system. Logitech manufactures a variety of mouse devices for computers. You may even have one of their products in your school on your CAD system. Over the years the designers at Logitech became aware 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

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 SalesForecst	0	06-01-89	06-01-89	Comp./Crit.
Rel IntlShipInfo	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.
SubmitPCBartwork	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 Componts	0	07-14-89	07-14-89	Scheduled
Rec 60 PWA's	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

FIGURE 3.64 Trackman Mouse

Heading Task Resource	Dur	Schd Start	Schd Finish	Status
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
Rel 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
Rel 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 PrePartsList	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 Ul 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.
Tray	66	05-26-89	08-30-89	In Prog.
RecTrckballProto	0	05-26-89	05-26-89	Comp./Crit.
Make Proto Drwgs	2w	05-26-89	06-14-89	Comp./Crit
Build Tooling	4w	07-17-89	08-11-89	Scheduled
Rec Hand Samples	0	08-11-89	08-11-89	Scheduled
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 PackageSpec	1	07-14-89	07-14-89	Scheduled
Make Die Vinyl	3	07-17-89	07-19-89	Scheduled
Rel 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	
Mftr 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

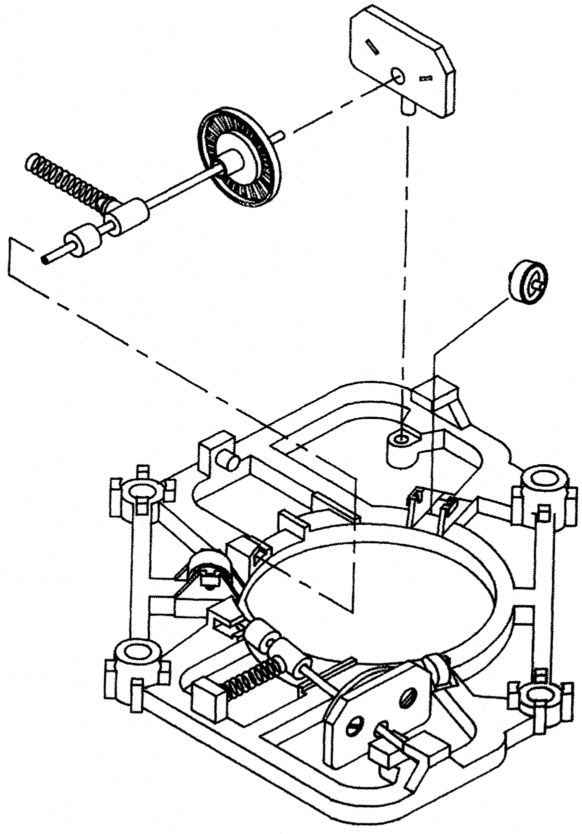
(b) Critical-path schedule for Trackman roller ball mouse—*Continues*

FIGURE 3.64 Trackman Mouse—*Continues*

Heading		**Schd**	**Schd**	
Task Resource	**Dur**	**Start**	**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 Approvl	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 MPS0		07-14-89	07-14-89	Scheduled
Rel PWA Schedule	0	07-20-89	07-20-89	Scheduled
Rel SW DupeSched	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->Mftr	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 Bareboards2	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 Applictn	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 PWA's #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 PWA's #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*

FIGURE 3.64 Trackman Mouse—*Continued*

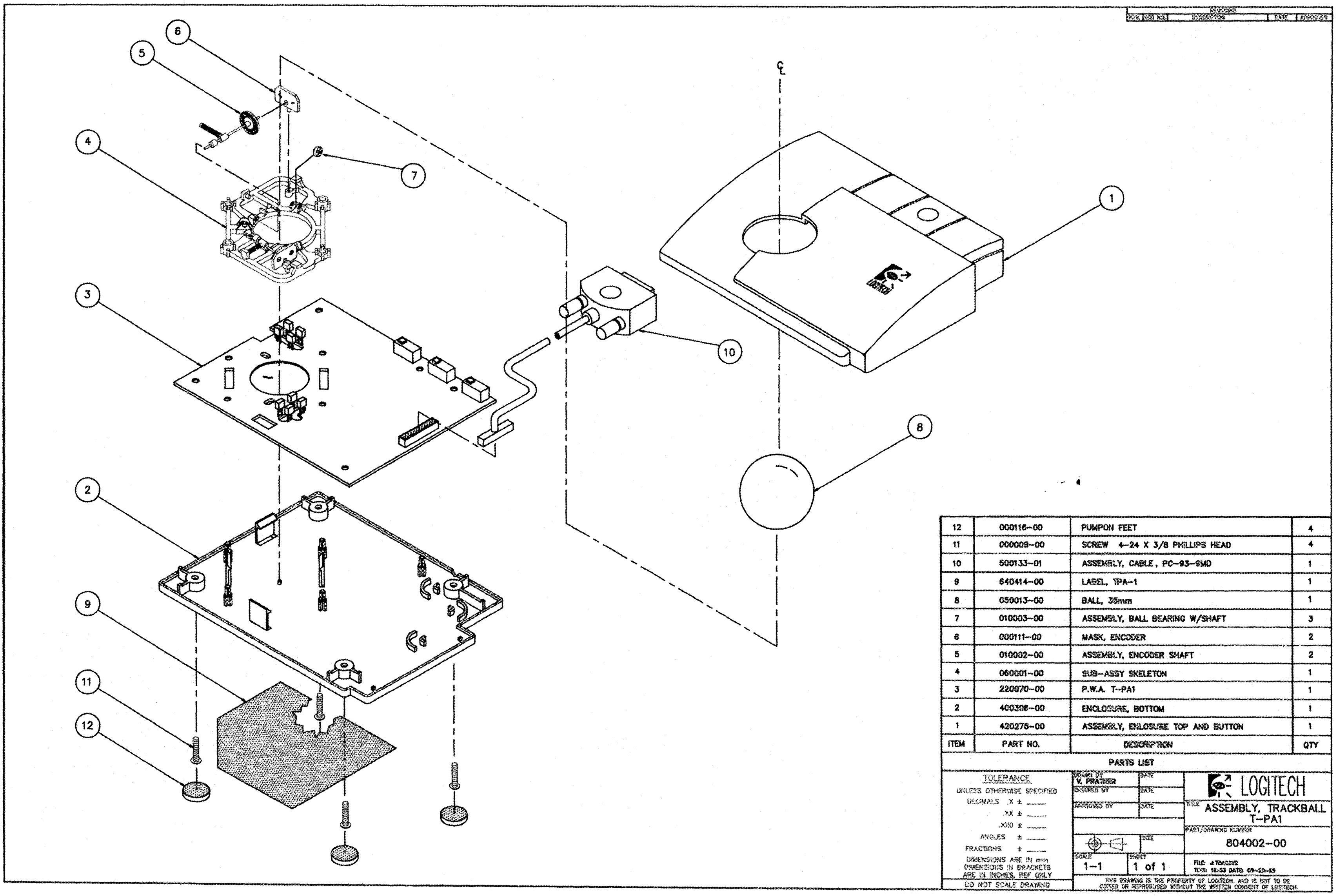


(c) Trackball subassembly

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.

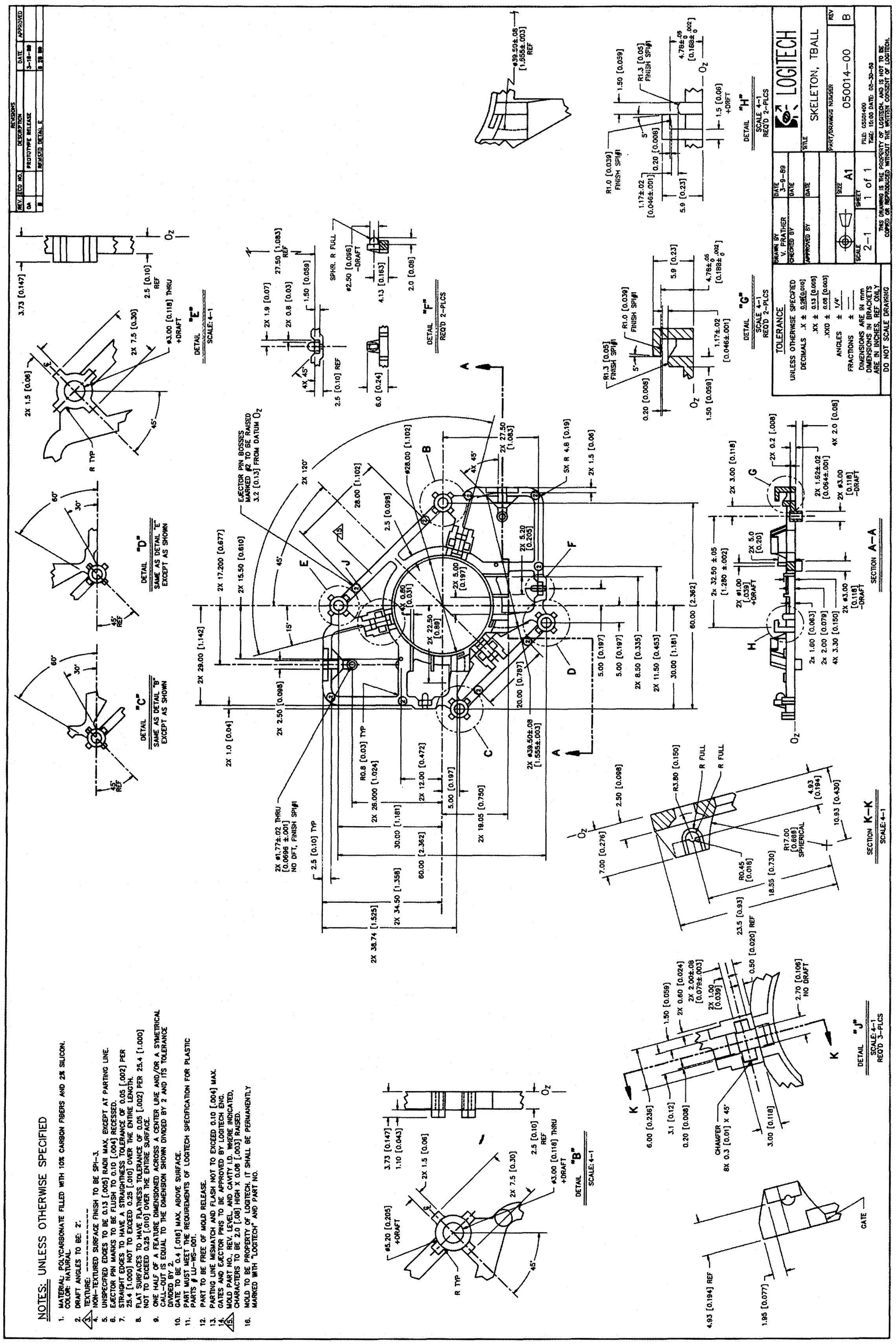


ITEM	PART NO.	DESCRIPTION	QTY
12	000116–00	PUMPON FEET	4
11	000009–00	SCREW 4–24 X 3/8 PHILLIPS HEAD	4
10	500133–01	ASSEMBLY, CABLE, PC–93–SMD	1
9	640414–00	LABEL, TPA–1	1
8	050013–00	BALL, 35mm	1
7	010003–00	ASSEMBLY, BALL BEARING W/SHAFT	3
6	000111–00	MASK, ENCODER	2
5	010002–00	ASSEMBLY, ENCODER SHAFT	2
4	060001–00	SUB–ASSY SKELETON	1
3	220070–00	P.W.A. T–PA1	1
2	400306–00	ENCLOSURE, BOTTOM	1
1	420276–00	ASSEMBLY, ENCLOSURE TOP AND BUTTON	1

PARTS LIST

(d) Trackball assembly

FIGURE 3.64 Trackman Mouse—*Continues*



REVISIONS

REV.	ECO NO.	DESCRIPTION	DATE	APPROVED
0A		PROTOTYPE RELEASE	3-18-89	
B		REMOVED DETAIL E	8-28-89	

NOTES: UNLESS OTHERWISE SPECIFIED

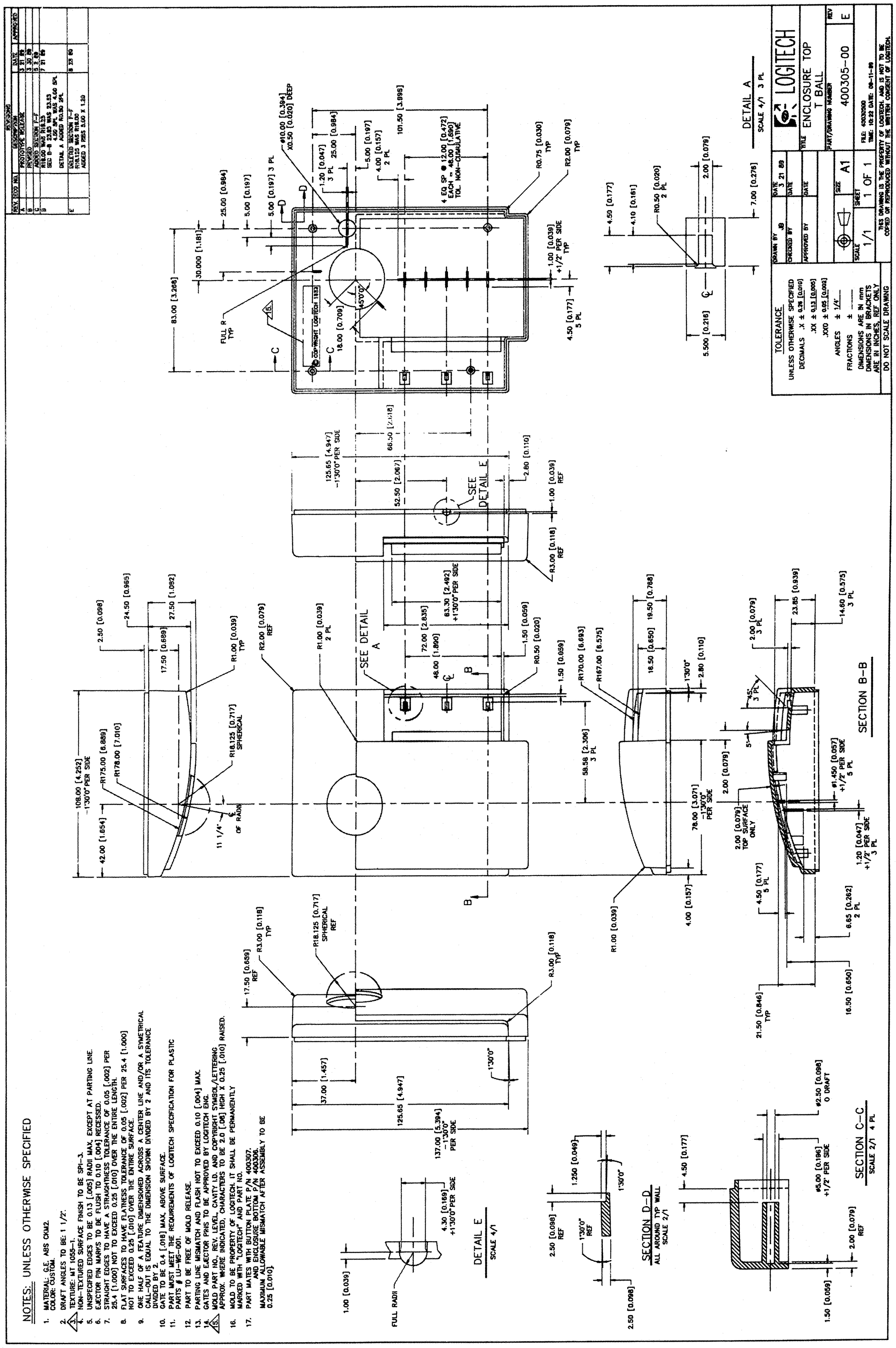
1. MATERIAL: POLYCARBONATE FILLED WITH 10% CARBON FIBERS AND 2% SILICON. COLOR: NATURAL.
2. DRAFT ANGLES TO BE: 2°.
3. TEXTURE: ----------
4. NON-TEXTURED SURFACE FINISH TO BE SPI-3.
5. UNSPECIFIED EDGES TO BE 0.13 [.005] RADII MAX, EXCEPT AT PARTING LINE.
6. EJECTOR PIN MARKS TO BE FLUSH TO 0.10 [.004] RECESSED.
7. STRAIGHT EDGES TO HAVE A STRAIGHTNESS TOLERANCE OF 0.05 [.002] PER 25.4 [1.000] NOT TO EXCEED 0.25 [.010] OVER THE ENTIRE LENGTH.
8. FLAT SURFACES TO HAVE FLATNESS TOLERANCE OF 0.05 [.002] PER 25.4 [1.000] NOT TO EXCEED 0.25 [.010] OVER THE ENTIRE SURFACE.
9. ONE HALF OF A FEATURE DIMENSIONED ACROSS A CENTER LINE AND/OR A SYMETRICAL CALL-OUT IS EQUAL TO THE DIMENSION SHOWN DIVIDED BY 2 AND ITS TOLERANCE DIVIDED BY 2.
10. GATE TO BE 0.4 [.016] MAX. ABOVE SURFACE.
11. PART MUST MEET THE REQUIREMENTS OF LOGITECH SPECIFICATION FOR PLASTIC PARTS # LU-WS-001.
12. PART TO BE FREE OF MOLD RELEASE.
13. PARTING LINE MISMATCH AND FLASH NOT TO EXCEED 0.10 [.004] MAX.
14. GATES AND EJECTOR PINS TO BE APPROVED BY LOGITECH ENG.
15. MOLD PART NO., REV. LEVEL, AND CAVITY I.D. WHERE INDICATED. CHARACTERS TO BE 2.0 [.08] HIGH X 0.08 [.003] RAISED.
16. MOLD TO BE PROPERTY OF LOGITECH. IT SHALL BE PERMANENTLY MARKED WITH "LOGITECH" AND PART NO.

TOLERANCE
UNLESS OTHERWISE SPECIFIED
DECIMALS .X ± 0.25 [0.010]
.XX ± 0.13 [0.005]
.XX0 ± 0.08 [0.003]
ANGLES ± 1/4°
FRACTIONS ± ——
DIMENSIONS ARE IN mm
DIMENSIONS IN BRACKETS ARE IN INCHES, REF ONLY
DO NOT SCALE DRAWING

DRAWN BY V. PRATHER DATE 3-9-89
CHECKED BY DATE
APPROVED BY DATE
LOGITECH
TITLE SKELETON, TBALL
PART/DRAWING NUMBER 050014-00
REV B
SIZE A1
SCALE 2-1
SHEET 1 of 1
FILE: 05001400
TIME: 15:00 DATE: 08-30-89
THIS DRAWING IS THE PROPERTY OF LOGITECH, AND IS NOT TO BE COPIED OR REPRODUCED WITHOUT THE WRITTEN CONSENT OF LOGITECH.

(e) Detail of skeleton, Trackball

FIGURE 3.64 Trackman Mouse—*Continued*



NOTES: UNLESS OTHERWISE SPECIFIED

1. MATERIAL: G.E. ABS CKM2.
   COLOR: CUSTOM.
2. DRAFT ANGLES TO BE: 1 1/2°.
3. TEXTURE: MT 1055–1.
4. NON–TEXTURED SURFACE FINISH TO BE SPI–3.
5. UNSPECIFIED EDGES TO BE 0.13 [.005] RADII MAX, EXCEPT AT PARTING LINE.
6. EJECTOR PIN MARKS TO BE FLUSH TO 0.10 [.004] RECESSED.
7. STRAIGHT EDGES TO HAVE A STRAIGHTNESS TOLERANCE OF 0.05 [.002] PER 25.4 [1.000] NOT TO EXCEED 0.25 [.010] OVER THE ENTIRE LENGTH.
8. FLAT SURFACES TO HAVE FLATNESS TOLERANCE OF 0.05 [.002] PER 25.4 [1.000] NOT TO EXCEED 0.25 [.010] OVER THE ENTIRE SURFACE.
9. ONE HALF OF A FEATURE DIMENSIONED ACROSS A CENTER LINE AND/OR A SYMETRICAL CALL–OUT IS EQUAL TO THE DIMENSION SHOWN DIVIDED BY 2 AND ITS TOLERANCE DIVIDED BY 2.
10. GATE TO BE 0.4 [.016] MAX, ABOVE SURFACE.
11. PART MUST MEET THE REQUIREMENTS OF LOGITECH SPECIFICATION FOR PLASTIC PARTS # LU–WS–001.
12. PART TO BE FREE OF MOLD RELEASE.
13. PARTING LINE MISMATCH AND FLASH NOT TO EXCEED 0.10 [.004] MAX.
14. GATES AND EJECTOR PINS TO BE APPROVED BY LOGITECH ENG.
15. MOLD PART NO., REV. LEVEL, CAVITY I.D. AND COPYRIGHT SYMBOL/LETTERING APPROX. WHERE INDICATED, CHARACTERS TO BE 2.0 [.08] HIGH X 0.25 [.010] RAISED.
16. MOLD TO BE PROPERTY OF LOGITECH. IT SHALL BE PERMANENTLY MARKED WITH "LOGITECH" AND PART NO.
17. PART MATES WITH BUTTON PLATE P/N 400307.
    AND ENCLOSURE BOTTOM P/N 400306.
    MAXIMUM ALLOWABLE MISMATCH AFTER ASSEMBLY TO BE 0.25 [0.010].

REVISIONS

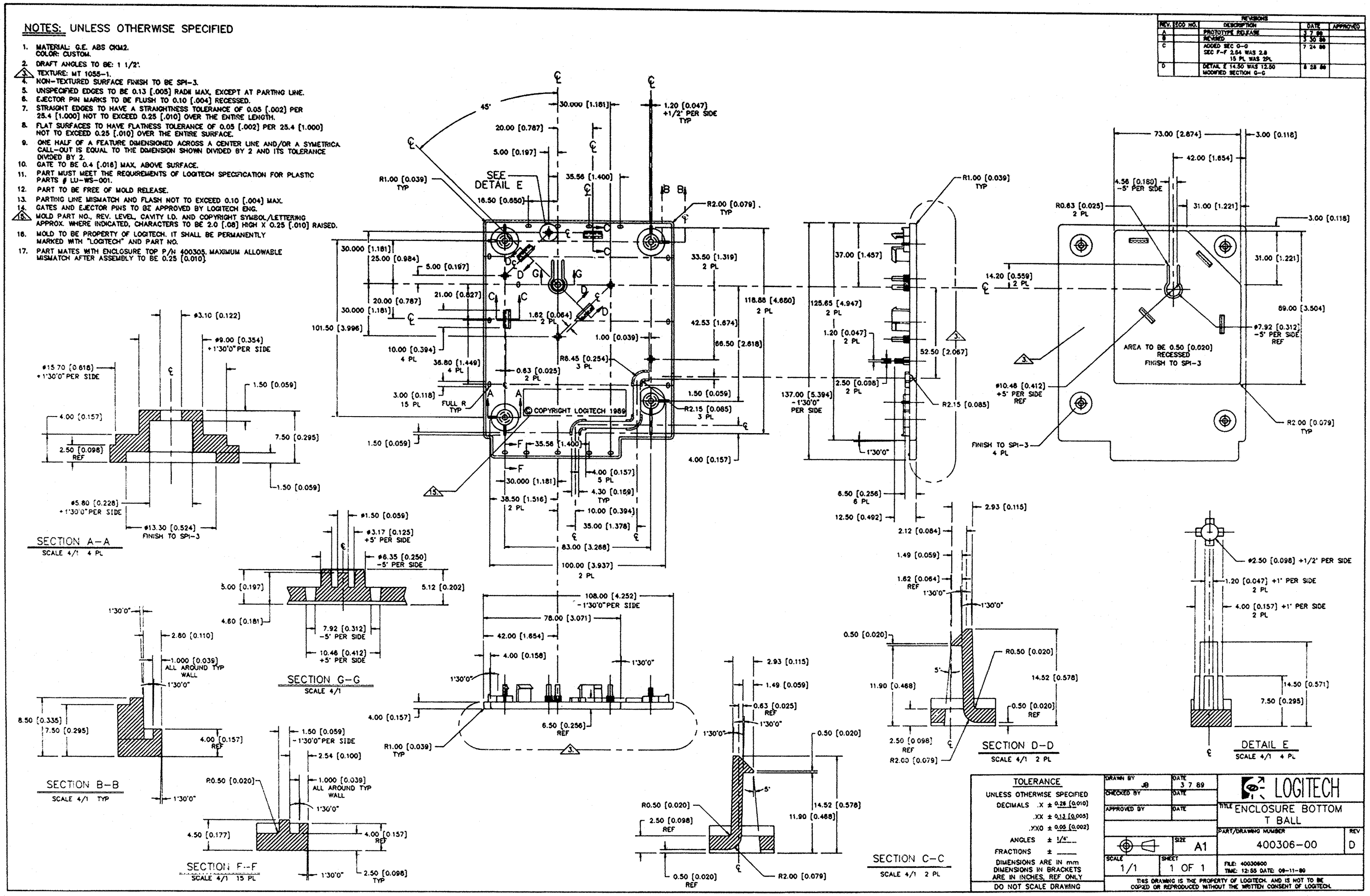
REV.	ECO NO.	DESCRIPTION	DATE	APPROVED
A		PROTOTYPE RELEASE	3 21 89	
B		REVISED	3 30 89	
C		ADDED SECTION F–F	5 2 89	
D		R18.00 WAS R18.25 SEC B–B 23.85 WAS 23.53 4.50 5PL WAS 4.00 5PL DETAIL A ADDED R0.50 2PL	7 21 89	
E		DELETED SECTION F–F R18.125 WAS R18.00 ADDED 3 RIBS 5.00 X 1.20	8 23 89	

TOLERANCE
UNLESS OTHERWISE SPECIFIED
DECIMALS .X ± 0.26 [0.010]
.XX ± 0.13 [0.005]
.XXO ± 0.05 [0.002]
ANGLES ± 1/4°
FRACTIONS ± ____
DIMENSIONS ARE IN mm
DIMENSIONS IN BRACKETS ARE IN INCHES, REF ONLY
DO NOT SCALE DRAWING

DRAWN BY JB DATE 3 21 89
CHECKED BY DATE
APPROVED BY DATE
LOGITECH
TITLE ENCLOSURE TOP T BALL
SIZE A1
PART/DRAWING NUMBER 400305–00
REV E
SCALE 1/1
SHEET 1 OF 1
FILE: 40030500
TIME: 10:22 DATE: 08–11–89
THIS DRAWING IS THE PROPERTY OF LOGITECH. AND IS NOT TO BE COPIED OR REPRODUCED WITHOUT THE WRITTEN CONSENT OF LOGITECH.

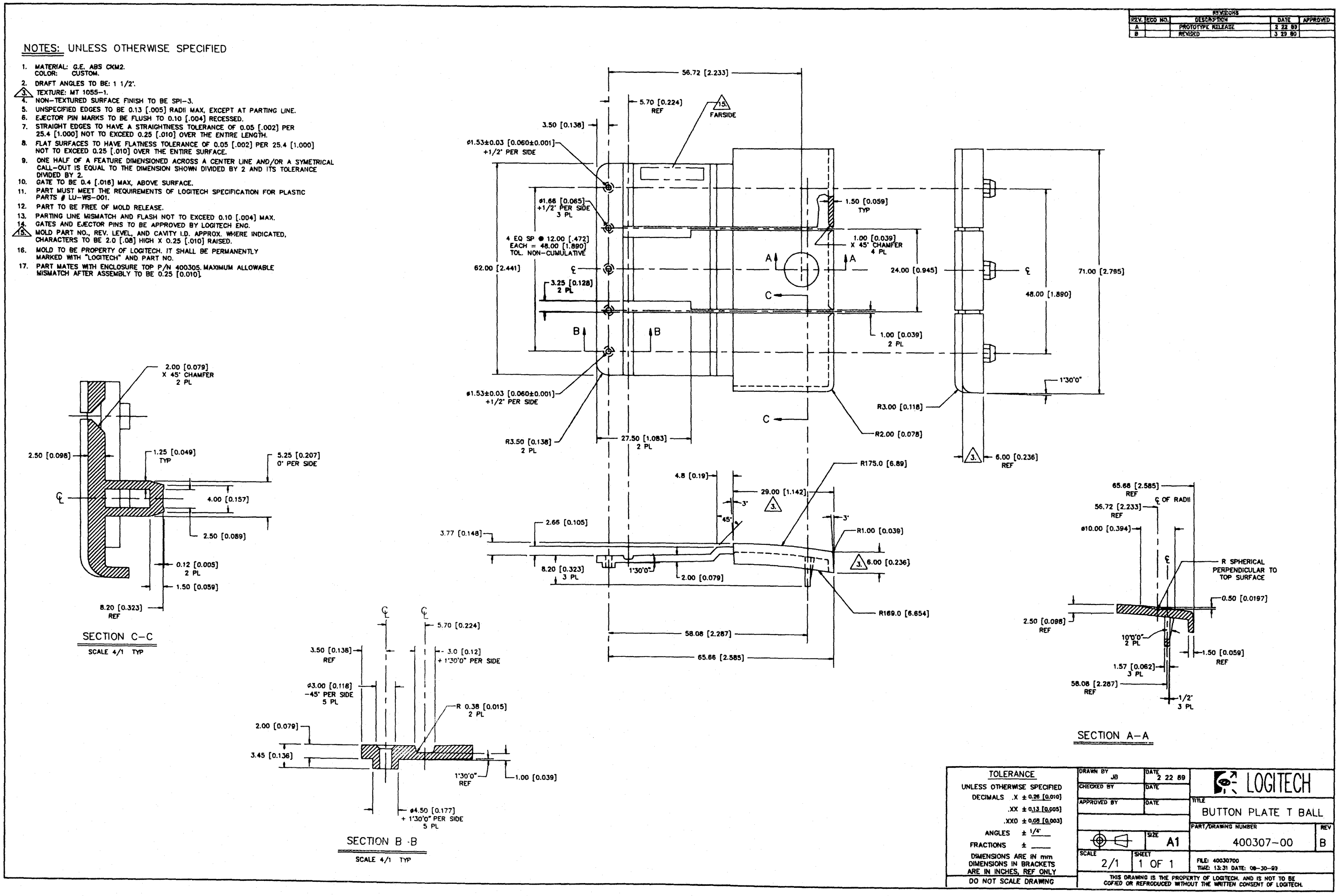
(f) Top enclosure of Trackball

FIGURE 3.64 Trackman Mouse—*Continues*



(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.
   c. Similarities, environmental requirements
   d. Checklist, brainstorming, material options
   e. Is there a simpler way?
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			
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?			
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			
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			
a. Could the product be affected by any of the following extremes at the customer's place of business:			
i. Voltage surges?			
ii. Service water hardness?			
iii. Pressure?			
iv. Temperature?			
v. External vibration?			
vi. External shock?			
vii. Ambient temperature?			
vii. 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			
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			
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 perfomance 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-sevice nondestructive evaluation?			

Continued

TABLE 3.1 Product Design Checklist—*Continued*

B. Good Design Practices			
1. Parts Breakdown			
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?			
2. Safety Practices			
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?			
3. Assembly and Installation			
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?			
4. Parts and Components			
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?			
5. Design Selection			
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?			
6. Measurements and Control			
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?			
7. Nondestructive Evaluation			
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			
1. Has an engineering analysis been performed to investigate			
a. The use of alternate, less expensive materials?			
b. Redesigning to reduce initial costs?			

TABLE 3.1 Product Design Checklist—*Continued*

C. Minimizing Costs—*Continued*			
c. The cost of maintenance, repairs, or operation?			
2. How reliable is the cost estimate?			
3. Is a service warranty provided by the manufacturer?			
a. Is the manufacturer's reputation for service good?			
b. How quickly will service be provided?			
4. Have manufacturing and production costs been optimized:			
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?			
D. Improving Reliability			
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.?			
E. Manufacturability and Production			
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?			
F. Shipping and Storage Requirements			
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:			
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. Patient 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?			
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a. Were provisions made for both intended use and foreseeable misuse?			
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c. Are there interlocks and safety devices?			
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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?