Bertoline: Fundamentals of Solid Modeling and Graphic Communications, 7e

Instructor Solutions Manual

Chapter 1: Introduction to Engineering Graphics Communication and the Product Lifecycle

Objectives and Overview

After completing this chapter, you will be able to:

1. Describe why the use of graphics is an effective means of communicating during the design process and throughout the product lifecycle.

2. Describe the model-centered design process.

3. Explain the role 3-D modeling plays in the engineering design process and the entire product lifecycle.

4. Describe the role of PLM and PDM in the engineering enterprise.

5. List and describe the modeling techniques used in design.

6. List and describe the analysis techniques used in design.

7. Describe additional technologies used to capture data, output, and visualize 3-D models.

Chapter 1 is an introduction to the graphics language and tools of the engineer and technologist. This chapter explains the role and importance of graphics communications in engineering design, and in the context of the greater product lifecycle. It explains why drawing and modeling are an effective way to communicate engineering concepts, relating past developments to modern practices. Current industry trends are also introduced, showing why engineers and technologists today have an even greater need to master graphics communication. The concept of visualization is introduced so students can begin to relate its importance to design graphics. There is a strong emphasis on communications and teamwork for solving design problems, as well as the communications artifacts used in the process. It is the authors' primary intent that students begin to understand that graphics is a powerful form of human communications that is enabled by a model-based enterprise (MBE) environment in the context of the product's lifecycle. Concepts and terms important to understanding modern graphics communication and its relationship to the model-based engineering design process are explained and defined.

Questions for Review

1. Explain the difference between engineers and technologists.
   Engineers are creative people who use technical means to solve problems. They design products, systems, devices, and structures to improve our living conditions. Technologists work with engineers and are concerned with the practical aspects of engineering in the designing, planning, and production of a product, process, or structure and in the development and implementation of tools to aid in the creation of the product, process, or structure. Technologists must be able to communicate quickly and accurately using graphics, by sketching

and modeling design problems and solutions, analyzing design solutions, and specifying production procedures.

2. How can visualizing help an engineer in the design process?
   Both engineers and technologists are finding thatsharing technical information through graphical means is becoming more important as more nontechnical people become involved in the design/manufacturing/sustainment process. As Figure 1.5 illustrates, the circle of people requiring technical information is widening rapidly, and engineering and technical information must be authored and delivered effectively to many other people who are not engineers or technologists, such as marketing, sales, and service personnel. Computer graphics can assist in the process. It can be the tool used to draw together many individuals with a wide range of visual needs and abilities
3. What are the three main areas or phases of the model-centered design process? Do the activities in these areas happen in a sequential fashion?
   Technical graphics is a real and complete language used in the design process for:
   1. Visualization
   2. Communication
   3. Documentation
   Graphical representations are used by individual engineers and designers to problem-solve about a technical problem they are working on (Figure 1.6). For an engineer, this problem can often be a 3-D object that is either being modified from an initial design or created from scratch. Part of this problem-solving process can be the use of informal drawings or sketches. While these types of drawings were historically done with pencil and paper, increasingly computer-based sketching and modeling tools are used to rapidly create multiple ideas for solutions to the problem.

4. Explain how PLM is used in the design process. What is its relationship to CIC?
   The manufacture of a new product now calls for the involvement of all the company's departments: engineering, strategy, marketing and sales, planning and production, procurement, finance, and human resources. PLM is a methodology that facilitates the simultaneous working of all these functional groups within an organization. A clear, complete, and unambiguous digital product definition is critical for modern PLM technology to be successful. The overall objective is to provide the capability for companies to design and simulate products "virtually" across an integrated enterprise, covering the entire lifecycle of a product, all without ever having to build a real prototype. This is achieved through advances in CAD, digital mockup, digital manufacturing simulation, web access, and other key technologies. As a result, companies are dramatically changing the way they do product design and management, including the integration of functions within an enterprise that, until recently, have been either "outside" or at the end of the product development process.

   Corporate intellectual capital (CIC) is the sum of retained knowledge that an organization accumulates in the course of delivering its products. In contemporary terms, this accumulation of knowledge, coupled with an easily accessible digital product definition, allows companies to leverage this information to make better business decisions. However, much effort is required to package that product and process data into a form in which it can be shared. In addition to the usual product and process data that is captured, many companies also capture operational product data while the product is in use. This performance data can then be compared to the nominal design and production data to make decisions about how the product is behaving over time or how it can be improved in the next iteration.

Corporate intellectual capital (CIC), as it relates to product design and manufacturing, often includes the following:

1. Product definition—all the information relating to what the product (or service) is: its specifications and geometry; materials definitions and how it is designed, manufactured, delivered, and supported.
2. Product history—any information relating to what the organization has done in the past that is of relevance for the delivery of the organization's product, such as audit trails required for legal or regulatory purposes or archives relating to past products.
3. Process definition—all information used to plan and execute the production and supply chain aspects of product realization, such as machining processes, supplier capability, and work instructions.
4. Process history—an archive of the actual processes, tools, and techniques used to make the product, including how that information deviates from the product definition and product history.
5. Best practice—this summarizes the experience gathered by the organization in the course of delivery of its products.

CIC consists of two types of data:

1. Content objects—product definition and all related information.
2. Metadata—data that describe the content, such as creation and last modified dates, author/owner, version/status, how it can be used and by whom, and so forth.

5. Outline the steps of problem identification in the ideation phase.

Problem identification is an ideation process in which the parameters of the design project are set before an attempt is made to find a solution to the design. Problem identification includes the following elements:

Problem statement, which summarizes the problem to be solved. Research, which gathers relevant information useful to the design team.

Data gathering, sometimes called feasibility study, which determines market needs, benchmarking with the competition, and rough physical measurements, such as weight and size.

Objectives, which list the things to be accomplished by the team.

Limitations, which list the factors in the design specifications.

Scheduling, which organizes activities into a sequence.

6. What kinds of graphics are used in the ideation phase?

Presentation graphics, design models, engineering notebook

7. What is the designer's notebook? How is it used? How has its role changed with the advent of CAD technology?

Designers should get into the habit of taking meticulous notes to ensure that ideas and decisions are kept for future reference. A designer will create many notes and documents which normally become part of the design file. Historically, this was done in a well-documented design notebook containing design sketches (Figure 1.23) with notes, calculations, signatures, and dates. One important reason for keeping good notes is to make it easier to document original designs, which is very important when applying for a patent. This information also is important to defend against possible lawsuits arising from the use of the product. The notebook is also a way of creating a history of design for a company (Figure 1.24). This historical record enabled new designers to quickly determine how design has progressed in a company. This historical record also became important when modifying existing designs or creating a related product. When this occurs, design decisions and previous design solutions may become a starting point for the modified design. This can save much time and money in the development of the new product.

The notebook is very similar to a diary that records the development of the design solution. It does not have to be neat, but it should be legible and contain all the notes, sketches, and calculations on sequentially numbered pages. A simple bound notebook may be all that is needed for a designer's notebook for a single project. Today's technology allows collaborative engineering through design across the World Wide Web (WWW), as described in more detail later in this chapter. Keeping a designer's notebook can be accomplished through a computer-based electronic notebook by serving, delivering, and storing the data created by the design team. New PLM tools for visualization and 3-D data sharing allow designers and others to share information from a secure, shared, and common digital product definition. This digital product definition contains much of the same information that a paper-based notebook would have contained, and much more, including product behavior simulations, materials analyses, and manufacturing or assembly definitions. This allows digital product information to be securely accessed by a wide variety of people in different departments and even different locations.

8. Outline the main activities in the refinement phase.

Refinement is a repetitive (iterative or cyclical) process used to test the preliminary design, make changes if necessary, and determine if the design meets the goals of the project (Figure 1.25). Refinement is the second major stage in the collaborative engineering design process and consists of three main areas: modeling, design analysis, and design visualization. These areas are subdivided further into activities that ultimately result in the selection of a single design solution. Historically this process would have included a series of mark-ups and revisions to a product's engineering drawings; however, in a digital model-centered design process, the activities in the refinement stage use the evolving 3-D CAD model as input.
The refinement stage normally begins with designers or CAD modelers using the rough sketches and computer models to create dimensionally accurate models or drawings (Figure 1.26). At this point, the engineers will likely have selected the materials for the component parts, considering such factors as heat, light, noise, vibration, humidity, strength, weight, size, loads, cost, and many others. The engineers work closely with the designer or CAD modeler so that the materials selected will work well with the proposed geometric form.

The preliminary design is often tested many times virtually, using finite element analysis software tools, kinematic and dynamics software tools, motion simulations, and spatial analysis before physical prototypes are built. The design is analyzed relative to the project objectives and problem statement, and manufacturing begins to determine the processes needed to produce the product. The preliminary design is also market tested to a small group. At this stage changes may be recommended in the initial design. The final step in the refinement stage is selection of the final design for the product.
The refinement stage is heavily dependent on graphics to document, visualize, analyze, and communicate the design idea. These models and drawings are often called design drawings (or models). Refinement models and drawings are technical models and drawings used to analyze and communicate preliminary design ideas (see Figure 1.26).

9. Describe the different kinds of models used in the design process.

Modeling is the process of representing abstract ideas, words, and forms, through the orderly use of simplified text and images. Engineers use models for thinking, visualizing, communicating, predicting, controlling, and training. Models are classified as either descriptive or predictive.
A descriptive model presents abstract ideas, products, or processes in a recognizable form. An example of a descriptive model is an engineering drawing or 3-D CAD model of a building or automobile (Figure 1.27). The drawing or model serves as a means of communication but cannot be used to predict behavior or performance. A predictive model is one that can be used to understand and predict the behavior/performance of ideas, products, or processes. An example of a predictive model is a finite element model of a bridge support, which is used to predict the mechanical behavior of the bridge under applied loads. (See Section 9.1.2 for a discussion of finite element models.)
During the refinement process, two types of models are useful: mathematical models and scale models.
A mathematical model uses mathematical equations to represent system components. This technique is useful for understanding and predicting the performance of large, complex systems. Normally, a large system is broken into its simpler components before being modeled. Figure 1.28 is an example of a mathematical model used to predict the power loss of thrust bearings when velocity is increased. By reading the graph, you can predict how much loss there will be without having to test the bearings physically at every operating speed. This results in a tremendous savings in time and cost during the refinement stage of the design process.
A scale model is a physical model created with relative physical proportions to represent system components. This is one of the most useful and easily understandable of all the modeling processes. The model can be full size or a replica made to scale. Before the advent of 3-D CAD modeling, physical models were made by skilled craftspersons from clay, wood, foam, or other materials (Figure 1.29). Physical models are extremely useful for conducting spatial, aesthetic, human factors, and property analyses. For example, the cellular phone could be modeled in foam or wood and given to the human factors engineers and the consumers group on the design team to get their feedback on the interaction between the model and the human test subjects. In addition, the circuitry of the cellular phone could be created as a working model using

breadboarding, which is a technique used by electrical engineers and technicians to test new circuits.

For most products today, 3-D CAD modeling, simulations, visualizations, and rapid prototyping, have reduced the need for creating physical models using traditional techniques. Rapid prototyping is a broad term used to describe several related processes that create real models directly from a 3-D CAD database (Figure 1.30). This can dramatically reduce the time between design and initial production.

10. Describe the different kinds of analysis techniques used in the design process.
Design analysis is the evaluation of a proposed design, based on the criteria established in the ideation phase. It is the second major area within the refinement process, and the whole design team is involved. Typical analyses performed on designs include the following:

Property analysis, which evaluates a design based on its physical properties, such as strength, size, volume, center of gravity, weight, and center of rotation, as well as on its thermal, fluid, and mechanical properties.

Mechanism analysis, which determines the motions and loads associated with mechanical systems made of rigid bodies connected by joints.

Functional analysis, which determines if the design does what it is intended to do; in other words, if the design performs the tasks and meets the requirements specified in the ideation phase.

Human factors analysis, which evaluates a design to determine if the product serves the physical, emotional, quality, mental, and safety needs of the consumer.

Aesthetic analysis, which evaluates a design based on its aesthetic qualities.

Market analysis, which determines if the design meets the needs of the consumer, based on the results of surveys or focus groups.

Financial analysis, which determines if the price of the proposed design will be in the projected price range set during the ideation phase.

11. Outline three ways the 3-D model database can be used in the implementation phase.
Implementation is the third and final phase in collaborative engineering design and is the process used to change the final design from an idea into a product, process, or structure. At this point, the design is finalized and any changes become very expensive. The implementation process includes nearly every phase of the business, such as planning, production, financing, marketing, service, and documentation (Figure 1.40). The goal of this phase is to make the design solution a reality for the enterprise and the consumer. Just as the 3-D model was used to drive the refinement process, the model database also drives the implementation phase. Similarly, information from the implementation phase goes into the database for use in future product development.

The planning process determines the most effective method of moving a product through the production cycle. Manufacturing engineers and technologists are the leaders in the planning process, as they schedule the machines and jobs necessary to create the product. Planning requires process sheets, data and material flow diagrams, project modeling and work organization charts, bills of material, work instructions, assembly instructions, and other documents (Figure 1.41). Modern planning techniques use geometry and metadata derivatives of the 3-D CAD model created during the design stage as inputs to computer-aided process planning (CAPP), material requirements

planning (MRP), requirements management, and just-in-time (JIT) scheduling software tools.

CAPP uses the computer model of the design to determine which machines and processes should be used. MRP calculates the raw materials needed to produce the product and uses solid models to assist in these calculations. For example, the solid model of a part can be analyzed to determine the volumes of various parts, and the results then can be used to calculate the amounts of different materials needed to make the parts.

Just-in-time (JIT) is an operational philosophy that tries to reduce cycle time while eliminating waste. Anything related to the manufacture of a product that does not add value to the product is considered waste. For example, inventory sitting idle in a warehouse for a long period of time does not add value to a product. A JIT system prevents waste by taking deliveries on orders only as they are needed.

12. What kinds of 3-D model derivatives might be produced as part of the design process?
Drawings, reports, simulations, visualizations, various detailed models.

13. What is the difference between conventions and standards?

The English language has many similarities to the graphics language. Following the standard rules of English makes the communication of thoughts between people easier. If the words in a sentence were presented in a random order, it would be very difficult for anyone to understand what was being said.

The graphics language must also follow a set of standards and conventions in order to make communication using technical graphics effective. However, these standards and conventions are not timeless, unchanging truths. Just as English gradually changes and we no longer speak in the manner of sixteenth-century Shakespeare, the standards and conventions of the graphics language have evolved over the years and are still changing as new technologies affect how 3-D models are produced and their accompanying drawings are derived.

Conventions commonly are accepted practices, rules, or methods within a company or a particular industry. In technical drawing, an example of a convention is the use of dashed lines on multiview drawings to designate a feature hidden from the current viewpoint (Figure 1.57).

Standards are sets of rules that govern how CAD models are made and technical drawings are represented. For example, mechanical drawings are dimensioned using an accepted set of standards, such as placing the dimension text such that it is read from the bottom of the sheet (Figure 1.58). Standards allow for the clear communication of technical ideas.

14. Describe two reverse engineering techniques.

The method of taking an existing product, accurately evaluating it, and putting the information into a CAD database is called reverse engineering. The measurements of a product are taken using a coordinate measuring machine (CMM). A CMM is an electromechanical device, with a probe on one end, that accurately measures objects and then inputs the 3-D data into a CAD system (Figure 1.60). The 3-D model can then be modified or checked for accuracy. Another form of reverse engineering is called scanning. By using lasers or specialized photographic equipment, the external surfaces of an object can be digitally captured in 3-D. The resulting data is used to create a surface model of the object.

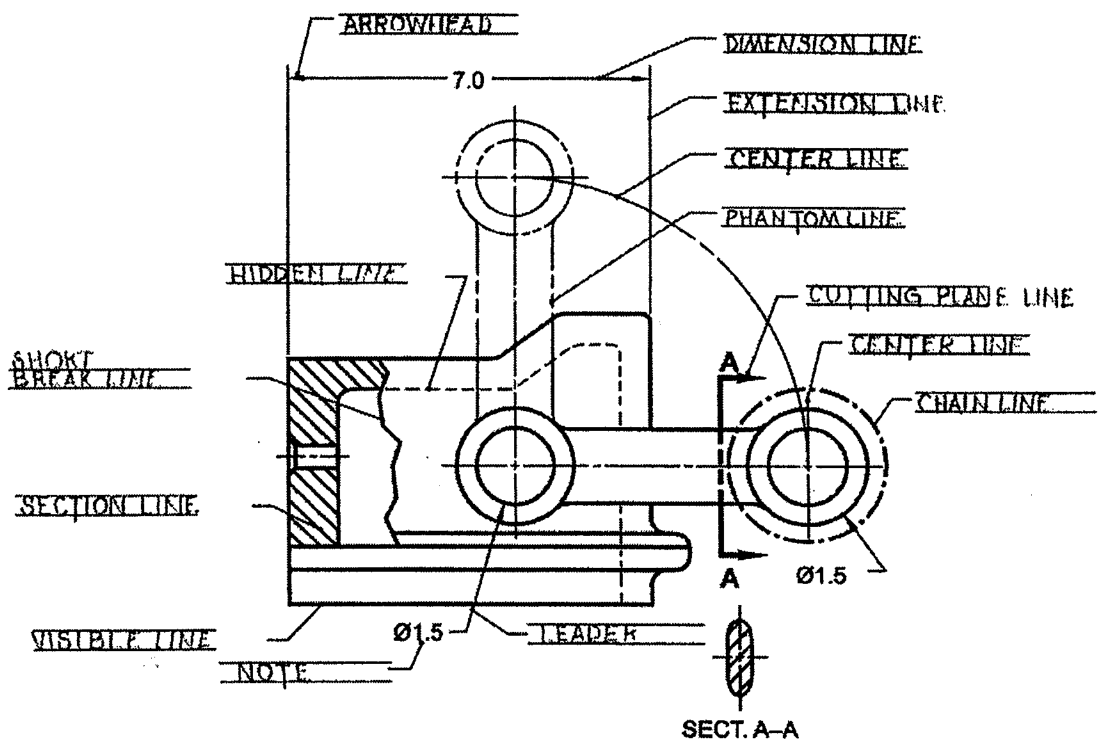
15. Describe two different rapid prototyping technologies.
The actual process used to create the printed part varies depending on the type of system being used. The actual making of the part can take many hours, depending on the size of the part. The basic process consists of creating a 3-D model of the part on a CAD system. The 3-D model then is translated into a file format compatible with a rapid prototyping system, the most popular being an STL file. The rapid prototyping system reads the STL file and breaks the 3-D model into a series of very thin layers. The layers are then used by the RP machine to build the physical model through additive manufacturing.

Additive manufacturing systems are categorized by the process used to create the real model. Stereolithography apparatus (SLA) was one of the first methods developed. It uses a process whereby a focused laser beam hardens a light-sensitive liquid polymer through a series of very thin slices (Figure 1.63). Selective laser sintering (SLS) is a process that uses a focused laser to fuse powdered plastic, metal, or ceramic through a series of very thin slices. Fused deposition modeling (FDM) uses molten plastic deposited in a series of thin layers to create the part. Laminated object manufacturing (LOM) creates real models from sheets of material such as paper or vinyl.

A newer category of RP systems is called 3-D printers, which typically use inexpensive plastic or powder-based materials to build physical models. By spraying a binding agent in the shape of the object's cross-sectional layers and adding new powder on top of the binder, or by laying down the heated monofilament from the spool in successive layers, 3-D printers can make low-cost physical models. More functional and precise 3-D printers are also available that use lasers to sinter metal powders into finished parts that can be used on real products.

16. Explain why an enterprise might want to store data in an off-site data warehouse.
Increasingly, enterprise data is stored off-site in data warehousing facilities. With high-speed Internet connections and software tools that manage data flow, users often can't tell the difference between CAD files that are stored on their local computers and those that are stored thousands of miles away. There are many advantages to off-site data warehousing. These facilities are specially designed for this task, having dedicated environmental controls and emergency power back-up systems. Massive amounts of digital storage in a single location means that it is very easy to back up existing data, move to new drive space if one fails, or expand into more space as demand increases. Off-site storage of back-ups also protects against fire or other catastrophes at the companies' engineering center.

17. Describe two different VR display techniques.
Head-mounted display, CAVE



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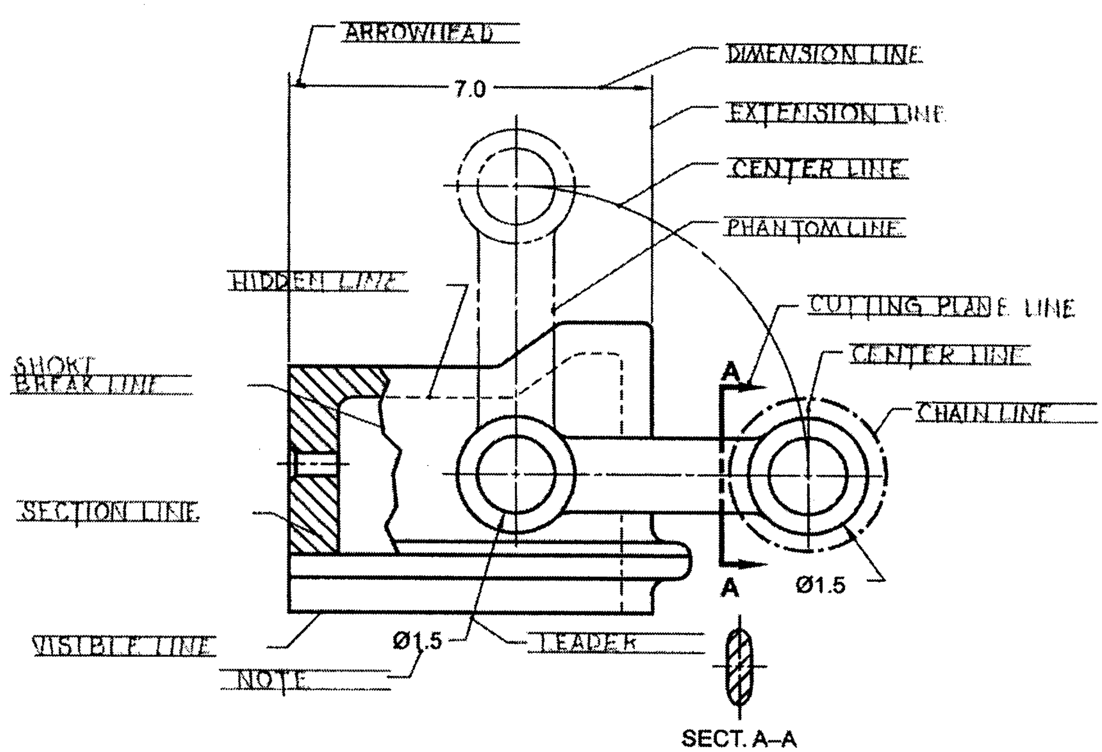

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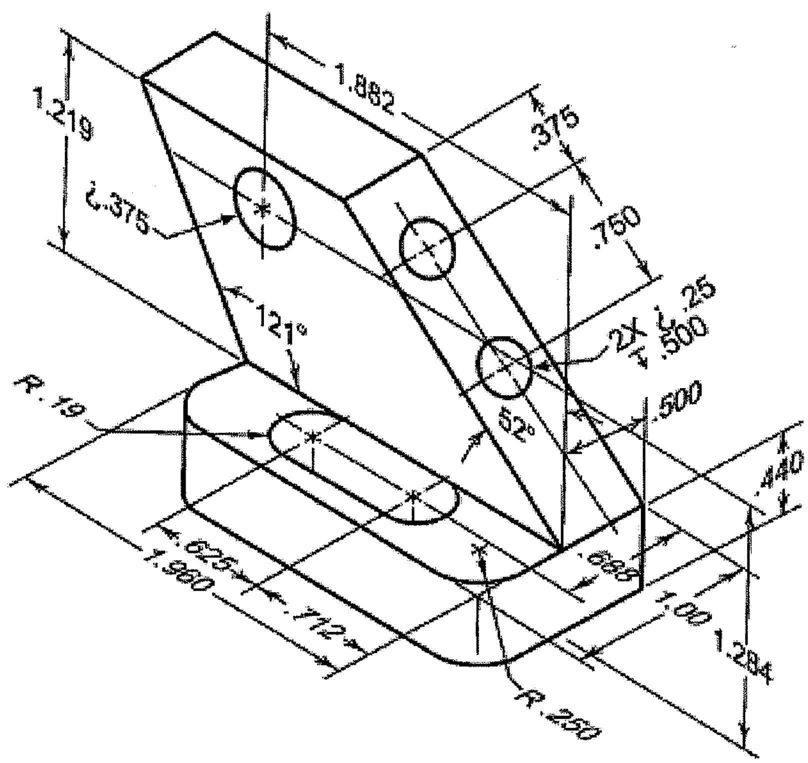
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Angle base