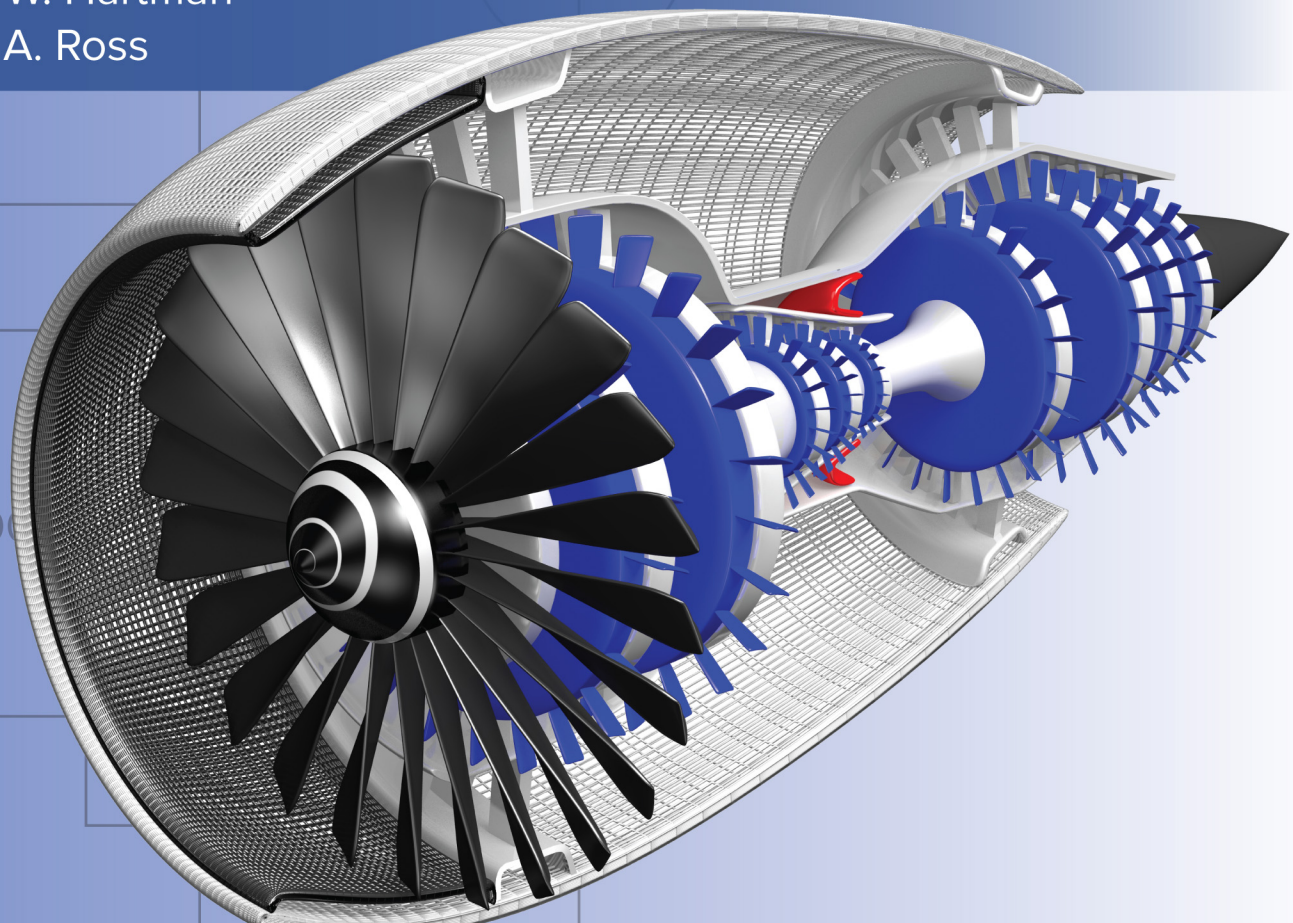


Fundamentals of Solid Modeling and Graphic Communication

Gary R. Bertoline
Nathan W. Hartman
William A. Ross



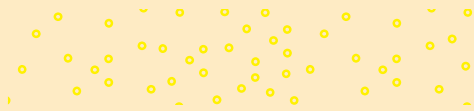
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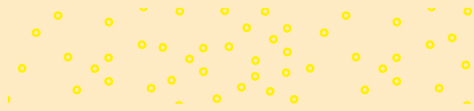
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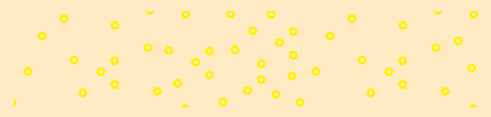
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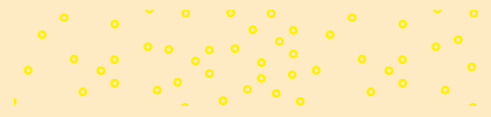
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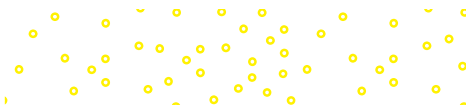
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Gary has authored numerous papers in journals and trade publications on engineering and computer graphics, computer-aided design, and visualization research. He has also authored and co-authored seven textbooks in the areas of computer-aided design and engineering design graphics with one, *Fundamentals of Solid Modeling and Graphic Communication* currently in its 7th edition. Gary's research interests are in scientific visualization, interactive immersive environments, distributed and grid computing, workforce education, and STEM education.



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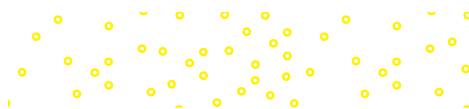
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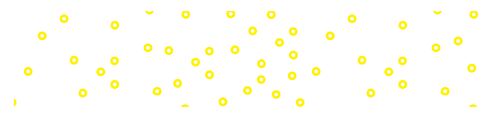
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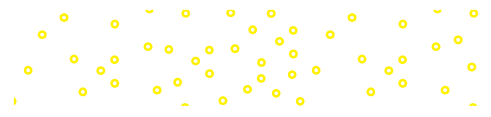
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Preface

Engineering and technical graphics have gone through significant changes in the last four decades, due to the use of computers and CAD software. Advances in digital technologies, information science, and modern manufacturing and materials have fundamentally altered the role of engineering and technical graphics communication in the 21st century. Gone are the days of creating 2-D drawings using manual methods and tools. Quickly fading are the days of using 2-D drawings to design and manufacture modern products and systems. Engineers and technologists still find it necessary to communicate and interpret designs, but they will do it by creating high-fidelity 3-D models and digital representations of the products they are developing, and those models will be reused and repurposed by numerous other people (and likely machines as well) over the course of the product lifecycle. As powerful as today's computers and design software have become, they are of little use to engineers and technologists who do not fully understand fundamental graphics principles and 3-D modeling strategies or do not possess a high-level visualization ability.

In addition to the evolution of CAD technologies, there has been a corresponding shift in the role of 2-D drawings. No longer are drawings made with manual drawing tools by hand. In fact, few people use 2-D CAD tools today. At one time, drawings were considered the document of record for products as they were manufactured and put into use. Even today, some companies still consider drawings to be the document of record. However, that is rapidly changing. Drawings are no longer constructed from scratch in most cases; they are extracted as derivatives from the 3-D model, with their driving dimensional information coming from the dimensional and geometric constraints used to create the 3-D CAD model. The central role of the 3-D model as the driving artifact of digital product definition information is the fundamental theme in this edition of the book, which is reflected in the new title and a more streamlined table of contents.

To the authors of this text, teaching graphics is not a job; it is a “life mission.” We feel that teaching is an important profession, and that the education of our engineers is critical to the future of our country. Further, we believe that technical graphics is an essential, fundamental part of a technologist's education. We also believe that many topics in graphics and the visualization process can be very difficult for some students to understand and learn. For these and other reasons, we have developed this text, which addresses both traditional and modern elements of technical graphics, using what we believe to be an interesting and straightforward approach.

In Chapter 1, you will learn about the “team” concept for solving design problems. The authors of this text used this concept, putting together a team of authors, reviewers, industry representatives, focus groups, and illustrators, and combining that team with the publishing expertise at McGraw-Hill to develop a modern approach to the teaching of technical graphics.

This new-generation graphics text therefore is based on the premise that there must be some fundamental changes in the content and process of graphics instruction. Although many graphics concepts remain the same, the fields of engineering and technical graphics are in a transition phase away from 2-D media and 2-D drawings towards the adoption of 3-D digital product definitions and models that possess the properties and characteristics and mimic the physical products and the environments in which they operate. We realize that hand sketching will continue to be an important part of engineering and technical graphics for some time to come. Therefore, the text contains an appropriate mix of hand sketching and CAD instruction.

Goals of the Text

The primary goal of this text is to help the engineering and technology student learn the techniques and standard practices of technical graphics, solid modeling, and the

role of the 3-D model within the lifecycle of the product. So that design ideas can be adequately communicated and produced. The text concentrates on the concepts and skills necessary for sketching, 3-D CAD modeling, and the concept of a model-based product definition. The primary goals of the text are to show how to:

1. Clearly represent and control mental images.
2. Graphically represent technical designs, using accepted standard practices.
3. Use plane and solid geometric forms to create and communicate design solutions.
4. Understand the role of the 3-D CAD model as a communications mechanism within a digital enterprise.
5. Solve technical design problems using 3-D modeling techniques.
6. Communicate graphically, using sketches, and CAD.
7. Apply technical graphics principles to many engineering disciplines.

What Is Different and Why

A major shift in this edition of the text is toward a strong emphasis on the 3-D model as the focal point for graphics communication with technical drawings as an intelligent by-product of the model. As such, there is a very strong emphasis on 3-D **solid modeling** exercises and problems in this edition. Extensive attention has been given to making 3-D solid modeling a primary method for creating technical and engineering graphics for design, documentation, manufacturing, and product management. Looking toward the future role of computer graphics in product design and development, new solid modeling exercises and problems in Chapters 3, 4, 5, 6, 7, 9, and 10 have been designed that focus on the following:

1. The creation of intelligent constraint based 3-D solid models based on their design intent.
2. Placing a strong emphasis on creating 3-D models based on the assembly and operability of mechanisms viewed as products as opposed to individual pieces and parts.
3. Making 3-D models that can become the core of the data pipeline for design, manufacturing, marketing, documentation, maintenance, and general communication concerning that product.

When developing the latest edition of this book, the author team has called upon many years of industry practice and engagement with companies and the standards communities alike to create a book that captures the fundamental elements of 21st-century engineering graphics communication. Historically, this textbook series has focused on the techniques, technology, and educational content necessary to teach students how to develop engineering graphics to support the design process and to enhance their personal visualization skills. Included were topics such as orthographic projection, auxiliary views, dimensioning techniques for drawings, sketching, and many others. These topics were presented in the context of creating a technical drawing to be used to communicate product information as part of the engineering design process and the production processes used to create the product.

However, as the technologies used to create and disseminate engineering graphics have evolved over the last three decades, many traditional instructional resources and techniques for use in classrooms have not. In that period of time, the educational community surrounding engineering graphics communication has continued to embrace the tools and techniques used in the creation of 2-D drawings as the centerpiece of instruction on engineering graphics communication, while treating the use of 3-D CAD as simply a related technique. In that same period of time, many industry sectors have made the transition to 3-D CAD as a staple for communicating product information through the enterprise; have eliminated many of the employment positions traditionally reserved for people skilled in drafting techniques and standards; and are currently on the precipice of eliminating the use of 2-D drawings in many aspects of their business. So why not prepare students to meet this new environment in which they will design and make products?

The seventh edition of *Fundamentals of Solid Modeling Graphics Communication* is intended to start the transition of engineering graphics instructional content and techniques away from the focus on 2-D drawing techniques and standards towards the creation and use of 3-D models as a primary communications mechanism within an enterprise. This book is intended to promote the idea that people within a manufacturing organization are authors and consumers of information alike, and that much of that information can be distributed between them using the content within the digital product model and tools used to create it. Students in engineering and technical graphics courses, modeling courses, CAD courses, and introductory manufacturing courses at the university, community and technical college, and high

school levels would benefit from the use of this book. Fundamentally, this book will not change one of the primary pillars on which engineering graphics is based—the need to communicate product information between people—however, it will begin to explore and support the trend towards the possibility of including machines in the communications loop where only humans had existed before. If that is to be done, 3-D models must include clear, complete, and unambiguous information, and the techniques illustrated in this book will support that change.

The seventh edition of *Fundamentals* fully embraces digital age graphics communication as a dynamic, interactive, and geometric process. Communication in the manufacturing enterprise using 3-D solid modeling with associated drawings, and the related uses of spread sheets and engineering math-related products, is presented as the intelligent core of the engineering design graphics process. Emphasis is on the shared 3-D database as the basis for disseminating product data used for designing, manufacturing, and sustaining products and systems over their projected lifetime (Product Lifecycle Management). When possible, case studies and industrial examples have been incorporated.

The seventh edition of *Fundamentals of Solid Modeling and Graphics Communication* contains a more focused look at leveraging the 3-D model as a communications mechanism throughout the product lifecycle. It includes the following items:

- A discussion of neutral file formats for data exchange
- A focus on model-based practice problems
- An overview of product lifecycle management, with the 3-D model playing a central role
- An initial review of current 3-D lightweight file formats used for displaying product model information.

Fundamentals of Solid Modeling and Graphics Communication presents a modern approach to engineering graphics, providing students with a strong foundation in 3-D solid modeling techniques and graphics communication in the engineering design process. The goal of this text is to help students learn the techniques and practices of technical graphics, enabling them to create and communicate successful design ideas. Design concepts are well integrated, including team design exercises and current design examples from industry.

Features of This Edition Include

- **NEW!!!** The seventh edition features new 3-D solid modeling problems for each chapter. Solid modeling creation and editing techniques are presented with new learning activities, as well as discussions of standards and CAD data exchange. The 3-D solid modeling activities focus on the assembly, design, and function of products through the inclusion of new assembly modeling projects. New exercises also emphasize visualization, graphical and spatial problem solving through the use of interactive solid modeling, sketching, and related documentation.
- The emphasis on 2-D drawings has been removed, along with many of the references for topics related to traditional drawings, such as auxiliary views, section views, and orthographic projection as stand-alone topics.
- Precise, full-color illustrations allow students to actually SEE the power of graphics and bring important concepts to life.
- Topics tied to industrial practice, such as product lifecycle management, digital enterprise, and model-based definition, are illuminated throughout the text.
- Visualization techniques are discussed throughout the text with an emphasis on 3-D model data re-use. Many exercises reinforce the importance of developing good visualization skills.
- **Design in Industry** boxes are presented to illustrate how graphics and design are being used in industry today.
- **Dream High Tech Jobs** explain how engineers and technologists have found interesting jobs after completing their education. You will read about how they are using their knowledge and skills to design products, devices, and systems.
- Many examples that use step-by-step procedures with illustrations are used to demonstrate how to create graphics elements or to solve problems. These step-by-step procedures show the student in simple terms how a model or drawing is produced.
- Discussion of file formats used in current model data exchange and archival practices.

Chapter Features

Every chapter has been planned carefully and written with a consistent writing, illustration, and design style and pedagogy. Students and instructors will learn quickly where to find information within chapters. The book was written as part of a more global instructional approach to engineering and technical graphics and will serve as a starting point for instructor and student.

Here is a sampling of the features inside *Fundamentals*:

Objectives Each chapter has a list of measurable objectives that can be used as a guide when studying the material presented in the text. Instructors also can use the objectives as a guide when writing tests and quizzes. The tests and quizzes included on the website for the text include questions for each objective in every chapter. This feature allows instructors to make sure that students learn and are tested based on the listed objectives.

Color as a Learning Tool This textbook uses four-color illustrations throughout to better present the material and improve learning. The selection and use of color in the text are consistent to enhance learning and teaching. Many of the color illustrations also are available to the instructor in the image library found on the website to supplement lectures, as explained in detail later in this Preface.

The use of color in the text was used specifically to enhance teaching, learning, and visualization. Workplanes are represented as a light pink (Figure 4.37). Projection and picture planes are a light purple color (Figure 10.39).

Important information in a figure is shown in red to highlight the feature and draw the attention of the reader (Figure 3.40). Color shading is often used on pictorial illustrations so the user can better visualize the three-dimensional form of the object (Figure 10.67). This is especially important for most students who are being asked to use their visual mode to think and create. Color shading highlights important features, more clearly shows different sides of objects, and adds more realism to the object being viewed.

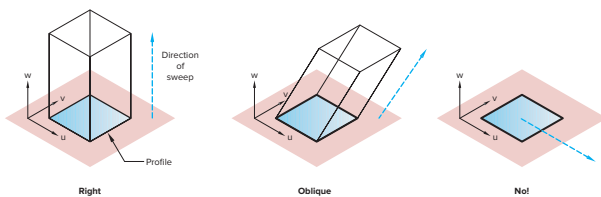


Figure 4.37 Types of linear sweeping operations

In some systems, linear sweeps are restricted to being perpendicular to the sketch plane.

Some texts use two colors, which are adequate for some illustrations, but our research with students clearly demonstrates that having the ability to display objects and text illustrations in many different colors is a huge advantage when teaching engineering and technical graphics.

Photographs and grabs of computer screens are much more interesting and show much more detail when in color (Figure 1.44). Many texts use four-color inserts to supplement the lack of color in the text. This forces

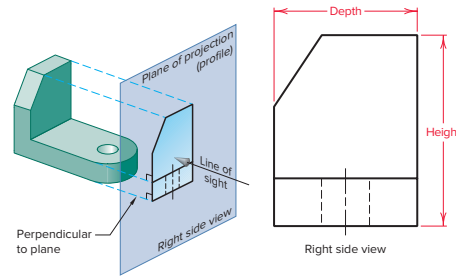


Figure 10.39 Profile view

A right side view of the object is created by projecting onto the profile plane of projection

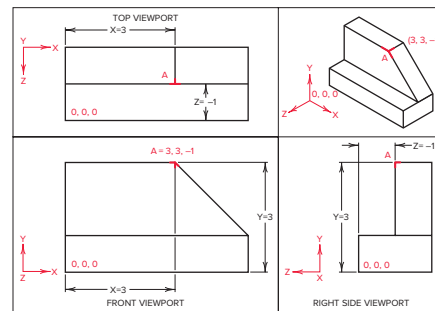


Figure 3.40 Display of coordinate axes in a multiview CAD drawing

Only two of the three coordinates can be seen in each view.

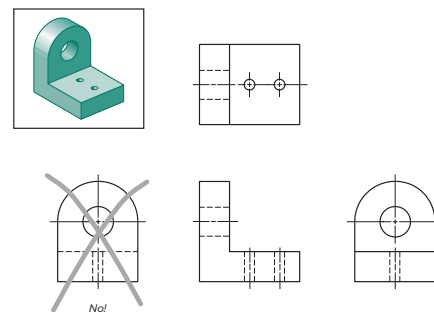


Figure 10.67 Most descriptive views

Select those views that are the most descriptive and have the fewest hidden lines. In this example, the right side view has fewer hidden lines than the left side view.



Figure 1.44 A computer-rendered image created by the technical illustrator using the CAD model

The technical illustrator can import the 3-D CAD model into a rendering program, where surface textures and light sources are applied.

(Courtesy of Robert McNeel & Associates.)

students to search the color insert section or look at the insert out of context of the readings. In some aspects of engineering design, such as finite element analysis, color is the method used to communicate or highlight areas of stress or temperature.

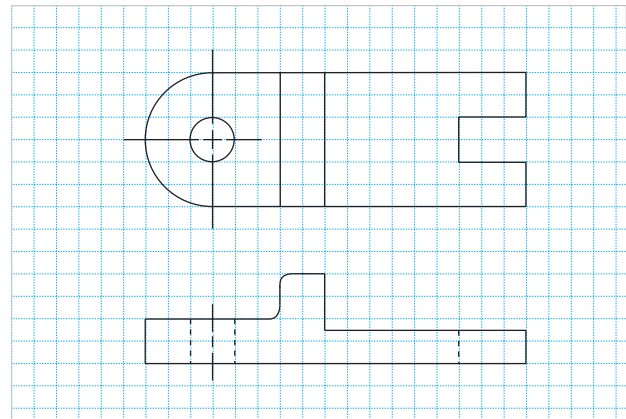
Design in Industry Every chapter includes a special feature covering some aspect of design as practiced in industry. This **Design in Industry** feature covers design in many types of industries so that students with varied engineering interests can see how design is used to solve problems. Many feature quotes from engineers working in industry explaining how they solved problems or used CAD tools to enhance the design process. All the **Design in Industry** items include figures to supplement the information presented.

Practice Problems This feature gives students drawing practice as they learn new concepts. Through immediate hands-on practice, students more readily can grasp the chapter material. To illustrate, in Chapter 6, “Product Manufacturing Information (PMI),” Practice Problem 6.1 provides a grid for students to sketch dimensions in a multiview drawing.

Practice Exercises A unique feature of the text is the use of practice exercises, which cause the student to pause and actively engage in some activity that immediately reinforces their learning. For example, Practice Exercise 7.2 in Chapter 7, “Standard Parts,” asks the student to find a few familiar objects and begin making isometric sketches. This exercise allows a student to experience and try making isometric sketches without the pressure of

Practice Problem 6.1

Sketch dimensions in decimal inches for the object shown in the multiview drawing.



graded assignments. Students have the opportunity to try to sketch isometric features, such as ellipses, and practice before having a formal assignment. They also are working with known objects that they can pick up and move, which is important in the visualization process. Being able to pick up objects is especially important for that segment of the population who are haptic learners and learn best when able to manipulate objects to be visualized.

Step-by-Step Illustrated Procedures Most chapters include many drawing examples that use step-by-step procedures with illustrations to demonstrate how to create graphics elements or to solve problems (Figure 4.39).

Integration of CAD Modeling The entire text has been edited (and in some cases, rewritten) to reflect the importance of solid modeling and the role of the 3-D CAD model as a mechanism for communication in modern digital enterprises. The role and necessity of the 2-D drawing as a document of record is diminishing, and as such, it is important to strike the proper balance between coverage of 2-D techniques and 3-D techniques in this book.

Dream High Tech Jobs This feature is included in many chapters and explains how engineers and technologists have found interesting jobs after completing their education. You will read about how they are using their knowledge and skills to design precuts, devices, and systems.

Questions for Review Each chapter includes an extensive list of questions for review. Included are questions meant to measure whether students learned the objective listed at the start of each chapter. Other questions are used to

reinforce the most important information presented in the chapter. The types of questions used require students to answer through writing or through sketching and drawing. Answers to questions are included in the instructor material included with the text.

Further Reading Many of the chapters include a list of books or articles from periodicals relevant to the content covered in the text

Problems Every chapter in the text includes an extensive number and variety of problem assignments. Most chapters include text-based problems that describe a problem to solve or drawing to create. The figure-based problems are very extensive and range from the very simple to complex. This arrangement allows the instructor to carefully increase the complexity of the problems as students learn and progress. The most complex drawings can be used to supplement assignments given to the most talented students or for group-based projects.

Most of the problems are of real parts made of plastic or light metals, materials commonly found in industry today.

The wide range and number of problems allow the instructor to frequently change assignments so that fresh problems are used from semester to semester. Additional problems are available on the website and through our workbooks. Most problems' solutions are provided to the instructor. Instructors may receive access to these password-protected solutions by contacting their local McGraw-Hill sales representative.

Classic Problems Many chapters include Classic Problems, which are additional problems that can be assigned. They have been taken from the seminal technical graphics textbooks by Thomas E. French, published by McGraw-Hill. Many of the problems are castings with machined surfaces, giving the student experience with additional materials and machining processes.

Glossary, Appendixes, and Index

At the end of the text is an extensive glossary containing the definitions of key terms shown in bold in the text. This glossary contains over 600 terms related to engineering and technical drawing, engineering design, CAD, and manufacturing.

Fundamentals of Solid Modeling and Graphic Communication, 7th Edition, contains supplementary information in the Appendixes useful to students, such as

metric equivalents, trigonometry functions, ANSI standard tables, welding symbols, and more.

An extensive index is included at the end of the text to assist the reader in finding topics quickly. This index is carefully cross-referenced so related terms easily can be found by the user.

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Finally, we would like to know if this book fulfills your needs. We have assembled a “team” of authors and curriculum specialists to develop graphics instructional material. As a user of this textbook, you are a part of this “team,” and we value your comments and suggestions. Please let us know if there are any misstatements, which we can then correct, or if you have any ideas for improving the material presented. Write in care of the publisher, McGraw-Hill, or e-mail Gary R. Bertoline at bertoline@purdue.edu.

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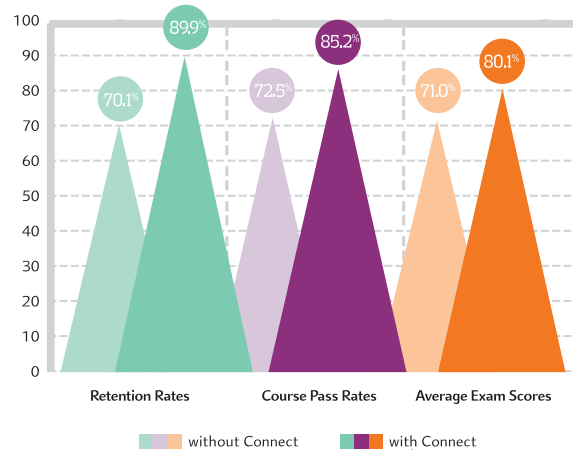
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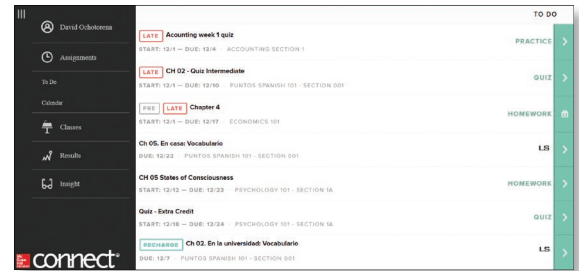


Robust Analytics and Reporting

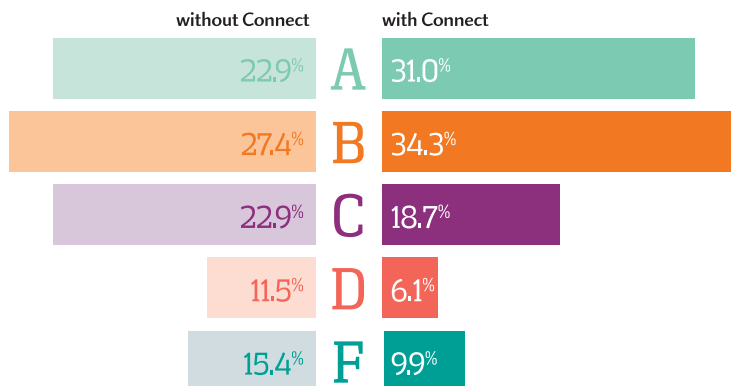
- Connect Insight® generates easy-to-read reports on individual students, the class as a whole, and on specific assignments.
- The Connect Insight dashboard delivers data on performance, study behavior, and effort. Instructors can quickly identify students who struggle and focus on material that the class has yet to master.
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CHAPTER

1

Introduction to Engineering Graphics Communication and the Product Lifecycle

A drawing is the reflection of the visible mind. On its surface we can probe, test, and develop the workings of our peculiar vision.

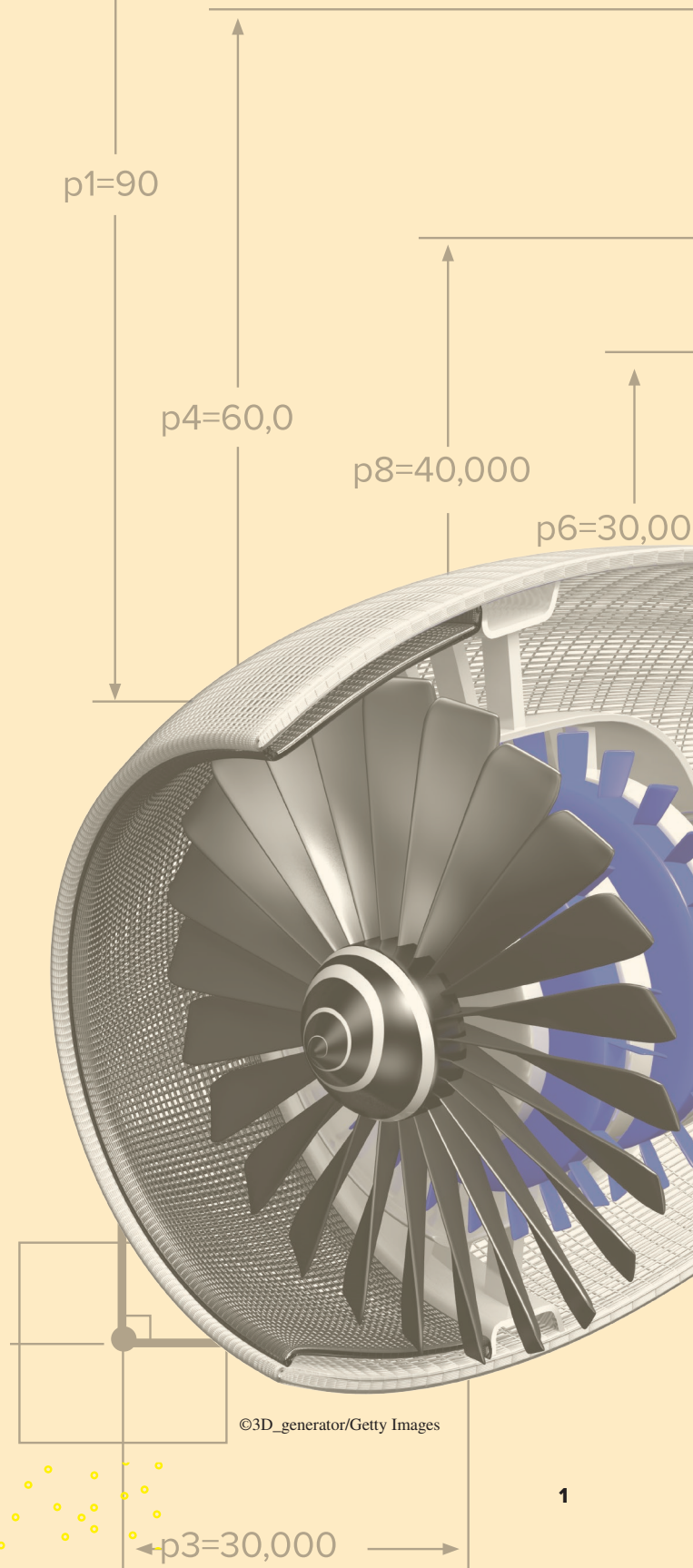
—Edward Hill

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.

1.1 Introduction

What is graphics communication? For one thing, it is an effective means of communicating technical ideas and problem solutions. Humans have historically used drawings, paintings, sculpture, models, and other graphical and visual forms of expression to share and document their ideas. Modern graphics communication, especially that which is used for the design and creation of products for humankind, are no different. What is different today is the manner in which those graphical forms of expression are created—usually in a visual form rather than a physical form—to support the design and creation of a product.

Look at what happens in engineering design. The process starts with the ability to visualize an idea in one's mind, to see the problem and the possible solutions. Then, sketches are often made to record and evaluate initial ideas. The next steps are where the modern processes of engineering graphics communication differ from those done historically. Geometric models are created from the sketches and are used as input for analysis, production, communicating with customers, maintenance, and many other activities related to the product. Detail and assembly drawings are only made if the consumer of the product information needs them for a specific task or if the terms and conditions under which the product is made and delivered require drawings to be made. Visualizing, sketching, modeling, and detailing are how engineers and technologists communicate as they design new products and structures for our technological world.

Graphics communication using engineering models and drawings is a language; a clear, precise language with definite rules that must be mastered if you are to be successful in engineering design. Once you know the language of graphics communication, it will influence the way you think, the way you approach problems. Why? Because humans tend to think using the languages they know. Thinking in the language of graphics, you will visualize problems more clearly and will use graphic images to find solutions with greater ease.

In engineering, 92 percent of the design process is graphically based. The other 8 percent is divided between mathematics and written and verbal communications. Why? Because graphics serves as the primary means of communication for the design process. Figure 1.1 shows a breakdown of how engineers spend their time. 3-D modeling and documentation comprise over 50 percent of the engineer's time and are purely visual and graphical activities. Engineering analysis depends largely on understanding the results of computer simulations that use the 3-D design model as an input to determine the product's or structure's performance in certain physical conditions, and manufacturing engineering and functional design also require the creation and reading of graphics in order to fully define and make the product or structure.

Why do graphics come into every phase of the engineer's job? To illustrate, look at the jet aircraft in Figure 1.2. Like any new product, it was designed for a specific task and within specified parameters; however, before the parts of the jet aircraft could be manufactured, a three-dimensional

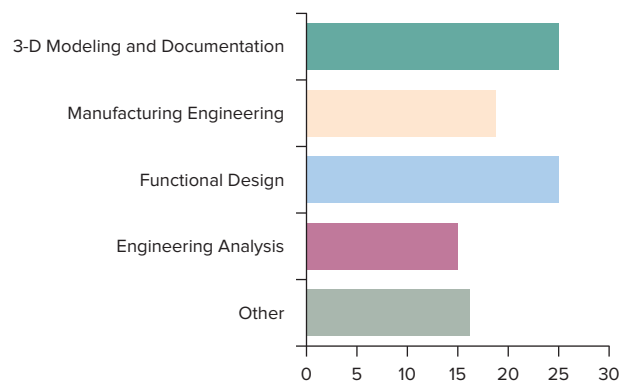


Figure 1.1 A total view of engineering divided into its major activities

Graphics plays a very important role in all areas of engineering, for documentation, communications, design, analysis, and modeling. Each of the activities listed is so heavily slanted toward graphics communication that engineering is 92 percent graphically based.

(3-D) model like that shown in Figure 1.3 had to be produced. Just imagine trying to communicate all the necessary details for designing and producing the aircraft verbally or in writing. It would be impossible!

A designer has to think about the many features of an object that cannot be communicated with verbal descriptions (Figure 1.4). These thoughts are dealt with in the mind of the designer using a visual, nonverbal process. This “visual image in the mind” can be reviewed and modified to test different solutions before it is ever communicated to someone else.



Figure 1.2

This jet aircraft would be impossible to create without computer graphics models and drawings. Drawings are the road maps that show how to manufacture or build products and structures.

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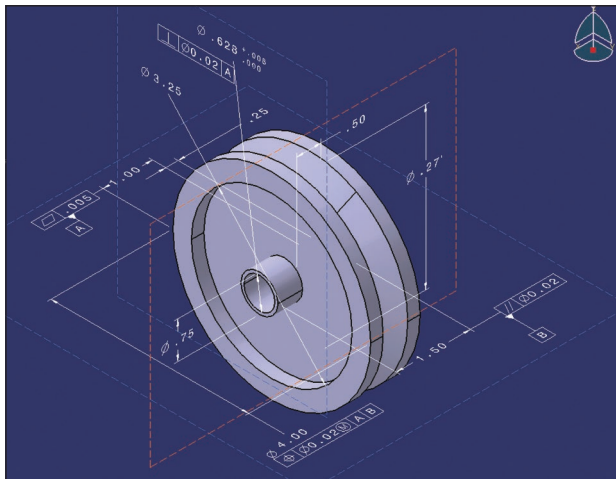


Figure 1.3 Model with dimensional controls

Computer models such as this one are used to produce manufactured parts. The 3-D model is also used to inspect parts after production.



Figure 1.4 Technical drawings used for communications

Technical drawings are a nonverbal method of communicating information. Descriptions of complex products or structures must be communicated with drawings. A designer uses a visual, nonverbal process. A visual image is formed in the mind, reviewed, modified, and ultimately communicated to someone else, all using visual and graphics processes.

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As the designer draws a line on paper or creates a 3-D model representation with a computer, he or she is translating the mental picture into a model or other graphical representation that will produce a similar picture in the mind of anyone who sees the drawing. This drawing or graphic representation is the medium through which visual images in the mind of the designer are converted into the real object.

Technical graphics can also communicate solutions to technical problems. Such technical graphics are produced according to certain standards and conventions so they can be read and accurately interpreted by anyone who has learned those standards and conventions.

The precision of technical graphics is aided by tools; some are thousands of years old and still in use today, and others are as new and rapidly changing as computer-aided design (CAD). This book will introduce you to the standards, conventions, techniques, and tools of technical graphics and will help you develop your technical skills so that your design ideas become a reality.

Engineers are creative people who use technical means to solve problems. They design products, systems, devices, and structures to improve our living conditions. Although problem solutions begin with thoughts or images in the mind of the designer, presentation devices and computer

graphics hardware and software are powerful tools for communicating those images to others. They also can aid the visualization process in the mind of the designer. As computer graphics have a greater impact in the field of engineering, engineers will need an ever-growing understanding of and facility in graphics communications.

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.

Both engineers and technologists are finding that sharing technical information through graphical means is becoming more important as more nontechnical people become involved in the design/manufacturing/sustainability 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.

Practice Exercise 1.1

1. Try to describe the part shown in Figure 1.44 using written instructions. The instructions must be of such detail that another person can make a sketch of the part.
2. Now try verbally describing the part to another person. Have the person make a sketch from your instructions.

These two examples will help you appreciate the difficulty in trying to use written or verbal means to describe even simple mechanical parts. Refer to Figure 1.6 and others in this text to get an idea of how complicated some parts are compared to this example. It is also important to note that air- and watercraft have thousands of parts. For example, the nuclear-powered Sea Wolf class submarine has over two million parts. Try using verbal or written instructions to describe that!

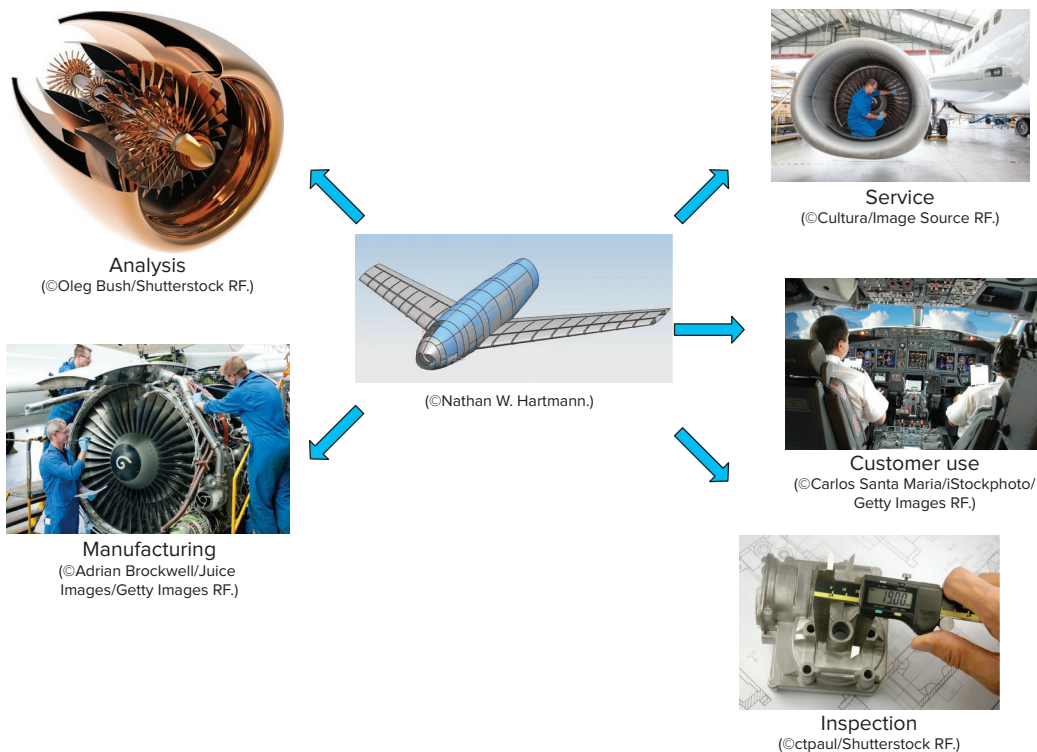


Figure 1.5 Users of graphics

The circle of people requiring technical information is growing rapidly.

1.2 The Importance of Graphics in the Design Process

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.

Graphic representations are useful as a permanent record of ideas as they are being mentally worked through by an engineer or designer. Later on in the design process, more refined graphic representations in the form of models or drawings can be used to communicate problem

solutions to other members of the larger team working on the design problem (Figure 1.7). The permanent, visible record of ideas means that they can be shared with others to work with at a later time (asynchronously) or used as part of a shared meeting time (synchronously) when ideas and problems are worked through collectively.

While informal sketches can be done by anyone, practice and instruction help one to quickly and accurately express ideas. When computer tools are used, more training is often needed so that the engineer/designer can appropriately represent his or her design solutions. As the designs become more refined, specialized knowledge is needed to use the agreed-upon standardized language of **technical drawing** and **modeling**. These standards, developed by organizations like the American National Standards Institute (ANSI) and the American Society of Mechanical Engineers (ASME), ensure accurate and precise communication of engineered design specifications (Figure 1.8).

1.2.1 Visualization

A powerful tool for design engineers is the ability to see in their minds the solution to problems. **Visualization** is the ability to mentally picture things that do not exist

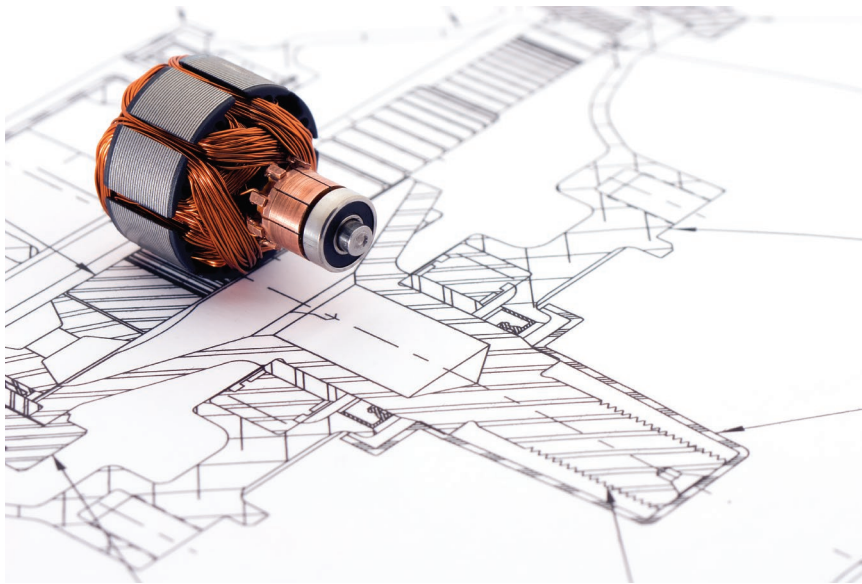


Figure 1.6 Technical drawing of an electric motor

Only experienced users of technical drawings can interpret the various lines, arcs, and circles sufficiently to get a clear mental picture of what this part looks like three-dimensionally.



Figure 1.7 3-D computer model of the interior of an automobile

This computer rendering of a 3-D computer model is more easily understood because more detail is given through the use of colors, lights, and shades and shadows.

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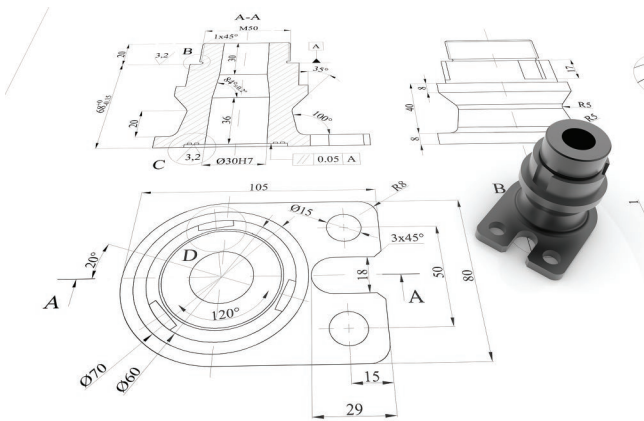


Figure 1.8

Technical drawings are used to communicate complex technical information.

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and to understand the interaction between them. Design engineers with good visualization ability can not only picture things in their minds, they can also control that mental image, allowing them to move around the image, change the form, look inside, and make other movements as if they were holding the object in their hands. Some of the greatest engineers and scientists throughout history have had powerful visualization ability, such as Albert Einstein, James Clerk Maxwell, Leonardo da Vinci, and Thomas Edison.

In his book titled *Engineering and the Mind's Eye*, Eugene Ferguson summarizes the importance of visualization to the design process. “It has been nonverbal

thinking, by and large, that has fixed the outlines and filled in the details of our material surroundings for, in their innumerable choices and decisions, technologists have determined the kind of world we live in, in a physical sense. Pyramids, cathedrals, and rockets exist not because of geometry, theory of structures, or thermodynamics, but because they were first a picture—literally a vision—in the minds of those who built them.”

Most designers will initially capture their mental images by sketching them on paper. Sometimes these sketches are very rough and quickly done to capture some fleeting detail in the mind of the designer. When communicating one’s sketch to others, the sketches must be refined (Figure 1.9).

Your ability to visualize should improve as you solve the problems located at the end of every chapter in this book. Visualization and the resulting sketch is the first phase in the whole process of graphics being used in the design process. You will find that as a professional engineer, the ability to visualize problem solutions and communicate them through your sketches will be one of your most important skills.

1.2.2 Communication

The second phase in the graphics produced to support the design process is **communication** models and drawings. In this phase your goal is to refine your initial sketches so your design solution can be communicated to others without ambiguity. In other words, you must be able to improve the clarity of your graphics to such an extent that others can visualize your design. This is done by adding more detail to your sketches, then creating a 3-D model

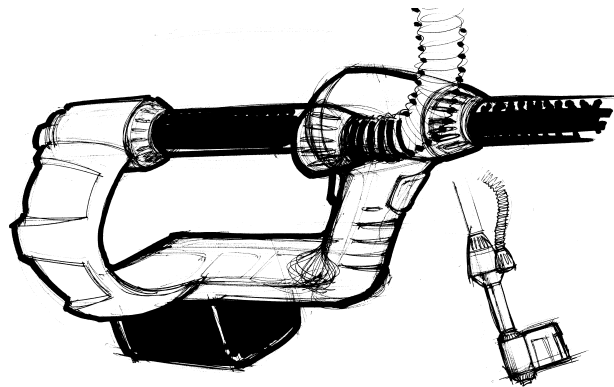


Figure 1.9 Design sketch of a hand digitizing system

These sketches allowed the designers to quickly explore and communicate design ideas.

Courtesy of Priority Designs (www.prioritydesigns.com)

using CAD software (Figure 1.10). The 3-D model is modified and changed as the design is refined. In the past, real models of the design were created for activities like product testing or production planning; however, many industries now use 3-D digital models to replace real models. Sometimes it is necessary to have real models, which can be produced from the 3-D model through a process called rapid prototyping, which will be explained later.

1.2.3 Documentation

After the design solution is finalized, graphics is the most effective way to permanently record that solution. Before 3-D modeling, **documentation** drawings were 2-D detail drawings that were copied through a process called blue-printing. Although many companies still create drawings,

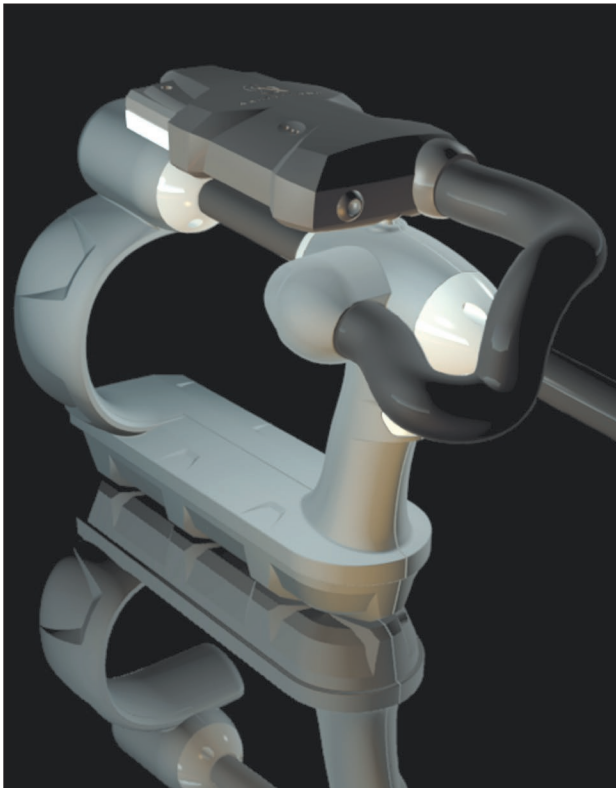


Figure 1.10 A refined 3-D model of the digitizing system used to communicate the design without ambiguity

With a CAD model, it is possible to test fit parts, analyze tolerances, and check interferences before making the actual components. It is also possible to locate the center of gravity and distribute the internal components to achieve perfect ergonomic weight and balance.

Courtesy of Priority Designs (www.prioritydesigns.com)

the trend is for companies to refine the 3-D model, which then is used directly by machine tools to create the design; measuring machines to inspect the design; and by sophisticated robots to help with the assembly of the design. Detail drawings still may be created, but the emphasis placed on their creation and use is shifting. Modern manufacturing organizations are moving toward the use of the 3-D model as the primary communication and documentation artifact of the design process, and drawings (when not used during production) are being used for things like meeting contractual obligations for legal and archival purposes (Figure 1.11). Two-dimensional documentation drawings follow very strict standard practices so everyone in the engineering field can “read” the drawing, and as 3-D modeling tools and processes have evolved, they are beginning to follow strict standard practices and techniques as well. These standards are the “language” used to communicate graphically. Advances in networking computer tools and storage, and the distribution of manufacturing organizations across the globe, means that electronic copies of 3-D models and 2-D drawings are increasingly being stored and accessed over the Internet to design, produce, and maintain products, processes, and structures.

1.3 The Engineering Design Process

Engineering design is one of the processes normally associated with the entire business or enterprise, from receipt of the order or product idea, to maintenance of the product, and all stages in between (Figure 1.12). The design process requires input about such areas as customer needs, materials, capital, energy, time requirements, and human knowledge and skills.

Two important societal concerns that an engineer must take into account are legal and environmental issues. Every business must operate within the law that governs their business. When designing, it is important that the engineer understand that legal issues may affect the designed product. Safety laws related to automobiles are an example of how government legislation can affect a design. Government regulations related to the environment may also have a bearing on the final outcome of the design. For example, the emission requirements on an automobile engine have a great effect on the final design.

Human knowledge input, such as an engineer’s knowledge of graphics, mathematics, and the sciences, will also have a great effect on the outcome of a finished product. Such knowledge is used by the engineer to analyze and solve problems, which ultimately make a product better by meeting more of the customer’s requirements.

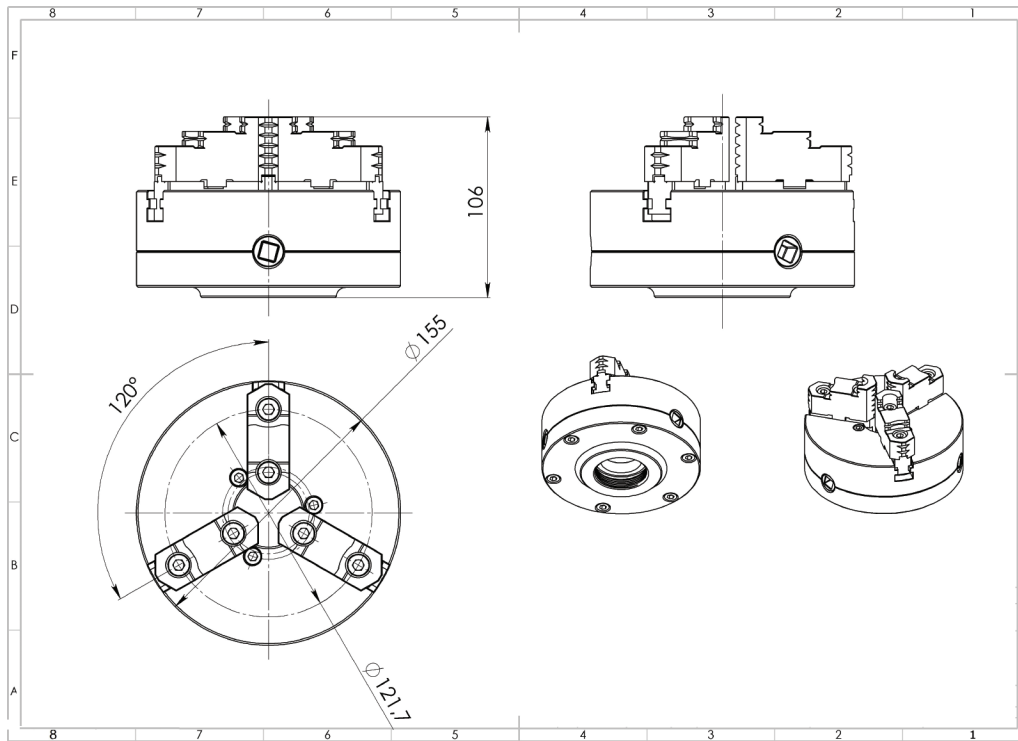


Figure 1.11 A detail drawing used in the documentation process

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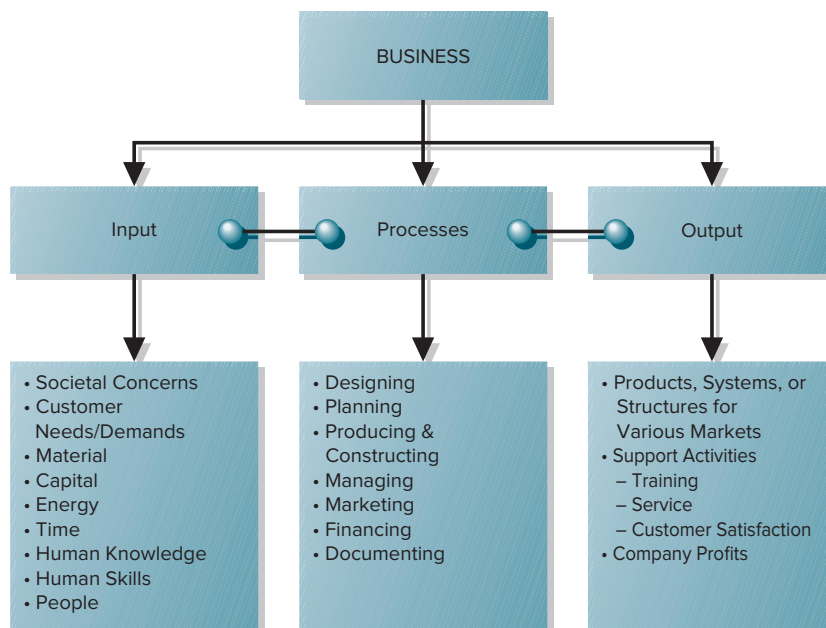


Figure 1.12 The business process

A manufacturing business or enterprise includes all the inputs, processes, and outputs necessary to produce a product or construct a structure. Designing is one of the major processes in such a business.

Design in Industry

Arc Second

This case study describes the design of a 3-D digitizing system. In this case study, you will see examples of how sketching is used and the importance of sketching in the design process to create this new product.

What Vulcan Does

The digitizing system consists of two laser transmitters and a wand receiver. The transmitters emit overlapping signals which create a digital grid, and the wand receiver picks up the signal and triangulates the position of the tip relative to the transmitters. In plain English, it means a person can walk around—free from wires—and simply click off precise measurements or navigate to a predetermined coordinate with ease.

The data is collected and saved to the CE box, and it can be downloaded directly into a CAD system via proprietary software. This allows for inspection, navigation, and modeling directly in CAD.

Brainstorm Sketching

To achieve our goals, we first brought all of our internal design staff together and created fast, rough brainstorm sketches. These sketches allow us to quickly explore and communicate our ideas with each other and the client. During the first week, work began in earnest to create a platform which would incorporate all of the features and functionality that Arc Second needed. It also was important to establish a language of aesthetics that would differentiate Arc Second from its competitors.

Presentation Model

After a final direction was chosen by the client, the design was transformed into a three-dimensional model, which allowed all team members on the project to see and touch it. This ensures that everybody involved is on the same page. At this point, the final aesthetic direction can be evaluated, as well as sizing and component packaging. Although many details will change, the overall look was locked in. Molded in solid foam, it was realistic enough to be shown at trade shows to determine consumer acceptance.

CAD Modeling

After the final design and graphics were chosen by the client, the foam model was digitized. This allowed our engineers to electronically model all of the components using Pro-Engineer (now known as Creo). We were now able to test-fit parts, analyze tolerances, and check interfaces before making the actual components. Additionally, our engineers were able to locate the center of gravity and

distribute the internal components to achieve a perfect ergonomic weight balance.

Engineering

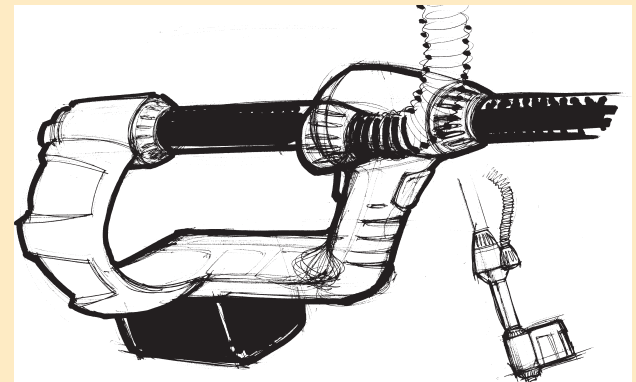
Our designers and engineers collaborated to streamline the engineering process. Whenever possible, “off the shelf” parts were utilized to reduce time to market. An accurate and fully detailed computer model was crucial for this project to come together on schedule.

Knowing that changes would likely be made, the Pro-E models were carefully constructed to best facilitate downstream modifications. This database allowed us to check clearance and interference, leave room for cables and fasteners, and give accurate, functional assembly drawings to the client.

Production Parts

Pleased with our work thus far, Arc Second was anxious to field-test these units. Our prototype staff was contracted to create functional prototypes before committing to costly hard tooling. Utilizing our engineer’s Pro-E data, we created RTV silicone molds from SLA masters. With these molds, we produced copies using two-part polyurethane. The units were then sprayed with a soft polyurethane coating which looked, felt, and performed like production injection molded parts. The coating also sealed the original material and protected it from UV rays. In addition, we cast the soft rubber “boots” that protected the handheld computer interface. All parts were test fitted in our shop before shipping to Arc Second for final assembly.

Ultimately, Priority Designs was contracted to produce 90 fully functioning Beta production units, which have been, and continue to be used and evaluated by consumers.



Courtesy of Priority Designs (www.prioritydesigns.com)