

MODERN GRAPHICS Communication

6th Edition

Frederick E. Giesecke | Shawna Lockhart
Marla Goodman | Cindy M. Johnson



FREE SAMPLE CHAPTER |



Decimal and Millimeter Equivalents

4ths	8ths	16ths	32nds	64ths	To 4 Places	To 3 Places	To 2 Places	Milli-meters	4ths	8ths	16ths	32nds	64ths	To 4 Places	To 3 Places	To 2 Places	Milli-meters		
$\frac{1}{4}$	$\frac{1}{8}$	$\frac{1}{16}$	$\frac{1}{32}$	$\frac{1}{64}$	.0156	.016	.02	.397	$\frac{3}{4}$	$\frac{5}{8}$	$\frac{9}{16}$	$\frac{17}{32}$	$\frac{33}{64}$	.5156	.516	.52	13.097	
				$\frac{35}{64}$	.5469	.547	.55	13.891										
			$\frac{37}{64}$	.5781	.578	.58	14.684											
			$\frac{39}{64}$	.6094	.609	.61	15.478											
		$\frac{3}{16}$	$\frac{7}{32}$	$\frac{5}{64}$	.0625	.062	.06	1.588			$\frac{11}{16}$	$\frac{19}{32}$	$\frac{41}{64}$	.6406	.641	.64	16.272	
				$\frac{43}{64}$	.6719	.672	.67	17.066										
			$\frac{45}{64}$	.7031	.703	.70	17.859											
			$\frac{47}{64}$	.7344	.734	.73	18.653											
		$\frac{3}{8}$	$\frac{5}{16}$	$\frac{9}{32}$	$\frac{13}{64}$	.2031	.203	.20		5.159	$\frac{7}{8}$	$\frac{13}{16}$	$\frac{25}{32}$	$\frac{49}{64}$	.7656	.766	.77	19.447
					$\frac{51}{64}$	.7969	.797	.80		20.241								
					$\frac{53}{64}$	.8281	.828	.83		21.034								
					$\frac{55}{64}$	.8594	.859	.86		21.828								
				$\frac{7}{16}$	$\frac{11}{32}$	$\frac{17}{64}$.2656	.266		.27		6.747	$\frac{15}{16}$	$\frac{29}{32}$	$\frac{57}{64}$.8906	.891	.89	22.622
						$\frac{59}{64}$	.9219	.922		.92		23.416						
					$\frac{61}{64}$	.9531	.953	.95		24.209								
					$\frac{63}{64}$	.9844	.984	.98		25.003								
	$\frac{25}{64}$		.3906	.391	.39	9.922	$\frac{31}{32}$	$\frac{61}{64}$	.9531	.953	.95	24.209						
	$\frac{27}{64}$		.4219	.422	.42	10.716		$\frac{63}{64}$	.9844	.984	.98	25.003						
	$\frac{29}{64}$		.4531	.453	.45	11.509		1.0000	1.000	1.00	25.400							
	$\frac{31}{64}$		.4844	.484	.48	12.303												
	$\frac{33}{64}$.5156	.516	.52	13.097													
	$\frac{35}{64}$.5469	.547	.55	13.891													
	$\frac{37}{64}$.5781	.578	.58	14.684													
	$\frac{39}{64}$.6094	.609	.61	15.478													
	$\frac{41}{64}$.6406	.641	.64	16.272														
	$\frac{43}{64}$.6719	.672	.67	17.066														
	$\frac{45}{64}$.7031	.703	.70	17.859														
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$\frac{61}{64}$.9531	.953	.95	24.209															
$\frac{63}{64}$.9844	.984	.98	25.003															
$\frac{64}{64}$	1.0000	1.000	1.00	25.400															

Metric measurements may be set off directly on drawings with the metric scale. Decimal measurements may be set off directly on drawings with the engineers' scale or the decimal scale.

Symbols for Instructors' Corrections

C Show construction

D Show dimensions; show given or required data

I Improve form or spacing

H Too heavy


NH Not heavy enough

ND Not dark enough

SL Sharpen pencil or compass lead

GL Use guidelines

A Improve arrowheads

 Error in circled area

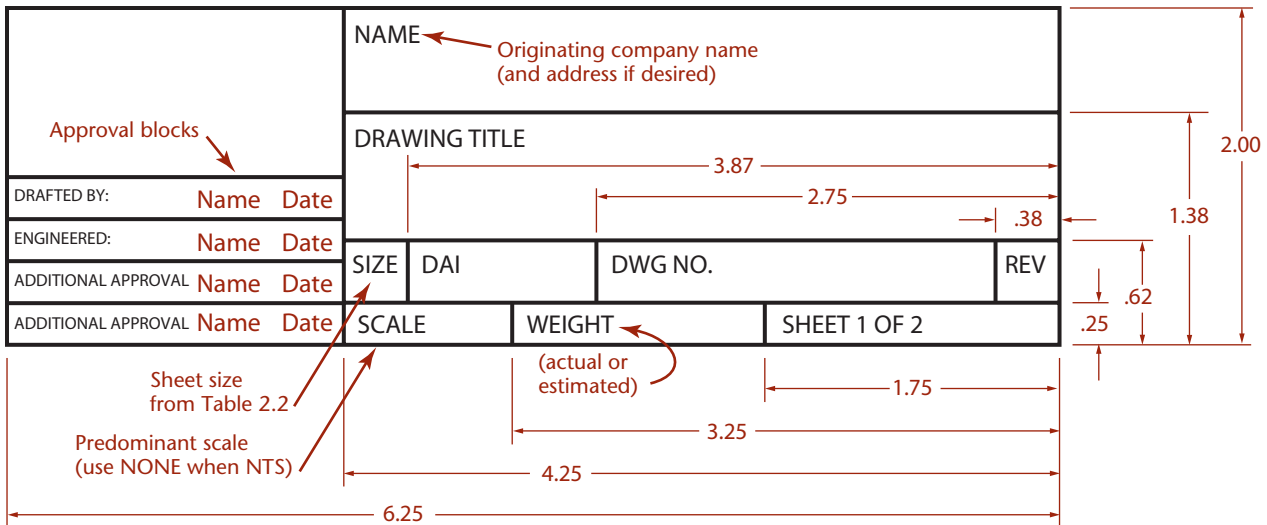


Fig. IV Typical Title Block

4	1			HANDLE
3	1			CYLINDER
2	2			GAGE PIN
1	1			BASE
FIND NO	QTY REQD	CAGE CODE NO	PART OR IDENTIFYING NO.	NOMENCLATURE

This example is arranged to fit above title block

.25

6.25

Fig. V Typical Parts List or Materials List

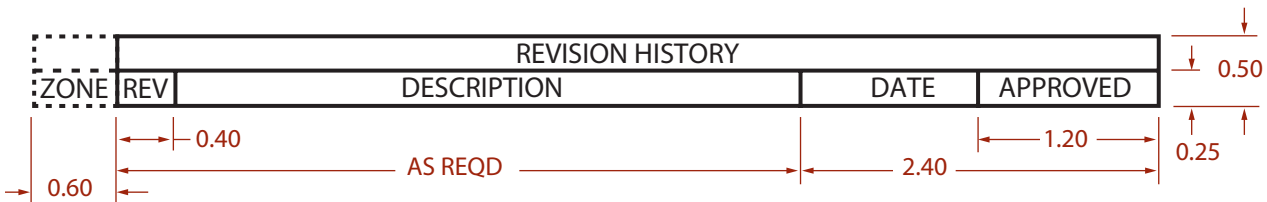


Fig. VI Typical Revision History Block

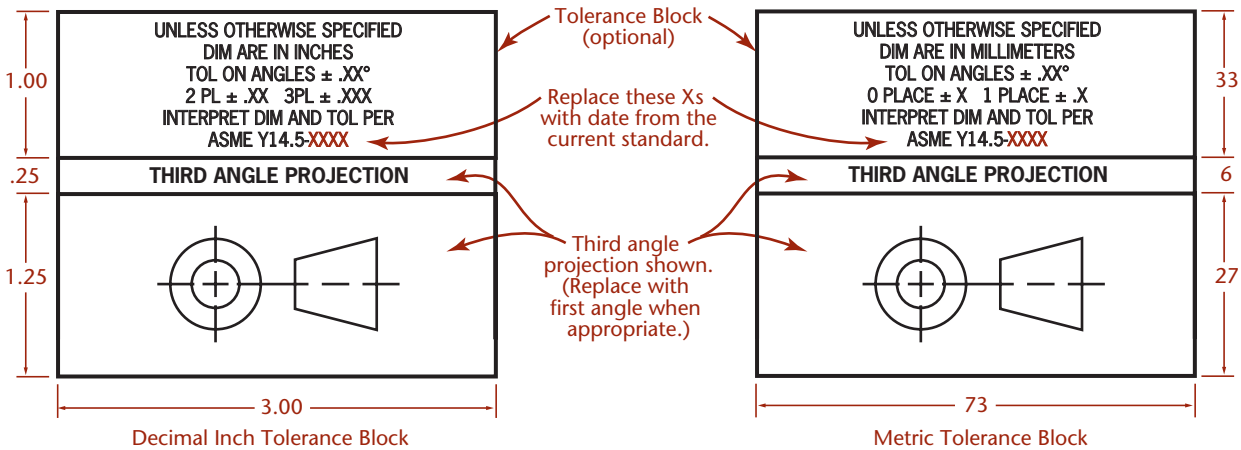


Fig. VII Inch and Millimeter Tolerance Block Examples. Note that both show third angle projection. Use the symbol for first angle projection when appropriate.

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SIXTH EDITION

MODERN GRAPHICS COMMUNICATION

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Library of Congress Control Number: 2023945393

\$PrintCode

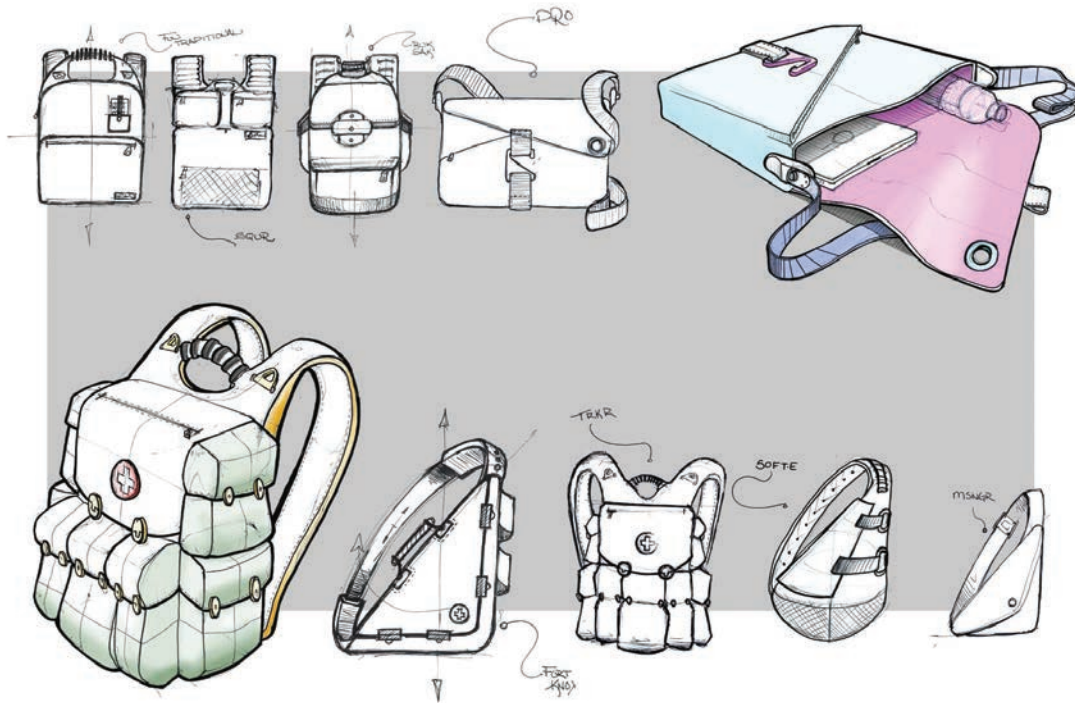


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ISBN 10: 0-13-827187-9
ISBN 13: 978-0-13-827187-9

SIXTH EDITION

MODERN GRAPHICS COMMUNICATION



Engineers, technicians, and designers need to master a variety of graphical communication techniques, from sketching concepts, such as these backpack designs, to creating detailed three-dimensional models suitable for analysis of design features. (Courtesy of André Cotan.)

ABOUT THIS BOOK

Modern Graphics Communication presents practices and techniques of sketching, visualization, design, and CAD that are important to today's graphics curriculum. Based on the long-standing authoritative text on the subject, Giesecke's *Technical Drawing*, this text preserves the time-tested graphics techniques that remain fundamental to the class, as it expands on the role that the 3D CAD database plays in design and documentation.

The topics of sketching and visualization skills are this book's primary focus and provide a solid conceptual basis for the CAD instruction most graphics students receive. This edition also illustrates the appli-

cation of both 3D and 2D modeling and technical drawing skills to real-world situations, and includes several in-depth case studies that link chapter content to industry practice. Each chapter lays a conceptual foundation that anchors the detailed sections on technique that follow. A wealth of step-by-step illustrated guides, worksheets, and end-of-chapter exercises help students visualize, practice, and retain those key concepts and techniques. Students who complete *Modern Graphics Communication* will leave with a full repertoire of skills—plus a lasting reference book—that they will find invaluable both in education and industry.

THE SIXTH EDITION

The sixth edition of *Modern Graphics Communication* builds on *Technical Drawing's* long history as an introduction to technical drawing and an easy-to-use reference for techniques and practices.

Updated Content

- Additional hands-on worksheets and grids for sketching and visualization practice.
- Coverage of 3D design and modeling techniques.
- Updates to current ASME standards, particularly for GD&T and surface finish symbology.
- Updated examples of rapid prototyping and direct printing.
- Updated software examples.
- Thoroughly checked for accuracy.
- Online chapters available for axonometric projection and perspective drawing.

TEACHING/LEARNING FEATURES

Visually-oriented students and busy professionals will quickly locate content by navigating these consistent chapter features.

- **Splash Spread** An attention-getting chapter opener interests readers and provides context for chapter content.
- **References and Web Links** Applicable references to standards and links to handy websites are at the beginning of each chapter.
- **Foundations Section** An introductory section, set off by a topic heading tab at the top of the page for easy navigation, covers the topic's usage and importance, visualization tips, and theory related to the drawing techniques.
- **Detail Section** This is the “brass tacks” part of the book, where detailed explanations of drawing and modeling techniques, variations, and examples are organized into quick-read sections, each numbered for quick reference in the detailed table of contents.
- **CAD at Work** These breakout pages include tips related to using the 2D or 3D CAD model to generate drawings.
- **Industry Case** 3D modeling practitioners share their best practices for modeling and documenting design.
- **Portfolio** Examples of finished drawings wrap up the chapter by showing real-world application of topics presented.
- **Key Words** Set in bold italics on first reference, key words are summarized at the end of the chapter.
- **Chapter Summary**
- **Review Questions**

- **Chapter Exercises** The excellent Giesecke problem sets feature updated exercises, including plastic and sheet metal parts, modeling exercises, assembly drawings from CAD models, and sketching problems.
- **Worksheets** Fifty-two worksheets and grids at the end of the text provide additional hands-on practice with chapter topics. Worksheets are also available in PDF format.

ABOUT THE AUTHORS

Frederick E. Giesecke, founder of the first formal architectural education program in Texas at what is today Texas A&M University, has been described as “a wunderkind of the first magnitude.” He joined the A&M faculty at the age of 17, after graduating in 1886 with a B.S. in Mechanical Engineering. By the age of 19, was appointed head of A&M's Department of Mechanical Drawing.

Having studied architectural drawing and design at Cornell University and the Massachusetts Institute of Technology, Giesecke also served as head of the Department of Architecture and the official college architect at Texas A&M, designing many campus buildings that are still standing today.

A long-time admirer of Giesecke's legacy, Shawna Lockhart was honored to carry on the commitment to clear, engaging, thorough, and well-organized presentation that began with the original author.

Lockhart is known as an early adopter and authority on CAD technologies. She is an instructor noted for outstanding dedication to students and for encouraging a broad spectrum of individuals, particularly women and minorities, to follow careers in engineering-related fields. Lockhart now works full time to ensure that the Giesecke graphics series continually applies to an evolving variety of technical disciplines.

ONLINE RESOURCES

An Instructor's Manual (9780138264659) and Lecture Slides in PowerPoint format (9780138264666) are available on the companion site for this book at <https://www.pearson.com/en-us/subject-catalog/p/modern-graphics-communication/P200000011547>.

Worksheets, additional appendices, and web chapters on axonometric projection and perspective drawing may be downloaded from www.peachpit.com. To access and download the bonus chapters:

1. Visit www.peachpit.com/moderngraphics.
2. Log in with your Peachpit account, or if you don't have one, create an account.
3. Register using this book's ISBN, 9780138271879, then click the Access Bonus Content link next to this book on your account's Registered Products page.

ACKNOWLEDGMENTS

Sincere thanks to all the individuals and companies who shared their expertise through drawings and advice with the readers of this book:

Robert A. Ackein, Marty Albini, Jacob Baron-Taltre, Albert Brown, Jr., Will Callahan, Ryan Cargo, Jason Cohn, David and Caroline Collett, André Cotan, David Demchenkov, Tim Devries, Jost Diedrichs, Steve Elpel, Joe Evers, Carl Fehres, Mark Gerisch, Joe Graney, Leo Greene, Tom Jungst, Scott Keller, Robert Kincaid, Brandon Larocque, Matt McCune, Stan McLean, Laine McNeil, Rob Mesaros, Cliff Moore, Jeremy Olson, Andrea Orr, Kelly Pavlik, Jeffrey Pentecost, Mark Perkins, David Pinchefskey, Robert Rath, Jake Reis, Erik Renna, Steve Sanford, Chad Schipman, Scott Schwartzenberger, Timothy Seaman, Mark Soares, Ben Staal, Bryan Strobel, Lee Sutherland, Kent Swendseid, Bill Townsend, Michael T. Wheelock, Alex Wilson, Douglas Wintin, Brandon Wold, Rick Zaik, and Jeff Zerr.

We gratefully acknowledge the contributions of reviewers to the development of this series:

Tarek Abdel-Salam, *East Carolina University*
 Robert A. Ackein, *Bates Technical College*
 Fred Brasfield, *Tarrant Community College*
 Charles Richard Cole, *Southern Polytechnic State University*
 Robert Conn, *Illinois Eastern Community Colleges—Wabash Valley College*
 Steven L. Dulmes, *College of Lake County*
 Jeff Levy, *New River Community College*
 J.D. Mather, *Pennsylvania College of Technology*
 Saeid Motavalli, *California State University East Bay*
 Mostafa A. Tossi, *Pennsylvania State Worthington Scranton*
 Michael T. Wheelock, *Idaho State University*
 Paige Wyatt, *Columbia Basin College*

A very special thanks to Robert Conn and J.D. Mather for their constructive comments and suggestions.

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The following features were designed to provide easy navigation and quick reference for students and professionals who look to Giesecke both as a helpfully-organized teaching text and a lasting reference.

CHAPTER OPENER

Topics that you can expect to learn about in this chapter are listed here.

A large illustration and an interesting overview give you a real-world context for what this chapter is about.

CHAPTER ONE

THE WORLDWIDE GRAPHIC LANGUAGE FOR DESIGN

OBJECTIVES

After studying the material in this chapter, you should be able to:

1. Describe the role of graphics in the design process.
2. Identify stages in the design process.
3. Contrast concurrent versus traditional design processes.
4. List five professions that use technical drawings.
5. Describe four creativity techniques.
6. Explain why standards are important.
7. Identify three purposes for technical drawings.

Refer to the following standard:
• ANSI/ASME Y14.100 Engineering Drawing Practices

THE WORLDWIDE GRAPHIC LANGUAGE FOR DESIGN 3



Conceptual Sketches. Exploring many design options through quick sketches is one method that Lunar, recently named one of the top 10 award-winning American product design firms by BusinessWeek magazine, uses to create beautiful products and successful brands. (Images courtesy of LUNAR.)

OVERVIEW

Regardless of the language they speak, people all over the world use technical drawings to communicate their ideas. Graphic representation is a basic, natural form of communication that isn't tied to a particular time or place. It is, in a sense, a universal language.

Accomplishing ideas, from the simplest to the most elaborate, requires teamwork. A new product, machine, structure, or system may exist in the mind of the engineer or designer, but before it can become a reality, the idea must be communicated to many different people. The ability to communicate design concepts quickly and accurately through technical drawings is key to meeting project budgets and time constraints. Effective graphic communication is also an advantage in the global marketplace, where team members may not always share a common language.

Like carpenters who learn to use the tools of their trade, engineers, architects, drafters, designers, manufacturers, and technicians learn the tools of technical drawing. They learn specific methods to represent ideas, designs, and specifications in a consistent way that others can understand. Being an effective graphic communicator ensures that the product, system, or structure that you envision is produced as you specified.

Drawing standards that apply to this chapter are shown here.

"SPOTLIGHT" SECTIONS

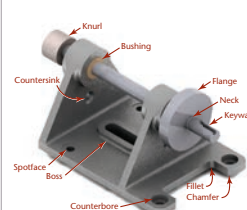
These sections add background information for key topics.

214 CHAPTER 5 MODELING AND DESIGN










SPOTLIGHT

Typical Features

Many CAD systems have aids to creating features that are a part of many engineering designs (see Figure 5.63) that can make creating your model even easier.



5.63 Commonly Manufactured Features

Feature	Example
Fillet: A rounded interior blend between surfaces; used, for example, to strengthen adjoining surfaces or to allow a part to be removed from a mold	
Round: A rounded exterior blend between surfaces; used to make edges and corners easier to handle, improve strength of castings, and allow for removal from a mold	
Counterbore: A cylindrical recess around a hole, usually to receive a bolt head or nut	
Countersink: A cone-shaped recess around a hole, often used to receive a tapered screw head	
Spotface: A shallow recess like a counterbore, used to provide a good bearing surface for a fastener	
Boss: A short raised protrusion above the surface of a part, often used to provide a strong flat bearing surface	
Lug: A flat or rounded tab protruding from a surface, usually to provide a method for attachment	
Flange: A flattened collar or rim around a cylindrical part to allow for attachment	
Chamfer: An angled surface, used on a cylinder to make it easier to start into a hole, or a plate to make it easier to handle	

“FOUNDATIONS” SECTION

This introductory section covers the chapter topic’s usage and importance, visualization tips, and theory related to the drawing and modeling techniques.

Color at the top of the page makes it easy to flip to the “Foundations” section.

234 CHAPTER 6 ORTHOGRAPHIC PROJECTION

UNDERSTANDING PROJECTION

To make and interpret drawings, you need to understand projection and the standard arrangement of views. You also need to be familiar with the geometry of solid objects and be able to visualize a 3D object that is represented in a 2D sketch or drawing. The ability to identify whether surfaces are normal, inclined, or oblique in orientation can help you visualize. Common features such as vertices, edges, contours, fillets, holes, and rounds are shown in a standard way, which makes drawings simpler to create and helps prevent them from being misinterpreted.

Views of Objects

A photograph shows an object as it appears to the observer but not necessarily as it is. It cannot describe the object accurately, no matter what distance or which direction it is taken from, because it does not show the exact shapes and sizes of the parts. It would be impossible to create an accurate 3D model of an object using only a photograph for reference because it shows only one view. It is a 2D representation of a 3D object.

Drawings are 2D representations as well, but unlike photos, they allow you to record sizes and shapes precisely. In engineering and other fields, a complete and clear description of the shape and size of an object is necessary to be sure that it is manufactured exactly as the designer intended. To provide this information about a 3D object, typically a standard way, which makes drawings simpler to create and helps prevent them from being misinterpreted.

The system of views is called **multiview projection**. Each view provides certain definite information. For example, a front view shows the true shape and size of surfaces that are parallel to the front of the object. An example of a 3D object and its front view projection is shown in Figure 6.1. Figure 6.2 shows the same part and the six principal viewing directions. Figure 6.3 shows the same six views of a house.

6.1 Front View of an Object

6.2 The Six Principal Views

6.3 Six Views of a House

“DETAIL” SECTION

This is the “brass tacks” of the book, where detailed techniques, variations, and examples are organized into quick-read sections, numbered for easy reference.

Content is broken into individual, numbered sections.

138 CHAPTER 4 GEOMETRY FOR MODELING AND DESIGN

4.6 DRAWING A TRIANGLE WITH SIDES GIVEN

Given the sides A , B , and C , as shown in Figure 4.29a.

Step 1. Draw one side, as C , in the desired position, and draw an arc with radius equal to side A .

Step 2. Lightly draw an arc with radius equal to side B .

Step 3. Draw sides A and B from the intersection of the arcs, as shown.

4.29 Drawing a Triangle with Sides Given

TIP
Using AutoCAD, you can enter the relative length and angle from the previous endpoint using the format: @lengthvalue<anglevalue

4.7 DRAWING A RIGHT TRIANGLE WITH HYPOTENUSE AND ONE SIDE GIVEN

Given sides S and R (Figure 4.30), with AB as a diameter equal to S , draw a semicircle. With A as center and R as radius, draw an arc intersecting the semicircle at C . Draw AC and CB to complete the right triangle.

4.30 Drawing a Right Triangle

4.8 LAYING OUT AN ANGLE

Many angles can be laid out directly with the triangle or protractor. For more accuracy, use one of the methods shown in Figure 4.31.

Tangent Method The tangent of angle θ is y/x , and $y = x \tan \theta$. Use a convenient value for x , preferably 10 units (Figure 4.31a). (The larger the unit, the more accurate will be the construction.) Look up the tangent of angle θ and multiply by 10, and measure $y = 10 \tan \theta$.

Sine Method Draw line x to any convenient length, preferably 10 units (Figure 4.31b). Find the sine of angle θ , multiply by 10, and draw arc with radius $R = 10 \sin \theta$. Draw the other side of the angle tangent to the arc, as shown.

Chord Method Draw line x of any convenient length, and draw an arc with any convenient radius R —say 10 units (Figure 4.31c). Find the chordal length C using the formula $C = 2 \sin \theta/2$. Machinists’ handbooks have chord tables. These tables are made using a radius of 1 unit, so it is easy to scale by multiplying the table values by the actual radius used.

EXAMPLE To set off $25-1/2^\circ$, find the natural sine of $25-1/2^\circ$, which is 0.4305. Then $R = 10 \text{ units} \times 0.4305 = 4.305 \text{ units}$.

EXAMPLE Half of $43^\circ 20' = 21^\circ 40'$. The sine of $21^\circ 40' = 0.3692$. $C = 2 \times 0.3692 = 0.7384$ for a 1 unit radius. For a 10 unit radius, $C = 7.384$ units.

EXAMPLE To set off $43^\circ 20'$, the chordal length C for 1 unit radius, as given in a table of chords, equals 0.7384. If $R = 10$ units, then $C = 7.384$ units.

4.31 Laying Out Angles

200 CHAPTER 5 MODELING AND DESIGN

CONSTRAINING A SKETCH

Like a hand-drawn sketch, the sketch for a constraint-based model captures the basic geometry of the feature as it would appear in a 2D view.

STEP BY STEP

- Sketch the basic shapes as you would see them in a 2D view. Many modelers will automatically constrain the sketch as you draw unless you turn this setting off in the software.
- Apply geometric constraints to define the geometry of the sketch. If it is important to your design intent that lines remain parallel, add that constraint. If arcs must remain tangent to lines, apply that constraint. Here, lines A and B have been defined to be parallel; note the parallel constraint symbol.
- Add dimensional constraints. The length of line B was sketched so that the software interpreted the dimensional constraint to be 3.34. The designer changed this dimension to 3.75 (the desired length), and the length of the line was updated to the new length.

5.24 BECOMING A 3D VISUALIZER 259

“STEP BY STEP” ACTIVITIES

Complicated processes are shown as step-by-step activities with each illustration right next to the text that explains it.

6.24 BECOMING A 3D VISUALIZER 259

USING A MITER LINE

Given two completed views you can use a miter line to transfer the depths and draw the side view of the object shown at right.

STEP BY STEP

- Locate the miter line a convenient distance away from the object to produce the desired spacing between views.
- Project the remaining points.
- Draw the view by locating each vertex of the surface on the projection line and across the miter line. To move the right-side view to the right or left, move the top view upward or downward by moving the miter line closer to or farther from the view. You don’t need to draw continuous lines between the top and side views via the miter line. Instead, make short dashes across the miter line and project from these. The 45° miter-line method is also convenient for transferring a large number of points, as when drawing a curve.

“CAD AT WORK”

CAD at Work sections break out examples related to using the 2D or 3D CAD model to generate drawings.

“INDUSTRY CASE”

Several industry practitioners share their approaches to modeling and documenting design.

INDUSTRY CASE

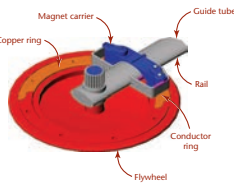
THE GEOMETRY OF 3D MODELING: USE THE SYMMETRY

Stratix ID used magnets to create a clean, quiet, zero maintenance brake for the exercise bike it designed for Park City Entertainment. When copper rings on the bike’s iron flywheel spin past four rare-earth magnets, they create current in circular flow (an eddy current) that sets up a magnetic field.

This opposing magnetic field dissipates power and slows the wheel. Moving the magnets onto and off the copper rings varies the amount of resistance delivered. When Marty Albini, Senior Mechanical Engineer, modeled the plastic magnet carrier for the brake, he started with the magnets and their behavior as the carrier moved them onto and off the copper rings (see Figure 4.84). “There is no one way to think about modeling a part,” Albini said. “The key is to design for the use of the part and the process that will be used to manufacture it.” To make the magnet carrier symmetrical, Albini started by modeling half of it.

The magnet carrier was designed as a part in the larger flywheel assembly, parts of which were already completed.

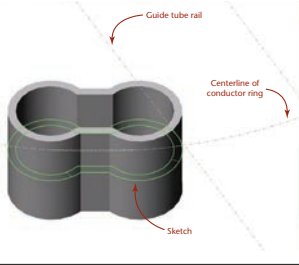
Each pair of magnets was attached to a backing bar that kept them a fixed distance apart. To begin, Albini started with the geometry he was sure of: the diameter of the magnets, the space between them, and the geometry of the conductor ring. He sketched an arc sized to form a pocket around one of the magnets so that its center point would be located on the centerline of the conductor ring (see Figure 4.85). He then sketched another similar arc but with its center point positioned to match the distance between the centers of the two magnets. He connected the two arcs with parallel lines to complete the sketch of the inside of the carrier. This outline was offset to the outside by the thickness of the wall of the holder. (Because this is an injection-molded plastic part, a uniform wall thickness was used throughout.) One final constraint was added to position



4.84 Flywheel Assembly. The magnet carrier for the brake was designed to move onto and off the conductor ring by sliding along an elliptical guide tube, pulled by a cable attached to the small tab in the middle of the carrier.

the carrier against the rail on the elliptical tube along which it would slide; the outside of the inner arc is tangent to this rail. With the sketch geometry fully defined, Albini extruded the sketch up to the top of the guide tube and down to the running clearance from the copper ring.

To add a lid to the holder, Albini used the SolidWorks Offset command to trace the outline of the holder. First, he clicked on the top of the holder to make its surface the active sketch plane. This is equivalent to changing the user coordinate system in other packages; it signals to SolidWorks that points picked from the screen lie on this plane. He then selected the



4.85 Extruding the Carrier. The magnet carrier was extruded up and down from the sketch, shown here as an outline in the middle of the extruded part. Notice that the sketch is tangent to the guide tube rail, and the centers of the arcs in the sketch are located on the centerline of the conductor ring.

“PORTFOLIO”

These pages offer examples of finished drawings showing real-world application of topics presented.

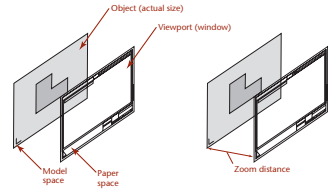
CAD at WORK

MODEL SPACE AND PAPER SPACE IN AUTOCAD

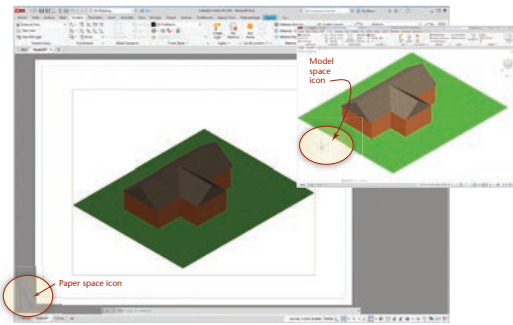
Using CAD, you can make an accurate model of the device or structure. To do this, you create the object at the actual size that it exists in the real world, using whatever system of measurement that you would use when constructing it.

On paper it is a different matter. You would have to have some really large sheets to print your building full size. AutoCAD software uses the concept of two “spaces,” model space and paper space, to describe how to transform the full-size CAD model to proportionate views that fit your sheet of paper.

Understanding scale as it relates to paper drawings or as it relates to creating layouts from a CAD drawing is an important concept for technical drawing because the ultimate goal is for drawings to be interpreted and used in the real world. Therefore, they must be easy to print and read.

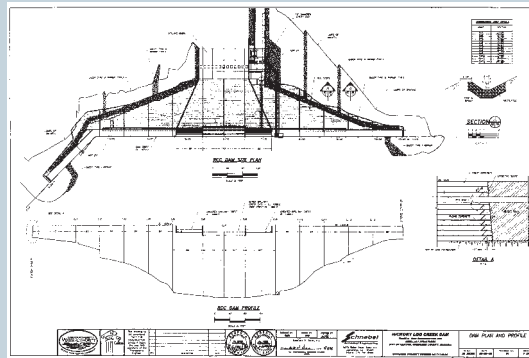


(A) In AutoCAD, paper space allows you to see how various views of the full-size model can be shown on a sheet of paper.

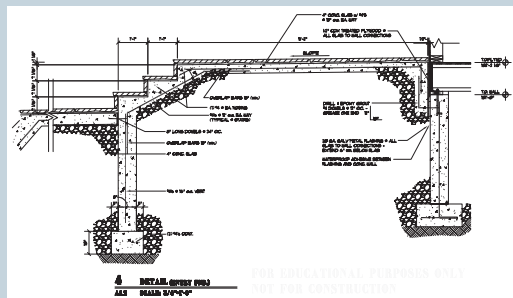


(B) The window at left shows a paper space representation of the full-size CAD model in the smaller window at right. Note that AutoCAD uses icons to help users differentiate the two “spaces.” (Autodesk screen shots reprinted courtesy of Autodesk, Inc.)

542 CHAPTER 11 DIMENSIONING



Plan and Profile for Dam Site (Courtesy of Schnabel Engineering.)

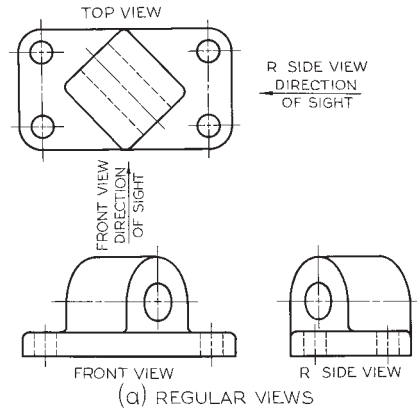
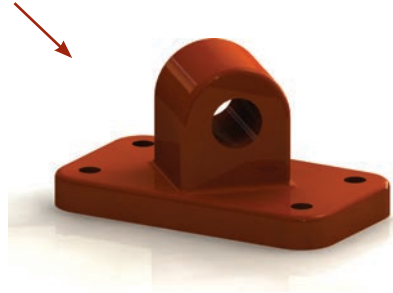


Portion of a Drawing Showing Dimensioned Architectural Details (Courtesy of Locati Architects.)

PORTFOLIO

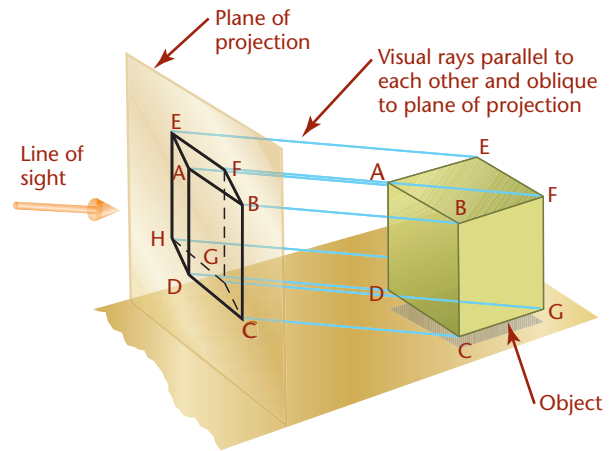
SOLID MODEL VISUALIZATION ART

Solid models bring views to life on the page to help you visualize the drawing.



ILLUSTRATIONS

Colored callouts differentiate explanatory text from annotations in technical drawings. Consistent use of color helps differentiate the meaning of projection lines, fold lines, and other drawing elements. A color key is provided for easy reference.



Color Key for Instructional Art

Item	In instructional art	In a technical drawing
Callout arrow		*
Dimension line		a thin (0.3mm) black line
Projection line		a lightly sketched line
Folding line		used in descriptive geometry
Picture plane on edge		*
Plane of projection		*
Cutting plane on edge		(see Chapter 6)
Cutting plane		*
Reference plane on edge		used in descriptive geometry
Reference plane		*
Viewing direction arrow		(see Chapter 6)
Horizon + ground line		
Rotation arrow		30°

* Not a typical feature of technical drawings. (Shown in this book for instructional purposes.)

CHAPTER REVIEW

Each chapter ends with Key Words, a Chapter Summary, and Review Questions.

Worksheets at the end of the book help students practice and retain information presented in the book.

Review and exercises are tabbed to make them easy to find. The color stripe corresponds to the alternating chapter color.

KEY WORDS

- Depth
- Edge
- First-Angle Projection
- Folding Lines
- Frontal Plane
- Glass Box
- Height
- Horizontal Plane
- Inclined Edge
- Inclined Surface
- Multiview Projection
- Necessary Views
- Normal Edge
- Normal Surface
- Oblique Edge
- Oblique Surface
- Orthographic
- Plane
- Plane of Projection
- Point
- Principal Views
- Profile Plane
- Projection Symbols
- Surfaces
- Third-Angle Projection
- Three Regular Views
- Width

CHAPTER SUMMARY

- Orthographic drawings are the result of projecting the image of a 3D object onto one of six standard planes of projection. The six standard views are often thought of as an unfolded glass box. The arrangement of the views in relation to one another is important. Views must line up with adjacent views, so that any point in one view projects to line up with that same point in the adjacent view. The standard arrangement of views shows the top, front, and right side of the object.
- Visualization is an important skill. You can build your visual abilities through practice and through understanding terms describing objects. For example, surfaces can be normal, inclined, or oblique. Normal surfaces appear true size in one principal view and as an edge in the other two

- Choice of scale is important for representing objects clearly on the drawing sheet.
- Hidden lines are used to show the intersections of surfaces, surfaces that appear on edge, and the limits of curved surfaces that are hidden from the viewing direction.
- Centerlines are used to show the axis of symmetry for features and paths of motion, and to indicate the arrangement for circular patterns.
- Creating CAD drawings involves applying the same concepts as in paper drawing. The main difference is that drawing geometry is stored more accurately using a computer than in any hand drawing. CAD drawing geometry can be reused in many ways and plotted to any scale as necessary.

WORKSHEETS

Use the following worksheets at the end of the book to practice skills for this chapter:

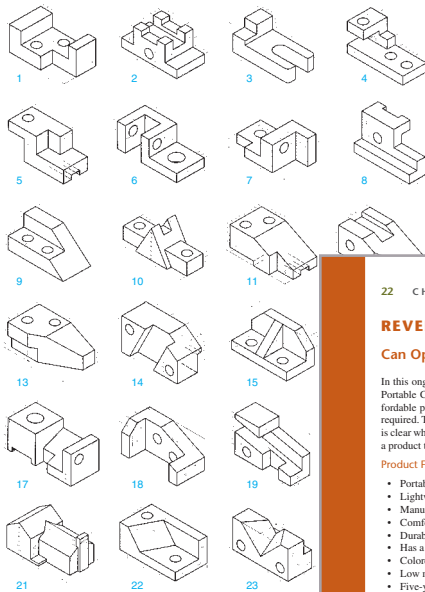
- Worksheets 14, 19, 20, 21, 22, 23, 24, 25, 26, 27

REVIEW QUESTIONS

1. Sketch the symbol for third-angle projection.
2. List the six principal views of projection.
3. Sketch the top, front, and right-side views of an object of your design having normal, inclined, and oblique surfaces.
4. In a drawing that shows the top, front, and right-side view, which two views show depth? Which view shows depth vertically on the sheet? Which view shows depth horizontally on the drawing sheet?
5. What is the definition of a normal surface? An inclined surface? An oblique surface?
6. What are three similarities between using a CAD program to create 2D drawing geometry and sketching on a sheet of paper? What are three differences?
7. What dimensions are the same between the top and front view: width, height, or depth? Between the front and right-side view? Between the top and right-side view?
8. List two ways of transferring depth between the top and right-side views.
9. If surface A contains corners 1, 2, 3, 4, and surface B contains 3, 4, 5, 6, what is the name of the line where surfaces A and B intersect?

CHAPTER EXERCISES

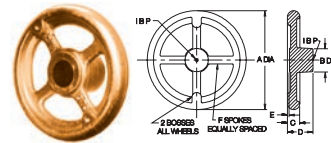
The Giesecke problem sets feature updated exercises including plastic and sheet metal parts, constraint-based modeling, sketching problems, and reverse engineering projects.



Exercise 6.5 Multiview Sketching Problems. Sketch necessary orthographic view either one or two problems per sheet as assigned by your instructor. These exercises are on metric A4 paper. The units shown may be either .500" and .250" or 10 mm and 5 mm.

Exercises for two reverse engineering projects are keyed to the chapter they best accompany.

Exercise 6.19 Create a constraint-based model of the four-spoke hand wheel shown such that it can be resized to match the dimensions in the table.



STRAIGHT SPOKES

PART NO.	CAST IRON	A	B	C	D	E	F
CL-4HWSF	4	1-1/2	5/8		1-11/16	1/8	
CL-5HWSF	5	1-1/2	3/4		1-13/16		4
CL-6HWSF	6	1-5/8			2-1/8	5/32	
CL-8HWSF	8	1-3/4			2-1/2	1/8	
CL-10HWSF	10	2-1/4	1		3-1/4		8
CL-12HWSF	12						
CL-14HWSF	14	3			3-3/4	3/32	

REVERSE ENGINEERING PROJECTS

Can Opener Project

In this ongoing project, you will reverse engineer an Amco Swing-A-Way 407WH Portable Can Opener. It is recommended you purchase a readily available and affordable product similar to this one, so you can make measurements directly when required. This effective and low-cost can opener seems simple in its familiarity, but it is clear when you begin to take one apart that considerable effort went into designing a product that is inexpensive, reliable, and easy to operate for most people.

Product Features

- Portable
- Lightweight
- Manually operated
- Comfortable to hold
- Durable construction
- Has a bottle opener
- Colored handles available
- Low maintenance
- Five-year warranty



SHOULDER	SCREW
PLATE	SCREW
CL-2-SS	
CL-3-SS	
CL-4-SS	
CL-5-SS	
CL-6-SS	
CL-7-SS	
CL-8-SS	
CL-9-SS	
CL-10-SS	
CL-11-SS	
CL-12-SS	
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CL-42-SS	
CL-43-SS	
CL-44-SS	
CL-45-SS	
CL-46-SS	
CL-47-SS	
CL-48-SS	
CL-49-SS	
CL-50-SS	

Exercises for Chapter 1

RE 1.1 This is far from the only can opener on the market. Use the Web to research manual can opener designs. Find at least three can opener models that are different from the Amco Swing-A-Way. Make a list of the features of each of the three.

RE 1.2 Create a diagram for the can opener. How many distinct parts are used in its manufacture? Which parts can be grouped together and preassembled as a unit?

Exercises for Chapter 2

RE 2.1 Make a table listing the dimensions of the can opener parts. Do not worry about measurements for now. Give names to the dimensions, such as lower handle length, lower handle height, and hole diameter.

RE 2.2 Which dimensions in the list you created are critical to the function of the can opener? Identify in your list the dimensions that must match dimensions on other parts for the can opener to function. Which dimensions will not be very important to the can opener's function?

RE 2.3 To accurately reverse engineer the can opener, you will need to make measurements for the part features. Metrology is the science of making measurements. The digital caliper is one commonly used measurement tool. The accuracy of a measurement is dependent on several factors, including the following:

- the skill of the operator
- the temperature at which the measurements are taken

BRIEF CONTENTS

CHAPTER ONE	THE WORLDWIDE LANGUAGE FOR GRAPHIC DESIGN	2
CHAPTER TWO	LAYOUTS AND LETTERING	30
CHAPTER THREE	VISUALIZATION AND SKETCHING	62
CHAPTER FOUR	GEOMETRY FOR MODELING AND DESIGN	124
CHAPTER FIVE	MODELING AND DESIGN	170
CHAPTER SIX	ORTHOGRAPHIC PROJECTION	232
CHAPTER SEVEN	2D DRAWING REPRESENTATION	284
CHAPTER EIGHT	SECTION VIEWS	326
CHAPTER NINE	AUXILIARY VIEWS	362
CHAPTER TEN	MODELING FOR MANUFACTURE AND ASSEMBLY	414
CHAPTER ELEVEN	DIMENSIONING	502
CHAPTER TWELVE	TOLERANCING	546
CHAPTER THIRTEEN	THREADS, FASTENERS, AND SPRINGS	592
CHAPTER FOURTEEN	WORKING DRAWINGS	636

GLOSSARY
APPENDICES
INDEX
WORKSHEETS

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CONTENTS

CHAPTER ONE

THE WORLDWIDE GRAPHIC LANGUAGE FOR DESIGN 2

UNDERSTANDING THE ROLE OF TECHNICAL DRAWINGS 4

- The Design Process 5
- Concurrent Engineering 6
- Computer-Aided Design and Product Development 6
- Designing Quality into Products 7
- The Digital Database 7

1.1 GRAPHICS TOOLS IN ACTION 8

- Design Phase: Problem Identification 8
- Design Phase: Ideation 9
- Design Phase: Decision Process/Design Selection 9
- Design Phase: Refinement 10
- Design Phase: Analysis 11
- Design Phase: Decision Process/Design Selection 12
- Design Phase: Implementation 13
- Design Phase: Documentation 14

1.2 RAPID PROTOTYPING 15

1.3 DRAFTING STANDARDS 16

1.4 CREATIVITY TECHNIQUES 16

- Examine Manufactured Products 16
- Study the Natural World 16
- Watch the Web 16
- Research Patent Drawings 17
- Design Groups 17

1.5 PRODUCT DEFINITION 18

1.6 SHOWING THE DESIGN PROCESS IN A PORTFOLIO 18

KEY WORDS 20

CHAPTER SUMMARY 20

REVIEW QUESTIONS 20

CHAPTER EXERCISES 21

REVERSE ENGINEERING PROJECTS 22

- Can Opener Project 22
- Locking Pliers Project 28

CHAPTER TWO

LAYOUTS AND LETTERING 30

UNDERSTANDING PROJECTION 32

- Types of Projection 32
- Drawing Vocabulary 34

2.1 ALPHABET OF LINES 34

2.2 FREEHAND LINES 36

2.3 MEASUREMENT SYSTEMS 36

- U.S. Customary Units 36
- The Metric System 36

2.4 DRAWING SCALE 37

2.5 SPECIFYING THE SCALE ON A DRAWING 37

2.6 LETTERING 40

2.7 LETTERING STANDARDS 40

2.8 USING GUIDELINES FOR HAND LETTERING 40

2.9 VERTICAL AND INCLINED LETTERS AND NUMERALS 41

2.10 FRACTIONS 43

2.11 SPACING OF LETTERS AND WORDS 44

2.12 LETTERING FOR TITLES 45

2.13 DRAWING PENCILS 46

2.14 TEMPLATES 47

2.15 CAD TOOLS 47

2.16 SKETCHING AND DRAWING MEDIA 49

2.17 STANDARD SHEETS 49

2.18 STANDARD LAYOUT ELEMENTS 50

- Margins and Borders 50
- Zones 50
- Typical Letter Sizes 50
- Title Block 51

2.19 LAYOUTS 52

2.20 PLANNING YOUR DRAWING OR SKETCH 52

Show Details Clearly 52

KEY WORDS 57

CHAPTER SUMMARY 57

REVIEW QUESTIONS 57

CHAPTER EXERCISES 58

Drawing Exercises 58

Lettering Exercises 60

CHAPTER THREE

VISUALIZATION AND SKETCHING 62

UNDERSTANDING SOLID OBJECTS 64

Types of Solids 64

UNDERSTANDING SKETCHING TECHNIQUES 66

Analyzing Complex Objects 66

Viewpoint 68

Shading 68

Edges and Vertices 69

Points and Lines 69

Angles 70

Drawings and Sketches 70

Freehand Sketching 71

3.1 TECHNIQUE OF LINES 72

Lineweights 72

3.2 SKETCHING STRAIGHT LINES 73

Blocking in a Freehand Drawing 73

3.3 SKETCHING CIRCLES, ARCS, AND ELLIPSES 75

Circles 75

Sketching Arcs 77

Sketching Ellipses 77

3.4 MAINTAINING PROPORTIONS 77

3.5 ONE-VIEW DRAWINGS 79

3.6 PICTORIAL SKETCHING 80

3.7 PROJECTION METHODS 82

3.8 AXONOMETRIC PROJECTION 82

Axonometric Projections and 3D Models 83

3.9 ISOMETRIC PROJECTION 84

Isometric Axes 84

Nonisometric Lines 84

Isometric Scales 84

3.10 ISOMETRIC DRAWINGS 85

3.11 MAKING AN ISOMETRIC DRAWING 86

3.12 OFFSET LOCATION MEASUREMENTS 88

Isometric Drawings of Inclined Surfaces 89

3.13 HIDDEN LINES AND CENTERLINES 89

3.14 ANGLES IN ISOMETRIC 90

3.15 IRREGULAR OBJECTS 91

3.16 CURVES IN ISOMETRIC 91

3.17 TRUE ELLIPSES IN ISOMETRIC 92

3.18 ORIENTING ELLIPSES IN ISOMETRIC DRAWINGS 93

3.19 DRAWING ISOMETRIC CYLINDERS 95

3.20 SCREW THREADS IN ISOMETRIC 95

3.21 ARCS IN ISOMETRIC 95

3.22 SPHERES IN ISOMETRIC 96

3.23 OBLIQUE SKETCHES 98

Appearance of Oblique Drawings 98

Choosing the Front Surface 98

Angle of Receding Lines 98

3.24 LENGTH OF RECEDING LINES 99

Cavalier Projection 99

Cabinet Projection 99

3.25 CHOICE OF POSITION IN OBLIQUE DRAWINGS 100

3.26 ELLIPSES FOR OBLIQUE DRAWINGS 100

3.27 ANGLES IN OBLIQUE PROJECTION 101

3.28 SKETCHING ASSEMBLIES 103

3.29 SKETCHING PERSPECTIVES 104

The Three Types of Perspective 105

Bird's-Eye View Versus Worm's-Eye View 107

3.30 CURVES AND CIRCLES IN PERSPECTIVE 107

3.31 SHADING 108

3.32 COMPUTER GRAPHICS 108

3.33 DRAWING ON DRAWING 109

KEY WORDS 116

CHAPTER SUMMARY 116

REVIEW QUESTIONS 116

SKETCHING EXERCISES 117

CHAPTER FOUR

GEOMETRY FOR MODELING AND DESIGN 124

- COORDINATES FOR 3D CAD MODELING 126**
 - Specifying Location 127
- GEOMETRIC ENTITIES 130**
 - Points 130
 - Lines 130
 - Planes 131
 - Circles 132
 - Arcs 133
- 4.1 MANUALLY BISECTING A LINE OR CIRCULAR ARC 134**
- 4.2 DRAWING TANGENTS TO TWO CIRCLES 135**
- 4.3 DRAWING AN ARC TANGENT TO A LINE OR ARC AND THROUGH A POINT 135**
- 4.4 BISECTING AN ANGLE 137**
- 4.5 DRAWING A LINE THROUGH A POINT AND PARALLEL TO A LINE 137**
- 4.6 DRAWING A TRIANGLE WITH SIDES GIVEN 138**
- 4.7 DRAWING A RIGHT TRIANGLE WITH HYPOTENUSE AND ONE SIDE GIVEN 138**
- 4.8 LAYING OUT AN ANGLE 138**
- 4.9 DRAWING AN EQUILATERAL TRIANGLE 139**
- 4.10 POLYGONS 139**
- 4.11 DRAWING A REGULAR PENTAGON 140**
- 4.12 DRAWING A HEXAGON 140**
- 4.13 ELLIPSES 141**
- 4.14 SPLINE CURVES 142**
- 4.15 GEOMETRIC RELATIONSHIPS 145**
- 4.16 SOLID PRIMITIVES 146**
 - Making Complex Shapes with Boolean Operations 147
- 4.17 RECOGNIZING SYMMETRY 149**
 - Right- and Left-Hand Parts 149
 - Parting-Line Symmetry 150
- 4.18 EXTRUDED FORMS 151**
 - Swept Shapes 151
- 4.19 REVOLVED FORMS 152**
- 4.20 IRREGULAR SURFACES 152**

- 4.21 USER COORDINATE SYSTEMS 153**
- 4.22 TRANSFORMATIONS 154**
 - Geometric Transformations 154
 - Viewing Transformations 155

KEY WORDS 161**CHAPTER SUMMARY 161****SKILLS SUMMARY 161****REVIEW QUESTIONS 161****CHAPTER EXERCISES 162**

CHAPTER FIVE

MODELING AND DESIGN 170**REFINEMENT AND MODELING 172****KINDS OF MODELS 173**

- Descriptive Models 173
- Analytical Models 174

- 5.1 2D MODELS 176**
 - Paper Drawings 176
 - 2D CAD Models 176
 - 2D Constraint-Based Modeling 178
- 5.2 3D MODELS 179**
 - Physical Models 179
 - 3D CAD Models 181
- 5.3 TYPES OF 3D MODELS 182**
 - Wireframe Models 182
 - Surface Models 184
 - Solid Models 190
- 5.4 CONSTRAINT-BASED MODELING 191**
- 5.5 CONSTRAINTS DEFINE THE GEOMETRY 193**
 - Feature-Based Modeling 196
- 5.6 PLANNING PARTS FOR DESIGN FLEXIBILITY 197**
- 5.7 SKETCH CONSTRAINTS 199**
 - Overconstrained Sketches 203
 - Underconstrained Sketches 203
 - Applying Constraints 203
 - Setting the Base Point 204
- 5.8 THE BASE FEATURE 205**
 - Adding Features to the Model 206
 - Parent-Child Relationships 207
 - Datum Planes and Surfaces 209
- 5.9 EDITING THE MODEL 212**
 - Standard Features 213
 - Working with Built-in Features 213
 - Complex Shapes 216

5.10 **CONSTRAINT-BASED MODELING MODES** 216
 Assemblies 217
 Drawings from the Model 218

5.11 **CHOOSING THE RIGHT MODELING METHOD** 222

KEY WORDS 228

CHAPTER SUMMARY 228

REVIEW QUESTIONS 228

CHAPTER EXERCISES 229

CHAPTER SIX

ORTHOGRAPHIC PROJECTION 232

UNDERSTANDING PROJECTION 234

Views of Objects 234
 The Six Standard Views 235
 Principal Dimensions 235
 Projection Method 236
 The Glass Box 236
 Spacing between Views 238
 Transferring Depth Dimensions 238
 Measuring from a Reference Surface 238
 Necessary Views 239
 Orientation of the Front View 240
 First- and Third-Angle Projection 240
 Third-Angle Projection 241
 Alternative Arrangements for Third-Angle Projection 242
 First-Angle Projection 242
 Projection System Drawing Symbol 242
 Hidden Lines 243
 Centerlines 244

6.1 **HIDDEN LINE TECHNIQUE** 244

6.2 **PRECEDENCE OF LINES** 244

6.3 **CENTERLINES** 246

6.4 **LAYING OUT A DRAWING** 246

6.5 **DEVELOPING VIEWS FROM 3D MODELS** 247
 Placing the Views 248
 Isometric Views 249

6.6 **VISUALIZATION** 250
 Surfaces, Edges, and Corners 250

6.7 **VIEWS OF SURFACES** 250

6.8 **NORMAL SURFACES** 251

6.9 **INCLINED SURFACES** 251

6.10 **OBLIQUE SURFACES** 251

6.11 **EDGES** 252

6.12 **NORMAL EDGES** 252

6.13 **INCLINED EDGES** 252

6.14 **OBLIQUE EDGES** 252

6.15 **PARALLEL EDGES** 252

6.16 **ANGLES** 253

6.17 **VERTICES** 253

6.18 **INTERPRETING POINTS** 253

6.19 **INTERPRETING LINES** 253

6.20 **SIMILAR SHAPES OF SURFACES** 254

6.21 **INTERPRETING VIEWS** 254

6.22 **MODELS** 256
 Rules for Visualizing from a Drawing:
 Putting It All Together 256

6.23 **PROJECTING A THIRD VIEW** 256

6.24 **BECOMING A 3D VISUALIZER** 258

KEY WORDS 262

CHAPTER SUMMARY 262

REVIEW QUESTIONS 262

CHAPTER EXERCISES 263

CHAPTER SEVEN

2D DRAWING REPRESENTATION 284

PRACTICES FOR 2D DOCUMENTATION DRAWINGS 286

Common Manufactured Features 286
 Conventional Representations 287
 Intersections and Tangencies 287
 Removed Views 287

7.1 **VISUALIZING AND DRAWING COMPLEX CYLINDRICAL SHAPES** 288

7.2 **CYLINDERS WHEN SLICED** 289

7.3 **CYLINDERS AND ELLIPSES** 290

7.4 **INTERSECTIONS AND TANGENCIES** 290
 Intersections of Cylinders 291

7.5 **FILLETS AND ROUNDS** 293

7.6 **RUNOUTS** 294

7.7 **CONVENTIONAL EDGES** 295

7.8 **NECESSARY VIEWS** 296

7.9 **PARTIAL VIEWS** 297
 Showing Enlarged Details 298
 Conventional Breaks 298

- 7.10 ALIGNMENT OF VIEWS 299
- 7.11 REMOVED VIEWS 300
- 7.12 RIGHT-HAND AND LEFT-HAND PARTS 301
- 7.13 REVOLUTION CONVENTIONS 302
 - Common Hole Features Shown in Orthographic Views 303
 - Common Features Shown in Orthographic Views 304

KEY WORDS 307

CHAPTER SUMMARY 307

REVIEW QUESTIONS 307

CHAPTER EXERCISES 308

CHAPTER EIGHT

SECTION VIEWS 326

UNDERSTANDING SECTIONS 328

- Sections of Single Parts 328
- Full Sections 328
- The Cutting Plane 328
- Lines behind the Cutting Plane 328

- 8.1 PLACEMENT OF SECTION VIEWS 331
- 8.2 LABELING CUTTING PLANES 332
- 8.3 LINE PRECEDENCE 332
- 8.4 RULES FOR LINES IN SECTION VIEWS 333
- 8.5 CUTTING-PLANE LINE STYLE 334
 - Visualizing Cutting-Plane Direction 334
- 8.6 SECTION-LINING TECHNIQUE 335
 - Section Lining Large Areas 336
 - Section-Lining Symbols 336
 - Section Lining in CAD 337
- 8.7 HALF SECTIONS 337
- 8.8 BROKEN OUT SECTIONS 338
- 8.9 REVOLVED SECTIONS 339
- 8.10 REMOVED SECTIONS 340
- 8.11 OFFSET SECTIONS 342
- 8.12 RIBS IN SECTION 343
- 8.13 ALIGNED SECTIONS 343
- 8.14 PARTIAL VIEWS 345
- 8.15 INTERSECTIONS IN SECTIONS 346
- 8.16 CONVENTIONAL BREAKS AND SECTIONS 346
- 8.17 ASSEMBLY SECTIONS 346

KEY WORDS 350

CHAPTER SUMMARY 350

REVIEW QUESTIONS 350

CHAPTER EXERCISES 351

CHAPTER NINE

AUXILIARY VIEWS 362

UNDERSTANDING AUXILIARY VIEWS 364

- The Auxiliary Plane 364
- Primary Auxiliary Views 365
- Visualizing an Auxiliary View as a Revolved Drawing 366
- Classification of Auxiliary Views 366
- Successive Auxiliary Views 368
- Secondary Auxiliary Views 368
- Reference Planes 369

- 9.1 USING TRIANGLES TO SKETCH AUXILIARY VIEWS 371
- 9.2 USING GRID PAPER TO SKETCH AUXILIARY VIEWS 371
- 9.3 USING CAD TO CREATE AUXILIARY VIEWS 373
- 9.4 CIRCLES AND ELLIPSES IN AUXILIARY VIEWS 373
- 9.5 HIDDEN LINES IN AUXILIARY VIEWS 373
- 9.6 PARTIAL AUXILIARY VIEWS 375
- 9.7 HALF AUXILIARY VIEWS 375
- 9.8 REVERSE CONSTRUCTION 375
- 9.9 AUXILIARY SECTIONS 376
- 9.10 VIEWING-PLANE LINES AND ARROWS 377
- 9.11 USES OF AUXILIARY VIEWS 378
- 9.12 TRUE LENGTH OF A LINE 378
- 9.13 POINT VIEW OF A LINE 380
 - Showing the Point View of a Line 380
- 9.14 EDGE VIEW OF A PLANE 381
 - Showing the Edge View of a Plane 381
- 9.15 TRUE SIZE OF AN OBLIQUE SURFACE 382
 - Showing the True Size and Shape of an Oblique Surface 382
- 9.16 DIHEDRAL ANGLES 384

UNDERSTANDING DEVELOPMENTS AND INTERSECTIONS 385

- Surface Terminology 385
- Developable Surfaces 386
- Principles of Intersections 386

9.17 DEVELOPMENTS	387
Finding the Intersection of a Plane and a Prism and Developing the Prism	387
Finding the Intersection of a Plane and a Cylinder and Developing the Cylinder	389
9.18 HEMS AND JOINTS FOR SHEET METAL AND OTHER MATERIALS	390
9.19 MORE EXAMPLES OF DEVELOPMENTS AND INTERSECTIONS	390
Developing a Plane and an Oblique Prism	390
Developing a Plane and an Oblique Cylinder	391
Developing a Plane and a Pyramid	391
Developing a Plane and a Cone	391
Developing a Hood and Flue	392
9.20 TRANSITION PIECES	393
9.21 TRIANGULATION	393
9.22 DEVELOPING A TRANSITION PIECE CONNECTING RECTANGULAR PIPES ON THE SAME AXIS	394
9.23 DEVELOPING A PLANE AND A SPHERE	394
9.24 REVOLUTION	395
Axis of Revolution	395
Creating a Revolved Drawing	395
9.25 PRIMARY AND SUCCESSIVE REVOLUTIONS	396
9.26 TRUE LENGTH OF A LINE: REVOLUTION METHOD	396
KEY WORDS	398
CHAPTER SUMMARY	398
REVIEW QUESTIONS	398
CHAPTER EXERCISES	399
Design Project	399
Auxiliary View Exercises	399
Revolution Exercises	407
Development Exercises	410

CHAPTER TEN

**MODELING FOR MANUFACTURE
AND ASSEMBLY 414****DESIGN FOR MANUFACTURE, ASSEMBLY,
DISASSEMBLY, AND SERVICE 416**

10.1 ASSEMBLY MODELS	418
Constraint-Based Assemblies	419
Choosing the Parent Part	420
Assembly Constraints	421
Managing Assembly Files	423
10.2 ASSEMBLIES AND DESIGN	424
Layout Drawings	425
Assembling to a Skeleton	425
Global Parameters	427
Seed Parts	428
Constraint-Based Drawing Elements	429
10.3 ASSEMBLIES AND SIMULATION	429
10.4 PARTS FOR ASSEMBLIES	430
Standard Parts	430
Fastener Libraries	431
10.5 USING YOUR MODEL TO CHECK FITS	432
Interference Checking	432
Accessibility Checking	433
10.6 MANUFACTURING PROCESSES	434
Designing Plastic Parts	434
Cast Parts	437
Modeling Machined Parts	437
Modeling Sheet Metal Parts	438
Other Methods of Production	440
10.7 DOS AND DON'TS OF PRACTICAL DESIGN	441
Casting Design	441
Practical Considerations	441
10.8 MANUFACTURING MATERIALS	443
Material Assignment in Models	444
10.9 APPEARANCE, SERVICE LIFE, AND RECYCLING	445
10.10 DIMENSIONAL ACCURACY AND SURFACE FINISH	445
10.11 NET-SHAPE MANUFACTURING	446
10.12 COMPUTER-INTEGRATED MANUFACTURING	447
10.13 SHARED MANUFACTURING	448
10.14 MANUFACTURING METHODS AND THE DRAWING	448
10.15 MODELING FOR TESTING AND REFINEMENT	451
10.16 DETERMINING MASS PROPERTIES	451
Understanding Mass Property Calculations	454
10.17 EXPORTING DATA FROM THE DATABASE	456
File Formats	456
Common Formats for Export	457
Vector versus Raster Data	459
10.18 DOWNSTREAM APPLICATIONS	460
Spreadsheets	460
Equation Solvers	460
Finite Element Analysis	463
Simulation Software	468

Human Factors	470
Integrated Modeling and Design Software	472
10.19 PROTOTYPING YOUR DESIGN	474
Rapid Prototyping	474
Translating the Model	474
Rapid Prototyping Systems	476
Rapid Tooling	480
KEY WORDS	486
CHAPTER SUMMARY	487
SKILLS SUMMARY	487
REVIEW QUESTIONS	488
CHAPTER EXERCISES	490
Mass Properties Exercises	500

CHAPTER ELEVEN

DIMENSIONING 502

UNDERSTANDING DIMENSIONING	504
Three Aspects of Good Dimensioning	505
Tolerance	505
Geometric Breakdown	506
11.1 LINES USED IN DIMENSIONING	506
11.2 USING DIMENSION AND EXTENSION LINES	508
11.3 ARROWHEADS	508
11.4 LEADERS	509
11.5 DRAWING SCALE AND DIMENSIONING	509
11.6 DIRECTION OF DIMENSION VALUES AND NOTES	510
11.7 DIMENSION UNITS	510
11.8 MILLIMETER VALUES	510
11.9 DECIMAL-INCH VALUES	511
11.10 RULES FOR DIMENSION VALUES	512
11.11 RULES FOR ROUNDING DECIMAL DIMENSION VALUES	512
11.12 DUAL DIMENSIONING	512
11.13 COMBINATION UNITS	513
11.14 DIMENSIONING SYMBOLS	513
11.15 PLACING AND SHOWING DIMENSIONS LEGIBLY	514
Rules for Placing Dimensions Properly	514
11.16 SUPERFLUOUS DIMENSIONS	516
11.17 DIMENSIONING ANGLES	517
11.18 DIMENSIONING ARCS	517
11.19 FILLETS AND ROUNDS	517
11.20 SIZE DIMENSIONING: PRISMS	518
11.21 SIZE DIMENSIONING: CYLINDERS	518
11.22 SIZE DIMENSIONING: HOLES	519
11.23 APPLYING STANDARD DIMENSIONING SYMBOLS	520
11.24 DIMENSIONING COUNTERBORES AND SPOTFACES WITH FILLETS	521
11.25 DIMENSIONING TRIANGULAR PRISMS, PYRAMIDS, AND CONES	522
11.26 DIMENSIONING CURVES	522
11.27 DIMENSIONING CURVED SURFACES	523
11.28 DIMENSIONING ROUNDED-END SHAPES	523
11.29 DIMENSIONING THREADS	524
11.30 DIMENSIONING TAPERS	524
11.31 DIMENSIONING CHAMFERS	524
11.32 SHAFT CENTERS	525
11.33 DIMENSIONING KEYWAYS	525
11.34 DIMENSIONING KNURLS	525
11.35 FINISH MARKS	526
11.36 SURFACE ROUGHNESS	526
Applications of Surface Roughness Symbols	527
11.37 LOCATION DIMENSIONS	530
11.38 MATING DIMENSIONS	532
11.39 COORDINATE DIMENSIONING	533
11.40 TABULAR DIMENSIONS	534
11.41 DIMENSIONING FOR NUMERICALLY-CONTROLLED MACHINING	534
11.42 MACHINE, PATTERN, AND FORGING DIMENSIONS	535
11.43 SHEET METAL BENDS	536
11.44 NOTES	536
11.45 STANDARDS	538
11.46 DOS AND DON'TS OF DIMENSIONING	538
KEY WORDS	543
CHAPTER SUMMARY	543
REVIEW QUESTIONS	543
CHAPTER EXERCISES	544

CHAPTER TWELVE

TOLERANCING 546**UNDERSTANDING TOLERANCE 548**

- Tolerance 548
- Quality Control 548
- Definitions for Size Designation 548
- Variations in Form 549
- Tolerance Envelope 549
- Implied Right Angles 550
- Fits between Mating Parts 551
- Selective Assembly 553
- Hole System 554
- Shaft System 554

- 12.1 SPECIFYING TOLERANCES 556**
- 12.2 GENERAL TOLERANCE NOTES 556**
- 12.3 LIMIT TOLERANCES 557**
 - Single-Limit Dimensioning 557
- 12.4 PLUS-OR-MINUS TOLERANCES 558**
- 12.5 TOLERANCE STACKING 559**
 - Chained or Continuous Dimensioning 559
 - Baseline Dimensioning 559
- 12.6 USING AMERICAN NATIONAL STANDARD LIMITS AND FIT TABLES 560**
- 12.7 TOLERANCES AND MACHINING PROCESSES 561**
- 12.8 METRIC SYSTEM OF TOLERANCES AND FITS 562**
- 12.9 PREFERRED SIZES 564**
- 12.10 PREFERRED FITS 564**
- 12.11 GEOMETRIC DIMENSIONING AND TOLERANCING 565**
- 12.12 SYMBOLS FOR TOLERANCES OF POSITION AND FORM 566**
- 12.13 DATUM FEATURES 568**
 - Datum Features Versus
 - Datum Feature Simulator 569
 - Datum Reference Frame 569
 - Datum Targets 570
- 12.14 POSITIONAL TOLERANCES 572**
- 12.15 MAXIMUM MATERIAL CONDITION 574**
 - Virtual Condition (VC) 575
- 12.16 TOLERANCES OF ANGLES 575**
- 12.17 FORM TOLERANCES FOR SINGLE FEATURES 576**
- 12.18 ORIENTATIONS FOR RELATED FEATURES 578**

12.19 USING GEOMETRIC DIMENSIONING AND TOLERANCING 580**12.20 TOLERANCES AND DIGITAL PRODUCT DEFINITION 581****12.21 COMPUTER GRAPHICS 582****KEY WORDS 587****CHAPTER SUMMARY 587****REVIEW QUESTIONS 588****CHAPTER EXERCISES 588**

- Design Project 588
- Tolerancing Projects 588

CHAPTER THIRTEEN

THREADS, FASTENERS, AND SPRINGS 592**UNDERSTANDING THREADS AND FASTENERS 594**

- Screw Thread Terms 595
- Screw Thread Forms 596
- Thread Pitch 597
- Thread Series 598
- Right-Hand and Left-Hand Threads 598
- Single and Multiple Threads 599
- American National Thread Fits 599
- Metric and Unified Thread Fits 600
- Three Methods for Drawing Thread 600

- 13.1 THREAD NOTES 604**
 - Acme Thread Notes 605
- 13.2 EXTERNAL THREAD SYMBOLS 606**
- 13.3 INTERNAL THREAD SYMBOLS 606**
- 13.4 DETAILED REPRESENTATION: METRIC, UNIFIED, AND AMERICAN NATIONAL THREADS 608**
 - Detailed Internal Square Thread 608
 - Detailed External Square Thread 608
- 13.5 THREADS IN ASSEMBLY 610**
- 13.6 MODELING THREAD 610**
- 13.7 AMERICAN NATIONAL STANDARD PIPE THREADS 610**
- 13.8 USE OF PHANTOM LINES 612**
- 13.9 TAPPED HOLES 612**
- 13.10 BOLTS, STUDS, AND SCREWS 613**
- 13.11 STANDARD BOLTS AND NUTS 614**
- 13.12 DRAWING STANDARD BOLTS 615**
- 13.13 SPECIFICATIONS FOR BOLTS AND NUTS 615**

13.14	LOCKNUTS AND LOCKING DEVICES	617
13.15	STANDARD CAP SCREWS	618
13.16	STANDARD MACHINE SCREWS	619
13.17	STANDARD SET SCREWS	620
13.18	AMERICAN NATIONAL STANDARD WOOD SCREWS	621
13.19	MISCELLANEOUS FASTENERS	621
13.20	KEYS	622
13.21	MACHINE PINS	622
13.22	RIVETS	623
	Riveted Joints	623
	Rivet Symbols	624
	Small Rivets	624
	Blind Rivets	624
13.23	SPRINGS	625
	Helical Springs	625
13.24	DRAWING HELICAL SPRINGS	626
13.25	MODELING SPRINGS	627
	KEY WORDS	631
	CHAPTER SUMMARY	631
	REVIEW QUESTIONS	631
	CHAPTER EXERCISES	631
	Design Project	631
	Thread and Fastener Projects	631

14.9	DRAWING NUMBERS	650
14.10	ZONING	650
14.11	CHECKING DRAWINGS	650
14.12	DRAWING REVISIONS	650
14.13	SIMPLIFYING DRAWINGS	651
14.14	PATENT DRAWINGS	652
	KEY WORDS	657
	CHAPTER SUMMARY	657
	REVIEW QUESTIONS	657
	CHAPTER EXERCISES	658
	Design Project	658
	Working Drawing Exercises	659

GLOSSARY G-1
APPENDICES A-1
INDEX I-1
WORKSHEETS W-1

CHAPTER FOURTEEN

WORKING DRAWINGS 636

	WORKING DRAWINGS OR CONSTRUCTION DRAWINGS	638
	Assembly Drawings	639
	Detail Drawings or Piece Part Drawings	640
14.1	SUBASSEMBLIES	642
14.2	IDENTIFICATION	642
	Multidetail Drawings	643
14.3	PARTS LISTS	644
14.4	ASSEMBLY SECTIONS	645
14.5	WORKING DRAWING ASSEMBLY	646
14.6	INSTALLATION ASSEMBLIES	647
14.7	CHECK ASSEMBLIES	647
14.8	WORKING DRAWING FORMATS	648
	Number of Details per Sheet	648
	Digital Drawing Transmittal	648
	Title and Record Strips	649

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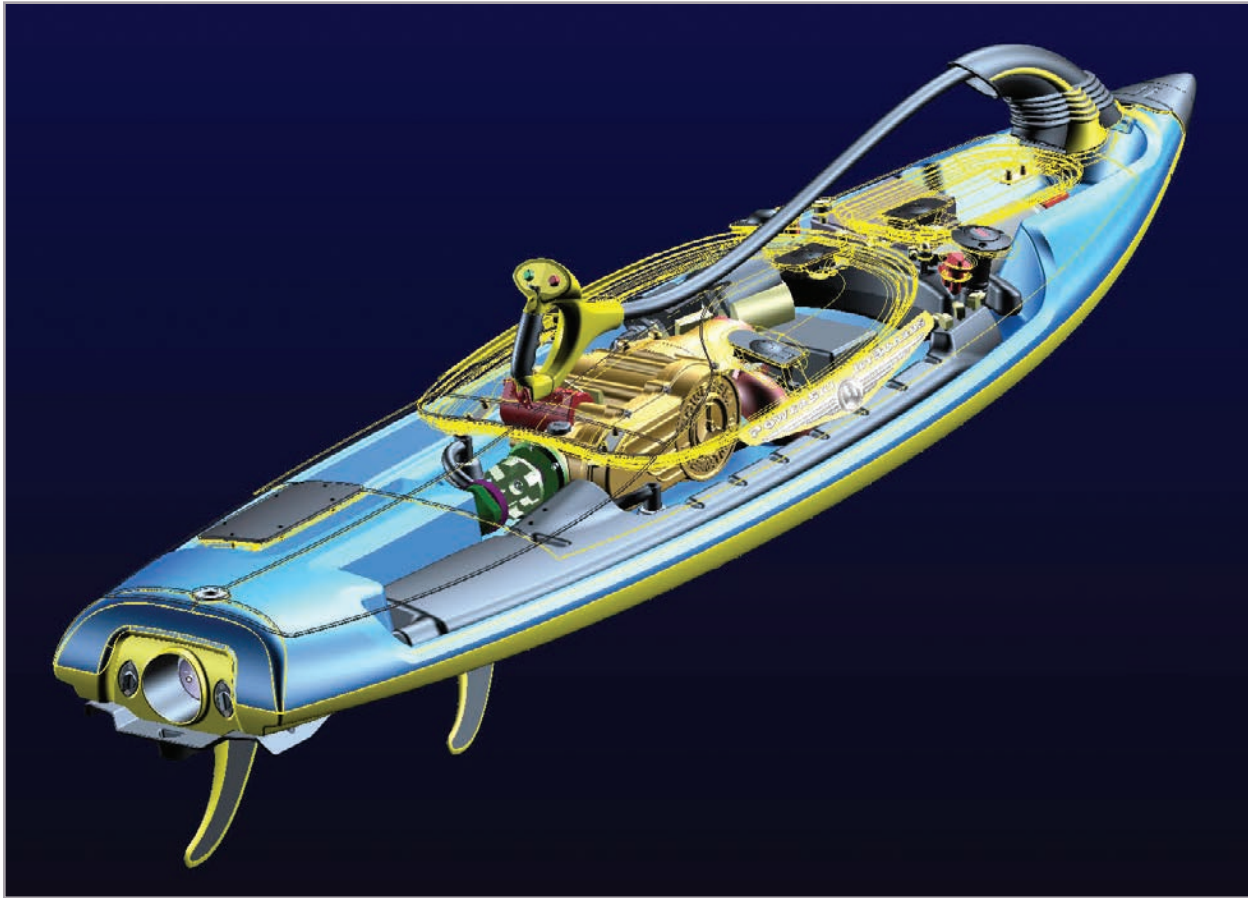
CHAPTER FOUR

GEOMETRY FOR MODELING AND DESIGN

OBJECTIVES

After studying the material in this chapter, you should be able to:

1. Identify and specify basic geometric elements and primitive shapes.
2. Select a 2D profile that best describes the shape of an object.
3. Identify mirrored shapes and sketch their lines of symmetry.
4. Identify shapes that can be formed by extrusion and sketch their cross sections.
5. Identify shapes that can be formed by revolution techniques and sketch their profiles.
6. Define Boolean operations.
7. Specify the Boolean operations to combine primitive shapes into a complex shape.
8. Work with Cartesian coordinates and user coordinate systems in a CAD system.
9. Identify the transformations common to CAD systems.



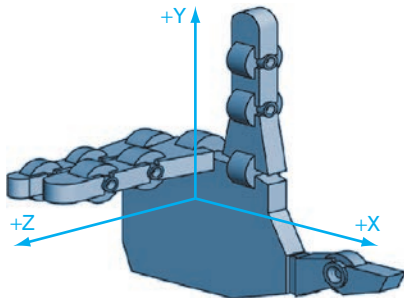
Many different geometric shapes were used to model this jetboard. The wireframe view of the top cover reveals several regular geometric shapes used to model the interior components. The graceful lines of the outer hull are defined by the irregular curves used to model it. (Courtesy of Leo Greene, www.e-Cognition.net.)

OVERVIEW

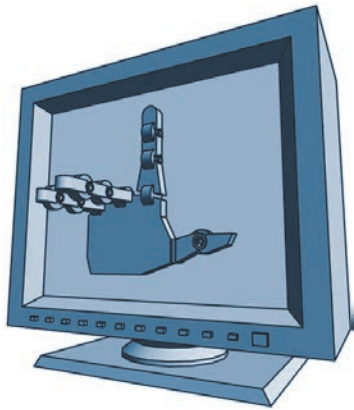
Engineering drawings combine basic geometric shapes and relationships to define complex objects. 2D drawings are composed of simple entities such as points, lines, arcs, and circles, as well as more complex entities such as ellipses and curves. Reviewing the basic geometry of these elements helps you define and combine these elements in your drawings and CAD models.

Accurate construction is critical to creating useful drawings. Lines drawn using a CAD system are highly accurate definitions—much greater than you can see on a computer monitor. Good manual drawing technique can typically produce a drawing accurate to about 1/40th of the drawing scale. For example, a hand-drawn survey created at 1" = 400' might be

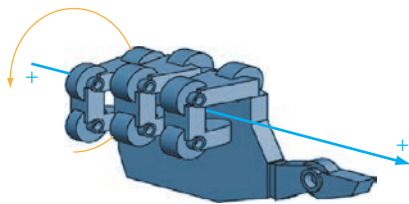
accurate to a range of plus or minus 10'. The internal precision of drawings created using CAD systems is limited by the 64 bits (base-2 places) typically used to represent decimal numbers in a CAD system. This produces a theoretical accuracy of around 1 in 10 quadrillion (10^{16}). If you drew two beams, each three times the distance from the Sun to Pluto, and made one of the beams just 1 mm longer than the other one, a CAD system could still accurately represent the difference between the two beams. Wow! That's a lot better than the 1 in 40 accuracy of a manual drawing. However, CAD drawings are accurate only if the drawing geometry is defined accurately when the drawing is created.



4.1 Right-Hand Rule



4.2 The Z-Axis. In systems that use the right-hand rule, the positive Z-axis points toward you when the face of the monitor is parallel to the X-Y plane.



4.3 Axis of Rotation. The curl of the fingers indicates the positive direction along the axis of rotation.

COORDINATES FOR 3D CAD MODELING

2D and 3D CAD drawing entities are stored in relationship to a Cartesian coordinate system. No matter what CAD software system you will be using, it is helpful to understand some basic similarities of coordinate systems.

Most CAD systems use the **right-hand rule** for coordinate systems; if you point the thumb of your right hand in the positive direction for the X-axis and your index finger in the positive direction for the Y-axis, your remaining fingers will curl in the positive direction for the Z-axis (shown in Figure 4.1). When the face of your monitor is the X-Y plane, the Z-axis is pointing toward you (see Figure 4.2).

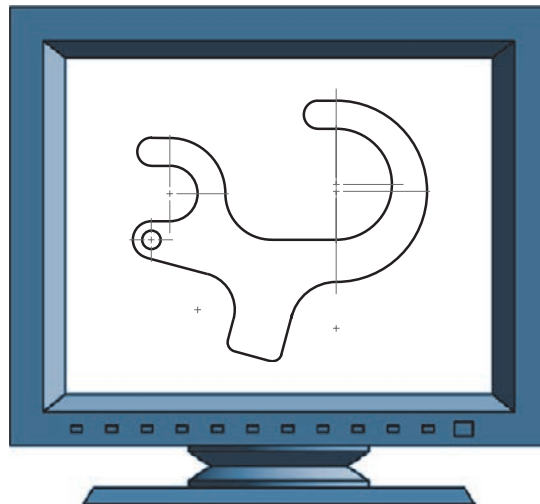
The right-hand rule is also used to determine the direction of rotation. For rotation using the right-hand rule, point your thumb in the positive direction along the axis of rotation. Your fingers will curl in the positive direction for the rotation, as shown in Figure 4.3.

Though rare, some CAD systems use a left-hand rule. In this case, the curl of the fingers on your left hand gives you the positive direction for the Z-axis. In this case, when the face of your computer monitor is the X-Y plane, the positive direction for the Z-axis extends into your computer monitor, not toward you.

A 2D CAD system uses only the X- and Y-coordinates of the Cartesian coordinate system. 3D CAD systems use X, Y, and Z. To represent 2D in a 3D CAD system, the view is straight down the Z-axis. Figure 4.4 shows a drawing created using only the X- and Y- values, leaving the Z-coordinates set to 0, to produce a 2D drawing.

Recall that each orthographic view shows only two of the three coordinate directions because the view is straight down one axis. 2D CAD drawings are the same: They show only the X- and Y-coordinates because you are looking straight down the Z-axis.

When the X-Y plane is aligned with the screen in a CAD system, the Z-axis is oriented horizontally. In machining and many other applications, the Z-axis is considered to be the vertical axis. In all cases, the coordinate axes are mutually perpendicular and oriented according to the right-hand or left-hand rule. Because the view can be rotated to be straight down any axis or any other direction, understanding how to use coordinates in the model is more important than visualizing the direction of the default axes and planes.

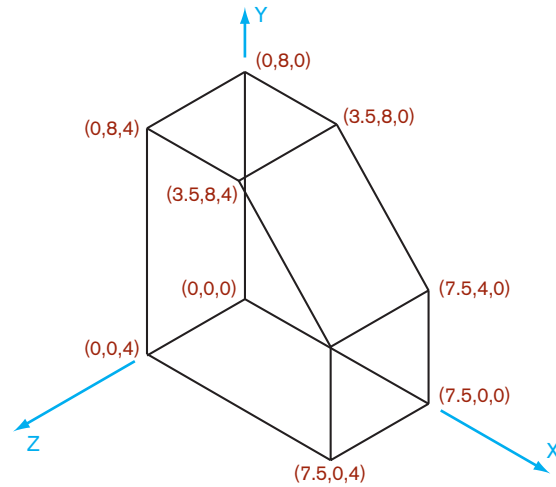


4.4 2D CAD Drawing. This drawing was created on the X-Y plane in the CAD system. It appears true shape because the viewing direction is perpendicular to the X-Y plane—straight down the Z-axis.

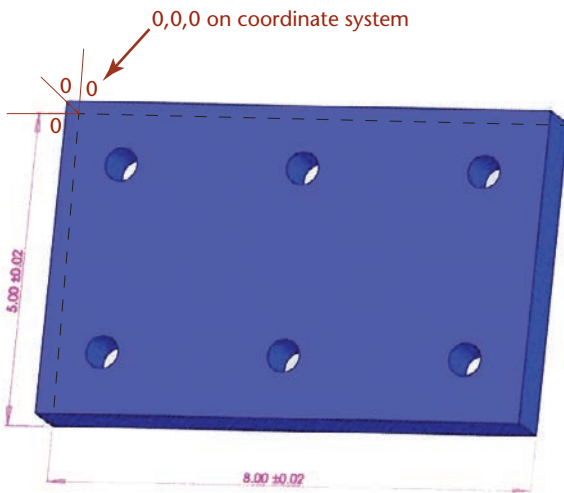
The vertices of the 3D shape shown in Figure 4.5 are identified by their X-, Y-, and Z-coordinates. Often, it is useful when modeling parts to locate the origin of the coordinate system at the lower left of the part, as shown in Figure 4.5. This location for the (0,0,0) point on a part is useful when the part is being machined, as it then makes all coordinates on the part positive (Figure 4.6). Some older numerically-controlled machinery will not interpret a file correctly if it has negative lengths or coordinates. CAD models are often exported to other systems for manufacturing parts, so try to create them in a common and useful way.

Specifying Location

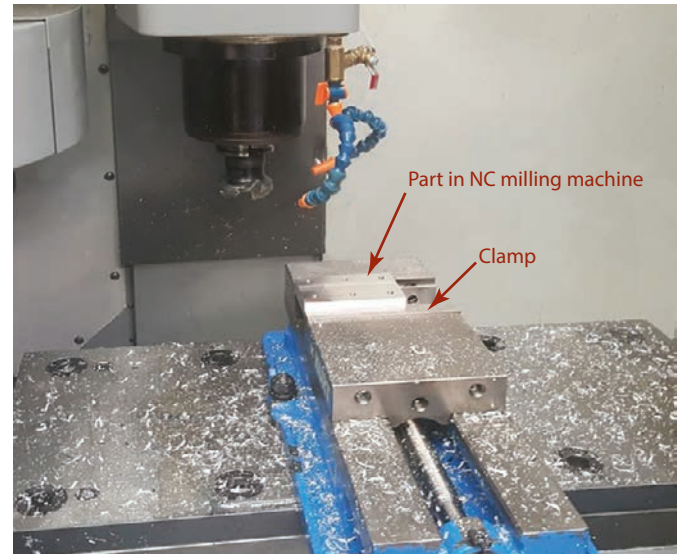
Even though the model is ultimately stored in a single Cartesian coordinate system, you may usually specify the location of features using other location methods as well. The most typical of these are relative, polar, cylindrical, and spherical coordinates. These coordinate formats are useful for specifying locations to define your CAD drawing geometry.



4.5 3D Coordinates for Vertices



4.6 This CAD model for a plate with 6 holes has its origin (0,0,0) at the back left of the part when it is set up for numerically-controlled machining. (Courtesy of Matt McCune, Autopilot, Inc.)



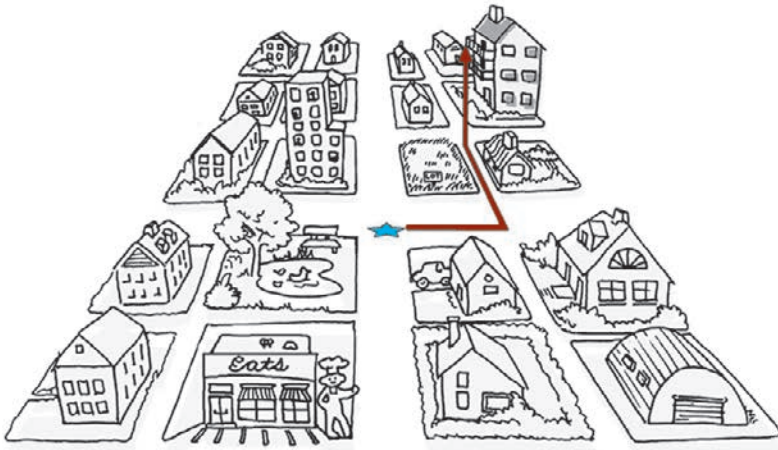
4.7 The part is clamped in place during machining. The back left corner of the part is the 0,0,0 location during the machining process. (Courtesy of Matt McCune, Autopilot, Inc.)

SPOTLIGHT

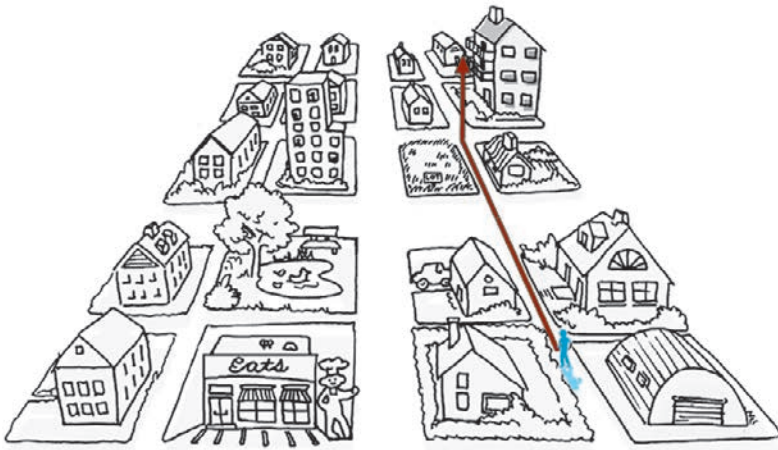
The First Coordinate System

René Descartes (1596–1650) was the French philosopher and mathematician for whom the Cartesian coordinate system is named. Descartes linked algebra and geometry to classify curves by the equations that describe them. His coordinate system remains the most commonly used coordinate system today for identifying points. A 2D coordinate system consists of a pair of lines, called the X- and Y-axes, drawn on a plane so that they intersect at right angles. The point of intersection is called the *origin*. A 3D coordinate system adds a third axis, referred to as the Z-axis, that is perpendicular to the two other axes. Each point in space can

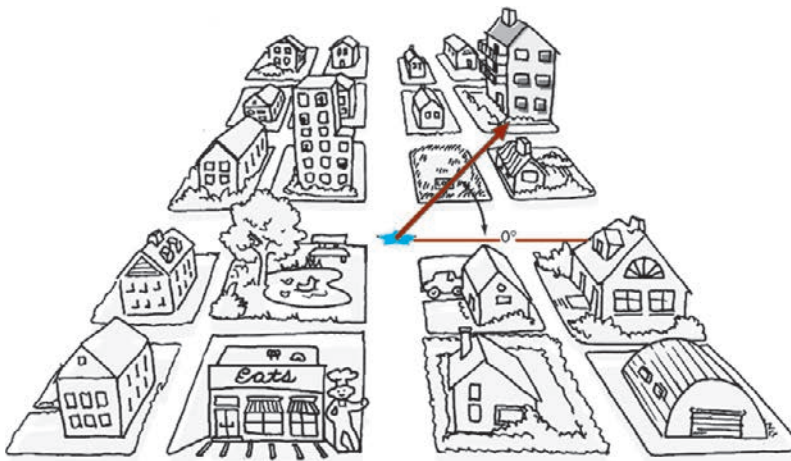
be described by numbers, called coordinates, that represent its distance from this set of axes. The Cartesian coordinate system made it possible to represent geometric entities by numerical and algebraic expressions. For example, a straight line is represented by a linear equation in the form $ax + by + c = 0$, where the x - and y -variables represent the X- and Y-coordinates for each point on the line. Descartes' work laid the foundation for the problem-solving methods of analytic geometry and was the first significant advance in geometry since those of the ancient Greeks.



4.8 Absolute coordinates define a location in terms of distance from the origin $(0,0,0)$, shown here as a star. These directions are useful because they do not change unless the origin changes.



4.9 Relative coordinates describe the location in terms of distance from a starting point. Relative coordinates to the same location differ according to the starting location.



4.10 Polar coordinates describe the location using an angle and distance from the origin (absolute) or starting point (relative).

Absolute Coordinates

Absolute coordinates are used to store the locations of points in a CAD database. These coordinates specify location in terms of distance from the origin in each of the three axis directions of the Cartesian coordinate system.

Think of giving someone directions to your house (or to a house in an area where the streets are laid out in rectangular blocks). One way to describe how to get to your house would be to tell the person how many blocks over and how many blocks up it is from two main streets (and how many floors up in the building, for 3D). The two main streets are like the X- and Y-axes of the Cartesian coordinate system, with the intersection as the origin. Figure 4.8 shows how you might locate a house with this type of absolute coordinate system.

Relative Coordinates

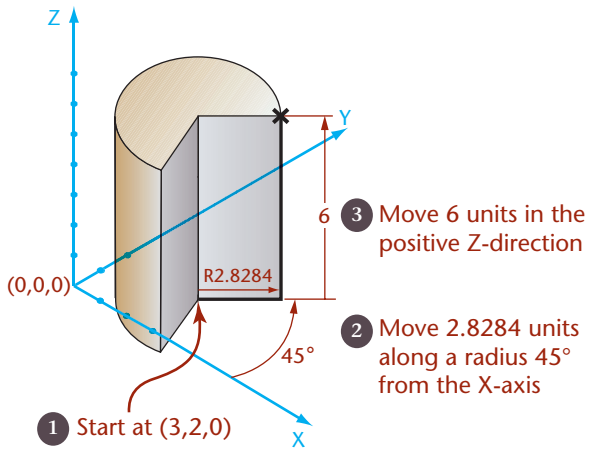
Instead of having to specify each location from the origin, you can use *relative coordinates* to specify a location by giving the number of units from a previous location. In other words, the location is defined relative to your previous location.

To understand relative coordinates, think about giving someone directions from his or her current position, not from two main streets. Figure 4.9 shows the same map again, but this time with the location of the house relative to the location of the person receiving directions.

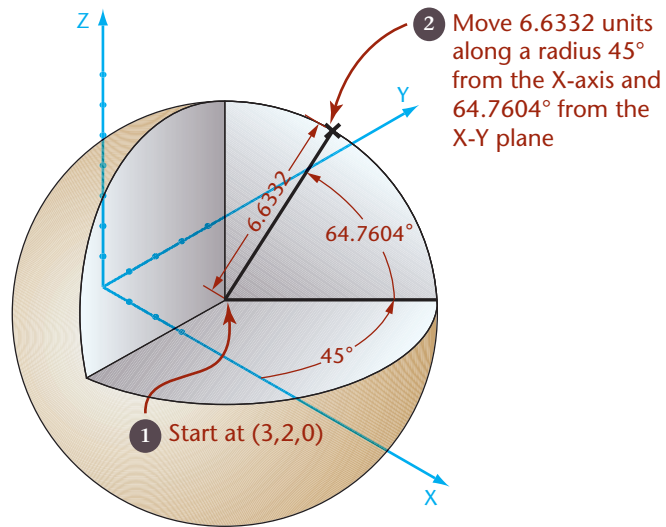
Polar Coordinates

Polar coordinates are used to locate an object by giving an angle (from the X-axis) and a distance. Polar coordinates can either be absolute, giving the angle and distance from the origin, or relative, giving the angle and distance from the current location.

Picture the same situation of having to give directions. You could tell the person to walk at a specified angle from the crossing of the two main streets, and how far to walk. Figure 4.10 shows the angle and direction for the shortcut across the empty lot using absolute polar coordinates. You could also give directions as an angle and distance relative to a starting point.



(a) Relative cylindrical coordinates
 $2.8284 < 45, 6$ from starting point $(3, 2, 0)$



(b) Relative spherical coordinates
 $6.6332 < 45 < 64.7604$ from starting point $(3, 2, 0)$

4.11 Relative Cylindrical and Spherical Coordinates. *The target points in (a) and (b) are described by relative coordinates from the starting point $(3, 2, 0)$. Although the paths to the point differ, the resulting endpoint is the same.*

Cylindrical and Spherical Coordinates

Cylindrical and spherical coordinates are similar to polar coordinates except that a 3D location is specified instead of one on a single flat plane (such as a map).

Cylindrical coordinates specify a 3D location based on a radius, angle, and distance (usually in the Z-axis direction). This gives a location as though it were on the edge of a cylinder. The radius tells how far the point is from the center (or origin); the angle is the angle from the X-axis along which the point is located; and the distance provides the height where the point is located on the cylinder. Cylindrical coordinates are similar to polar coordinates, but they add distance in the Z-direction.

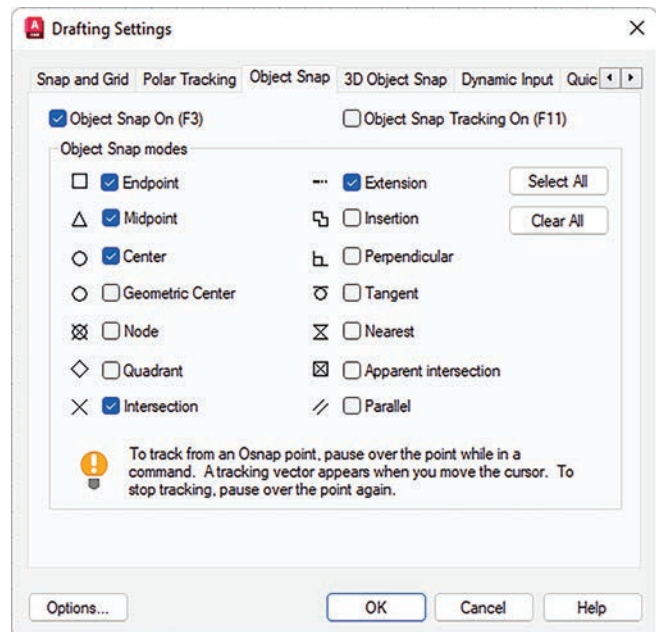
Figure 4.11a depicts relative cylindrical coordinates used to specify a location, where the starting point serves as the center of the cylinder.

Spherical coordinates specify a 3D location by the radius, an angle from the X-axis, and the angle from the X-Y plane. These coordinates locate a point on a sphere, where the origin of the coordinate system is at the center of the sphere. The radius gives the size of the sphere; the angle from the X-axis locates a place on the equator. The second angle gives the location from the plane of the equator to a point on the sphere in line with the location specified on the equator. Figure 4.11b depicts relative spherical coordinates, where the starting point serves as the center of the sphere.

Even though you may use these different systems to enter information into your 3D drawings, the end result is stored using one set of Cartesian coordinates.

Using Existing Geometry to Specify Location

Most CAD packages offer a means of specifying location by specifying the relationship of a point to existing objects in the model or drawing. For example, AutoCAD's "object snap" feature lets you enter a location by "snapping" to the endpoint of a line, the center of a circle, the intersection of two lines, and so on (Figure 4.12). Using existing geometry to locate new entities is faster than entering coordinates. This feature also



4.12 Object snaps are aids for selecting locations on existing CAD drawing geometry. (Autodesk screen shots reprinted courtesy of Autodesk, Inc.)

allows you to capture geometric relationships between objects without calculating the exact location of a point. For example, you can snap to the midpoint of a line or the nearest point of tangency on a circle. The software calculates the exact location.

GEOMETRIC ENTITIES

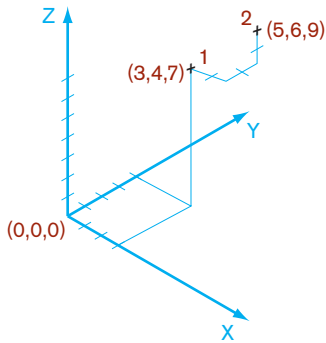
Points

Points are geometric constructs. Points are considered to have no width, height, or depth. They are used to indicate locations in space. In CAD drawings, a point is located by its coordinates and usually shown with some sort of marker like a cross, circle, or other representation. Many CAD systems allow you to choose the style and size of the mark that is used to represent points.

Most CAD systems offer three ways to specify a point:

- Type in the coordinates (of any kind) for the point (see Figure 4.13).
- Pick a point from the screen with a pointing device (mouse or tablet).
- Specify the location of a point by its relationship to existing geometry (e.g., an endpoint of a line, an intersection of two lines, or a center point).

Picking a point from the screen is a quick way to enter points when the exact location is not important, but the accuracy of the CAD database makes it impossible to enter a location accurately in this way.



4.13 Specifying Points. Point 1 was added to the drawing by typing the absolute coordinates 3,4,7. Point 2 was added relative to Point 1 with the relative coordinates @2,2,2.

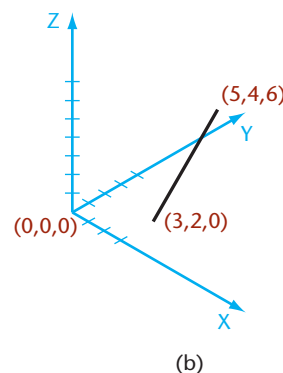
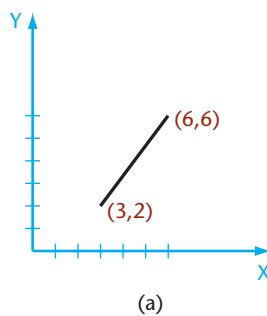
Lines

A straight line is defined as the shortest distance between two points. Geometrically, a line has length but no other dimension such as width or thickness. Lines are used in drawings to represent the edge view of a surface, the limiting element of a contoured surface, or the edge formed where two surfaces on an object join. In a CAD database, lines are typically stored by the coordinates of their endpoints.

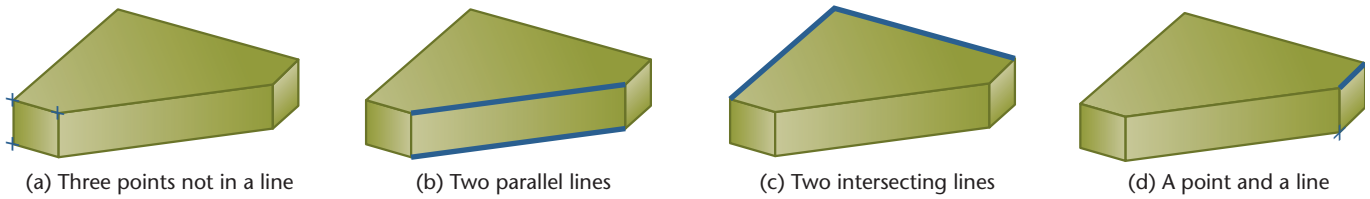
For the lines shown in Figure 4.14, the table below shows how you can specify the second endpoint for a particular type of coordinate entry. (For either or both endpoints, you can also snap to existing geometry without entering any coordinates.)

The @ sign in AutoCAD indicates relative

	(a) Second Endpoint for 2D Line	(b) Second Endpoint for 3D Line
Absolute	6,6	5,4,6
Relative	@3,4	@2,2,6
Relative polar	@5<53.13	n/a
Relative cylindrical	n/a	@2.8284<45,6
Relative spherical	n/a	@6.6332<45<64.7606



4.14 Specifying Lines. (a) This 2D line was drawn from endpoint (3,2) to (6,6). (b) This 3D line was drawn from endpoint (3,2,0) to (5,4,6).



4.15 Defining a Plane. *The highlighted entities in each image define a plane.*

Planes

Planes are defined by any of the following (see Figure 4.15):

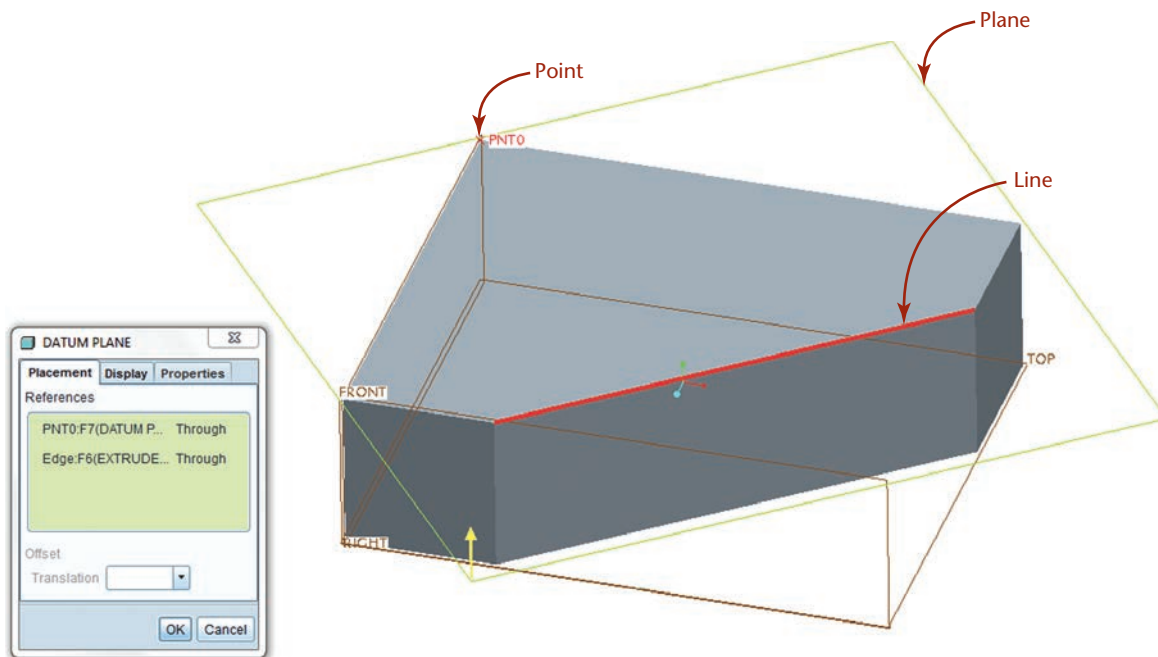
- Three points not lying in a straight line
- Two parallel lines
- Two intersecting lines
- A point and a line

The last three ways to define a plane are all special cases of the more general case—three points not in a straight line. Knowing what can determine a plane can help you understand the geometry of solid objects and use the geometry as you model in CAD.

For example, a face on an object is a plane that extends between the vertices and edges of the surface. Most CAD programs allow you to align new entities with an existing plane. You can use any face on the object—whether it is normal, inclined, or oblique—to define a plane for aligning a new entity.

Defining planes on the object or in 3D space is an important skill for working in 3D CAD. The software provides tools for defining new planes (see Figure 4.16). The options for these tools are based on the geometry of planes, as defined in the preceding list. Typical choices allow the use of any three points not in a line, two parallel lines, two intersecting lines, a point and a line, or being parallel to, perpendicular to, or at an angle from an existing plane.

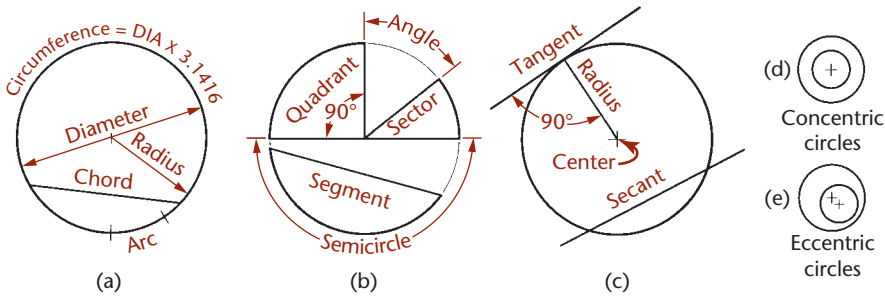
A plane may serve as a coordinate-system orientation that shows a surface true shape. You will learn more about orienting work planes to take advantage of the object’s geometry later in this chapter.



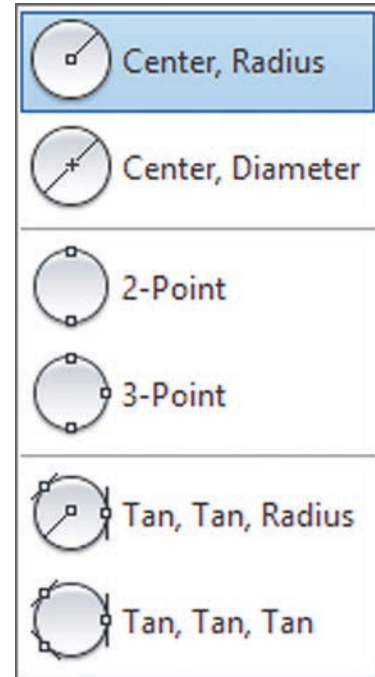
4.16 Defining a Plane in CAD. *A point and a line (the edge between two surfaces in this case) were used to define a plane in this Pro/ENGINEER model.*

Circles

A circle is a set of points that are equidistant from a center point. The distance from the center to one of the points is the radius (see Figure 4.17). The distance across the center to any two points on opposite sides is the diameter. The circumference of a circle contains 360° of arc. In a CAD file, a circle is often stored as a center point and a radius.



4.17 The Circle



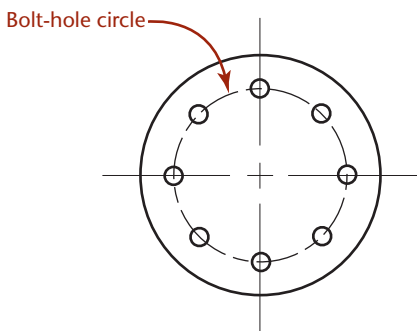
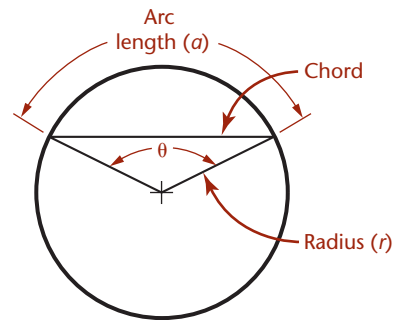
4.18 AutoCAD Circle Construction Options (Autodesk screen shots reprinted courtesy of Autodesk, Inc.)

SPOTLIGHT

Formulas for Circles and Arcs

- r = radius
- C = circumference
- π = pi $\cong 3.14159$
- a = arc length
- A = area
- L = chord length
- θ (theta) = included angle
- rad (radian) = the included angle of an arc length such that the arc length is equal to the radius

$C = 2\pi r$, the curved distance around a circle
 $A = \pi r^2$, the area of a circle
 $a = 2\pi r \times \theta/360$, so the arc length = $0.01745r\theta$ when you know its radius, r , and the included angle, θ , in degrees
 $a = r \times \theta$ (when the included angle is measured in radians)



Bolt-Hole Circle Chord Lengths

To determine the distance between centers for equally spaced holes on a bolt-hole circle:

$n = 180/\text{number of holes in pattern}$
 $L = \sin n \times \text{bolt-hole circle diameter}$

EXAMPLE: 8-hole pattern on a 10.00-diameter circle:

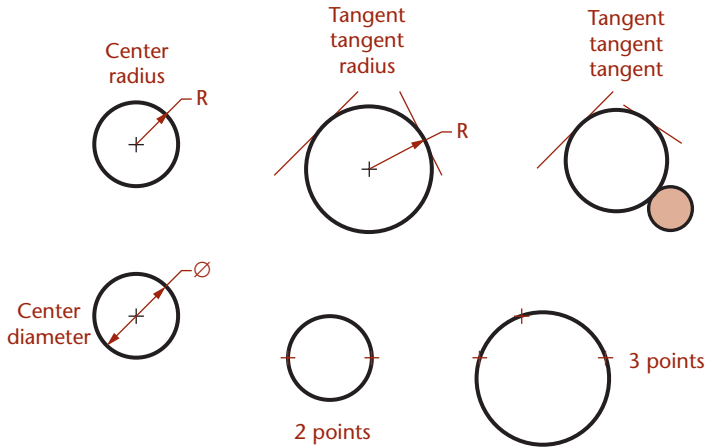
$180/8 = 22.5$
 \sin of 22.5 is .383
 $.383 \times 10 = 3.83$ (chord length)

For more useful formulas, see Appendix 1.

Most CAD systems allow you to define a circle by specifying any one of the following:

- The center and a diameter
- The center and a radius
- Two points on the diameter
- Three points on the circle
- A radius and two entities to which the circle is tangent
- Three entities to which the circle is tangent

These methods are illustrated in Figure 4.19.

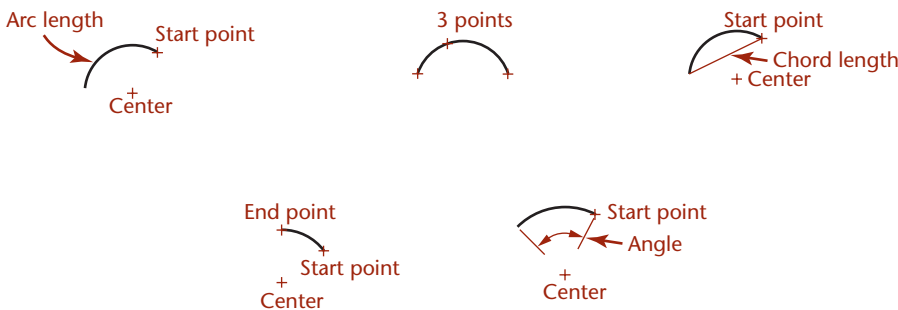


4.19 Ways to Define a Circle

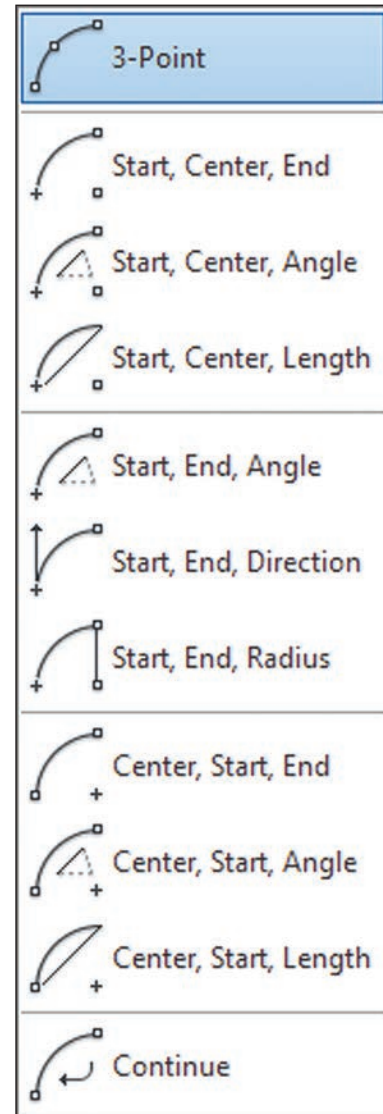
Arcs

An arc is a portion of a circle. An arc can be defined by specifying any one of the following (see Figure 4.20):

- A center, radius, and angle measure (sometimes called the *included angle* or *delta angle*)
- A center, radius, and chord length
- A center, radius, and arc length
- The endpoints and a radius
- The endpoints and a chord length
- The endpoints and arc length
- The endpoints and one other point on the arc (3 points)



4.20 Defining Arcs. Arcs can be defined many different ways. Like circles, arcs may be located from a center point or an endpoint, making it easy to locate them relative to other entities in the model.



4.21 AutoCAD Arc Construction Options (Autodesk screen shots reprinted courtesy of Autodesk, Inc.)

4.1 MANUALLY BISECTING A LINE OR CIRCULAR ARC

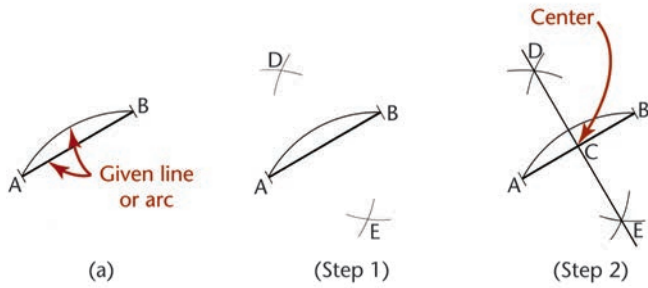


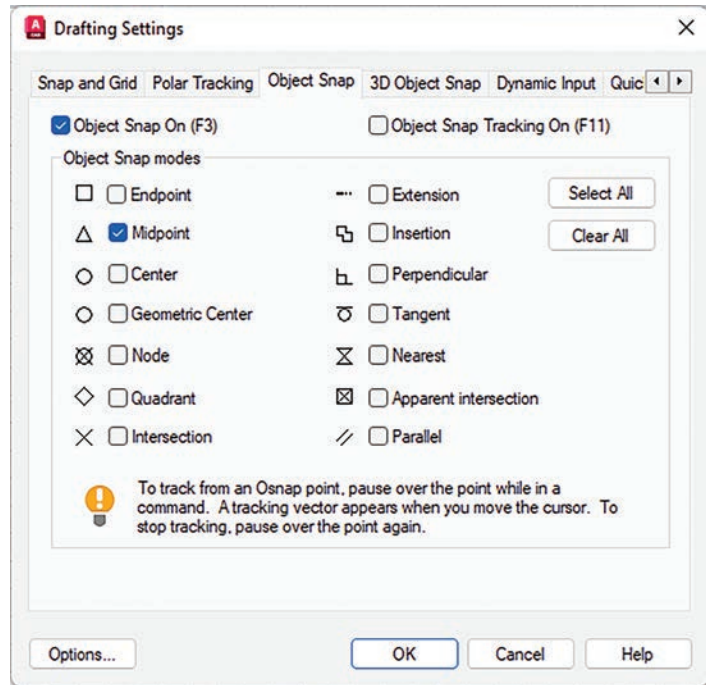
Figure 4.22a shows the given line or arc AB to be bisected.
 Step 1. From A and B draw equal arcs with their centers at the endpoints and a with radius greater than half AB .
 Step 2. Join intersections D and E with a straight line to locate center C .

4.22 Bisecting a Line or a Circular Arc

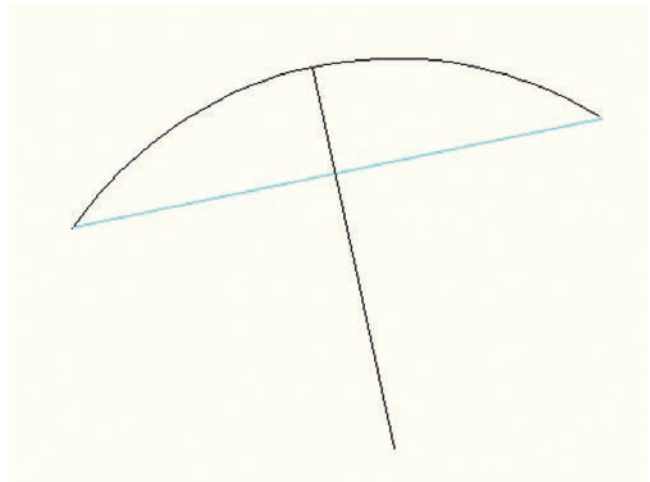
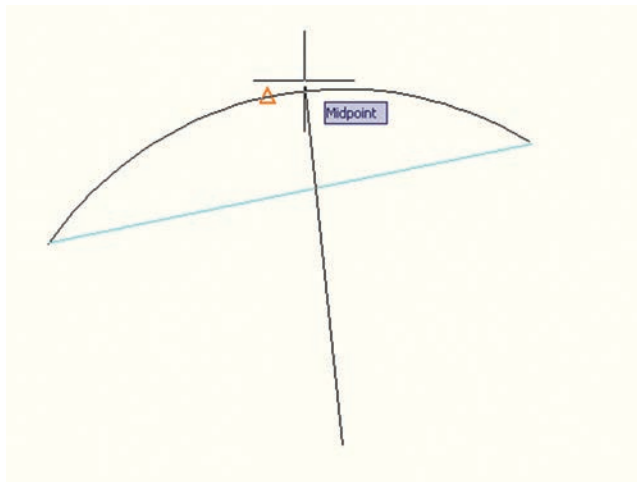
TIP

Accurate Geometry with AutoCAD

Using object snaps (Figure A) to locate drawing geometry, such as the midpoint of the arc shown in Figure B, is a quick and easy way to draw a line bisecting an arc or another line.



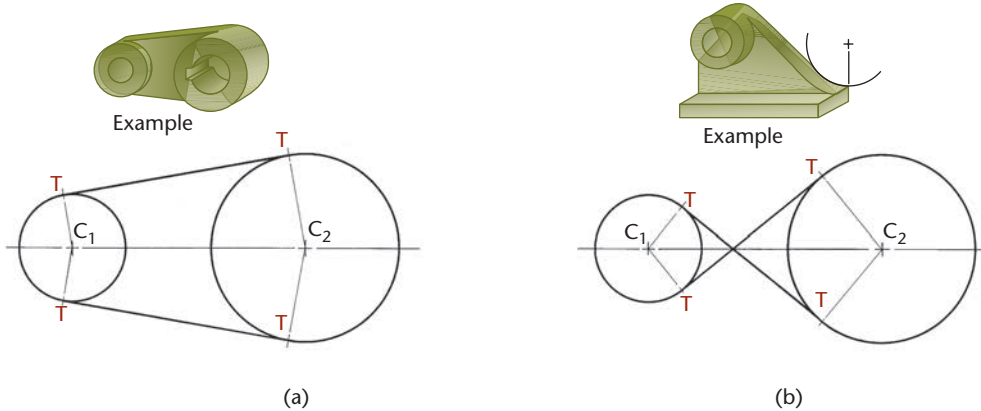
(A) The AutoCAD Drafting Settings dialog box can be used to turn on objects snaps, a method of selecting locations on drawing geometry. (Autodesk screen shots reprinted courtesy of Autodesk Inc.)



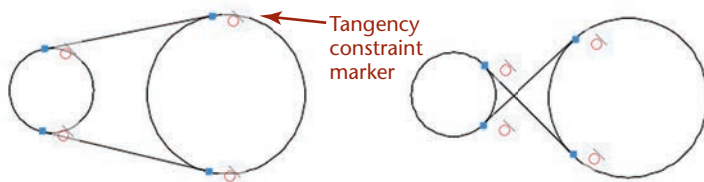
(B) Bisecting a Line or a Circular Arc Using AutoCAD's Midpoint Object Snap

4.2 DRAWING TANGENTS TO TWO CIRCLES

When drawing entities tangent to a circle, there are two locations that satisfy the condition of tangency. When using a CAD system, select a point close to the tangent location you intend.



4.23 Drawing Tangents to Two Circles



4.24 Tangency constraints for two identical sets of circles are shown in AutoCAD.

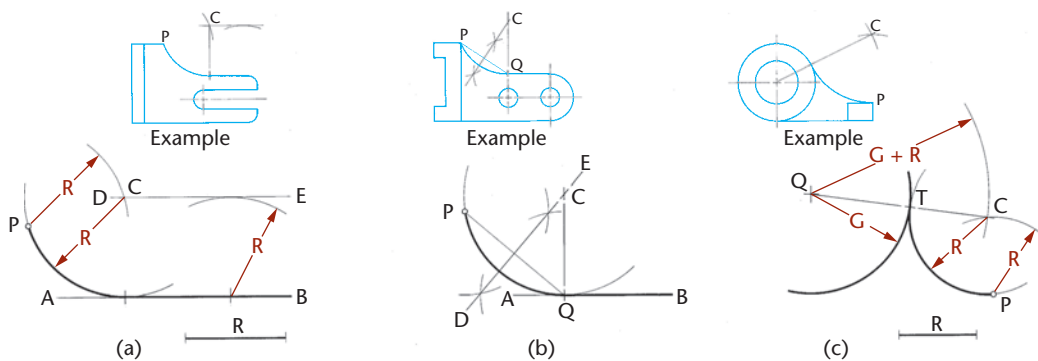
4.3 DRAWING AN ARC TANGENT TO A LINE OR ARC AND THROUGH A POINT

Given line AB , point P , and radius R (Figure 4.25a), draw line DE parallel to the given line and distance R from it. From P draw an arc with radius R , cutting line DE at C , the center of the required tangent arc.

Given line AB , with tangent point Q on the line and point P (Figure 4.25b), draw PQ , which will be a chord of the required arc. Draw perpendicular bisector DE , and at Q draw a

line perpendicular to the line to intersect DE at C , the center of the required tangent arc.

Given an arc with center Q , point P , and radius R (Figure 4.25c), from P , draw an arc with radius R . From Q , draw an arc with radius equal to that of the given arc plus R . The intersection C of the arcs is the center of the required tangent arc.



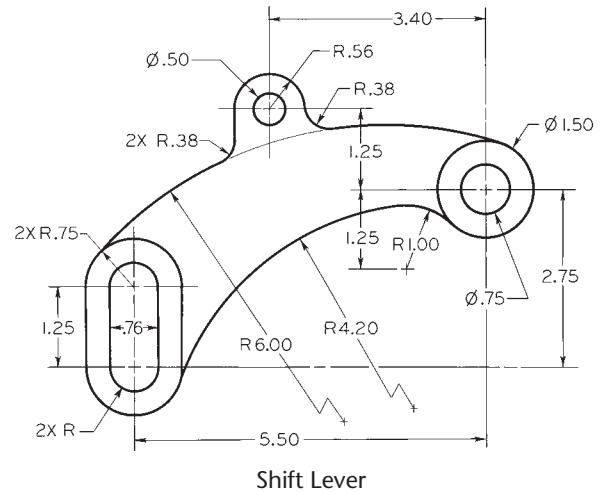
4.25 Tangents. These are often easy constructions using CAD and object snaps.

DRAWING AN ARC TANGENT TO TWO ARCS

Creating Construction Geometry

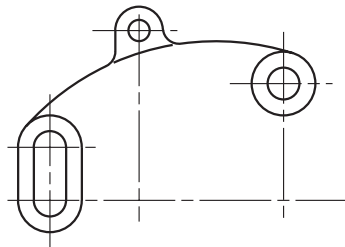
CAD software typically provides a command option to draw a circle or arc tangent to two entities (any combination of arcs, circles, or lines) given the radius. For example, the AutoCAD **Circle** command has an option called **Ttr** (tangent, tangent, radius). When you use this command, you first select the two drawing objects to which the new circle will be tangent and then enter the radius.

Take a look at the shift lever drawing. To draw this figure you must use a geometric construction to find the center of the 1.00-radius tangent arc. Before the lower 4.20-radius arc can be drawn, the smaller 1.00-radius arc must be constructed tangent to the 1.50 diameter circle. When an arc is tangent to a circle, its center must be the radius distance away from that circle.

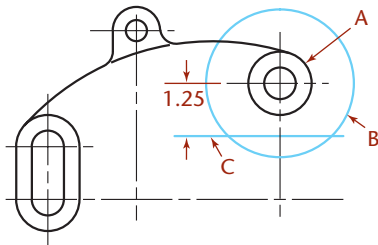


STEP by STEP

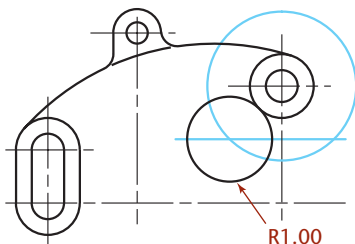
- 1 Use basic CAD commands to draw the portions shown.



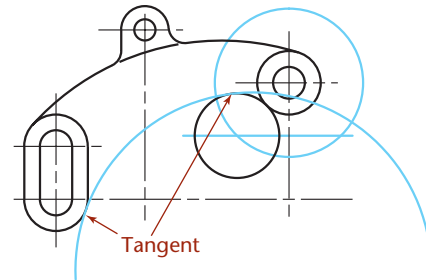
- 2 Construct circle B with a radius 1.00 larger than circle A. You can use the AutoCAD **Offset** command to do this quickly. The desired tangent arc must have its center somewhere on circle B. The vertical dimension of 1.25 is given between the two centers in the drawing. Construct line C at this distance. The only point that is on both the circle and the line is the center of the desired tangent arc.



- 3 Draw the 1.00-radius circle tangent to the 1.50-diameter circle and centered on the point just found.



- 4 Next, construct the lower 4.20-radius arc to be tangent to the lower curve at the left and to the 1.00-radius circle. Then, trim the circles at their intersections to form the desired arcs.



Geometric Constraints

Using geometric constraints is another way to create this CAD geometry. When geometric constraints are used, a general-case arc can be drawn that is not perfectly tangent. Then, a tangent constraint, the vertical dimension between the arc center and the circle, and the required radius can be applied to the arc as drawn. The software will then calculate the correct arc based on these constraints.

If the desired distance changes, the dimensional constraint values can be updated, and the software will recalculate the new arc. Not all software provides constraint-based modeling, especially in a 2D drafting context. The AutoCAD software has had this feature since release 2010.

When using constraint-based modeling, you still must understand the drawing geometry clearly to create a consistent set of geometric and dimensional constraints.

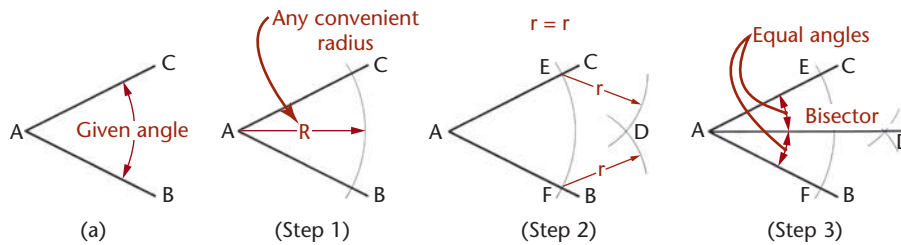
TIP

Two different tangent circles with the same radius are possible—one as shown and one that includes both circles. To get the desired arc using AutoCAD, select near the tangent location for the correctly positioned arc.

4.4 BISECTING AN ANGLE

Figure 4.26a shows the given angle BAC to be bisected.

- Step 1. Lightly draw large arc with center at A to intersect lines AC and AB .
 Step 2. Lightly draw equal arcs r with radius slightly larger than half BC , to intersect at D .
 Step 3. Draw line AD , which bisects the angle.

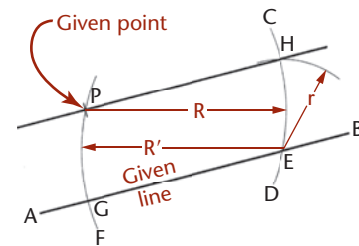


4.26 Bisecting an Angle

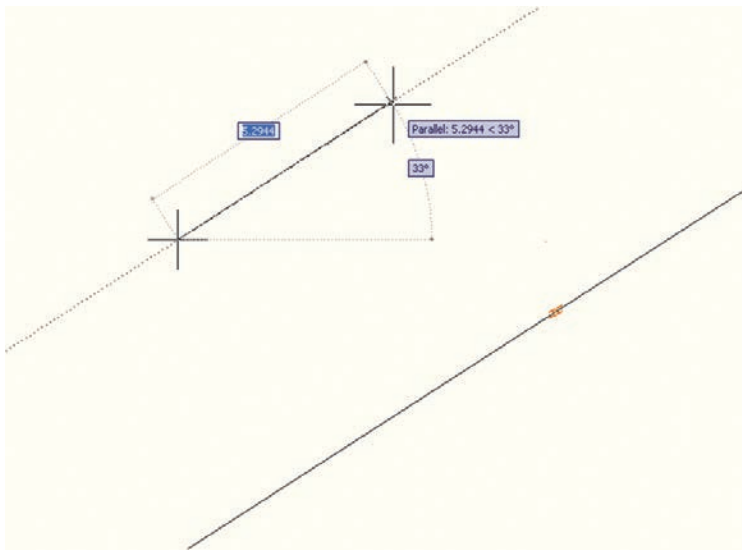
4.5 DRAWING A LINE THROUGH A POINT AND PARALLEL TO A LINE

With given point P as center, and any convenient radius R , draw arc CD to intersect the given line AB at E (Figure 4.27). With E as center and the same radius, strike arc R' to intersect the given line at G . With PG as radius and E as center, strike arc r to locate point H . The line PH is the required parallel line.

Using AutoCAD, you can quickly draw a new line parallel to a given line and through a given point using the **Offset** command with the **Through** option. Another method is to use the **Parallel** object snap while drawing the line as shown in Figure 4.28. You can also copy the original line and place the copy through the point.



4.27 Drawing a Line through a Point



4.28 Drawing a Line through a Point

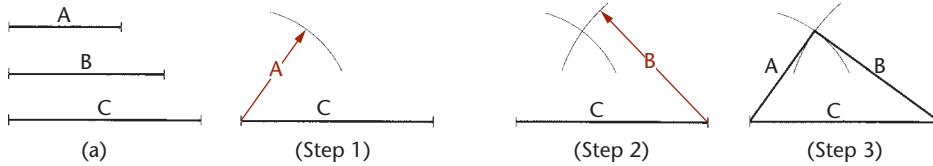
4.6 DRAWING A TRIANGLE WITH SIDES GIVEN

Given the sides A , B , and C , as shown in Figure 4.29a,

Step 1. Draw one side, as C , in the desired position, and draw an arc with radius equal to side A .

Step 2. Lightly draw an arc with radius equal to side B .

Step 3. Draw sides A and B from the intersection of the arcs, as shown.

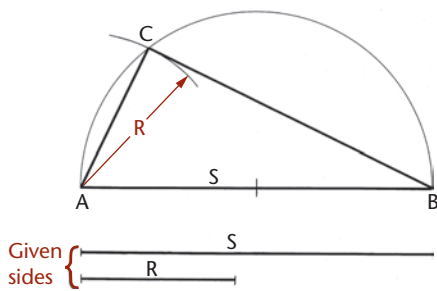


TIP
Using AutoCAD, you can enter the relative length and angle from the previous endpoint using the format:
`@lengthvalue<anglevalue`

4.29 Drawing a Triangle with Sides Given

4.7 DRAWING A RIGHT TRIANGLE WITH HYPOTENUSE AND ONE SIDE GIVEN

Given sides S and R (Figure 4.30), with AB as a diameter equal to S , draw a semicircle. With A as center and R as radius, draw an arc intersecting the semicircle at C . Draw AC and CB to complete the right triangle.



4.30 Drawing a Right Triangle

4.8 LAYING OUT AN ANGLE

Many angles can be laid out directly with the triangle or protractor. For more accuracy, use one of the methods shown in Figure 4.31.

Tangent Method The tangent of angle θ is y/x , and $y = x \tan \theta$. Use a convenient value for x , preferably 10 units (Figure 4.31a). (The larger the unit, the more accurate will be the construction.) Look up the tangent of angle θ and multiply by 10, and measure $y = 10 \tan \theta$.

EXAMPLE To set off $31-1/2^\circ$, find the natural tangent of $31-1/2^\circ$, which is 0.6128. Then, $y = 10 \text{ units} \times 0.6128 = 6.128 \text{ units}$.

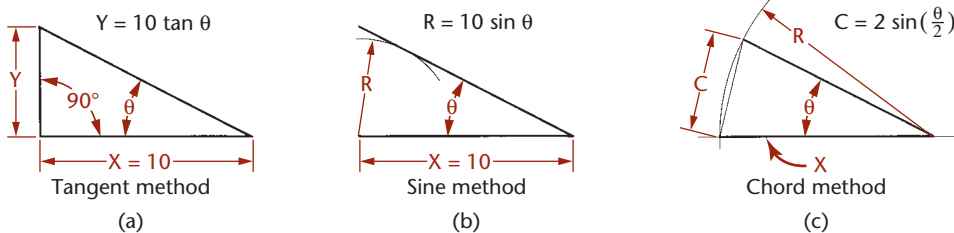
Sine Method Draw line x to any convenient length, preferably 10 units (Figure 4.31b). Find the sine of angle θ , multiply by 10, and draw arc with radius $R = 10 \sin \theta$. Draw the other side of the angle tangent to the arc, as shown.

EXAMPLE To set off $25-1/2^\circ$, find the natural sine of $25-1/2^\circ$, which is 0.4305. Then $R = 10 \text{ units} \times 0.4305 = 4.305 \text{ units}$.

Chord Method Draw line x of any convenient length, and draw an arc with any convenient radius R —say 10 units (Figure 4.31c). Find the chordal length C using the formula $C = 2 \sin \theta/2$. Machinists' handbooks have chord tables. These tables are made using a radius of 1 unit, so it is easy to scale by multiplying the table values by the actual radius used.

EXAMPLE Half of $43^\circ 20' = 21^\circ 40'$. The sine of $21^\circ 40' = 0.3692$. $C = 2 \times 0.3692 = 0.7384$ for a 1 unit radius. For a 10 unit radius, $C = 7.384 \text{ units}$.

EXAMPLE To set off $43^\circ 20'$, the chordal length C for 1 unit radius, as given in a table of chords, equals 0.7384. If $R = 10 \text{ units}$, then $C = 7.384 \text{ units}$.

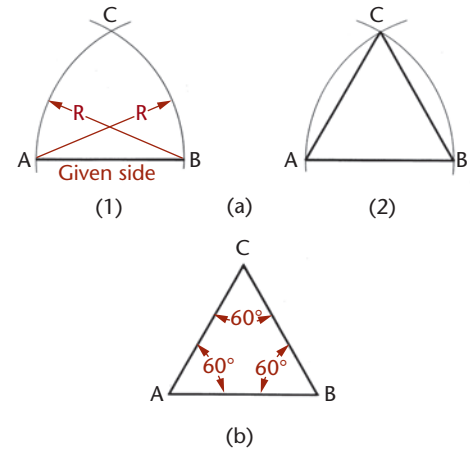


4.31 Laying Out Angles

4.9 DRAWING AN EQUILATERAL TRIANGLE

Side AB is given. With A and B as centers and AB as radius, lightly construct arcs to intersect at C (Figure 4.32a). Draw lines AC and BC to complete the triangle.

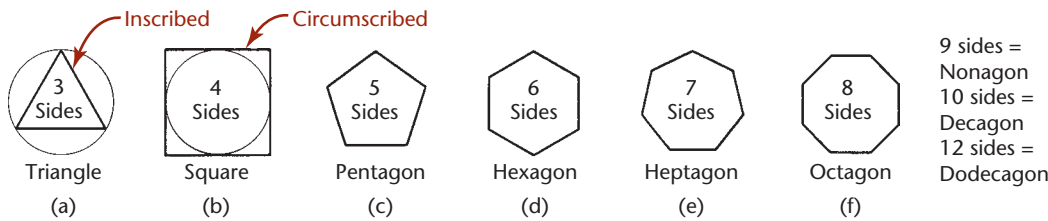
Alternative Method Draw lines through points A and B , making angles of 60° with the given line and intersecting C (Figure 4.32b).



4.32 Drawing an Equilateral Triangle

4.10 POLYGONS

A polygon is any plane figure bounded by straight lines (Figure 4.33). If the polygon has equal angles and equal sides, it can be inscribed in or circumscribed around a circle and is called a regular polygon.



4.33 Regular Polygons

Polygon
Creates an equilateral closed polyline

You can specify the different parameters of the polygon including the number of sides. The difference between the inscribed and circumscribed options is shown.

POLYGON
Press F1 for more help

TIP

The AutoCAD **Polygon** command is used to draw regular polygons with any number of sides. The polygon can be based on the radius of an inscribed or circumscribed circle. The length of an edge of the polygon can also be used to define the size. Figure 4.34 shows the quick help for the **Polygon** command. The **Rectangle** command is another quick way to make a square in AutoCAD.

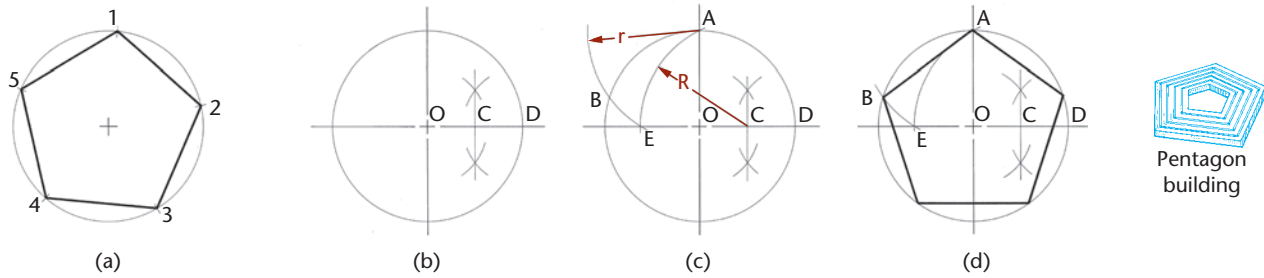
4.34 Polygons can be defined by the number of sides and whether they are inscribed in or circumscribed around a circle. (Autodesk screen shots reprinted courtesy of Autodesk, Inc.)

4.11 DRAWING A REGULAR PENTAGON

Dividers Method: Divide the circumference of the circumscribed circle into five equal parts with the dividers, and join the points with straight lines (Figure 4.35a).

Geometric Method:

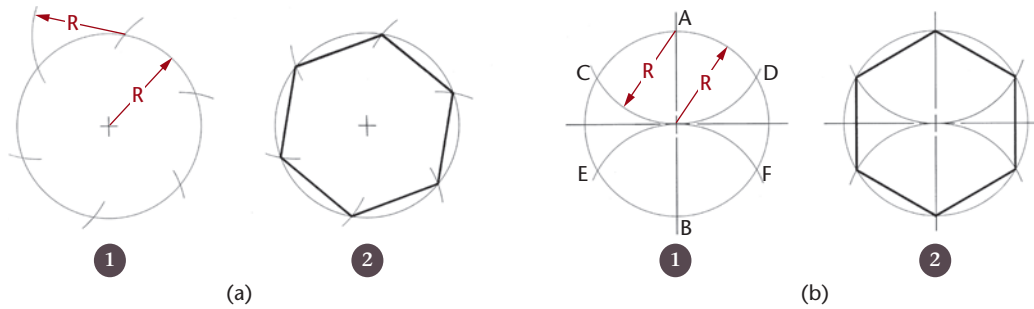
- Step 1. Bisect radius OD at C (Figure 4.35b).
- Step 2. Use C as the center and CA as the radius to lightly draw arc AE . With A as center and AE as radius, draw arc EB (Figure 4.35c).
- Step 3. Draw line AB , then measure off distances AB around the circumference of the circle. Draw the sides of the pentagon through these points (Figure 4.35d).



4.35 Drawing a Pentagon

4.12 DRAWING A HEXAGON

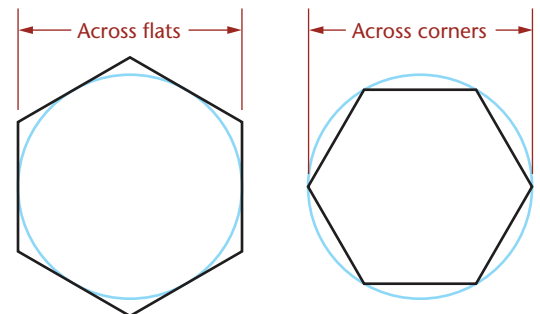
Each side of a hexagon is equal to the radius of the circumscribed circle (Figure 4.36a). To use a compass or dividers, use the radius of the circle to mark the six points of the hexagon around the circle. Connect the points with straight lines. Check your accuracy by making sure the opposite sides of the hexagon are parallel.



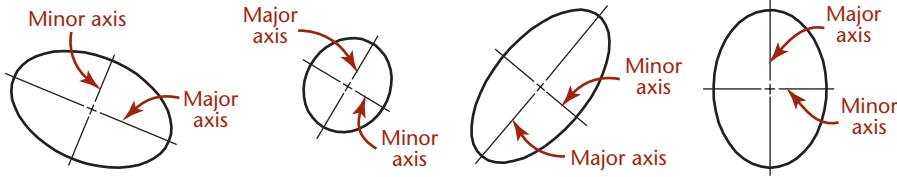
4.36 Drawing a Hexagon

Centerline Variation Draw vertical and horizontal centerlines (Figure 4.36b). With A and B as centers and radius equal to that of the circle, draw arcs to intersect the circle at $C, D, E,$ and F , and complete the hexagon as shown.

Hexagons, especially when drawn to create bolt heads, are usually dimensioned by the distance across the flat sides (not across the corners). When creating a hexagon using CAD, it is typical to draw it as circumscribed about a circle, so that the circle diameter is defining the distance across the flat sides of the hexagon (see Figure 4.37).



4.37 Across Flats vs. Across Corners



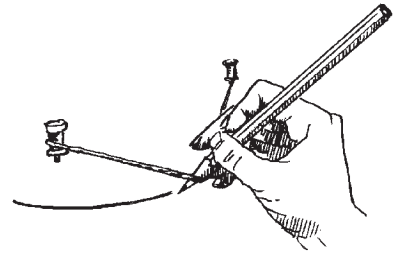
4.38 Major and Minor Axes of Some Ellipses

4.13 ELLIPSES

An ellipse can be defined by its major and minor axis distances. The major axis is the longer axis of the ellipse; the minor axis is the shorter axis. Some ellipses are shown and labeled in Figure 4.38.

An ellipse is created by a point moving along a path where the sum of its distances from two points, each called a focus of an ellipse (foci is the plural form), is equal to the major diameter. As an aid in understanding the shape of an ellipse, imagine pinning the ends of a string in the locations of the foci, then sliding a pencil along inside the string, keeping it tightly stretched, as in Figure 4.39. You would not use this technique when sketching, but it serves as a good illustration of the definition of an ellipse.

Most CAD systems provide an Ellipse command that lets you enter the major and minor axis lengths, center, or the angle of rotation for a circle that is to appear elliptical.

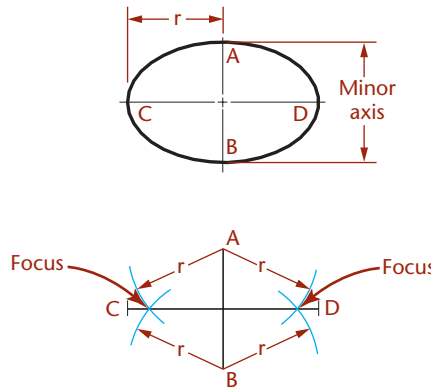


4.39 Pencil and String Method. *When an ellipse is created with the pencil-and-string method, the length of the string between the foci is equal to the length of the major axis of the ellipse. Any point that can be reached by a pencil inside the string when it is pulled taut meets the condition that its distances from the two foci sum to the length of the major diameter.*

SPOTLIGHT

Locating the Foci of an Ellipse

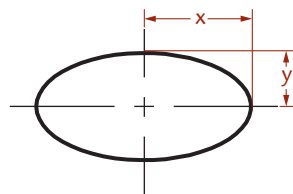
To locate the foci of an ellipse, draw arcs with their centers at the ends of the minor axis and their radii equal to half the major axis. The intersection of each pair of arcs is a focus of the ellipse.



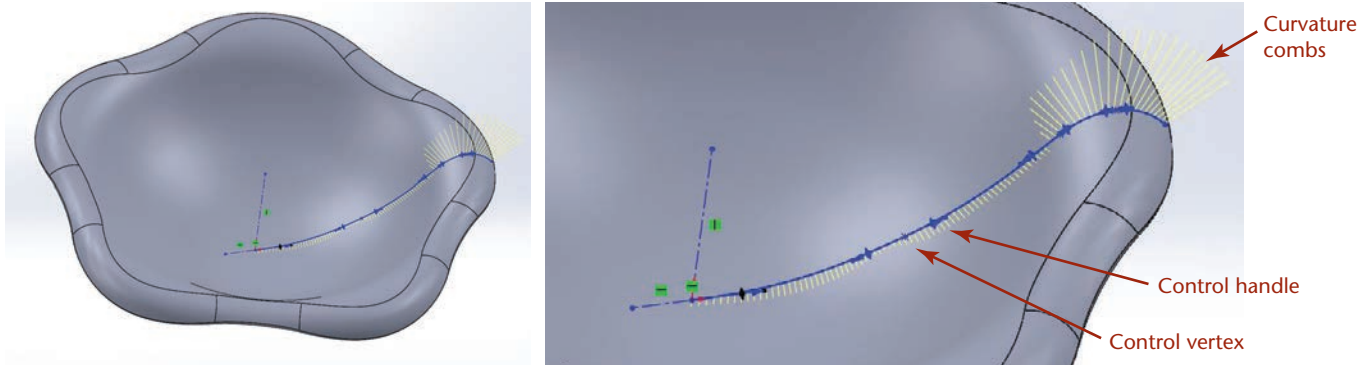
SPOTLIGHT

The Perimeter of an Ellipse

The perimeter, P , of an ellipse is a set of points defined by their distance from the two foci. The sum of the distances from any point on the ellipse to the two foci must be equal to the length of the major diameter. The perimeter of an ellipse may be approximated in different ways. Many CAD packages use infinite series to most closely approximate the perimeter. The mathematical relationship of each point on the ellipse to the major and minor axes may be seen in the approximation of the perimeter at right:



$$P = 2\pi \sqrt{\frac{x^2 + y^2}{2}}$$



4.14 SPLINE CURVES

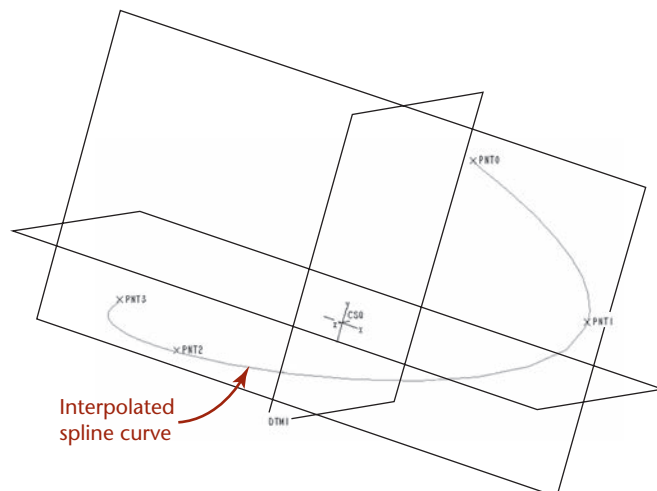
Splines are used to describe complex, or *freeform*, curves. Many surfaces cannot be easily defined using simple curves such as circles, arcs, or ellipses. For example, the flowing curves used in automobile design blend many different curves into a smooth surface. Creating lifelike shapes and aerodynamic forms may require spline curves (Figure 4.40).

The word *spline* originally described a flexible piece of plastic or rubber used to draw irregular curves between points. Mathematical methods generate the points on the curve for CAD applications.

One way to create an irregular curve is to draw curves between each set of points. The points and the tangencies at each point are used in a polynomial equation that determines the shape of the curve. This type of curve is useful in the design of a ship's hull or an aircraft wing. Because this kind of irregular curve passes through all the points used to define the curve, it is sometimes called an *interpolated spline* or a *cubic spline*. An example and its vertices are shown in Figure 4.41.

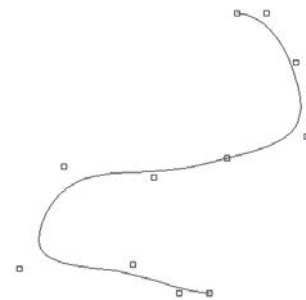
Other spline curves are approximated: they are defined by a set of vertices. The resulting curve does not pass through all the vertices. Instead, the vertices "pull" the curve in the direction of the vertex. Complex curves can be created with relatively few vertices using approximation methods. Figure 4.42 shows a 3D approximated spline curve and its vertices.

The mathematical definition for this type of spline curve uses the X- and Y- (and Z- for a 3D shape) coordinates and a parameter, generally referred to as u . A polynomial equation is used to generate functions in u for each point used to specify the curve. The resulting functions are then blended to generate a curve that is influenced by each point specified but not necessarily coincident with any of them.



4.41 Interpolated Spline. An interpolated spline curve passes through all the points used to define the curve.

4.40 Complex Curves. The organic shape of this flowerlike bowl was created using SolidWorks splines. Splines can be controlled in a variety of ways. The enlarged view shows the curvature combs used to view the effect of the controlling curves that make up the spline. Dragging a control handle changes the direction of the curve at the control vertex. (Courtesy of Robert Kincaid.)



4.42 Approximated Spline. Except for the beginning and endpoints, the fit points for the spline curve stored in the database do not always lie on the curve. They are used to derive the curve mathematically.

SPOTLIGHT

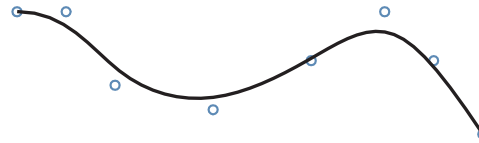
B-Splines

The *Bezier curve* was one of the first methods to use spline approximation to create flowing curves in CAD applications. The first and last vertices are on the curve, but the rest of the vertices contribute to a blended curve between them. The Bezier method uses a polynomial curve to approximate the shape of a polygon formed by the specified vertices. The order of the polynomial is 1 degree less than the number of vertices in the polygon (see Figure 4.43).

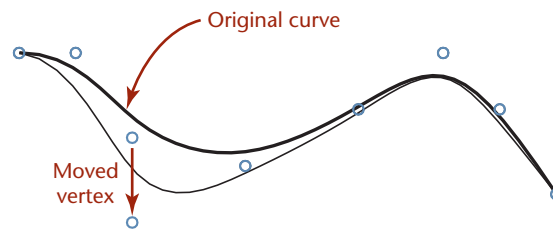
The Bezier method is named for Pierre Bezier, a pioneer in computer-generated surface modeling at Renault, the French automobile manufacturer. Bezier sought an easier way of controlling complex curves, such as those defined in automobile surfaces. His technique allowed designers to shape natural-looking curves more easily than they could by specifying points that had to lie on the resulting curve, yet the technique also provided control over the shape of the curve. Changing the slope of each line segment defined by a set of vertices adjusts the slope of the resulting curve (see Figure 4.44). One disadvantage of the Bezier formula is that the polynomial curve is defined by the combined influence of every vertex: a change to any vertex redraws the entire curve between the start point and endpoint.

A *B-spline* approximation is a special case of the Bezier curve that is more commonly used in engineering to give the designer more control when editing the curve. A B-spline is a blended piecewise polynomial curve passing near a set of control points. The spline is referred to as *piecewise* because the blending functions used to combine the polynomial curves can vary over the different segments of the curve. Thus, when a control point changes, only the piece of the curve defined by the new point and the vertices near it change, not the whole curve (see Figure 4.45). B-splines may or may not pass through the first and last points in the vertex set. Another difference is that for the B-spline the order of the polynomial can be set independently of the number of vertices or control points defining the curve.

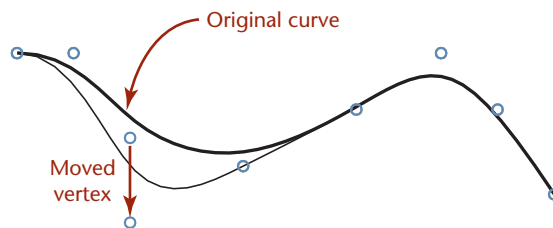
In addition to being able to locally modify the curve, many modelers allow sets of vertices to be weighted differently. The weighting, sometimes called tolerance, determines how closely the curve should fit the set of vertices. Curves can range from fitting all the points to being loosely controlled by the vertices. This type of curve is called a nonuniform rational B-spline, or *NURBS* curve. A rational curve (or surface) is one that has a weight associated with each control point.



4.43 Bezier Curve. A Bezier curve passes through the first and last vertex but uses the other vertices as control points to generate a blended curve.

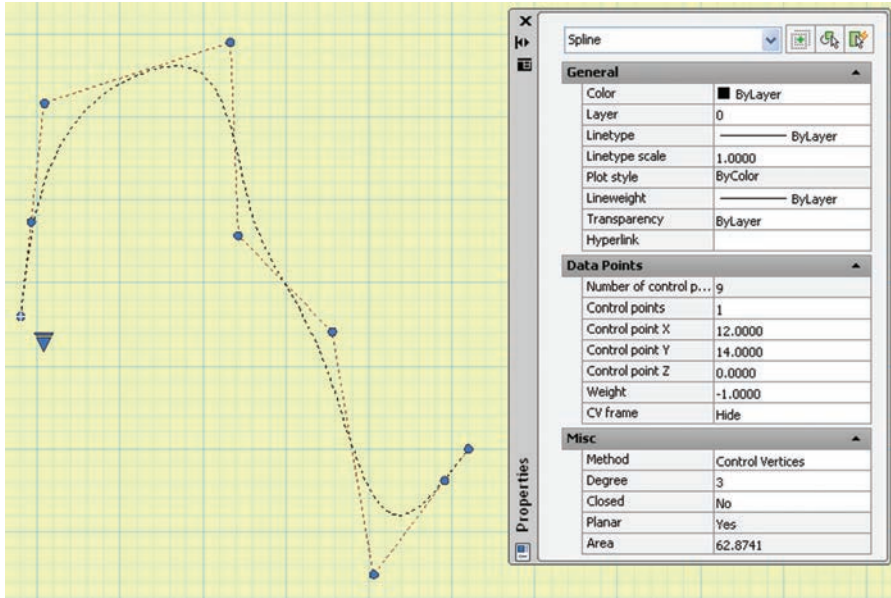


4.44 Editing a Bezier Curve. Every vertex contributes to the shape of a Bezier curve. Changing the location of a single vertex redraws the entire curve.

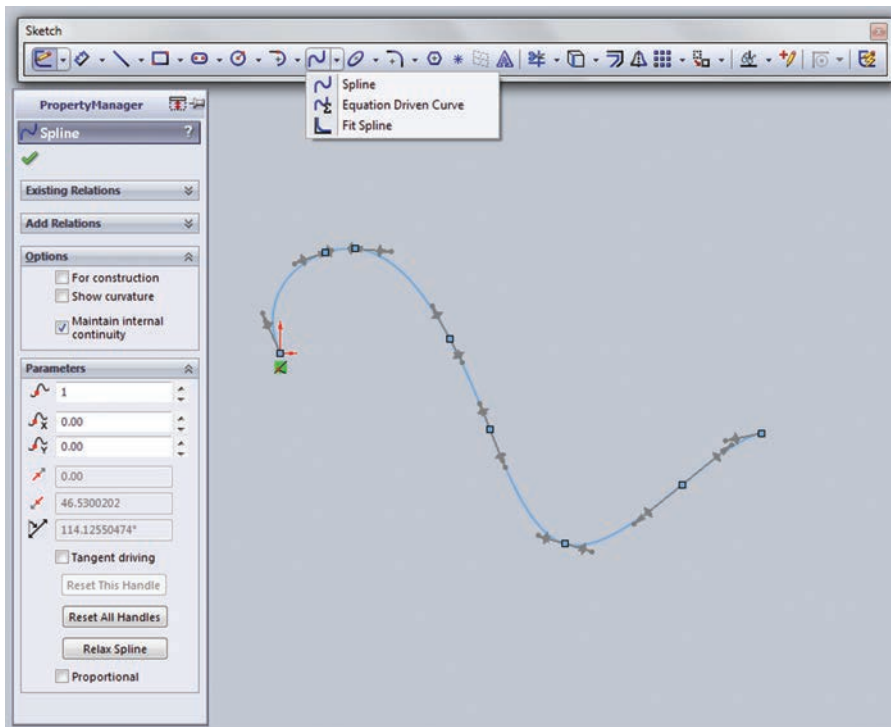


4.45 B-Spline Approximation. The B-spline is constructed piecewise, so changing a vertex affects the shape of the curve near only that vertex and its neighbors.

Splines are drawn in CAD systems based on the mathematical relationships defining their geometry. Figure 4.46 shows an approximated spline drawn using AutoCAD. Figure 4.47 shows an interpolated spline drawn using SolidWorks. Both curves are drawn with a spline command, and both provide a dialog box that allows you to change properties defining the curve; however, the properties that are controlled vary by the type of spline being created by the software package. You should be familiar with the terms used by your modeling software for creating different types of spline curves.



4.46 Approximated Spline. This spline drawn in AutoCAD is pulled toward the defined control points. The Properties dialog box at the right allows you to change the weighting factor for each control point. (Autodesk screen shots reprinted courtesy of Autodesk, Inc.)



4.47 Interpolated Spline. This SolidWorks spline passes through each control point. Software tools allow you to control spline properties. (Image courtesy of ©2016 Dassault Systèmes SolidWorks Corporation.)

4.15 GEOMETRIC RELATIONSHIPS

When you are sketching, you often imply a relationship, such as being parallel or perpendicular, by the appearance of the lines or through notes or dimensions. When you are creating a CAD model you use drawing aids to specify these relationships between geometric entities.

Two lines or planes are **parallel** when they are an equal distance apart at every point. Parallel entities never intersect, even if extended to infinity. Figure 4.48 shows an example of parallel lines.

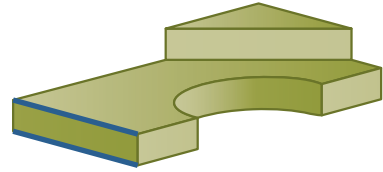
Two lines or planes are **perpendicular** when they intersect at right angles (or when the intersection that would be formed if they were extended would be a right angle), as in Figure 4.49.

Two entities **intersect** if they have at least one point in common. Two straight lines intersect at only a single point. A circle and a straight line intersect at two points, as shown in Figure 4.50.

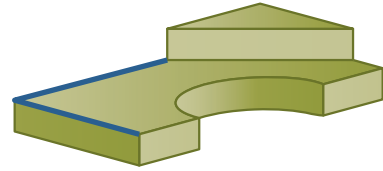
When two lines intersect, they define an angle as shown in Figure 4.51.

The term **apparent intersection** refers to lines that appear to intersect in a 2D view or on a computer monitor but actually do not touch, as shown in Figure 4.52. When you look at a wireframe view of a model, the 2D view may show lines crossing each other when, in fact, the lines do not intersect in 3D space. Changing the view of the model can help you determine whether an intersection is actual or apparent.

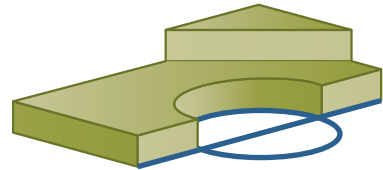
Two entities are **tangent** if they touch each other but do not intersect, even if extended to infinity, as shown in Figure 4.53. A line that is tangent to a circle will have only one point in common with the circle.



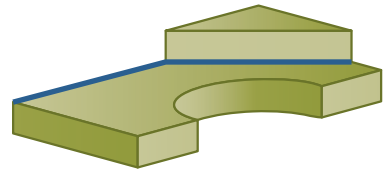
4.48 The highlighted lines are parallel.



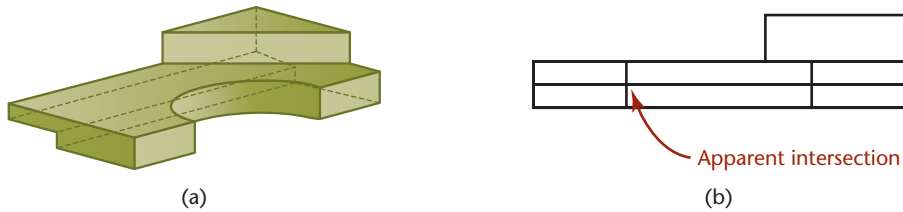
4.49 The highlighted lines are perpendicular.



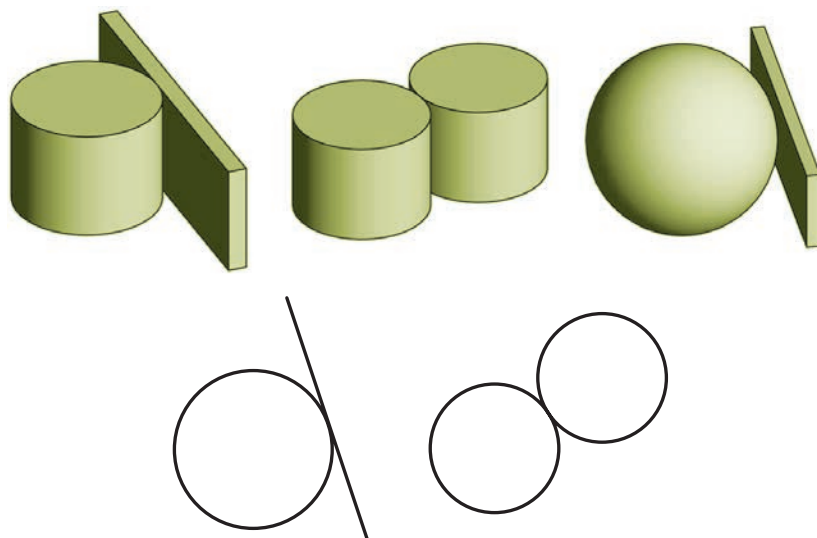
4.50 The highlighted circle intersects the highlighted line at two different points.



4.51 An angle is defined by the space between two lines (such as those highlighted here) or planes that intersect.



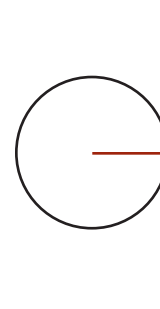
4.52 Apparent Intersection. From the shaded view of this model in (a), it is clear that the back lines do not intersect the half-circular shape. In the wireframe front view in (b), the lines appear to intersect.



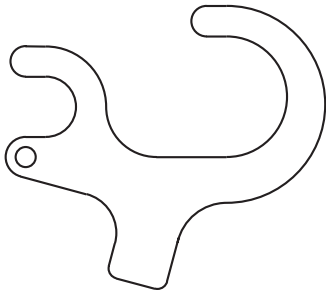
4.53 Tangency. Lines that are tangent to an entity have one point in common but never intersect. 3D objects may be tangent at a single point or along a line.

When a line is tangent to a circle, a radial line from the center of the circle is perpendicular at the point of tangency, as shown in Figure 4.54. Knowing this can be useful in creating sketches and models.

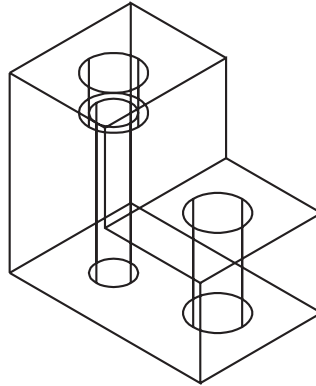
The regular geometry of points, lines, circles, arcs, and ellipses is the foundation for many CAD drawings that are created from these types of entities alone. Figure 4.55 shows a 2D CAD drawing that uses only lines, circles, and arcs to create the shapes shown. Figure 4.56 shows a 3D wireframe model that is also made entirely of lines, circles, and arcs. Many complex-looking 2D and 3D images are made solely from combinations of these shapes. Recognizing these shapes and understanding the many ways you can specify them in the CAD environment are key modeling skills.



4.54 A radial line from the point where a line is tangent to a circle will always be perpendicular to that line.



4.55 A 2D Drawing Made of Only Lines, Circles, and Arcs

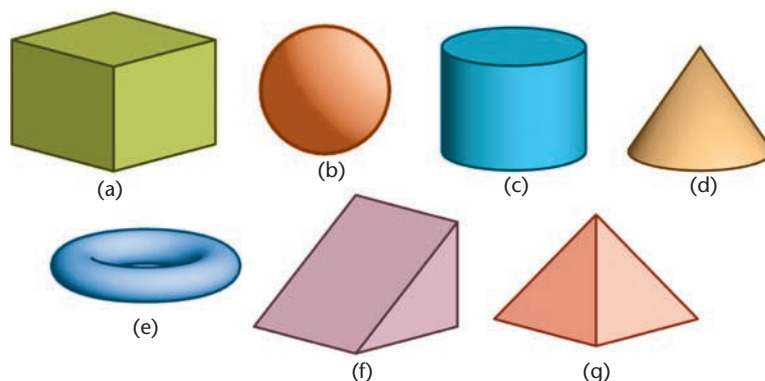


4.56 A 3D Model Made of Only Lines, Circles, and Arcs

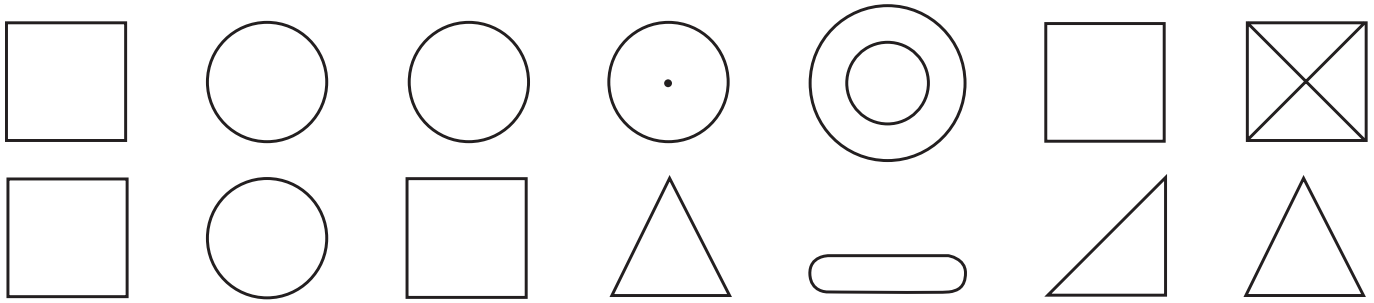
4.16 SOLID PRIMITIVES

Many 3D objects can be visualized, sketched, and modeled in a CAD system by combining simple 3D shapes or primitives. They are the building blocks for many solid objects. You should become familiar with these common shapes and their geometry. The same primitives that are useful when sketching objects are also used to create 3D models of those objects.

A common set of primitive solids used to build more complex objects is shown in Figure 4.57. Which of these objects are polyhedra? Which are bounded by single-curved surfaces? Which are bounded by double-curved surfaces? How many vertices do you see on the cone? How many on the wedge? How many edges do you see on the box? Familiarity with the appearance of these primitive shapes when shown in orthographic views can help you in interpreting drawings and in recognizing features that make up objects. Figure 4.58 shows the primitives in two orthographic views.



4.57 Solid Primitives. The most common solid primitives are (a) box, (b) sphere, (c) cylinder, (d) cone, (e) torus, (f) wedge, and (g) pyramid.



4.58 Match the top and front views shown here with the primitives shown in Figure 4.57.

Review the orthographic views and match each to the isometric of the same primitive shown in Figure 4.57.

Look around and identify some solid primitives that make up the shapes you see. The ability to identify the primitive shapes can help you model features of the objects using a CAD system (see Figure 4.59). Also, knowing how primitive shapes appear in orthographic views can help you sketch these features correctly and read drawings that others have created.

Making Complex Shapes with Boolean Operations

Boolean operations, common to most 3D modelers, allow you to join, subtract, and intersect solids. Boolean operations are named for the English mathematician George Boole, who developed them to describe how sets can be combined. Applied to solid modeling, Boolean operations describe how volumes can be combined to create new solids.



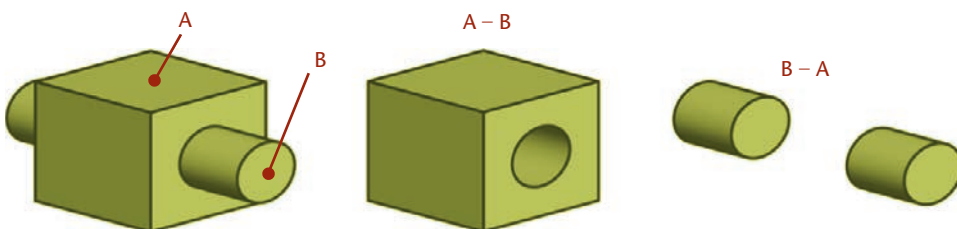
4.59 Complex Shapes. The 3D solid primitives in this illustration show basic shapes that make up a telephone handset. (Photo copyright Everything/Shutterstock.)

The three Boolean operations, defined in Table 4.1, are

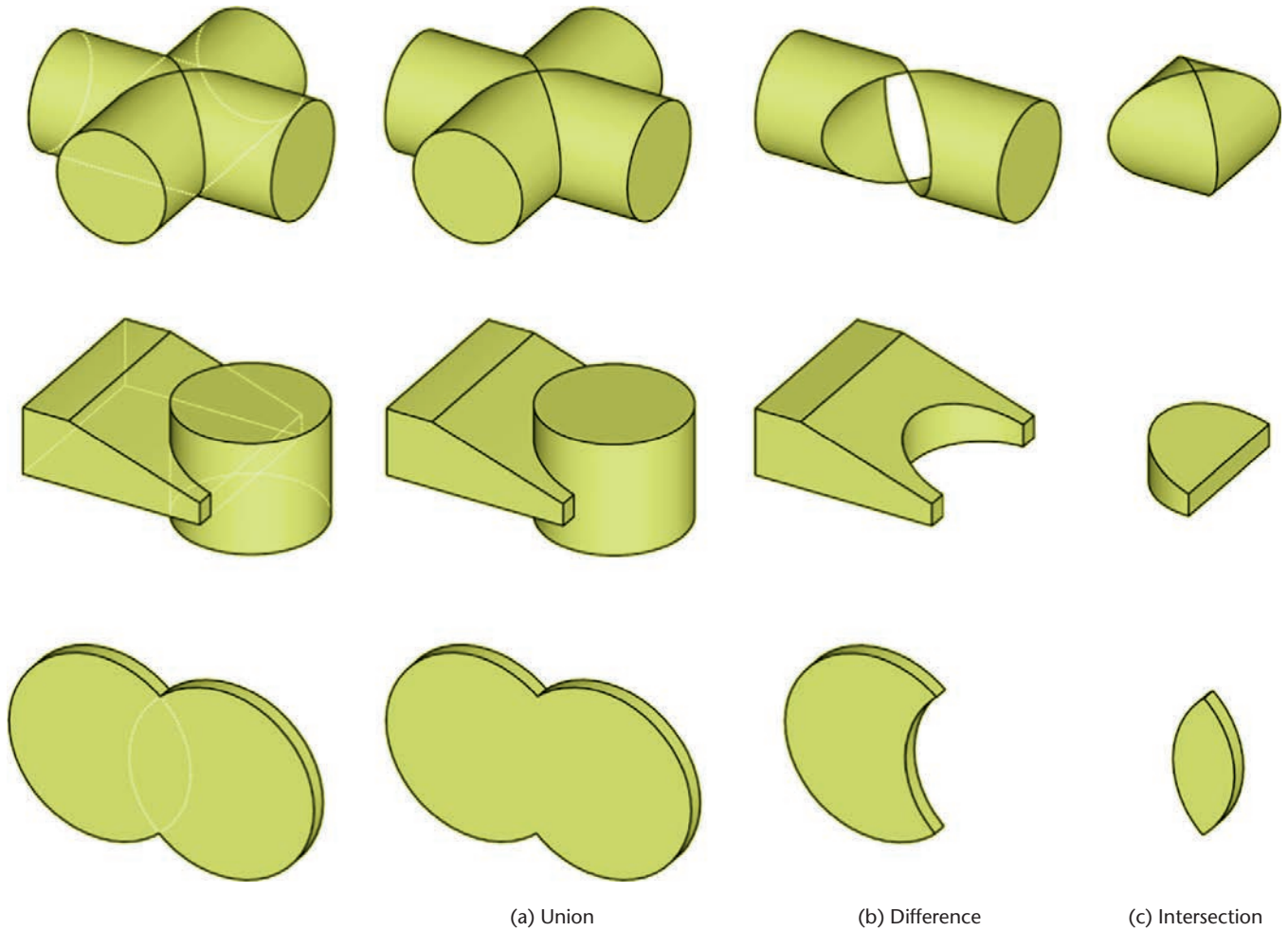
- Union (join/add)
- Difference (subtract)
- Intersection

Table 4.1 Boolean Operations

Name	Definition	Venn Diagram
Union (join/add)	The volume in both sets is combined or added. Overlap is eliminated. Order does not matter: A union B is the same as B union A.	
Difference (subtract)	The volume from one set is subtracted or eliminated from the volume in another set. The eliminated set is completely eliminated—even the portion that does not overlap the other volume. The order of the sets selected when using difference <i>does</i> matter (see Figure 4.60). A subtract B is not the same as B subtract A.	
Intersection	The volume common to both sets is retained. Order does not matter: B intersect A is the same as A intersect B.	



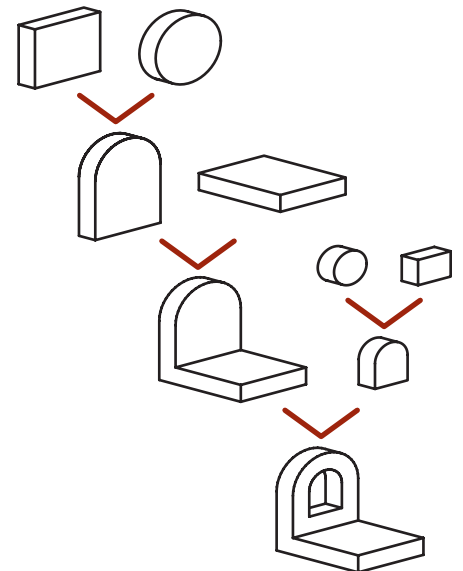
4.60 Order Matters in Subtraction. The models here illustrate how $A - B$ differs significantly from $B - A$.



4.61 Boolean Operations. *The three sets of models at left produce the results shown at right when the two solids are (a) unioned, (b) subtracted, and (c) intersected.*

Figure 4.61 illustrates the result of the Boolean operations on three pairs of solid models. Look at some everyday objects around you and make a list of the primitive solid shapes and Boolean operations needed to make them.

Figure 4.62 shows a bookend and a list of the primitives available in the CAD system used to create it, along with the Boolean operations used to make the part.

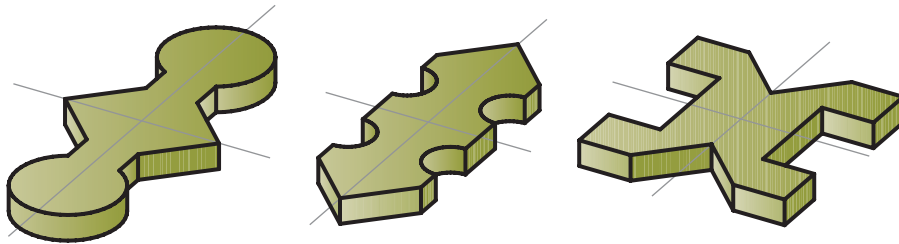


4.62 Shapes in a Bookend. *This diagram shows how basic shapes were combined to make a bookend. The box and cylinder at the top were unioned, then the resulting end piece and another box were unioned. To form the cutout in the end piece, another cylinder and box were unioned, then the resulting shape was subtracted from the end piece.*

4.17 RECOGNIZING SYMMETRY

An object is symmetrical when it has the same exact shape on opposite sides of a dividing line (or plane) or about a center or axis. Recognizing the symmetry of objects can help you in your design work and when you are sketching or using CAD to represent an object. Figure 4.63 shows a shape that is symmetrical about several axes of symmetry (of which two are shown) as well as about the center point of the circle.

Mirrored shapes have symmetry where points on opposite sides of the dividing line (or mirror line) are the same distance away from the mirror line. For a 2D mirrored shape, the axis of symmetry is the mirror line. For a 3D mirrored shape, the symmetry is about a plane. Examples of 3D mirrored shapes are shown in Figure 4.64.



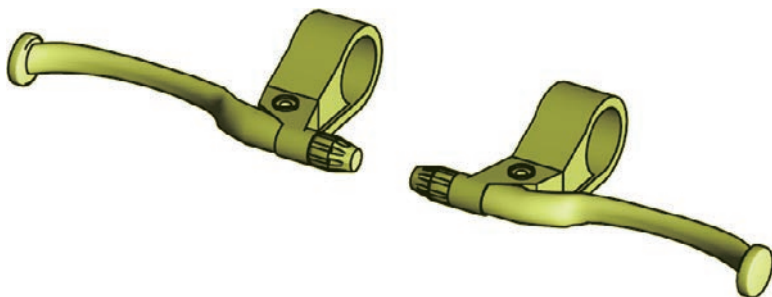
4.64 3D Mirrored Shapes. Each of these symmetrical shapes has two mirror lines, indicated by the thin axis lines. To create one of these parts, you could model one quarter of it, mirror it across one of the mirror lines, then mirror the resulting half across the perpendicular mirror line.

To simplify sketching, you need to show only half the object if it is symmetrical (Figure 4.65). A centerline line pattern provides a visual reference for the mirror line on the part.

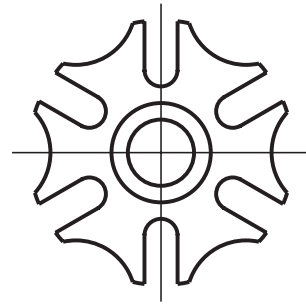
Most CAD systems have a command available to mirror existing features to create new features. You can save a lot of modeling time by noticing the symmetry of the object and copying or mirroring the existing geometry to create new features.

Right- and Left-Hand Parts

Many parts function in pairs for the right and left sides of a device. A brake lever for the left side of a mountain bike is a mirror image of the brake lever for the right side of the bike (Figure 4.66). Using CAD, you can create the part for the left side by mirroring the entire part. On sketches you can indicate a note such as RIGHT-HAND PART IS SHOWN. LEFT-HAND PART IS OPPOSITE. Right-hand and left-hand are often abbreviated as RH and LH in drawing notes.



4.66 Right- and Left-hand Brake Levers



4.63 Symmetrical Part. Symmetrical parts can have symmetry about a line or point, or both.



4.65 Orthographic sketches of symmetrical parts may show only half of the object.

TIP

Using symmetry when you model can be important when the design requires it. When the design calls for symmetrical features to be the same, mirroring the feature ensures that the two resulting features will be the same.

Parting-Line Symmetry

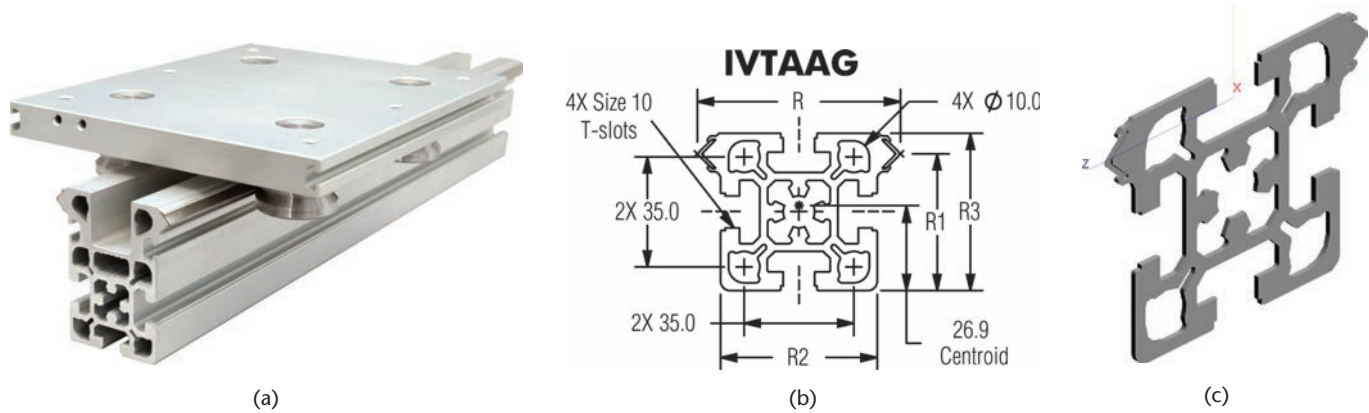
Molded symmetrical parts are often made using a mold with two halves, one on each side of the axis of symmetry. The axis or line where two mold parts join is called a *parting line*. When items are removed from a mold, sometimes a small ridge of material is left on the object. See if you can notice a parting line on a molded object such as your toothbrush or a screwdriver handle such as the one shown in Figure 4.67. Does the parting line define a plane about which the object is symmetrical? Can you determine why that plane was chosen? Does it make it easier to remove the part from the mold? As you are developing your sketching and modeling skills think about the axis of symmetry for parts and how it could affect their manufacture.



4.67 Parting Line. The parting line on a molded part is often visible as a ridge of material.



4.68 Two Halves of a Mold Used to Form a Strap (shown at left). (Two straps can be molded at once.)

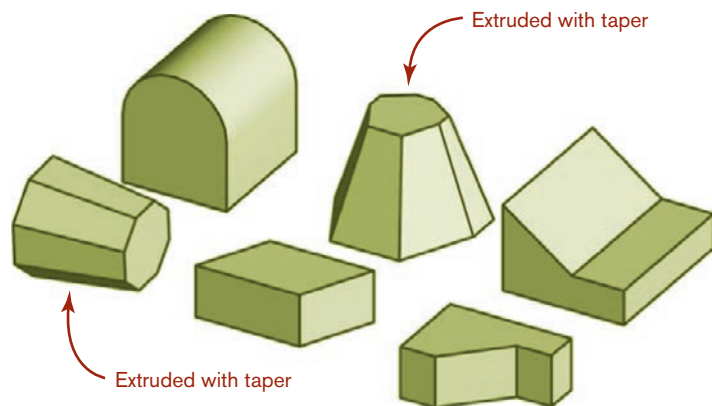


4.69 Extruded Shape. Symmetry and several common geometric shapes were used to create this linear guide system. The rail in (a) was created by forcing aluminum through an opening with the shape of its cross section. The extruded length was then cut to the required length. The solid model in (c) was created by defining the 2D cross-sectional shape (b) and specifying a length for the extrusion. (Integrated configuration of Integral V™ linear guides courtesy of PBCLinear.)

4.18 EXTRUDED FORMS

Extrusion is the manufacturing process of forcing material through a shaped opening (Figure 4.69). Extrusion in CAD modeling creates a 3D shape in a way similar to the extrusion manufacturing process. This modeling method is common even when the part will not be manufactured as an extrusion.

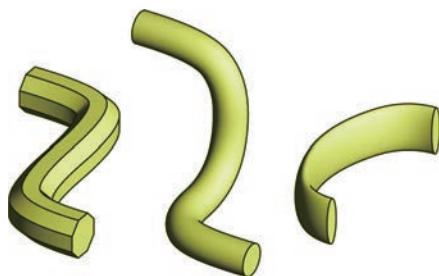
To create a shape by extrusion, sketch the 2D outline of the basic shape of the object (usually called a profile), and then specify the length for the extrusion. Most 3D CAD systems provide an Extrude command. Some CAD systems allow a taper (or draft) angle to be specified to narrow the shape over its length (Figure 4.70).



4.70 These CAD models were formed by extruding a 2D outline. Two of the models were extruded with a taper.

Swept Shapes

A swept form is a special case of an extruded form. Sweeping describes extruding a shape along a curved path. To sweep a shape in CAD, create the 2D profile and a 2D or 3D curve to serve as the path. Some swept shapes are shown in Figure 4.71.

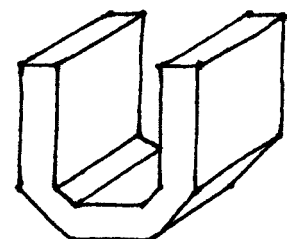


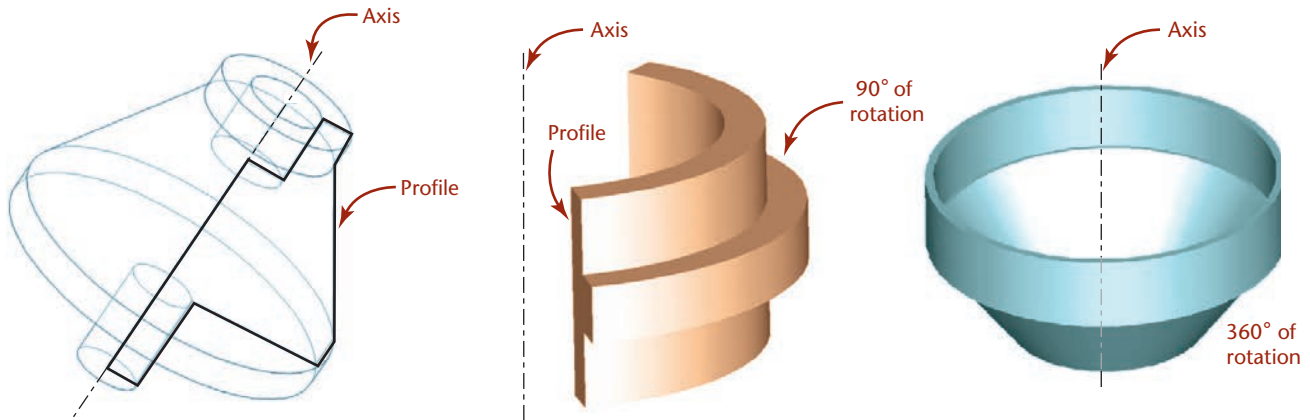
4.71 Swept Shapes. These shapes started as an octagon, a circle, and an ellipse, then were swept along a curved path.

SPOTLIGHT

Sketching Extruded Shapes

Shapes that can be created using extrusion are often easily sketched as oblique projections. To sketch extruded shapes, show the shape (or profile) that will be extruded parallel to the front viewing plane in the sketch. Copy this same shape over and up in the sketch based on the angle and distance you want to use to represent the depth. Then, sketch in the lines for the receding edges.



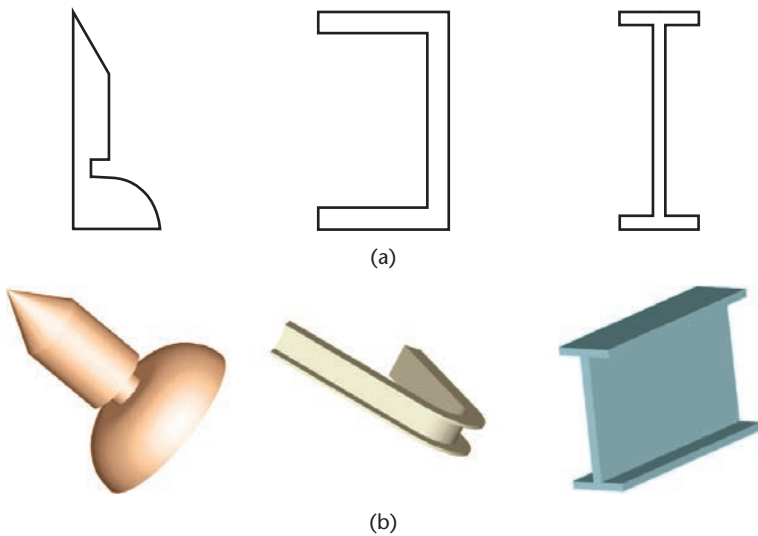


4.72 Revolved Shapes. Each of the solids shown here was created by revolving a 2D shape around an axis.

4.19 REVOLVED FORMS

Revolution creates 3D forms from basic shapes by revolving a 2D profile around an axis to create a closed solid object. To create a revolved solid, create the 2D shape to be revolved, specify an axis about which to revolve it, then indicate the number of degrees of revolution. Figure 4.72 shows some shapes created by revolution.

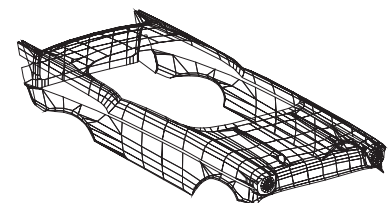
Often, a 2D sketch is used to create 3D CAD models. Look at the examples shown in Figure 4.73 and match them to the 2D profile used to create the part. For each part, decide whether extrusion, revolution, or sweeping was used to create it.



4.73 What operation would you choose to transform the profiles shown in (a) into the models in (b)?

4.20 IRREGULAR SURFACES

Not every object can be modeled using the basic geometric shapes explored in this chapter. Irregular surfaces are those that cannot be unfolded or unrolled to lie in a flat plane. Solids that have irregular or warped surfaces cannot be created merely by extrusion or revolution. These irregular surfaces are created using surface modeling techniques. Spline curves are frequently the building blocks of the irregular surfaces found on car and snowmobile bodies, molded exterior parts, aircraft, and other (usually exterior) surfaces of common objects, such as an ergonomic mouse. An example of an irregular surface is shown in Figure 4.74. You will learn more about modeling irregular surfaces in Chapter 5.



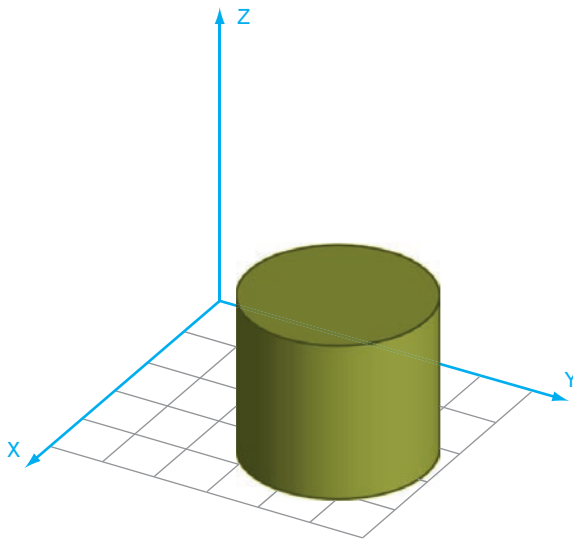
4.74 Irregular Surfaces

4.21 USER COORDINATE SYSTEMS

Most CAD systems allow you to create your own coordinate systems to aid in creating drawing geometry. These are often termed user coordinate systems (in AutoCAD, for example) or local coordinate systems, in contrast with the default coordinate system (sometimes called the world coordinate system or absolute coordinate system) that is used to store the model in the drawing database. To use many CAD commands effectively, you must know how to orient a user coordinate system.

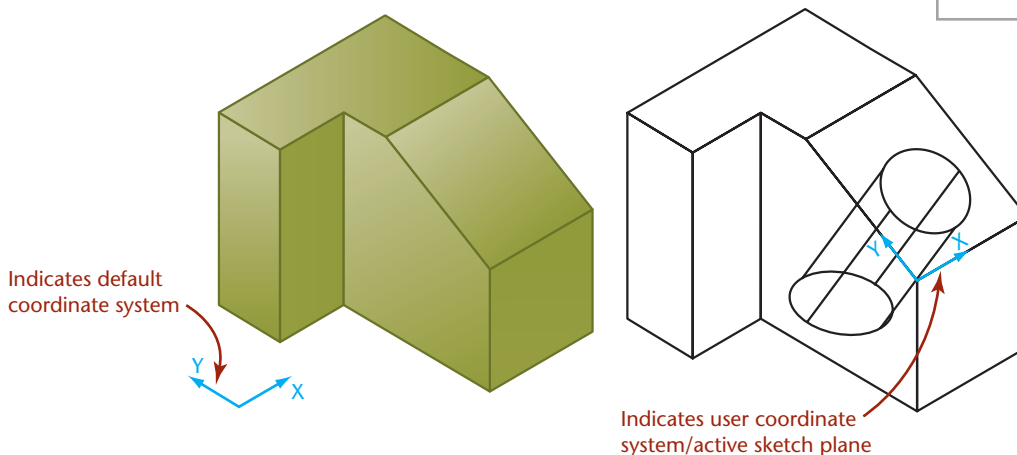
Most CAD systems create primitive shapes the same way each time with respect to the current X-, Y-, and Z-directions. For example the circular shape of the cylinder is always in the current X-Y plane, as shown in Figure 4.75.

To create a cylinder oriented differently, create a user coordinate system in the desired orientation (Figure 4.76).

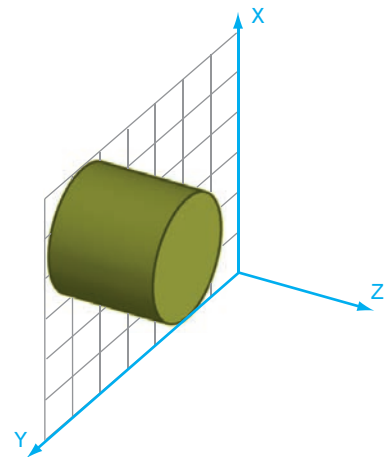
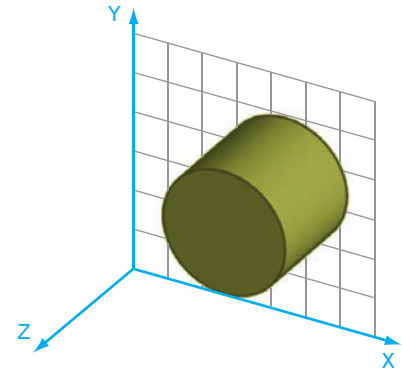


4.75 Cylinder Construction. The cylinder is created with the circular base on the X-Y plane and the height in Z.

To create the hole perpendicular to the oblique surface shown in Figure 4.77, create a new local coordinate system aligned with the inclined surface. After you have specified the location of the hole using the more convenient local coordinate system, the CAD software translates the location of the hole to the world (default) coordinate system.



4.77 Drawing on an Inclined Plane. A new coordinate system is defined relative to the slanted surface to make it easy to create the hole.



4.76 These cylinders were created after the X-Y plane of the coordinate system was reoriented.

TIP

All CAD systems have a symbol that indicates the location of the coordinate axes—both the global one used to store the model and any user-defined one that is active. Explore your modeler so you are familiar with the way it indicates each.

Many CAD systems have a command to define the plane for a user coordinate system by specifying three points. This is often an easy way to orient a new coordinate system—especially when it needs to align with an oblique or inclined surface. Other solid modeling systems allow the user to select an existing part surface on which to draw the new shape. This is analogous to setting the X-Y plane of the user coordinate system to coincide with the selected surface. With constraint-based modelers a “sketch plane” often is selected on which a basic shape is drawn that will be used to form a part feature. This defines a coordinate system for the sketch plane.

A user or local coordinate system is useful for creating geometry in a model. Changing the local coordinate system does not change the default coordinate system where the model data are stored.

4.22 TRANSFORMATIONS

A 3D CAD package uses the default Cartesian coordinate system to store information about the model. One way it may be stored is as a matrix (rows and columns of numbers) representing the vertices of the object. Once the object is defined, the software uses mathematical methods to transform the matrix (and the object) in various ways. There are two basic kinds of transformations: those that transform the model itself (called geometric transformations) and those that merely change the view of the model (called viewing transformations).

Geometric Transformations

The model stored in the computer is changed using three basic transformations (or changes): moving (sometimes called translation), rotating, and scaling. When you select a CAD command that uses one of these transformations, the CAD data stored in your model are converted mathematically to produce the result. Commands such as Move (or Translate), Rotate, and Scale transform the object on the coordinate system and change the coordinates stored in the 3D model database.

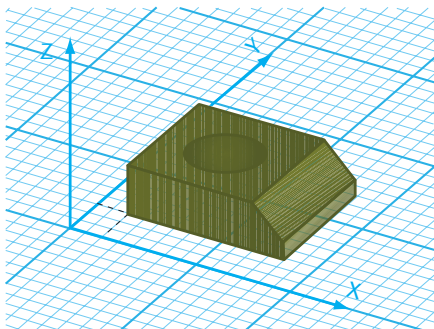
Figure 4.78 shows a part after translation. The model was moved over 2 units in the X-direction and 3 units in the Y-direction. The corner of the object is no longer located at the origin of the coordinate system.

Figure 4.79 illustrates the effect of rotation. The rotated object is situated at a different location in the coordinate system. Figure 4.80 shows the effect of scaling. The scaled object is larger dimensionally than the previous object.

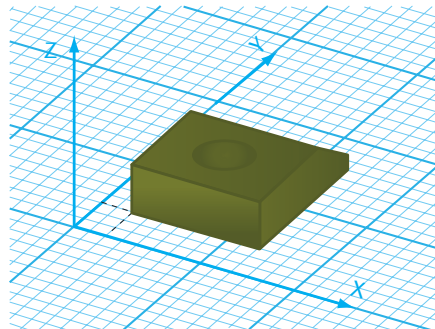
TIP

The following command names are typically used when transforming geometry:

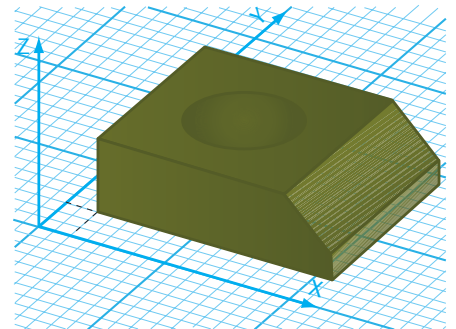
- Move
- Rotate
- Scale



4.78 Translation. *This model has been moved 2 units in the X-direction and 3 units in the Y-direction.*

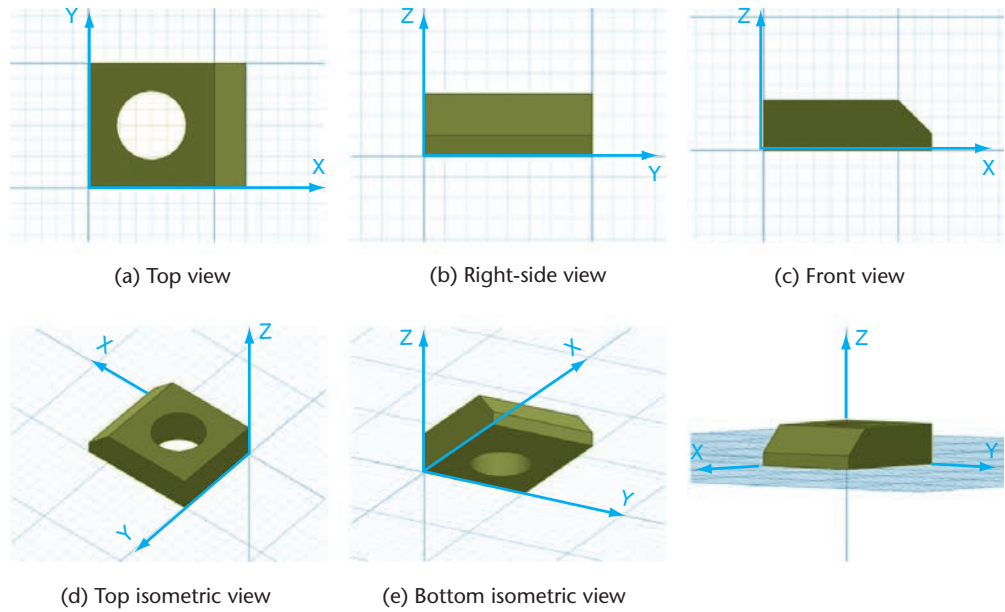


4.79 Rotation. *This model has been rotated in the X-Y plane.*



4.80 Scaling. *This model has been scaled to 1.5 times its previous size.*

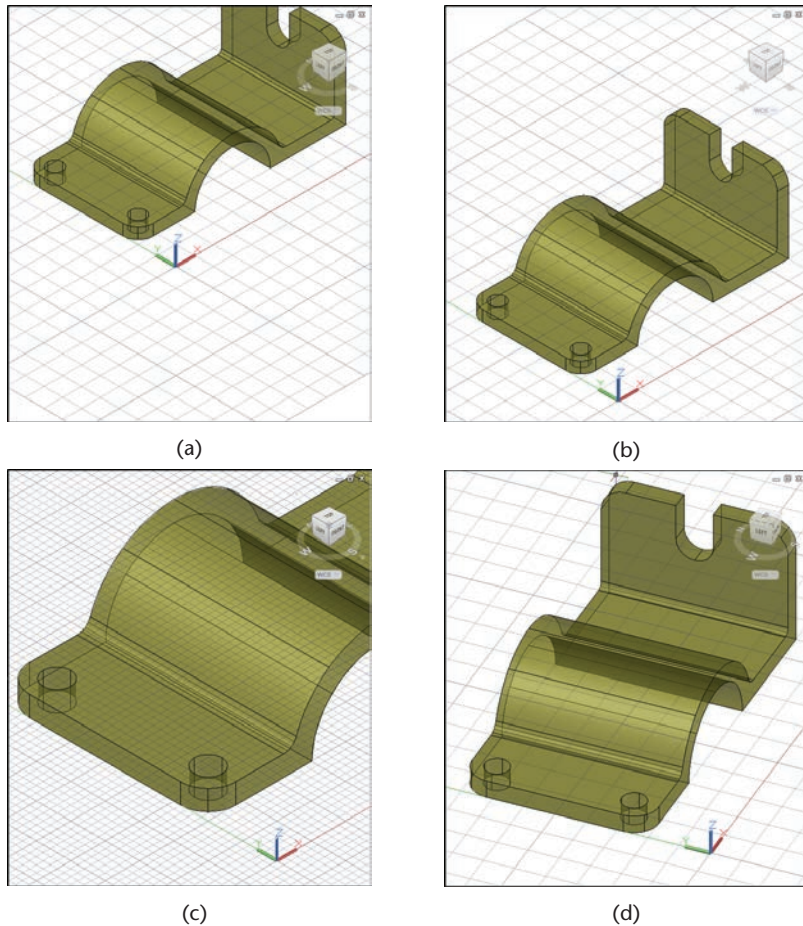
4.81 Changing the View. Note that the location of the model relative to the coordinate axes does not change in any of the different views. Changing the view does not transform the model itself.



Viewing Transformations

A viewing transformation does not change the coordinate system or the location of the model on the coordinate system; it simply changes your view of the model. The model's vertices are stored in the computer at the same coordinate locations no matter the direction from which the model is viewed on the monitor (Figure 4.81).

Although the model's coordinates do not change when the view does, the software does mathematically transform the model database to produce the new appearance of the model on the screen. This viewing transformation is stored as a separate



4.82 Common View Transformations. Panning moved the view of the objects in (a) to expose a different portion of the part in (b). In (c), the view is enlarged to show more detail. In (d), the view is rotated to a different line of sight. In each case, the viewing transformation applies to all the objects in the view and does not affect the location of the objects on the coordinate system. (Notice that the position relative to the coordinate system icon does not change.)

part of the model file (or a separate file) and does not affect the coordinates of the stored model. Viewing transformations change the view on the screen but do not change the model relative to the coordinate system.

Common viewing transformations are illustrated in Figure 4.82. Panning moves the location of the view on the screen. If the monitor were a hole through which you were viewing a piece of paper, panning would be analogous to sliding the piece of paper to expose a different portion of it through the hole. Zooming enlarges or reduces the view of the objects and operates similar to a telephoto lens on a camera. A view rotation is actually a change of viewpoint; the object appears to be rotated, but it is your point of view that is changing. The object itself remains in the same location on the coordinate system.

Viewing controls transform only the viewing transformation file, changing just your view. Commands to scale the object on the coordinate system transform the object's coordinates in the database.

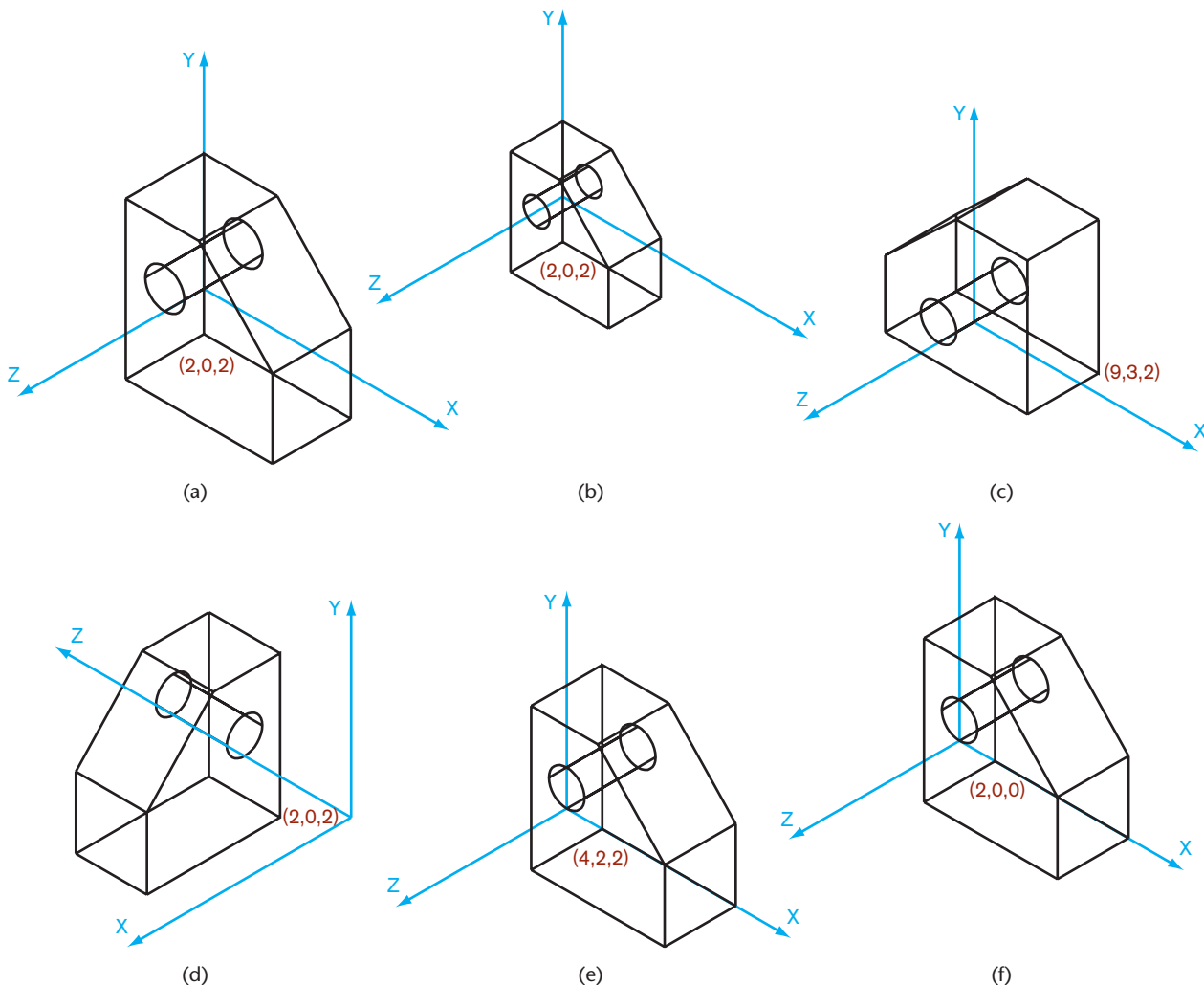
Examine the six models and their coordinates in Figure 4.83. Which are views that look different because of changes in viewing controls? Which look different because the objects were rotated, moved, or scaled on the coordinate system?

You will use the basic geometric shapes and concepts outlined in this chapter to build CAD models and create accurate freehand sketches. The ability to visualize geometric entities on the Cartesian coordinate system will help you manipulate the coordinate system when modeling in CAD.

TIP

The following are typical command names for view transformations:

- Pan
- Spin (or Rotate View)
- Zoom



4.83 Geometric or Viewing Transformation? *Three of these models are the same, but the viewing location, zoom, or rotation has changed. Three have been transformed to different locations on the coordinate system.*

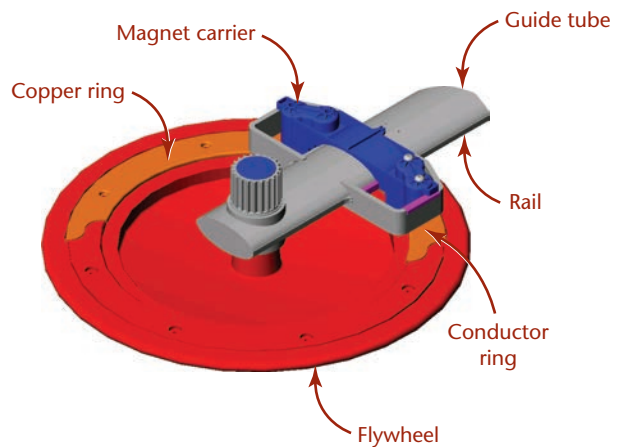
THE GEOMETRY OF 3D MODELING: USE THE SYMMETRY

Stratix ID used magnets to create a clean, quiet, zero maintenance brake for the exercise bike it designed for Park City Entertainment. When copper rings on the bike's iron flywheel spin past four rare-earth magnets, they create current in circular flow (an eddy current) that sets up a magnetic field.

This opposing magnetic field dissipates power and slows the wheel. Moving the magnets onto and off the copper rings varies the amount of resistance delivered. When Marty Albini, Senior Mechanical Engineer, modeled the plastic magnet carrier for the brake, he started with the magnets and their behavior as the carrier moved them onto and off the copper rings (see Figure 4.84). "There is no one way to think about modeling a part," Albini said. "The key is to design for the use of the part and the process that will be used to manufacture it." To make the magnet carrier symmetrical, Albini started by modeling half of it.

The magnet carrier was designed as a part in the larger flywheel assembly, parts of which were already completed.

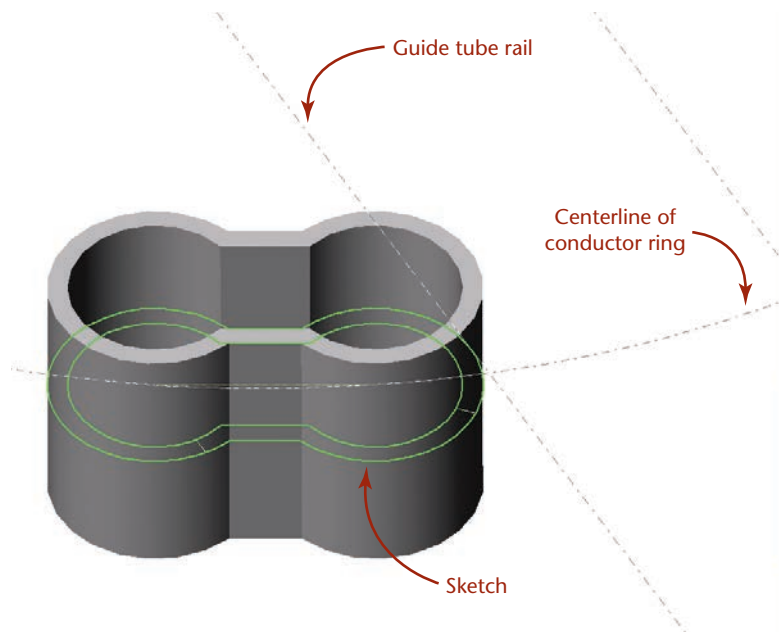
Each pair of magnets was attached to a backing bar that kept them a fixed distance apart. To begin, Albini started with the geometry he was sure of: the diameter of the magnets, the space between them, and the geometry of the conductor ring. He sketched an arc sized to form a pocket around one of the magnets so that its center point would be located on the centerline of the conductor ring (see Figure 4.85). He then sketched another similar arc but with its center point positioned to match the distance between the centers of the two magnets. He connected the two arcs with parallel lines to complete the sketch of the inside of the carrier. This outline was offset to the outside by the thickness of the wall of the holder. (Because this is an injection-molded plastic part, a uniform wall thickness was used throughout.) One final constraint was added to position



4.84 Flywheel Assembly. The magnet carrier for the brake was designed to move onto and off the conductor ring by sliding along an elliptical guide tube, pulled by a cable attached to the small tab in the middle of the carrier.

the carrier against the rail on the elliptical tube along which it would slide: the outside of the inner arc is tangent to this rail. With the sketch geometry fully defined, Albini extruded the sketch up to the top of the guide tube and down to the running clearance from the copper ring.

To add a lid to the holder, Albini used the SolidWorks **Offset** command to trace the outline of the holder. First, he clicked on the top of the holder to make its surface the active sketch plane. This is equivalent to changing the user coordinate system in other packages: it signals to SolidWorks that points picked from the screen lie on this plane. He then selected the



4.85 Extruding the Carrier. The magnet carrier was extruded up and down from the sketch, shown here as an outline in the middle of the extruded part. Notice that the sketch is tangent to the guide tube rail, and the centers of the arcs in the sketch are located on the centerline of the conductor ring.

top edges of the holder and used the **Offset** command with a 0 offset to “trace” the outline as a new sketch. To form the lid, he extruded the sketch up (in the positive Z-direction) the distance of the uniform wall thickness.

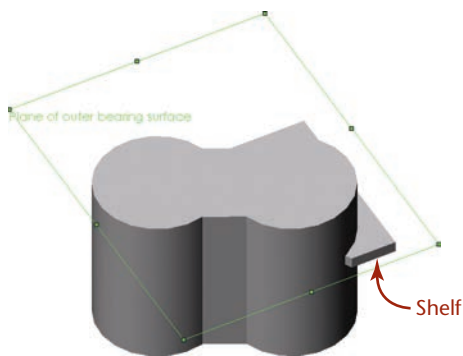
SolidWorks joined this lid to the magnet holder automatically because both features are in the same part and have surfaces that are coincident. This built-in operation is similar to a Boolean join in that the two shapes are combined to be one.

For the next feature, Albin created a “shelf” at the height of the rail on which the holder will slide. Using **Offset** again, he traced the outline of the holder on the sketch plane, then added parallel and perpendicular lines to sketch the outline of the bottom of the shelf. The outline was then extruded up by the wall thickness. The distance from the outside of the magnet holder to the edge of the shelf created a surface that would sit on the rail (see Figure 4.86).

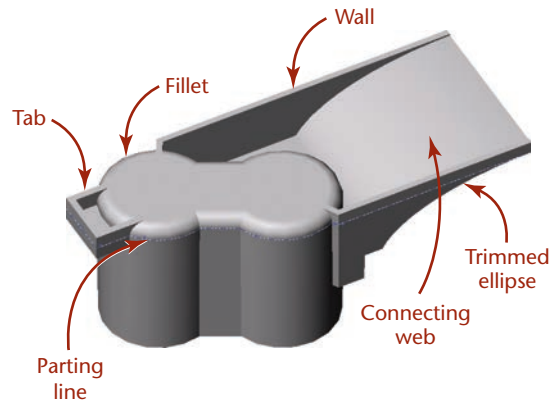
Two walls were added by offsetting the edge of the shelf toward the magnet holder by the wall thickness, then offsetting the edge again by 0. Lines were added to connect the endpoints into an enclosed shape to be extruded. (In SolidWorks, an extrusion can be specified to extend in one or both directions, and to extend to a vertex, a known distance, the next surface, or the last surface encountered.) For the walls, Albin extruded them to the top surface of the magnet holder “lid.”

The connecting web between the magnet holders needed to match the shape of the elliptical tube in the flywheel assembly (see Figure 4.87). To make it, Albin sketched an ellipse on the newly created wall. An ellipse is a sketching primitive that can be specified by entering the length of the major and minor axes. Albin used the dimensions from the tube for the first ellipse sketch, then drew a second one with the same center point but with longer axes so that a gap equal to the wall thickness between them would be formed. The two ellipses were trimmed off at the bottom surface of the shelf and at the midpoint, and lines were drawn to make a closed outline. The finished sketch was extruded to the outside surface of the opposite wall.

More walls were sketched and extruded from the bottom surface of the shelf. Then, the wall over the connecting web was sketched and extruded down to the web.



4.86 Changing the Sketch Plane. *The surface of the rail was used as the sketch plane for the “shelf” on which the magnet carrier will slide.*



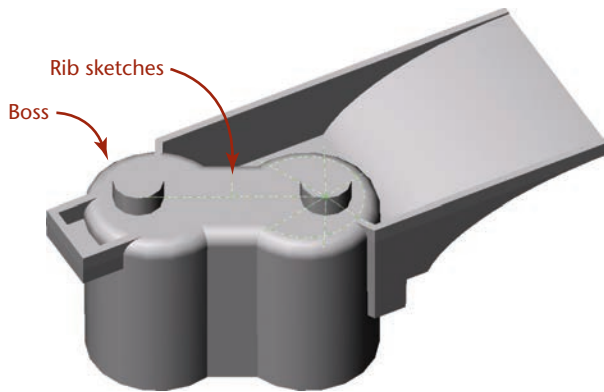
4.87 *This view of the magnet carrier shows the elliptical shape of the connecting web and the rectangular shape of the tab. The parting line for the part, shown here as a dotted white line, is located at the edge of the fillet on the top of the magnet chambers.*

The next step was to add the rounded edges for the top of the magnet holder. Albin invoked the **Fillet** command and selected to round all the edges of the top surface at once. As it created the fillet, SolidWorks maintained the relationship between the wall surfaces that intersected the top edge of the holder and extended them to the new location of the edge.

Next, Albin created a tab at the end of the part that would rest on the plastic collar in the assembly that went all the way around the magnet carrier. He first extruded a rectangular shape up from the top of the collar to form the “floor” of the tab. The walls of the tab required two additional extrusions.

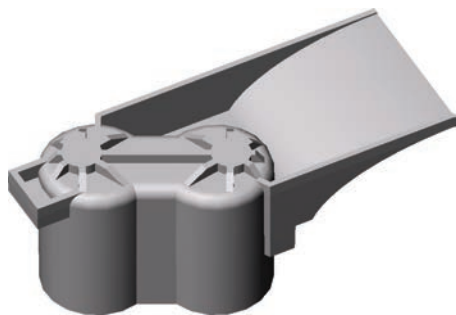
The fillet at the top of the magnet holder provided the location for the parting line—the line where the two halves of the mold would come apart and release the part. Albin added a parting plane and used the built-in **Draft** option to add taper to the part so it would come out of the mold. After selecting all the surfaces below the parting plane, he specified a draft angle, and SolidWorks adjusted all the surfaces. This feature of SolidWorks makes it easy to add the draft angle after a part is finished. When draft is added, the geometry of the part becomes more complex and harder to work with. A cylinder with draft added becomes a truncated cone, for example, and the angles at which its edges intersect other edges vary along its length.

The next step was to add the bosses at the top of the magnet chambers that would support the bolts controlling the depth of the magnets. As it was a design goal to make the top of the chamber as stiff as possible to limit flex caused by the attraction of the magnets to the flywheel, the bosses were placed as far apart as possible, and ribs were added for rigidity. The bosses were sketched as circles on the top surface of the magnet holder with their centers concentric with the holes in the bar connecting the magnets below. Both bosses were extruded up in the same operation.



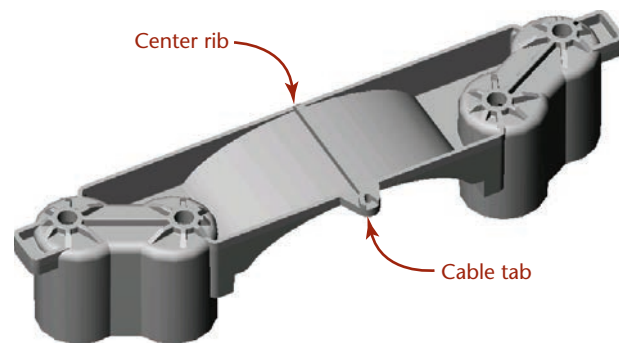
4.88 Bosses and Ribs. *Sketched circles were extruded to form the bosses on the top of the magnet chamber. The dotted lines shown here on the top of the chamber pass through the center point of the bosses and were used to locate the center rib and radial ribs.*

Ribs in SolidWorks are built-in features. To create a rib, you simply draw a line and specify a width, and SolidWorks creates the rib and ends it at the first surface it encounters. To create the center rib, Albini sketched a line on the plane at the top of the bosses and specified a width (ribs on a plastic part are usually two thirds of the thickness of the walls). The rib was formed down to the top surface of the holder lid. For the ribs around the bosses, Albini did as Obi Wan Kenobi might have advised: “Use the symmetry, Luke.” He sketched the lines for ribs radially from the center points of the bosses (see Figure 4.88). To create the ribs, Albini created four of them on one boss, then mirrored them once to complete the set for one boss, then mirrored all the ribs from one boss to the other boss. Once all the ribs were formed, he cut the tops off the ribs and bosses to achieve the shape shown in Figure 4.89.



4.89 *This view of the magnet carrier shows the symmetry of the ribs and the shape that resulted from “slicing off” the top of the bosses after the ribs were formed.*

The result was a stiffer rib and a shape that could not be achieved with a single rib operation. To complete the part, circles were drawn concentric to the bosses and extruded to form holes that go through the part (see Figure 4.90). Draft was added to the ribs and walls to make the part release from the mold easily. Fillets were added to round all the edges, reducing stresses and eliminating hot spots in the mold. Then, the part was mirrored to create the other half. The center rib and tab for attaching the cable were added and more edges filleted. Draft was added to the inside of the holder, and the part was complete.



4.90 *Circles concentric with the bosses were extruded to form the holes before the part was mirrored and remaining features added to finish the magnet carrier.*

DEFINING DRAWING GEOMETRY

2D CAD programs may allow drawing geometry to be controlled through *constraints* or *parametric* definitions. AutoCAD is one software platform that now provides this tool. In AutoCAD, constraints are associations that can be applied to 2D geometry to restrict how the drawing behaves when a change is made.

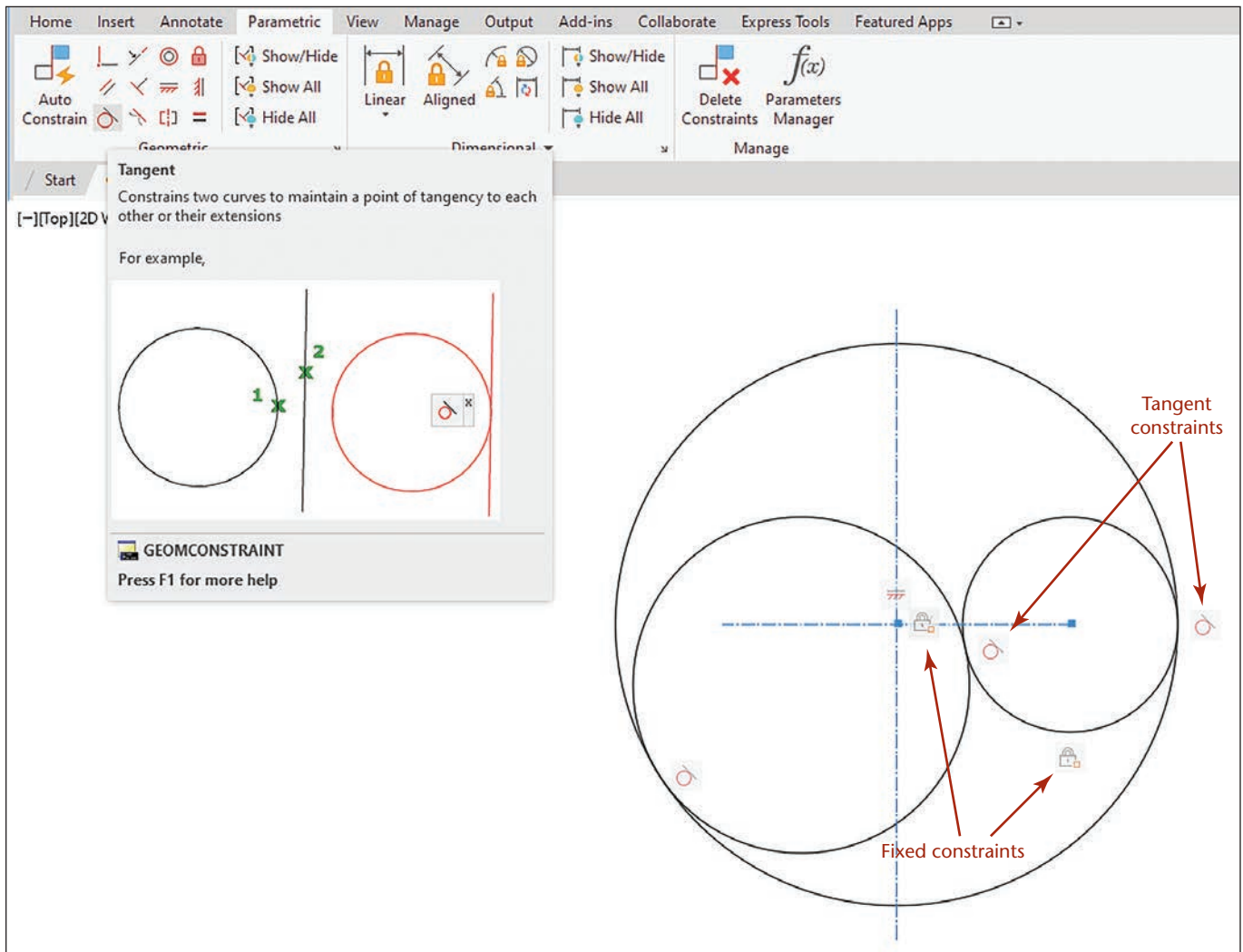
Constraints are of two types:

- *Geometric constraints* create geometric relationships between drawing objects, such as requiring that a circle remain tangent to a line, even when its radius is updated.
- *Dimensional constraints* define distances, angles, and radii for drawing objects. These dimensional constraints typically can also be defined by equations, making them a powerful tool.

Usually, it is best to define the geometric constraints first and then apply dimensional constraints. This way the essential geometry of the shape is defined, and the dimensions can be changed as the size requirements vary.

Figure A shows an AutoCAD drawing that uses fixed and tangent constraints. The fixed constraint allows you to force a drawing object to stay in a permanent location on the coordinate system. The tangent constraint defines a relationship between two drawing objects, such as circles, arcs, and lines.

Understanding geometric relationships is a key skill for creating drawings that use parametric constraints. When geometric constraints are applied awkwardly or when the software does not provide a robust tool for constraining the shape, it can be difficult to get good results when updating drawings.



(A) AutoCAD provides tools for defining geometric and dimensional constraints to control drawing geometry. (Autodesk screen shots reprinted courtesy of Autodesk, Inc.)

KEY WORDS

Absolute Coordinate System	Parallel
Absolute Coordinates	Perpendicular
Angle	Piecewise
Apparent Intersection	Polar Coordinates
Bezier Curve	Primitives
B-Spline	Radius
Cubic Spline	Relative Coordinates
Cylindrical Coordinates	Revolution
Default Coordinate System	Right-Hand Rule
Diameter	Spherical Coordinates
Extrusion	Spline
Focus of an Ellipse	Sweeping
Freeform	Symmetrical
Interpolated Spline	Transformations
Local Coordinate System	Translation
Mirrored	User Coordinate System
NURBS Curve	World Coordinate System

CHAPTER SUMMARY

- Understanding how to produce accurate geometry is required for technical drawings whether constructed by hand or using a CAD system.
- All drawings are made up of points, lines, arcs, circles, and other basic elements in relation to each other. Whether you are drawing manually or using CAD, the techniques are based on the relationships between basic geometric elements.
- CAD systems often produce the same result as a complicated hand construction technique in a single step. A good understanding of drawing geometry helps you produce quick and accurate CAD drawings as well as manual drawings.

SKILLS SUMMARY

You should be able to convert and interpret different coordinate formats used to describe point locations and be familiar with some of the basic geometry useful in creating CAD drawings. You should also be able to identify and sketch primitive shapes joined by Boolean operations. In addition, you should be able to visualize and sketch revolved and extruded shapes.

WORKSHEETS

Use the following worksheet at the end of the book to practice skills for this chapter:

- Worksheet 18

REVIEW QUESTIONS

1. What tools are useful for drawing straight lines?
2. What tools are used for drawing arcs and circles?
3. How many ways can an arc be tangent to one line? To two lines? To a line and an arc? To two arcs? Draw examples of each.
4. Draw an approximate ellipse with a major diameter of 6" and a minor diameter of 3". Draw a second approximate ellipse with a major diameter of 200 mm and a minor diameter of 100 mm.
5. Give one example of a construction technique for CAD that requires a good understanding of drawing geometry.
6. What is typical accuracy for manually created drawings?
7. What accuracies may be possible using a CAD system?
8. Sketch some objects that you use or would design that have right-hand and left-hand parts, such as a pair of in-line skates or side-mounted stereo computer speakers.
9. In solid modeling, simple 3D shapes are often used to create more complex objects. These are called primitives. Using an isometric grid, draw seven primitives.
10. What is a Boolean operation? Define two Boolean operations by sketching an example of each in isometric view.
11. Consider primitives and Boolean operations that could be used to create a "rough" model of each of the items shown below. Using the photos as underlays, sketch primitives that could be used to create items a–d.

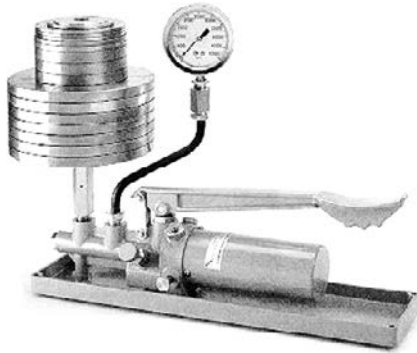
- a. Handlebar-mount gun rack



- b. ACME Corporation reduction gear



c. Ashcroft Model 1305D deadweight pressure tester



d. Davis Instruments solar-powered digital thermometer



12. Use nothing but solid primitives to create a model of a steam locomotive. Sketch the shapes and note the Boolean operations that would be used to union, difference, or intersect them, or create the model using Boolean operations with your modeling software. Use at least one box, sphere, cylinder, cone, torus, wedge, and pyramid in your design.

CHAPTER EXERCISES

Exercise 4.1 Draw inclined line AB 65 mm long. Bisect it with line CD .

Exercise 4.2 Draw any angle. Label its vertex C . Bisect the angle and transfer half the angle to place its vertex at arbitrary point D .

Exercise 4.3 Draw an inclined line EF . Use distance GH equal to 42 mm. Draw a new line parallel to EF and distance GH away.

Exercise 4.4 Draw line JK 95 mm long. Draw a second line LM 58 mm long. Divide JK into five equal parts. Use a different method than you selected to divide line JK to divide line LM into three equal parts.

Exercise 4.5 Draw line OP 92 mm long. Divide it into three proportional parts with the ratio 3:5:9.

Exercise 4.6 Draw a line 87 mm long. Divide it into parts proportional to the square of x , where $x = 1, 2, 3$, and 4.

Exercise 4.7 Draw a triangle with the sides 76 mm, 85 mm, and 65 mm. Bisect the three interior angles. The bisectors should meet at a point. Draw a circle inscribed in the triangle, with the point where the bisectors meet as its center.

Exercise 4.8 Draw a right triangle that has a hypotenuse of 65 mm and one leg 40 mm. Draw a circle through the three vertices.

Exercise 4.9 Draw inclined line QR 84 mm long. Mark point P on the line 32 mm from Q . Draw a line perpendicular to QR at point P . Select any point S 45.5 mm from line QR . Draw a line perpendicular from S to line QR .

Exercise 4.10 Draw two lines forming an angle of 35.5° .

Exercise 4.11 Draw two lines forming an angle of 33.16° .

Exercise 4.12 Draw an equilateral triangle with sides of 63.5 mm. Bisect the interior angles. Draw a circle inscribed in the triangle.

Exercise 4.13 Draw an inclined line TJ 55 mm long. Using line TJ as one of the sides, construct a square.

Exercise 4.14 Create a 54-mm-diameter circle. Inscribe a square in the circle, and circumscribe a square around the circle.

Exercise 4.15 Create a 65-mm-diameter circle. Find the vertices of an inscribed regular pentagon. Join these vertices to form a five-pointed star.

Exercise 4.16 Create a 65-mm-diameter circle. Inscribe a hexagon, and circumscribe a hexagon.

Exercise 4.17 Create a square with 63.5 mm sides. Inscribe an octagon.

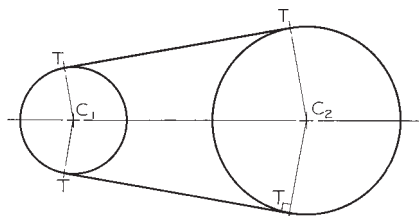
Exercise 4.18 Draw a triangle with sides 50 mm, 38 mm, and 73 mm. Copy the triangle to a new location and rotate it 180° .

Exercise 4.19 Make a rectangle 88 mm wide and 61 mm high. Scale copies of this rectangle, first to 70 mm wide and then to 58 mm wide.

Exercise 4.20 Draw three points spaced apart randomly. Create a circle through the three points.

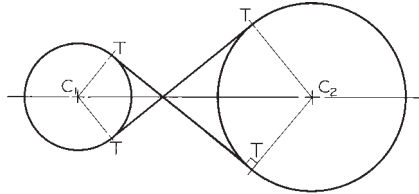
Exercise 4.21 Draw a 58-mm-diameter circle. From any point S on the left side of the circle, draw a line tangent to the circle at point S . Create a point T , to the right of the circle and 50 mm from its center. Draw two tangents to the circle from point T .

Exercise 4.22 Open-Belt Tangents. Draw a horizontal centerline near the center of the drawing area. On this centerline, draw two circles spaced 54 mm apart, one with a diameter of 50 mm, the other with a diameter of 38 mm. Draw “open-belt”-style tangents to the circles.



Open belt

Exercise 4.23 Crossed-Belt Tangents. Use the same instructions as Exercise 4.22, but for “crossed-belt”-style tangents.



Crossed belt

Exercise 4.24 Draw a vertical line VW . Mark point P 44 mm to the right of line VW . Draw a 56-mm-diameter circle through point P and tangent to line VW .

Exercise 4.25 Draw a vertical line XY . Mark point P 44 mm to the right of line XY . Mark point Q on line XY and 50 mm from P . Draw a circle through P and tangent to XY at point Q .

Exercise 4.26 Draw a 64-mm-diameter circle with center C . Create point P to the lower right and 60 mm from C . Draw a 25-mm-radius arc through P and tangent to the circle.

Exercise 4.27 Draw intersecting vertical and horizontal lines, each 65 mm long. Draw a 38-mm-radius arc tangent to the two lines.

Exercise 4.28 Draw a horizontal line. Create a point on the line. Through this point, draw a line upward to the right at 60° from horizontal. Draw 35-mm-radius arcs in an obtuse and an acute angle tangent to the two lines.

Exercise 4.29 Draw two intersecting lines to form a 60° angle. Create point P on one line a distance of 45 mm from

the intersection. Draw an arc tangent to both lines with one point of tangency at P .

Exercise 4.30 Draw a vertical line AB . In the lower right of the drawing, create a 42-mm-radius arc with its center 75 mm to the right of the line. Draw a 25-mm-radius arc tangent to the first arc and to line AB .

Exercise 4.31 With centers 86 mm apart, draw arcs of radii 44 mm and 24 mm. Draw a 32-mm-radius arc tangent to the two arcs.

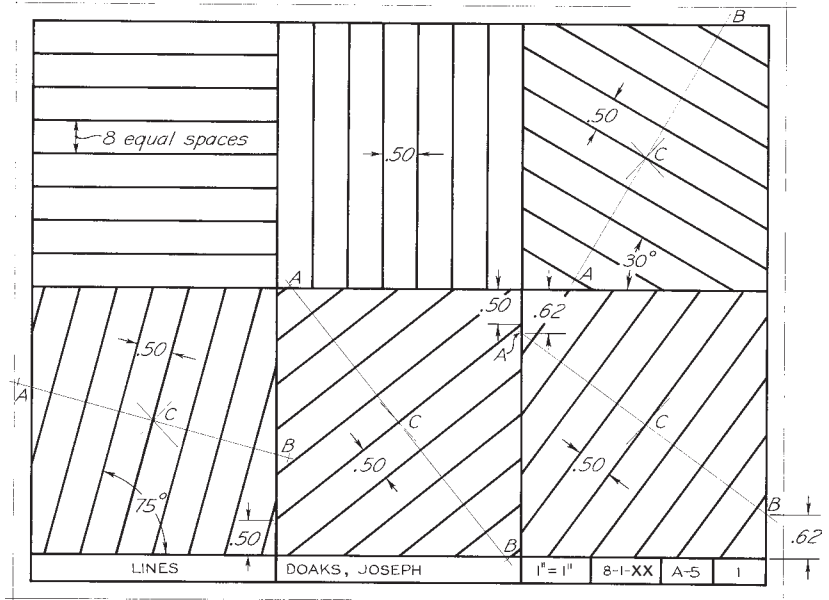
Exercise 4.32 Draw a horizontal centerline near the center of the drawing area. On this centerline, draw two circles spaced 54 mm apart, one with a diameter of 50 mm, the other with a diameter of 38 mm. Draw a 50-mm-radius arc tangent to the circles and enclosing only the smaller one.

Exercise 4.33 Draw two parallel inclined lines 45 mm apart. Mark a point on each line. Connect the two points with an ogee curve tangent to the two parallel lines. (An ogee curve is a curve tangent to both lines.)

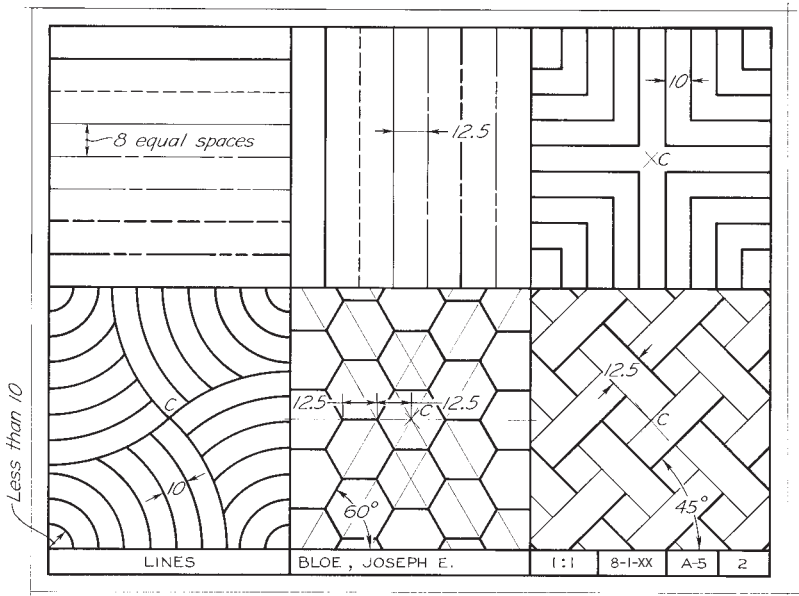
Exercise 4.34 Draw a 54-mm-radius arc that subtends an angle of 90° . Find the length of the arc.

Exercise 4.35 Draw a horizontal major axis 10 mm long and a minor axis 64 mm long to intersect near the center of the drawing space. Draw an ellipse using these axes.

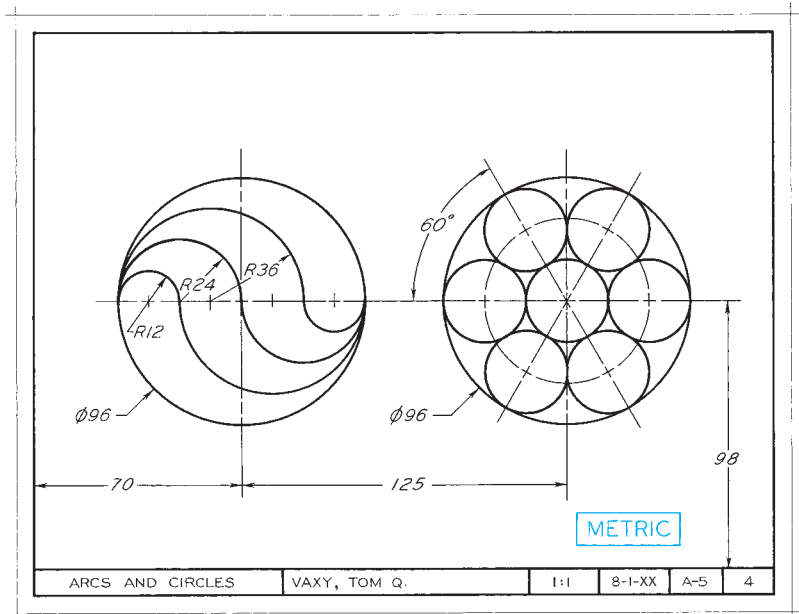
Exercise 4.36 Create six equal rectangles and draw visible lines, as shown. Omit dimensions and instructional notes.



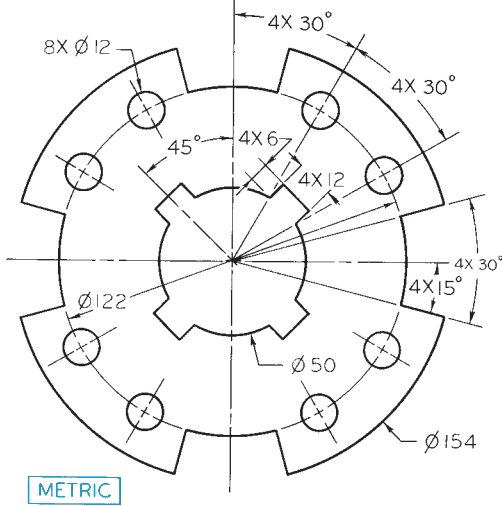
Exercise 4.37 Create six equal rectangles and draw lines as shown. In the first two spaces, draw examples of the standard line patterns used in technical drawings: visible, hidden, construction, centerlines, cutting-plane lines, and phantom. In the remaining spaces, locate centers *C* by diagonals, and then work constructions out from them. Omit the metric dimensions and instructional notes.



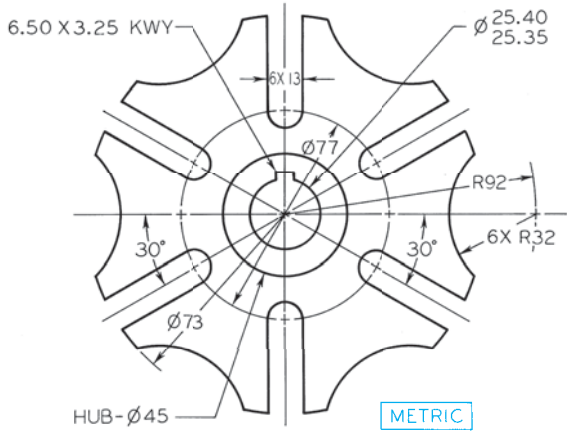
Exercise 4.38 Draw the figures as shown. Omit all dimensions.



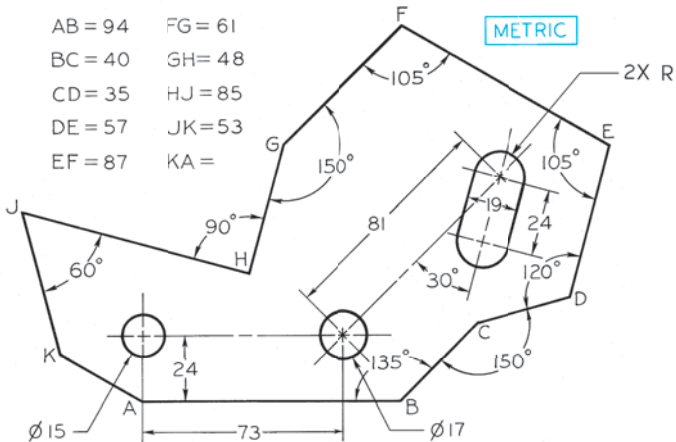
Exercise 4.39 Draw the friction plate. Omit dimensions and notes.



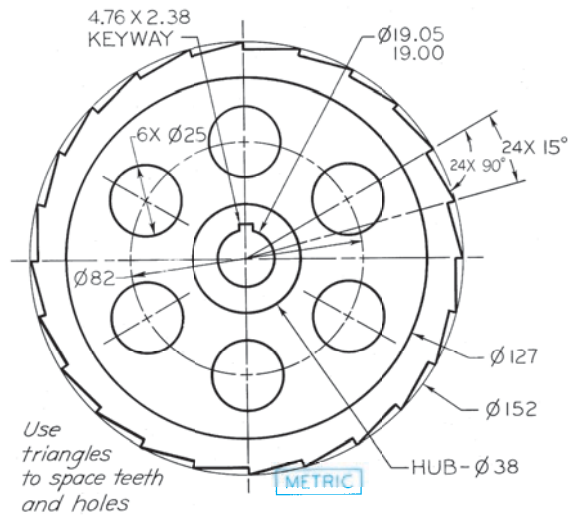
Exercise 4.40 Draw the Geneva cam. Omit dimensions and notes.



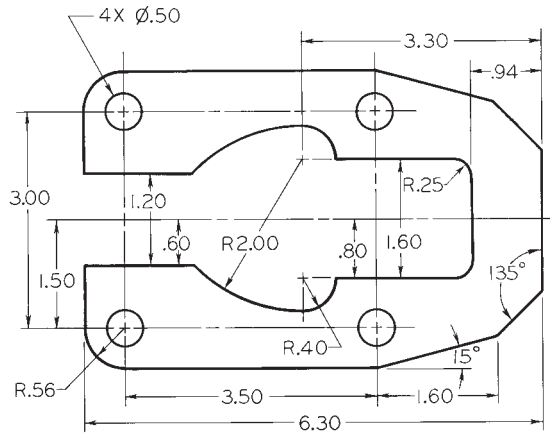
Exercise 4.41 Draw accurately in pencil the shear plate. Give the length of KA. Omit the other dimensions and notes.



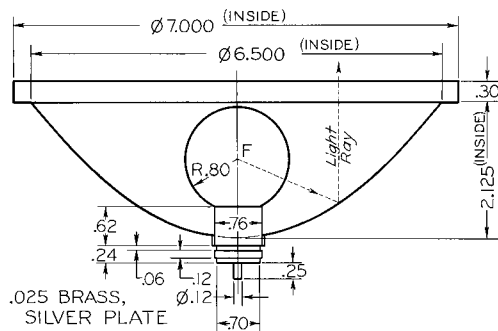
Exercise 4.42 Draw the ratchet wheel using pencil. Omit the dimensions and notes.



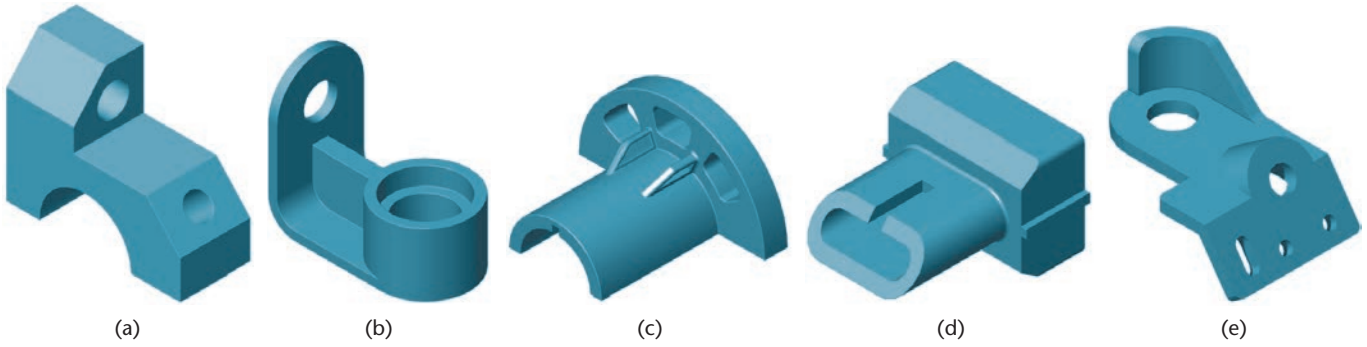
Exercise 4.43 Draw the latch plate using pencil. Omit the dimensions and notes.



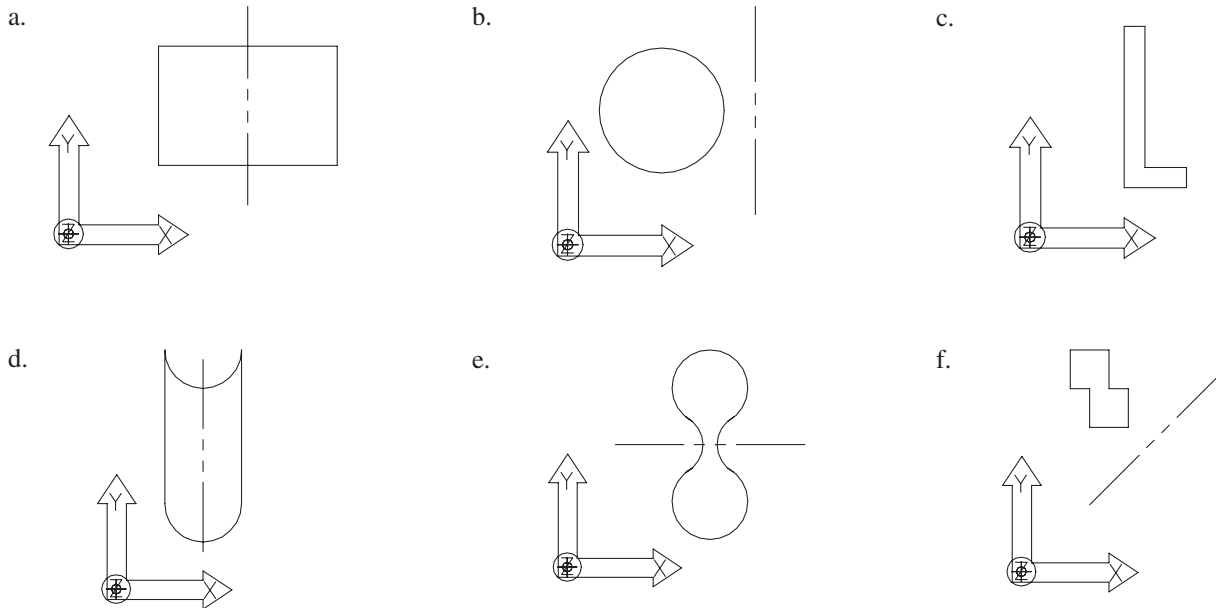
Exercise 4.44 Draw the parabolic floodlight reflector shown.



Exercise 4.45 Identify the solid primitives and Boolean operations you could use to create the following objects.

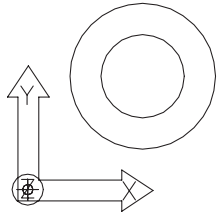


Exercise 4.46 Use an isometric grid to help sketch the solids formed by revolving the following shapes about the axis shown. Coordinates are defined by the X-Y-Z icon, with positive X to the right, positive Y up, and positive Z out of the page.

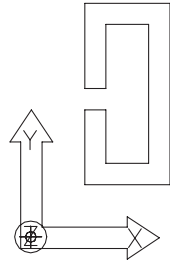


Exercise 4.47 Use an isometric grid to help sketch the solids formed by extruding the following shapes along the axis specified. Coordinates are defined by the X-Y-Z icon, with positive X to the right, positive Y up, and positive Z out of the page.

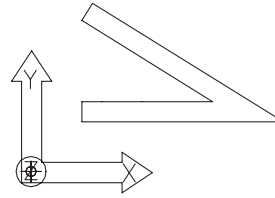
a. Extrude 6 inches in the positive Z-direction.



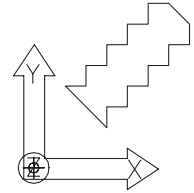
b. Extrude 4 inches in the positive Z-direction.



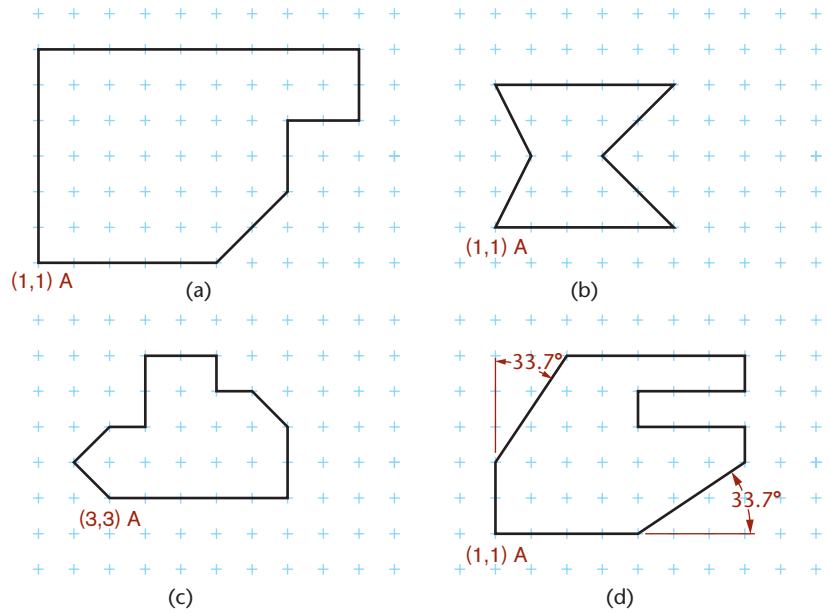
c. Extrude 6 inches in the positive Z-direction.



d. Extrude 4 inches in the positive Z-direction.



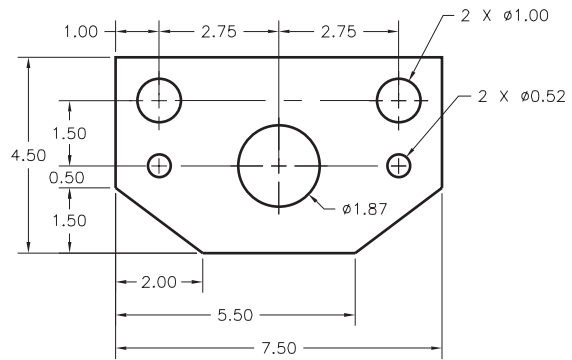
Exercise 4.48 Starting at point A in each of the figures, list the coordinates for each point in order as relative coordinates from the previous point.



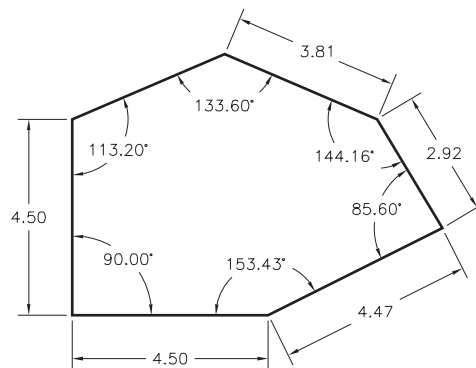
Exercise 4.49 Plot the coordinates in each of the lists on grid paper. Each point represents the endpoint of a line from the previous point, unless otherwise indicated. Relative coordinates are preceded by @.

- | | | | |
|------------|---------------|--------|-----------|
| a. X, Y | b. 0.00, 0.00 | c. 0,0 | d. 2,2 |
| 1.00, 1.00 | 3.00, 0.00 | @2<0 | @-1<0 |
| 4.00, 1.00 | 4.00, 1.00 | @3<30 | @3<90 |
| 4.00, 2.00 | 5.00, 0.00 | @3<-30 | @4<-30 |
| 6.00, 2.00 | 6.00, 1.00 | @2<0 | @3<30 |
| 6.00, 1.00 | 7.00, 0.00 | @4<90 | @1<0 |
| 8.00, 1.00 | 8.00, 1.00 | 0,4 | @3.24<230 |
| 8.00, 4.00 | 9.00, 0.00 | @4<-90 | @4<180 |
| 5.00, 4.00 | 10.00, 1.00 | | |
| 4.00, 5.00 | 10.00, 3.00 | | |
| 1.00, 5.00 | 9.00, 4.00 | | |
| 1.00, 1.00 | 8.00, 3.00 | | |
| | 7.00, 4.00 | | |
| | 6.00, 3.00 | | |
| | 5.00, 4.00 | | |
| | 4.00, 3.00 | | |

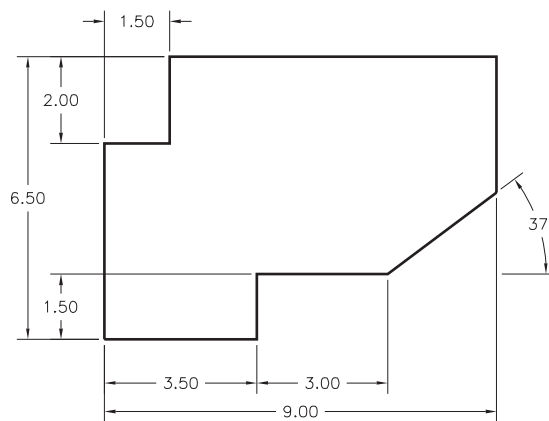
Exercise 4.50 Using the information provided on the drawing, determine the coordinates you would use (absolute, relative, or polar) and the order in which you would enter them to create the figure.



Exercise 4.51 Using the information provided on the drawing, determine the coordinates you would use (absolute, relative, or polar) and the order in which you would enter them to create the figure.



Exercise 4.52 Using the information provided on the drawing, determine the coordinates you would use (absolute, relative, or polar) and the order in which you would enter them to create the figure.



INDEX

- 2D CAD models, 176–177
 - 2D drawings. *See also* drawings.
 - aligned sections, 302
 - aligning views, 299–300
 - break lines, 297–298
 - common manufactured features, 286, 304
 - complex cylindrical shapes, 288
 - conventional breaks, 298–299
 - conventional edges, 295
 - conventions, 287
 - cylinders, 289–290
 - cylinders when sliced, 289
 - ellipses, 290
 - enlarged details, 298
 - fillets, 293–294
 - hole features, in orthographic views, 303
 - intersections, 287, 290–291
 - left-hand parts, 301–302
 - necessary views, 296–297
 - partial views, 297–298
 - plotting curves by hand, 289
 - portfolio, 305–306
 - removed views, 287, 299–301
 - revolution conventions, 302
 - revolved sectional views, 302
 - right-hand parts, 301–302
 - rounds, 293–294
 - runouts, 294
 - tangencies, 287, 290–291
 - tangent surfaces, hiding, 292
 - 2D models
 - constraint-based modeling, 178
 - paper drawings, 176
 - wireframe, 222
 - 3D CAD modeling
 - assembly drawings, example, 654–656
 - case study: exercise bike brake, 157–159
 - combining shapes. *See* solid primitives.
 - coordinates, 126–130
 - creating auxiliary views, 397
 - projections and, 83
 - vertices, 127
 - virtual prototypes, 181
 - VR (virtual reality), 181
 - 3D models
 - developing views from, 247–248
 - isometric projection, 83
 - physical models, 179–180
 - prototypes, 179–180
 - solid models, 190, 223
 - surface models, 184–189
 - types of, 182–183, 223
 - visualizing, 258
 - wireframe modeling, 182–183, 223
 - 3D printing, as prototyping tool, 479
 - 3D shapes, formulas for, A-6–A-7
 - 8-pitch thread, 598
 - 12-pitch thread, 598
 - 16-pitch thread, 598
 - 30° angles, estimating, 90
 - 45° miter line, 238, 259
- A**
- abbreviations, dimensioning, 537
 - Ability Fabricators, Inc., case study, 449–450
 - absolute coordinates, 128, 153
 - AC (adaptive control), 447
 - accessibility, checking fits, 433
 - accuracy
 - checking working drawings, 650
 - dimensional, 445–446
 - importance of, 70
 - isometric drawings, 94
 - surface models, 188
 - verifying, 455
 - working drawings, 650
 - Acme threads
 - detailed description, 607
 - fits, 605
 - forms, 596
 - notes, 605
 - specifications, A-29
 - actual local feature, 548
 - actual mating envelope, 549
 - actual minimal material envelope, 549
 - actual size, 548
 - adaptive control (AC), 447
 - adjacent views, 369
 - AI (artificial intelligence), 448
 - aircraft, assembling, 445–446
 - Albini, Marty, 157
 - align (coincident) constraint, 422
 - align offset, 422
 - aligned sections, 302, 343–345
 - Allen, Chris, 115
 - Allen key screw drivers, 619
 - allowance, 450, 548
 - alloys and their characteristics, 443
 - alternate views, 369
 - aluminum, as drawing medium, 49
 - American National screw threads, A-25–A-27
 - American National Standard cap screws, 618
 - American National Standard Drafting Manual - Y14*, 16
 - American National Standard pipe thread, 610–611
 - American National Standard Unified screw threads, A-25–A-27
 - American National Standards Institute (ANSI) standards, 16
 - bolts, 614–615, A-30 to A-32
 - cap screws, 618, A-33 to A-34
 - clearance locational fits, A-10–A-11
 - cotter pins, A-44
 - dimensions, 520–521, 538
 - force and shrink fits, A-14–A-15
 - locational interference fits, A-13
 - machine screws, A-35–A-36
 - metric hole basis clearance fits, A-17–A-18
 - metric hole basis transition and interference fits, A-21–A-22
 - metric shaft basis clearance fits, A-21–A-22
 - metric shaft basis transition and interference fits, A-23–A-24
 - nuts, 614–615, A-30–A-32
 - rivets, 623–624
 - running and sliding fits, A-8–A-9
 - screw threads, 598–599, 604–605, A-25
 - sheets, 49
 - slotted and socket head cap screws, 618, A-33–A-34
 - springs, 625
 - taper pins, A-43
 - tolerance, 560, 566
 - transition locational fits, A-12
 - twist drill sizes, A-28
 - washers, A-40 to A-41
 - wood screws, 621
 - Woodruff keys, A-38
 - American National thread, 594, 596
 - American National thread fits, 599
 - American Society for Engineering Education (ASEE), 16
 - analysis stage, design process, 5, 11–12
 - analytical models, 174–175
 - analyzing complex objects, 66–67
 - angle of thread, 595
 - angles
 - bisecting, 137
 - dihedral, 384

- angles, *continued*
 dimensioning, 517
 implied right, 550
 isometric drawings, 90
 oblique projection, 101
 sketching techniques, 70
 tolerance, 575
 views of, 253
- angles, laying out
 chord method, 138
 sine method, 138
 tangent method, 138
- angular perspective. *See* two-point perspective.
- angular tolerance, 558
- angularity, specifying, 578–579
- annotation scaling, 54
- ANSI (American National Standards Institute), 16
- ANSI B4.1 Preferred Limits for Fits for Cylindrical Parts*, 560
- ANSI B4.2* standard, 562
- ANSI/ASME Y14.5* standard, 565–567
- apparent intersection, 145
- appearance, manufacturing materials, 445
- approval block, 51
- approximated curves, 142, 144
- Archimedes, history of the screw principle, 595
- architects' scale, 39
- arcs
 bisecting manually, 134
 defining, 132–133
 delta angles, 133
 dimensioning, 517
 drawing tangents to, 135–136
 formulas for, 132–133
 included angles, 133
 isometric, 95
 sketching, 76–77, 95
- arrowheads, dimensioning, 508
- artificial intelligence (AI), 448
- ASCII file formats, 456–457
- ASEE (American Society for Engineering Education), 16
- ASME Y14.41 Digital Product Definition Data Practices*, 540
- ASME Y14.43* standard, 569
- ASME/ANSI Y14.6 Screw Thread Representation*, 598, 604
- ASME Y14.5* standard, 580
- assemblies
 constraint-based modeling, 217–218
 DFA (design for assembly), 416
 simulation, 429
 sketching techniques, 103
- assemblies, and design
 assembling to a skeleton, 425–426
 bottom-up design, 424, 449–450
 constraint-based drawing elements, 428–429
 global parameters, 427–428
 layout drawings, 425
 middle-out design, 424
 overview, 424
 seed parts, 428–429
 top-down design, 424, 449–450
- assemblies, checking fits
 accessibility, 433
 ergonomics, 433
 interference, 432–433
- assembly constraints, 421–422
- assembly drawings
 3D CAD, example, 654–656
 assembly sections, 640, 645–646
 check assemblies, 647
 dimensions, 640
 exploded views, 639–640
 hidden lines, 640
 installation assemblies, 647
 outline assemblies, 647
 overview, 639–640
 poche, 645
 section lining, 645
 views, 639
 working drawings, 638
- assembly files, managing, 423
- assembly mode, constraint-based modeling, 216
- assembly models
 constraint-based assemblies, 419
 dynamic assemblies, 418, 421
 parent parts, choosing, 420
 static assemblies, 418
 subassemblies, 418
- assembly parts
 fastener libraries, 431
 standard parts, 430–431, 646
- assembly sections, 346, 640, 645–646
- associativity, constraint-based modeling, 218
- AutoCAD
 2D CAD models, 176–177
 2D constraints, 178
 annotation scaling, 54
 constraint defaults, changing, 201
 constraints, 136, 160
 geometric construction geometry, 136
 isometric drawings, 97
 mass properties, 455
 object snap, 129, 134, 137
 perspective views, 111
 scaling text, 54
- automated assembly, 447
- automated materials handling, 447
- auxiliary plane, 364
- auxiliary sections, 376
- auxiliary views
 adjacent views, 369
 alternate views, 369
 circles and ellipses, 372, 373
 classification of, 366
 creating with CAD, 373, 397
 depth, 366–367
 descriptive geometry, 378
 developments and intersections, 385–395
 front adjacent, 366
 half, 375
 height, 366–367
 hidden lines, 373
 partial, 375
 plotting curves manually, 374–375
 primary, 365
 projecting, 370–371
 purpose of, 364, 378
 reference planes, 369
 reverse construction, 375
 secondary, 368
 showing true size, 364, 372
 sketching, 371
 successive, 368
 third, 368
 top adjacent, 366
 visualizing as revolved drawing, 366
 width, 366–367
- auxiliary views, developments
 definition, 385
 equator, 395
 great circle, 394–395
 hems and joints, 390
 a hood and a flue, 392–393
 laying out a surface, 387
 meridian, 395
 a plane and a cone, 391–392
 a plane and a pyramid, 391
 a plane and a sphere, 394–395
 a plane and an oblique cylinder, 391
 a plane and an oblique prism, 390
 polyconic method for developing a sphere, 395
 polycylindrical method for developing a sphere, 395
 transition pieces, 393–394
 triangulation, 393
- auxiliary views, intersections
 a plane and a cylinder, 389
 a plane and a prism, 387–388
 principles of, 386
- axes, positioning in isometric drawings, 85
- axes method for sketching ellipses, 76
- axis of revolution, 395
- axis of screw, 595
- axonometric projection, 32, 82–83
- axonometric sketches, 81
- B**
- BA (bend allowance), 536
- ball tags, 642–643
- balloon numbers, 642–643
- Baron-Taltre, Jacob, 109
- barreled parts, tolerance, 549
- Barrett Technology, 219–221
- BarrettHand, 219–221
- base features, 205–206
- base points, setting, 204–205
- baseline dimensioning, 531, 559
- basic angle tolerancing method, 575
- basic dimension symbols, 567
- basic hole system, 554–555, 563

- basic shaft system, 554–555, 563
 - basic size, metric tolerances, 562
 - batter, 517
 - bend allowance, 450, 536
 - Bezier, Pierre, 143
 - Bezier curves, 143–144
 - bidirectional associativity, constraint-based modeling, 218
 - bilateral system of tolerances, 558
 - bilateral tolerance, 548
 - bill of material (BOM), 642, 644–645
 - bird's-eye view, 107
 - bisecting
 - angles, 137
 - arcs, 134
 - lines, 74, 134
 - blind holes, 213
 - blind rivets, 624
 - blocking, freehand, 73
 - blocking irregular objects, sketching techniques, 78
 - bolts and nuts
 - bolt lengths, 615
 - clearance holes, 613
 - definition, 613
 - drawing standard bolts, 615
 - finish, 614
 - hex head bolt grades, 617
 - lock nuts, 617
 - overview of bolts, 614
 - proportions, 614
 - SAE grades, 617
 - sketching, 616
 - specifications, A-30–A-32
 - thread lengths, 614
 - threads, 614
 - bolts and nuts, lock nuts and locking devices
 - cotter pins, 617, A-44
 - lock washers, 617, A-41
 - overview, 617
 - set screws, 617, 620
 - BOM (bill of material), 642, 644–645
 - Boole, George, 147
 - Boolean operations, 147–148
 - border blocking, 73
 - borders, 50
 - boss, 214, 286
 - bottom views, 234–235
 - bottom-up design, 424, 449–450
 - bowed parts, tolerance, 549
 - box construction
 - isometric drawings, 86
 - oblique drawings, 101
 - box primitive, 146
 - bracket method for dual dimensioning, 512
 - brake press, 438
 - break lines, 297–298
 - breaks, in 2D drawings, 298–299
 - BREP (boundary representation), 184
 - Briggs, Robert, 610
 - Briggs standard threads, 610–611
 - broken out sections, 338
 - B-splines, 143–144
 - built-in features, 213
 - bushing, 214, 286
 - butress thread, 597
- C**
- C (centralizing) thread fits, 605
 - cabinet projection, 99
 - CAD (computer-aided design). *See also* 3D CAD modeling: AutoCAD.
 - advantages of, 47
 - creating auxiliary views, 373
 - database, 540
 - definition, 7
 - lettering examples, 40
 - model space, 48
 - paper space, 48
 - in product development, 6–7
 - CAE (computer-aided engineering), 7
 - calibration and inspection of tolerances, 555
 - CAM (computer-aided manufacturing), 7, 458
 - cap screws
 - American National Standard, 618
 - sketching, 616
 - specifications, A-30–A-32
 - CAPP (computer-aided process planning), 447
 - case studies
 - Ability Fabricators, Inc., 449–450
 - bicycle frame, 653
 - brake assembly, 465–467
 - coffee brewer, 418, 421
 - exercise bike brake, 157–159
 - floating bridge, 191–192
 - furniture design, 109
 - graphics and design process, Santa Cruz Bicycles, 8–15
 - heart model, 186
 - modeling sheet metal parts, 449–450
 - Oral-B toothbrush design, 112–115
 - patent application, 653
 - robot hand, 219–221
 - Santa Cruz Bicycles, 8–15
 - sheet metal modeling, 449–450
 - sketching techniques, 109, 112–115
 - Smart Tourniquet, 224–227
 - surface modeling, 224–227
 - symmetry, 157–159
 - vibration analysis, Quantel USA, 481–482
 - Zuma coffee brewer, 418, 421
 - case studies, Santa Cruz Bicycles
 - analysis, 11–12
 - constraint-based modeling, 11
 - design intent, 11
 - design selection, 9–10, 12–13
 - development, 10–11
 - documentation, 14–15
 - ideation, 9
 - implementation, 3
 - mules, 10
 - parametric modeling, 11
 - problem identification, 8
 - prototypes, 10, 15
 - rapid prototyping, 15
 - refinement, 10–11
 - universal possibilities, 9
 - casting
 - design tips, 441–442
 - metal parts, 437
 - overview, 437
 - sand casting, 437, 448
 - cavalier projection, 99
 - cavities, 480
 - cellular manufacturing, 447–448
 - center of gravity, 453
 - centering words in title blocks, 45
 - centerline method
 - for four-center ellipses, 94
 - for sketching circles, 75
 - centerlines
 - dimensioning, 506
 - isometric drawings, 89
 - uses for, 244, 246
 - centralizing (C) thread fits, 605
 - centroid, 453
 - ceramic manufacturing materials, 443
 - cgs (centimeter-gram-second) system, 456
 - chained dimensions, 559
 - chamfers
 - definition, 214, 286, 524
 - dimensioning, 524
 - checking assemblies, 647
 - chord method for laying out angles, 138
 - chordal dimensions, 523
 - circled numbers in drawings, 642–643
 - circles
 - in auxiliary views, 373
 - Circle command, 136
 - circumference, 132
 - defining, 132–133
 - description, 132
 - diameter, 132
 - drawing tangents to, 135
 - formulas for, 132–133, A-2
 - great, 394–395
 - oblique, 98, 100
 - radius, 132
 - circles, sketching
 - centerline method, 75
 - enclosing square method, 75
 - freehand compass, 75
 - paper method, 75
 - in perspectives, 107
 - circularity (roundness), tolerances, 576
 - circumference, 132
 - Class 1 thread fits, 599
 - Class 2 thread fits, 599
 - Class 3 thread fits, 599
 - clearances
 - fits, 551, A-10, A-17
 - holes, 612–613
 - CLIP (continuous liquid interface production), 477
 - close running fits, A-8
 - close sliding fits, A-8

- CMM (coordinate measuring machine), 16
- CNC (computer numerical control), 447
- coarse threads, 598
- coffee brewer, case study, 418, 421
- coincident (align) constraint, 422
- combination screw drivers, 619
- combination units, dimensioning, 513
- combined tolerance symbols, 567
- combining surfaces, 187
- comma-delimited text format, 457
- common manufactured features, 286, 304
- company name, in title blocks, 51
- complex cylindrical shapes, in 2D drawings, 288
- complex surfaces, 187, 216
- composite materials, 443
- compression springs, 625
- computer graphics, sketching techniques, 108
- computer numerical control (CNC), 447
- computer-aided design (CAD). *See* CAD.
- computer-aided engineering (CAE), 7
- computer-aided manufacturing (CAM), 7, 458
- computer-aided process planning (CAPP), 447
- computer-integrated manufacturing
 - AC (adaptive control), 447
 - AI (artificial intelligence), 448
 - automated assembly, 447
 - automated materials handling, 447
 - CAPP (computer-aided process planning), 447
 - cellular manufacturing, 447–448
 - CNC (computer numerical control), 447
 - expert systems, 448
 - FMS (flexible manufacturing systems), 448
 - GT (group technology), 447
 - industrial robots, 447
 - JIT (just-in-time) production, 447
- concentric (insert) constraint, 422
- concentricity tolerance, 579–580
- concurrent design process, 6
- concurrent engineering, 6
- cones
 - definition, 65
 - developments, 391–392
 - dimensioning, 522
 - examples, 65
 - formulas for, A-6
 - primitive, 146
- conic sections, 386
- constraining
 - degrees of freedom, 570
 - sketches, 110
- constraint-based modeling
 - 2D models, 178
 - advantages of, 191
 - assemblies, 217–218, 419
 - case studies, 11, 157–159, 191–192, 219–221
 - cosmetic dimensions, 195
 - definition, 178
 - design intent, 197–198, 219–221
 - drawing elements, 428–429
 - driven dimensions, 194, 195
 - driving dimensions, 194
 - feature dimensions, 194
 - feature-based modeling, 196–197
 - formulas in dimensions, 194–195
 - global parameters, 195
 - parameters, 193
 - reference dimensions, 195
 - variables, 193
- constraint-based modeling, features
 - adding, 206
 - base features, 205–206
 - built-in, 213
 - datums, 209–211
 - editing, 212
 - existing, specifying an edge for, 206
 - hole properties, 213
 - parent-child relationships, 207–209
 - placed, 213
 - standard, 213
- constraint-based modeling, software for
 - applying constraints, 203
 - base points, setting, 204–205
 - constraint defaults, changing, 201
 - constraint relationships, table of, 202
 - design intent, 197–198
 - overconstrained sketches, 203
 - sketch constraints, 199–202
 - underconstrained sketches, 203
- constraint-based modeling modes
 - assembly mode, 216
 - associativity, 218
 - bidirectional associativity, 218
 - drawing mode, 216
 - drawings from the model, 218–221
 - part mode, 216
 - subassemblies, 216
- constraints
 - applying, 203
 - base points, setting, 204–205
 - AutoCAD, 160
 - defaults, changing, 201
 - design intent, 197–198
 - geometric, 193
 - overconstrained sketches, 203
 - sketch constraints, 110, 199–202
 - underconstrained sketches, 203
 - relationships, table of, 202
 - size, 193
 - SolidWorks, 202
 - types of, 193
- construction drawings. *See* working drawings.
- construction lines, 36, 66
- continuous dimensioning, 559
- continuous liquid interface production (CLIP), 477
- contours, sketching techniques, 67
- conventions for 2D drawings, 287
 - breaks, 298–299, 346
 - edges, 295
- Coon's patch, 187
- coordinate dimensions, 531, 533
- coordinate measuring machine (CMM), 16
- coordinate systems
 - for 3D CAD modeling, 126–130, 153
 - invention of, 127
 - left-hand rule, 126
 - local, 153
 - origins (point of intersection), 127
 - right-hand rule, 126
 - specifying location, 126, 129–130
 - user-created, 153–154
 - world, 153
 - X- and Y-axes, 127
- coordinates
 - absolute, 128
 - cylindrical, 129
 - definition, 127
 - polar, 128
 - relative, 128
 - spherical, 129
- cores, 480
- corner views, 250. *See also* vertices.
- corners, rounding on plastic parts, 436
- cosmetic dimensions, 195
- cost estimates, modeling, 461–462
- cotter pins, 617, A-44
- counterbored holes
 - definition, 213–214, 286
 - dimensioning, 521
- countersunk holes, 213, 286, 521
- creativity techniques
 - examining manufactured products, 16
 - following engineering design websites, 16
 - forming teams, 17
 - functional decomposition, 16
 - researching patent drawings, 17
 - reverse engineering existing products, 16
 - studying the natural world, 16
- crest (of thread), 595
- cross section. *See* section views.
- cubes, formulas for, A-6
- cubic splines, 142
- curved surfaces, dimensioning, 523
- curves
 - dimensioning, 522
 - freeform. *See* spline curves.
 - isometric drawings, 91
 - perspectives, 107
 - plotting by hand in 2D drawings, 289
- cutaway views. *See* section views.
- cutting planes
 - choosing, 331
 - description, 328
 - direction, visualizing, 334
 - half sections, 337
 - labeling, 332
- cutting-plane lines
 - definition, 328
 - illustration, 329
 - line style, 334

- cylinder primitive, 146
- cylinders
 - in 2D drawings, 290
 - complex shapes in 2D drawings, 288
 - definition, 65
 - elements of, 65
 - examples, 65
 - formulas for, A-7
 - intersection with a plane, 389
 - isometric drawings, 95
 - size dimensioning, 518–519
 - sliced, 289
- cylindrical coordinates, 129
- cylindricity tolerance, 576, 577

- D**
- da Vinci, Leonardo, 17, 595
- DAI (Design Activity Identification), in title
 - blocks, 51
- databases, 7
- datum
 - description, 209–211
 - identifying, 567
 - targets, 570
 - tolerance symbols, 567, A-45
- datum features, 568–571
 - versus* datum feature simulator, 569, 571
- datum planes, 209–211
- datum reference frame, 569
- datum targets, 570
- daylight polymer printing (DPP), 477
- decimal dimension values, rounding, 512
- decimal-inch values, dimensioning, 511
- default coordinate system, 153
- Define, Measure, Analyze, Improve, and Control (DMAIC), 7
- degrees of freedom, constraining, 570
- delta angles, 133
- depth
 - auxiliary views, 366–367
 - thread, 595
 - in orthographic views, 235
- depth dimensions, transferring, 238
- derived surfaces, 187
- Descartes, René, 127
- descriptive geometry, 177, 378
- descriptive models, 173
- Design Activity Identification (DAI), in title
 - blocks, 51
- design for assembly (DFA), 416
- design for manufacture (DFM), 416
- Design for Six Sigma (DFSS), 7
- design intent
 - capturing, 219–221
 - case study: Santa Cruz Bicycles, 11
 - constraint-based modeling, 197–198
 - planning for, 197–198
- design process
 - case study: Santa Cruz bicycles, 8–15
 - concurrent, 6
 - critical design review, 12
 - definition, 5
 - design intent, 11
 - life cycle design, 6
 - in a portfolio, 18–19
 - stages of, 5–6, 8–15
 - designing quality into products, 7
 - detail drawings, 638, 640–641
 - detailed thread drawings, 600–601, 603
 - developable surfaces, 386
 - development of a surface, 385
 - developments
 - definition, 385
 - equator, 395
 - generatrix, 385
 - great circle, 394–395
 - hems and joints, 390
 - hood and flue, 392–393
 - hyperboloids, 385
 - intersections, 385–389
 - laying out a surface, 387
 - meridian, 395
 - plane and a cone, 391–392
 - plane and a pyramid, 391
 - plane and a sphere, 394–395
 - plane and an oblique cylinder, 391
 - plane and an oblique prism, 390
 - polyconic method, 395
 - polycylindric method, 395
 - surface types, 385
 - transition pieces, 393–394
 - triangulation, 393
 - deviation, metric tolerances, 562
 - DFA (design for assembly), 416
 - DFM (design for manufacture), 416
 - DFSS (Design for Six Sigma), 7
 - diameter, 132
 - difference (subtract) operation, 147–148
 - digital databases, 7
 - digital product definition, 581–584
 - digitizing, surface models, 187
 - dihedral angles, 384
 - dimension lines, 506, 508
 - dimension values, rules for, 512
 - dimensional accuracy, 445–446
 - dimensional constraints, 160
 - dimensioning
 - abbreviations, 537
 - angles, 517
 - arcs, 517
 - arrowheads, 508
 - BA (bend allowance), 536
 - centerlines, 506
 - chamfers, 524
 - choosing dimensions, 505
 - cones, 522
 - coordinate, 533
 - counterbores, 521
 - curved surfaces, 523
 - curves, 522
 - cylinders, 518–519
 - direction of values and notes, 510
 - dos and don'ts, 538–539
 - drawing scale, indicating, 509
 - extension lines, 506, 508
 - fillets, 517
 - finish marks, 526
 - general notes, 536
 - geometric breakdown, 506–507
 - holes, 519–520
 - IML (inside mold line), 536
 - isometric drawings, 86
 - keyways, 525
 - knurls, 525
 - lay symbols, 529
 - leaders, 509
 - legibility, 510, 514–515
 - lines used in, 506
 - local notes, 536–537
 - mold line, 536
 - neutral axis, 536
 - for numerically-controlled machining, 534
 - OML (outside mold line), 536
 - overview, 504–506
 - placing dimensions, 505, 514–515
 - portfolio, 541–542
 - prisms, 518
 - pyramids, 522
 - roughness values, 528
 - rounded-end shapes, 523
 - rounds, 517
 - shaft centers, 525
 - sheet metal bends, 536
 - spotfaces, 521
 - standards, 538
 - stretchout, 536
 - supplementary notes, 536–537
 - surface roughness, 526–527
 - surface texture symbols, 527–528, 529
 - symbols, 513, 520–521
 - tabular, 534
 - tapers, 524
 - technique, 505
 - in terms of material removal, 515
 - threads, 524
 - tolerance, 505
 - triangular prisms, 522
 - units, 510–512
 - waviness values, 528
 - dimensioning units
 - bracket method, dual dimensioning, 512
 - combination units, 513
 - decimal-inch values, 511
 - dimension values, rules for, 512
 - dual dimensioning, 512
 - millimeter values, 510–511
 - overview, 510
 - position method, dual dimensioning, 512
 - rounding decimal dimension values, 512
 - unidirectional dimensioning, 512
 - dimensions
 - assembly drawings, 640
 - baseline, 531
 - chordal, 523
 - coordinate, 531
 - forging, 535
 - holes about a common center, 530–531
 - location, 506, 530–531

- dimensions, *continued*
 - machine, 535
 - mating, 532
 - pattern, 535
 - size, 506–507
 - superfluous, 516
 - units of measure, 505
 - dimetric projection, 83
 - direct light processing (DLP), 477
 - digital light synthesis (DLS), 477
 - Dividers Method for drawing
 - pentagons, 140
 - dividing lines equally or proportionally, 74
 - DLP (direct light processing), 477
 - DLS (digital light synthesis), 477
 - DMAIC (Define, Measure, Analyze, Improve, and Control), 7
 - documentation
 - design process, 5
 - purpose of technical drawing, 4
 - dos and don'ts, dimensioning, 538–539
 - double-curved surfaces, 64, 385
 - double-square screw drivers, 619
 - doughnut-shaped solids. *See* tori.
 - downloading, fasteners, 628
 - downstream applications. *See* modeling, downstream applications.
 - DPP (daylight polymer printing), 477
 - draft, plastic parts, 434, 436
 - drafting standards. *See* standards.
 - Drawing Exchange Format (DXF), 458
 - drawing media, 49
 - drawing mode, constraint-based modeling, 216
 - drawing number, in title blocks, 51
 - drawing pencils, 45–46
 - drawing scales, 37–39, 74
 - dividing lines equally or proportionally, 74
 - laying out a scale drawing, 38
 - drawings. *See also* 2D drawings; sketching.
 - ball tags, 642–643
 - balloon numbers, 642–643
 - BOM (bill of material), 642, 644–645
 - circled numbers, 642–643
 - detail, 640–641
 - identification, 642–643
 - of individual parts, 640–641
 - laying out, 246
 - multidetail, 643
 - part, 640–641
 - piece part, 640–641
 - reading, 255
 - sheet metal, 448, 483, 484
 - size, in title blocks, 51
 - standard bolts, 615
 - subassemblies, 642
 - title, in title blocks, 51
 - welding, 448, 484
 - drawings, assembly
 - 3D CAD, example, 654–656
 - assembly sections, 640, 645–646
 - checking assemblies, 647
 - dimensions, 640
 - exploded views, 639–640
 - filling sectioned areas, 645
 - hatching sectioned areas, 645
 - hidden lines, 640
 - installation assemblies, 647
 - outline assemblies, 647
 - overview, 639–640
 - poche, 645
 - views, 639
 - working drawing assembly, 638, 646–647
 - drawings, lines. *See also* lines.
 - definition, 34
 - freehand technique, 34, 36
 - types of, 34–35
 - drawings, scale. *See also* scale.
 - architect's scale, 39
 - definition, 37
 - indicating, 509
 - laying out a drawing, 38
 - specifying on a drawing, 37
 - driven dimensions, 194, 195
 - driving dimensions, 194
 - dual dimensioning, 512
 - Dview, AutoCAD command, 111
 - DXF (Drawing Exchange Format), 458
 - dynamic assemblies, 418, 421
- E**
- ECOs (engineering change orders), 7
 - edges
 - in 2D drawings, 295
 - sketching techniques, 69
 - in views, 250–252
 - editing
 - features, 212
 - surface models, 188
 - EDM (enterprise data management), 7
 - egg-shaped solids. *See* ellipsoids.
 - 8-pitch thread, 598
 - eight-point method for sketching ellipses, 92
 - ejector pins, plastic parts, 434–435
 - elasticity, 464
 - elements
 - cylinders, 65
 - standard layouts, 50–51
 - surface, 385
 - ellipses
 - in 2D drawings, 290
 - approximating perimeter of, 141
 - in auxiliary views, 373
 - double-curved surface, 385
 - drawing, 141
 - ellipsoids, 65, 385
 - formulas for, A-5
 - locating the foci of, 141
 - orienting in isometric drawings, 93
 - pencil and string method for drawing, 141
 - sketching, 76
 - ellipsoids, 65, 385
 - elliptical cylinder, formulas for, A-7
 - embryo heart model, 186
 - enclosing square method for sketching circles, 75
 - enclosing-rectangle method for four-center ellipses, 94
 - engineering change orders (ECOs), 7
 - engineering design Web sites, as design aids, 16
 - engineers' drawing scale, 37
 - enlarging shapes with a grid of squares, 78
 - enterprise data management (EDM), 7
 - equation solvers, 460
 - equator, 395
 - erasers, 46
 - ergonomics, 433, 470–471
 - essential shapes, 66
 - examining manufactured products, as design aid, 16
 - expert systems, 448
 - exploded views, assembly drawings, 639–640
 - export formats, 457–459
 - extension lines, 506, 508
 - extension springs, 625–626
 - external square thread, 608
 - external threads
 - defined, 595
 - dimensioning, 524
 - forms, 596–597
 - notes, 604–605
 - symbols, 606
 - extruded forms, 151
 - extruded surfaces, 184–185
 - extrusion, definition, 151
- F**
- factor of safety, 451
 - fasteners
 - downloading, 628
 - overview, 594, 621
 - portfolio, 629–630
 - FDM (fused deposition modeling), 478
 - FEA (finite element analysis), 174, 190, 463–467
 - feather keys, 622
 - features. *See also* constraint-based modeling, features.
 - datum, 568–571
 - definition, 196
 - first created. *See* base feature.
 - size designation, 548
 - tolerance, 548
 - feature control frame, 566
 - feature dimensions, 194
 - feature of size, 548
 - feature-based modeling, 196–197. *See also* constraint-based modeling.
 - ferrous metals, manufacturing materials, 443
 - field rivets, 624
 - file formats, 456–457
 - fillets
 - in 2D drawings, 293–294
 - definition, 214, 286

- description, 215
 - dimensioning, 517
 - example, 214–215, 286
 - shading, 293
 - filling sectioned areas, assembly drawings, 645
 - fillister head cap screws, 618
 - fine thread, 598
 - finish, bolts, 614
 - finish marks, dimensioning, 526
 - finishing operations, 448
 - finite element analysis (FEA), 174, 190, 463–467
 - finite elements, 463
 - first-angle projection, 240–241, 242–243
 - fit. *See also* tolerance.
 - allowance, 548–549, 551
 - assemblies. *See* assemblies, checking fits.
 - case study, 583
 - clearance locational, A-10–A-11
 - force and shrink, A-14–A-15
 - interference, 551, 554–555, A-13, A-19
 - line, 552
 - locational interference, A-13
 - mating parts, 551
 - metric hole basis clearance, A-17–A-18
 - metric hole basis transition and interference, A-19–A-20
 - metric shaft basis clearance, A-21–A-22
 - metric shaft basis transition and interference, A-23–A-24
 - metric system, 562–563
 - running and sliding, A-8–A-9
 - specifying, 552
 - study, 583
 - thread, 599–600
 - transition locational, 552, A-12
 - types and subtypes, 560
 - fit, threads
 - Acme thread notes, 605
 - American National thread fits, 599
 - C (centralizing), 605
 - definition and classes, 599
 - G (general purpose), 605
 - metric, 600
 - unified, 600
 - flag notes, 537
 - flanges, 214, 286
 - flat head cap screws, 618
 - flat keys, 622, A-37
 - flat patterns. *See also* developments.
 - definition, 385
 - modeling sheet metal parts, 438–439
 - flat springs, 625–626
 - flatness, tolerance, 576
 - flip constraint, 422
 - floating bridge, case study, 191–192
 - FMS (flexible manufacturing systems), 448
 - foci of an ellipse, locating, 141
 - folding lines, 237, 364
 - fonts (lettering), 40
 - force fits, A14–A15
 - foreshortening, 83
 - forging, 448, 535
 - form tolerance
 - for single features, 576–577
 - tolerance symbols, 566–568
 - variations, 549
 - forming metal, principal methods, 448
 - formulas
 - circles and arcs, 132
 - in dimensions, 194–195
 - for geometric entities, A-2–A-7
 - operators, table of, 195
 - formulas for
 - 3D shapes, A-6–A-7
 - circles, A-2
 - cones, A-6
 - cubes, A-6
 - cylinders, A-7
 - ellipses, A-5
 - elliptical cylinder, A-7
 - four-sided polygons, A-4
 - frustum of a cylinder, A-7
 - geometric entities, A-2–A-7
 - operators, table of, 195
 - parabolas, A-5
 - prisms, A-7
 - pyramids, A-6
 - rectangular prisms, A-6
 - regular polygons, A-5
 - triangles, A-4
 - 45° miter line, 238, 259
 - four-center ellipses, sketching, 93–94
 - fps (foot-pound-second) system, 456
 - fractions, lettering, 43
 - freeform curves. *See* spline curves.
 - freehand compass, 75
 - freehand sketching
 - arcs, 77
 - blocking in borders, 71
 - construction lines, 36
 - ellipses, 76
 - finding the midpoint on a line, 71
 - lines, 34, 36, 71
 - long freehand lines, 73
 - front adjacent, 366
 - front orientation, 240
 - front views, 234–236
 - frontal plane projection, 236
 - frustum, 65, A-7
 - full sections
 - definition, 328–329
 - visualizing, 330–331
 - functional decomposition, as design aid, 16
 - fundamental deviation, metric tolerances, 562–563
 - fused deposition modeling (FDM), 478
- G**
- G (general purpose) notes for thread fits, 605
 - gage
 - line thickness, 34
 - thread pitch, 597
 - wire, standards, A-42
 - gage blocks, 555
 - gauge, sheet metal, 450
 - GDT (geometric dimensioning and tolerancing), 565–582, A-45–A-48
 - general notes, dimensioning, 536
 - general purpose (G) notes for thread fits, 605
 - generatrix, 385
 - Genesis space capsule crash, 70
 - geometric breakdown, dimensioning, 506–507
 - geometric characteristic symbols, 566, A-45
 - geometric constraints, 136, 160, 193
 - geometric constructions
 - angle layout, 138
 - arcs, 133
 - arcs tangent to arcs, 136
 - bisecting angles, 137
 - bisecting lines and circular arcs, 134
 - circles, 132–133,
 - conic sections, 386
 - ellipses, 141, 143–47
 - equilateral triangles, 139
 - geometric entities, 130–133
 - hexagons, 139
 - parallel lines, 137
 - pentagons, 140
 - polygons, 139–140
 - spline curves, 142–144
 - tangents with arcs, 135–136
 - tangents with circles, 135
 - triangles, 138, 139
 - geometric continuity, 215
 - geometric dimensioning and tolerancing (GDT), 565–582, A-45–A-48
 - geometric entities, formulas for, A-2–A-7
 - geometric method for drawing
 - pentagons, 140
 - geometric methods for plane figures, 78
 - geometric tolerances. *See* GDT (geometric dimensioning and tolerancing).
 - geometric transformations, 154
 - gib head keys, 622, A-37
 - glass box, 236–238
 - global parameters
 - assemblies and design, 427–428
 - definition, 195
 - grade (slope), 517
 - graphics exchange format, 457–458
 - great circle, 394–395
 - grid paper
 - sketching auxiliary views, 371
 - grids, W-97–W-105. *See also* work-sheets.
 - GT (group technology), 447
 - guidelines, for lettering, 40, 42
- H**
- half auxiliary views, 375
 - half sections, 337
 - haptic devices, 181

- hatching
 - description, 68
 - section lining, 335
 - sectioned areas, assembly drawings, 645
 - heart model, 186
 - height, in views, 235
 - height auxiliary views, 366–367
 - helical springs, 625–627
 - hems, 390, 439
 - hex head bolts
 - grades, 617
 - sketching, 616
 - hex screw drivers, 619
 - hexagon head cap screws, 618
 - hexagon socket cap screws, 618
 - hexagons
 - centerline variation, 140
 - drawing, 140
 - hexalobular screw drivers, 619
 - hidden lines
 - assembly drawings, 640
 - in auxiliary views, 373
 - correct and incorrect practices, 245
 - description, 243
 - intersecting, 243
 - isometric drawings, 89
 - techniques for drawing, 244
 - hole features, in orthographic views, 303
 - hole properties, 213
 - hole system
 - metric tolerances, 563
 - tolerances, 554–555
 - holes
 - blind, 213
 - counterbored, 213
 - countersunk, 213
 - locating about a common center, 530–531
 - size dimensioning, 519–520
 - spotface, 213
 - through, 213
 - hood and a flue, developing, 392–393
 - horizon line, 107
 - horizontal plane projection, 236
 - human factors, 433, 470–471
 - HumanCAD software models, 471
 - hyperboloids, double-curved surface, 385
- I**
- ideation, design process, 5
 - case study: Santa Cruz Bicycles, 9
 - universal possibilities, 9
 - identifying drawings, 642–643
 - IGES (Initial Graphics Exchange Specification), 458
 - IML (inside mold line), dimensioning, 536
 - implementation, design process, 3, 5
 - implied right angles, tolerances, 550
 - inch-pound-second (ips) system, 456
 - inclined edges, in views, 252
 - inclined (italic) fonts, 40–42
 - inclined surfaces
 - isometric drawings, 89
 - in views, 250–251
 - included angles, 133
 - industrial robots, 447
 - injection-molding, plastic parts, 434, 436
 - insert (concentric) constraint, 422
 - installation assemblies, assembly drawings, 647
 - integrated modeling and design, 472–473
 - interference, checking fits, 432–433
 - Interference Detection command, 583
 - interference fit
 - locational, A-13
 - metric tolerances, 563
 - preferred metric hole basis, A-19–A-20
 - preferred metric shaft basis, A-23–A-24
 - tolerances, 551, 554–555
 - internal square thread, 608
 - internal thread, 595
 - internal thread symbols, 606
 - international drafting standards, 16
 - International Organization for Standards (ISO), 16
 - international tolerance grade (IT), 562
 - international tolerance grades, A-16
 - interpolated patches, 187
 - interpolated splines, 142, 144
 - interpolating polynomials, 467
 - interpreting
 - lines, 253
 - points, 253
 - views, 254
 - intersecting hidden lines, 243
 - intersection operation, 147–148
 - intersections
 - in 2D drawings, 287, 290–291
 - apparent intersection, 145
 - definition, 145, 385
 - plane and a cylinder, 389
 - plane and a prism, 387–388
 - principles of, 386
 - in sections, 346
 - investment casting, 480
 - ips (inch-pound-second) system, 456
 - irregular objects, isometric drawings, 91
 - irregular surfaces, 152
 - ISO (International Organization for Standards), 16
 - isometric axes, 84
 - isometric drawings
 - 30° angles, estimating, 90
 - angles, 90
 - arcs, 95
 - with AutoCAD software, 97
 - box construction, 86
 - centerlines, 89
 - curves, 91
 - cylinders, 95
 - definition, 85
 - dimensioning, 86
 - ellipses, 92–95
 - hidden lines, 89
 - inclined surfaces, 89
 - irregular objects, 91
 - nonisometric lines, 88
 - normal surfaces, 86–87
 - from an object, 96
 - oblique surfaces, 89
 - offset location measurements, 88
 - overview, 85
 - positioning the axes, 85
 - of rectangular objects, 86
 - screw threads, 95
 - spheres, 96
 - isometric ellipses
 - accuracy, 94
 - centerline method for four-center ellipses, 94
 - eight-point method, 92
 - enclosing-rectangle method for four-center ellipses, 94
 - four-center ellipses, 93–94
 - with nonisometric lines, 92
 - for oblique drawings, 100
 - orienting ellipses in isometric drawings, 93
 - Orth method for four-center ellipses, 94
 - random-line method, 92
 - with templates, 95
 - true ellipses, 92
 - isometric projection, 83–84
 - isometric scales, 84
 - isometric views, 249
 - IT (international tolerance grade), 562
 - italic (inclined) fonts, 40–42
- J**
- JIT (just-in-time) production, 447
 - Jo blocks, 555
 - join/add (union) operation, 147–148
 - joints
 - riveted, 623
 - sheet metal, 390
- K**
- kerned pairs of letters, 44
 - keys
 - feather, 622
 - flat, 622, A-37
 - gib head, 622, A-37
 - plain taper, A-37
 - Pratt & Whitney, 622, A-39
 - square, 622, A-37
 - Woodruff, 622, A-38
 - keyway/keyseat
 - definition, 214, 286
 - dimensioning, 525
 - example, 214, 286
 - K-factor, 450
 - knuckle thread, 597
 - knurls
 - definition, 214, 286
 - dimensioning, 525
- L**
- labeling cutting planes, 332
 - laminated object manufacturing (LOM), 478

- landscape orientation, 49
 - Larocque, Brandon, 219
 - lay symbols, 528–529
 - layers, 2D CAD models, 176
 - laying out a drawing, 38
 - layout drawings, assemblies, and design, 425
 - layouts
 - borders, 50
 - definition, 52
 - letter sizes, 50
 - margins, 50
 - planning, 52–53
 - portfolio, 55–56
 - title block, 51
 - zone numbers, 50
 - zones, 50
 - lead (of a screw thread), 595
 - lead grades for drawing pencils, 46
 - leaders, dimensioning, 509
 - least material condition (LMC), tolerance symbols, 567
 - left- and right-hand parts, 149, 301–302
 - left-hand rule of coordinate systems, 126
 - left-hand screw threads, 598
 - left-handed lettering, 45
 - left-side views, 234–235
 - legibility, dimensioning, 510, 514–515
 - length, in views, 235
 - letter sizes, on page layout, 50
 - lettering
 - CAD examples, 40
 - centering words in the title block, 45
 - consistent letter height, 40
 - definition, 34
 - fractions, 43
 - guidelines, 40, 42
 - by hand, 40
 - inclined (italic), 41–42
 - kerned pairs of letters, 44
 - for left-handers, 45
 - with a pencil, 45
 - spacing, 40, 44
 - stability, 44
 - standards, 40
 - template for, 42
 - for titles, 45
 - vertical, 41
 - lettering (fonts), 40
 - library of standard punches, 439
 - life cycle design, 6
 - life-cycle analysis, 473
 - limit dimensions, 552
 - limit tolerances, 557
 - line fit, 552
 - line gage, 34
 - line patterns, 72
 - lines
 - bisecting manually, 74, 134
 - break, 297
 - center. *See* centerlines.
 - description, 130
 - dividing equally or proportionally, 74
 - drawing through points, 137
 - folding, 237
 - freehand construction, 36
 - hidden. *See* hidden lines.
 - interpreting, 253
 - parallel. *See* parallel lines.
 - perpendicular. *See* perpendicular lines.
 - point view, 380
 - precedence, 244
 - sketching techniques, 69
 - specifying, 130
 - styles, 34–35
 - thick, 34
 - thin, 34
 - true length, in CAD, 378–379
 - used in dimensioning, 506
 - lines, cutting-plane
 - definition, 328
 - illustration, 329
 - line style, 334
 - lines, section views
 - behind the cutting plane, 328
 - general rules for, 333
 - lines, sketching
 - blocking, freehand, 73
 - border blocking, 73
 - calculating proportions, 74
 - dividing lines, 74
 - equal parts, 74
 - finding a midpoint, 73
 - line patterns, 72
 - lineweights, 72
 - long freehand lines, 73
 - parallel, exaggerating closely spaced, 74
 - proportional parts, 74
 - straight lines, 73
 - techniques for, 72
 - lines of sight. *See* projectors.
 - lineweights, 72
 - LMC (least material condition), tolerance symbols, 567
 - local coordinate systems, 153
 - local notes, dimensioning, 536–537
 - location, specifying with coordinate systems, 126, 129–130
 - location dimensions, 506, 530–531
 - lock nuts and locking devices
 - cotter pins, 617, A-44
 - lock washers, 617, A-41
 - overview, 617
 - set screws, 617, 620
 - lock washers, 617, A-41
 - lofting, 185–186
 - LOM (laminated object manufacturing), 478
 - long freehand lines, 73
 - lower deviation, metric tolerances, 562
 - lugs, 214, 286
 - LUNAR, 112–115
- M**
- machine dimensions, 535
 - machine pins, 622
 - machine screws, 613, A-35–A-36. *See also* cap screws.
 - machined parts, modeling, 437–438
 - machining parts, 448
 - machining processes, tolerances, 561
 - major diameter (of a screw thread), 595
 - manufacturing materials
 - alloys and their characteristics, 443
 - appearance, 445
 - ceramics, 443
 - composite materials, 443
 - ferrous metals, 443
 - materials assignment, 444
 - nanomaterials, 443
 - nonferrous metals, 443
 - plastics, 443
 - product failure, definition, 443
 - recycling, 445
 - service life, 445
 - manufacturing processes
 - assembling an aircraft, 445–446
 - brake press, 438
 - cast parts, 437, 441–442, 448
 - computer integrated. *See* computer-integrated manufacturing.
 - common production methods, 440
 - DFM (design for manufacture), 416
 - dimensional accuracy, 445–446
 - forging, 448
 - library of standard punches, 439
 - machined parts, modeling, 437–438
 - machining, 448
 - metal forming, principal methods, 448
 - molds, 437, 480
 - nanofabrication, 446
 - nanotechnology, 446
 - net-shape manufacturing, 446
 - permanent molds, 437
 - sand casting, 437, 448
 - shared manufacturing, 448
 - Standard for Aluminum Sand and Permanent Mold Castings*, 437
 - surface finish, 445–446
 - welding drawings, 448, 484
 - manufacturing processes, plastic parts
 - constant wall thickness, 436
 - draft, 434
 - draft angle, 436
 - drawings, portfolio, 483
 - ejector pins, 434–435
 - injection-molding characteristics, 434
 - injection-molding guidelines, 436
 - parting line, 434–435
 - projections, 436
 - rounding corners, 436
 - taper, 434
 - manufacturing processes, sheet metal
 - bend allowance, 450
 - case study: Ability Fabricators, Inc., 449–450
 - gauge, 450
 - hems, 439
 - K-factor, 450

manufacturing processes, sheet metal,
continued
 modeling, 438–440, 449–450
 sheet metal drawings, 448, 483, 484
 thickness, 450

margins, 50

mass, 452

mass density, 453

mass properties, determining. *See* modeling,
 determining mass properties.

master, creating, 480

mate constraint, 422

mate offset, 422

material files, 444

material jetting, as prototyping tool, 479

materials assignment, 444

mating dimensions, 532

maximum material condition (MMC),
 tolerance symbols, 567, 574–575

McLean, Stan, 449–450

McNeil, Laine, 481–482

measurement systems, definition, 34

measuring, from a reference surface, 238

media for drawing, 49

meridian, 395

meshes, 185, 463–464

metal forming, principal methods, 448

metal parts, casting, 437

metric fastener standard, 594

metric fits, tolerance symbols, 563

metric screw threads, A-25–A-27

metric system
 description, 36–37
 dual dimensioning systems, 36–37
 preferred scale ratios, 37
 unit conversion, 37

metric thread, 596

metric thread fits, 600

metric tolerances, 562–563

middle-out design, 424

midpoint of a line, finding, 73

millimeter values, dimensioning, 510–511

milling machines, tolerances, 561

minor diameter (of a screw thread), 595

mirrored shapes, 149

MMC (maximum material condition),
 tolerance symbols, 567, 574–575

model space, 48

modeling
 case study: brake assembly, 465–467
 case study: robot hand, 219–221
 case study: surface modeling, 224–227
 factors of safety, 451
 interpolating polynomials, 467
 machined parts, 437–438
 P-elements, interpolating, 467
 sheet metal parts, 438–440, 449–450
 sheet metal parts, case study, 449–450
 springs, 627
 threads, 610
 visible embryo heart model,
 example, 186

modeling, determining mass properties
 accuracy, verifying, 455
 calculations, 454–456
 center of gravity, 453
 centroid, 453
 cgs (centimeter-gram-second)
 system, 456
 fps (foot-pound-second) system, 456
 ips (inch-pound-second) system, 456
 mass, 452
 mass density, 453
 moment of inertia, 453
 overview, 451
 portfolio, 485
 pounds force, 456
 pounds mass, 456
 radii of gyration, 453
 right cylinder, 452
 SI (*Système International*), 456
 surface area, 452
 units and assumptions, 455–456
 volume, 452

modeling, downstream applications
 elasticity, 464
 equation solvers, 460
 FEA (finite element analysis), 463–467
 finite elements, 463
 going green, 473
 human factors, 470–471
 HumanCAD software models, 471
 integrated modeling and design, 472–473
 meshes, 463–464
 ROBOGUIDE software, 469–470
 simulation software, 468–470
 spreadsheets, 460
 virtual prototypes, 469
 what-if analysis, 460

modeling, exporting data from the database
 ASCII file formats, 456–457
 comma-delimited text format, 457
 common export formats, 457–459
 for cost estimates, 461–462
 DXF (Drawing Exchange Format), 458
 file formats, 456–457
 graphics exchange format, 457–458
 IGES (Initial Graphics Exchange
 Specification), 458
 native file formats, 456–457
 native formats, 459
 neutral formats, 459
 overview, 456
 space-delimited text format, 457
 STEP (Standard for the Exchange of
 Product model data), 458
 STL (STereo Lithography) format, 458
 tab-delimited text format, 457
 vector *versus* raster data, 459

modeling, for testing and refinement
 case study: testing vibration analysis,
 481–482
 overview, 451

models
 2D. *See* 2D models.

3D. *See* 3D models.
 choosing a method, 222–223
 creating, 256
 definition, 172
 machined parts, 437–438
 materials assignment, 444
 molded parts, 434–437
 qualities of, 175
 sheet metal parts, 438–440

models, types of
 analytical, 174–175
 comparison of characteristics, 222–223
 descriptive, 173
 FEA (finite element analysis) model,
 174, 190
 motion analysis, 175
 scale, example, 173
 solid, 190
 surface, 184–189
 constraint-based, 191–192

mold line, dimensioning, 536

molds
 casting metal parts, 437
 plastic parts, 434–436
 cavities and cores, 480
 permanent, 437

moment of inertia, 453

motion analysis, 175

Mountz, John, 19

mules, 10

multidetail drawings, 643

multiple threads, 599

multiview projections
 definition, 32
 description, 234
 illustration, 82

N

name, in title blocks, 51

nanofabrication, 446

nanomaterials, 443

nanotechnology, 446

NASA space capsule crash, 70

native file formats, 456–457, 459

necessary views, 239–240, 296–297

neck, 214, 286

negative space, 67

Neptune Seatech Oy, 191–192

net-shape manufacturing, 446

neutral axis, dimensioning, 536

neutral formats, 459

nominal size
 metric tolerances, 562
 tolerances, 548

nonferrous metals, 443

nonisometric lines
 isometric drawings, 88
 isometric projection, 84
 sketching ellipses, 92

normal edges, in views, 252

normal surfaces
 isometric drawings, 86–87
 in views, 250–251

- notes, dimensioning
 - direction of values and notes, 510
 - general notes, 536
 - local notes, 536–537
 - supplementary notes, 536–537
 - thread, 604–605
 - tolerance, 556
 - numbering, working drawings, 650
 - numerically-controlled machining, dimensioning, 534
 - NURBS (nonuniform rational B-spline) curves, 143
 - NURBS-based surfaces, 185–186, 188
 - nuts. *See* bolts and nuts.
- O**
- object snap feature
 - definition, 129
 - drawing parallel lines, 137
 - enabling, 134
 - locating drawing geometry, 134
 - oblique cylinder, development with a plane, 391
 - oblique drawings. *See* sketching techniques, oblique sketches.
 - oblique edges, in views, 252
 - oblique prism, development with a plane, 390
 - oblique projection
 - angles, 101
 - cabinet projection, 99
 - cavalier projection, 99
 - definition, 32
 - receding lines, 99
 - oblique projectors, 99
 - oblique surfaces
 - isometric drawings, 89
 - showing true size and shape, 382–383
 - in views, 250–251
 - Offset command, 137, 157–159
 - offset constraint, 422
 - offset measurements
 - creating irregular shapes, 78
 - isometric drawings, 88
 - offset sections, 342
 - OML (outside mold line), dimensioning, 536
 - one-point perspective, 105
 - one-view drawings, 79
 - opposite views, 239–240
 - orient (parallel) constraint, 422
 - origins (point of intersection), 127
 - Orr, Andrea, 115
 - Orth method for four-center ellipses, 94
 - orthographic, definition, 236
 - orthographic projection
 - axonometric projection, 82
 - centerlines, 244, 246
 - definition, 32, 236
 - hidden lines, 243, 244, 245
 - indicating symmetrical axes of objects. *See* centerlines.
 - laying out a drawing, 246
 - line precedence, 244
 - multiview projection, 82
 - versus* photographs, 243
 - portfolio, 260–261
 - outline assemblies, assembly drawings, 647
 - outside mold line (OML), dimensioning, 536
 - overconstrained sketches, 203
- P**
- paper
 - conservation, 648
 - for drawing and drafting, 49
 - landscape orientation, 49
 - for sketching, 49
 - standard sheet sizes, 49
 - paper drawings
 - 2D models, 176–177
 - versus* other models, 222–223
 - paper method for sketching circles, 75
 - paper space, 48
 - parabolas, formulas for, A-5
 - parallel (orient) constraint, 422
 - parallel edges, in views, 252
 - parallel lines
 - closely spaced, exaggerating, 74
 - definition, 145
 - drawing, 137
 - receding lines, 99
 - symbol for, 69
 - parallel perspective. *See* one-point perspective.
 - parallel projections, 32
 - parallelepiped, 65
 - parallelism tolerance, 578–579
 - parameters, 193
 - parametric modeling, 110 *See also* constraint-based modeling.
 - floating bridge example, 191–192
 - Santa Cruz Bicycles, 11
 - parent parts, choosing, 420
 - parent-child relationships, features, 207–209
 - part mode, constraint-based modeling, 216
 - partial auxiliary views, 375
 - partial sections, 341
 - partial views, 297–298, 345
 - parting line, plastic parts, 434–435
 - parting-line symmetry, 150
 - parts drawings, 640–641
 - parts list. *See* BOM (bill of material).
 - patches
 - Coon's, 187
 - interpolated, 187
 - surface, 187
 - patent applications, working drawings, 652
 - patent drawings, as design aids, 17
 - pattern dimensions, 535
 - PDM (product data management), 7
 - P-elements, interpolating, 467
 - pencil and string method for drawing ellipses, 141
 - pencils, for drawing. *See* drawing pencils.
 - pentagons, drawing, 140
 - Pentecost, Jeffrey, 186
 - perfect form envelope, 549
 - permanent molds, 437
 - perpendicular constraint, 422
 - perpendicular lines
 - definition, 145
 - symbol for, 69
 - perpendicularity tolerance, 578–579
 - perspective projections, 32
 - perspective sketches, 81
 - perspectives
 - angular. *See* two-point perspective.
 - in AutoCAD, 111
 - bird's-eye view, 107
 - circles, 107
 - curves, 107
 - horizon line, 107
 - one-point, 105
 - parallel. *See* one-point perspective.
 - pictorial sketching, 80–82
 - three-point, 105, 106
 - two-point, 105, 106
 - types of, 104–105. *See also* specific types.
 - vanishing point, 104
 - worm's-eye view, 107
 - phantom lines, 612
 - Phillips, Henry F., 619
 - Phillips screw drivers, 619
 - photographs *versus* orthographic projections, 243
 - physical datum feature simulators, 569
 - physical models
 - description, 179–180
 - versus* other models, 222–223
 - pictorial sketching, 80–82
 - piece part drawings, 640–641
 - piecewise splines, 143
 - piercing points, 32
 - pipe threads, 610–611
 - pitch diameter, 595
 - placed features, 213
 - placing, section views, 331–332
 - placing dimensions, 505, 514–515
 - plain taper keys, A-37
 - plan. *See* top view.
 - planar surfaces, 64
 - plane figures, geometric methods for sketching, 78
 - plane of projection, 32, 236
 - planes
 - angles between. *See* dihedral angles.
 - auxiliary, 364
 - cutting. *See* cutting planes.
 - defining, 131
 - definition, 131, 385
 - edge view, 381
 - intersecting with a prism, 387–388
 - intersection with a cylinder, 389
 - planes, developments with
 - a cone, 391–392
 - an oblique cylinder, 391
 - an oblique prism, 390
 - a pyramid, 391
 - a sphere, 394–395

- plastic parts, manufacturing. *See* manufacturing processes, plastic parts.
 - plastics, manufacturing materials, 443
 - plotting curves manually, in auxiliary views, 374–375
 - plus-or-minus tolerances, 558
 - poche, 645
 - points
 - description, 130
 - drawing arcs through, 135
 - drawing lines through, 137
 - interpreting, 253
 - sketching techniques, 69
 - specifying, 130
 - polar coordinates, 128
 - polyconic method for developing a sphere, 395
 - polycylindric method for developing a sphere, 395
 - polyester film, as drawing medium, 49
 - Polygon command, 139
 - polygons
 - drawing, 139
 - formulas for, A-3–A-5
 - rectangle method for sketching, 78
 - sketching techniques, 78
 - triangle method for sketching, 78
 - polyhedra, 64
 - pop rivets, 624
 - portfolios (examples)
 - 2D drawings, 305–306
 - determining mass properties, 485
 - dimensioning, 541–542
 - fasteners, 629–630
 - layouts, 55–56
 - molded plastic parts drawings, 483
 - orthographic projection, 260–261
 - section views, 348–349
 - sheet metal drawings, 483, 484
 - showing your design process, 18–19
 - threads, drawing, 629
 - tolerances, 584–586
 - welded assembly drawings, 484
 - welding drawings, 484
 - position, tolerance symbols, 566–568
 - position method for dual dimensioning, 512
 - positional tolerance, 572–574
 - pounds force, 456
 - pounds mass, 456
 - pozidriv screw drivers, 619
 - Pratt & Whitney keys, 622, A-39
 - preferred fits, metric tolerances, 564–565, A-17–A-24
 - preferred sizes, metric tolerances, 564
 - primary auxiliary view, 365
 - primary datum, 569
 - primary revolution, 396
 - primitives. *See* solid primitives.
 - principal dimensions, 235
 - principal views, 234–235
 - prisms
 - definition and examples, 65
 - formulas for, A-7
 - intersecting with a plane, 387–388
 - size dimensioning, 518
 - triangular, dimensioning, 522
 - truncated, 65
 - types of, 65
 - problem identification, design process
 - case study: Santa Cruz Bicycles, 8
 - definition, 5
 - product data management (PDM), 7
 - product definition, 18
 - product failure, 443
 - product life cycle, 6
 - profile plane projection, 236
 - profile tolerance, 576–577
 - projecting, 370–371
 - projection methods
 - first angle, 240–241, 242–243
 - frontal plane, 236
 - horizontal plane, 236
 - orthographic, 236
 - plane of projection, 236
 - profile plane, 236
 - projecting at right angles. *See* orthographic projection.
 - third angle, 240–242
 - projection symbols, 241
 - projections
 - cabinet, 99
 - cavalier, 99
 - definition, 233
 - length of receding lines, 99
 - multiview, 234
 - piercing points, 32
 - plane of projection, 32
 - plastic parts, 436
 - principal dimensions, 235
 - principal views, 234–235
 - projectors, 32
 - station point, 32
 - of a third view, 256–258
 - types of, 32–33
 - views of objects, 234
 - projectors
 - definition, 32
 - oblique, 99
 - perspective, 104
 - proportion
 - bolts, 614
 - definition, 77
 - sketching techniques, 77
 - prototype drawings. *See* seed parts.
 - prototypes
 - 3D models, 179–180
 - case study: Santa Cruz Bicycles, 10, 15
 - virtual prototypes, 469
 - prototypes, in the design process
 - case study: Santa Cruz bicycles, 10, 15
 - definition, 10
 - rapid prototyping, 15
 - prototyping
 - overview, 474
 - translating the model, 474–476
 - rapid prototypes, 476–479
 - virtual prototypes, 469
 - prototyping, RP (rapid prototyping)
 - 3D printing, 479
 - case study, 15
 - CLIP (continuous liquid interface production), 477
 - DLP (direct light processing), 477
 - DLS (digital light synthesis), 477
 - DPP (daylight polymer printing), 477
 - DMP (direct metal printing), 477
 - DMLS (direct metal laser sintering), 477
 - EBM (electron beam melting), 477
 - FDM (fused deposition modeling), 478
 - investment casting, 480
 - LOM (laminated object manufacturing), 478
 - master, creating, 480
 - material jetting, 479
 - overview, 474
 - rapid tooling, 480
 - SGC (solid ground curing), 476–477
 - SLA (stereolithography apparatus), 476
 - SLS (selective laser sintering), 477–478
 - systems for, 476–479
 - TSF (topographic shell fabrication), 478
 - pyramid primitive, 146
 - pyramids
 - definition and examples, 65
 - development with a plane, 391
 - dimensioning, 522
 - formulas for, A-6
- Q**
- QC (quality certify)
 - calibration and inspection, tolerance, 555
 - gage blocks, 555
 - Jo blocks, 555
 - tolerances, 548
 - QFD (Quality Function Deployment), 7
 - quality, 7
 - Quality Function Deployment (QFD), 7
 - Quantel USA, case study, 481–482
- R**
- radial leader line, 519–520
 - radii of gyration, 453
 - radius, 132
 - arcs, 517
 - dimension symbols, 513
 - isometric spheres, 96
 - radius method for sketching arcs, 76
 - random-line method for sketching ellipses, 92
 - rapid prototyping. *See* prototyping, RP (rapid prototyping).
 - rapid tooling, 480
 - raster *versus* vector data, 459
 - rational curves, 143
 - reading drawings, 255
 - rear views, 234–235
 - receding lines
 - angle, 98

- length, 99
 - oblique projection, 99
 - sketching techniques, 103
 - recess for a bolt head. *See* counterbore.
 - Rectangle command, 139
 - rectangle method for sketching ellipses, 76
 - rectangular objects, isometric drawings, 86
 - rectangular prisms, formulas for, A-6
 - recycling, manufacturing materials, 445
 - reference dimensions, 195, 559
 - reference planes, 369
 - reference surface, measuring from, 238
 - reference to a datum, tolerance symbols, 567
 - refinement
 - case study: Santa Cruz Bicycles, 10–11
 - definition, 5
 - and modeling, 172
 - regular polygons, formulas for, A-5
 - regular polyhedra, 64
 - regular views, 239–240
 - relative coordinates, 128
 - removed sections, section views, 340–342
 - removed views, 2D drawings, 287, 299–301
 - reverse construction, 375
 - reverse engineering
 - existing products, 16
 - surface models, 187
 - revision blocks, 51
 - revision numbers, working drawings, 650–651
 - revision tracking, in title blocks, 51
 - revolution conventions, 2D drawings, 302
 - revolutions
 - axis of, 395
 - creating revolved drawings, 395
 - definition, 395
 - primary, 396
 - successive, 396
 - true length of a line, 396
 - revolved sections
 - 2D drawings, 302
 - section views, 339–340
 - revolved shapes, 152
 - revolved surfaces, 184–185
 - revolving objects, to create views, 235
 - ribs in section, 343
 - right- and left-hand parts, 149, 301–302
 - right angles, implied, 550
 - right cylinder, determining mass
 - properties, 452
 - right-hand parts, 2D drawings, 301–302
 - right-hand rule of coordinate systems, 126
 - right-hand screw threads, 598
 - right-side views, 234–235
 - rivet symbols, 624
 - riveted joints, 623
 - rivets, 623–624
 - ROBOGUIDE software, 469–470
 - robot hand, case study, 219–221
 - robotic assembly, 447
 - robots, industrial, 447
 - Roman fonts, 40
 - root (of a screw thread), 595
 - rotation arrows, 340
 - rotation transformation, 154
 - rough sketches, 110
 - roughness values, dimensioning, 528–529
 - round head cap screws, 618
 - rounded-end shapes, dimensioning, 523
 - rounding
 - corners on plastic parts, 436
 - decimal dimension values, 512
 - roundness (circularity), tolerances, 576
 - rounds
 - 2D drawings, 293–294
 - definition, 214, 286
 - dimensioning, 517
 - example, 214–215, 286
 - shading, 293
 - RP (rapid prototyping). *See* prototyping, RP.
 - ruled surfaces, 385
 - running fits, A-8–A9
 - runouts, 294. *See also* fillets.
 - Ryschkewitsch, Michael, 70
- S**
- SAE (Society of Automotive Engineers), 16
 - SAE grades for bolts, 617
 - Salazar, Jeff, 112
 - sand casting, 437, 448
 - sans serif fonts, 40
 - Santa Cruz Bicycles. *See* case studies, Santa Cruz bicycles.
 - scale
 - definition, 34
 - of drawings, indicating, 509
 - measuring instrument. *See* scales.
 - in title blocks, 51
 - scale models, example, 173
 - scales, 37–39
 - scaling text, 54
 - scaling transformations, 154
 - schematic thread drawings, 600, 602–603, 611
 - screw drivers, types of, 619
 - screw principle, history of the, 595
 - screw threads. *See also* threads.
 - 8-pitch, 598
 - 12-pitch, 598
 - 16-pitch, 598
 - American National, A-25–A-27
 - definition, 595
 - isometric drawings, 95
 - metric, A-25–A-27
 - square, A-37
 - screw threads, Acme
 - detailed description, 607
 - forms, 596
 - notes, 605
 - specifications, A-29
 - screws
 - cap, 618
 - American National Standard, 618
 - fillister head screws, 618
 - flat head screws, 618
 - heads, 618–619, A-33–A-34
 - hexagon head screws, 618
 - hexagon socket screws, 618
 - machine, 619, A-35–A-36
 - miscellaneous, 621
 - round head screws, 618
 - set, 620
 - sketching, 475
 - slotted head screws, 618
 - thread. *See* threads.
 - wood, 621
 - secondary auxiliary view, 368
 - secondary datum, 569
 - section lining. *See also* section views.
 - in CAD, 337
 - correct and incorrect techniques, 335
 - definition and illustration, 328
 - hatching, 335
 - large areas, 336
 - symbols, 336
 - section views
 - aligned sections, 343–345
 - assembly sections, 346
 - auxiliary, 376
 - broken out sections, 338
 - CAD techniques for, 347
 - conventional breaks, 346
 - cutting-plane lines, 328–329, 334
 - cutting planes, 328, 334, 332
 - full sections, 328–329, 330
 - half sections, 337
 - intersections in sections, 346
 - lines behind the cutting plane, 328
 - line rules, 333
 - offset sections, 342
 - partial sections, 341
 - partial views, 345
 - placing, 331–332
 - portfolio, 348–349
 - purposes of, 328
 - removed sections, 340–342
 - revolved sections, 339–340
 - ribs in section, 343
 - rotation arrows, 340
 - section lining, 328
 - shortening objects. *See* conventional breaks.
 - of single parts, 328
 - security T screw drivers, 619
 - seed parts, 428–429
 - selective assembly, 552
 - selective laser sintering (SLS), 477–478
 - Sellers, William, 594
 - series of thread, 595, 598
 - serif fonts, 40
 - service life, manufacturing materials, 445
 - set screws
 - definition, 613
 - as locking device, 617
 - standard, 620
 - SGC (solid ground curing), 476–477
 - shading, sketching techniques, 68, 108
 - shaft centers, dimensioning, 525

- shafts
 - basic shaft system, 554–555, 563
 - shaft basis clearance fits, A-21–A-22
 - shaft basis transition and interference fits, A-23–A-24
 - metric tolerances, 563
 - tolerancing, 554
- shared manufacturing, 448
- sharp-V thread, 596
- sheet metal, manufacturing. *See* manufacturing processes, sheet metal.
- sheet metal bends, dimensioning
 - BA (bend allowance), 536
 - general notes, 536
 - IML (inside mold line), 536
 - local notes, 536–537
 - mold line, 536
 - neutral axis, 536
 - OML (outside mold line), 536
 - sheet metal bends, 536
 - stretchout, 536
 - supplementary notes, 536–537
- sheet metal parts, modeling, 438–440, 449–450
- sheet number, in title blocks, 51
- sheet revision block, 51
- sheet size, in title blocks, 51
- shop rivets, 624
- shortening identical features, 612
- showing an inclined elliptical surface in true size, 372
- showing true size, 364
- shrink fits, A14–A15
- SI (*Système International*), 456
- side of a screw thread, 595
- side views, 234–236
- simplified thread drawings, 600, 602–603, 611
- simplifying, working drawings, 651
- simulation software, 468–470
- sine method for laying out angles, 138
- single thread, 599
- single-curved surfaces, 64, 385
- single-limit dimensioning, 557
- single-view drawings. *See* one-view drawings.
- Six Sigma, 7
- 16-pitch thread, 598
- size constraints, 193
- size designation for tolerance, 548
- size dimensioning
 - cylinders, 518–519
 - holes, 519–520
 - prisms, 518
- skeleton
 - assembling to, 425–426
 - modeling, 210–211
- sketch constraints, 199–202
- sketching. *See also* drawings.
 - assemblies, 103
 - auxiliary views, 371
 - bolts and nuts, 616
 - cap screws, 616
 - circles, arcs, ellipses, 75–77
 - hex head bolts, 616
 - nuts, 616
 - pictorials, 80–82
 - perspectives, 104
 - plane figures, 78
 - straight lines, 73
 - thread, 603
- sketching techniques. *See also* isometric drawings, sketching.
 - accuracy, importance of, 70
 - analyzing complex objects, 66–67
 - angles, 70
 - arcs, 76
 - assemblies, 103
 - blocking irregular objects, 78
 - box construction, 86, 101
 - case study: Oral-B toothbrush, 112–115
 - circles, 75
 - with computer graphics, 108
 - constraining sketches, 110
 - construction lines, 66
 - contours, 67
 - edges, 69
 - ellipses, 76
 - enlarging shapes with a grid of squares, 78
 - essential shapes, 66
 - extruded shapes, 151
 - freehand, 71, 109
 - freehand compass, 75
 - geometric methods for plane figures, 78
 - hatching, 68
 - important skills, 70
 - irregular shapes using offset measurements, 78
 - lines, 69. *See also* lines, sketching.
 - maintaining proportions, 77
 - negative space, 67
 - one-view drawings, 79
 - parametric modeling, 110
 - points, 69
 - polygons, 78
 - receding lines, 103
 - rectangle method for sketching polygons, 78
 - rough sketches, 110
 - shading, 68, 108
 - stippling, 68
 - triangle method for sketching polygons, 78
 - vanishing point, 103
 - vertices, 69
 - viewpoint, 68
- sketching techniques, oblique sketches
 - angles, 101
 - angle of receding lines, 98
 - appearance of, 98
 - box construction, 101
 - choice of position, 100
 - choosing the front surface, 98
 - definition, 81, 98
 - ellipses for, 100
 - length of receding lines, 99
 - overview, 98
 - pictorial sketches, 80–82
 - projection methods, 82
 - skeleton construction, 102
- sketching techniques, perspectives
 - angular. *See* two-point perspective. in AutoCAD, 111
 - bird's-eye view, 107
 - circles, 107
 - curves, 107
 - horizon line, 107
 - one-point, 105
 - parallel. *See* one-point perspective.
 - pictorial sketching, 80–82
 - three-point, 105, 106
 - two-point, 105, 106
 - types of, 104–105. *See also* specific types.
 - worm's-eye view, 107
- sketching techniques, pictorial sketching. *See also* sketching techniques, oblique sketches.
 - axonometric sketches, 81
 - definition, 80
 - overview, 80–82
 - perspective sketches, 81
- sketching techniques, projection methods
 - for 3D CAD models, 83
 - axonometric, 82–83
 - dimetric, 83
 - foreshortening, 83
 - isometric, 83
 - multiview, 82
 - orthographic, 82
 - overview, 82
 - trimetric, 83
 - types of, 82. *See also* specific types.
- SLA (stereolithography apparatus), 476
- sliding fits, A-8–A-9
- slope (grade), 517
- slotted head screws, 618, A-33–A-34
- slotted screw drivers, 619
- SLS (selective laser sintering), 477–478
- small rivets, 624
- Smart Tourniquet, case study, 224–227
- Society of Automotive Engineers (SAE), 16
- socket head screws, A-33–A-34
- solid ground curing (SGC), 476–477
- solid models
 - description, 190
 - versus* other models, 223
- solid objects, 64–65. *See also* specific types.
 - definition, 64
 - double curved surfaces, 64
 - planar surfaces, 64
 - single curved surfaces, 64
 - surfaces, 64
 - types of, 64–65
 - warped surfaces, 64
- solid primitives
 - Boolean operations, 147–148

- box, 146
- cone, 146
- cylinder, 146
- difference (subtract) operation, 147–148
- drawing complex shapes with Boolean operations, 147–148
- intersection operation, 147–148
- overview, 146–147
- pyramid, 146
- sphere, 146
- torus, 146
- union (join/add) operation, 147–148
- wedge, 146
- SolidWorks
 - assembly file management, 423
 - constraint relationships, table of, 202
 - drag-and-drop fasteners, 431
 - fit study, 583
 - operators, table of, 195
 - Pack and Go feature, 423
- space-delimited text format, 457
- spacing
 - lettering. *See* lettering, spacing.
 - parallel lines, 74
 - section lining, 335
 - between views, 238
- specific gravity, 444
- sphere primitive, 146
- spheres
 - definition, 65
 - developments, 394–395
 - double-curved surfaces, 385
 - examples, 65
 - isometric drawings, 96
- spherical coordinates, 129
- spline, definition, 142
- spline curves
 - approximated curves, 142, 144
 - Bezier curves, 143–144
 - B-spline approximation, 143
 - B-splines, 143–144
 - cubic splines, 142
 - drawing, 142–144
 - interpolated splines, 142, 144
 - NURBS (nonuniform rational B-spline) curves, 143
 - overview, 142
 - piecewise splines, 143
 - rational curves, 143
- spotfaces, 213, 214, 286
- spreadsheets, 460
- springs
 - flat, 625–626
 - helical, 625–627
 - modeling, 627
 - portfolio, 629
- springs, helical
 - compression springs, 625
 - definition, 625
 - drawing, 626–627
 - extension springs, 625–626
 - torsion springs, 625–626
 - types of, 625
- square keys, 622, A-37
- square threads, 596, 609, A-37
- squares, drawing, 139
- stability, of lettering, 44
- standard features, 213
- Standard for Aluminum Sand and Permanent Mold Castings*, 437
- Standard for the Exchange of Product model data (STEP), 458
- standard punches, library of, 439
- standard worm thread, 596
- standards. *See also* specific standards.
 - ANSI, *See* American National Standards Institute standards.
 - dimensioning, 538
 - international, 16
 - lettering, 40
 - wire gage, A-42
- standards organizations
 - ANSI (American National Standards Institute), 16
 - ISO (International Organization for Standards), 16
 - SAE (Society of Automotive Engineers), 16
 - United States, 16
- standards publications
 - American National Standard Drafting Manual - Y14*, 16
 - ANSI B4.1 Preferred Limits for Fits for Cylindrical Parts*, 560
 - ANSI B4.2*, 562
 - ANSI/ASME Y14.5* standard, 565–566, 580
 - ANSI/ASME Y14.5M-2009* standard, 567
 - ASEE (American Society for Engineering Education), 16
 - ASME Y14.41 Digital Product Definition Data Practices*, 540
 - ASME Y14.43*, 569
 - ASME/ANSI Y14.6 Screw Thread Representation*, 598, 604
 - Standard for Aluminum Sand and Permanent Mold Castings*, 437
- static assemblies, 418
- station point, 32
- STEP (Standard for the Exchange of Product model data), 458
- stereolithography apparatus (SLA), 476
- stippling, sketching techniques, 68
- STL (STereo Lithography) format, 458
- straight lines, 73
- straightness tolerances, 576
- Strategix Vision, 224
- stretchout, dimensioning, 536
- Stryker SmartPump tourniquet system, 224–227
- studs, definition, 613
- studying the natural world, as a design aid, 16
- subassemblies
 - constraint-based modeling, 216
 - definition, 418
 - drawing, 642
- subtract (difference) operation, 147–148
- successive auxiliary views, 368
- successive revolutions, 396
- superfluous dimensions, 516
- supplementary, tolerance symbols, 567
- surface area, determining mass properties, 452
- surface continuity, 215
- surface finish, 445–446
- surface models
 - accuracy, 188
 - BREP (boundary representation), 184
 - case studies, Smart Tourniquet, 224–227
 - choosing a method for, 224–227
 - combining surfaces, 187
 - complex surfaces, 187, 216
 - Coon's patches, 187
 - definition, 184
 - derived surfaces, 187
 - digitizing, 187
 - editing, 188
 - extruded surfaces, 184–185
 - interpolated patches, 187
 - lofting, 185–186
 - meshes, 185
 - NURBS-based surfaces, 185–186
 - versus* other model types, 223
 - patches, 187
 - reverse engineering, 187
 - revolved surfaces, 184–185
 - surface information in the database, 184
 - surface normal, 184
 - sweeping, 185–186
 - tessellation lines, 189
 - TINs (triangulated irregular networks), 185
 - trimming, 187
 - tweaking, 188
 - uses for, 189
- surface normal vector, 184
- surface patches, 187
- surface roughness, dimensioning, 526–527
- surface texture symbols, 527–528, 529
- surfaces
 - ellipsoids, 385
 - generatrix, 385
 - hyperboloids, 385
 - intersections, definition, 385
 - plane, 385
 - ruled surfaces, 385
 - single-curved surface, 385
 - spheres, 385
 - tori, 385
 - types of, 64. *See also* specific types.
 - in views. *See* views, surfaces.
 - warped, 385
- sweeping, 185–186
- Swendseid, Kurt, 224
- swept shapes, 151
- symbols
 - comparison of, A-48

- symbols, *continued*
 - dimensioning, 513, 520–521, 527–529, 529
 - projection, 241
 - section lining, 336
 - surface texture, 527–529
 - tolerance, 567, 571
 - symbols, form and proportion of
 - datum, A-45
 - dimensioning symbols and letters, A-47
 - geometric characteristics, A-45
 - geometric dimensioning, A-46
 - modifying symbols, A-46
 - symmetry
 - case study: exercise bike brake, 157–159
 - definition, 149
 - mirrored shapes, 149
 - parting line, 150
 - right- and left-hand parts, 149
 - Système International (SI)*, 456
- T**
- tab-delimited text format, 457
 - tabular dimensioning, 534
 - tabulated tolerances, 579–580
 - tangencies, 2D drawings, 287, 290–291
 - tangency, definition, 145
 - tangent constraint, 422
 - tangent method for
 - laying out angles, 138
 - sketching arcs, 76
 - tangent surfaces, hiding in 2D drawings, 292
 - tangents
 - drawing to arcs, 135–136
 - drawing to circles, 135
 - tap breakage, 612
 - tap drills, 612
 - taper, plastic parts, 434
 - taper pins, specifications, A-43
 - tapered parts, tolerance, 549
 - tapers, 524
 - tapped holes, 612
 - teams, as design aids, 17
 - technical drawing, 4–5. *See also* specific forms.
 - template files, saving settings, 429
 - templates for
 - drawing, 47
 - lettering, 42
 - seed parts, 428–429
 - sketching arcs, 77
 - sketching ellipses, 95
 - tertiary datum, 569
 - tessellation lines, 189
 - theoretically exact datum feature
 - simulators, 569
 - thick lines, 34
 - thickness
 - sheet metal, 450
 - in views, 235
 - thin lines, 34
 - third auxiliary view, 368
 - third-angle projection, 240–242
 - 30° angles, estimating, 90
 - Thornburg, Kent, 186
 - thread fits, 599–600, 605
 - thread forms
 - Acme thread, 596
 - American national thread, 596
 - buttress thread, 597
 - knuckle thread, 597
 - metric thread, 596
 - sharp-V, 596
 - square thread, 596
 - standard worm thread, 596
 - UNEF (unified extra fine thread series), 596
 - Unified thread, 594
 - Whitworth thread, 594, 596
 - thread lengths, bolts, 614
 - thread notes, 604–605
 - thread pitch, 595, 597
 - thread pitch gage, 597
 - thread series, 595, 598
 - thread symbols, 606
 - threads. *See also* screw threads.
 - Acme, 596, A-29
 - American national thread, 594
 - angle of thread, 595
 - in assembly, 620
 - axis of screw, 595
 - basic applications, 594
 - bolts, 614
 - clearance holes, 612
 - crest, 595
 - depth of thread, 595
 - dimensioning, 524
 - external threads, 595
 - history of the screw principle, 595
 - internal thread, 595
 - isometric drawings, 95
 - lead, 595
 - major diameter, 595
 - metric fastener standard, 594
 - minor diameter, 595
 - multiple threads, 599
 - pitch diameter, 595
 - right-hand/left-left hand, 598
 - root, 595
 - series of thread, 595, 598
 - side, 595
 - single thread, 599
 - tap breakage, 612
 - tap drills, 612
 - tapped holes, 612
 - threads, drawing
 - Acme thread notes, 605
 - Acme threads, detailed description, 607
 - American National Standard pipe thread, 610–611
 - Briggs standard threads, 610–611
 - detailed, 600–601, 603
 - external square thread, 608
 - internal square thread, 608
 - modeling thread, 610
 - phantom lines, 612
 - pipe threads, 610–611
 - portfolio, 629
 - schematic, 600, 602–603, 611
 - shortening identical features, 612
 - simplified, 600, 602–603, 611
 - square threads, 609
 - tapped holes, 612
 - thread notes, 604–605
 - threads in assembly, 620
 - three dimensional. *See* 3D.
 - 3D figures. *See* solid objects.
 - three-point perspective, 105, 106
 - through holes, 213
 - Through option, 137
 - TINs (triangulated irregular networks), 185
 - title blocks
 - centering words in, 45
 - components of, 51
 - definition, 34
 - general notes in, 550, 556
 - lettering for, 45
 - tolerance
 - actual local feature, 548
 - actual mating envelope, 549
 - actual minimal material envelope, 549
 - actual size, 548
 - allowance, 548
 - angular, 558, 575
 - ANSI standard, 560, 565, 580
 - applying with computer graphics, 582
 - barreled parts, 549
 - baseline dimensioning, 559
 - basic angle tolerancing method, 575
 - bilateral, 548
 - bilateral system, 558
 - bowed parts, 549
 - calibration and inspection, 555
 - case study, 583
 - chained dimensions, 559
 - circularity (roundness), 576
 - clearance fit, 551
 - continuous dimensions, 559
 - cylindricity, 576, 577
 - definition, 548
 - digital product definition, 581–584
 - dimensioning, 505
 - feature, 548
 - feature of size, 548
 - fit, specifying, 552
 - fit types and subtypes, 560
 - fits between mating parts, 551
 - flatness, 576
 - form tolerances for single features, 576–577
 - gage blocks, 555
 - GDT (geometric dimensioning and tolerancing), 565–582
 - general notes, 556
 - hole system, 554–555
 - implied right angles, 550
 - interference fit, 551, 554–555
 - international tolerance grades, A-16
 - Jo blocks, 555

- limit, 557
 - limit dimensions, 552
 - line fit, 552
 - and machining processes, 561
 - metric tolerances, 562
 - milling machines, 561
 - nominal size, 548
 - overview, 548
 - perfect form envelope, 549
 - plus-or-minus, 558
 - portfolio, 584–586
 - positional, 572–574
 - profile, 576–577
 - QC (quality certify), 548
 - reference dimensions, 559
 - selective assembly, 552
 - shaft system, 554
 - single-limit dimensioning, 557
 - size designation, 548
 - specifying, 556
 - straightness, 576
 - tabulated, 579–580
 - tapered parts, 549
 - transition fit, 552
 - true-position dimensioning, 572–574
 - unilateral system, 558
 - variations in form, 549
 - waisted parts, 549
 - tolerance, datum features
 - ASME Y14.43, 569
 - constraining degrees of freedom, 570
 - datum features *versus* datum feature simulator, 569
 - datum reference frame, 569
 - datum targets, 570
 - overview, 568
 - physical datum feature simulators, 569
 - primary datum, 569
 - secondary datum, 569
 - tertiary datum, 569
 - theoretically exact datum feature simulators, 569
 - tolerance, metric fits
 - ANSI B4.2 standard, 562
 - basic size, 562
 - deviation, 562
 - fundamental deviation, 562–563
 - hole system, 563
 - interference fit, 563
 - IT (international tolerance grade), 562
 - lower deviation, 562
 - nominal size, 562
 - overview, 562
 - preferred fits, 564–565
 - preferred sizes, 564
 - shaft system, 563
 - tolerance, 562
 - tolerance symbols, 563
 - tolerance zone, 562–563
 - transition fit, 563
 - upper deviation, 562
 - tolerance, orientations for related features
 - angularity, 578–579
 - concentricity, 579
 - parallelism, 578–579
 - perpendicularity, 578–579
 - tolerance envelope, 549
 - tolerance grades, A-16
 - tolerance stacking, 559
 - tolerance symbols
 - ANSI/ASME Y14.5 standard, 566–567
 - basic dimensions, 567
 - combined, 567
 - datum feature simulator, 571
 - datum features, 571
 - datum identifying, 567
 - feature control frame, 566
 - form, 566–568
 - form tolerance, 567
 - geometric characteristics, 566
 - LMC (least material condition), 567
 - metric fits, 563
 - metric tolerances, 563
 - MMC (maximum material condition), 567, 574–575
 - position, 566–568
 - reference to a datum, 567
 - supplementary, 567
 - tolerance zone, metric tolerances, 562–563
 - top adjacent, 366
 - top views, 234–236
 - top-down design, 424, 449–450
 - topographic shell fabrication (TSF), 478
 - tori, 65, 146, 385
 - torsion springs, 625–626
 - tourniquet, case study, 224–227
 - Townsend, William, 219
 - trammel method for sketching arcs and ellipses, 76
 - transformations
 - geometric, 154
 - viewing, 155–156
 - transition fits
 - definition, 552
 - metric tolerances, 563
 - hole basis, 554, A-23–24
 - shaft basis, 554, A-23–A-24
 - locational, A-12
 - transition pieces, developing, 393–394
 - translation, 154
 - triangles
 - drawing, 138–139
 - formulas for, A-4
 - sketching auxiliary views with, 371
 - triangular prisms, dimensioning, 522
 - triangulated irregular networks (TINs), 185
 - triangulation, finding the development of an oblique cone, 393
 - trimetric projection, 83
 - trimming surface models, 187
 - true ellipses, 92
 - true size, showing
 - in auxiliary views, 364
 - inclined elliptical surface, 372
 - line length, with revolutions, 396
 - lines, true length in CAD, 378–379
 - oblique surfaces, 382–383
 - true-position dimensioning,
 - tolerances, 572–574
 - truncated prisms, 65
 - TSF (topographic shell fabrication), 478
 - tweaking surface models, 188
 - 12-pitch thread, 598
 - twist bits, sizes, A-28–A-29
 - two-point perspective, 105, 106
- U**
- UN threads, 598
 - underconstrained sketches, 203
 - UNEF (unified extra fine thread series), 596
 - unidirectional dimensioning, 512
 - unified thread, 594
 - fits, 600
 - unilateral system of tolerances, 558
 - union (join/add) operation, 147–148
 - United States, drafting standards, 16
 - units of measure, for dimensions, 505
 - universal possibilities, case study: Santa Cruz Bicycles, 9
 - UNJ threads, 598
 - UNR threads, 598
 - upper deviation, metric tolerances, 562
 - U.S. customary units. *See also* metric system.
 - definition, 36
 - dual dimensioning systems, 36–37
 - unit conversion, 37
 - user coordinate systems, 153–154
- V**
- vanishing point, 103
 - variables, *versus* parameters, 193
 - variations in form, tolerances, 549
 - vector *versus* raster data, 459
 - vertical lettering, 41
 - vertices. *See also* points.
 - 3D CAD modeling, 127
 - identifying with numbers, 250
 - sketching techniques, 69
 - viewing direction arrow, 377
 - viewing transformations, 155–156
 - viewing-plane lines, definition, 377
 - viewpoint, sketching techniques, 68
 - views. *See also* auxiliary views; orthographic projection; section views.
 - 45° miter line, 238, 259
 - alignment, 299–300
 - angles, 253
 - arranging on paper, 235. *See also* glass box.
 - assembly drawings, 639
 - bottom, 234–235
 - corners, 250. *See also* vertices.
 - creating by revolving objects, 235
 - depth, 235
 - developing from 3D models, 247–248
 - edges, 250, 252
 - folding lines, 237
 - front, 234–236

- views, *continued*
 - front, orientation, 240
 - glass box, 236–238
 - height, 235
 - interpreting, 254
 - isometric, 249
 - left side, 234–235
 - length, 235
 - lines, interpreting, 253
 - measuring from a reference surface, 238
 - necessary, 239–240, 296–297
 - opposites, 239–240
 - partial, 297–298, 345
 - placing, 248–249
 - planes, definition, 250
 - points, interpreting, 253
 - principal, 234–235
 - principal dimensions, 235
 - rear, 234–235
 - regular, 239–240
 - removed, 287, 299–301
 - revolved sections, 302
 - right side, 234–235
 - showing height. *See* elevation.
 - side, 234–236
 - spacing between, 238
 - thickness, 235
 - top, 234–236
 - transferring depth dimensions, 238
 - vertices, 250, 253
 - visualizing, 250
 - width, 235
 - views, surfaces
 - definition, 250
 - inclined, 250–251
 - normal, 250–251
 - oblique, 250–251
 - orientation to the plane of
 - projection, 250–251
 - similar shapes, 254
 - using numbers to identify vertices, 250
 - virtual condition, 575
 - virtual prototypes, 181, 469
 - visual rays. *See* projectors.
 - visualization
 - from a drawing, 256
 - purpose of technical drawing, 4
 - visualizing
 - 2D complex cylindrical shapes, 288
 - in 3D, 258
 - edges, 250
 - full sections, 330–331
 - with models, 256
 - as revolved drawing, 366
 - views, 250
 - volume, determining mass properties, 452
 - VR (virtual reality), 3D CAD models, 181
- W**
- waisted parts, tolerance, 549
 - wall thickness, plastic parts, 436
 - warped surfaces, 64, 385
 - washers
 - lock, 617, A-41
 - plain, A-40
 - waviness values, dimensioning, 529
 - wedge primitive, 146
 - weight of the part, in title blocks, 51
 - welding drawings
 - metal forming, 448
 - portfolio, 484
 - what-if analysis, 460
 - Whitworth, Joseph, 594
 - Whitworth thread, 594, 596
 - width, in views, 235
 - width auxiliary views, 366–367
 - wire gage standards, A-42
 - wireframe, 2D models, 222
 - wireframe modeler *versus* wireframe
 - display, 183
 - wireframe modeling, 3D models,
 - 182–183, 223
 - wireframe skeleton, 425–426
 - Woodruff keys, 622, A-38
 - working drawing assembly, 638, 646–647
 - working drawings
 - checking accuracy, 650
 - definition, 638
 - detail drawings, 638
 - numbering, 650
 - paper conservation, 648
 - for patent applications, 652–653
 - revision numbers, 650–651
 - simplifying, 651
 - zoning, 650
 - working drawings, formats
 - digital drawing transmittal, 648
 - number of details per sheet, 648
 - PDF (Portable Document Format), 648
 - title and record strips, 649
 - worksheets
 - blocking, W-13, W-19, W-27, W-29, W-33, W-43
 - Boolean operators, W-37
 - circles and ellipses, W-15
 - concept sketching, W-31, W-33, W-35
 - developments, W-71, W-73
 - dimensioning, W-75–W-83
 - glass box, W-39, W-41, W-67
 - grids, W-97–W-1049
 - hatching, W-95
 - hidden lines, W-45
 - inclined surfaces, W-47
 - lettering, W-7, W-9, W-11
 - lines and curves, W-3, W-17, W-25, W-45, W-49, W-69
 - measurements and scale, W-5, W-21
 - negative space, W-13, W-33
 - orthographic sketches, W-29, W-43, W-47, W-49
 - pictorials, W-23, W-25, W-27, W-31, W-33, W-35
 - sections, W-57–W-65
 - surfaces, W-47, W-51–W-55
 - thread symbols, W-93
 - tolerances, W-85–W-91
 - transferring dimensions, W-41, W-43
 - world coordinate system, 153
 - worm’s-eye view, 107
- X**
- X- and Y-axes, coordinate systems, 127
- Z**
- zone numbers, 50
 - zones, 50
 - zoning, working drawings, 650
 - Zuma coffee brewer, case study, 418, 421