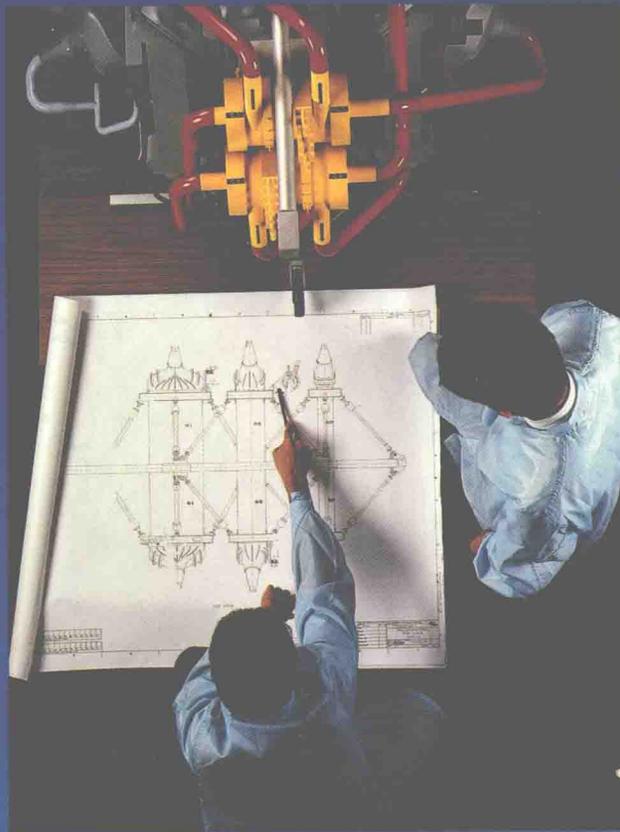


ENGINEERING DRAWING AND DESIGN

FIFTH
EDITION



CECIL JENSEN ● JAY D. HELSEL

Engineering Drawing and Design

Fifth Edition

Cecil Jensen

Former Technical Director
R. S. McLaughlin Collegiate and
Vocational Institute
Oshawa, Ontario, Canada

Jay D. Helsel

Professor and Chairman
Department of Industry
and Technology
California University of Pennsylvania
California, Pennsylvania

GLENCoe

McGraw-Hill

New York, New York Columbus, Ohio Mission Hills, California Peoria, Illinois

Photo Credit: Cover photo courtesy of Wayne Eastep

Jensen, Cecil Howard

[Engineering drawing and design / Cecil Jensen, Jay D. Helsel.
5th ed.

p. cm.

Includes index.

ISBN 0-02-801795-1

1. Mechanical drawing. 2. Engineering design. I. Helsel, Jay D.

II. Title.

T353.J47 1996

604.2—dc20

94-11373

CIP

Photo credits for part and chapter openers: Part One, Comstock, Inc. Part Two, Charly Franklin/FPG International. Part Three, Andrew Sacks/Tony Stone Images. Part Four, Earl Zubkoff Photography. Part Five, Martin Rogers/Tony Stone Images. Chapters 1-27, Aaron Haupt. Other credits: Photos 27-7-1 and 27-7-5 by OrCAD, Inc.

Imprint 1997

Copyright © 1996 by Glencoe/McGraw-Hill. All rights reserved. Except as permitted under the United States Copyright Act, no part of this publication may be reproduced or distributed in any form or by any means, or stored in a database or retrieval system, without prior written permission of the publisher.

This printing includes references to ASME Y14.5M-1994.

Printed in the United States of America.

Send all inquiries to:
Glencoe/McGraw-Hill
936 Eastwind Drive
Westerville, OH 43081

ISBN 0-02-801795-1

5 6 7 8 9 10 11 12 13 14 15 004/043 03 02 01 00 99 98 97

ABOUT THE AUTHORS

CECIL JENSEN is the author or coauthor of many successful technical books, including *Engineering Drawing and Design*, *Fundamentals of Engineering Drawing*, *Fundamentals of Engineering Graphics* (formerly called *Drafting Fundamentals*), *Interpreting Engineering Drawings*, *Geometric Dimensioning and Tolerancing for Engineering and Manufacturing Technology*, *Architectural Drawing and Design for Residential Construction*, *Home Planning and Design*, and *Interior Design*. Some of these books are printed in three languages and are used in many countries.

He has 27 years of teaching experience in mechanical and architectural drafting, and was a technical director for a large vocational school in Canada. He has also been responsible for the supervision of the teaching of technical courses for General Motors apprentices in Oshawa, Canada. Before entering the teaching profession, Mr. Jensen gained several years of design experience in the industry.

Mr. Jensen is a member of the Canadian Standards Committee (CSA) on Technical Drawings (which includes both mechanical and architectural drawing), and is chairman of the Committee on Dimensioning and Tolerancing. Mr. Jensen is Canada's representative on the American (ANSI) Standards for Dimensioning and Tolerancing, and has represented Canada at two world (ISO) conferences in Oslo (Norway) and Paris on the standardization of technical drawings.

He took an early retirement from the teaching profession in order to devote his full attention to writing.

JAY D. HELSEL is a professor of industry and technology at California University of Pennsylvania. He completed his undergraduate work at California State College and was awarded a master's degree from Pennsylvania State University. He has done advanced graduate work at West Virginia and at the University of Pittsburgh, where he completed a doctoral degree in educational communications and technology. In addition, Dr. Helsel holds a certificate in airbrush techniques and technical illustration from the Pittsburgh Art Institute.

He has worked in industry and has taught drafting, metalworking, woodworking, and a variety of laboratory and professional courses at both the secondary and college levels. During the past 25 years, he has also worked as a free-lance artist and illustrator. His work appears in many technical publications.

Dr. Helsel is coauthor of *Engineering Drawing and Design*, *Fundamentals of Engineering Drawing*, *Programmed Blueprint Reading*, *Mechanical Drawing*, and *Computer-Aided Engineering Drawing*.

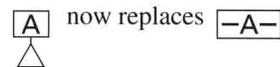
DRAWING STANDARDS UPDATE

The recently published standard *ASME Y14.5M—1994 Dimensioning and Tolerancing*, a revision of *ANSI Y14.5M—1982*, contains additions and modifications to improve national and international drawing communications. This was accomplished by adopting many of the International Organization for Standardization (ISO) drawing standards.

The publication of this standard came at a time when *Engineering Drawing and Design*, 5th edition was ready for publication. In order that the fifth edition of *Engineering Drawing and Design* reflect the current standards adopted by the ISO, the United States, and Canada, this section of the text was introduced to provide current drawing standards to the user. This second printing includes changes in Chapter 16 to be consistent with *ASME Y14.5M—1994*. This will ensure that the students and teaching staff using this text will be informed of the latest drawing requirements.

Significant changes found in *ASME Y14.5M—1994* are:

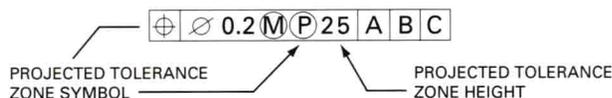
- Adoption of the universal (ISO) datum feature symbol.



The drawing and placement of this symbol is explained in Unit 16–5.

- Discontinuance of the use of the RFS symbol (Ⓢ). The “regardless of feature size” condition now applies where the symbol for MMC and LMC are not stated on size features. This now conforms with ISO practices and is explained in Unit 16–4.

- Placement of the projected tolerance zone symbol and its height in the feature control frame, following the stated tolerance and any modifier. The dimension indicating the minimum height of the projected tolerance zone is placed after the projected tolerance zone symbol. See Unit 16–10.



- Revision of the designation from ANSI to ASME to reflect The American Society of Mechanical Engineers as the preparing organization.
- Reinstatement of the symmetry symbol \equiv , to be applied only on an RFS basis. See Unit 16–14.

ACKNOWLEDGMENTS

The authors are indebted to the members of ASME Y14.5M–1994 Dimensioning and Tolerancing, and the members of the CAN/CSA–B78.2–M91 Dimensioning and Tolerancing of Technical Drawings for the countless hours they have contributed to making such a successful standard.

We also wish to thank Donald Voisinnet, Professor of Engineering Technology and Coordinator of Design and Drafting at the Niagara County Community College, for his assistance in developing Chapter 2 Computer-Aided Drafting (CAD); Sherwood Davis, Professor at Salt Lake Community College, for his revision of Chapter 27 Electrical and Electronic Drawings; and Dennis Short, Associate Professor in the

Technical Graphics Department of the School of Technology at Purdue University, for his development of the *Instructor's Wraparound Edition* and the instructional material to be included in *Instructor's Management System*.

The authors thank the many people who helped in the preparation of this edition including John Beck, the executive editor, Freida O'Neil-Robinson, the editor, and Jennifer King, the senior production editor.

The authors and staff of Glencoe/McGraw-Hill wish to express their appreciation to the following individuals for their professional review of the text and sample design.

Kenneth Arnold
Tulsa Equipment Manufacturing Co.

Michael Holler
Paragon Films, Inc.

Deb Rosenweig
York Technical Institute

Tom Brennan
ITT Technical Institute

Stanley Hopkins
New England Institute of Technology

M. Peter Saxon, III
Porter and Chester Institute

Judith Dalton
ITT Technical Institute

Tommy Justice
John Patterson State Technical College

Dan Steinke
ITT Technical Institute

Thomas Eddins
Clayton State College

Hamid Khan
Ball State University

Mostafa Tossi
Penn State Worthington Scranton

Melvin Freeman
Houston Community College

Harold Lott
Calhoun Community College

George Voll
ITT Technical Institute

Joseph Greenfield
Suny College of Technology

Walter Reed
Oregon Polytechnic Institute

David Webb
Salt Lake Community College

Mel Hartley
Bessmer State Technical

PREFACE

Engineering Drawing and Design is written as an introductory course to prepare students for drafting careers in a modern, technology-intensive industry. Technical drafting, like all technical areas, is constantly changing. The computer has revolutionized the way in which drawings and parts are made. Thus, in this new edition, the authors have made every effort to translate the most current technical information available into the most useful form from the standpoint of both instructor and student. The latest developments and current practices in all areas of graphic communication, CAD, functional drafting, material representation, shop processes, geometric tolerancing, true positioning, numerical control, electronic drafting, and metrication have been incorporated into this edition. The approach used synthesizes, simplifies, and converts complex drafting standards and procedures into understandable instructional units.

Before beginning to work on this edition, a questionnaire was mailed to a number of users and non-users of the text requesting their input on text material and format. In response to the reviewers' suggestions and recommendations, we have incorporated major changes in the fifth edition. The suggestions and changes are:

1. Using a two-column format, rather than a three-column format, which is easier for students to read.
2. Updating the photographs of drafting and CAD equipment. The first three chapters of this edition provide up-to-date color photographs of drafting equipment. In addition, two eight-page color inserts are included as photo essays covering various engineering areas.
3. A greater selection of drawing and design projects. For this edition, we have added over three hundred projects throughout the text.
4. More information on geometric tolerancing and how to apply it to various drawings. This edition has three to four times more information and assignments on this subject than any other current text.
5. Deleting CAD icons and applications throughout the existing text. The reviewers felt that the CAD reference manuals which accompany CAD software packages provide adequate coverage of CAD usage.
6. Continuing to use the unit approach to teach the subject matter. Reviewers find this approach to be a real bonus. It allows them to readily put together a customized program that suits the needs of their students and local industry by choosing the appropriate units. This edition continues to divide chapters into mini-teaching units.
7. Supporting the design concepts covered in the text through drawing practice. While time constraints often limit the use of design units in the instructional program, graduates often find these concepts to be extremely useful in drafting and design experience. Instructors can choose those units they feel appropriate to their program.
8. Continuing to cover current ANSI and ISO drawing practices better than every other text. It is a basic requirement of any engineering drawing text to keep the instructors aware of the latest drawing standards and practices. In this edition, we again included the latest drawing standards on:
 - Methods of representation (Unit 6–1)
 - Symbols representation for installed rivets used in aerospace equipment (Unit 11–5)
 - Simplified representation on drawing (Unit 14–1), a new standard being prepared by ISO and ANSI

These simplified representations have been used for years by American industries as a cost-saving feature. They are covered in this edition of *Engineering Drawing and Design* as they have been since the second edition.

In addition to the major changes incorporated from the reviewers' recommendations, this edition also provides other new features including key terms and a new two-color design. Each chapter begins with the important terms and their definitions. The new two-color design is used to highlight the text's features and enhance its appearance.

Engineering Drawing and Design, 5th edition is supported by ancillary products including some which are new to this edition. The following summarizes the major changes in the instructor and student support material:

- *Instructor's Wraparound Edition of the Textbook.* For the first time, the drafting instructor has a comprehensive teaching guide. This unique and innovative two-color teaching guide combines the student edition with the instructor's edition to provide a wealth of teaching support. Chapter and part overviews, unit objectives, teaching tips, and critical thinking exercises specifically focus on major concepts. Real world engineering drawing facts and technical references provide an interesting learning link. Pop quizzes, evaluation standards, and reteaching strategies are combined into this unprecedented publication.
- *Instructor's Management System.* This comprehensive solutions manual details solutions to many of the end-of-chapter drawing problems. It also provides instructors with course objectives, instructional tips, teaching transparencies, and chapter tests.
- *Instructor's CD-ROM Program.* The CD-ROM includes all of the drawing solutions from the Instructor's Management System. It also provides tutorial drawings which are excellent for instructional use.

- *Problems Workbook for Engineering Drawing and Design.* Many reviewers suggested that we include a problems workbook to enable their students to have more practice. A correlated problems workbook is now available.
- *Text-Workbook for Geometric Tolerancing.* Many of the reviewers also suggested that we include additional coverage of geometric tolerancing in a separate book. This up-to-date text is intended for those instructors who emphasize geometric tolerancing in their program.

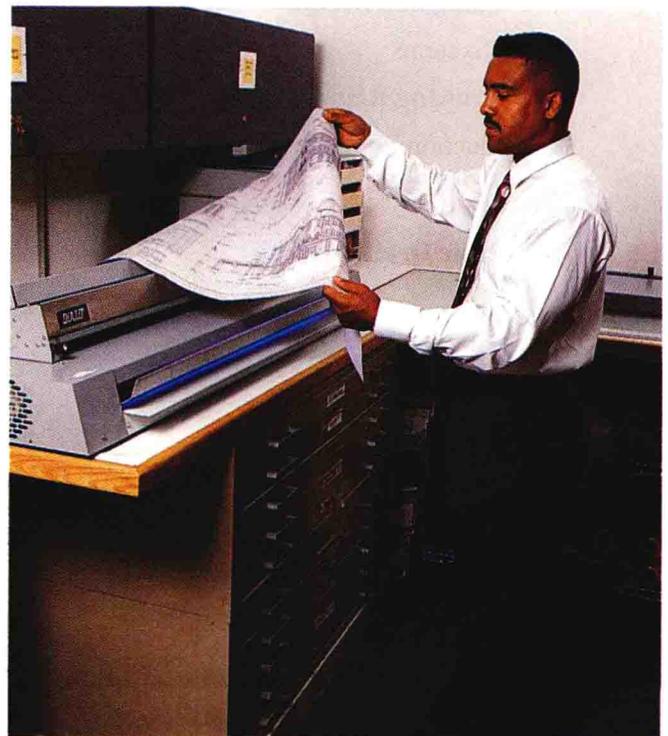
Comments and suggestions concerning this and future editions of the text are most welcomed.

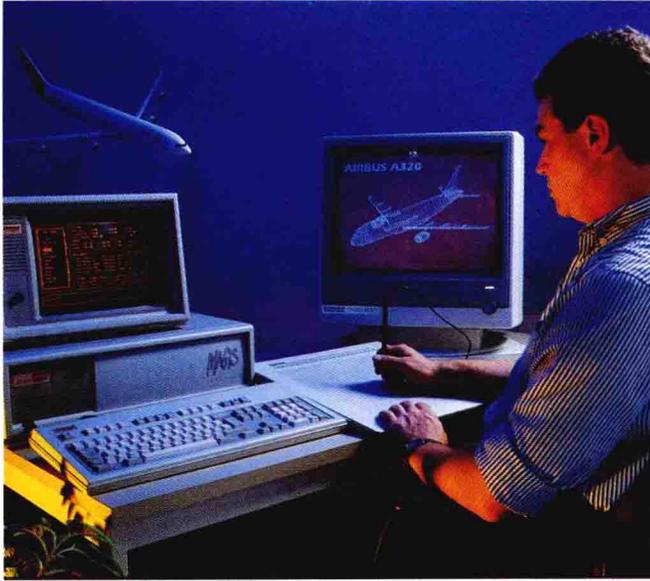
Cecil Jensen and Jay Helsel

CONTENTS

PART 1 Basic Drawing and Design 1

Chapter 1 Engineering Graphics as a Language	2	Alphanumeric Keyboard	27
Definitions	2	Function Keypad	27
1-1 The Language of Industry	2	Graphics Tablet	27
Drawing Standards	4	Cursor Controls	29
1-2 Careers in Engineering Graphics	4	2-4 Output Equipment	30
The Student	4	Monitors	30
Places of Employment	4	Plotters	32
Training, Qualifications, and Advancement	5	Printers and Printer/Plotters	33
Employment Outlook	5	2-5 Computer-Aided Manufacturing	34
1-3 The Drafting Office	6	Numerical Control	34
1-4 Manual Drafting	7	Robotics	34
Drafting Furniture	7		
Drafting Equipment	7		
Basic Equipment	18		
Assignments for Chapter 1	20		
Chapter 2 Computer-Aided Drafting (CAD)	22		
Definitions	22		
2-1 Introduction to Computer-Aided Drafting (CAD)	22		
Components of a CAD System	22		
2-2 Processing and Storage Equipment	23		
Central Processing Unit	24		
Software	24		
Storage Units	26		
2-3 Input Devices	27		





Chapter 3 Drawing Media, Filing, Storage, and Reproduction 35

Definitions 35

3-1 Drawing Media and Format 35

Drawing Media 35

Standard Drawing Sizes 36

Drawing Format 37

3-2 Filing and Storage 39

Filing Systems 40

3-3 Drawing Reproduction 42

Reproduction Equipment 43

Chapter 4 Basic Drafting Skills 45

Definitions 45

4-1 Straight Line Work, Lettering, and Erasing 45

Manual Drafting 45

CAD 52

4-2 Circles and Arcs 54

Center Lines 54

CAD 54

Drawing Circles and Arcs 54

CAD 54

4-3 Drawing Irregular Curves 55

CAD 56

4-4 Sketching 56

Types of Sketches 56

Overlays 56

Nature of a Sketch 57

Views Needed For a Sketch 58

Materials for Sketching 58

Freehand Lines 58

Proportions for Sketching 59

Circles and Arcs 59

Getting Started 59

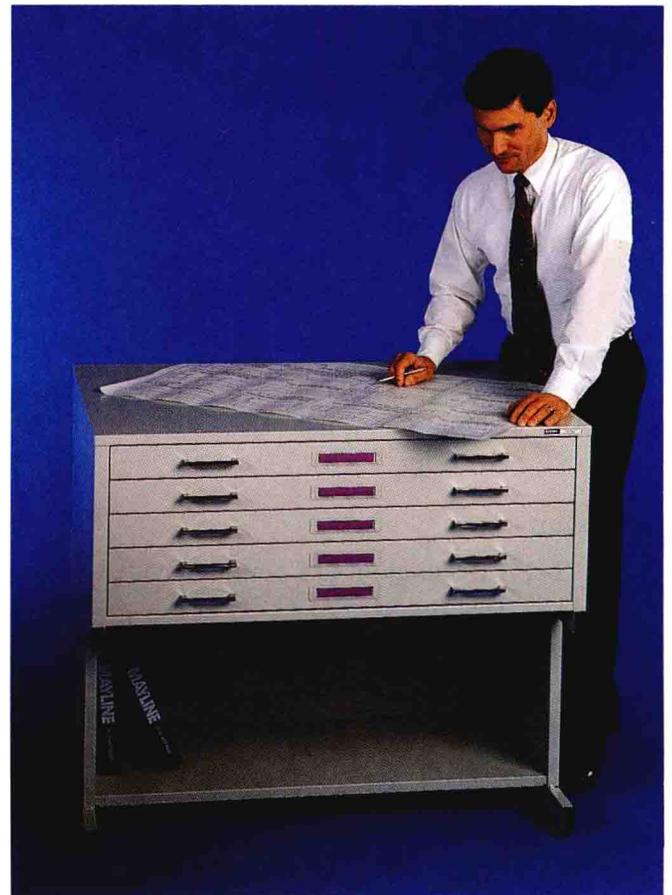
CAD 59

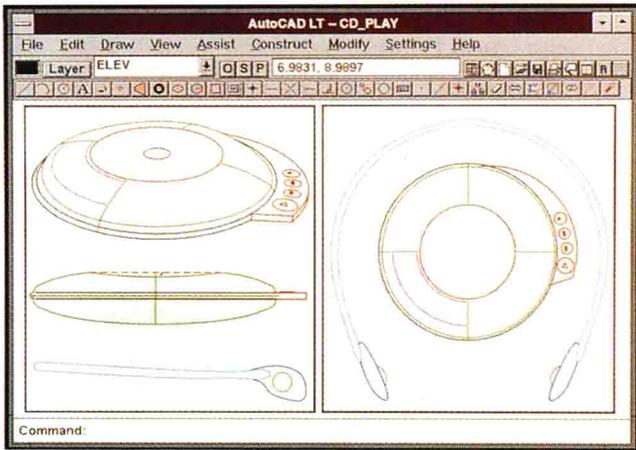
4-5 Inking 61

Drawing Ink 61

Using Ink Equipment 62

Assignments for Chapter 4 65





Chapter 5 Applied Geometry 76

Definitions 76

5-1 Beginning Geometry: Straight Lines 76

5-2 Arcs and Circles 78

5-3 Polygons 80

5-4 Ellipse 82

5-5 Helix and Parabola 83

Helix 83

Parabola 83

Assignments for Chapter 5 84

Chapter 6 Theory of Shape Description 92

Definitions 92

6-1 Orthographic Representations 93

Theory of Shape Description 93

Orthographic Representations 93

Methods of Representation 93

CAD Coordinate Input for Orthographic Representation 96

6-2 Arrangement and Construction of Views 98

Spacing the Views 98

Use of a Miter Line 99

CAD 99

6-3 All Surfaces Parallel and All Edges and Lines Visible 99

6-4 Hidden Surfaces and Edges 100

6-5 Inclined Surfaces 101

6-6 Circular Features 101

Center Lines 102

6-7 Oblique Surfaces 103

6-8 One- and Two-View Drawings 104

View Selection 104

One-View Drawings 104

Two-View Drawings 104

6-9 Special Views 104

Partial Views 104

Rear Views and Enlarged Views 104

6-10 Conventional Representation of Common Features 106

Repetitive Details 106

Repetitive Parts 107

Square Sections 107

6-11 Conventional Breaks 107

6-12 Materials of Construction 107

Transparent Materials 108

6-13 Cylindrical Intersections 108

6-14 Foreshortened Projection 108

Holes Revolved to Show True Distance from Center 108

6-15 Intersections of Unfinished Surfaces 108

Assignments for Chapter 6 110

Chapter 7 Auxiliary Views and Revolutions 136

Definitions 136

7-1 Primary Auxiliary Views 136

Dimensioning Auxiliary Views 138

7-2 Circular Features in Auxiliary Projection 138

7-3 Multi-Auxiliary-View Drawings 139

7-4 Secondary Auxiliary Views 140

7-5 Revolutions 142

Reference Planes 142



Revolutions	142
The Rule of Revolution	145
True Shape of an Oblique Surface Found by Successive Revolutions	145
Auxiliary Views and Revolved Views	145
True Length of a Line	146
7-6 Locating Points and Lines in Space	147
Points in Space	147
Lines in Space	148
True Length of an Oblique Line by Auxiliary Projection	148
Point on a Line	148
Point-On-Point View of a Line	148
7-7 Planes in Space	148
Locating a Line in a Plane	150
Locating a Point on a Plane	151
Locating the Piercing Point of a Line and a Plane—Cutting-Plane Method	151
Locating the Piercing Point of a Line and a Plane—Auxiliary View Method	151
7-8 Establishing Visibility of Lines in Space	152
Visibility of Oblique Lines by Testing	152
Visibility of Lines and Surfaces by Testing	152
Visibility of Lines and Surfaces by Observation	152

7-9 Distances Between Lines and Points	154
Distance from a Point to a Line	154
Shortest Distance Between Two Oblique Lines	154
7-10 Edge and True View of Planes	155
Planes in Combination	156
7-11 Angles Between Lines and Planes	156
The Angle a Line Makes with a Plane	156
Edge Lines of Two Planes	157
Assignments for Chapter 7	158

Chapter 8 Basic Dimensioning	171
Definitions	171
8-1 Basic Dimensioning	171
Dimensioning	171
Units of Measurement	175
Dual Dimensioning	176
Angular Units	176
Reading Direction	177
Basic Rules for Dimensioning	178
Symmetrical Outlines	178
Reference Dimensions	178
Not-to-Scale Dimensions	178
Operational Names	179
Abbreviations	179
8-2 Dimensioning Circular Features	179
Diameters	179
Radii	180
8-3 Dimensioning Common Features	183
Repetitive Features and Dimensions	183
Chamfers	183
Slopes and Tapers	183
Knurls	184
Formed Parts	185
Undercuts	185
Limited Lengths and Areas	186
Wire, Sheet Metal, and Drill Rod	186



8-4 Dimensioning Methods	186
Rectangular Coordinate Dimensioning	186
Polar Coordinate Dimensioning	188
Chordal Dimensioning	188
True-Position Dimensioning	188
Chain Dimensioning	188
Datum or Common-Point Dimensioning	189
8-5 Limits and Tolerances	189
Key Concepts	190
Tolerancing	191
Additional Rules for Dimensioning	194
8-6 Fits and Allowances	195
Fits	195
Allowance	195
Description of Fits	195

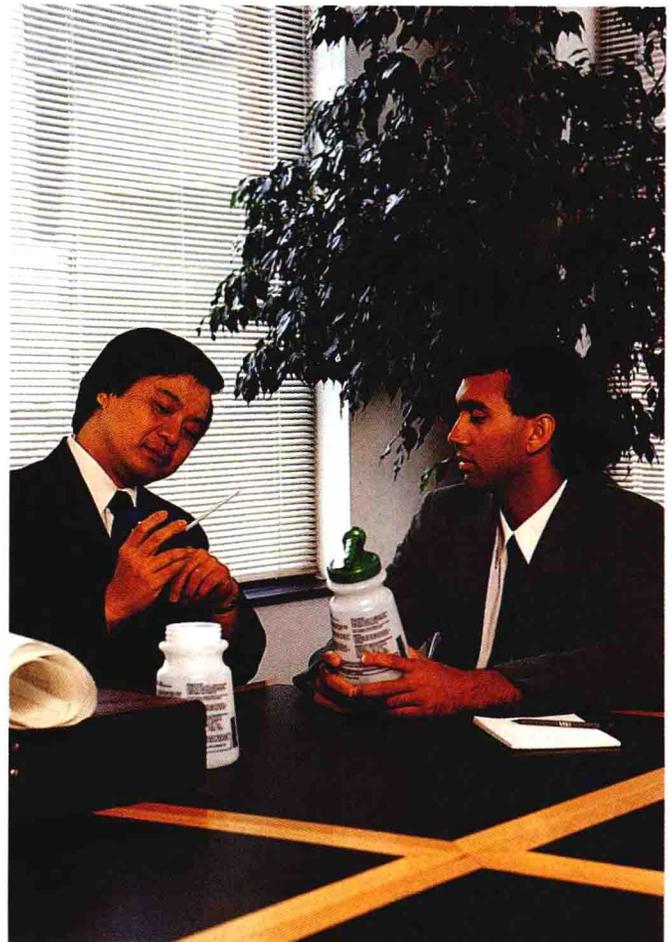
Interchangeability of Parts	196
Standard Inch Fits	196
Basic Hole System	198
Basic Shaft System	198
Preferred Metric Limits and Fits	199
8-7 Surface Texture	202
Surface Texture Characteristics	202
Surface Texture Symbol	203
Application	203
Machined Surfaces	208
Assignments for Chapter 8	209

Chapter 9 Sections	227
Definitions	227
9-1 Sectional Views	227
Cutting-Plane Lines	228
Full Sections	229
Section Lining	229
9-2 Two or More Sectional Views on One Drawing	230
9-3 Half-Sections	231
9-4 Threads in Section	232
Threaded Assemblies	232
9-5 Assemblies in Section	232
Section Lining on Assembly Drawings	232
9-6 Offset Sections	234
9-7 Ribs, Holes, and Lugs in Section	234
Ribs in Sections	234
Holes in Sections	237
Lugs in Section	237
9-8 Revolved and Removed Sections	237
Placement of Sectional Views	237
9-9 Spokes and Arms in Section	238
9-10 Partial or Broken-Out Sections	238
9-11 Phantom or Hidden Sections	239
9-12 Sectional Drawing Review	239
Assignments for Chapter 9	240

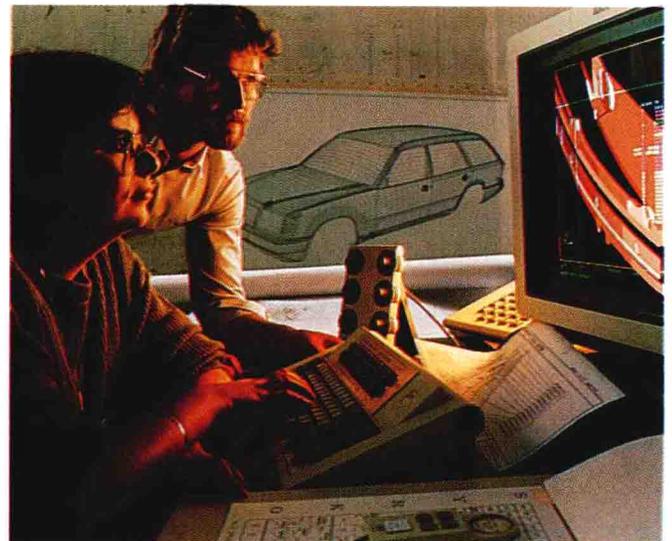
Chapter 10 Threaded Fasteners	260	Studs	274
Definitions	260	Washers	275
10-1 Simplified Thread Representation	260	Terms Related to Threaded Fasteners	276
Screw Threads	261	Specifying Fasteners	277
Thread Forms	261	10-4 Special Fasteners	277
Thread Representation	262	Setscrews	277
Right- and Left-Hand Threads	263	Keeping Fasteners Tight	278
Single and Multiple Threads	263	Locknuts	278
Simplified Thread Representation	264	Captive or Self-Retaining Nuts	279
Threaded Assemblies	264	Inserts	279
Inch Threads	264	Sealing Fasteners	281
Metric Threads	265	10-5 Fasteners for Light-Gage Metal, Plastic, and Wood	282
Pipe Threads	267	Tapping Screws	282
10-2 Detailed and Schematic Thread Representation	267	Special Tapping Screws	282
Detailed Thread Representation	267	Assignments for Chapter 10	283
Schematic Thread Representation	269		
10-3 Common Threaded Fasteners	269	Chapter 11 Miscellaneous Types of Fasteners	292
Fastener Selection	269	Definitions	292
Fastener Definitions	270	11-1 Keys, Splines, and Serrations	293
The Change to Metric Fasteners	270	Keys	293
Fastener Configuration	270	Splines and Serrations	294
Property Classes of Fasteners	272	11-2 Pin Fasteners	296
Drawing a Bolt and Nut	274	Semipermanent Pins	296
		Quick-Release Pins	297
		11-3 Retaining Rings	298
		Stamped Retaining Rings	298
		Wire-Formed Retaining Rings	299
		Spiral-Wound Retaining Rings	299
		11-4 Springs	300
		Types of Springs	300
		Spring Drawings	301
		Spring Clips	303
		11-5 Rivets	304
		Standard Rivets	304



Large Rivets	305	Titanium	336
Rivets for Aerospace Equipment	305	Beryllium	336
Small Rivets	307	Refractory Metals	337
Blind Rivets	308	Precious Metals	337
11–6 Welded Fasteners	311	12–4 Plastics	337
Resistance-Welded Fasteners	311	Thermoplastics	338
Arc-Welded Studs	311	Thermosetting Plastics	339
11–7 Adhesive Fastenings	313	Machining	339
Adhesion Versus Stress	313	Material Selection	339
Joint Design	314	Forming Processes	341
11–8 Fastener Review for Chapters 10 and 11	315	12–5 Rubber	342
Assignments for Chapter 11	315	Material and Characteristics	342
Chapter 12 Manufacturing Materials	327	Kinds of Rubber	342
Definitions	327	Assembly Methods	342
12–1 Cast Irons and Ferrous Metals	327	Design Considerations	343
Ferrous Metals	327	Assignments for Chapter 12	344
Cast Iron	327		
12–2 Carbon Steel	329		
Carbon and Low-Alloy Cast Steels	329		
High-Alloy Cast Steels	329		
Carbon Steels	329		
Steel Specification	329		
SAE and AISI—Systems of Steel Identification	331		
High-Strength Low-Alloy Steels	333		
Low- and Medium-Alloy Steels	334		
Stainless Steels	334		
Free-Machining Steels	334		
12–3 Nonferrous Metals	335		
Manufacturing with Metals	335		
Aluminum	336		
Copper	336		
Nickel	336		
Magnesium	336		
Zinc	336		



Chapter 13 Forming Processes	347	13–2 Forgings	360
		Closed-Die Forging	360
		General Design Rules	360
Definitions	347	Drafting Practices	361
13–1 Metal Castings	347	13–3 Powder Metallurgy	363
Forming Processes	347	Design Considerations	365
Casting Processes	348	13–4 Plastic Molded Parts	366
Selection of Process	351	Single Parts	366
Design Considerations	351	Assemblies	366
Casting Datums	357	Drawings	370
Machining Datums	358	Assignments for Chapter 13	371
PART 3 Working Drawings and Design	379		
Chapter 14 Detail and Assembly Drawings	380	14–5 Drawing Revisions	394
Definitions	380	14–6 Assembly Drawings	395
14–1 Drawing Quality Assurance	380	Design Assembly Drawings	396
Review Considerations	380	Installation Assembly Drawings	396
Drawing Considerations	381	Assembly Drawings for Catalogs	396
Fabrication Considerations	381	Item List	396
Installation Considerations	382	14–7 Exploded Assembly Drawings	398
14–2 Functional Drafting	382	14–8 Detail Assembly Drawings	398
Procedural Shortcuts	382	14–9 Subassembly Drawings	401
Manual Drafting Equipment and Materials	384	Assignments for Chapter 14	401
Reducing the Number of Drawings Required	384		
Simplified Representations in Drawings	385		
Freehand Sketching	387		
Reproduction Shortcuts	387		
Photodrawings	389		
14–3 Detail Drawings	389		
Detail Drawing Requirements	390		
Drawing Checklist	390		
Qualifications of a Detailer	390		
Manufacturing Methods	392		
14–4 Multiple Detail Drawings	393		



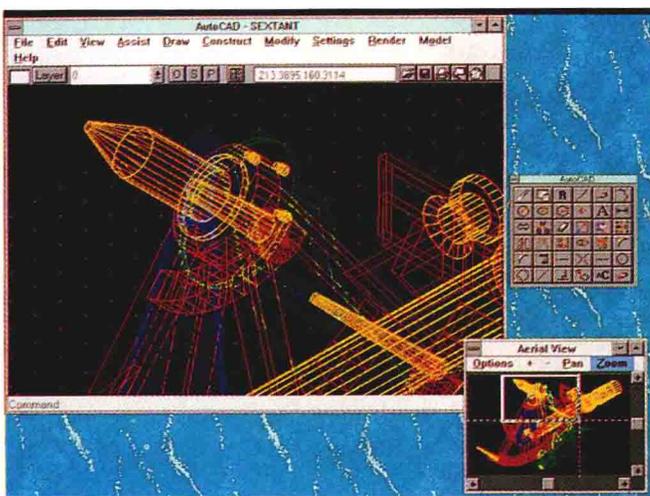
Chapter 15 Pictorial Drawings	441
Definitions	441
15-1 Pictorial Drawings	441
Axonometric Projection	442
Isometric Drawings	442
CAD	446
15-2 Curved Surfaces in Isometric	446
Circles and Arcs in Isometric	446
Isometric Templates	447
Sketching Circles and Arcs	447
Drawing Irregular Curves in Isometric	448
CAD	448
15-3 Common Features in Isometric	449
Isometric Sectioning	449
Fillet and Rounds	450
Threads	450
Break Lines	450
Isometric Assembly Drawings	450
15-4 Oblique Projection	450
Inclined Surfaces	450
Oblique Sketching	451
Dimensioning Oblique Drawings	451
CAD	453
15-5 Common Features in Oblique	453
Circles and Arcs	453

Oblique Sectioning	454
Treatment of Conventional Features	454
CAD	454
15-6 Parallel, or One-Point, Perspective	456
Perspective Projection	456
Types of Perspective Drawings	457
Parallel, or One-Point, Perspective	458
15-7 Angular, or Two-Point, Perspective	460
Angular-Perspective Grids	463
CAD	464
Assignments for Chapter 15	465

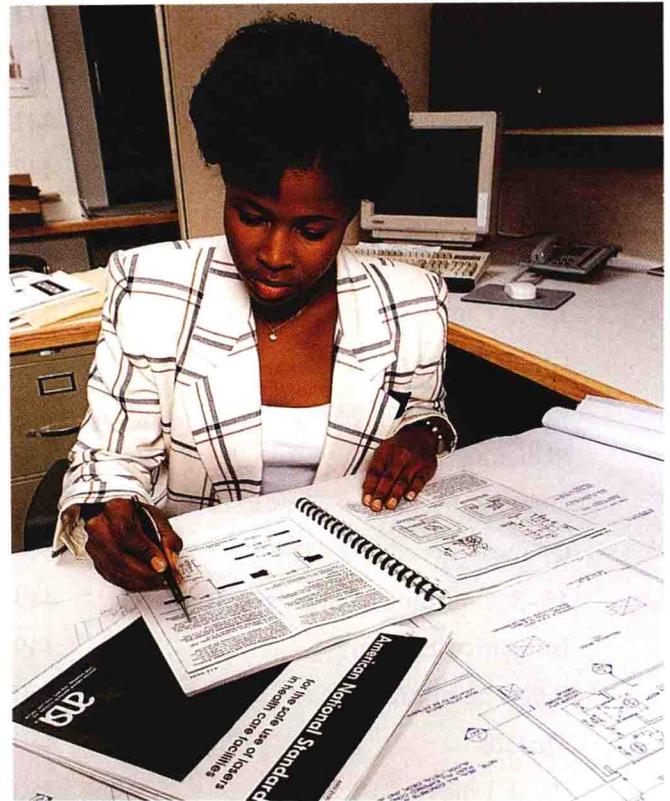
Chapter 16 Geometric Dimensioning and Tolerancing 481

Definitions 481

16-1 Modern Engineering Tolerancing	482
Basic Concepts	482
Interpretation of Drawings and Dimensions	484
16-2 Geometric Tolerancing	487
Feature Control Frame	489
Form Tolerances	490
Straightness	490
16-3 Flatness	493
Flatness of a Surface	493
Flatness Per Unit Area	493
Two or More Flat Surfaces in One Plane	494
16-4 Straightness of a Feature of Size	494
Features of Size	494
Material Condition Symbols	496
Applicability of RFS, MMC, and LMC	496
Straightness of a Feature of Size	499
16-5 Datums and the Three-Plane Concept	502
Datums	502
Datums for Geometric Tolerancing	503



Three-Plane System	503
Identification of Datums	503
16-6 Orientation Tolerancing of Flat Surfaces	506
Reference to a Datum	506
Angularity Tolerance	506
Perpendicularity Tolerance	507
Parallelism Tolerance	507
Control in Two Directions	508
16-7 Datum Features Subject to Size Variation	508
Parts with Cylindrical Datum Features	509
RFS and MMC Applications	509
16-8 Orientation Tolerancing for Features of Size	515
Angularity Tolerance	515
Parallelism Tolerance	515
Perpendicularity Tolerance	515
Control in Two Directions	517
Control on an MMC Basis	517
Internal Cylindrical Features	517
External Cylindrical Features	520
16-9 Positional Tolerancing	521
Tolerancing Methods	521
Coordinate Tolerancing	522
Positional Tolerancing	524
16-10 Projected Tolerance Zone	531
16-11 Datum Targets	533
Datum Target Symbol	533
Identification Targets	534
Targets Not in the Same Plane	536
Partial Surfaces as Datums	537
Dimensioning for Target Location	537
16-12 Circularity (Roundness) and Cylindricity	537
Circularity	537
Cylindricity	539



16-13 Profile Tolerancing	541
Profiles	541
Profile Symbols	541
Profile-of-a-Line Tolerance	541
Profile-of-a-Surface Tolerance	543
16-14 Correlative Tolerances	546
Coplanarity	546
Concentricity	547
Coaxiality	548
Symmetry	548
Runout	551
16-15 Positional Tolerancing for Noncylindrical Features	553
Noncircular Features at MMC	553
16-16 Positional Tolerancing for Multiple Patterns of Features	556
Composite Positional Tolerancing	558
16-17 Formulas for Positional Tolerancing	563