

Contents

PREFACE, *xi*

ABOUT THE AUTHORS, *1*

Part One

Global Implementation for Technical Graphics, 3

1 Introduction to Graphics Communications, 5

Objectives, *5*

- 1.1 Introduction, *6*
- 1.2 Human Communications, *8*
- 1.3 The Importance of Technical Graphics, *10*
 - 1.3.1 Visualization, *12*
 - 1.3.2 Communication, *14*
- 1.4 A Brief History of Graphics Communications, *14*
 - 1.4.1 Descriptive Geometry, *17*
 - 1.4.2 Computer Graphics, *17*
- 1.5 Visual Science, *18*
 - 1.5.1 Geometry, *20*
 - 1.5.2 Standards and Conventions, *21*
- 1.6 What You Will Learn, *23*
- 1.7 Specialists and Technical Drawings, *23*
- 1.8 Engineering Technology, *24*
- 1.9 Summary, *24*

2 The Engineering Design Process, 27

Objectives and Overview, *27*

Introduction, *28*

- 2.1 Design, *28*
 - 2.1.1 Aesthetic Design, *30*
 - 2.1.2 Functional Design, *30*
- 2.2 Engineering Design, *30*
 - 2.2.1 Product Design, *30*
 - 2.2.2 System Design, *30*
 - 2.2.3 Traditional Engineering Design, *31*
 - 2.2.4 Concurrent Engineering Design, *31*
 - 2.2.5 Collaborative Engineering, *32*
 - 2.2.6 Virtual Product Representation, *33*
 - 2.2.7 Prototyping, *33*
 - 2.2.8 Productivity Tools, *36*
- 2.3 The Digital Enterprise, *36*
 - 2.3.1 EDM/PDM, *38*
 - 2.3.2 Internet, Intranet, and Extranet, *38*

2.3.3 Product Life Cycle Management (PLM), *38*

2.3.4 e-Business, *41*

2.3.5 Design Teams, *41*

2.3.6 Members of Design Teams, *44*

2.4 Summary, *44*

3 Design in Industry, 46

Objectives and Overview, *46*

3.1 The Engineering Design Process, *47*

3.2 Types of Design Projects, *48*

3.3 Ideation, *49*

3.3.1 Problem Identification, *49*

3.3.2 Preliminary Ideas Statement, *51*

3.3.3 Preliminary Design, *52*

3.3.4 Ideation Resources, *53*

3.3.5 The Designer's Notebook, *53*

3.4 Refinement, *55*

3.4.1 Modeling, *57*

3.4.2 Computer Simulation and Animation, *60*

3.4.3 Design Analysis, *60*

3.5 Design Review Meetings, *66*

3.6 Implementation, *67*

3.6.1 Planning, *67*

3.6.2 Production, *67*

3.6.3 Marketing, *67*

3.6.4 Finance, *69*

3.6.5 Management, *70*

3.6.6 Service, *72*

3.6.7 Documentation, *72*

3.7 Drawing Control, *81*

3.7.1 Product Data Control, *81*

3.7.2 File Management, *83*

3.7.3 ISO 9000, *83*

3.8 Other Engineering Design Methods, *84*

3.9 Virtual Reality, *85*

3.10 Summary, *96*

4 The Role of Technical Graphics in Production, Automation, and Manufacturing Processes, 109

Objectives, *109*

Introduction, *109*

4.1 Integration in Manufacturing, *110*

4.1.1 Computer-Integrated Manufacturing, *110*

4.1.2 Rapid Prototyping, *113*

- 4.1.3 Design for Manufacturability and Assembly, *114*
- 4.1.4 Computer Simulations and Workplace Models, *114*
- 4.2 Manufacturing Planning, Controlling, and Processing, *115*
 - 4.2.1 Planning, *116*
 - 4.2.2 Controlling and Processing, *120*
- 4.3 Quality in Manufacturing, *121*
 - 4.3.1 The Rise of Total Quality Management, *121*
 - 4.3.2 Manufacturing Quality Control, *123*
- 4.4 The New Philosophies Driving Manufacturing Operations, *124*
 - 4.4.1 Just-in-Time Manufacturing, *125*
 - 4.4.2 The Toyota Production System, *126*
 - 4.4.3 The Emergence of “Lean Production”, *128*
- 4.5 Summary, *129*

Part Two

Fundamentals of Technical Graphics, 133

5 Design Visualization, 135

Objectives, *135*

Introduction, *135*

- 5.1 Visualization Abilities, *136*
- 5.2 The Visualization Cycle, *137*
- 5.3 Design Visualization, *138*
- 5.4 Solid Object Features, *138*
 - 5.4.1 Solid Object Attributes, *138*
- 5.5 Visualization Techniques for Technical Drawings, *140*
 - 5.5.1 Image Planes, *141*
 - 5.5.2 Object-Image Plane Orientation, *142*
 - 5.5.3 Multiple-Image Planes, *145*
 - 5.5.4 Choosing a View to Describe an Object, *148*
- 5.6 Other Visualization Techniques, *148*
 - 5.6.1 Alternative Projection Techniques, *149*
 - 5.6.2 Shading, *150*
 - 5.6.3 Visualizing Multiple Objects, *151*
- 5.7 Graphical Analysis of Engineering Data, *152*
 - 5.7.1 Data Visualization Elements, *152*
 - 5.7.2 Visualizations for One Independent Variable, *154*
 - 5.7.3 Visualizations for Two Independent Variables, *159*
- 5.8 Virtual Reality and Visualization, *161*
- 5.9 Visualization Uses, *161*
 - 5.9.1 Mechanical Design, *161*
 - 5.9.2 Civil Projects, *163*
 - 5.9.3 Future Directions, *164*
- 5.10 Summary, *164*

6 Technical Drawing Tools, 187

Objectives, *187*

Introduction, *188*

- 6.1 Technical Drawing Tools, *188*

- 6.2 Computer-Aided Drawing Tools, *188*
 - 6.2.1 The Central Processing Unit (CPU), *188*
 - 6.2.2 Computer Operating System, *189*
 - 6.2.3 Display Devices, *189*
 - 6.2.4 Input Devices, *190*
 - 6.2.5 Output Devices, *192*
 - 6.2.6 Storage Devices and Media, *194*
- 6.3 Traditional Tools, *196*
 - 6.3.1 Straightedges, *197*
 - 6.3.2 Protractors, *198*
 - 6.3.3 Pencils, *198*
 - 6.3.4 Drawing Paper, *200*
 - 6.3.5 Triangles, *201*
- 6.4 Line Drawing Techniques, *201*
 - 6.4.1 Erasing, *203*
 - 6.4.2 Drawing a Line through Two Points, *203*
 - 6.4.3 Drawing Parallel Lines, *204*
 - 6.4.4 Drawing Perpendicular Lines, *205*
 - 6.4.5 Drawing Lines at Angles Relative to a Given Line, *205*
 - 6.4.6 Drawing Irregular Curves, *206*
- 6.5 Scales, *208*
 - 6.5.1 Architect’s Scale, *209*
 - 6.5.2 Civil Engineer’s Scale, *210*
 - 6.5.3 Mechanical Engineer’s Scale, *211*
 - 6.5.4 Metric Scale, *215*
- 6.6 Drawing Instrument Set, *216*
 - 6.6.1 Compass, *216*
 - 6.6.2 Dividers, *217*
- 6.7 Templates, *218*
- 6.8 Technique for Laying Out a Drawing Sheet, *219*
- 6.9 Technique for Drawing Using Traditional Tools, *220*
- 6.10 Summary, *222*

7 Sketching and Text, 237

Objectives, *237*

Introduction, *238*

- 7.1 Technical Sketching, *238*
 - 7.1.1 Freehand Sketching Tools, *240*
- 7.2 Sketching Technique, *242*
 - 7.2.1 Straight Lines, *242*
 - 7.2.2 Curved Lines, *245*
 - 7.2.3 Contour Sketching, *246*
 - 7.2.4 Negative Space Sketching, *247*
 - 7.2.5 Upside-Down Sketching, *248*
- 7.3 Proportions and Construction Lines, *248*
- 7.4 Types of Sketches, *251*
- 7.5 Introduction to Projections, *252*
 - 7.5.1 Isometric Pictorials, *253*
 - 7.5.2 Isometric Ellipses, *256*
 - 7.5.3 Isometric Grid Paper, *259*
 - 7.5.4 Oblique Pictorials, *260*
 - 7.5.5 Multiview Projections, *262*
- 7.6 Multiview Sketching Technique, *264*
 - 7.6.1 Line Conventions, *266*
 - 7.6.2 Precedence of Lines, *268*
 - 7.6.3 Conventional Practices for Circles and Arcs, *268*

- 7.7 Multiview Sketches, 269
 - 7.7.1 One-View Sketches, 270
 - 7.7.2 Two-View Sketches, 270
 - 7.7.3 Three-View Sketches, 271
- 7.8 Perspective Projection, 273
 - 7.8.1 One-Point Perspective Sketch, 277
 - 7.8.2 Two-Point Perspective Sketch, 278
 - 7.8.3 Perspective Circles, 280
- 7.9 Sketching Using a Constraint-Based Modeling Software Program, 281
- 7.10 Lettering, 283
 - 7.10.1 Lettering Standards, 284
 - 7.10.2 Hand Lettering, 284
 - 7.10.3 Alternate Text Styles, 286
 - 7.10.4 Computer Lettering Technique, 287
- 7.11 Text on Drawings, 289
- 7.12 Summary, 290

8 Engineering Geometry and Construction, 305

Objectives, 305

Introduction, 306

- 8.1 Engineering Geometry, 306
- 8.2 Shape Description, 306
- 8.3 Coordinate Space, 306
 - 8.3.1 Right-Hand Rule, 309
 - 8.3.2 Polar Coordinates, 310
 - 8.3.3 Cylindrical Coordinates, 311
 - 8.3.4 Spherical Coordinates, 311
 - 8.3.5 Absolute and Relative Coordinates, 311
 - 8.3.6 World and Local Coordinate Systems, 312
- 8.4 Geometric Elements, 313
- 8.5 Points, Lines, Circles, and Arcs, 313
 - 8.5.1 Points, 315
 - 8.5.2 Lines, 315
 - 8.5.3 Tangencies, 321
 - 8.5.4 Circles, 330
 - 8.5.5 Ogee Curves, 332
 - 8.5.6 Irregular Curves of Arcs, 334
 - 8.5.7 Rectified Arcs, 334
- 8.6 Conic Curves, 337
 - 8.6.1 Parabolas, 337
 - 8.6.2 Hyperbolas, 339
 - 8.6.3 Ellipses, 343
- 8.7 Roulettes, 350
 - 8.7.1 Spirals, 350
 - 8.7.2 Cycloids, 351
 - 8.7.3 Involutives, 352
- 8.8 Double-Curved Lines, Including Helixes, 355
- 8.9 Freeform Curves, 356
 - 8.9.1 Spline Curves, 356
 - 8.9.2 Bezier and B-Spline Curves, 356
- 8.10 Angles, 360
 - 8.10.1 Bisecting an Angle, 361
 - 8.10.2 Transferring an Angle, 361
- 8.11 Planes, 361
- 8.12 Surfaces, 362
 - 8.12.1 Two-Dimensional Surfaces, 364
 - 8.12.2 Ruled Surfaces, 373
 - 8.12.3 Double-Curved Surfaces, 381
 - 8.12.4 Freeform Surfaces, 383
 - 8.12.5 Fractal Curves and Surfaces, 385
- 8.13 Summary, 386

9 Three-Dimensional Modeling, 399

Objectives, 399

Introduction, 400

- 9.1 Wireframe Modeling, 400
- 9.2 Surface Modeling, 403
- 9.3 Solid Modeling, 408
 - 9.3.1 Constructive Solid Geometry, 408
 - 9.3.2 Boundary Representation (B-Rep) Modeling, 410
 - 9.3.3 Hybrid Modeling, 413
- 9.4 Constraint-Based Modeling, 414
- 9.5 Feature Analysis, 415
- 9.6 Feature Definition, 417
 - 9.6.1 Features from Generalized Sweeps, 417
 - 9.6.2 Construction Geometry, 418
 - 9.6.3 Sketching the Profile, 419
 - 9.6.4 Constraining the Profile, 423
 - 9.6.5 Completing the Feature Definition, 427
 - 9.6.6 Feature Planning Strategies, 430
- 9.7 Editing Part Features, 434
 - 9.7.1 Understanding Feature Order, 435
 - 9.7.2 Editing Feature Properties, 439
- 9.8 Duplicating Part Features, 440
- 9.9 Assembly Modeling, 441
- 9.10 Geometric Transformations, 446
- 9.11 3-D Viewing Techniques, 449
 - 9.11.1 The View Camera, 449
 - 9.11.2 View Camera Operation, 450
 - 9.11.3 View Camera Strategy, 453
- 9.12 3-D Modeling and the Design Process, 454
 - 9.12.1 Sketch Modeling, 455
 - 9.12.2 Prototyping, 455
 - 9.12.3 Analysis, 458
- 9.13 Computer-Aided Manufacturing (CAM), 462
- 9.14 Data Associativity, 464
- 9.15 Data Exchange Standards, 466
- 9.16 Summary, 469

10 Multiview Drawings, 488

Objectives, 488

Introduction, 489

- 10.1 Projection Theory, 489
 - 10.1.1 Line of Sight (LOS), 489
 - 10.1.2 Plane of Projection, 489
 - 10.1.3 Parallel versus Perspective Projection, 489
- 10.2 Multiview Projection Planes, 489
 - 10.2.1 Frontal Plane of Projection, 489
 - 10.2.2 Horizontal Plane of Projection, 493
 - 10.2.3 Profile Plane of Projection, 493
 - 10.2.4 Orientation of Views from Projection Planes, 495
- 10.3 Advantages of Multiview Drawings, 495

- 10.4 The Six Principal Views, 497
 - 10.4.1 Conventional View Placement, 500
 - 10.4.2 First- and Third-Angle Projection, 502
 - 10.4.3 Adjacent Views, 502
 - 10.4.4 Related Views, 504
 - 10.4.5 Central View, 504
 - 10.4.6 Line Conventions, 504
 - 10.4.7 Multiviews from 3-D CAD Models, 511
- 10.5 View Selection, 515
- 10.6 Fundamental Views of Edges and Planes, 516
 - 10.6.1 Edge Lines, 518
 - 10.6.2 Principal Planes, 520
 - 10.6.3 Inclined Planes, 521
 - 10.6.4 Oblique Planes, 521
- 10.7 Multiview Representations, 521
 - 10.7.1 Points, 521
 - 10.7.2 Planes, 521
 - 10.7.3 Change of Planes (Edge Lines), 524
 - 10.7.4 Angles of Planes, 524
 - 10.7.5 Curved Surfaces, 524
 - 10.7.6 Holes, 526
 - 10.7.7 Fillets, Rounds, Finished Surfaces, and Chamfers, 528
 - 10.7.8 Runouts, 530
 - 10.7.9 Elliptical Surfaces, 530
 - 10.7.10 Irregular or Space Curves, 531
 - 10.7.11 Intersecting Cylinders, 531
 - 10.7.12 Cylinders Intersecting Prisms and Holes, 532
- 10.8 Multiview Drawing Visualization, 532
 - 10.8.1 Projection Studies, 533
 - 10.8.2 Physical Model Construction, 533
 - 10.8.3 Adjacent Areas, 534
 - 10.8.4 Similar Shapes, 538
 - 10.8.5 Surface Labeling, 538
 - 10.8.6 Missing Lines, 539
 - 10.8.7 Vertex Labeling, 540
 - 10.8.8 Analysis by Solids, 540
 - 10.8.9 Analysis by Surfaces, 542
- 10.9 ANSI Standards for Multiview Drawings, 543
 - 10.9.1 Partial Views, 543
 - 10.9.2 Revolution Conventions, 544
 - 10.9.3 Removed Views, 545
- 10.10 Summary, 545
- 11 Axonometric and Oblique Drawings, 577**
 - Objectives, 577
 - Introduction, 577
 - 11.1 Axonometric Drawings, 578
 - 11.1.1 Axonometric Drawing Classification, 578
 - 11.2 Isometric Axonometric Projections, 579
 - 11.2.1 Isometric Axonometric Drawings, 582
 - 11.3 Dimetric Projection, 607
 - 11.3.1 Approximate Dimetric Drawings, 607
 - 11.3.2 Dimetric Scales and Ellipse Angles, 608
 - 11.4 Trimetric Projection, 611
 - 11.5 Oblique Drawings, 611
 - 11.5.1 Oblique Projection Theory, 613
 - 11.5.2 Oblique Drawing Classifications, 613

- 11.5.3 Object Orientation Rules, 614
- 11.5.4 Oblique Drawing Construction, 616
- 11.5.5 Standards for Dimensions, 621
- 11.6 Summary, 621

12 Perspective Drawings, 631

- Objectives, 631
- Introduction, 631
- 12.1 Background, 632
- 12.2 Terminology, 633
- 12.3 Perspective Drawing Classifications, 636
- 12.4 Variables Selection, 637
- 12.5 One-Point Perspectives, 638
 - 12.5.1 Plan View Method, 638
 - 12.5.2 Circular Features, 640
- 12.6 Two-Point Perspectives, 640
 - 12.6.1 Plan View Method, 640
 - 12.6.2 Measuring Line Method, 642
- 12.7 Objects Behind the Picture Plane, 644
- 12.8 Perspective Grids, 644
- 12.9 CAD Perspective Drawings, 645
- 12.10 Summary, 647

13 Auxiliary Views, 652

- Objectives, 652
- Introduction, 652
- 13.1 Auxiliary View Projection Theory, 653
 - 13.1.1 Fold-Line Method, 653
 - 13.1.2 Reference Plane Method, 654
- 13.2 Auxiliary View Classifications, 656
 - 13.2.1 Reference or Fold-Line Labeling Conventions, 657
 - 13.2.2 Depth Auxiliary View, 658
 - 13.2.3 Height Auxiliary View, 659
 - 13.2.4 Width Auxiliary View, 660
 - 13.2.5 Partial Auxiliary Views, 660
 - 13.2.6 Half Auxiliary Views, 661
 - 13.2.7 Curves, 661
 - 13.2.8 Auxiliary Views Using CAD, 663
- 13.3 Auxiliary View Applications, 664
 - 13.3.1 Reverse Construction, 664
 - 13.3.2 View in a Specified Direction: Point View of a Line, 665
 - 13.3.3 Dihedral Angles, 666
 - 13.3.3 Successive Auxiliary Views: True Size of Oblique Surfaces, 668
- 13.4 Summary, 670

Part Three Descriptive Geometry, 689

14 Fundamentals of Descriptive Geometry, 691

- Objectives, 691
- Introduction, 691
- 14.1 Descriptive Geometry Methods, 692
- 14.2 Reference Planes, 693
- 14.3 Points, 694

- 14.4 The Coordinate System, 694
 - 14.5 Lines, 695
 - 14.5.1 Spatial Location of a Line, 697
 - 14.5.2 Point on a Line, 697
 - 14.5.3 True Length of a Line, 697
 - 14.5.4 Point View of a Line, 701
 - 14.6 Planes, 703
 - 14.6.1 Principal Views of Planes, 703
 - 14.6.2 Edge View of a Plane, 705
 - 14.6.3 True Size of a Plane, 705
 - 14.6.4 Angle between Two Planes, 706
 - 14.7 Summary, 706
- 15 Intersections and Developments, 716**
- Introduction, 717
- 15.1 Intersections and Developments, 717
 - 15.2 Intersections, 717
 - 15.2.1 Correct Multiview Representations: Visibility, 718
 - 15.2.2 Intersection of Two Lines, 720
 - 15.2.3 Intersection of a Line and a Plane, 720
 - 15.2.4 Intersection of Two Planes, 722
 - 15.2.5 Intersection of a Plane and a Solid, 725
 - 15.2.6 Intersection of Two Solids, 728
 - 15.2.7 CAD Techniques, 734
 - 15.3 Developments, 735
 - 15.3.1 Classifications, 736
 - 15.3.2 Creating Developments, 736
 - 15.3.3 Transition Piece Developments, 743
 - 15.3.4 Approximate Developments, 745
 - 15.3.5 CAD Techniques, 746
 - 15.4 Summary, 747
- Part Four**
- Standard Technical Graphics Practices, 757**
- 16 Section Views, 759**
- Objectives, 759
- Introduction, 759
- 16.1 Sectioning Basics, 761
 - 16.1.1 CAD Technique, 764
 - 16.1.2 Visualization of Section Views, 765
 - 16.2 Cutting Plane Lines, 766
 - 16.2.1 Placement of Cutting Plane Lines, 767
 - 16.3 Section Line Practices, 769
 - 16.3.1 Material Symbols, 769
 - 16.3.2 Drawing Techniques, 770
 - 16.3.3 Outline Sections, 771
 - 16.3.4 Thin Wall Sections, 771
 - 16.4 Section View Types, 773
 - 16.4.1 Full Sections, 773
 - 16.4.2 Half Sections, 775
 - 16.4.3 Broken-Out Sections, 775
 - 16.4.4 Revolved Sections, 775
 - 16.4.5 Removed Sections, 776
 - 16.4.6 Offset Sections, 778
 - 16.4.7 Assembly Sections, 778
 - 16.4.8 Auxiliary Sections, 780
 - 16.5 Special Sectioning Conventions, 781
 - 16.5.1 Ribs, Webs, and Other Thin Features, 781
 - 16.5.2 Aligned Sections, 781
 - 16.5.3 Conventional Breaks, 784
 - 16.6 3-D CAD Techniques, 788
 - 16.7 Summary, 790
- 17 Dimensioning and Tolerancing Practices, 818**
- Objectives, 818
- Introduction, 818
- 17.1 Dimensioning, 819
 - 17.2 Size and Location Dimensions, 819
 - 17.2.1 Units of Measure, 819
 - 17.2.2 Terminology, 821
 - 17.2.3 Basic Concepts, 821
 - 17.2.4 Size Dimensions, 823
 - 17.2.5 Location and Orientation Dimensions, 824
 - 17.2.6 Coordinate Dimensions, 824
 - 17.2.7 Standard Practices, 825
 - 17.3 Detail Dimensioning, 829
 - 17.3.1 Diameter versus Radius, 831
 - 17.3.2 Holes and blind Holes, 832
 - 17.3.3 Counterbored Holes, 833
 - 17.3.4 Spotfaces, 833
 - 17.3.5 Countersinks, 833
 - 17.3.6 Screw Threads, 833
 - 17.3.7 Grooves, 833
 - 17.3.8 Manufacturers' Gauges, 834
 - 17.4 Dimensioning Techniques, 834
 - 17.4.1 The Dimensioning Process, 836
 - 17.4.2 Dimensioning Guidelines, 837
 - 17.4.3 ASME Standard Dimensioning Rules, 839
 - 17.5 Tolerancing, 842
 - 17.5.1 Interchangeability, 843
 - 17.6 Tolerance Representation, 843
 - 17.6.1 General Tolerances, 843
 - 17.6.2 Limit Dimensions, 844
 - 17.6.3 Plus and Minus Dimensions, 844
 - 17.6.4 Single Limit Dimensions, 844
 - 17.6.5 Important Terms, 845
 - 17.6.6 Fit Types, 846
 - 17.6.7 Fit Type Determination, 847
 - 17.6.8 Tolerance Costs, 847
 - 17.6.9 Functional Dimensioning, 848
 - 17.6.10 Tolerance Stack-Up, 848
 - 17.6.11 Metric Limits and Fits, 850
 - 17.6.12 Standard Precision Fits: English Units, 853
 - 17.7 Tolerances in CAD, 859
 - 17.7.1 Geometric Accuracy, 859
 - 17.7.2 Associative Dimensioning, 860
 - 17.8 Surface Texture Symbols, 862
 - 17.9 Summary, 863
- 18 Geometric Dimensioning and Tolerancing (GDT), 875**
- Introduction, 875
- 18.1 Overview, 876
 - 18.2 GDT Symbols, 877
 - 18.3 Individual Feature of Size, 878

- 18.4 Maximum Material Condition, 879
 - 18.4.1 Material Condition Symbols, 879
 - 18.4.2 Departure from MMC, 879
 - 18.4.3 Perfect Form at MMC, 879
 - 18.4.4 Separation of Control Types, 880
 - 18.5 Inspection Tools, 880
 - 18.6 Datums and Datum Features, 881
 - 18.6.1 Datum Uses, 882
 - 18.6.2 Datums and Assembly, 882
 - 18.6.3 Datum Feature Control, 882
 - 18.6.4 Datum Reference Frame, 883
 - 18.6.5 Primary Datum, 883
 - 18.6.6 Secondary and Tertiary Datums, 884
 - 18.6.7 Datum Feature Symbols, 884
 - 18.7 Geometric Controls, 884
 - 18.7.1 Perfection, 884
 - 18.7.2 Tolerance Zones, 884
 - 18.7.3 Virtual Condition, 884
 - 18.7.4 Inspection Processes, 885
 - 18.7.5 Form Controls, 885
 - 18.7.6 Orientation Controls, 889
 - 18.7.7 Location Controls, 892
 - 18.8 Tolerance Calculations, 898
 - 18.8.1 Floating Fastener Tolerancing, 898
 - 18.8.2 Fixed Fastener Tolerancing, 898
 - 18.8.3 Hole Diameter Tolerancing, 898
 - 18.9 Design Applications, 898
 - 18.9.1 Five-Step GDT Process, 898
 - 18.9.2 Application Example, 898
 - 18.10 Statistical Process Control, 900
 - 18.10.1 SPC and Geometrics, 900
 - 18.10.2 Tolerance Analysis, 901
 - 18.11 Summary, 901
- 19 Fastening Devices and Methods, 908**
- Objectives, 908
 - Introduction, 908
 - 19.1 Fasteners, 909
 - 19.2 Threaded Fasteners, 909
 - 19.2.1 Applications, 909
 - 19.2.2 Thread Terminology, 910
 - 19.3 Thread Specifications: English System, 910
 - 19.3.1 Form, 910
 - 19.3.2 Series, 912
 - 19.3.3 Class of Fit, 912
 - 19.3.4 Single and Multiple Threads, 912
 - 19.3.5 Right- and Left-Hand Threads, 913
 - 19.3.6 Thread Pitch, 913
 - 19.3.7 Thread Notes, 913
 - 19.3.8 Thread Grades, 916
 - 19.4 Thread Specifications: Metric System, 916
 - 19.5 Thread Tables, 918
 - 19.6 Thread Drawings, 918
 - 19.6.1 Simplified Representation, 920
 - 19.6.2 Schematic Representation, 922
 - 19.6.3 Assembly Sections, 923
 - 19.6.4 Pipe Threads, 924
 - 19.6.5 CAD Techniques, 925

- 19.7 Design for Assembly (DFA), 925
 - 19.8 Standard Bolts, Studs, and Screws, 927
 - 19.8.1 Standard Bolts, 927
 - 19.8.2 Standard Nuts, 931
 - 19.8.3 Head Style Design Considerations, 932
 - 19.8.4 Standard Cap Screws, 932
 - 19.8.5 Standard Machine Screws, 933
 - 19.8.6 Standard Set Screws, 935
 - 19.8.7 Other Threaded Fastener Types, 935
 - 19.8.8 Locking Devices, 937
 - 19.8.9 Templates, 938
 - 19.8.10 CAD Techniques, 938
 - 19.9 Nonthreaded Fasteners, 938
 - 19.9.1 Standard Plain Washers, 938
 - 19.9.2 Standard Lock Washers, 939
 - 19.9.3 Pins, 939
 - 19.9.4 Keys, 939
 - 19.9.5 Rivets, 940
 - 19.10 Springs, 941
 - 19.11 Summary, 943
- 20 Working Drawings, 949**
- Objectives, 949
 - Introduction, 949
 - 20.1 Basic Concepts, 950
 - 20.2 Working Drawings, 951
 - 20.2.1 Detail Drawings, 951
 - 20.2.2 Assembly Drawings, 953
 - 20.2.3 Part Numbers, 958
 - 20.2.4 Drawing Numbers, 960
 - 20.2.5 Title Blocks, 960
 - 20.2.6 Parts Lists, 965
 - 20.2.7 Part Identification, 966
 - 20.2.8 Revision Block, 966
 - 20.2.9 Scale Specifications, 966
 - 20.2.10 Tolerance Specifications, 967
 - 20.2.11 Zones, 968
 - 20.2.12 Accuracy Checks, 968
 - 20.2.13 Tabular Drawings, 969
 - 20.2.14 Working Assembly Drawing, 970
 - 20.2.15 Engineering Change Orders, 971
 - 20.3 Reprographics, 973
 - 20.3.1 Drawing Storage: Traditional Drawings, 974
 - 20.3.2 Reproduction Techniques, 974
 - 20.3.3 Digital Technologies, 975
 - 20.4 Standard Parts, 976
 - 20.5 Using CAD to Create a Detailed Working Drawing from a 3-D Model, 977
 - 20.6 Summary, 979
- 21 Technical Data Presentation, 1064**
- Objectives, 1064
 - Introduction, 1065
 - 21.1 Data Visualization in Engineering and Design, 1065
 - 21.2 Data Visualization Elements, 1066
 - 21.2.1 Data Types, 1067
 - 21.2.2 Marks, 1069
 - 21.2.3 Encoding Data Variables, 1070

- 21.3 Visualization Methods, *1070*
 - 21.3.1 Visualizations for One Independent Variable, *1070*
 - 21.3.2 Visualizations for Two Independent Variables, *1075*
 - 21.3.3 Visualizations for Functional Relationships, *1080*
 - 21.4 Object Rendering, *1081*
 - 21.4.1 The Rendering Pipeline, *1082*
 - 21.4.2 Visible Surface Determination, *1088*
 - 21.4.3 Light Definition, *1083*
 - 21.4.4 Basic Shading Techniques, *1086*
 - 21.4.5 Advanced Shading Techniques, *1088*
 - 21.4.6 Color Definition, *1089*
 - 21.4.7 Surface Detail Definitions, *1094*
 - 21.5 Information Integration, *1096*
 - 21.5.1 Text and Graphics, *1096*
 - 21.5.2 Animation, *1097*
 - 21.5.3 Hypermedia, *1098*
 - 21.6 Summary, *1098*
- 22 Mechanisms: Gears, Cams, Bearings, and Linkages, 1105**
- Objectives, *1105*
 - Introduction, *1106*
 - 22.1 Basic Definitions, *1106*
 - 22.2 Gears, *1106*
 - 22.2.1 Gear Classifications, *1107*
 - 22.2.2 Parallel Shafting, *1107*
 - 22.2.3 Intersecting Shafting, *1108*
 - 22.2.4 Nonintersecting Shafting, *1109*
 - 22.2.5 Gear Teeth Geometry, *1110*
 - 22.2.6 Pressure Angle, *1111*
 - 22.2.7 Gear and Pinion Ratios, *1111*
 - 22.2.8 Spur Gears: Definitions and Formulas, *1112*
 - 22.2.9 Spur Gears: Graphical Representation, *1112*
 - 22.2.10 CAD Applications, *1119*
 - 22.2.11 Racks, *1120*
 - 22.2.12 Worm Gears, *1120*
 - 22.2.13 Bevel Gears, *1121*
 - 22.3 Cams, *1123*
 - 22.3.1 Cam Types, *1124*
 - 22.3.2 Follower Types, *1125*
 - 22.3.3 Displacement Diagrams, *1125*
 - 22.3.4 Motion Types, *1125*
 - 22.3.5 Uniform Motion Displacement Diagram, *1126*
 - 22.3.6 Harmonic Motion Displacement Diagram, *1126*
 - 22.3.7 Uniformly Accelerated Motion Displacement Diagram, *1127*
 - 22.3.8 Combination Motion Displacement Diagram, *1130*
 - 22.3.9 Cam Profile, *1130*
 - 22.3.10 Offset CAM Profile Drawing, *1132*
 - 22.3.11 CAD Applications, *1133*
 - 22.4 Linkages, *1133*
 - 22.4.1 Symbols, *1133*
 - 22.4.2 Linkage Types, *1134*
 - 22.4.3 Linkage Analysis, *1134*
- 22.5 Bearings, 1137**
- 22.5.1 Plain Bearings, *1137*
 - 22.5.2 Rolling Contact Bearings, *1137*
 - 22.5.3 Graphical Representations, *1137*
- 22.6 Summary, *1140*
- 23 Electronic Drawings, 1146**
- Objectives, *1146*
 - Introduction, *1146*
 - 23.1 Block Diagrams, *1147*
 - 23.2 Schematic Drawings, *1148*
 - 23.3 Wiring and Cabling Diagrams, *1153*
 - 23.4 Printed Circuit Boards, *1154*
 - 23.4.1 Circuit Board Drawings, *1155*
 - 23.4.2 Circuit Board Layout and Design, *1158*
 - 23.4.3 CAD Layout and Design Software, *1160*
 - 23.5 Summary, *1160*
- 24 Piping Drawings, 1163**
- Objectives, *1163*
 - Introduction, *1163*
 - 24.1 Overview, *1164*
 - 24.2 Pipe Types, *1164*
 - 24.2.1 Steel, *1164*
 - 24.2.2 Cast Iron, *1165*
 - 24.2.3 Copper, *1165*
 - 24.2.4 Plastic, *1166*
 - 24.2.5 Other Pipe Materials, *1166*
 - 24.3 Pipe Connections, *1166*
 - 24.3.1 Weld Connections, *1166*
 - 24.3.2 Screw Connections, *1166*
 - 24.3.3 Flange Connections, *1166*
 - 24.4 Pipe Fittings, *1166*
 - 24.5 Valves, *1167*
 - 24.6 Pipe Drawings, *1167*
 - 24.6.1 Plan Drawings, *1168*
 - 24.6.2 Isometric Drawings, *1171*
 - 24.6.3 Spool Drawings, *1174*
 - 24.6.4 Dimensions and Notes, *1174*
 - 24.7 CAD-Based Process Plant Design Programs, *1174*
 - 24.8 Summary, *1179*
- 25 Welding Drawings, 1187**
- Objectives, *1187*
 - Introduction, *1187*
 - 25.1 Overview, *1188*
 - 25.2 Welding Processes, *1188*
 - 25.2.1 Gas and Arc Welding, *1190*
 - 25.2.2 Resistance Welding, *1190*
 - 25.3 Welded Joint Types, *1190*
 - 25.4 Weld Symbols, *1190*
 - 25.5 Weld Types, *1192*
 - 25.5.1 Fillet Welds, *1192*
 - 25.5.2 Groove Welds, *1194*
 - 25.5.3 Plug Welds, *1196*
 - 25.5.4 Spot Welds, *1196*

- 25.5.5 Seam Welds, 1198
- 25.5.6 Surface Welds, 1199
- 25.6 Weld Length and Increments, 1199
- 25.7 Welding Templates, 1200
- 25.8 Weld Symbols and CAD, 1200
- 25.9 Summary, 1202

GLOSSARY, G-1–G-24

APPENDIXES

1. Abbreviations for Engineering Drawings, A-1–A-9
2. Metric Equivalents, A-10
3. Geometric Dimensioning and Tolerancing Symbols, A-11
4. Values for Important Properties of Materials, A-12
5. Trigonometry Functions, A-13
6. Properties of Geometric Elements, A-14–A-20
7. ANSI Running and Sliding Fits (RC), A-21
8. ANSI Clearance Locational Fits (LC), A-22
9. ANSI Transition Locational Fits (LT), A-23
10. ANSI Interference Locational Fits (LN), A-24
11. ANSI Force and Shrink Fits (FN), A-25
12. Description of Preferred Metric Fits, A-26
13. ANSI Preferred Hole Basis Metric Clearance Fits, A-27
14. ANSI Preferred Hole Basis Transition and Interference Fits, A-28
15. ANSI Preferred Shaft Basis Metric Clearance Fits, A-29
16. ANSI Preferred Shaft Basis Metric Transition and Interference Fits, A-30
17. Unified Standard Screw Thread Series, A-31
18. Thread Sizes and Dimensions, A-32
19. Tap Drill Sizes for American National Thread Forms, A-33
20. Hex Cap Screws (Finished Hex Bolts), A-33
21. Socket Head Cap Screws (1960 Series), A-34
22. Square Head Bolts, A-34
23. Hex Nuts and Hex Jam Nuts, A-35
24. Square Nuts, A-35
25. ANSI Metric Hex Jam Nuts and Heavy Hex Nuts, A-36
26. ANSI Metric Hex Nuts, Styles 1 and 2, A-36
27. ANSI Metric Slotted Hex Nuts and Hex Flange Nuts, A-37
28. ANSI Square and Hexagon Machine Screw Nuts and Flat Head Machine Screws, A-38
29. ANSI Slotted Flat Countersunk Head Cap Screws, A-39
30. ANSI Slotted Round and Fillester Head Cap Screws, A-39
31. Drill and Counterbore Sizes for Socket Head Cap Screw, A-40
32. ANSI Hexagon and Spline Socket Head Cap Screws, A-40
33. ANSI Hexagon Socket Head Shoulder Screws, A-41
34. Drill and Counterbore Sizes for Metric Socket Head Cap Screws, A-41
35. ANSI Socket Head Cap Screws—Metric Series, A-42
36. ANSI Metric Hex Bolts, A-42
37. ANSI Metric Hex Cap Screws, A-43
38. ANSI Hex and Hex Flange Head Metric Machine Screws, A-44
39. ANSI Slotted Flat Head Metric Machine Screws, A-45
40. ANSI Slotted Headless Set Screws, A-46
41. ANSI Hexagon and Spline Socket Set Screws, A-46
42. ANSI Hexagon and Spline Socket Set Screw Optional Cup Points, A-47
43. ANSI Square Head Set Screws, A-48
44. ANSI Taper Pipe Threads (NPT), A-49
45. ANSI Metric Plain Washers, A-50
46. ANSI Type A Plain Washers—Preferred Sizes, A-51
47. ANSI Type A Plain Washers—Additional Selected Sizes, A-51
48. ANSI Type B Plain Washers, A-52
49. ANSI Helical Spring Lock Washers, A-53
50. ANSI Internal and External Tooth Lock Washers, A-53
51. ANSI Keyseat Dimensions for Woodruff Keys, A-54
52. ANSI Standard Woodruff Keys, A-55
53. Key Size versus Shaft Diameter—Key Size and Keyway Depth, A-56
54. ANSI Standard Plain and Gib Head Keys, A-56
55. ANSI Chamfered, Square End, and Taper Pins, A-57
56. British Standard Parallel Steel Dowel Pins—Metric Series, A-58
57. ANSI Cotter and Clevis Pins, A-59
58. Piping Symbols, A-60–A-61
59. Electronic Symbols, A-62–A-63
60. Welding Symbols, A-64

INDEX, I-1–I-12