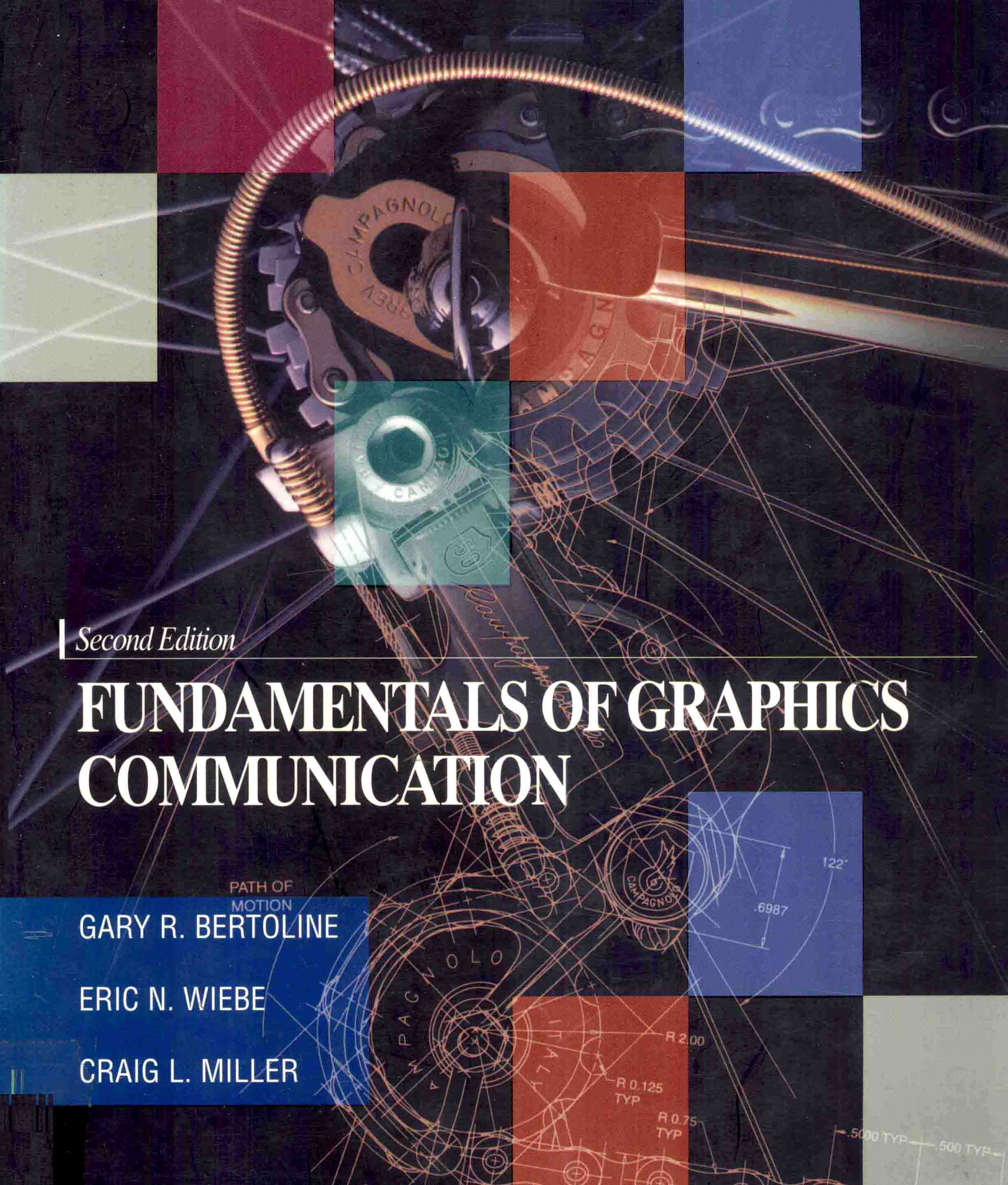


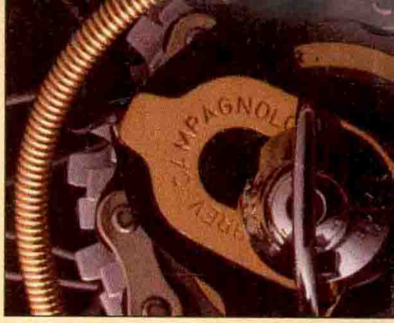
Second Edition

FUNDAMENTALS OF GRAPHICS COMMUNICATION

GARY R. BERTOLINE

ERIC N. WIEBE

CRAIG L. MILLER



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Fundamentals of Graphics Communication

Gary R. Bertoline
Purdue University

Eric N. Wiebe
North Carolina State University

Craig L. Miller
Purdue University

with contributions from
Leonard O. Nasman

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"If I have seen further . . . it is by standing upon the shoulders of Giants." Isaac Newton

This book is dedicated to the pioneers in graphics, and our teachers, colleagues, family, and students from whom we have learned so much and owe our gratitude.

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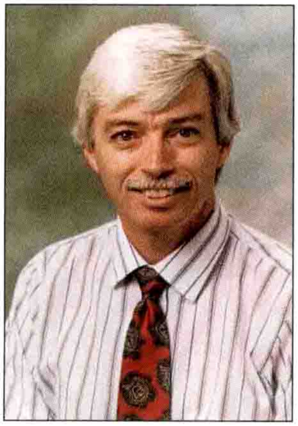
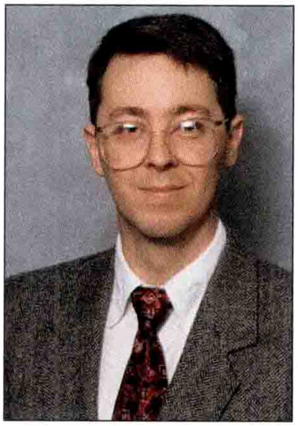


Gary R. Bertoline

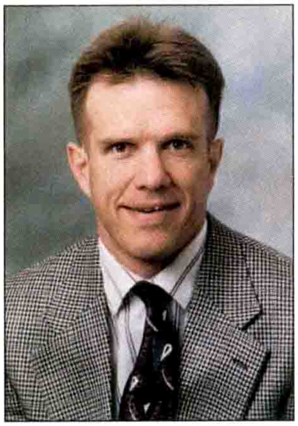
Gary R. Bertoline is Professor of Technical Graphics and head of the Department of Technical Graphics at Purdue University. He earned his B.S. degree in Industrial Technology at Northern Michigan University in 1974, M.Ed. in Industrial Technology at Miami University in 1979, and Ph.D. at The Ohio State University in Industrial Technology in 1987. His graduate work focused on the integration of CAD into engineering graphics and visualization. He has 20 years' experience teaching graphics at all levels from elementary school to senior citizens. Prof. Bertoline taught junior high and high school graphics at St. Henry High School, St. Henry, Ohio; drafting/design technology at Wright State University, Lake Campus, Celina, Ohio; and engineering graphics at The Ohio State University, Columbus, Ohio.

Prof. Bertoline has authored numerous publications, authored or co-authored seven textbooks and workbooks, and made over 50 presentations throughout the world. He has won the Frank Oppenheimer Award three times for best paper at the Engineering Design Graphics Division Mid-year Meeting. He has developed many graphics courses, including CAD, solid modeling, and multimedia, and has integrated many modern topics into traditional engineering graphics courses, such as modeling, animation, and visualization. Prof. Bertoline has conducted research in cognitive visualization and was the co-author for a curriculum study in engineering graphics funded by SIGGRAPH. He is on the editorial board for the *Engineering Design Graphics Journal* and is the Irwin Graphics Series Editor. He is a member of the American Society for Engineering Education, SIGGRAPH, Epsilon Pi Tau, and National Association of Industrial Technology. He is a certified Industrial Technologist and recipient of the Orthogonal Medal for outstanding contributions to the advancement of Graphic Science by North Carolina State University in 1992, and the 1995 inaugural recipient of the Steve M. Slaby International Award for Outstanding Contributions in Graphics Education.



Eric N. Wiebe

Eric N. Wiebe has been teaching in the Graphic Communications Program at North Carolina State University since 1989. He earned his B.A. degree in Chemistry from Duke University in 1982, an M.A. in Industrial Design at North Carolina State in 1987, and his Ph.D. from North Carolina State University in 1996. Before going to graduate school, Prof. Wiebe worked as a chemist and in the A/E/C industry. His graduate work in industrial design focused on the role of computer graphics and CAD in the design process. After completing his master's, Prof. Wiebe helped develop a photorealistic rendering and modeling system for architectural and design professionals and worked as a private consultant. Since coming to teach at North Carolina State, Prof. Wiebe has developed and taught a 3-D solid modeling course for six years. In addition, he coordinated the introduction of CAD into the introductory engineering graphics course. Prof. Wiebe has developed a course on scientific visualization, which looks at the graphic representation of technical and scientific data. Since coming to North Carolina State, he has continued to work as a consultant to industry and has been active at the university level on the integration of computing in academics. He has authored numerous publications and the CAD workbook: *The Student Edition of Generic CADD*. In addition to being on the editorial review board of the *Engineering Design Graphics Journal,* he is a member of the American Society for Engineering Education, the American Design Drafting Association, and the Human Factors and Ergonomics Society.



Craig L. Miller

Craig L. Miller is an Associate Professor in the Department of Technical Graphics at Purdue University. He received his B.S. and M.Ed. at Bowling Green State University in Ohio and his Ph.D. from The Ohio State University. Prior to joining the faculty at Purdue, he served three years as a graduate teaching associate in the Department of Engineering Graphics at The Ohio State University. He has also taught as a graduate teaching assistant in the College of Technology at Bowling Green State University, at the high school level, and adult education in a vocational school. Prof. Miller was honored twice as the recipient of the Purdue University School of Technology's Outstanding Nontenured Faculty Award in 1992 and 1993. Prof. Miller's business experience includes serving as a computer-based training specialist and consultant to Arthur Andersen & Company and Nationwide Insurance Company, and he served as Vice President of Spectrum Multimedia Services, Inc. Prof. Miller is very active in the ASEE, having served as session chairperson and on various committees. He has been honored with the Frank Oppenheimer Award for best paper at the EDGD Mid-year Meeting. He is an active member of Epsilon Pi Tau, National Association of Industrial Technology (NAIT), American Society for Engineering Education (ASEE), ASEE-Engineering Design Graphics Division (EDGD), and the National Society for Performance Instruction (NSPI). Prof. Miller has presented over 15 papers at professional conferences in North America and Australia. He has authored papers in journals on engineering and technical graphics, CADD, and visualization research. His research interests are in measuring and advancing students' spatial abilities and historical research. He was also involved in an international curriculum development with the Royal Melbourne Institute of Technology.

Foreword

It is well accepted that documentation of engineering design drawings is a universal need in industry. All persons involved in engineering design at some time use engineering drawings. Engineers, technologists, and technicians alike often need to see designs expressed in the language of design documentation. This language has long and deep roots. The concepts of design representation, from multiview drawings to pictorials to dimensioning, have evolved only slowly. However, the method of expressing these concepts has changed rapidly with the conversion from freehand drawings to computer-aided-design (CAD) drawings.

This shift to CAD-generated design drawings has created difficulties for textbook authors. How does one best create a modern, useful text that includes both universal concepts of design representation and yet effectively includes CAD techniques? There have been two strategies that have proven to be only partially effective. One strategy is to take an existing traditional text with emphasis on freehand drawings and add text insertions here and there regarding CAD use. The result is often a lack of smooth continuity of topics covered.

Another partially effective strategy is to delete CAD use entirely and require the reader to use a supplemental CAD book to see applications of CAD in design documentation. This approach gives the reader or instructor flexibility of choice but does require two texts.

A third strategy has been adopted by the authors of this text. This strategy fully integrates concepts with CAD representations. The continuity and flow within the text's content can be seamless and natural. This strategy does require a clean-slate approach. Existing texts are not modified. Instead, a fresh new text is developed. The effort required for such a text is high. However, the rewards can include a cohesive modern text incorporating both the necessary traditional concepts of design representation along with appropriate CAD expression of those concepts.

Such an integrated approach provides a text that can serve a wide audience. On one hand, persons used to a traditional format will be comfortable with this text. The contents follow a well-established pattern: sketching, graphical geometry, multiview and pictorial drawings, auxiliary views, sectioning, dimensioning, working drawings, and design. This pattern has worked well for both instructors and students for decades. Within this pattern lie all the fundamental concepts of design representation.

On the other hand, the content is given a unique and valuable freshness with the use of current CAD representations. This successful inclusion of CAD should please all users. Examples, illustrations, industrial applications—all are done in color and with clarity using CAD. The integrated use of CAD eliminates any appearance of random CAD insertions as can be seen in some other texts.

As an author of fifteen years in the area of engineering design graphics, I view *Fundamentals of Graphics Communication* as a text both thorough in basic concepts and also very current in CAD presentations. The result is distinctly superior to the majority of texts available in this field. The instructor and user should not only benefit from this text but also enjoy it.

Robert J. Foster
Pennsylvania State University

Preface

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

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

Engineering and technical graphics have gone through significant changes in the last decade, due to the use of computers and CAD software. It seems as if some new hardware or software development that impacts technical graphics is occurring every year. Although these changes are important to the subject of technical graphics, there is much about the curriculum that has not changed. Engineers and technologists still find it necessary to communicate and interpret designs, using graphics methods such as drawings or computer models. As powerful as today's computers and CAD software have become, they are of little use to engineers and technologists who do not fully understand fundamental graphics principles and 3-D modeling strategies, or do not possess a high-level visualization ability.

This new-generation graphics text is therefore based on the premise that there must be some fundamental changes in the content and process of graphics instruction. Although many graphics concepts remain the same, the fields of engineering and technical graphics are in a transition phase from hand tools to the computer, and the emphasis of instruction is changing from drafter to 3-D geometric modeler, using computers instead of paper and pencil. Much of this text is still dedicated to the instruction of graphics using hand tools, but the instruction is generic, so that either hand tools or computers can be used. A reasonable mix of hand tool and computer tool instruction is afforded by the use of CAD reference icons (◎) throughout this text. These icons appear to denote CAD-specific material in a companion workbook for either AutoCAD or CADKEY. When *Fundamentals of Graphics Communication* is ordered along with *AutoCAD Companion* by James Leach or *The Companion for CadKEY 97* by John Cherng, a reference template linking the two books will be included. We hope that the link between this book and an accompanying CAD book will allow you the flexibility to cover a variety of drawing tools.

The primary goal of this text is to help the engineering and technology student learn the techniques and standard practices of technical graphics, so that design ideas can be adequately communicated and produced. The text concentrates on the concepts and skills necessary to use both hand tools and 2-D or 3-D CAD. The primary goals of the text are to show how to:

1. Clearly represent and control mental images.
2. Graphically represent technical designs, using accepted standard practices.
3. Use plane and solid geometric forms to create and communicate design solutions.
4. Analyze graphics models, using descriptive and spatial geometry.
5. Solve technical design problems, using traditional tools or CAD.
6. Communicate graphically, using sketches, traditional tools, and CAD.
7. Apply technical graphics principles to many engineering disciplines.

Accompanying this text is a free student CD-ROM containing animations of important graphics concepts, AutoCAD problems, and other study aids. When a topic from the text has corresponding CD-ROM material, a CD-ROM icon has been placed near the bottom right side of the material. Also, students and instructors should visit the Web site for the book at *www.mhhe.com/Bertoline* to obtain access to other learning tools such as outlines, additional problems, Web links, supplements, etc. We hope that the use of these resources, either in the classroom or at home, will enrich the student's experience in using *Fundamentals of Graphics Communication*.

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We want to thank the following for reviewing this second edition:

Larry Beuder, *Loyola–Marymount*
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The authors would also like to thank the publisher, WCB/McGraw-Hill, for its support of this project. This has been an expensive and time-consuming process for the authors and the publisher. Few publishers are willing to make the investment necessary to produce a comprehensive, modern graphics text from scratch. The technical graphics profession is indebted to WCB/McGraw-Hill for taking the risk of defining a discipline in transition. The authors would like to thank Tom Casson, for his support and encouragement throughout the project; Bill Stenquist, for the many hours he spent with the authors designing the contents and the strategy necessary to complete a project of this size and complexity; John Wannemacher, for his creative marketing and willingness to work with the authors to see that instructors would understand the features of this text; and Kelley Butcher for all the work she put into this project. She is simply the best developmental editor with whom the authors have ever worked. Betsy Jones has given us the support and direction needed to complete the project and stay focused at a time when everything needed to be done "yesterday." Our thanks also to the production staff at WCB/McGraw-Hill, especially Scott Hamilton, Michael Warrell, Keri Johnson, and Gladys True, who pulled the graphics and text together into a beautifully designed and easy-to-use textbook, and Barry Bergin at Interactive Composition who set the type, composed the pages, and assisted with the illustrations to produce the bound book. There are many others at WCB/McGraw-Hill, who assisted on this project, and we are grateful for all they have done to make this text a success.

Gary Bertoline would like to especially thank his wife, Ada, and his children, Bryan, Kevin, and Carolyn, for the sacrifices they made so that he might fulfill this important mission in his life. His thanks also go to Caroline and Robert Bertoline, who encouraged him to pursue his studies. He would also like to thank all his colleagues, especially those at Purdue University and The Ohio State University, his instructors at Northern Michigan University who inspired him to pursue graphics as a discipline, and Wallace Rigotti who taught him the basics.

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

Gary R. Bertoline
Eric N. Wiebe
Craig L. Miller

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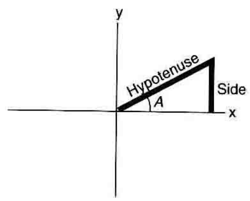
Appendix 1 Metric Equivalents

Length	
U.S. to Metric	**Metric to U.S.**
1 inch = 2.540 centimeters 1 foot = 0.305 meter 1 yard = 0.914 meter 1 mile = 1.609 kilometers	1 millimeter = 0.039 inch 1 centimeter = 0.394 inch 1 meter = 3.281 feet, or 1.094 yards 1 kilometer = 0.621 mile
Area	
1 inch^2 = 6.451 centimeter^2 1 foot^2 = 0.093 meter^2 1 yard^2 = 0.836 meter^2 1 acre^2 = 4,046.873 meter^2	1 millimeter^2 = 0.00155 inch^2 1 centimeter^2 = 0.155 inch^2 1 meter^2 = 10.764 foot^2, or 1.196 yard^2 1 kilometer^2 = 0.386 mile^2, or 247.04 acre^2
Volume	
1 inch^3 = 16.387 centimeter^3 1 foot^3 = 0.28 meter^3 1 yard^3 = 0.764 meter^3 1 quart = 0.946 liter 1 gallon = 0.003785 meter^3	1 centimeter^3 = 0.061 inch^3 1 meter^3 = 35.314 foot^3, or 1.308 yard^3 1 liter = 0.2642 gallons 1 liter = 1.057 quarts 1 meter^3 = 264.02 gallons
Weight	
1 ounce = 28.349 grams 1 pound = 0.454 kilogram 1 ton = 0.907 metric ton	1 gram = 0.035 ounce 1 kilogram = 2.205 pounds 1 metric ton = 1.102 tons
Velocity	
1 foot/second = 0.305 meter/second 1 mile/hour = 0.447 meter/second	1 meter/second = 3.281 feet/second 1 kilometer/hour = 0.621 mile/second
Acceleration	
1 inch/second^2 = 0.0254 meter/second^2 1 foot/second^2 = 0.305 meter/second^2	1 meter/second^2 = 3.278 feet/second^2
Force	
N (Newton) = basic unit of force, kg-m/s^2. A mass of one kilogram (1kg) exerts a gravitational force of 9.8 N (theoretically, 9.80665 N) at mean sea level.	
Density	
1 pound/inch^3 = 27.68 grams/centimeter^3	1 gram/centimeter^3 = 0.591 ounce/inch^3

Prefix	Symbol	Multiplier
tera	T	1,000,000,000,000
giga	G	1,000,000,000
mega	M	1,000,000
kilo	k	1,000
hecto	h	100
deka	da	10
—		1
deci	d	0.1
centi	c	0.01
milli	m	0.001
micro	μ	0.000001
nano	n	0.000000001
pico	p	0.000000000001

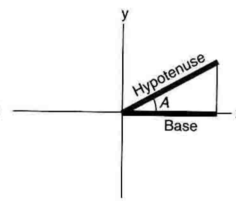
Appendix 2 Trigonometry Functions

SINE



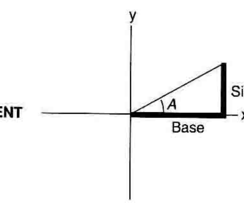
$\sin A = \frac{\text{Side}}{\text{Hypotenuse}}$

COSINE



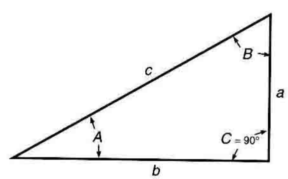
$\cos A = \frac{\text{Base}}{\text{Hypotenuse}}$

TANGENT



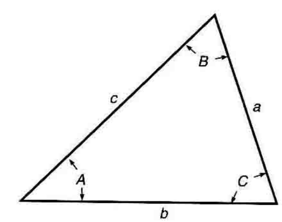
$\tan A = \frac{\text{Side}}{\text{Base}}$

Right Triangles



Known Sides and Angles	Unknown Sides and Angles			Area
a,b	$c = \sqrt{a^2+b^2}$	$A = \text{arc tan}\ \frac{a}{b}$	$B = \text{arc tan}\ \frac{b}{a}$	$\frac{ab}{2}$
a,c	$b = \sqrt{c^2 - a^2}$	$A = \text{arc sin}\ \frac{a}{c}$	$B = \text{arc cos}\ \frac{a}{c}$	$\frac{a\sqrt{c^2 - a^2}}{2}$
b,c	$a = \sqrt{c^2 - b^2}$	$A = \text{arc cos}\ \frac{b}{c}$	$B = \text{arc sin}\ \frac{b}{c}$	$\frac{b\sqrt{c^2 - b^2}}{2}$
a, ∠A	$b = \frac{a}{\tan A}$	$c = \frac{a}{\sin A}$	$B = 90° - A$	$\frac{a^2}{2 \tan A}$
a, ∠B	$b = a \tan B$	$c = \frac{a}{\cos B}$	$A = 90° - B$	$\frac{a^2 \tan B}{2}$
b, ∠A	$a = b \tan A$	$c = \frac{b}{\cos A}$	$B = 90° - A$	$\frac{b^2 \tan A}{2}$
b, ∠B	$a = \frac{b}{\tan B}$	$c = \frac{b}{\sin B}$	$A = 90° - B$	$\frac{b^2}{2 \tan B}$
c, ∠A	$a = c \sin A$	$b = cx \cos A$	$B = 90° - A$	$c^2 \sin A \cos A$
c, ∠B	$a = c \cos B$	$b = cx \sin B$	$A = 90° - B$	$c^2 \sin B \cos B$

Oblique Triangles



Known Sides and Angles	Unknown Sides and Angles			Area
a, b, c	$A = \text{arc cos}\ \frac{b^2 + c^2 - a^2}{2bc}$	$B = \text{arc sin}\ \frac{b \sin A}{a}$	$C = 180° - A - B$	$\frac{ab \sin C}{2}$
a, b, ∠C	$c = \sqrt{a^2 + b^2 - (2ab \cos C)}$	$A = \text{arc tan}\ \frac{a \sin C}{b - (a \cos C)}$	$B = 180° - A - C$	$\frac{ab \sin C}{2}$
a, b, ∠A (∠B less than 90°)	$B = \text{arc sin}\ \frac{b \sin A}{a}$	$C = 180° - A - B$	$c = \frac{a \sin C}{\sin A}$	$\frac{ab \sin C}{2}$
a, b, ∠A (∠B greater than 90°)	$B = 180° - \text{arc sin}\ \frac{b \sin A}{a}$	$C = 180° - A - B$	$c = \frac{a \sin C}{\sin A}$	$\frac{ab \sin C}{2}$
a, ∠A, ∠B	$b = \frac{a \sin B}{\sin A}$	$C = 180° - A - B$	$c = \frac{a \sin C}{\sin A}$	$\frac{ab \sin C}{2}$

Appendix 3 ANSI Running and Sliding Fits (RC)

American National Standard Running and Sliding Fits (ANSI B4.1-1967, R1979)

Tolerance limits given in body of table are added or subtracted to basic size (as indicated by + or − sign) to obtain maximum and minimum sizes of mating parts.

Nominal Size Range, Inches	Class RC 1			Class RC 2			Class RC 3			Class RC 4		
		Standard Tolerance Limits			Standard Tolerance Limits			Standard Tolerance Limits			Standard Tolerance Limits	
	Clearance*	Hole H5	Shaft g4	Clearance*	Hole H6	Shaft g5	Clearance*	Hole H7	Shaft f6	Clearance*	Hole H8	Shaft f7
Over To	Values shown below are in thousandths of an inch											
0– 0.12	0.1 0.45	+0.2 0	−0.1 −0.25	0.1 0.55	+0.25 0	−0.1 −0.3	0.3 0.95	+0.4 0	−0.3 −0.55	0.3 1.3	+0.6 0	−0.3 −0.7
0.12– 0.24	0.15 0.5	+0.2 0	−0.15 −0.3	0.15 0.65	+0.3 0	−0.15 −0.35	0.4 1.12	+0.5 0	−0.4 −0.7	0.4 1.6	+0.7 0	−0.4 −0.9
0.24– 0.40	0.2 0.6	+0.25 0	−0.2 −0.35	0.2 0.85	+0.4 0	−0.2 −0.45	0.5 1.5	+0.6 0	−0.5 −0.9	0.5 2.0	+0.9 0	−0.5 −1.1
0.40– 0.71	0.25 0.75	+0.3 0	−0.25 −0.45	0.25 0.95	+0.4 0	−0.25 −0.55	0.6 1.7	+0.7 0	−0.6 −1.0	0.6 2.3	+1.0 0	−0.6 −1.3
0.71– 1.19	0.3 0.95	+0.4 0	−0.3 −0.55	0.3 1.2	+0.5 0	−0.3 −0.7	0.8 2.1	+0.8 0	−0.8 −1.3	0.8 2.8	+1.2 0	−0.8 −1.6
1.19– 1.97	0.4 1.1	+0.4 0	−0.4 −0.7	0.4 1.4	+0.6 0	−0.4 −0.8	1.0 2.6	+1.0 0	−1.0 −1.6	1.0 3.6	+1.6 0	−1.0 −2.0
1.97– 3.15	0.4 1.2	+0.5 0	−0.4 −0.7	0.4 1.6	+0.7 0	−0.4 −0.9	1.2 3.1	+1.2 0	−1.2 −1.9	1.2 4.2	+1.8 0	−1.2 −2.4
3.15– 4.73	0.5 1.5	+0.6 0	−0.5 −0.9	0.5 2.0	+0.9 0	−0.5 −1.1	1.4 3.7	+1.4 0	−1.4 −2.3	1.4 5.0	+2.2 0	−1.4 −2.8
4.73– 7.09	0.6 1.8	+0.7 0	−0.6 −1.1	0.6 2.3	+1.0 0	−0.6 −1.3	1.6 4.2	+1.6 0	−1.6 −2.6	1.6 5.7	+2.5 0	−1.6 −3.2
7.09– 9.85	0.6 2.0	+0.8 0	−0.6 −1.2	0.6 2.6	+1.2 0	−0.6 −1.4	2.0 5.0	+1.8 0	−2.0 −3.2	2.0 6.6	+2.8 0	−2.0 −3.8
9.85–12.41	0.8 2.3	+0.9 0	−0.8 −1.4	0.8 2.9	+1.2 0	−0.8 −1.7	2.5 5.7	+2.0 0	−2.5 −3.7	2.5 7.5	+3.0 0	−2.5 −4.5
12.41–15.75	1.0 2.7	+1.0 0	−1.0 −1.7	1.0 3.4	+1.4 0	−1.0 −2.0	3.0 6.6	+2.2 0	−3.0 −4.4	3.0 8.7	+3.5 0	−3.0 −5.2
15.75–19.69	1.2 3.0	+1.0 0	−1.2 −2.0	1.2 3.8	+1.6 0	−1.2 −2.2	4.0 8.1	+2.5 0	−4.0 −5.6	4.0 10.5	+4.0 0	−4.0 −6.5

See footnotes at end of table.

Nominal Size Range, Inches	Class RC 5			Class RC 6			Class RC 7			Class RC 8			Class RC 9		
		Standard Tolerance Limits			Standard Tolerance Limits			Standard Tolerance Limits			Standard Tolerance Limits			Standard Tolerance Limits	
	Clearance*	Hole H8	Shaft e7	Clearance*	Hole H9	Shaft e8	Clearance*	Hole H9	Shaft d8	Clearance*	Hole H10	Shaft c9	Clearance*	Hole H11	Shaft
Over To	Values shown below are in thousandths of an inch														
0– 0.12	0.6 1.6	+0.6 0	− 0.6 − 1.0	0.6 2.2	+1.0 0	− 0.6 − 1.2	1.0 2.6	+1.0 0	− 1.0 − 1.6	2.5 5.1	+ 1.6 0	− 2.5 − 3.5	4.0 8.1	+ 2.5 0	− 4.0 − 5.6
0.12– 0.24	0.8 2.0	+0.7 0	− 0.8 − 1.3	0.8 2.7	+1.2 0	− 0.8 − 1.5	1.2 3.1	+1.2 0	− 1.2 − 1.9	2.8 5.8	+ 1.8 0	− 2.8 − 4.0	4.5 9.0	+ 3.0 0	− 4.5 − 6.0
0.24– 0.40	1.0 2.5	+0.9 0	− 1.0 − 1.6	1.0 3.3	+1.4 0	− 1.0 − 1.9	1.6 3.9	+1.4 0	− 1.6 − 2.5	3.0 6.6	+ 2.2 0	− 3.0 − 4.4	5.0 10.7	+ 3.5 0	− 5.0 − 7.2
0.40– 0.71	1.2 2.9	+1.0 0	− 1.2 − 1.9	1.2 3.8	+1.6 0	− 1.2 − 2.2	2.0 4.6	+1.6 0	− 2.0 − 3.0	3.5 7.9	+ 2.8 0	− 3.5 − 5.1	6.0 12.8	+ 4.0 0	− 6.0 − 8.8
0.71– 1.19	1.6 3.6	+1.2 0	− 1.6 − 2.4	1.6 4.8	+2.0 0	− 1.6 − 2.8	2.5 5.7	+2.0 0	− 2.5 − 3.7	4.5 10.0	+ 3.5 0	− 4.5 − 6.5	7.0 15.5	+ 5.0 0	− 7.0 − 10.5
1.19– 1.97	2.0 4.6	+1.6 0	− 2.0 − 3.0	2.0 6.1	+2.5 0	− 2.0 − 3.6	3.0 7.1	+2.5 0	− 3.0 − 4.6	5.0 11.5	+ 4.0 0	− 5.0 − 7.5	8.0 18.0	+ 6.0 0	− 8.0 − 12.0
1.97– 3.15	2.5 5.5	+1.8 0	− 2.5 − 3.7	2.5 7.3	+3.0 0	− 2.5 − 4.3	4.0 8.8	+3.0 0	− 4.0 − 5.8	6.0 13.5	+ 4.5 0	− 6.0 − 9.0	9.0 20.5	+ 7.0 0	− 9.0 − 13.5
3.15– 4.73	3.0 6.6	+2.2 0	− 3.0 − 4.4	3.0 8.7	+3.5 0	− 3.0 − 5.2	5.0 10.7	+3.5 0	− 5.0 − 7.2	7.0 15.5	+ 5.0 0	− 7.0 − 10.5	10.0 24.0	+ 9.0 0	− 10.0 − 15.0
4.73– 7.09	3.5 7.6	+2.5 0	− 3.5 − 5.1	3.5 10.0	+4.0 0	− 3.5 − 6.0	6.0 12.5	+4.0 0	− 6.0 − 8.5	8.0 18.0	+ 6.0 0	− 8.0 − 12.0	12.0 28.0	+ 10.0 0	− 12.0 − 18.0
7.09– 9.85	4.0 8.6	+2.8 0	− 4.0 − 5.8	4.0 11.3	+4.5 0	− 4.0 − 6.8	7.0 14.3	+4.5 0	− 7.0 − 9.8	10.0 21.5	+ 7.0 0	− 10.0 − 14.5	15.0 34.0	+ 12.0 0	− 15.0 − 22.0
9.85–12.41	5.0 10.0	+3.0 0	− 5.0 − 7.0	5.0 13.0	+5.0 0	− 5.0 − 8.0	8.0 16.0	+5.0 0	− 8.0 − 11.0	12.0 25.0	+ 8.0 0	− 12.0 − 17.0	18.0 38.0	+ 12.0 0	− 18.0 − 26.0
12.41–15.75	6.0 11.7	+3.5 0	− 6.0 − 8.2	6.0 15.5	+6.0 0	− 6.0 − 9.5	10.0 19.5	+6.0 0	− 10.0 − 13.5	14.0 29.0	+ 9.0 0	− 14.0 − 20.0	22.0 45.0	+ 14.0 0	− 22.0 − 31.0
15.75–19.69	8.0 14.5	+4.0 0	− 8.0 − 10.5	8.0 18.0	+6.0 0	− 8.0 − 12.0	12.0 22.0	+6.0 0	− 12.0 − 16.0	16.0 32.0	+ 10.0 0	− 16.0 − 22.0	25.0 51.0	+ 16.0 0	− 25.0 − 35.0

All data above heavy lines are in accord with ABC agreements. Symbols H5, g4, etc. are hole and shaft designations in ABC system. Limits for sizes above 19.69 inches are also given in the ANSI Standard.

* Pairs of values shown represent minimum and maximum amounts of clearance resulting from application of standard tolerance limits.

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Appendix 4 ANSI Clearance Locational Fits (LC)

American National Standard Clearance Locational Fits (ANSI B4.1-1967, R1979)

Tolerance limits given in body of table are added or subtracted to basic size (as indicated by + or − sign) to obtain maximum and minimum sizes of mating parts.

Nominal Size Range, Inches	Class LC 1			Class LC 2			Class LC 3			Class LC 4			Class LC 5		
		Standard Tolerance Limits			Standard Tolerance Limits			Standard Tolerance Limits			Standard Tolerance Limits			Standard Tolerance Limits	
Over To	Clearance*	Hole H6	Shaft h5	Clearance*	Hole H7	Shaft h6	Clearance*	Hole H8	Shaft h7	Clearance*	Hole H10	Shaft h9	Clearance*	Hole H7	Shaft g6
	Values shown below are in thousandths of an inch														
0– 0.12	0 0.45	+0.25 0	0 −0.2	0 0.65	+0.4 0	0 −0.25	0 1	+0.6 0	0 −0.4	0 2.6	+1.6 0	0 −1.0	0.1 0.75	+0.4 0	−0.1 −0.35
0.12– 0.24	0 0.5	+0.3 0	0 −0.2	0 0.8	+0.5 0	0 −0.3	0 1.2	+0.7 0	0 −0.5	0 3.0	+1.8 0	0 −1.2	0.15 0.95	+0.5 0	−0.15 −0.45
0.24– 0.40	0 0.65	+0.4 0	0 −0.25	0 1.0	+0.6 0	0 −0.4	0 1.5	+0.9 0	0 −0.6	0 3.6	+2.2 0	0 −1.4	0.2 1.2	+0.6 0	−0.2 −0.6
0.40– 0.71	0 0.7	+0.4 0	0 −0.3	0 1.1	+0.7 0	0 −0.4	0 1.7	+1.0 0	0 −0.7	0 4.4	+2.8 0	0 −1.6	0.25 1.35	+0.7 0	−0.25 −0.65
0.71– 1.19	0 0.9	+0.5 0	0 −0.4	0 1.3	+0.8 0	0 −0.5	0 2	+1.2 0	0 −0.8	0 5.5	+3.5 0	0 −2.0	0.3 1.6	+0.8 0	−0.3 −0.8
1.19– 1.97	0 1.0	+0.6 0	0 −0.4	0 1.6	+1.0 0	0 −0.6	0 2.6	+1.6 0	0 −1	0 6.5	+4.0 0	0 −2.5	0.4 2.0	+1.0 0	−0.4 −1.0
1.97– 3.15	0 1.2	+0.7 0	0 −0.5	0 1.9	+1.2 0	0 −0.7	0 3	+1.8 0	0 −1.2	0 7.5	+4.5 0	0 −3	0.4 2.3	+1.2 0	−0.4 −1.1
3.15– 4.73	0 1.5	+0.9 0	0 −0.6	0 2.3	+1.4 0	0 −0.9	0 3.6	+2.2 0	0 −1.4	0 8.5	+5.0 0	0 −3.5	0.5 2.8	+1.4 0	−0.5 −1.4
4.73– 7.09	0 1.7	+1.0 0	0 −0.7	0 2.6	+1.6 0	0 −1.0	0 4.1	+2.5 0	0 −1.6	0 10.0	+6.0 0	0 −4	0.6 3.2	+1.6 0	−0.6 −1.6
7.09– 9.85	0 2.0	+1.2 0	0 −0.8	0 3.0	+1.8 0	0 −1.2	0 4.6	+2.8 0	0 −1.8	0 11.5	+7.0 0	0 −4.5	0.6 3.6	+1.8 0	−0.6 −1.8
9.85–12.41	0 2.1	+1.2 0	0 −0.9	0 3.2	+2.0 0	0 −1.2	0 5	+3.0 0	0 −2.0	0 13.0	+8.0 0	0 −5	0.7 3.9	+2.0 0	−0.7 −1.9
12.41–15.75	0 2.4	+1.4 0	0 −1.0	0 3.6	+2.2 0	0 −1.4	0 5.7	+3.5 0	0 −2.2	0 15.0	+9.0 0	0 −6	0.7 4.3	+2.2 0	−0.7 −2.1
15.75–19.69	0 2.6	+1.6 0	0 −1.0	0 4.1	+2.5 0	0 −1.6	0 6.5	+4 0	0 −2.5	0 16.0	+10.0 0	0 −6	0.8 4.9	+2.5 0	−0.8 −2.4

See footnotes at end of table.

Nominal Size Range, Inches	Class LC 6			Class LC 7			Class LC 8			Class LC 9			Class LC 10			Class LC 11		
		Std. Tolerance Limits			Std. Tolerance Limits			Std. Tolerance Limits			Std. Tolerance Limits			Std. Tolerance Limits			Std. Tolerance Limits	
Over To	Clearance*	Hole H9	Shaft f8	Clearance*	Hole H10	Shaft e9	Clearance*	Hole H10	Shaft d9	Clearance*	Hole H11	Shaft c10	Clearance*	Hole H12	Shaft	Clearance*	Hole H13	Shaft
	Values shown below are in thousandths of an inch																	
0– 0.12	0.3 1.9	+1.0 0	−0.3 −0.9	0.6 3.2	+1.6 0	−0.6 −1.6	1.0 2.0	+1.6 0	−1.0 −2.0	2.5 6.6	+2.5 0	−2.5 −4.1	4 12	+4 0	−4 −8	5 17	+6 0	−5 −11
0.12– 0.24	0.4 2.3	+1.2 0	−0.4 −1.1	0.8 3.8	+1.8 0	−0.8 −2.0	1.2 4.2	+1.8 0	−1.2 −2.4	2.8 7.6	+3.0 0	−2.8 −4.6	4.5 14.5	+5 0	−4.5 −9.5	6 20	+7 0	−6 −13
0.24– 0.40	0.5 2.8	+1.4 0	−0.5 −1.4	1.0 4.6	+2.2 0	−1.0 −2.4	1.6 5.2	+2.2 0	−1.6 −3.0	3.0 8.7	+3.5 0	−3.0 −5.2	5 17	+6 0	−5 −11	7 25	+9 0	−7 −16
0.40– 0.71	0.6 3.2	+1.6 0	−0.6 −1.6	1.2 5.6	+2.8 0	−1.2 −2.8	2.0 6.4	+2.8 0	−2.0 −3.6	3.5 10.3	+4.0 0	−3.5 −6.3	6 20	+7 0	−6 −13	8 28	+10 0	−8 −18
0.71– 1.19	0.8 4.0	+2.0 0	−0.8 −2.0	1.6 7.1	+3.5 0	−1.6 −3.6	2.5 8.0	+3.5 0	−2.5 −4.5	4.5 13.0	+5.0 0	−4.5 −8.0	7 23	+8 0	−7 −15	10 34	+12 0	−10 −22
1.19– 1.97	1.0 5.1	+2.5 0	−1.0 −2.6	2.0 8.5	+4.0 0	−2.0 −4.5	3.6 9.5	+4.0 0	−3.0 −5.5	5.0 15.0	+6 0	−5.0 −9.0	8 28	+10 0	−8 −18	12 44	+16 0	−12 −28
1.97– 3.15	1.2 6.0	+3.0 0	−1.0 −3.0	2.5 10.0	+4.5 0	−2.5 −5.5	4.0 11.5	+4.5 0	−4.0 −7.0	6.0 17.5	+7 0	−6.0 −10.5	10 34	+12 0	−10 −22	14 50	+18 0	−14 −32
3.15– 4.73	1.4 7.1	+3.5 0	−1.4 −3.6	3.0 11.5	+5.0 0	−3.0 −6.5	5.0 13.5	+5.0 0	−5.0 −8.5	7 21	+9 0	−7 −12	11 39	+14 0	−11 −25	16 60	+22 0	−16 −38
4.73– 7.09	1.6 8.1	+4.0 0	−1.6 −4.1	3.5 13.5	+6.0 0	−3.5 −7.5	6 16	+6 0	−6 −10	8 24	+10 0	−8 −14	12 44	+16 0	−12 −28	18 68	+25 0	−18 −43
7.09– 9.85	2.0 9.3	+4.5 0	−2.0 −4.8	4.0 15.5	+7.0 0	−4.0 −8.5	7 18.5	+7 0	−7 −11.5	10 29	+12 0	−10 −17	16 52	+18 0	−16 −34	22 78	+28 0	−22 −50
9.85–12.41	2.2 10.2	+5.0 0	−2.2 −5.2	4.5 17.5	+8.0 0	−4.5 −9.5	7 20	+8 0	−7 −12	12 32	+12 0	−12 −20	20 60	+20 0	−20 −40	28 88	+30 0	−28 −58
12.41–15.75	2.5 12.0	+6.0 0	−2.5 −6.0	5.0 20.0	+9.0 0	−5 −11	8 23	+9 0	−8 −14	14 37	+14 0	−14 −23	22 66	+22 0	−22 −44	30 100	+35 0	−30 −65
15.75–19.69	2.8 12.8	+6.0 0	−2.8 −6.8	5.0 21.0	+10.0 0	−5 −11	9 25	+10 0	−9 −15	16 42	+16 0	−16 −26	25 75	+25 0	−25 −50	35 115	+40 0	−35 −75

All data above heavy lines are in accordance with American-British-Canadian (ABC) agreements. Symbols H6, H7, s6, etc. are hole and shaft designations in ABC system. Limits for sizes above 19.69 inches are not covered by ABC agreements but are given in the ANSI Standard.

* Pairs of values shown represent minimum and maximum amounts of interference resulting from application of standard tolerance limits.

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Appendix 5 ANSI Transition Locational Fits (LT)

ANSI Standard Transition Locational Fits (ANSI B4.1-1967, R1979)

Nominal Size Range, Inches	Class LT 1			Class LT 2			Class LT 3			Class LT 4			Class LT 5			Class LT 6		
		Std. Tolerance Limits			Std. Tolerance Limits			Std. Tolerance Limits			Std. Tolerance Limits			Std. Tolerance Limits			Std. Tolerance Limits	
Over To	Fit*	Hole H7	Shaft js6	Fit*	Hole H8	Shaft js7	Fit*	Hole H7	Shaft k6	Fit*	Hole H8	Shaft k7	Fit*	Hole H7	Shaft n6	Fit*	Hole H7	Shaft n7
	Values shown below are in thousandths of an inch																	
0– 0.12	−0.12 +0.52	+0.4 0	+0.12 −0.12	−0.2 +0.8	+0.6 0	+0.2 −0.2							−0.5 +0.15	+0.4 0	+0.5 +0.25	−0.65 +0.15	+0.4 0	+0.65 +0.25
0.12– 0.24	−0.15 +0.65	+0.5 0	+0.15 −0.15	−0.25 +0.95	+0.7 0	+0.25 −0.25							−0.6 +0.2	+0.5 0	+0.6 +0.3	−0.8 +0.2	+0.5 0	+0.8 +0.3
0.24– 0.40	−0.2 +0.8	+0.6 0	+0.2 −0.2	−0.3 +1.2	+0.9 0	+0.3 −0.3	−0.5 +0.5	+0.6 0	+0.5 +0.1	−0.7 +0.8	+0.9 0	+0.7 +0.1	−0.8 +0.2	+0.6 0	+0.8 +0.4	−1.0 +0.2	+0.6 0	+1.0 +0.4
0.40– 0.71	−0.2 +0.9	+0.7 0	+0.2 −0.2	−0.35 +1.35	+1.0 0	+0.35 −0.35	−0.5 +0.6	+0.7 0	+0.5 +0.1	−0,8 +0.9	+1.0 0	+0.8 +0.1	−0.9 +0.2	+0.7 0	+0.9 +0.5	−1.2 +0.2	+0.7 0	+1.2 +0.5
0.71– 1.19	−0.25 +1.05	+0.8 0	+0.25 −0.25	−0.4 +1.6	+1.2 0	+0.4 −0.4	−0.6 +0.7	+0.8 0	+0.6 +0.1	−0.9 +1.1	+1.2 0	+0.9 +0.1	−1.1 +0.2	+0.8 0	+1.1 +0.6	−1.4 +0.2	+0.8 0	+1.4 +0.6
1.19– 1.97	−0.3 +1.3	+1.0 0	+0.3 −0.3	−0.5 +2.1	+1.6 0	+0.5 −0.5	−0.7 +0.9	+1.0 0	+0.7 +0.1	−1.1 +1.5	+1.6 0	+1.1 +0.1	−1.3 +0.3	+1.0 0	+1.3 +0.7	−1.7 +0.3	+1.0 0	+1.7 +0.7
1.97– 3.15	−0.3 +1.5	+1.2 0	+0.3 −0.3	−0.6 +2.4	+1.8 0	+0.6 −0.6	−0.8 +1.1	+1.2 0	+0.8 +0.1	−1.3 +1.7	+1.8 0	+1.3 +0.1	−1.5 +0.4	+1.2 0	+1.5 +0.8	−2.0 +0.4	+1.2 0	+2.0 +0.8
3.15– 4.73	−0.4 +1.8	+1.4 0	+0.4 −0.4	−0.7 +2.9	+2.2 0	+0.7 −0.7	−1.0 +1.3	+1.4 0	+1.0 +0.1	−1.5 +2.1	+2.2 0	+1.5 +0.1	−1.9 +0.4	+1.4 0	+1.9 +1.0	−2.4 +0.4	+1.4 0	+2.4 +1.0
4.73– 7.09	−0.5 +2.1	+1.6 0	+0.5 −0.5	−0.8 +3.3	+2.5 0	+0.8 −0.8	−1.1 +1.5	+1.6 0	+1.1 +0.1	−1.7 +2.4	+2.5 0	+1.7 +0.1	−2.2 +0.4	+1.6 0	+2.2 +1.2	−2.8 +0.4	+1.6 0	+2.8 +1.2
7.09– 9.85	−0.6 +2.4	+1.8 0	+0.6 −0.6	−0.9 +3.7	+2.8 0	+0.9 −0.9	−1.4 +1.6	+1.8 0	+1.4 +0.2	−2.0 +2.6	+2.8 0	+2.0 +0.2	−2.6 +0.4	+1.8 0	+2.6 +1.4	−3.2 +0.4	+1.8 0	+3.2 +1.4
9.85–12.41	−0.6 +2.6	+2.0 0	+0.6 −0.6	−1.0 +4.0	+3.0 0	+1.0 −1.0	−1.4 +1.8	+2.0 0	+1.4 +0.2	−2.2 +2.8	+3.0 0	+2.2 +0.2	−2.6 +0.6	+2.0 0	+2.6 +1.4	−3.4 +0.6	+2.0 0	+3.4 +1.4
12.41–15.75	−0.7 +2.9	+2.2 0	+0.7 −0.7	−1.0 +4.5	+3.5 0	+1.0 −1.0	−1.6 +2.0	+2.2 0	+1.6 +0.2	−2.4 +3.3	+3.5 0	+2.4 +0.2	−3.0 +0.6	+2.2 0	+3.0 +1.6	−3.8 +0.6	+2.2 0	+3.8 +1.6
15.75–19.69	−0.8 +3.3	+2.5 0	+0.8 −0.8	−1.2 +5.2	+4.0 0	+1.2 −1.2	−1.8 +2.3	+2.5 0	+1.8 +0.2	−2.7 +3.8	+4.0 0	+2.7 +0.2	−3.4 +0.7	+2.5 0	+3.4 +1.8	−4.3 +0.7	+2.5 0	+4.3 +1.8

All data above heavy lines are in accord with ABC agreements. Symbols H7, js6, etc. are hole and shaft designations in ABC system.

* Pairs of values shown represent maximum amount of interference (−) and maximum amount of clearance (+) resulting from application of standard tolerance limits.

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