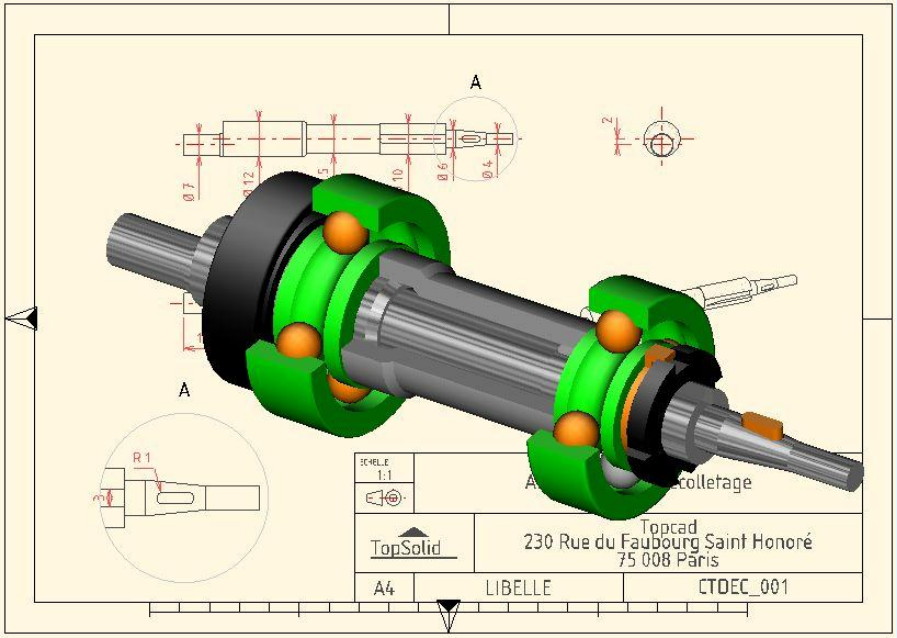
Product Design (Part 4)



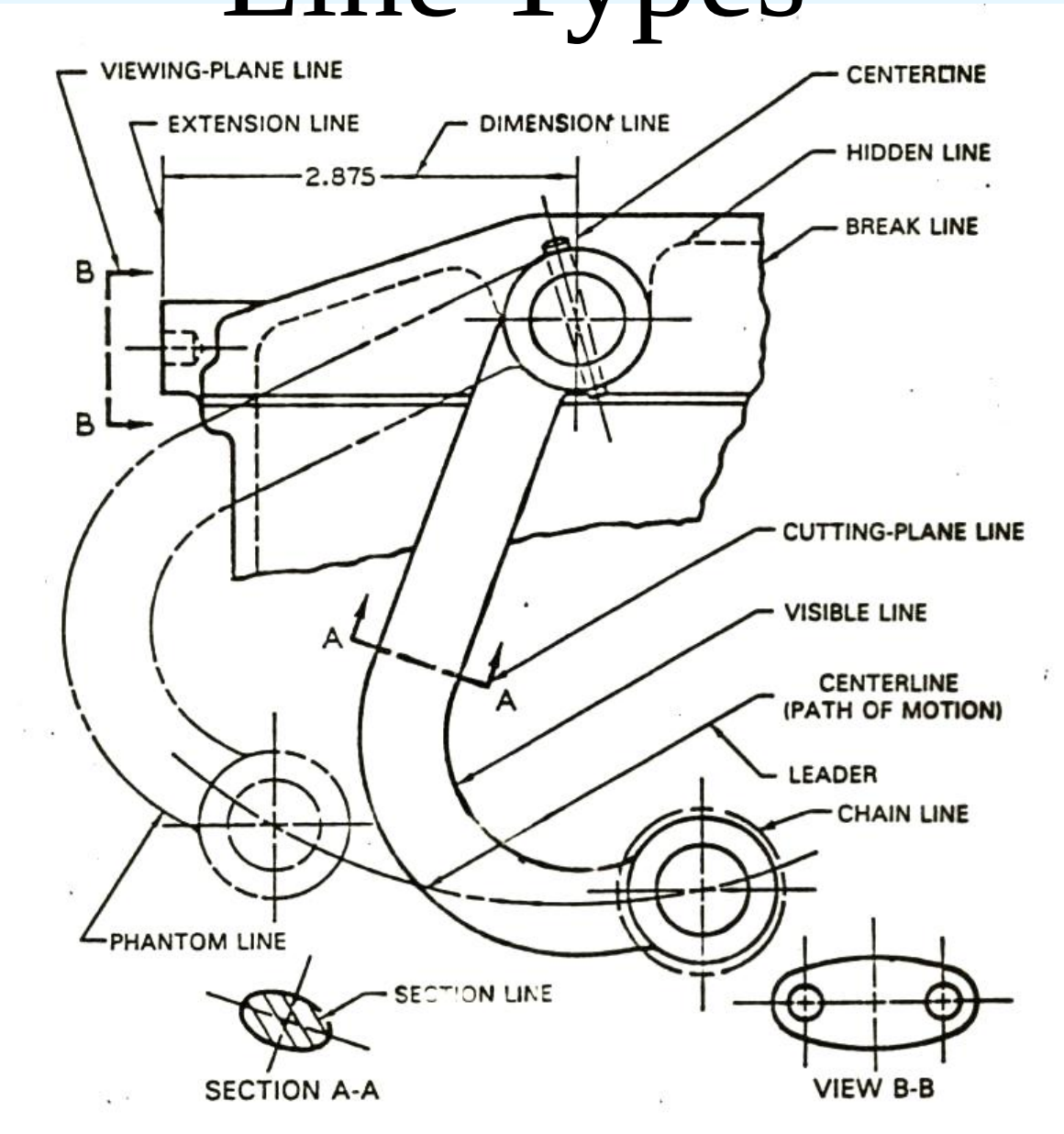
Engineering Drawing

Chapter 16

Drawing Standards

- Line conventions and lettering-ANSI/ASME Y14.2M-1992
- Multiview and sectional view drawings-ANSI/ASME Y14.3M-1994
- Pictorial drawing-ANSI/ASME Y14.4M-1989(1994)
- Dimensioning and tolerancing-ANSI/ASME Y14.5M-1994

Line Types

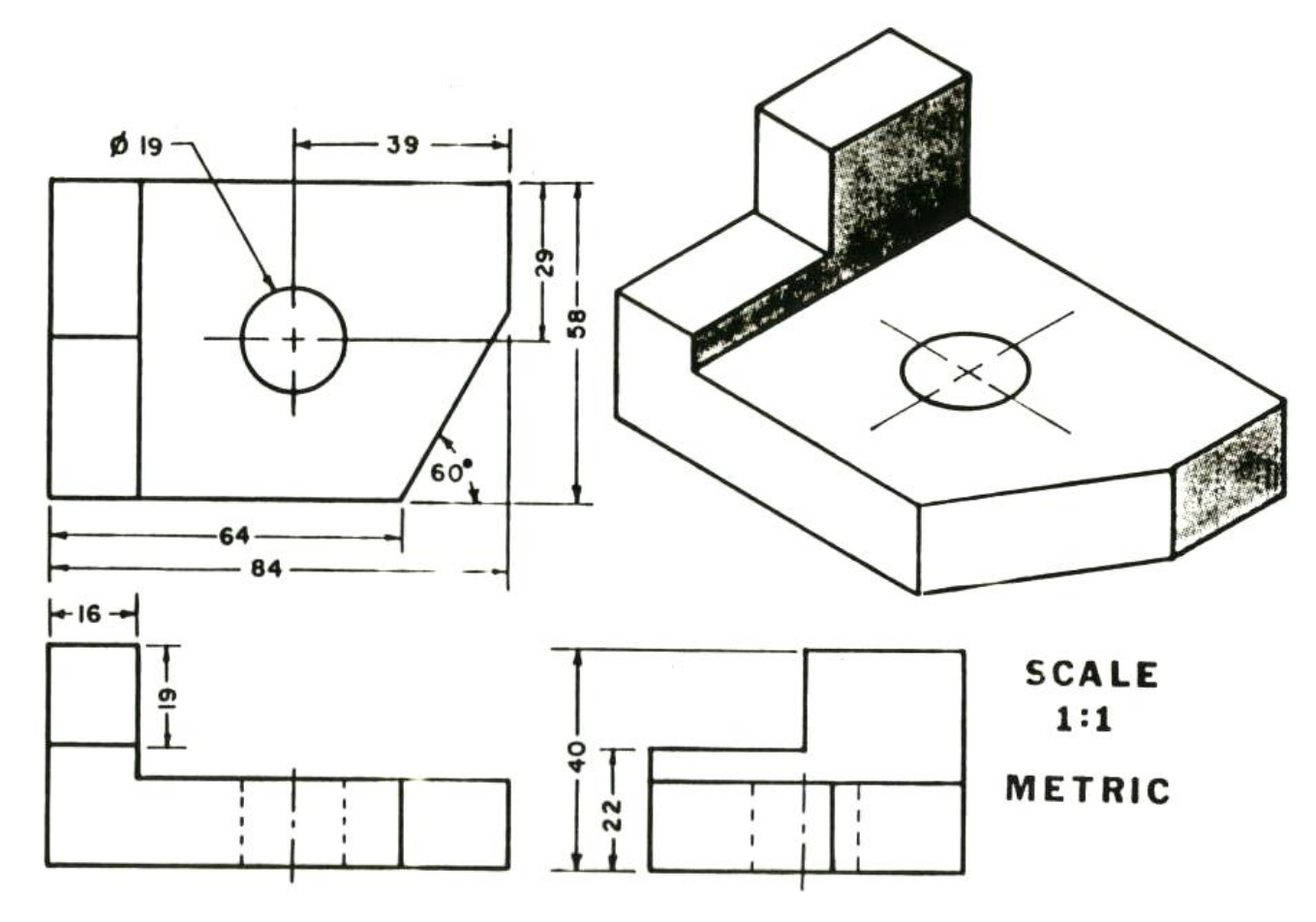

VIEWING-PLANE LINE
EXTENSION LINE
DIMENSION LINE
CENTERLINE
HIDDEN LINE
BREAK LINE
2.875
B
B
CUTTING-PLANE LINE
VISIBLE LINE
A
A
CENTERLINE
(PATH OF MOTION)
LEADER
CHAIN LINE
PHANTOM LINE
SECTION LINE
SECTION A-A
VIEW B-B

Line Types

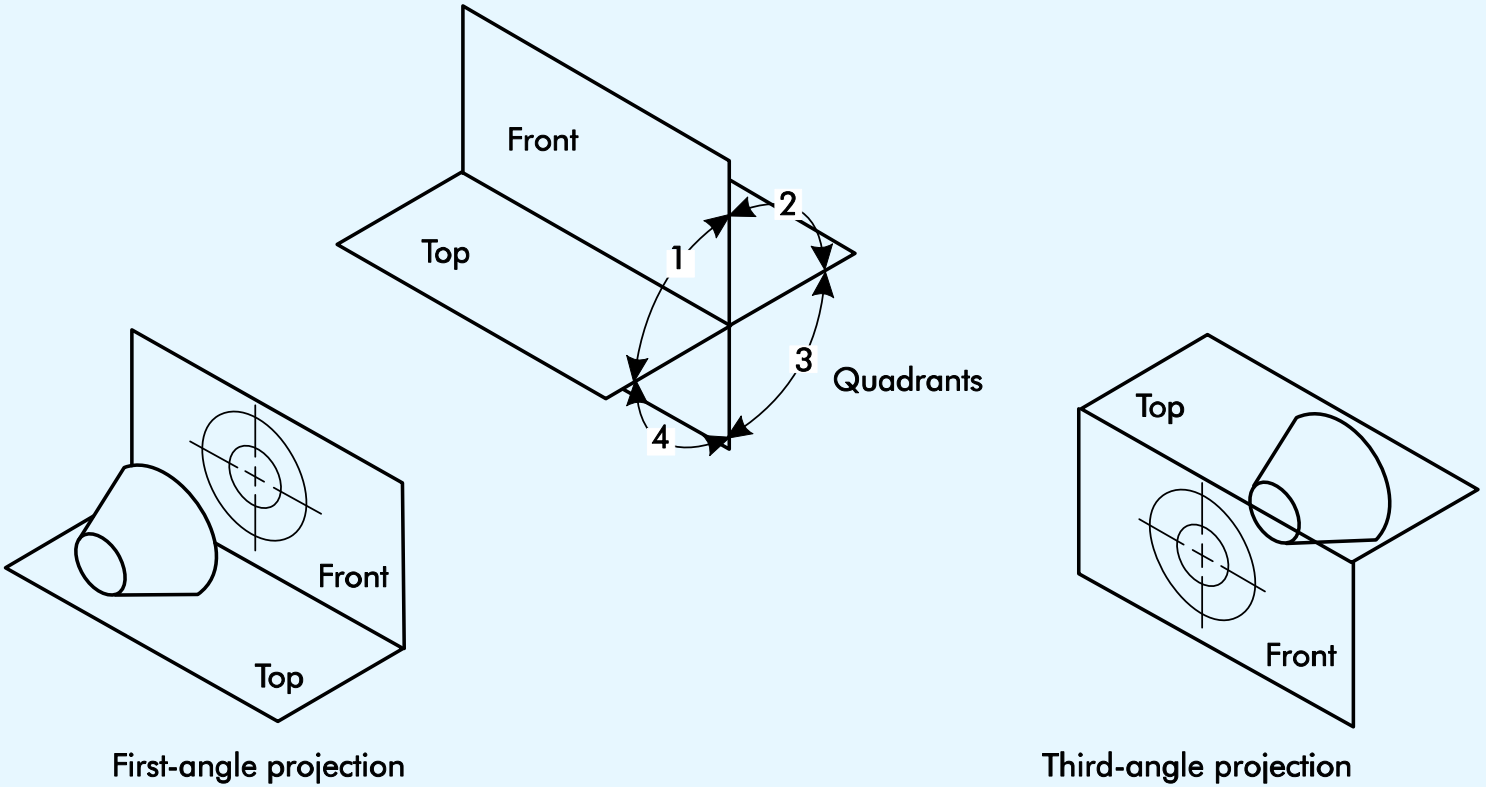
Line Type	Application
Visible or object	Visible edges of parts
Hidden	Hidden edges of parts that are not directly visible in a view
Section	Cut surfaces of a cross section
Center	Center positions of holes, shafts, radii, and arcs
Dimension	Size and location of part features
Extension	Locate the extent of the dimension
Leader	Special details, notes, or specifications
Cutting plane	Position and path of an imaginary cut made to form a sectional view
Short break	End of the partially illustrated portion of a small detail
Long break	End of the partially illustrated portion of a large detail
Phantom	Position and relationship of adjacent parts and alternate positions of moving parts

F 16-1

Engineering Drawing

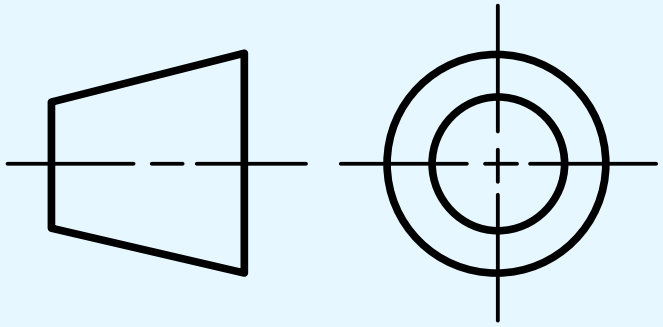


Multiview Projection

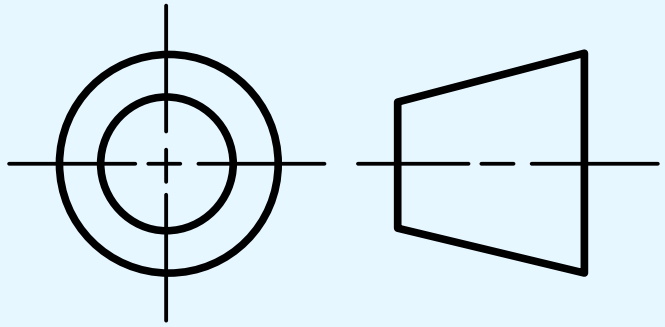


F 16-2 Standards

Projection Symbols



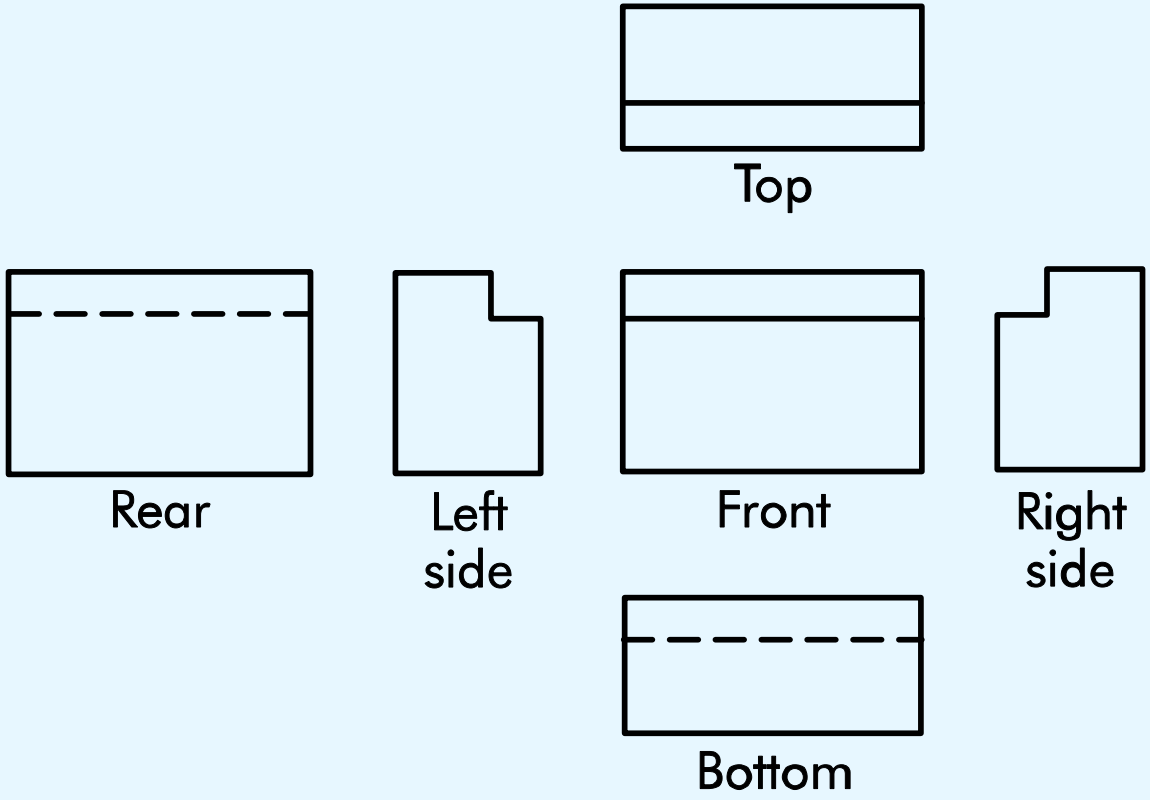
First-angle projection



Third-angle projection

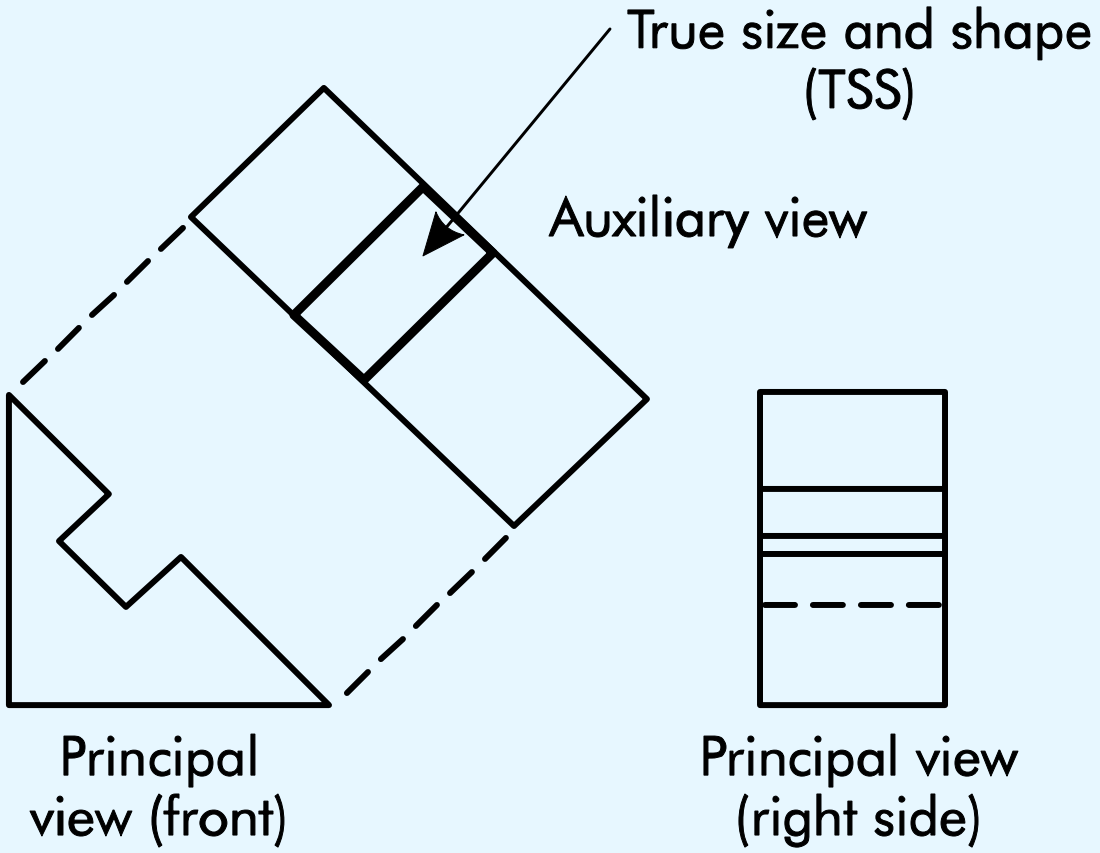
F 16-3 Symbols

Third Angle Projection



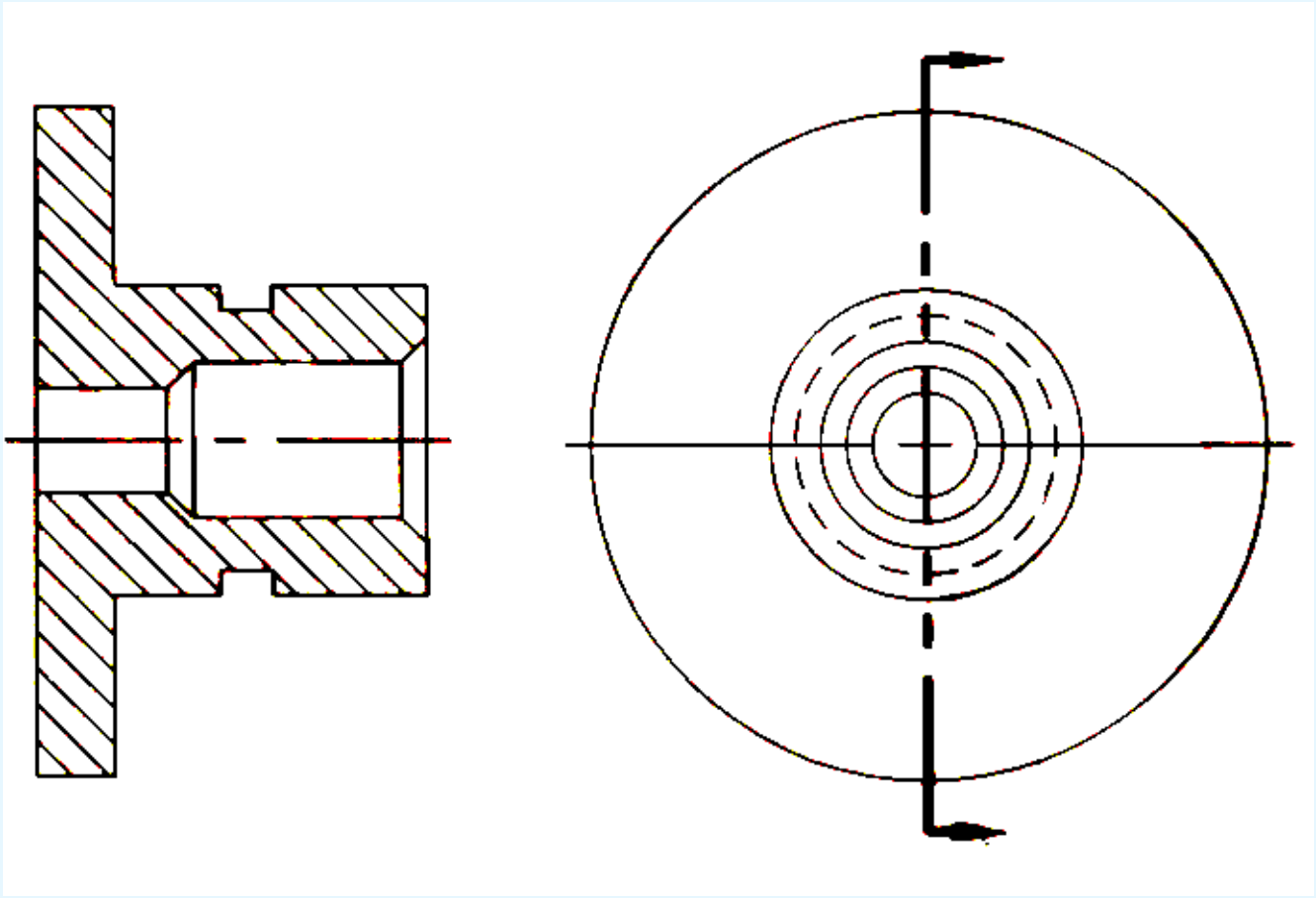
F 16-4 Six principal views

Primary Auxiliary View

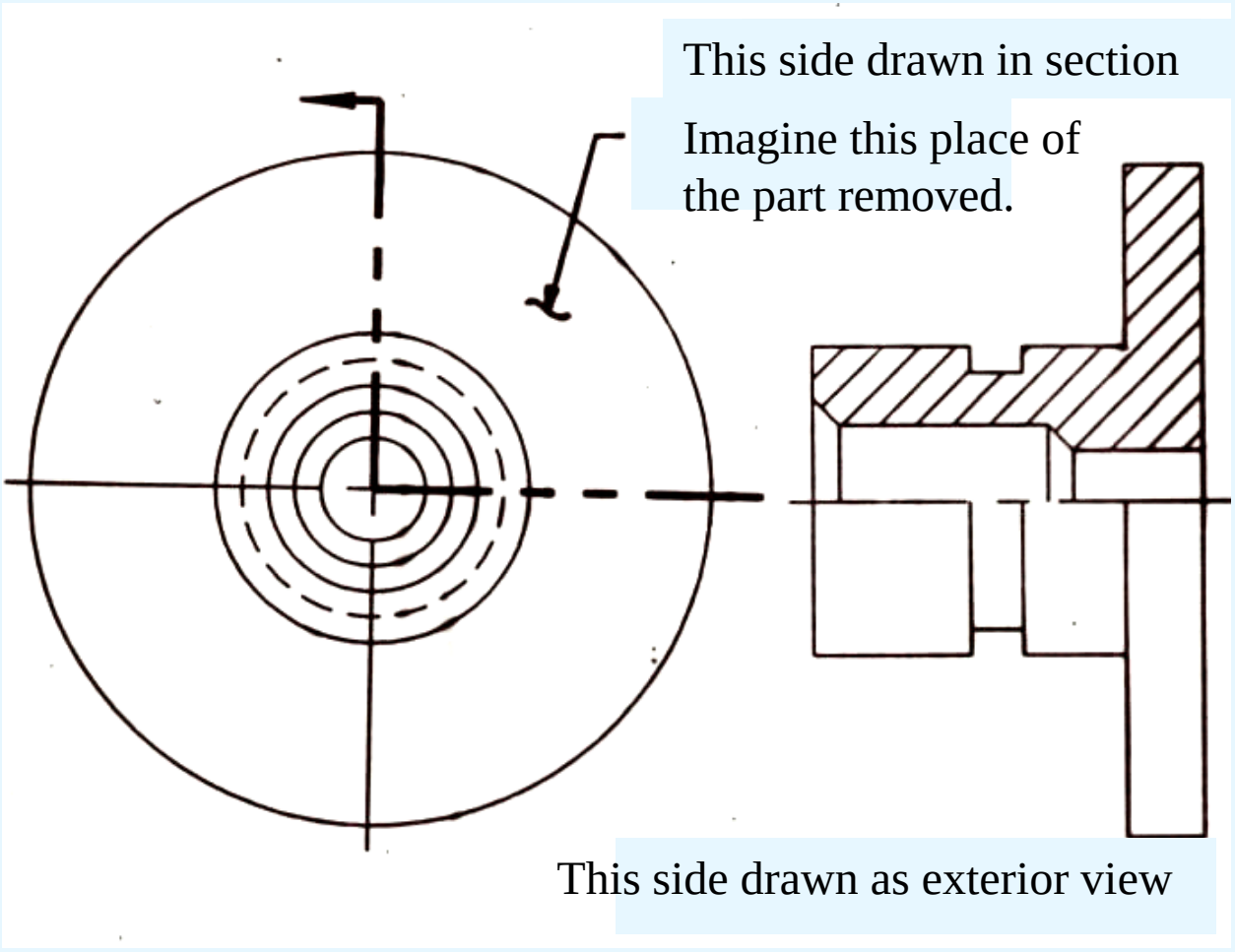


F 16-5 Auxiliary view

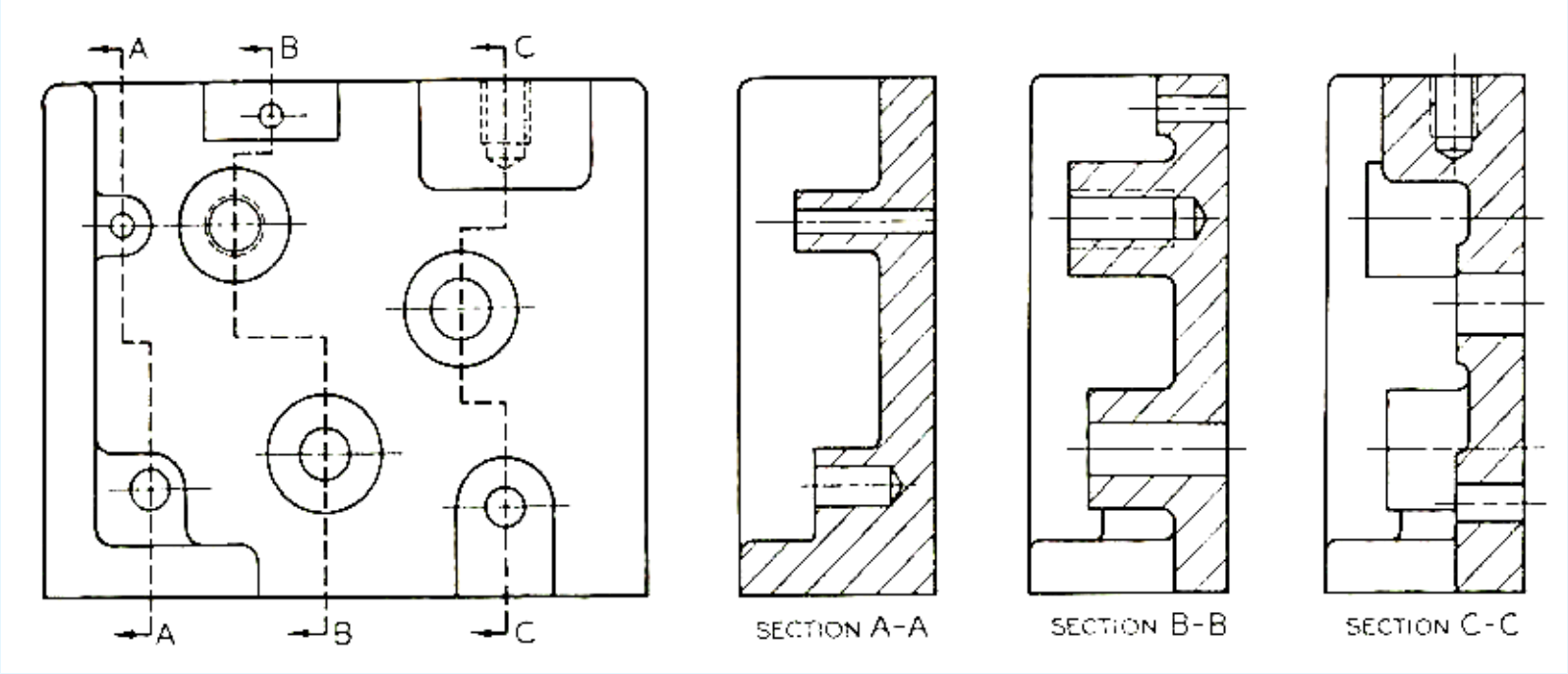
Full Section



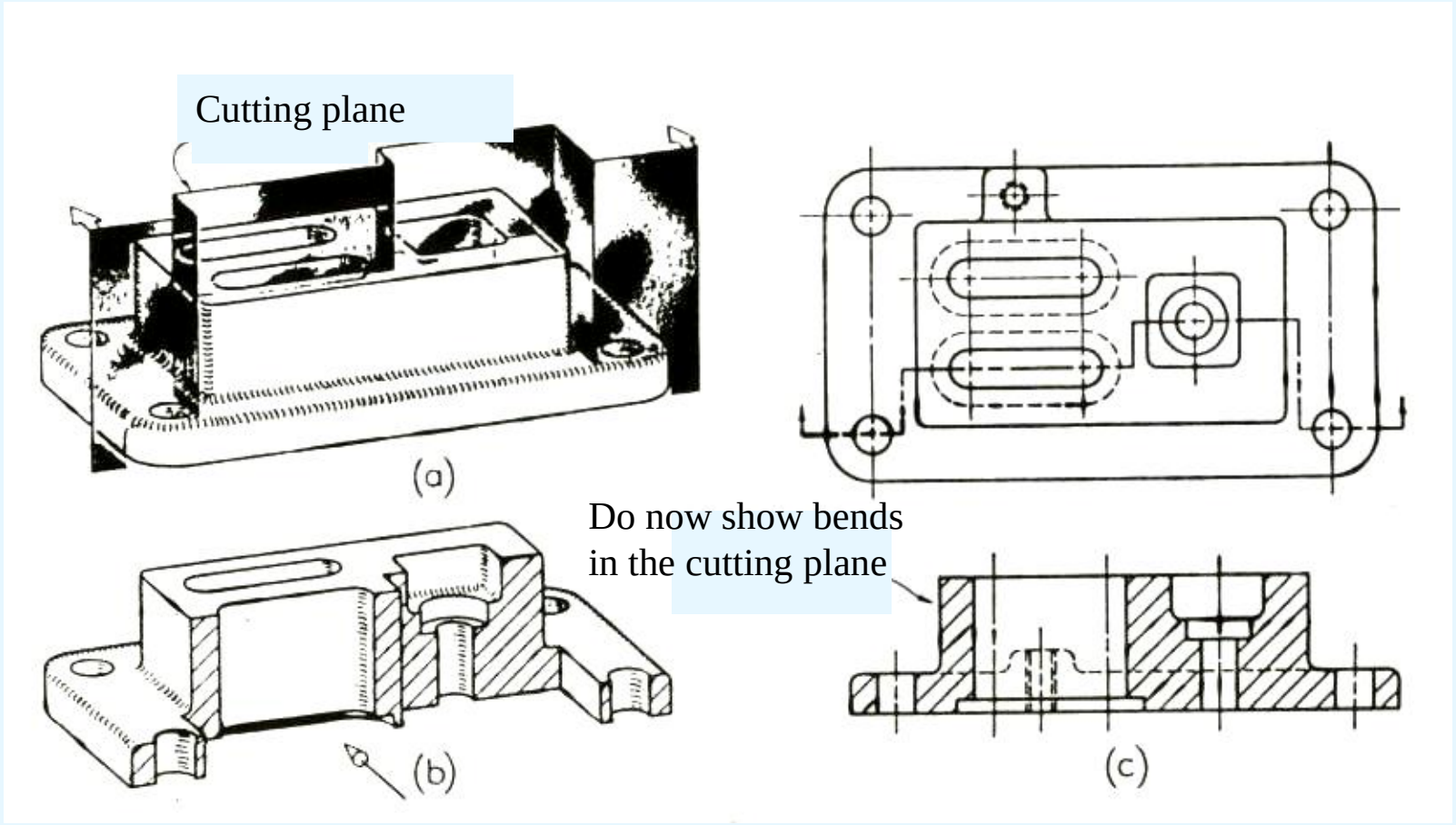
Half Section



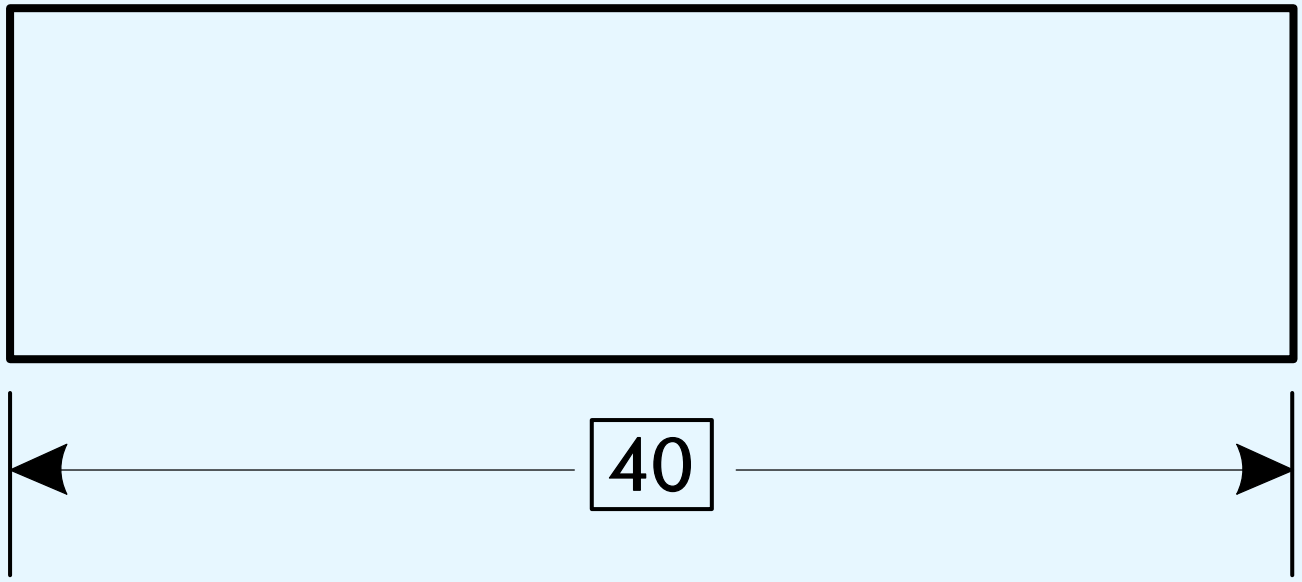
Offset Section



Offset Section

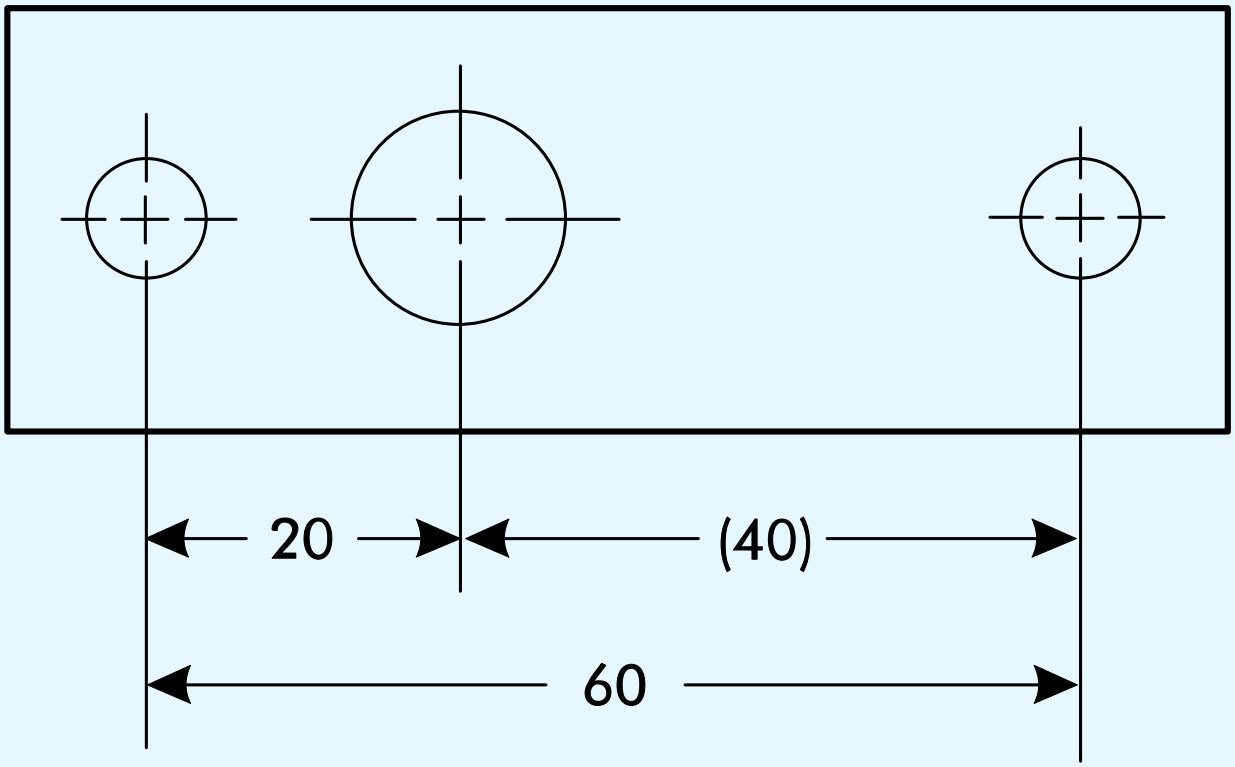


Dimensioning



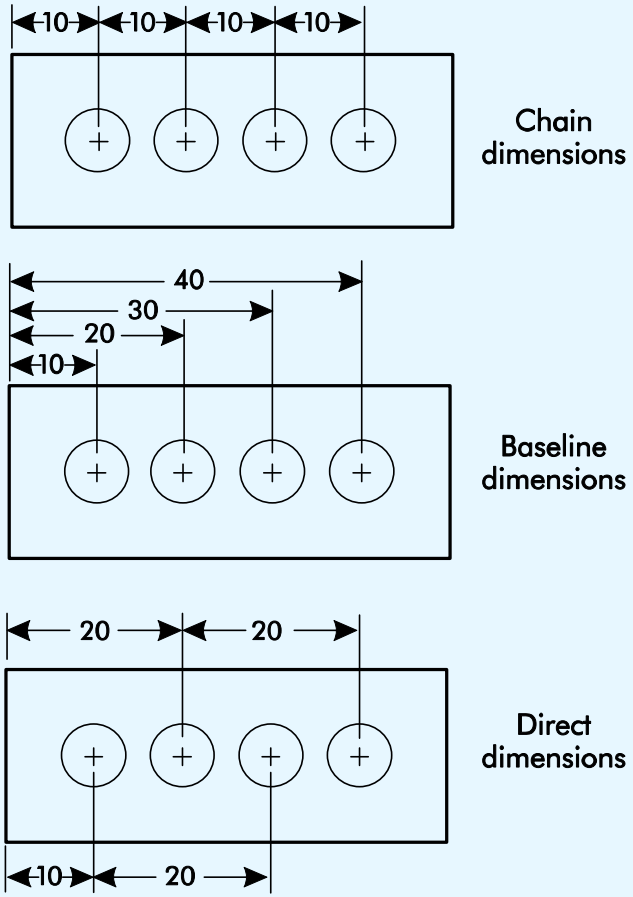
F 16-8 Basic dimension

Dimensioning



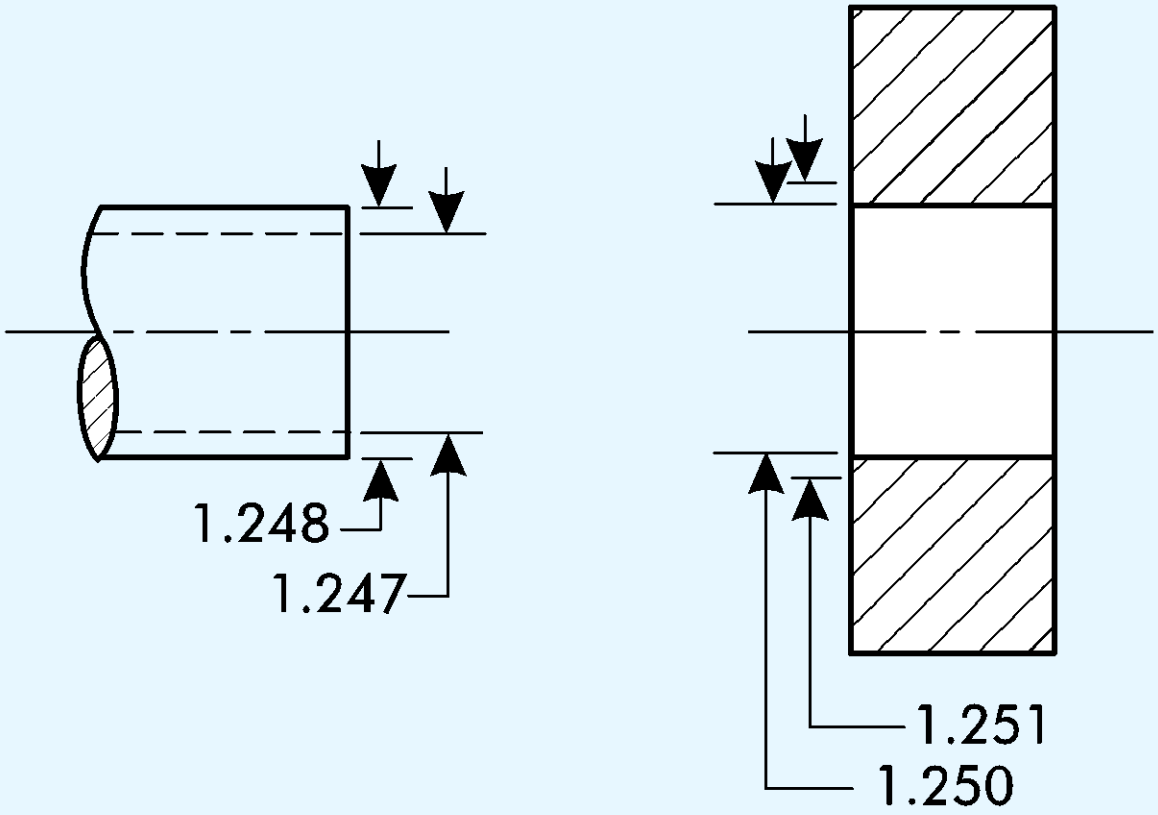
F 16-9 Reference dimension

Dimensioning



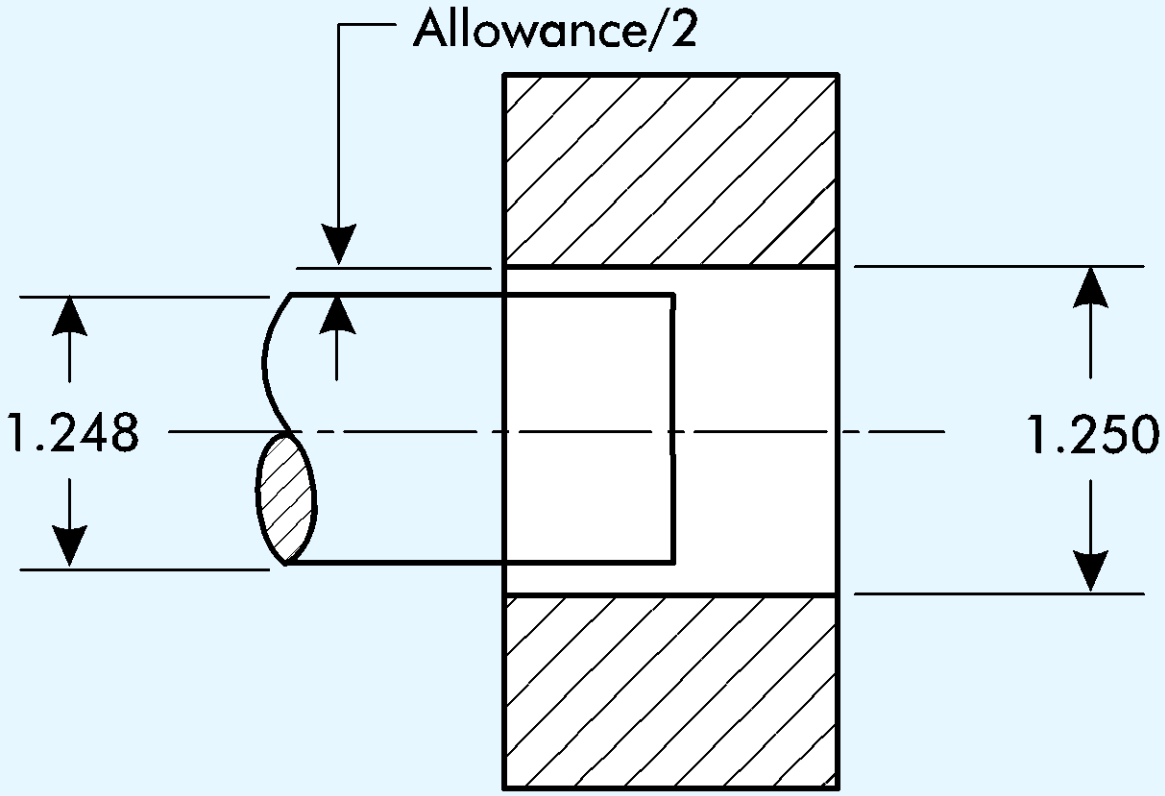
F 16-10 Types of dimensioning

Tolerancing



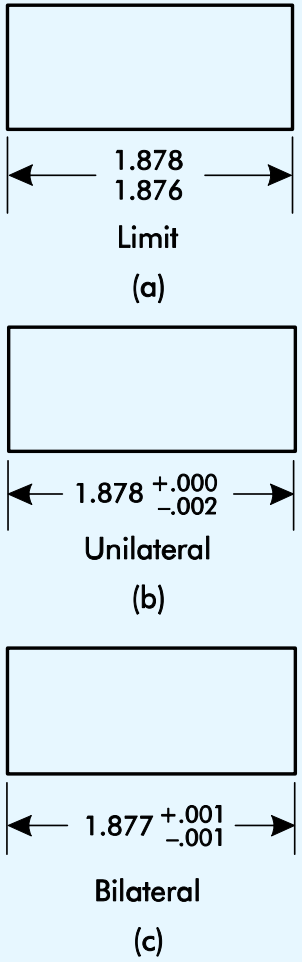
F 16-11 Mating parts (inches)

Tolerancing



F 16-12 Mating parts (inches)

Tolerancing



F 16-13 Tolerances (inches)

System of Fits

- Hole basis: The system of fits where the minimum hole size is the basic size.

- Shaft basis: The system of fits where the minimum shaft size is the basic size

Fit Types

- Clearance: Gap between mating parts
- Interference: No clearance, force required for assembly
- Transition: Result in either a clearance or an interference fit

Types of Fits

- RC-running and sliding fits
- LC-clearance locational fits
- LT-transition locational fits
- LN-interference locational fits
- FN-force and shrink fits

THE AMERICAN NATIONAL STANDARDS INSTITUTE HAS DEVELOPED FIVE TABLES TO GIVE A SERIES OF FITS ON A UNILATERAL HOLE BASIS. THE FITS OF MATING PARTS IN ANY CLASS PRODUCE APPROXIMATELY SIMILAR PERFORMANCE IN ALL RANGES.

FUNCTIONS OF FITS:

1. RUNNING FITS. 2. LOCATIONAL FITS. 3. FORCE FITS.

SYMBOLS ARE USED TO REFER TO CLASSES OF FITS:

RC RUNNING OR SLIDING FIT | LT TRANSITION FIT
LC LOCATIONAL CLEARANCE FIT | LN LOCATIONAL INTERFERENCE FIT
FN FORCE AND SHRINK FIT

THUS "RC 7" INDICATES A CLASS 7 RUNNING FIT.
THE SYMBOLS ARE NOT USED ON MANUFACTURING DRAWINGS; INSTEAD THE SIZES ARE SPECIFIED.

RUNNING AND SLIDING FITS — Limits are in thousandths of an inch.

Nominal Size Range Inches Over	To	Class RC 1 Limits of Clearance	Class RC 1 Standard Limits Hole H5	Class RC 1 Standard Limits Shaft g4	Class RC 2 Limits of Clearance	Class RC 2 Standard Limits Hole H6	Class RC 2 Standard Limits Shaft g5	Class RC 3 Limits of Clearance	Class RC 3 Standard Limits Hole H7	Class RC 3 Standard Limits Shaft f6	Class RC 7 Limits of Clearance	Class RC 7 Standard Limits Hole H9	Class RC 7 Standard Limits Shaft d8	Class RC 8 Limits of Clearance	Class RC 8 Standard Limits Hole H10	Class RC 8 Standard Limits Shaft c9	Class RC 9 Limits of Clearance	Class RC 9 Standard Limits Hole H11	Class RC 9 Standard Limits Shaft
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	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	0.15 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	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	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	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	0.25																+ 4.0 0	– 6.0 – 8.8

THERE ARE NINE CLASSES OF RC FITS (4,5,6 NOT SHOWN.)

RC 1 AND RC 2 – SLIDING FITS.
RC 3 – PRECISION RUNNING FITS.
RC 4 – CLOSE RUNNING FITS.
RC 5 AND RC 6 – MEDIUM RUNNING FITS.
RC 7 – FREE RUNNING FITS.
RC 8 AND RC 9 – LOOSE RUNNING FITS.

FOR COMPLETE LIMITS TABLES SEE B4.1 1967.

5 Running and Sliding Fits[a]—American National Standard

RC 1 *Close sliding fits* are intended for the accurate location of parts which must assemble without perceptible play.

RC 2 *Sliding fits* are intended for accurate location, but with greater maximum clearance than class RC 1. Parts made to this fit move and turn easily but are not intended to run freely, and in the larger sizes may seize with small temperature changes.

RC 3 *Precision running fits* are about the closest fits which can be expected to run freely, and are intended for precision work at slow speeds and light journal pressures, but are not suitable where appreciable temperature differences are likely to be encountered.

RC 4 *Close running fits* are intended chiefly for running fits on accurate machinery with moderate surface speeds and journal pressures, where accurate location and minimum play are desired.

Basic hole system. Limits are in thousandths of an inch. See §14.8.

Limits for hole and shaft are applied algebraically to the basic size to obtain the limits of size for the parts.

Data in **boldface** are in accordance with ABC agreements.

Symbols H5, g5, etc., are hole and shaft designations used in ABC System.

FORCE OR SHRINK FITS ARE A SPECIAL TYPE OF FITS WITH CONSTANT BORE PRESSURE THROUGHOUT THE RANGE OF SIZES.

THERE ARE FIVE CLASSES OF FN FITS:

FN 1—LIGHT DRIVE FITS. | FN 3—HEAVY DRIVE FITS.

FN 2—MEDIUM DRIVE FITS. | FN 4 AND FN 5—FORCE OR SHRINK FITS.

FORCE AND SHRINK FITS

Nominal Size Range Inches		Class FN 1			Class FN 2			Class FN 3			Class FN 4			Class FN 5		
		Limits of Interference	Standard Limits		Limits of Interference	Standard Limits		Limits of Interference	Standard Limits		Limits of Interference	Standard Limits		Limits of Interference	Standard Limits	
Over	To		Hole H6	Shaft		Hole H7	Shaft s6		Hole H7	Shaft t6		Hole H7	Shaft u6		Hole H7	Shaft x7
0	0.12	0.05 0.5	+0.25 − 0	+ 0.5 + 0.3	0.2 0.85	+ 0.4 − 0	+ 0.85 + 0.6				0.3 0.95	+ 0.4 − 0	+ 0.95 + 0.7	0.5 1.3	+ 0.4 − 0	+ 1.3 + 0.9
0.12	0.24	0.1 0.6	+0.3 − 0	+ 0.6 + 0.4	0.2 1.0	+ 0.5 − 0	+ 1.0 + 0.7				0.4 1.2	+ 0.5 − 0	+ 1.2 + 0.9	0.7 1.7	+ 0.5 − 0	+ 1.7 + 1.2
0.71	0.95	0.2 1.1	+0.5 − 0	+ 1.1 + 0.7	0.6 1.9	+ 0.8 − 0	+ 1.9 + 1.4				0.8 2.1	+ 0.8 − 0	+ 2.1 + 1.6	1.4 3.0	+ 0.8 − 0	+ 3.0 + 2.2
0.95	1.19	0.3 1.2	+0.5 − 0	+ 1.2 + 0.8	0.6 1.9	+ 0.8 − 0	+ 1.9 + 1.4	0.8 2.1	+ 0.8 − 0	+ 2.1 + 1.6	1.0 2.3	+ 0.8 − 0	+ 2.3 + 1.8	1.7 3.3	+ 0.8 − 0	+ 3.3 + 2.5

Nominal size range (in.)†	Class RC 1			Class RC 2			Class RC 3			Class RC 4		
	Limits of clearance	Standard limits		Limits of clearance	Standard limits		Limits of clearance	Standard limits		Limits of clearance.	Standard limits	
Over To		Hole H5	Shaft g4		Hole H6	Shaft g5		Hole H7	Shaft f6		Hole H8	Shaft f7
0–.12	.1 .45	+.2 0	−.1 .25	.1 .55	+.25 0	−.1 −.3	.3 .95	+.4 0	−.3 −.55	.3 1.3	+.6 0	−.3 −.7
.12–.24	.15 .5	+.2 0	−.15 −.3	.15 .65	+.3 0	−.15 −.35	.4 1.12	+.5 0	−.4 −.7	.4 1.6	+.7 0	−.4 −.9
.24–.40	.2 .6	.25 0	−.2 −.35	.2 .85	+.4 0	−.2 −.45	.5 1.5	+.6 0	−.5 −.9	.5 2.0	+.9 0	−.5 −1.1
.40–.71	.25 .75	+.3 0	−.25 −.45	.25 .95	+.4 0	−.25 −.55	.6 1.7	+.7 0	−.6 −1.0	.6 2.3	+1.0 0	−.6 −1.3
.71–1.19	.3 .95	+.4 0	−.3 −.55	.3 1.2	+.5 0	−.3 −.7	.8 2.1	+.8 0	−.8 −1.3	.8 2.8	+1.2 0	−.8 −1.6
1.19–1.97	.4 1.1	+.4 0	−.4 −.7	.4 1.4	+.6 0	−.4 −.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	.4 1.2	+.5 0	−.4 −.7	.4 1.6	+.7 0	−.4 −.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	.5 1.5	+.6 0	−.5 −.9	.5 2.0	+.9 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	.6 1.8	+.7 0	−.6 −1.1	.6 2.3	+1.0 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

Table 52A-2 American National standard running and sliding fits

Nominal size range (in.)	Class RC 5			Class RC 6			Class RC 7			Class RC 8			Class RC 9		
	Limits of clearance	Standard limits		Limits of clearance	Standard limits		Limits of clearance	Standard limits		Limits of clearance	Standard limits		Limits of clearance	Standard limits	
Over To		Hole H8	Shaft e7		Hole H9	Shaft e8		Hole H9	Shaft d8		Hole H10	Shaft c9		Hole H11	Shaft
0–.12	.6 1.6	+.6 −0	−.6 −1.0	.6 2.2	+1.0 −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
.12–.24	.8 2.0	+.7 −0	−.8 −1.3	.8 2.7	+1.2 −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
.24–.40	1.0 2.5	+.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
.40–.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
.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

Nominal Size Range, inches		Class RC 1			Class RC 2			Class RC 3			Class RC 4		
		Limits of Clearance	Standard Limits		Limits of Clearance	Standard Limits		Limits of Clearance	Standard Limits		Limits of Clearance	Standard Limits	
Over	To		Hole H5	Shaft g4		Hole H6	Shaft g5		Hole H7	Shaft f6		Hole H8	Shaft f7
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

Nominal size range (in.)	Class FN 1			Class FN 2			Class FN 3			Class FN 4			Class FN 5		
	Limits of interference	Standard limits		Limits of interference	Standard limits		Limits of interference	Standard limits		Limits of interference	Standard limits		Limits of interference	Standard limits	
Over To		Hole H6	Shaft		Hole H7	Shaft s6		Hole H7	Shaft t6		Hole H7	Shaft u6		Hole H8	Shaft z7
0–.12	.05 .5	+.25 −0	+.5 +.3	.2 .85	+.4 −0	+.85 +.6				.3 .95	+.4 −0	+.95 +.7	.3 1.3	+.6 −0	+1.3 +.9
.12–.24	.1 .6	+.3 −0	+.6 +.4	.2 1.0	+.5 −0	+1.0 +.7				.4 1.2	+.5 −0	+1.2 +.9	.5 1.7	+.7 −0	+1.7 +1.2
.24–.40	.1 .75	+.4 −0	+.75 +.5	.4 1.4	+.6 −0	+1.4 +1.0				.6 1.6	+.6 −0	+1.6 +1.2	.5 2.0	+.9 −0	+2.0 +1.4
.40–.56	.1 .8	+.4 −0	+.8 +.5	.5 1.6	+.7 −0	+1.6 +1.2				.7 1.8	+.7 −0	+1.8 +1.4	.6 2.3	+1.0 −0	+2.3 +1.6
.56–.71	.2 .9	+.4 −0	+.9 +.6	.5 1.6	+.7 −0	+1.6 +1.2				.7 1.8	+.7 −0	+1.8 +1.4	.8 2.5	+1.0 −0	+2.5 +1.8
.71–.95	.2 1.1	+.5 −0	+1.1 +.7	.6 1.9	+.8 −0	+1.9 +1.4				.8 2.1	+.8 −0	+2.1 +1.6	1.0 3.0	+1.2 −0	+3.0 +2.2
.95–1.19	.3 1.2	+.5 −0	+1.2 +.8	.6 1.9	+.8 −0	+1.9 +1.4	.8 2.1	+.8 −0	+2.1 +1.6	1.0 2.3	+.8 −0	+2.3 +1.8	1.3 3.3	+1.2 −0	+3.3 +2.5
1.19–1.58	.3 1.3	+.6 −0	+1.3 +.9	.8 2.4	+1.0 −0	+2.4 +1.8	1.0 2.6	+1.0 −0	+2.6 +2.0	1.5 3.1	+1.0 −0	+3.1 +2.5	1.4 4.0	+1.6 −0	+4.0 +3.0
1.58–1.97	.4 1.4	+.6 −0	+1.4 +1.0	.8 2.4	+1.0 −0	+2.4 +1.8	1.2 2.8	+1.0 −0	+2.8 +2.2	1.8 3.4	+1.0 −0	+3.4 +2.8	2.4 5.0	+1.6 −0	+5.0 +4.0
1.97–2.56	.6 1.8	+.7 −0	+1.8 +1.3	.8 2.7	+1.2 −0	+2.7 +2.0	1.3 3.2	+1.2 −0	+3.2 +2.5	2.3 4.2	+1.2 −0	+4.2 +3.5	3.2 6.2	+1.8 −0	+6.2 +5.0
2.56–3.15	.7 1.9	+.7 −0	+1.9 +1.4	1.0 2.9	+1.2 −0	+2.9 +2.2	1.8 3.7	+1.2 −0	+3.7 +3.0	2.8 4.7	+1.2 −0	+4.7 +4.0	4.2 7.2	+1.8 −0	+7.2 +6.0
3.15–3.94	.9 2.4	+.9 −0	+2.4 +1.8	1.4 3.7	+1.4 −0	+3.7 +2.8	2.1 4.4	+1.4 −0	+4.4 +3.5	3.6 5.9	+1.4 −0	+5.9 +5.0	4.8 8.4	+2.2 −0	+8.4 +7.0
3.94–4.73	1.1 2.6	+.9 −0	+2.6 +2.0	1.6 3.9	+1.4 −0	+3.9 +3.0	2.6 4.9	+1.4 −0	+4.9 +4.0	4.6 6.9	+1.4 −0	+6.9 +6.0	5.8 9.4	+2.2 −0	+9.4 +8.0

TABLE 5 RUNNING AND SLIDING FITS

LIMITS ARE IN THOUSANDTHS OF AN INCH

Nominal Size Range Inches Over	To	Class RC 1 Limits of Clearance	Class RC 1 Standard Limits Hole H5	Class RC 1 Standard Limits Shaft g4	Class RC 2 Limits of Clearance	Class RC 2 Standard Limits Hole H6	Class RC 2 Standard Limits Shaft g5	Class RC 3 Limits of Clearance	Class RC 3 Standard Limits Hole H7	Class RC 3 Standard Limits Shaft f6	Class RC 4 Limits of Clearance	Class RC 4 Standard Limits Hole H8	Class RC 4 Standard Limits Shaft f7
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	+ 0.5	– 0.4	0.4	+ 0.7	– 0.4	1.2	+ 1.2	– 1.2	1.2	+ 1.8	– 1.2 – 2.4

USA STANDARDS

PROBLEM: FIND THE LIMITS DIMENSION FOR AN 11/16" (.6875) DIA SHAFT WITH AN RC 4 FIT.

1. LOCATE THE NOMINAL RANGE.
2. FIND THE LIMITS IN THE RC4 SHAFT COLUMN.
3. APPLY THE LIMITS ALGEBRAICALLY.

BASIC SIZE: .6875 .6875
LIMITS: –.0006 –.0013
LIMITS DIMENSION: .6869 .6862

TABLE 5 RUNNING AND SLIDING FITS

LIMITS ARE IN THOUSANDTHS OF AN INCH

Nominal Size Range Inches		Class RC 1			Class RC 2			Class RC 3			Class RC 4		
		Limits of Clearance	Standard Limits		Limits of Clearance	Standard Limits		Limits of Clearance	Standard Limits		Limits of Clearance	Standard Limits	
Over	To		Hole H5	Shaft g4		Hole H6	Shaft g5		Hole H7	Shaft f6		Hole H8	Shaft f7
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	+ 0.5	– 0.4	0.4	+ 0.7	– 0.4	1.2	+ 1.2	– 1.2	1.2	+ 1.8	– 1.2 – 2.4

USA STANDARDS

PROBLEM: FIND THE LIMITS DIMENSION FOR AN 11/16" (.6875) DIA HOLE WITH AN RC 4 FIT.

1. LOCATE THE NOMINAL RANGE.
2. FIND THE LIMITS IN THE RC 4 HOLE COLUMN.
3. APPLY THE LIMITS ALGEBRAICALLY.

BASIC SIZE:	.6875	.6875
LIMITS:	.0000	+.0010
LIMITS DIMENSION:	.6875	.6885

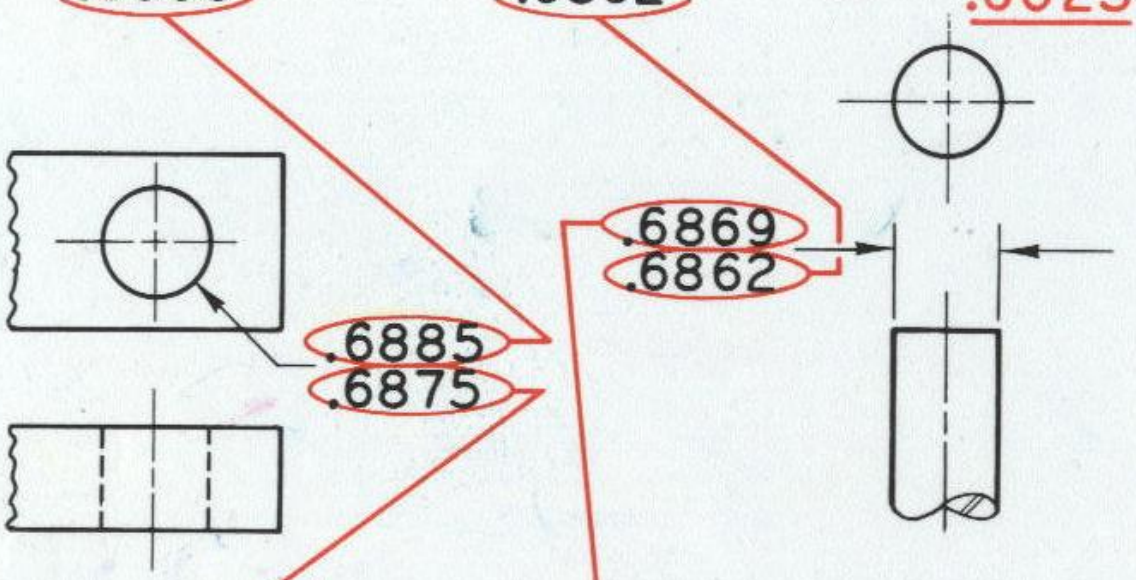
LIMITS FOR OTHER TYPES OF FITS ARE APPLIED IN LIKE MANNER.

ALLOWANCE

THE DIFFERENCE BETWEEN THE LARGEST AND SMALLEST ACCEPTABLE MATING PARTS.

(LARGEST HOLE) − (SMALLEST SHAFT) = (MAX ALLOW)

.6885 − .6862 = .0023



.6875 − .6869 = .0006

(SMALLEST HOLE) − (LARGEST SHAFT) = (MIN ALLOW)

Hole Basis	Shaft Basis	Description
H11/c11	C11/hll	Loose running fit for wide commercial tolerances or allowances on external members.
H9/d9	D9/h9	Free running fit for running accurate machines and for accurate location at moderate speeds and journal pressures.
H8/f7	F8/h7	Close running fit for running on accurate machines and for accurate location at moderate speeds and journal pressures.
H7/g6	G7/h6	Sliding fit not intended to run freely, but to move and turn freely and locate accurately.
H7/h6	H7/h6	Locational clearance fit provides snug fit for locating stationary parts: but can freely assembled and disassembled.

Hole Basis	Shaft Basis	Description
H7/n6	N7/h6	Location transition fit for more accurate location where greater interference is permissible.
H7/p6	P7/h6	Locational interference fit for parts requiring rigidity and alignment with prime accuracy of location but without special bore pressure requirements.
H7/s6	P7/h6	Medium drive fit for ordinary steel parts or shrink fits on light sections, the tightest fit usable with cast iron.
H7/u6	U7/h6	Force fit suitable for parts which can be highly stressed or for shrink fits where the heavy pressing forces required are impractical.

Symbols and Their Definitions as Applied Holes and Shafts

- Basic Size
- HOLE
- Fundamental Deviation

40 H8

- Tolerance Grade
- IT Grade

- Basic Size
- SHAFT
- Fundamental Deviation

40 F7

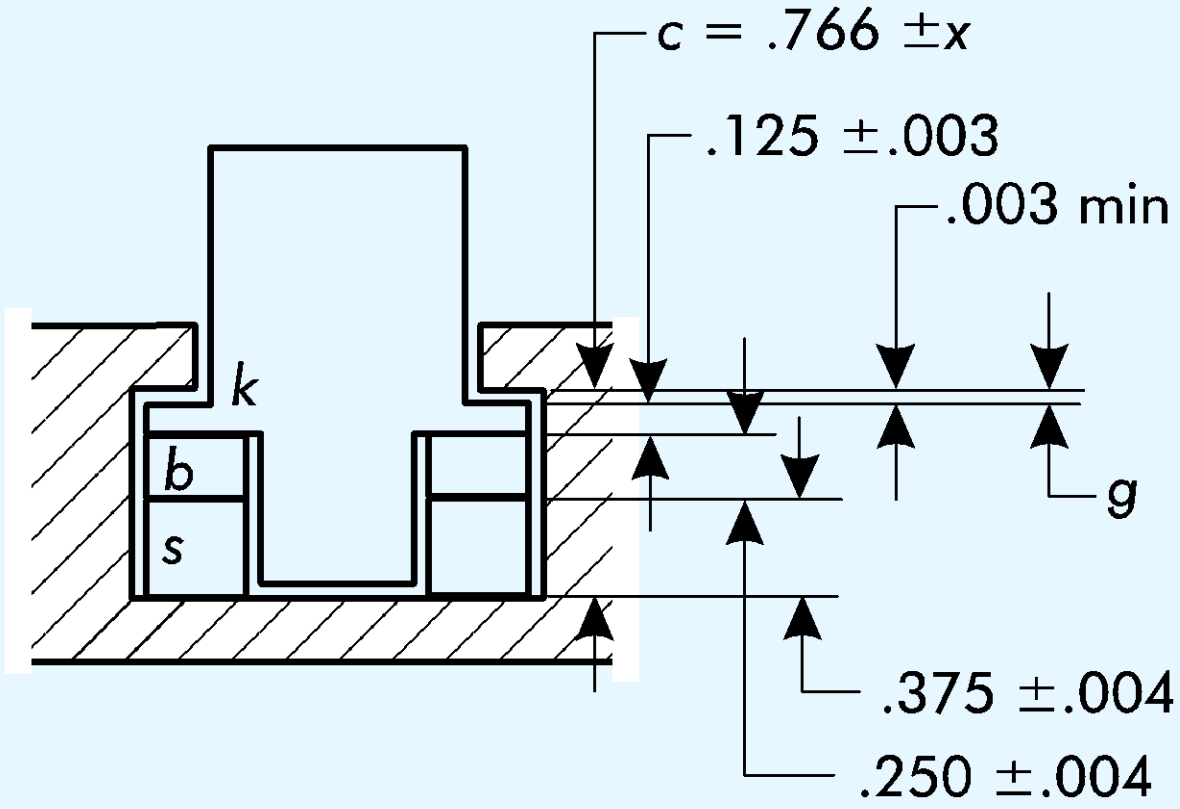
- Tolerance Grade
- IT Grade

- Basic Size
- FIT
- Hole Tolerance

40 H8/f7

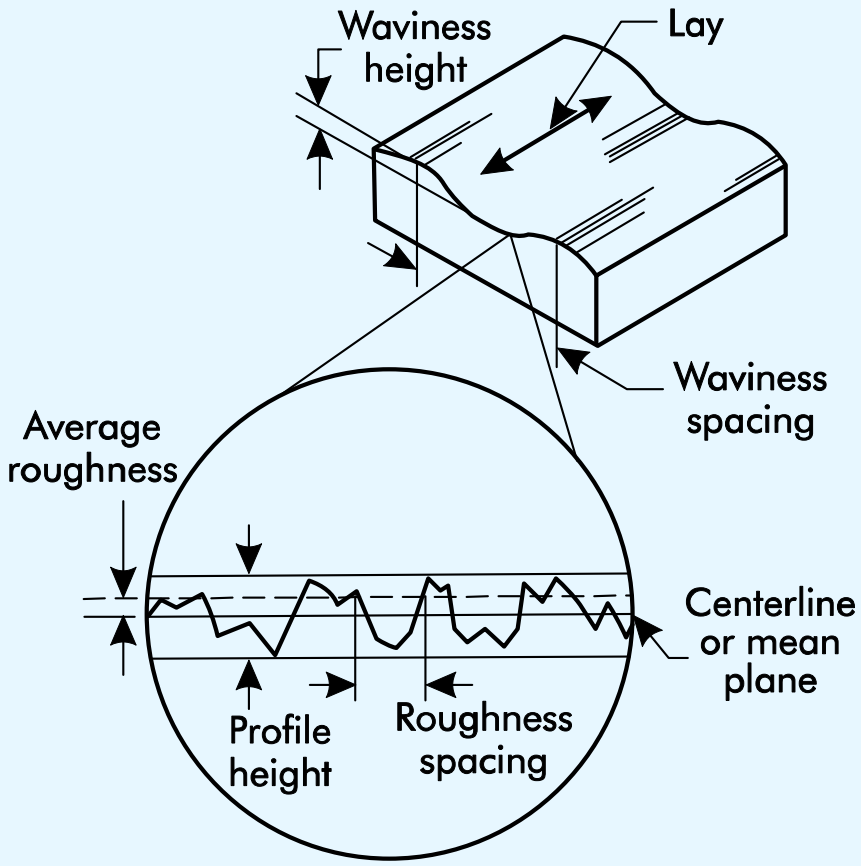
- Fit
- Shaft Tolerance

Tolerances for Interchangeability



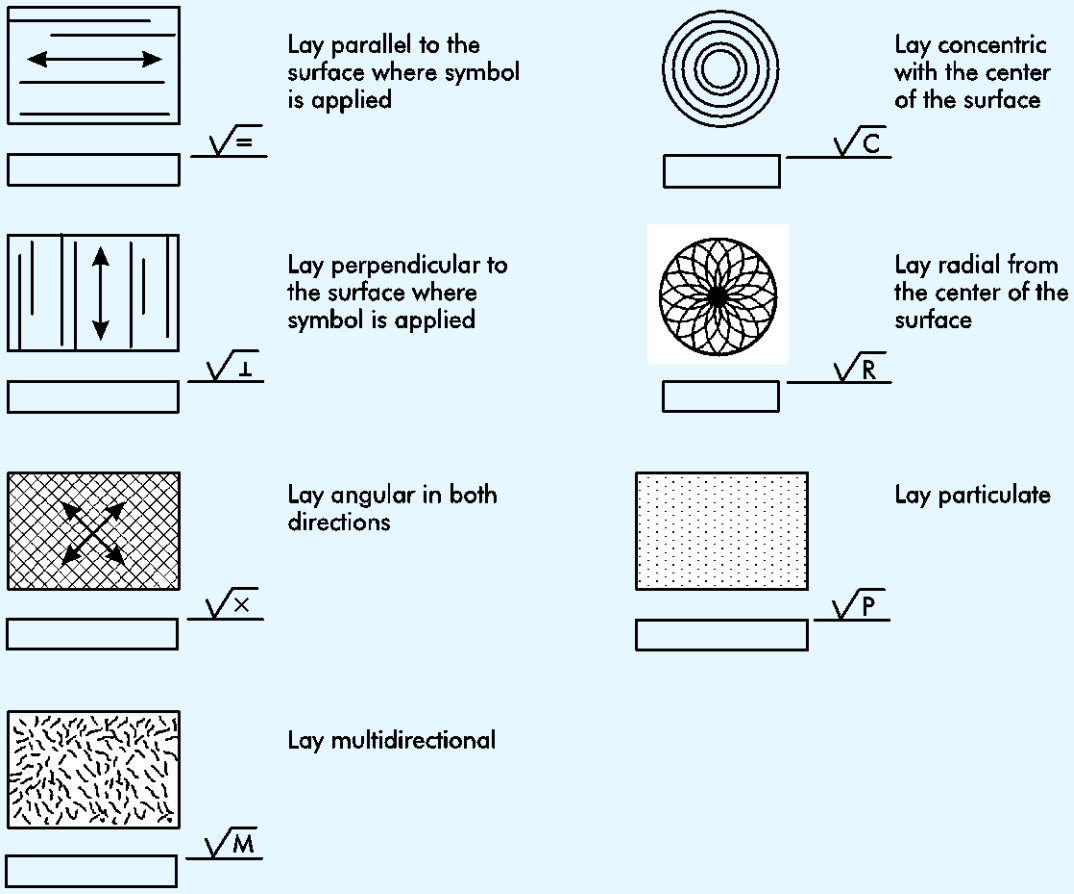
F 16-14 Car knob assembly

Surface Texture



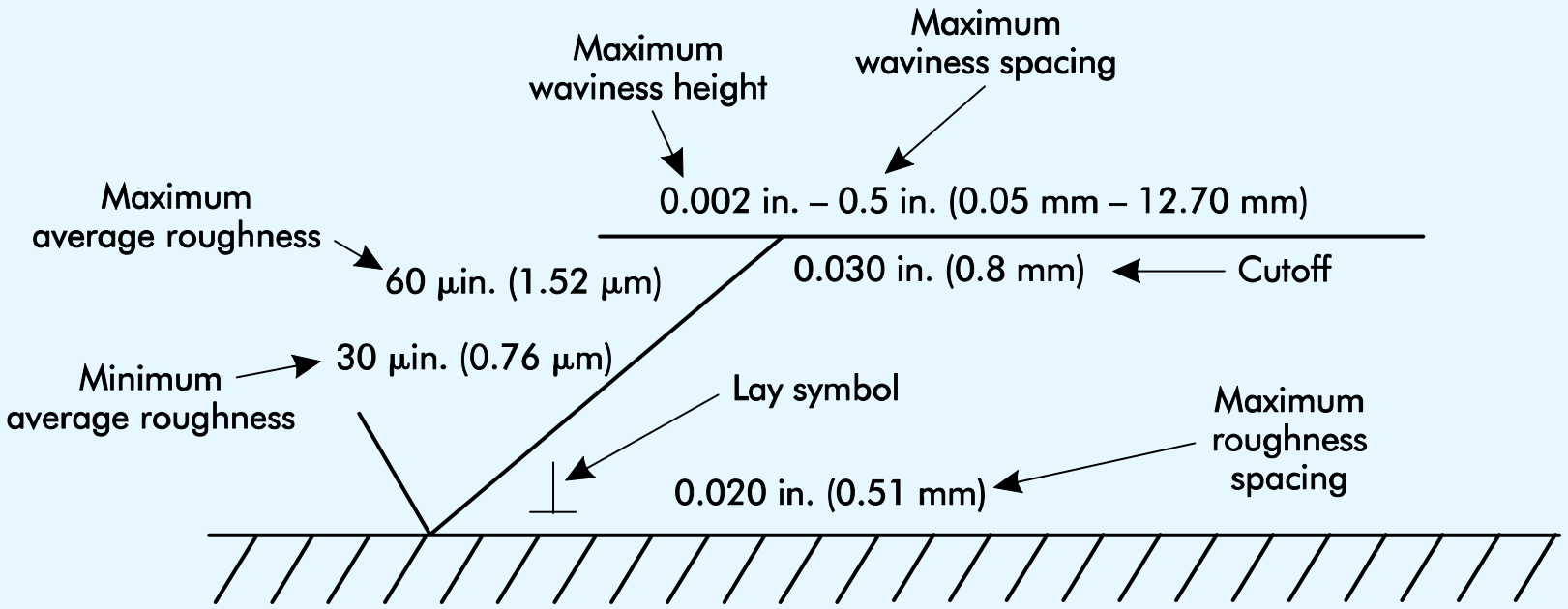
F 16-15 Criteria

Surface Symbols



F 16-16 Standard lay Designations

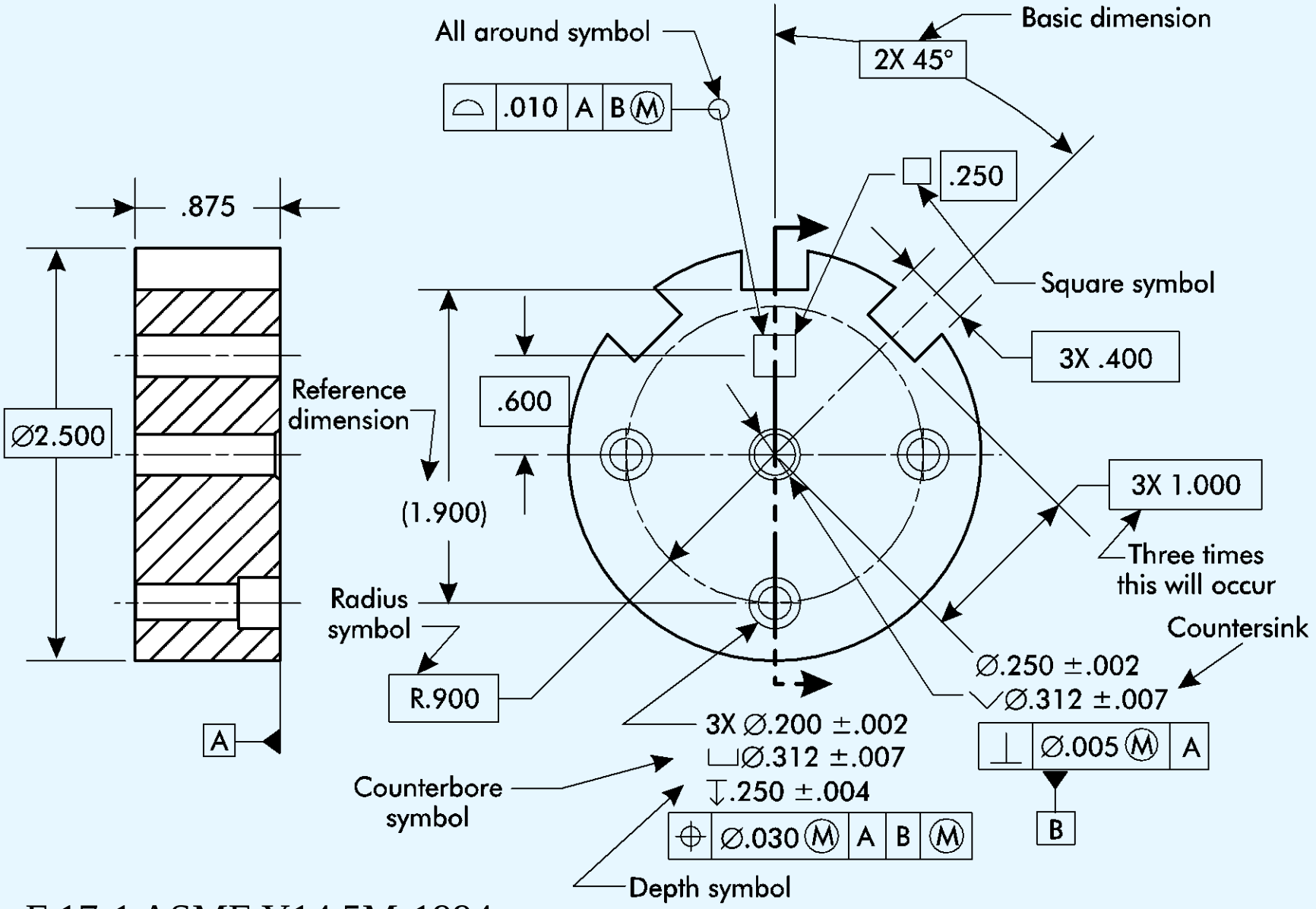
Surface Symbols



F 16-17 Applications

Geometric Dimensioning and Tolerancing

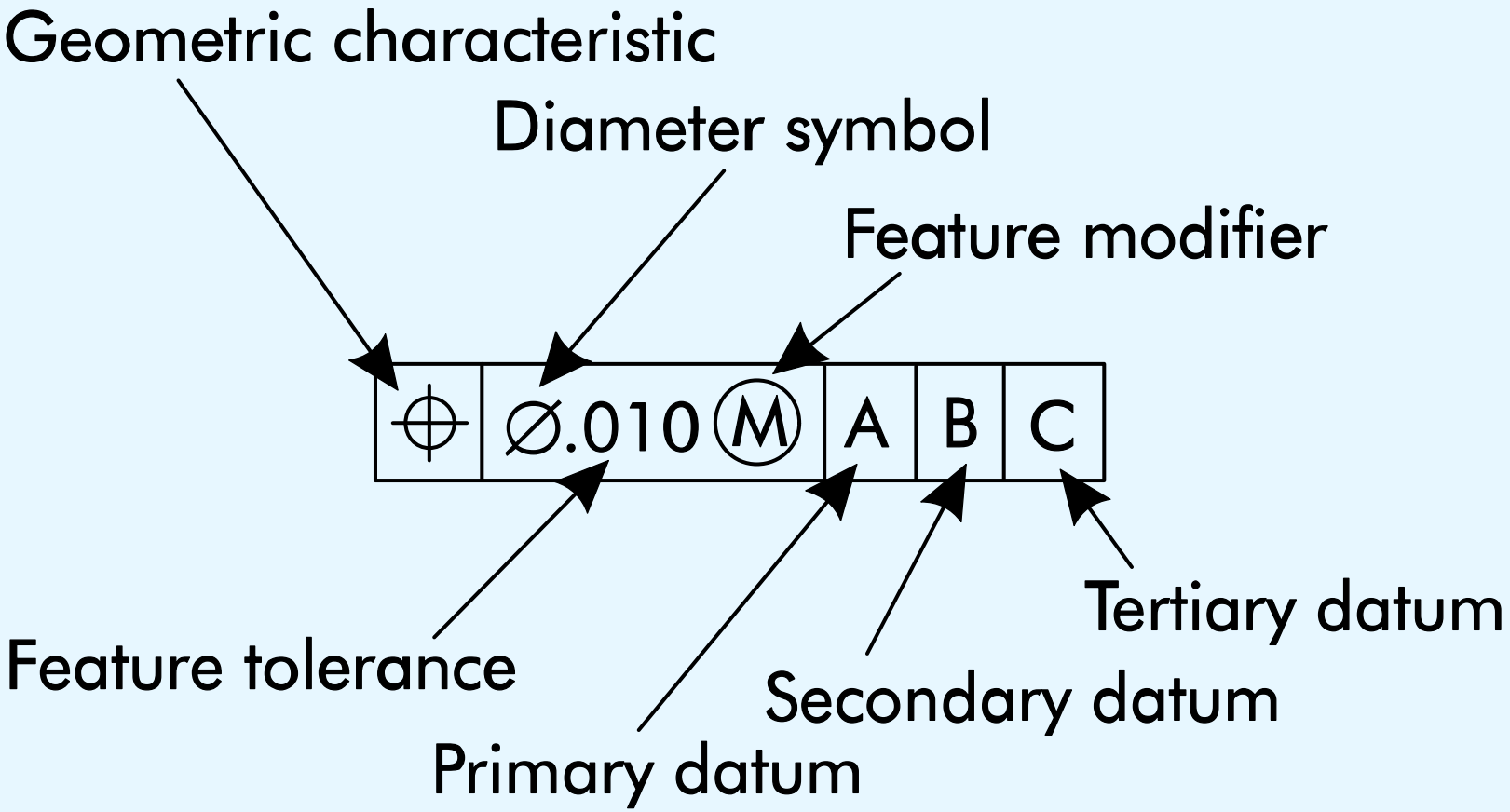
Chapter 17



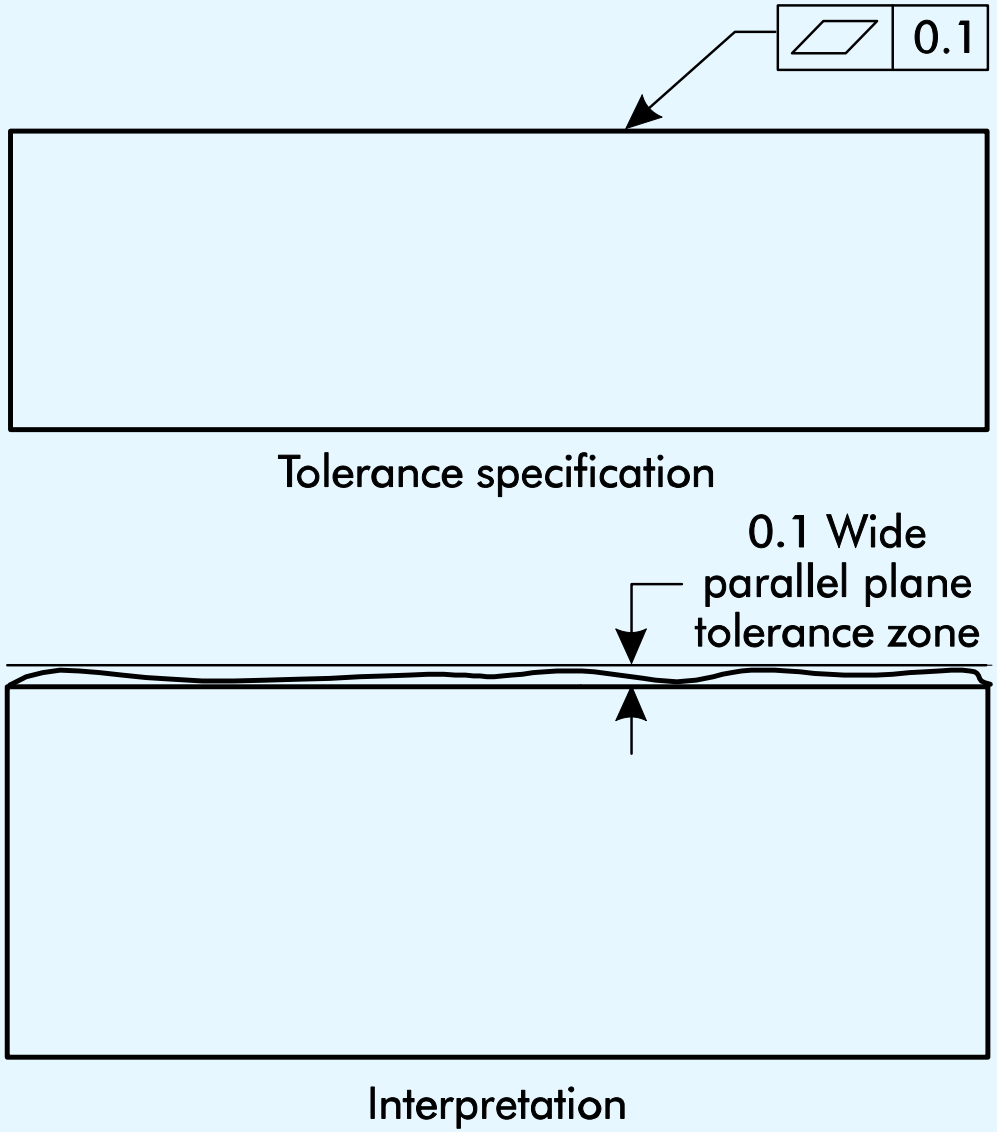
F 17-1 ASME Y14.5M-1994

	Type of Tolerance	Characteristic	Symbol
For individual features	Form	Flatness	
		Straightness	
		Circularity (roundness)	
		Cylindricity	
For individual or related features	Profile	Profile of a surface	
		Profile of a line	
For related features	Orientation	Angularity	
		Perpendicularity	
		Parallelism	
	Location	Position	
		Concentricity	
		Symmetry	
	Runout	Circular runout	
		Total runout	

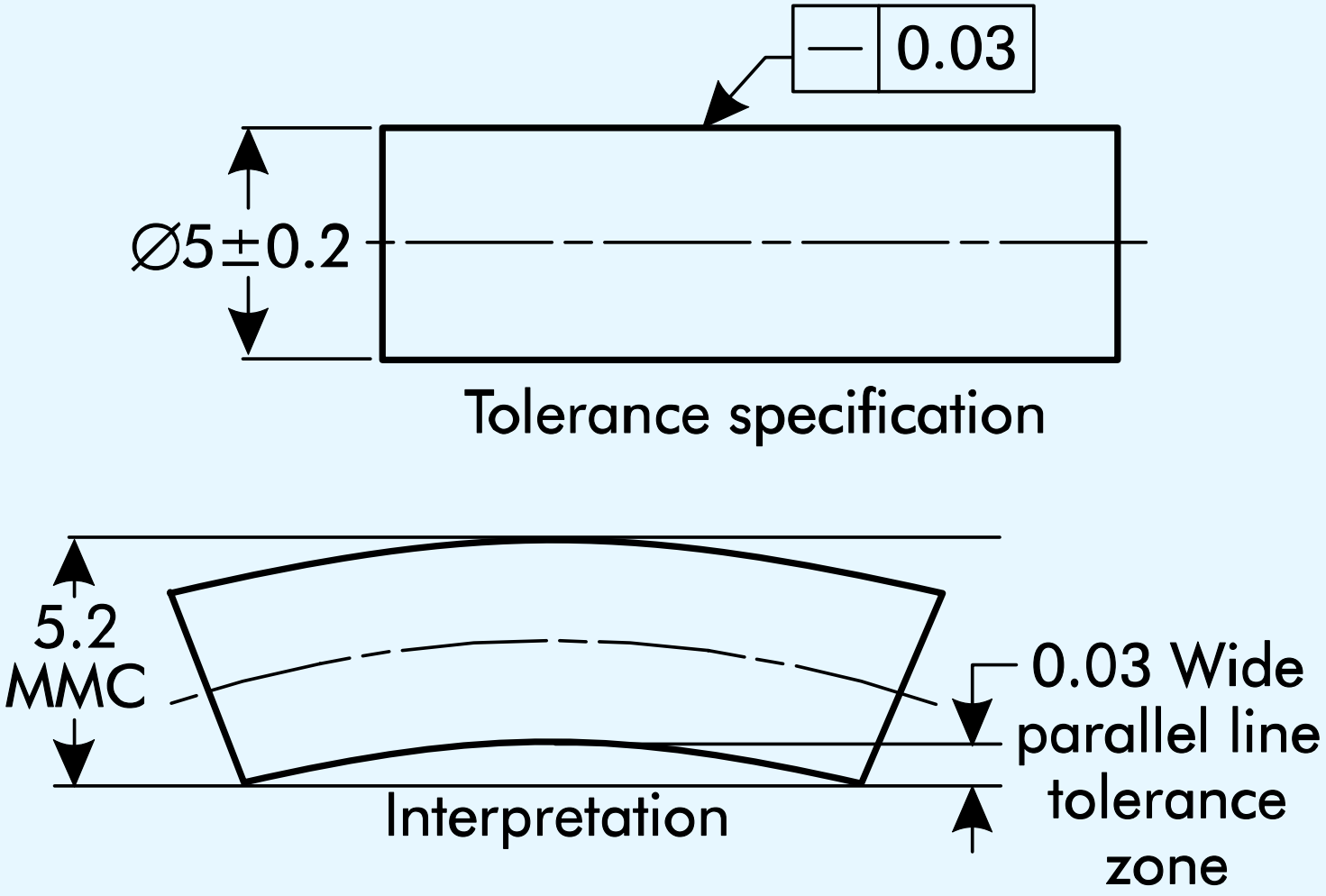
F 17-2 GD&T Tolerances and Symbols



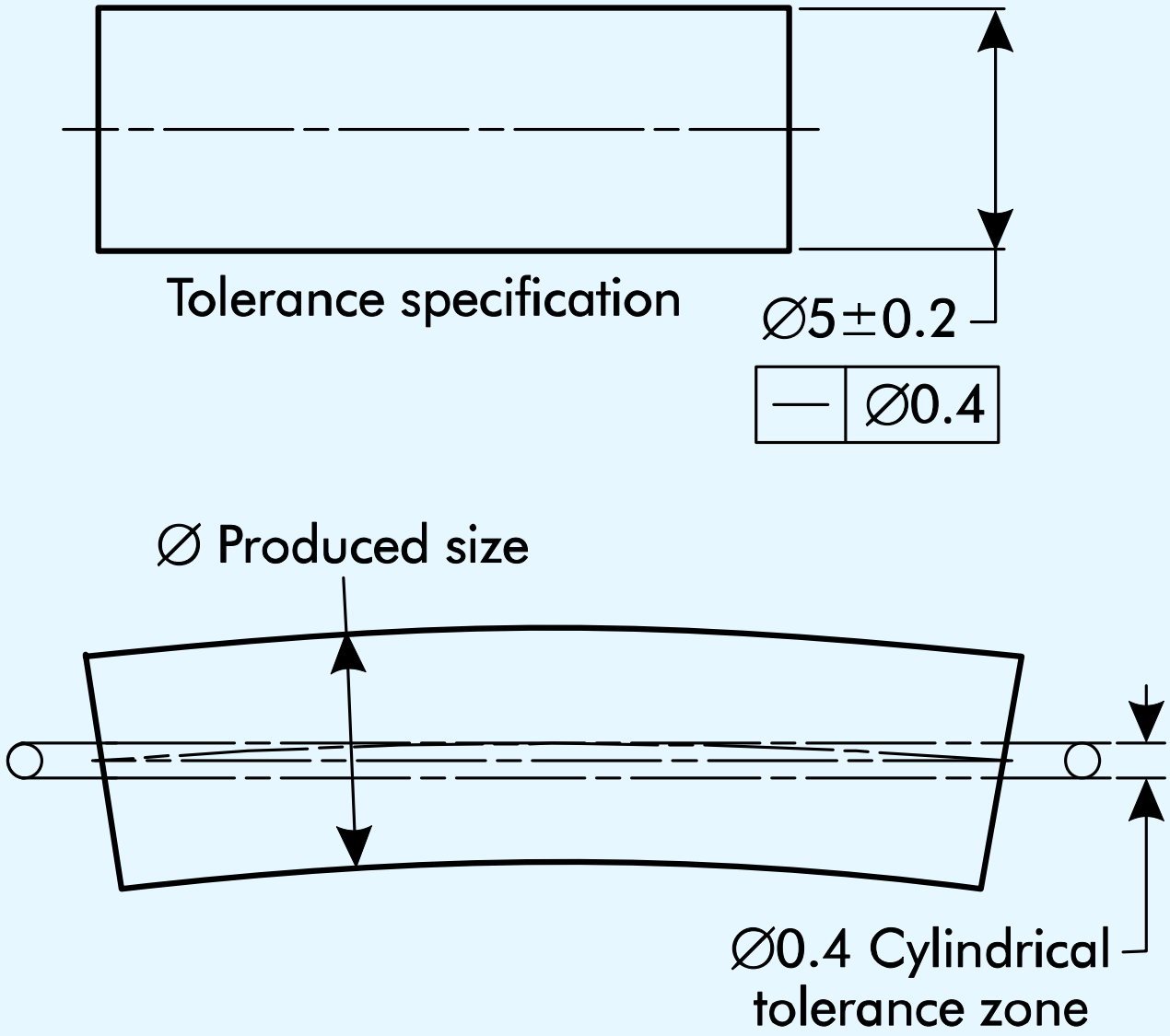
F 17-3 Feature control frame



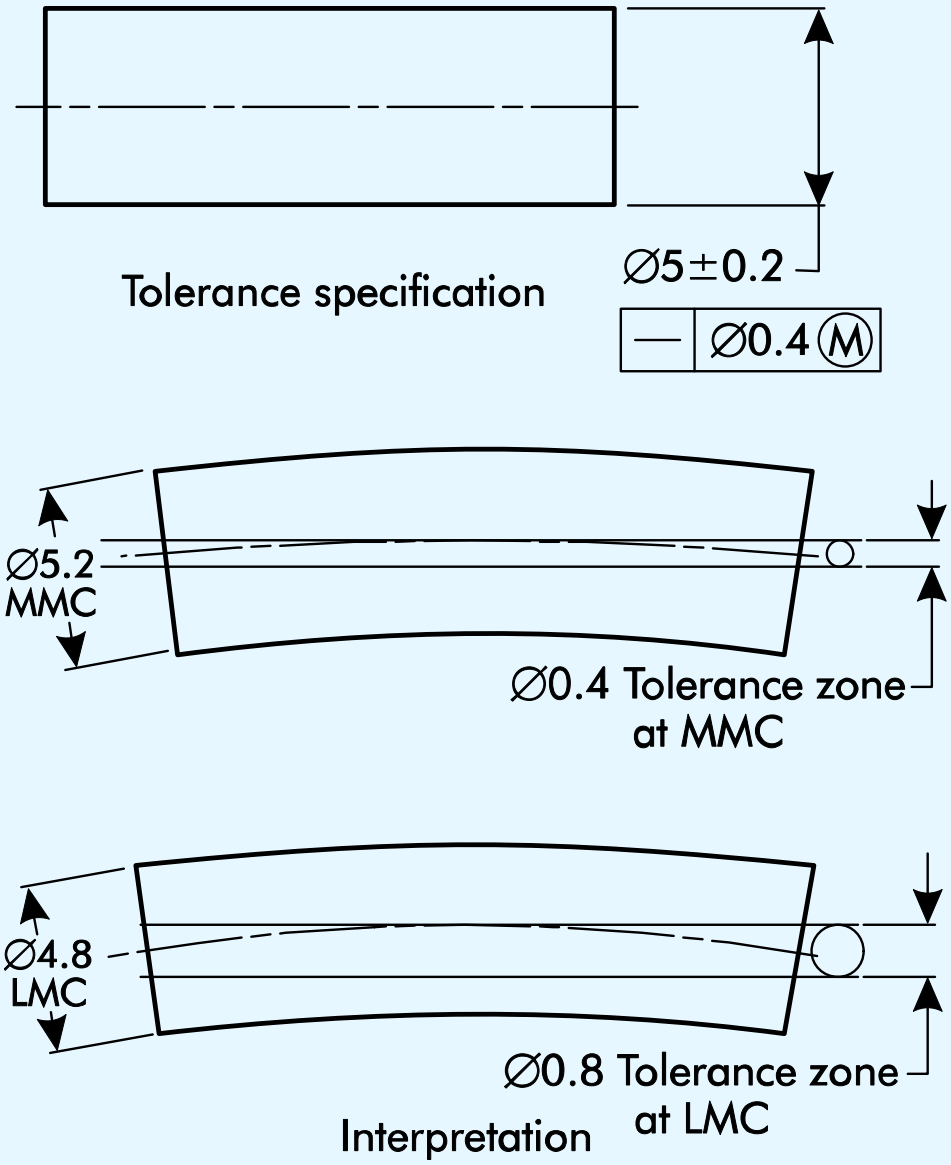
F 17-4 Flatness



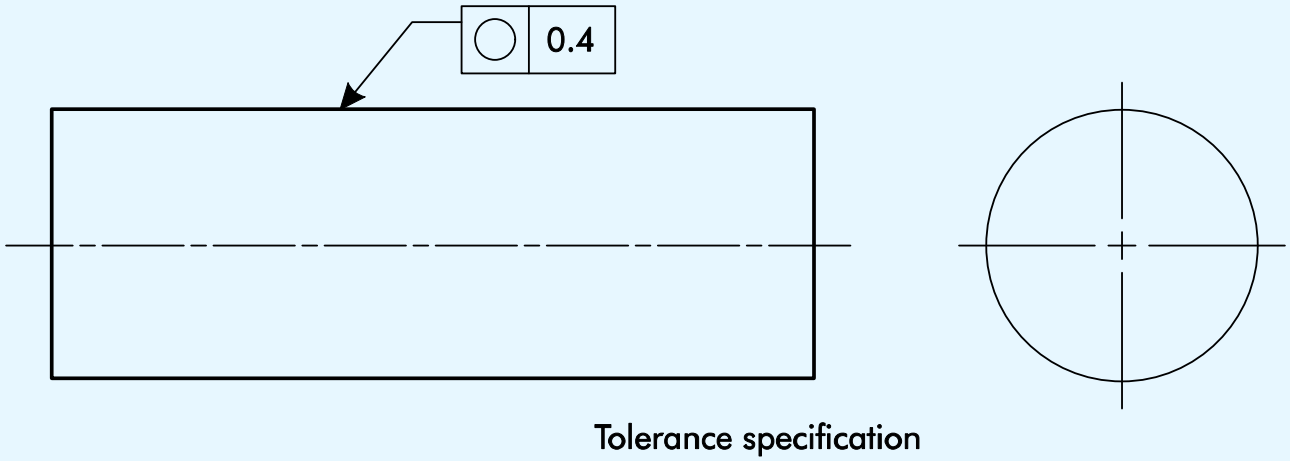
F 17-5 Surface Straightness



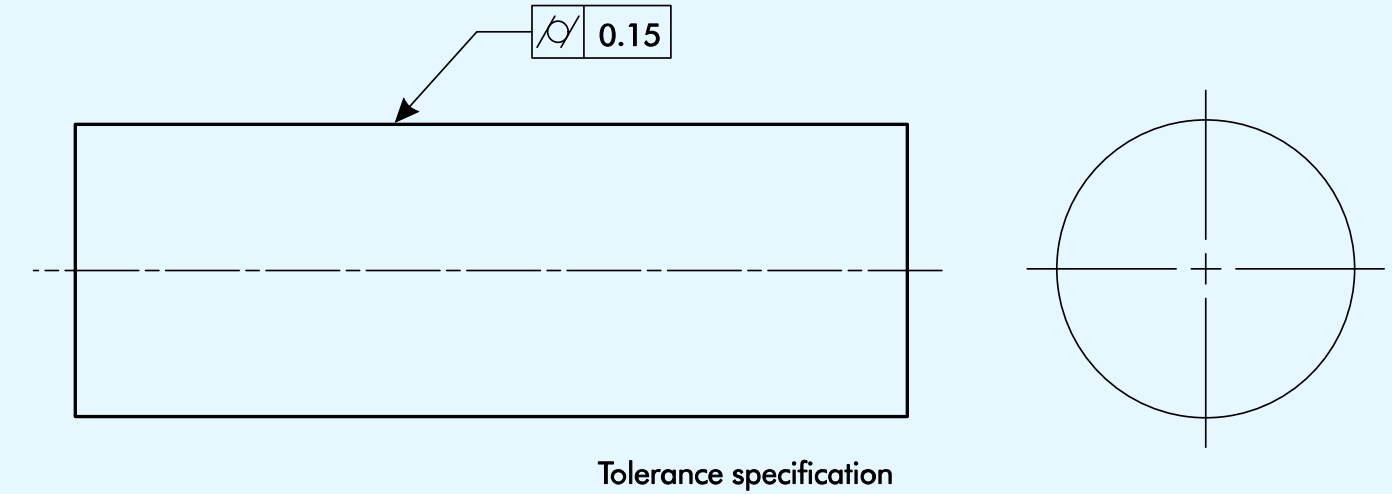
F 17-6 Axis straightness

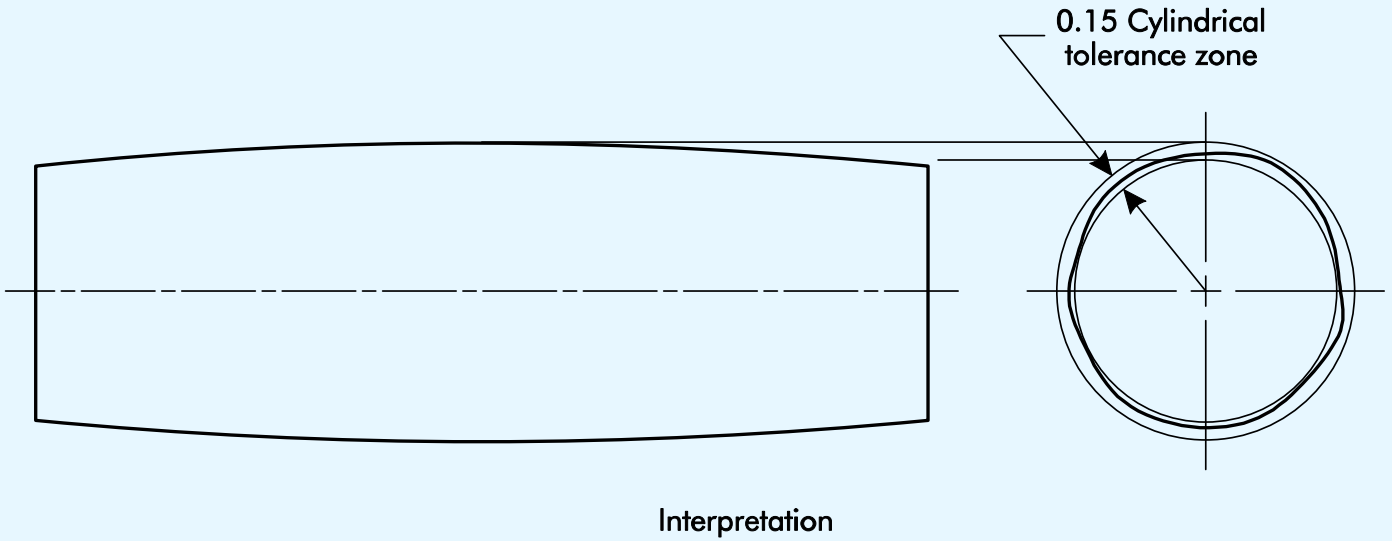


F 17-7 Axis straightness

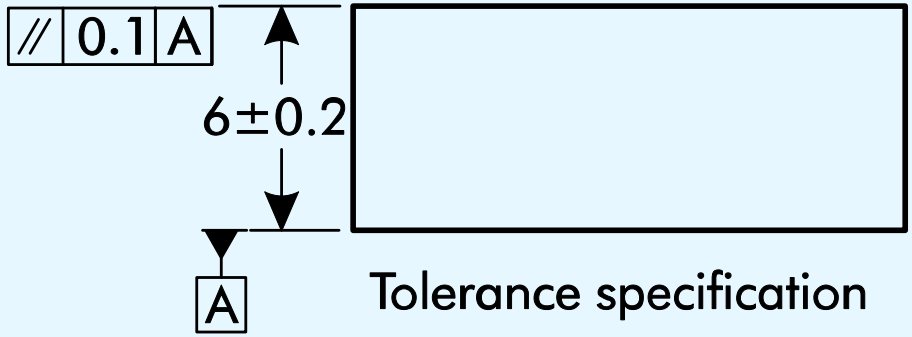


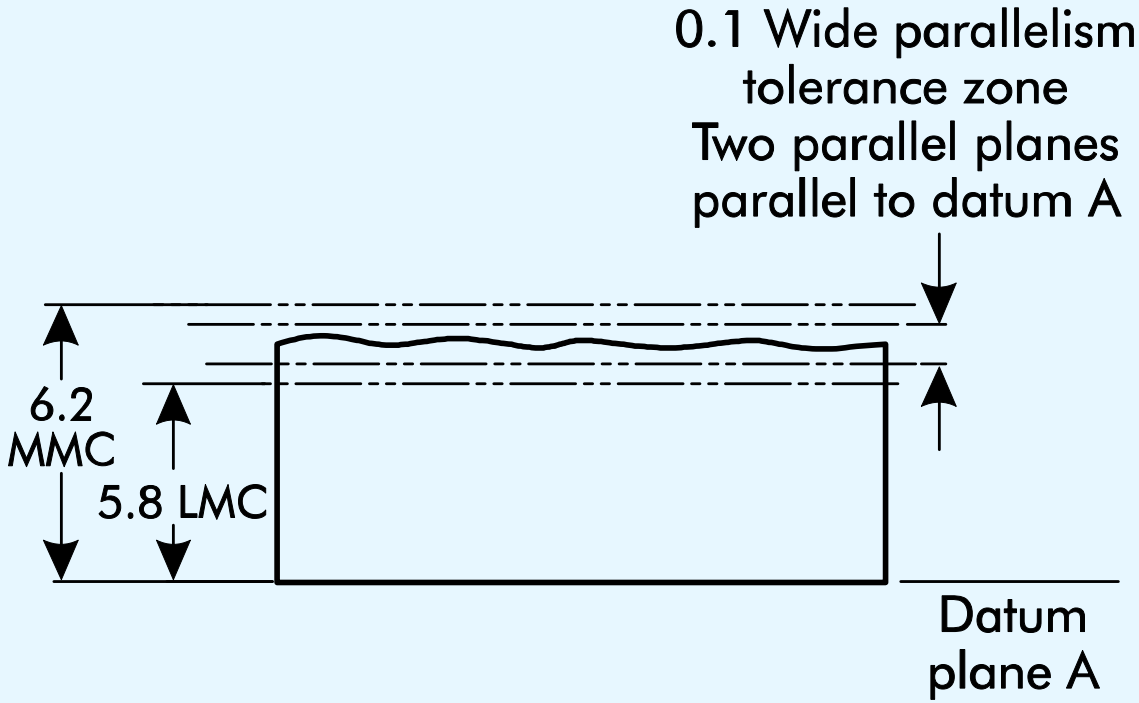
F 17-8 Circularity



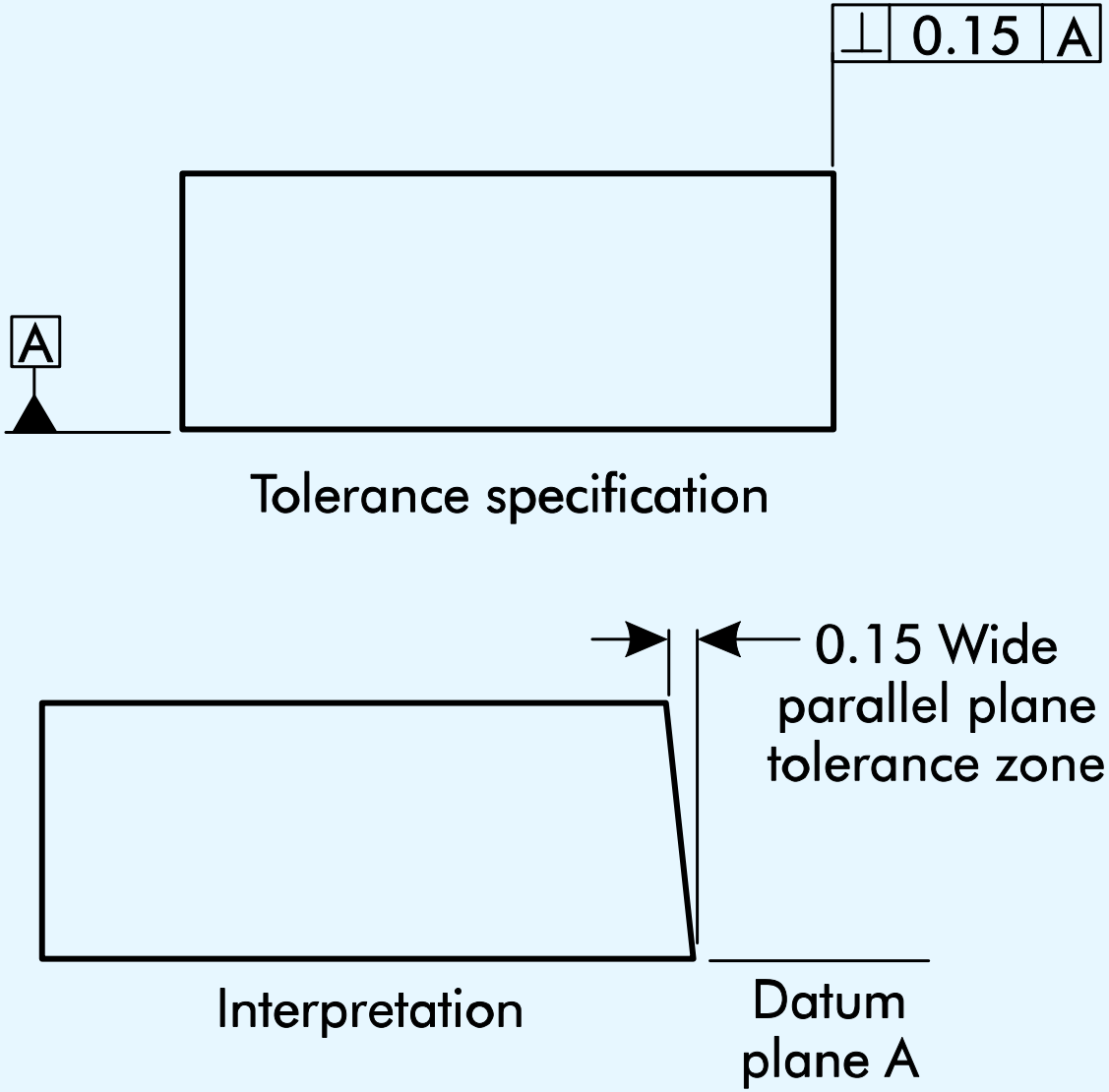


F 17-9 Cylindricity

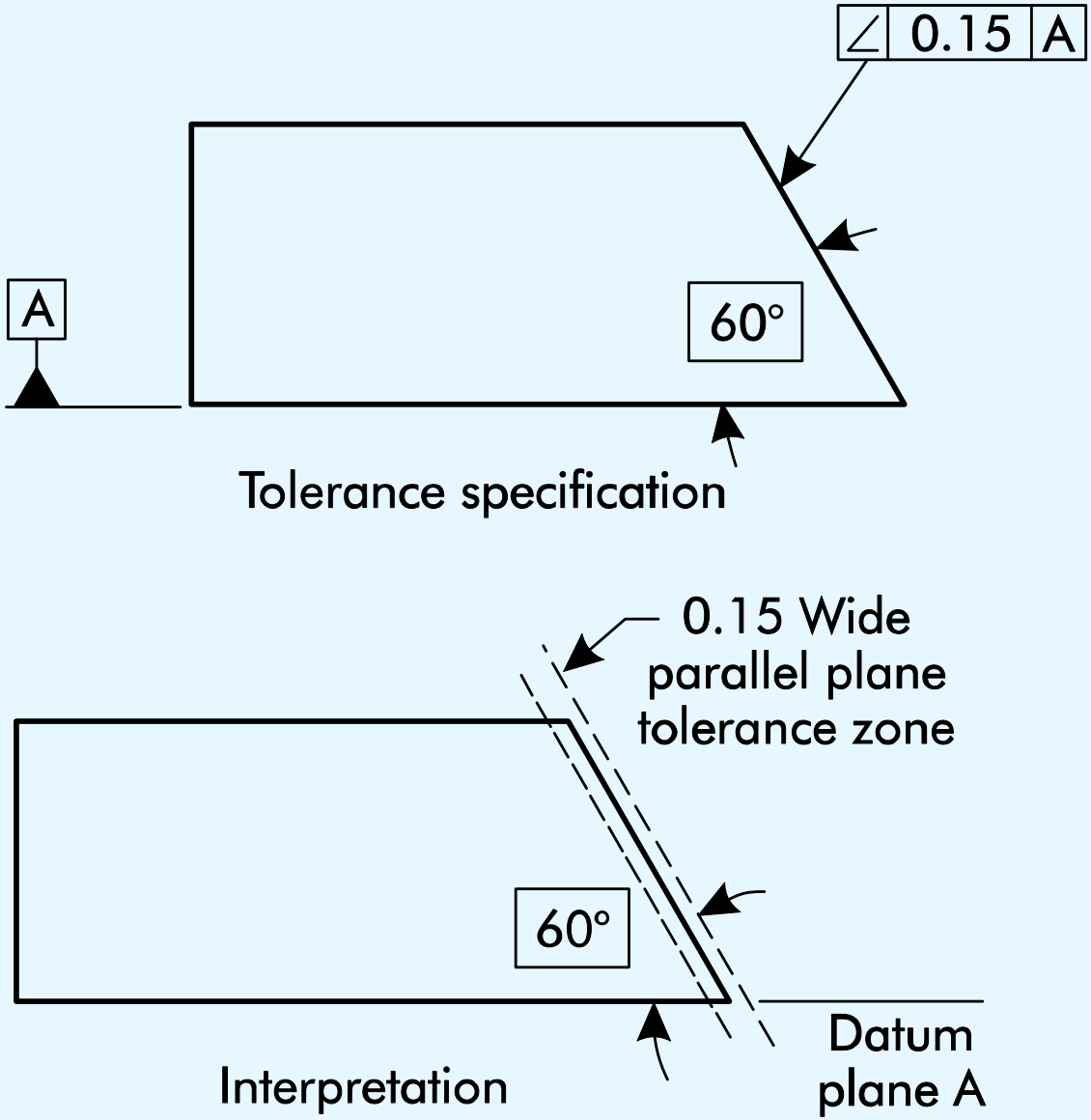




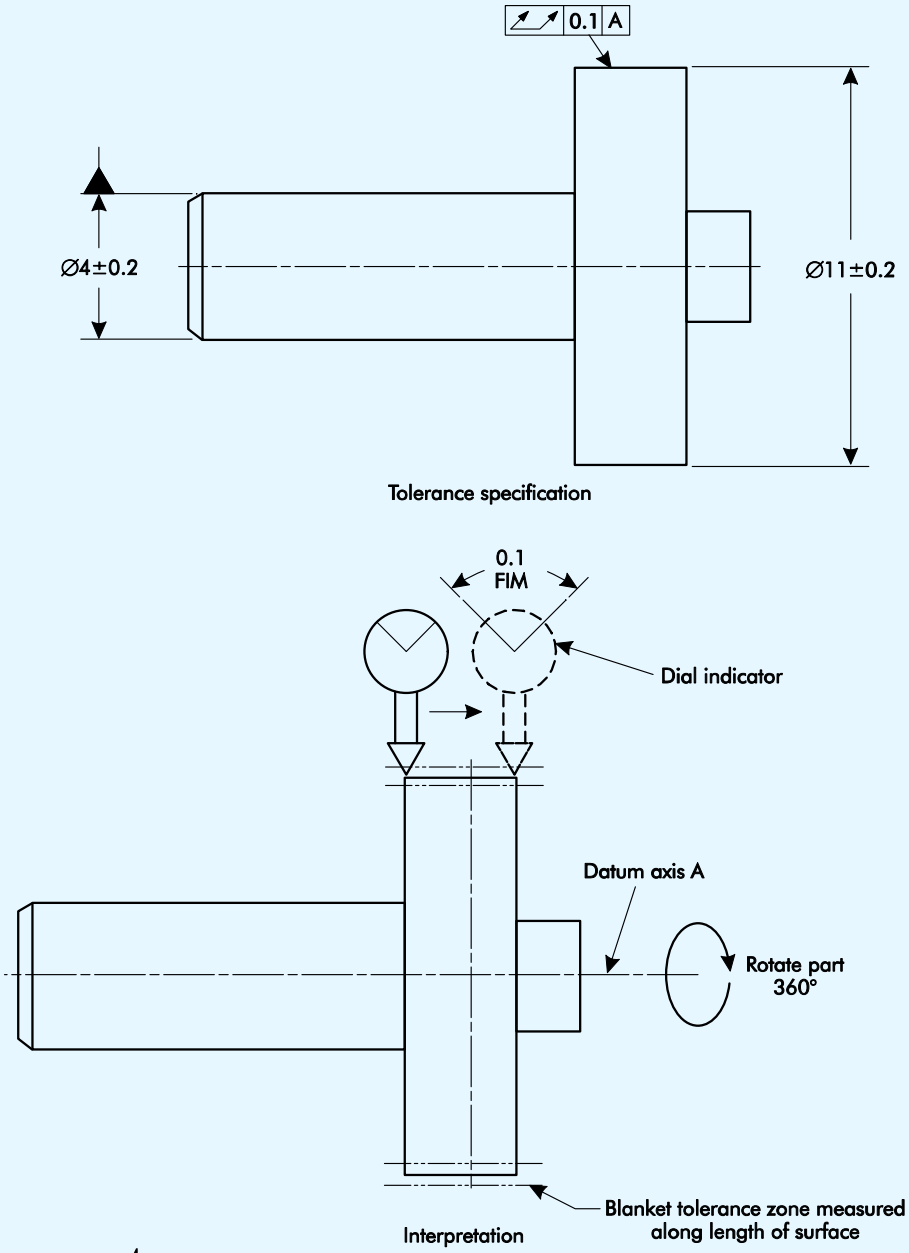
F 17-10 Parallelism



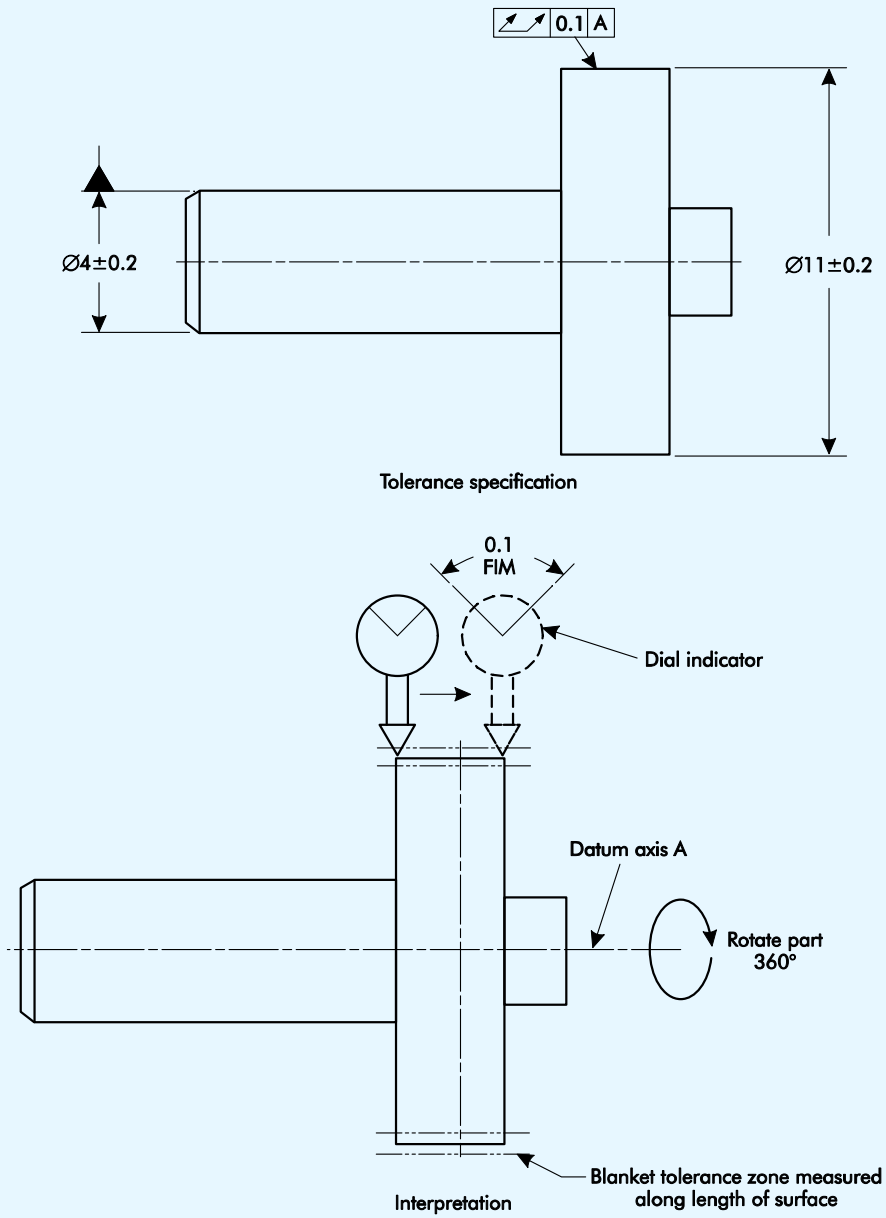
F 17-11 Perpendicularity



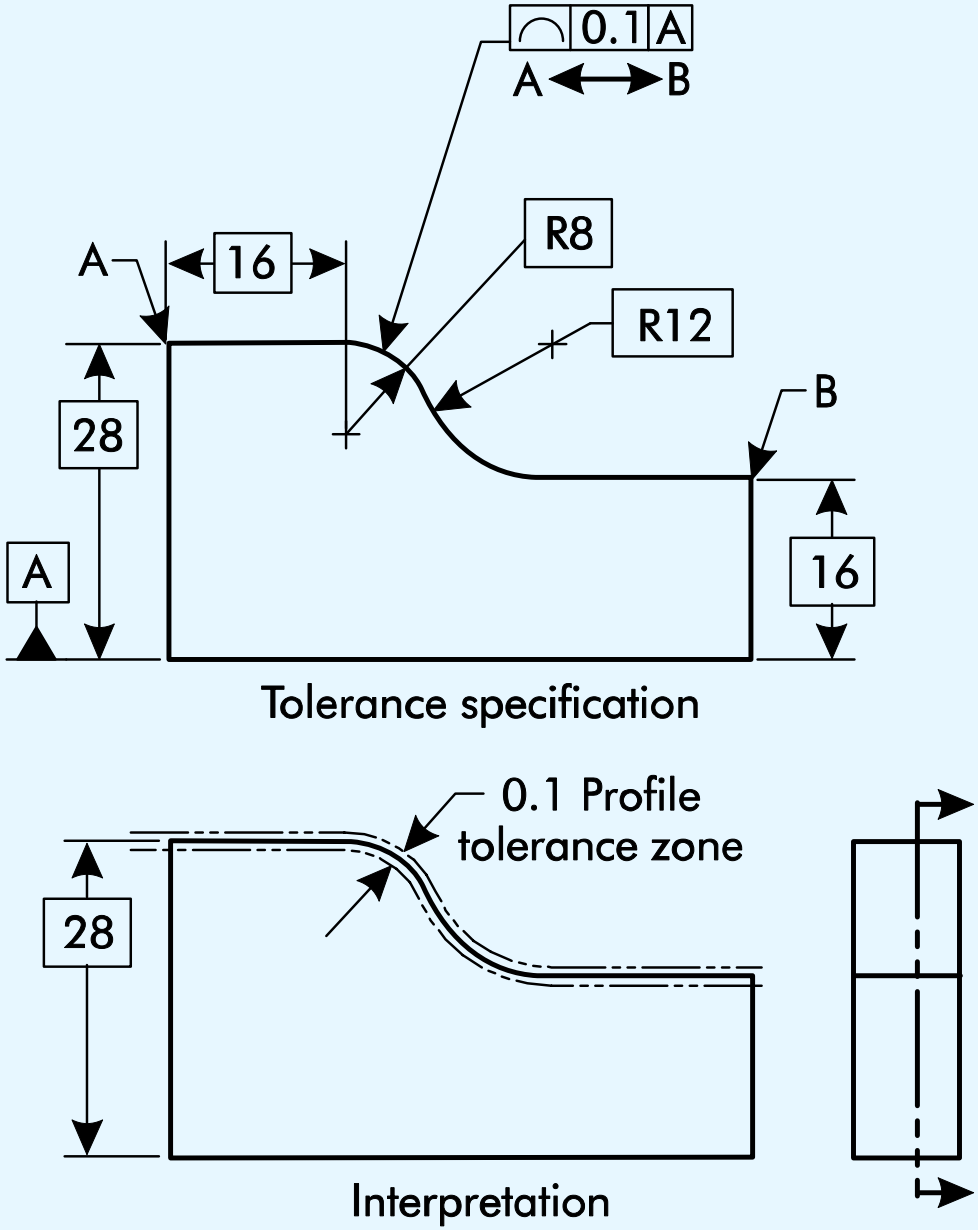
F 17-12 Angularity



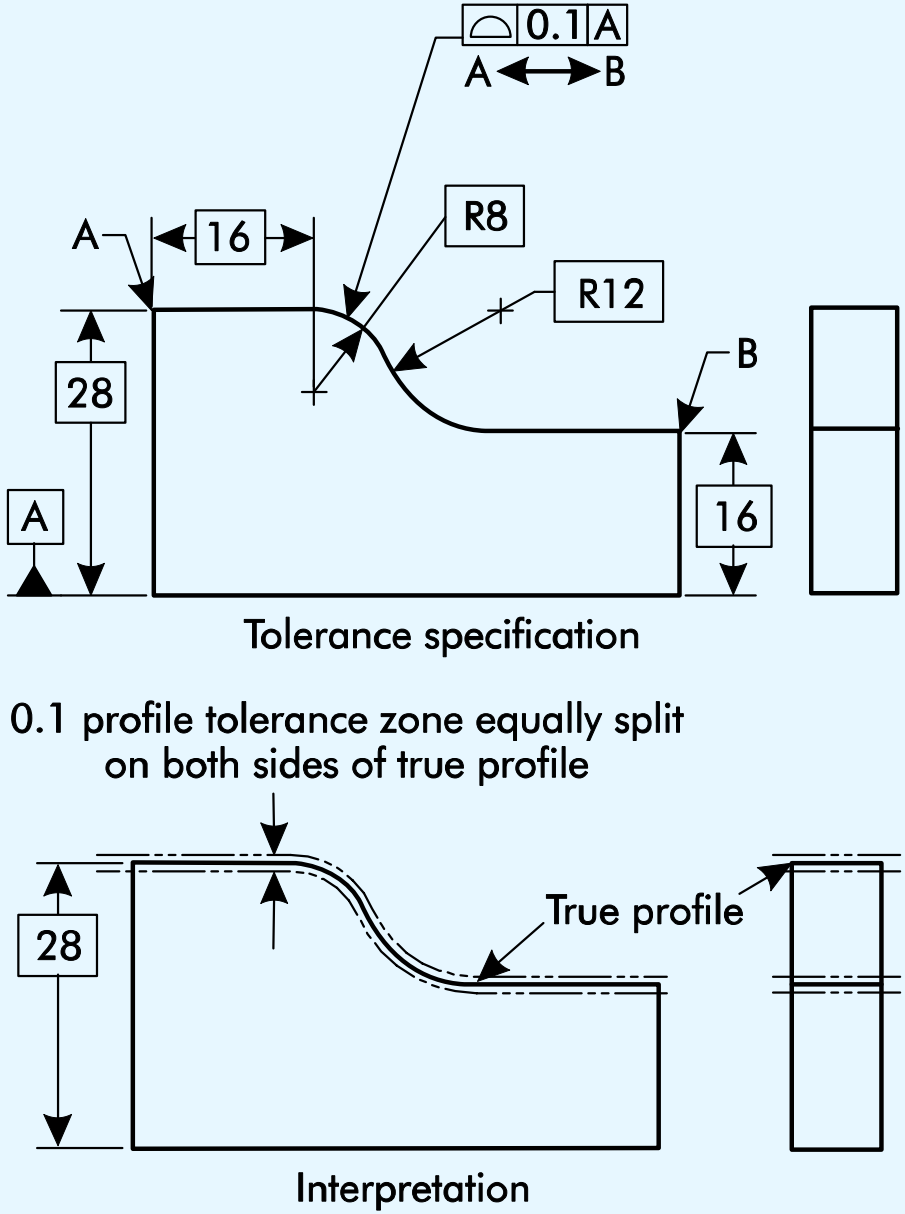
F 17-13 Circular runout



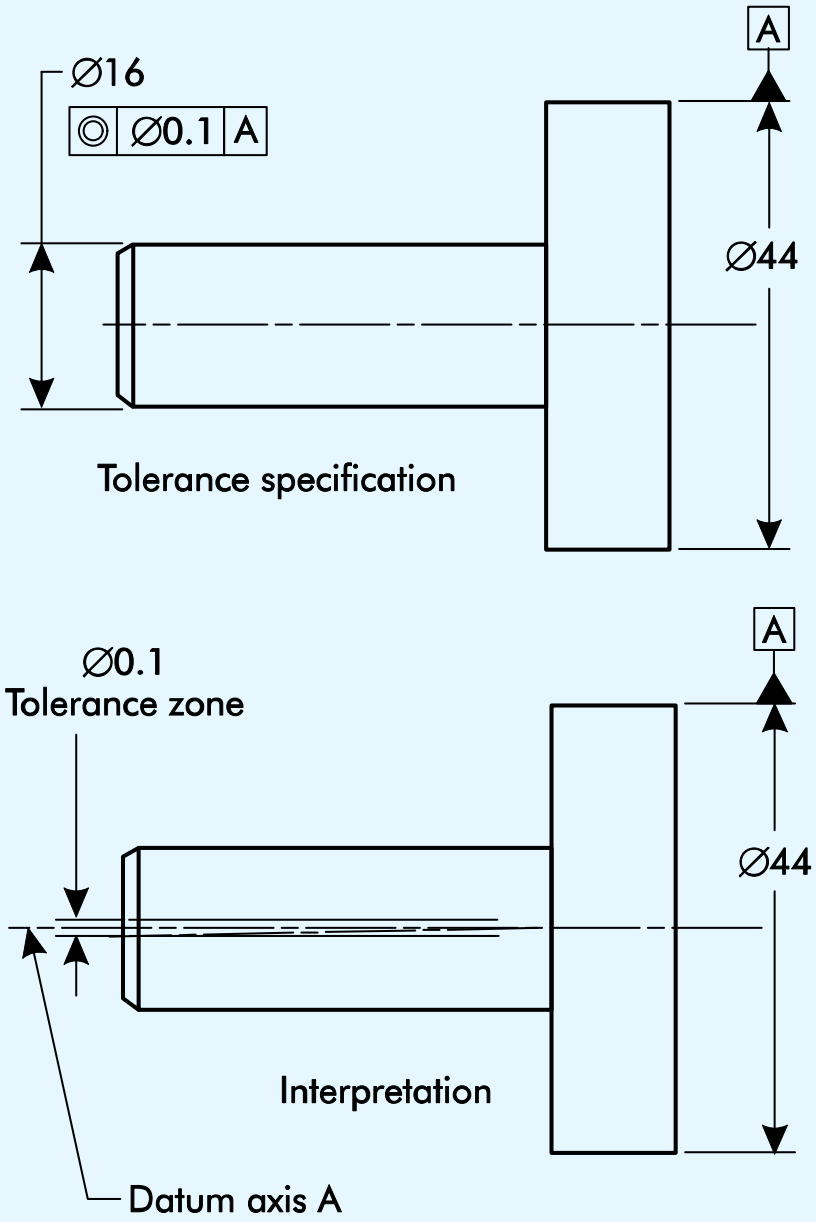
F 17-14 Total runout



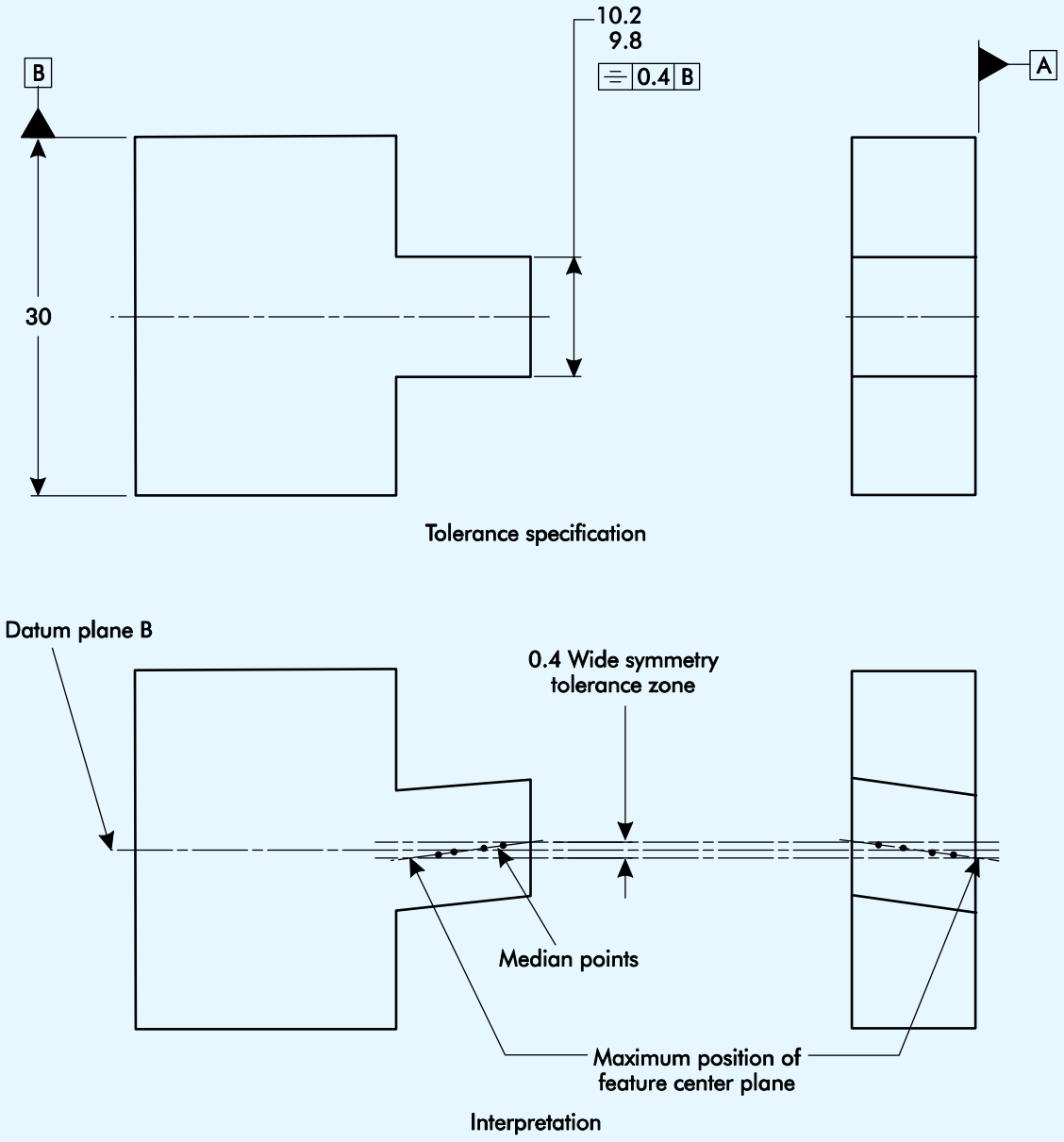
F 17-15 Profile of a line



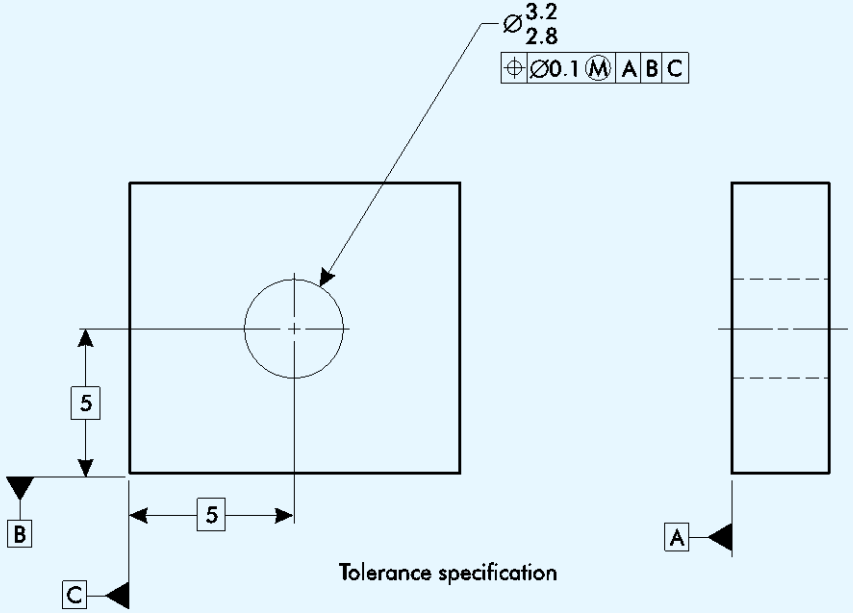
F 17-16 Profile of a surface

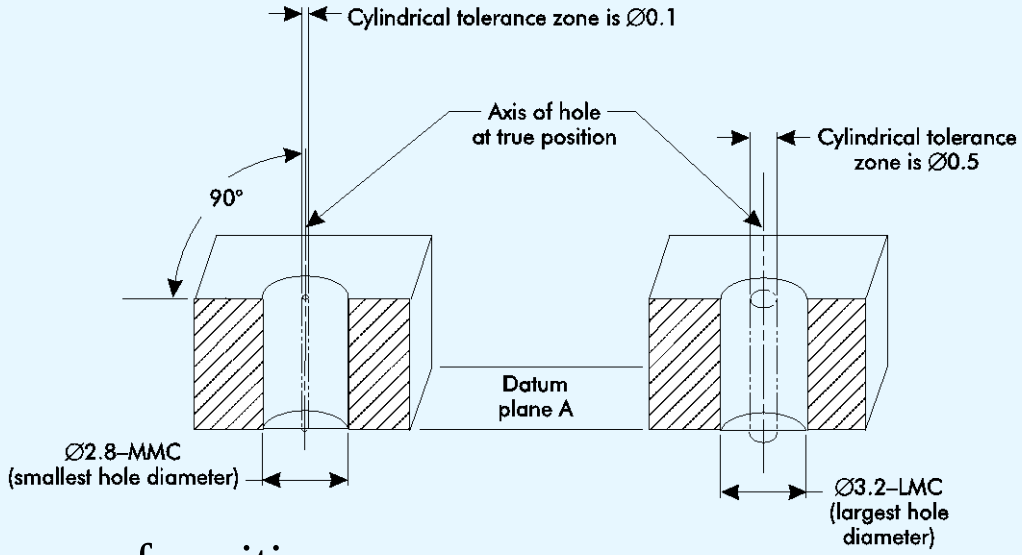


F 17-17 Concentricity



F 17-18 Symmetry





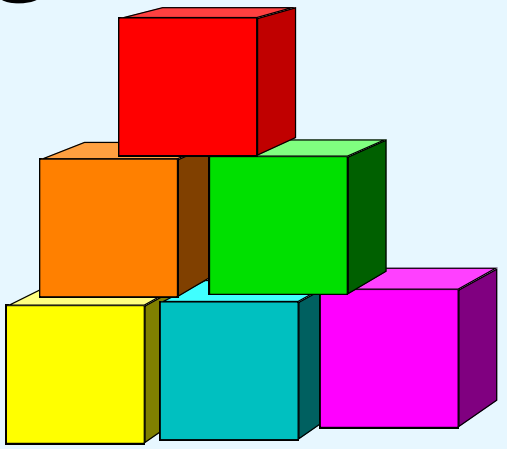
F 17-19 Tolerance of position

Computer-Aided Design

Chapter 18

3D Modeling Methods

- 1. Wire Frame
- 2. Surface Modeling
- 3. Solid Modeling



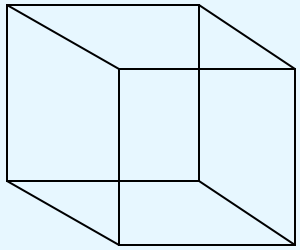
Wire Frame

A. Advantages

1. Easiest to construct
2. Infinite number of views possible

B. Disadvantages

1. Difficult to visualize complex objects
2. Mass properties cannot be calculated



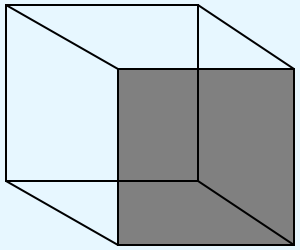
Surface Modeling

A. Advantages

1. Better representation of object compared to wire frame
2. Can be used to determine machine tool paths

B. Disadvantages

1. Not a complete representation of real object
2. Cannot be sectioned



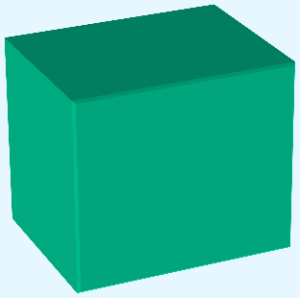
Solid Modeling

A. Advantages

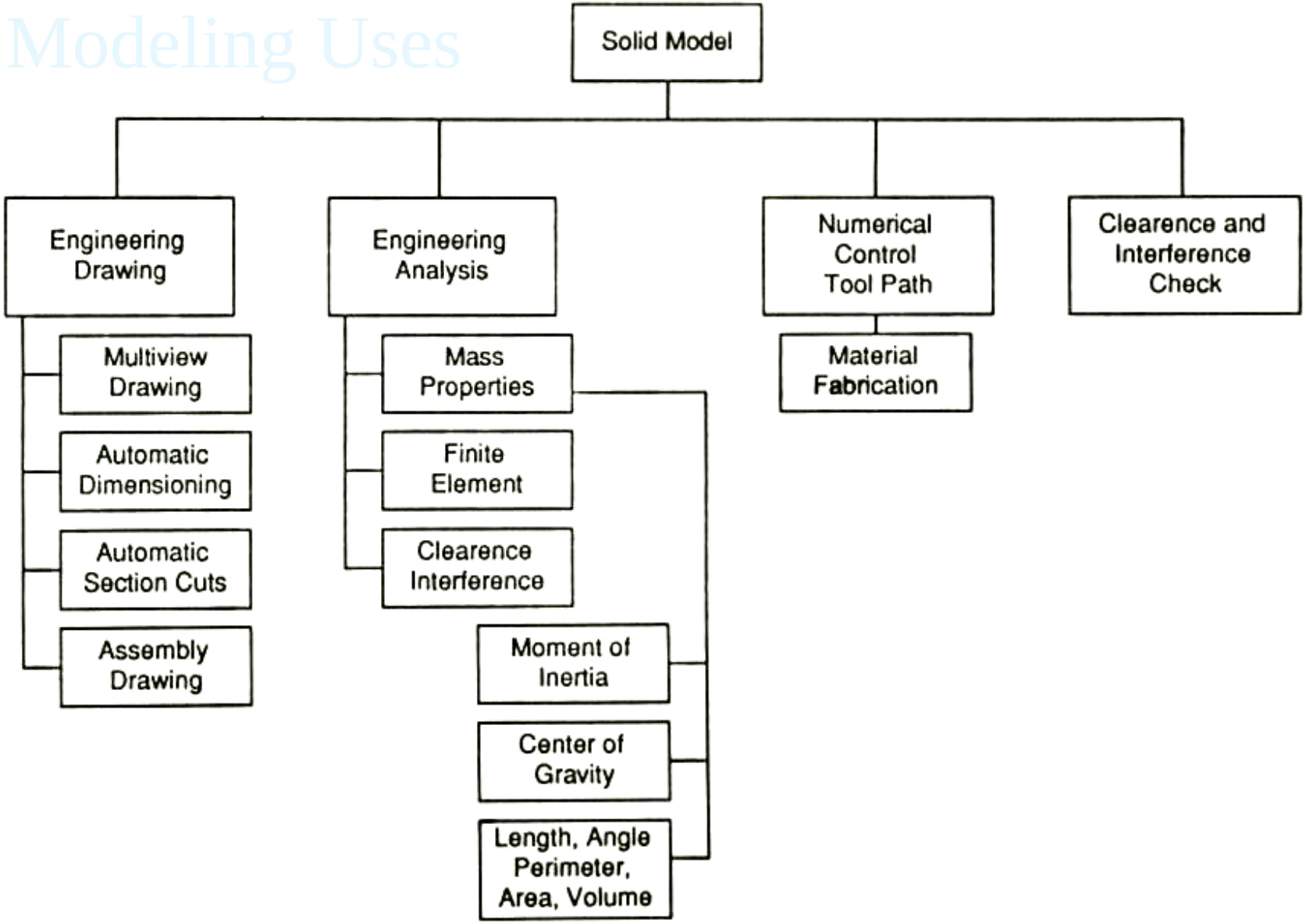
1. True 3D object
2. Elimination of ambiguity in viewing model
3. Section cuts can be produced and displayed
4. Mass properties may be calculated

B. Disadvantages

1. Software more expensive
2. More memory is required



Modeling Uses



Circuit Board Layout

- CAD software designed for printed circuit boards (PCB) has features unique to that application.
- Current surface mount technology (SMT) and the continued miniaturization of integrated-circuit products makes the design of most PCBs a complex task

PCB Design Considerations

- The number of layers in a final board assembly (single-sided, double sided, and multilayered)
- The miniaturization of components and the effect on pin spacing and number of pins in a conductor
- Conductor routing and board layers

Design Considerations Contd.

- The frequency of the current in the different circuits and the resulting inductance
- Heat dissipation
- The placement of similar types of components

Rapid Prototyping Methods

- Stereolithography apparatus (SLA)
- Solid ground curing (SGC)
- Laminated object manufacturing (LOM)
- Fused deposition modeling (FDM)
- Selective laser sintering (SLS)
- Ballistic particle manufacturing (BPM)

Advantages of Rapid Prototyping

- Produce three dimensional parts within hours
- Create masters and patterns
- Accelerate prototype production
- Achieve major savings in production of soft and hard tooling
- Increase manufacturing capabilities with low volume production runs
- Add impact to marketing concept presentations with hands-on models
- Improve the accuracy of vendor bid response

Disadvantages of Rapid Prototyping

- Parts typically cannot be used for physical testing
- Parts have surface finish quality and tolerance limitations
- Special techniques and materials are required of some systems
- Equipment is expensive

Product Design Tools

Chapter 19

Manufacturing Strategies

- Customer Response
- Entrepreneurial Manufacturing
- Time Based Strategy
- Managing For Speed Product

Customer Responsive

- Targets quality improvement and customer service
- Uses short-run manufacturing via the work cell concept

Entrepreneurial Manufacturing

- Requires flexible system capable of shifting from one product to another on short notice

- Success is dependent upon a company's capacity to create new markets for specialized high-value-added products.

Time Based Strategy

- Organization of process components and standardization
- Length of production run
- Complexity of scheduling procedures
- Favors smaller increments of improvement in new products, but introduces them more often

Managing for Speed Product

Depends on:

- Organizing product development for speed
- Organizing product manufacturing for speed
- Using miscellaneous techniques for speed
- Using computer-aided technology for speed

Manufacturing Strategies

Customer Responsive

Entrepreneurial Manufacturing

All strategies focus on delivering a quality product at a competitive price simultaneously responding to customer needs, and striving for continuous improvement.

Time Based Strategy

Managing For Speed Product

Concurrent Engineering Principles

- Understand your customer
- Use product development teams
- Integrate process design
- Involve suppliers and subcontractors early
- Use digital product models
- Integrate CAE, CAD, and CAM tools
- Use quality engineering and reliability techniques
- Create an efficient development approach
- Improve the design process continuously

Part/ process name Part number	Part/ process function	Potential failure mode	Potential effect(s) of failure	▽	Potential cause(s)/ mechanism(s) of failure	Current controls	Occurrence	Severity	Detection	RPN	Recommended action(s) status	Actions taken	Area responsible for actions taken	Occurrence	Severity	Detection	RPN

F 19-1 Process failure mode and analysis

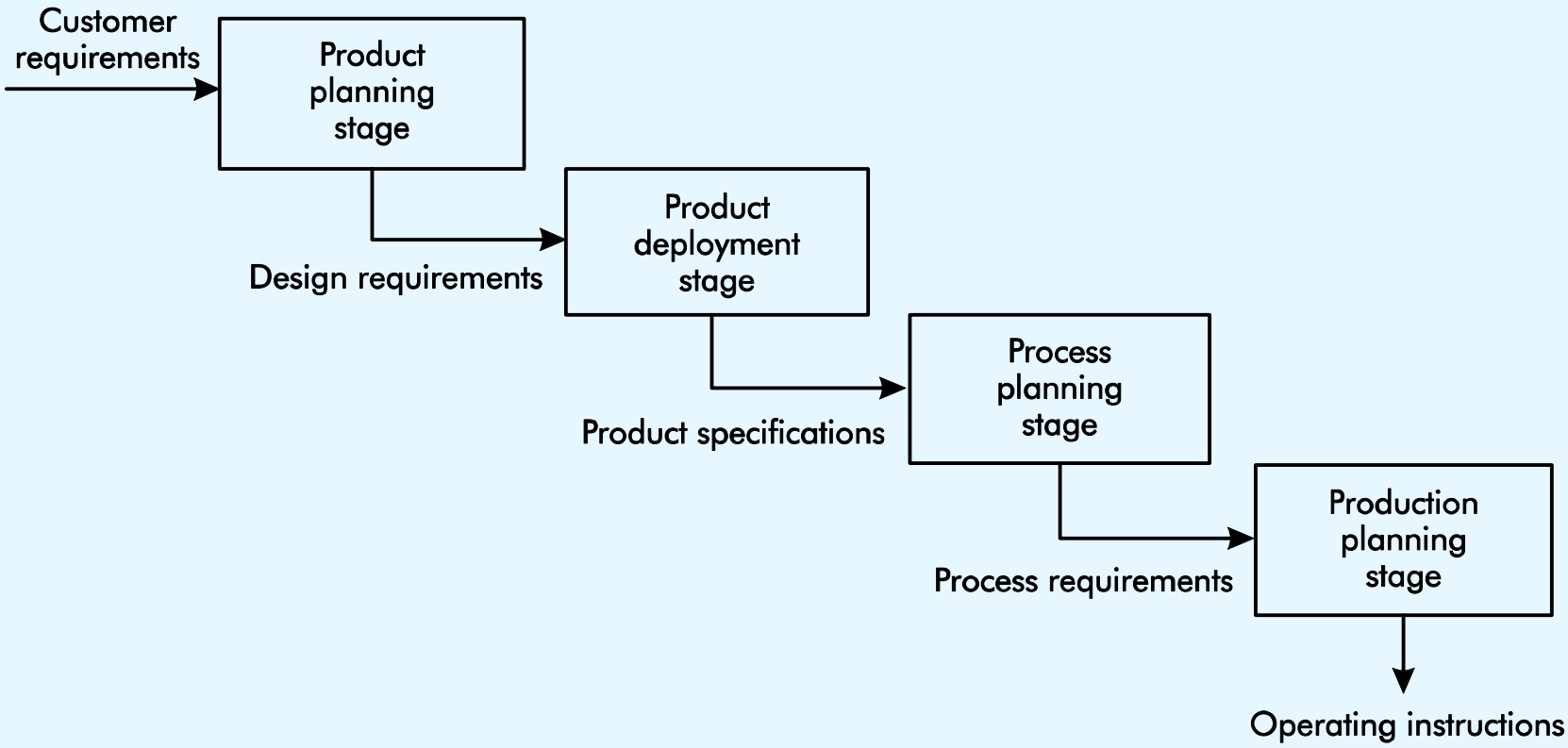
Quality Function Deployment (QFD)

- A strategy/technique of listening to the "voice of the customer"

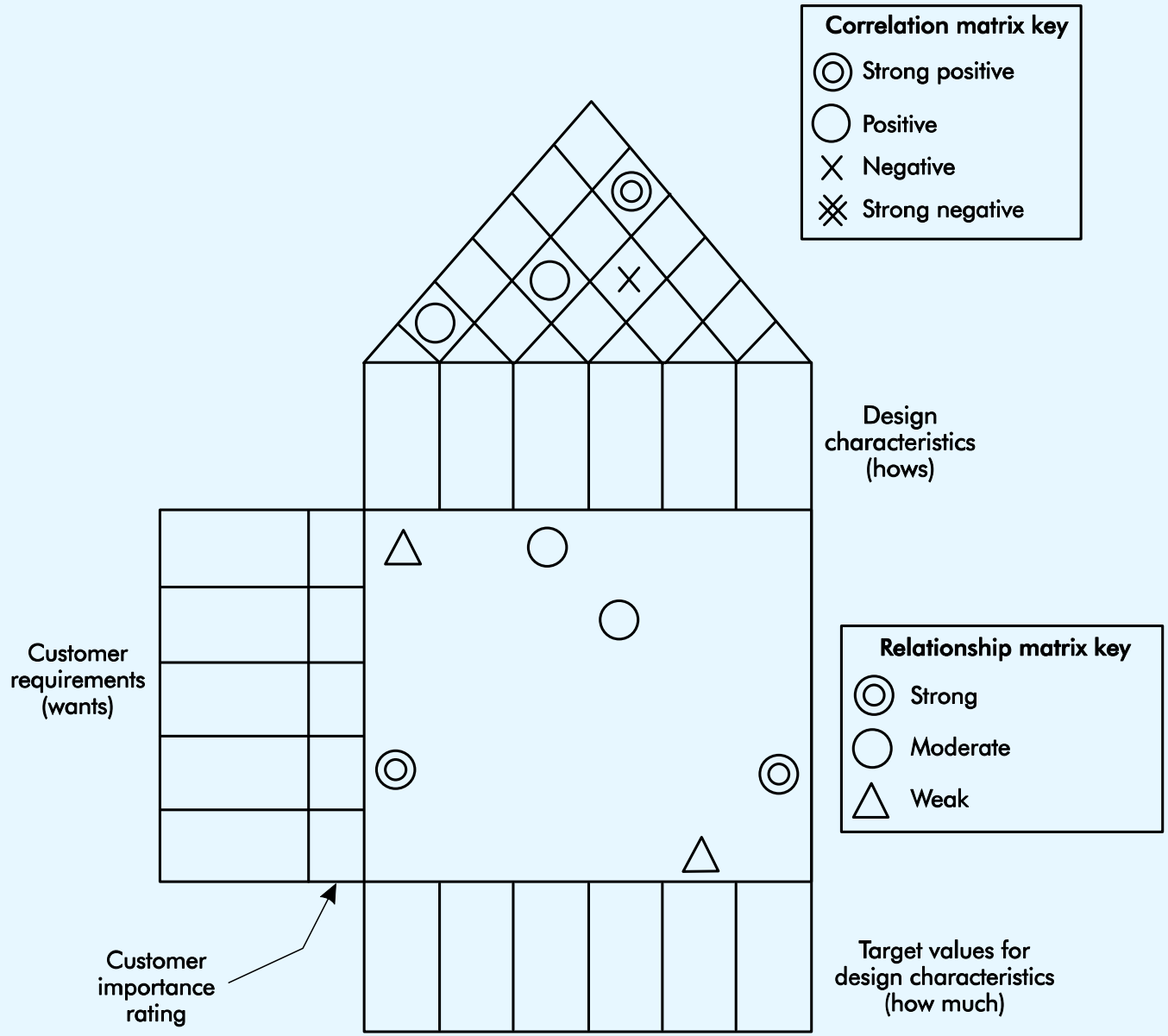
Benefits of Using a Quality Function Deployment Strategy

- Earlier determination of key product characteristics
- Documentation of actual customers' needs rather than decisions based on opinions
- Reduction in product development costs
- Reduction in time required to bring a new product to market
- Greater customer satisfaction due to lower costs and improved responsiveness
- Reduction in number of engineering changes across the product's life cycle

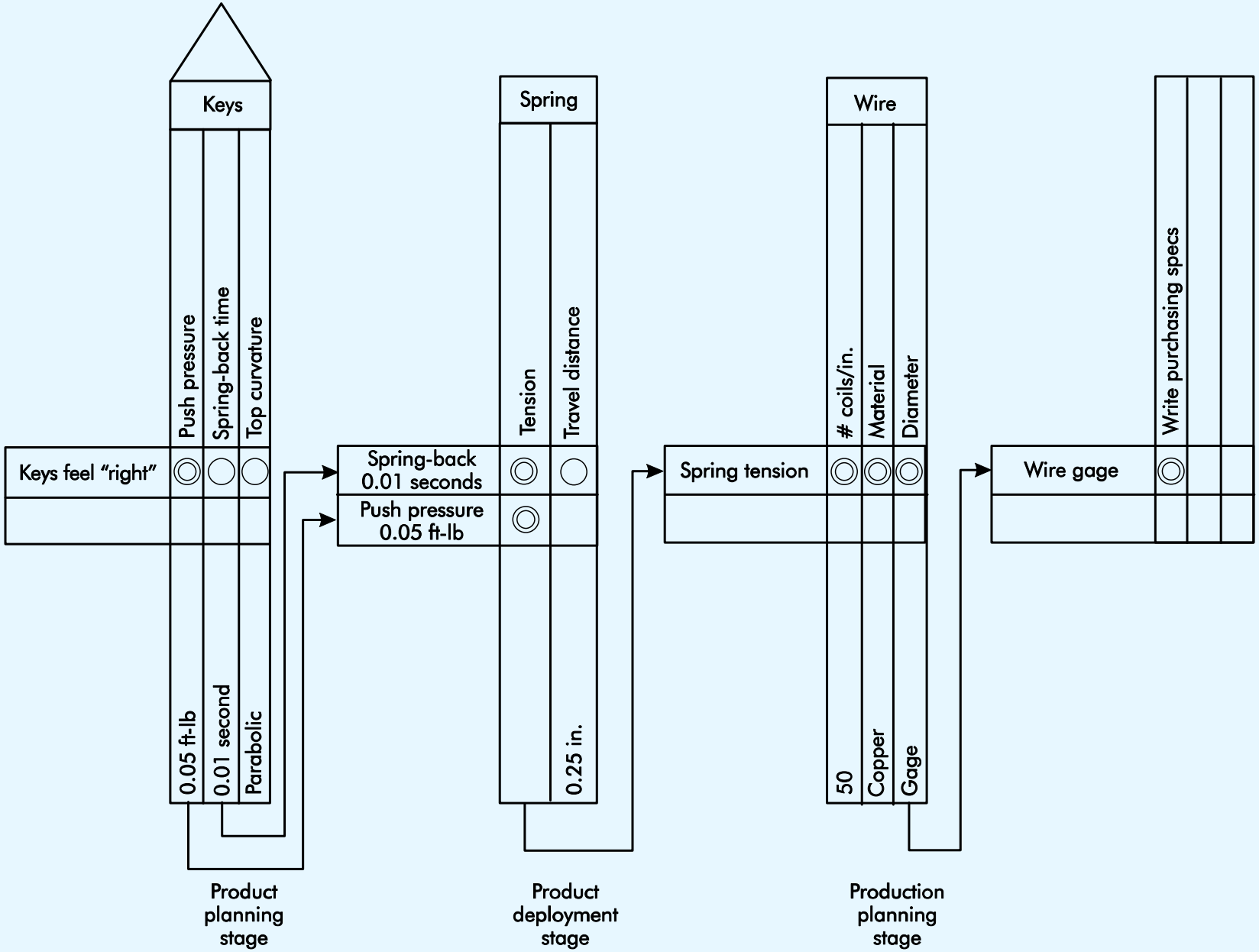
Quality Function Deployment (QFD)



F 19-2 Four stages of QFD



F 19-3 House of quality



F 19-4 QFD matrices

Group Technology (GT)

- An approach to reduce manufacturing system information content by identifying and exploiting the sameness or similarity of parts based on their geometrical shape and/or similarities in their production process.

Part Families

- Design-oriented: Have similar design feature, such as geometric shape
- Manufacturing-oriented: Can be based on any number of different considerations, such as parts manufactured by the same plant or same materials

Methods of Grouping Parts

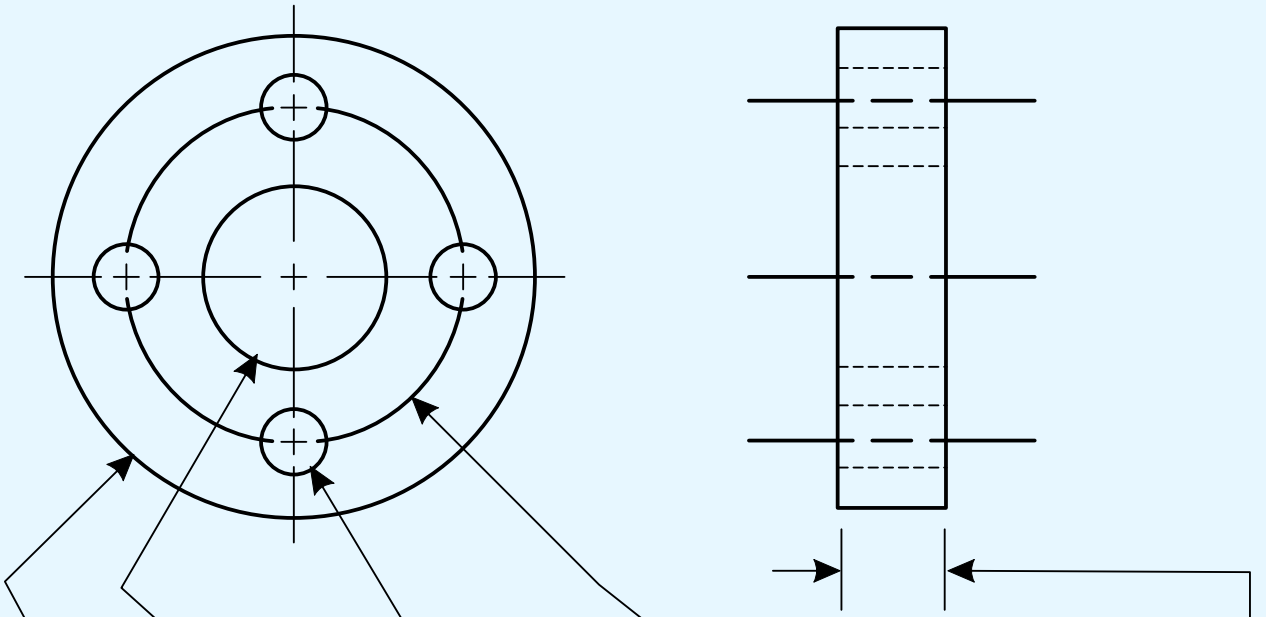
- Visual inspection
- Production flow analysis (PFA)
- Classification and coding

  (Most effective and widely used)

Two Main Coding Systems

1. Attribute-based (polycodes)

2. Hierarchical-based (monocodes)



	Outside diameter (in.)	Center hole diameter (in.)	Bolt hole diameter (in.)	Bolt circle diameter (in.)	Thickness (in.)
1	4.000	1.000	0.250	2.500	0.250
2	6.000	1.500	0.500	3.750	0.500
3	8.000	2.000	0.750	5.000	0.750
4	10.000	2.500	1.000	6.250	1.000

F 19-5 Attribute-based coding

Group number = ____ ____ ____ ____ + part number

	1st digit		2nd digit		3rd digit		4th digit
1	Shaft	1	Diameter < 1 in.	1	Length < 6 in.	1	Carbon steel
						2	Stainless steel
				2	Length > 6 in.	1	Carbon steel
						2	Stainless steel
		2	Diameter > 1 in.	1	Length < 6 in.	1	Carbon steel
						2	Stainless steel
				2	Length > 6 in.	1	Carbon steel
						2	Stainless steel
2	Bushing	1	Inside diameter < 1 in.	1	Outside diameter < 1 in.	1	Metal
						2	Plastic
				2	Outside diameter > 1 in.	1	Metal
						2	Plastic
		2	Inside diameter > 1 in.	1	Outside diameter < 2 in.	1	Metal
						2	Plastic
				2	Outside diameter > 2 in.	1	Metal
						2	Plastic
3	Sheet	1	Thickness < 0.030 in.	1	Length < 20 in.	1	Metal
						2	Plastic
				2	Length > 20 in.	1	Metal
						2	Plastic
		2	Thickness > 0.030 in.	1	Length < 20 in.	1	Metal
						2	Plastic
				2	Length > 20 in.	1	Metal
						2	Plastic

F 19-6 Hierarchical-based coding