

Fig. 7 .... Relation Between Velocity and Velocity Head for Standard Air

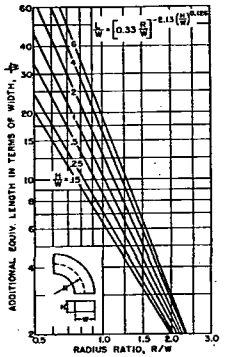


Fig. 8 .... Loss in 90-Deg Elbows of Rectangular Cross-Section

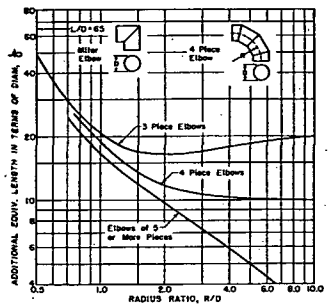


Fig. 9 .... Loss in 90-Deg Elbows of Round Cross-Section

Table 3 .... Pressure Losses Due to Elbows

(Additional Equivalent Losses in Excess of Friction to Intersection of Center Lines)

TYPE	ILLUSTRATION	CONDITIONS	PRESSURE LOSS C^a	L/D	L/W
MITER		RECTANGULAR OR ROUND; WITH OR WITHOUT VANES	$\frac{H}{90}$ TIMES VALUE FOR SIMILAR 90-DEG. ELBOW[9]		
90-DEG. ROUND SECTION		MITER	1.30[b]	65[b]	
		R/D=0.5	0.90		
		0.75	0.45	23	
		1.0	0.33	17	
		1.5	0.24	12	
		2.0	0.19	10	
90-DEG. RECTANGULAR SECTION		R/W R/W			
		MITER	1.25[b]		25[b]
		0.5	1.25		25
		0.25 0.75	0.60		12
		1.0	0.37		7
		1.5	0.19		4
		MITER	1.47		49
		0.5	1.10		40
		0.5 0.75	0.50		18
		1.0	0.28		9
		1.5	0.13		4
		MITER	1.50		75
		0.5	1.00		50
		1.0 0.75	0.41		21
		1.0	0.22		11
		1.5	0.09		4.5
		MITER	1.38		110
		0.5	0.96		65
		4.0 0.75	0.37		45
		1.0	0.19		17
		1.5	0.07		6
90-DEG. SQUARE SECTION WITH SPLITTER VANES		R/W R/W R/W R/W			
		MITER 0.5			26[10]
		0.5 0.4	0.70[a]		19
		0.7 0.6			12
		1.0 1.0	0.13		7.2
		1.5	0.12		
		MITER 0.3 0.5			22[10]
		0.5 0.2 0.4	0.45		18
		0.75 0.4 0.7	0.12		
		1.0 0.7 1.0	0.10		
		1.5 1.3 1.8	0.15		
MITER WITH TURNING VANES		PLATE VANES	0.35[b]		
	PLATE	FORMED VANES	0.10[b]		
	FORMED				
MITER TEE WITH VANES		CONSIDER EQUAL TO A SIMILAR ELBOW. BASE LOSS ON ENTERING VELOCITY.			
RADIUS TEE					

[a] Values based on f values of approximately 0.02.
[b] Values calculated from L/D and L/W values of Reference 6 for $f = 0.02$.
Note: Superscript numbers refer to references at end of chapter.

2000 cfm, the ASHAE FRICTION CHART, Fig. 3, gives a loss of 0.6 in. of water per 100 ft. of 12.4-in. diameter duct. Thus the loss from A to D is $0.6 \times 58/100 = 0.348$ in. of water.

The use of elbows of radius ratio, $R/W = 1.5$, is considered good practice with respect to both installation and operation. In a given rectangular duct 6 by 24 in., for example, the elbow loss will be greater for a flat bend where the aspect ratio, $H/W = 1/4$, than if the bend of the same radius ratio had been made in the plane of the narrow dimension giving an aspect ratio, $H/W = 4$.

Data now available for losses in compound bends,[7, 8] where two or more elbows are close together, do not warrant refinement of design calculations beyond use of the sum of the losses for the individual elbows. Actually, the losses are somewhat less than for two bends when they are placed to form a U bend, and somewhat more when they form a reversed, or S bend.

Where angles of other than 90-deg bend are encountered, the loss may be considered as directly proportional to the angle of bend. Losses[9] for elbows discharging air directly into a large space are higher than those given for elbows within duct systems.

Turning vanes may be advantageously employed in elbows, both to reduce the pressure loss and to provide a more uniform velocity distribution downstream from the bend.[9, 10] Vanes and concentric splitters are particularly recommended where miter elbows are used, because even the simplest vane forms will produce a substantial saving in pressure loss.

Table 4 .... Pressure Losses Due to Area Changes

TYPE	ILLUSTRATION	CONDITIONS A_1/A_2	LOSS COEFFICIENT C_1	C_2
ABRUPT EXPANSION	A_1 A_2	0.1	0.81	81
		0.2	0.64	16
		0.3	0.49	5
		0.4	0.36	2.25
		0.5	0.25	1.00
		0.6	0.16	0.45
		0.7	0.09	0.16
		0.8	0.04	0.06
		0.9	0.01	0.01
GRADUAL EXPANSION	A_1 A_2 θ	θ	C_D	
		5°	0.17[9]	
		7°	0.22	
		10°	0.28	
		20°	0.43	
		30°	0.59	
		40°	0.73	
ABRUPT EXIT	A_1 A_2 (A_2=∞)	A_1/A_2=0.0	1.00	
SQUARE EDGE ORIFICE EXIT	A_1 A_2	A_2/A_1	C_2	
		0.0	2.50[12]	
		0.2	2.44	
		0.4	2.26	
		0.6	1.98	
		0.8	1.54	
		1.0	1.00	
BAR ACROSS DUCT		L/D	C	
		0.10	0.79	
		0.25	1.4	
		0.50	4.0	
PIPE ACROSS DUCT		L/D	C	
		0.10	0.20[9]	
		0.25	0.55	
		0.50	2.0	
STREAM-LINED STRUT ACROSS DUCT		L/D	C	
		0.10	0.07[9]	
		0.25	-0.23	
		0.50	0.90	

TYPE	ILLUSTRATION	CONDITIONS A_2/A_1	LOSS COEFFICIENT C_2
ABRUPT CONTRACTION SQUARE EDGE	A_1 A_2	0.0	0.34[12]
		0.2	0.32
		0.4	0.25
		0.6	0.18
		0.8	0.06
GRADUAL CONTRACTION	A_1 A_2 θ	θ	
		30°	0.02[9]
		45°	0.04
		60°	0.07
EQUAL AREA TRANSFORMATION	A_1 A_2 θ	$A_1 = A_2$ θ ≤ 45°	C 0.15[9]
FLANGED ENTRANCE		$A=\infty$	C 0.34[12]
DUCT ENTRANCE		$A=\infty$	C 0.85[9]
FORMED ENTRANCE		$A=\infty$	C 0.03[9]
SQUARE EDGE ORIFICE ENTRANCE	A_1 A_2	A_2/A_1	C_2
		0.0	2.50[12]
		0.2	1.90
		0.4	1.39
		0.6	0.98
		0.8	0.61
		1.0	0.34
SQUARE EDGE ORIFICE IN DUCT	$A_1 = A_2$	A_2/A	C_2
		0.0	2.50[12]
		0.2	1.86
		0.4	1.21
		0.6	0.64
		0.8	0.20
		1.0	0.0

Note 1: Subscript on C indicates cross-section at which velocity is calculated (See, for example, Equation 10 in text.)
Note 2: Superscript numbers refer to references at end of chapter.

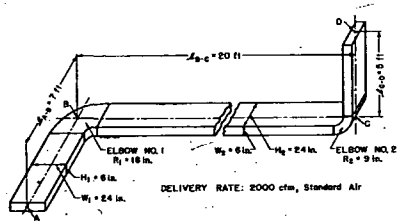


Fig. 10 .... Portion of Duct System for *Example 5*

Table 5 .... Ratio of Pressure Loss to Branch Velocity Pressure

Take-off Angle	Ratio of Velocity in Branch to Velocity in Main Duct 0.4	0.6	0.8	1.0	1.5	2.0	3.0
90-deg	6.5	3.1	2.0	1.5	0.95	0.74	0.62
60-deg	5.0	2.2	1.3	0.77	0.47	0.47	0.58
45-deg	3.5	1.3	0.64	0.43	0.40	0.45	0.54

LOSSES DUE TO AREA CHANGES

Area changes in ducts, generally unavoidable, are necessitated frequently by the building construction or changes in the volume of air carried. Experimental investigations[13, 13, 14, 15] of pressure changes, and pressure losses at changes of the area of duct cross-sections, indicate that the excess pressure loss over the normal friction loss is a dynamic loss due to a faster stream expanding into a slower stream, as determined by the actual areas occupied by the flow rather than the areas of the duct. No perceptible dynamic loss is due to the converging of the air stream itself where the flow is contracted, but the air stream continues to converge beyond the edge of the contraction and reaches a minimum at the *vena contracta*. For contraction, therefore, the dynamic loss is caused by expansion from the vena contracta to the full area following the contraction. Abrupt contraction in area may therefore be considered as a special condition of abrupt enlargement. Fig. 11 illustrates (*a*) abrupt enlargement and (*b*) abrupt contraction.

For a sudden symmetrical enlargement, a theoretical expression for the loss is

$$H_e = \left(\frac{V_1 - V_2}{4005}\right)^2 = \left(1 - \frac{A_1}{A_2}\right)^2 \left(\frac{V_1}{4005}\right)^2$$

$$= C_1 \left(\frac{V_1}{4005}\right)^2 = C_2 \left(\frac{V_2}{4005}\right)^2 \qquad (8)$$

where

H_e = pressure loss due to sudden enlargement, based on standard air, inches of water.
V_1 = velocity of standard air in the inlet duct, feet per minute.

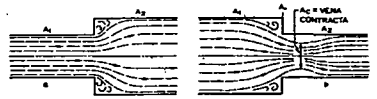


Fig. 11 .... Air Flow at Abrupt Enlargement or Contraction of Air Stream