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
45-DEG.		RECTANGULAR OR ROUND; WITH OR WITHOUT VANES	45/90 TIMES VALUE FOR SIMILAR 90-DEG. ELBOW[b]		
90-DEG. ROUND SECTION		MITER	1.30[a]	60[a]	
		R/D=0.5	0.90		
		0.75	0.45	33	
		1.0	0.33	27	
		1.5	0.24	22	
		2.0	0.19	20	
90-DEG. RECTANGULAR SECTION		H/W	R/W		
		0.25	MITER	1.25[b]		25[b]
			0.5	1.23		29
			0.75	0.60		12
			1.0	0.37		7
			1.5	0.19		4
		0.5	MITER	1.47		49
			0.5	1.10		40
			0.75	0.50		18
			1.0	0.28		9
			1.5	0.13		4
		1.0	MITER	1.50		75
			0.5	1.00		50
			0.75	0.41		21
			1.0	0.22		11
			1.5	0.09		4.5
		4.0	MITER	1.38		110
			0.5	0.98		80
			0.75	0.37		45
			1.0	0.19		17
			1.5	0.07		6
90-DEG. SQUARE SECTION WITH SPLITTER VANES		R_1/W R_2/W R_3/W			
		MITER 0.5				28[b]
		0.5 0.4		0.70[b]		19
		0.7 0.8				12
		1.0 1.0		0.13		7.2
		1.5		0.12		
		MITER 0.5 0.5				23[b]
		0.5 0.2 0.4		0.45		16
		0.75 0.4 0.7		0.12		
		1.0 0.7 1.0		0.10		
		1.5 1.3 1.5		0.13		
MITER WITH TURNING VANES	PLATE / FORMED	C=0.10 TO 0.35[a] DEPENDING ON MANUFACTURE			
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 References 6 for f = 0.02.
Note: Superscript numbers refer to references at end of chapter.

Solution: For elbow No. 1 the radius ratio is R_1/W_1 = 18/24 = 0.75 and the aspect ratio is H_1/W_1 = 6/24 = 0.25. The additional equivalent length for elbow No. 1 in terms of W is obtained from Fig. 8; $(L/W)_1$ = 11.5. Thus L_1 = 11.5 × 24/12 = 23 additional equivalent feet. Similarly, for elbow No. 2, the radius ratio is R_2/W_2 = 9/6 = 1.5 and the aspect ratio is H_2/W_2 = 24/6 = 4.0; Fig. 8 gives $(L/W)_2$ = 6, so L_2 = 6 × 6/12 = 3 additional equivalent feet.

The total length of the straight runs from A to D is $l = l_{A-B} + l_{B-C} + l_{C-D}$ = 7 + 20 + 5 = 32 ft and the additional equivalent length due to the elbows is $L = L_1 + L_2$ = 23 + 3 = 26 ft. Thus the equivalent length of the system from A to D is $l + L$ = 32 + 26 = 58 ft of 6 by 24 in. duct.

The diameter of a circular duct, equivalent in friction and capacity to this rectangular duct, is 12.4 in., as given by the table of circular equivalents, Table 2. At a delivery rate of 2000 cfm, the ASHRAE 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 × 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 = ¼ 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[8] 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.

PRESSURE LOSSES IN DIVIDED-FLOW FITTINGS

Analysis[11] of available data for losses at branch take-offs indicates that: (1) the loss in the straight-through section is about 35 percent of that for abrupt enlargement involving the same ratios of velocities, (2) the loss in the diverted-flow section depends on the ratio of the velocity of diverted flow to total flow and on the angle the take-off makes with the main, and (3) the loss is at a minimum for a natural relation that exists between these two variables. Some representative branch losses are given in Table 5.

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

TYPE	ILLUSTRATION	CONDITIONS	LOSS COEFFICIENT
ABRUPT EXPANSION	A_1 A_2	A_1/A_2	C_1	C_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	0.18
		0.8	0.04	0.06
		0.9	0.01	0.01
GRADUAL EXPANSION	A_1 A_2 θ	θ	C_2
		5°	0.17[9]
		7°	0.22
		10°	0.28
		20°	0.45
		30°	0.59
		40°	0.73
ABRUPT EXIT	A_1 A_2 A_2/A_1=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	1.96
		0.8	1.54
		1.0	1.00
BAR ACROSS DUCT	L/D D L	L/D	C
		0.10	0.75
		0.25	1.4
		0.50	4.0
PIPE ACROSS DUCT	L/D D L	L/D	C
		0.10	0.20[9]
		0.25	0.33
		0.50	2.0
STREAM-LINED STRUT ACROSS DUCT	L/D D L	L/D	C_1
		0.10	0.07[9]
		0.25	0.23
		0.50	0.90

TYPE	ILLUSTRATION	CONDITIONS	LOSS COEFFICIENT
ABRUPT CONTRACTION SQUARE EDGE	A_1 A_2	A_2/A_1	C_2
		0.0	0.34[12]
		0.2	0.32
		0.4	0.25
		0.6	0.18
		0.8	0.08
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 $\theta \leq 14°$	A_1/A_2	C
			0.15[9]
FLANGED ENTRANCE	A_1 A_2 A_2/A_1=0		C
			0.34[12]
DUCT ENTRANCE	A_1 A_2 A_2/A_1=0		C
			0.85[9]
FORMED ENTRANCE	A_1 A_2 A_2/A_1=0		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	0.96
		0.8	0.61
		1.0	0.34
SQUARE EDGE ORIFICE IN DUCT	A_1 A_2 $A_2 \leq A_1$	A_2/A_1	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.

LOSSES DUE TO AREA CHANGES

Area changes in ducts, which are generally unavoidable, are frequently necessitated by the building construction or changes in the volume of air carried. Experimental investigations[13,14,15] of pressure changes and of 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 one, due to a faster stream expanding into a slower stream, as determined by the actual areas occupied by the flow, rather than by 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:

$$H_s = \left(\frac{V_1 - V_2}{4005}\right)^2 = \left(1 - \frac{A_1}{A_2}\right)^2 \left(\frac{V_1}{4005}\right)^2 = C_1 \left(\frac{V_1}{4005}\right)^2 = C_2 \left(\frac{V_2}{4005}\right)^2 \quad (8)$$

where

H_s = 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.
V_2 = velocity of standard air in the outlet duct, feet per minute.
A_1 = area of the inlet duct, square feet.
A_2 = area of the outlet duct, square feet.
C_1 = loss coefficient based on area A_1.
C_2 = loss coefficient based on area A_2.

For a gradual symmetrical enlargement, Equation 8 changes to:

$$H_{es} = C_e \left(\frac{V_1 - V_2}{4005}\right)^2 = C_e C_1 \left(\frac{V_1}{4005}\right)^2 = C_e C_2 \left(\frac{V_2}{4005}\right)^2 \quad (9)$$

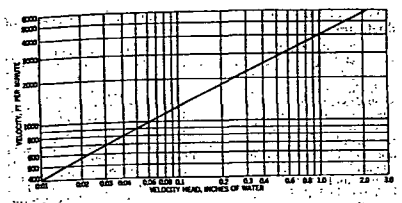

Fig. 7 . . . . Relation Between Velocity and Velocity Head for Standard Air

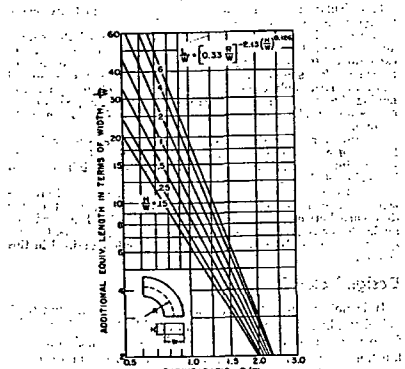

Fig. 8 . . . Loss in 90-Deg Elbows of Rectangular Cross-Section

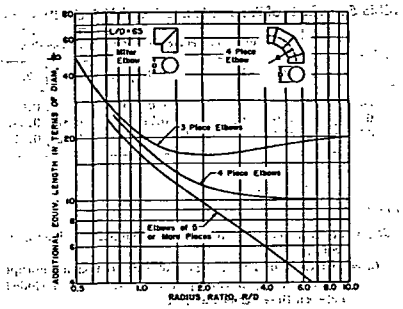

Fig. 9 . . . . Loss in 90-Deg Elbows of Round Cross-Section

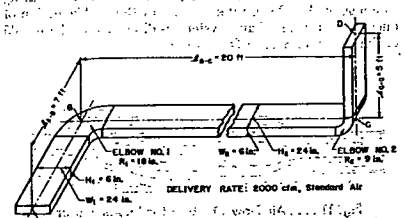

Fig. 10 . . . . Portion of Duct System for *Example 5*