good results may be expected when the radius to the center of the elbow is 1.5 times the pipe diameter or duct width parallel to the radius. Examination of Fig. 4 will indicate that little advantage is to be gained by selecting elbows having a centerline radius of more than two diameters[11]. Elbows having a radius of more than three diameters show a slightly increased resistance due to the increased length of pipe but, when used, they reduce the over-all resistance of the system and therefore should not be avoided.

TABLE 3. EFFECT OF VANES ON PRESSURE LOSS OF 7-INCH SQUARE VENTILATING DUCT[a]

Expressed in feet of total equivalent length of duct (ELD)

SQUARE MITER ELBOW

	Radius Ratio						
R1 / W	R_1/W	0	.2	.4	.6	.8	1.0
	ELD, ft	41.1	30.5	27.5	30.1	37.7	38.5
R1, R2	R_1/W	0	.2	.3			
	R_2/W	0	.4	.5			
	ELD, ft	41.1	23.5	23.3			
R1, R2, R3	R_1/W	0	.2	.3			
	R_2/W	0	.4	.5			
	R_3/W	0	.6	.7			
	ELD, ft	41.1	20.7	22.2			

VANE	A	B	C	D
ELD, ft	21.8	17.0	17.9	17.8

STANDARD ELBOWS WITH VARIOUS RADII

	Radius Ratio						
R1 / W	R_1/W	0	.2	.4	.6	.8	1.0
	ELD, ft	39.7	23.3	22.0	25.7	28.9	39.7
R1, R2	R_1/W	0	.2	.3	.4	.5	.6
	R_2/W	0	.4	.5	.6	.7	.8
	ELD, ft	39.7	20.0	22.0	23.0	23.8	25.7
1½" L.R.	R_1/W	0	.4	.6	.8	1.0	1.2
	ELD, ft	25.3	17.7	16.5	18.7	23.5	25.6
4" L.R.	R_1/W	0	.7	.8	.9	1.0	1.2
	ELD, ft	14.2	13.3	13.0	12.7	12.5	12.7

[a] For more complete data see A.S.H.V.E. RESEARCH REPORT No. 1216—Effect of Vanes in Reducing Pressure Loss in Elbows in 7-Inch Square Ventilating Duct, by M. C. Stuart, C. F. Warner and W. C. Roberts (A.S.H.V.E. TRANSACTIONS, Vol. 48, 1942, p. 409).

Note A: Vane *A* made up of a large number of small splitters; *B* made up of a small number of large splitters bent on a large radius, *C* hollow vanes having different outside and inside curvature; and *D* four splitters with $R/W = 0.4$. Elbow same as *D* except 2 in. trailing edge on the end of each splitter, ELD in feet = 17.0.

Where space conditions necessitate the use of short radius or miter elbows in square or rectangular duct work, turning vanes should be used to reduce the pressure losses. Rough or raw edges on the vanes should be avoided to prevent objectionable noise. Table 3 shows typical types of vanes and gives the resistance, expressed in equivalent length of straight pipe, for a 7-in. x 7-in. elbow of each type.

The pressure loss through elbows of less than 90 deg may be assumed to be directly proportional to the ratio of the angle through which the turn is made. The resistance will vary widely for the large degree turns depending upon the aspect ratio and the length of straight pipe between the elbows but, for practical purposes, it may be assumed that the ratio remains proportional to the angle through which the turn is made. Reverse 90 deg elbow turns should be avoided wherever possible but, where used, the friction indicated in Fig. 4 should be doubled for the second elbow. Additional tests are needed on the loss of pressure in elbows and other types of duct fittings in order to reconcile the difference between values shown in Fig. 4 and results of more recent tests shown in Table 3. A study of this subject is in progress at the A.S.H.V.E. Research Laboratory for the purpose of obtaining such data.

LOSSES DUE TO AREA CHANGES

Area changes in ducts are generally unavoidable, necessitated frequently by the building construction or due to changes in the volume of air carried. Experimental investigations[12,13] of pressure changes and pressure losses at changes of the area of cross-section of duct indicate that the excess pressure loss over the normal friction loss is a shock 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 shock loss is due to the converging of the air stream itself where

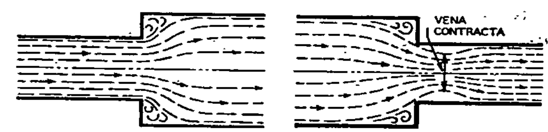

FIG. 5. AIR FLOW AT ABRUPT ENLARGEMENT OR CONTRACTION OF AIR STREAM

the flow is contracted, but the converging of the air stream causes the flow to contract beyond the edge of the constriction, forming a *vena contracta* in which the area of cross-section of the air stream is the minimum immediately following the edge of the constriction. For contraction, therefore, the shock loss is caused by expansion from the vena contracta to the full area following the contraction. Enlargement in area may be considered as a special condition of general expansion following contraction. Fig. 5 illustrates (a) abrupt enlargement and (b) abrupt contraction.

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

$$h_e = \left(1 - \frac{A_1}{A_2}\right)^2 \frac{v_1^2}{2g} = \frac{(v_1 - v_2)^2}{2g} \tag{6}$$

or, for standard air:

$$H_e = \left(1 - \frac{A_1}{A_2}\right)^2 \left(\frac{V_1}{4005}\right)^2 = \left(\frac{V_1 - V_2}{4005}\right)^2 \tag{7}$$

where

h_e = pressure loss due to sudden enlargement, inches of water.
H_e = pressure loss due to sudden enlargement, based on standard air, inches of water.
V_1 = velocity in the smaller duct, in feet per min.
V_2 = velocity in the larger duct, in feet per min.
A_1 = area of the smaller duct.
A_2 = area of the larger duct.