is obtained from Fig. 7: $(L/W)_1 = 11.5$. Thus $L_1 = 11.5 \times 24/12 = 23$ additional equivalent feet. Similarly for elbow No. 2, the ratio radius is $\frac{R_2}{W_2} = \frac{9}{6} = 1.5$ and the aspect ratio is $\frac{H_2}{W_2} = \frac{24}{6} = 4.0$; Fig. 7 gives $(L/W)_2 = 6$, so $L_2 = 6 \times 6/12 = 3$ 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 1. At a delivery rate of 2000 cfm, the A.S.H.A.E. 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, $H/W = 1/4$, then 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 loss data for elbows, both with and without vanes, are tabulated in condensed form, in Table 2.

PRESSURE LOSSES IN DIVIDED-FLOW FITTINGS

Data for losses at branch take-offs are quite meager and therefore an A.S.H.A.E. cooperative investigation is under way for the purpose of obtaining additional data on losses for typical take-off fittings. Analysis[11] of available data indicates that the loss in the straight-through section is about 35 percent of that for abrupt expansion (see next section, Losses Due to Area Changes) involving the same ratios of velocities; that 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 is at a minimum for a natural relation that exists between these two variables. That is, there is a natural angle of efflux corresponding to the velocity ratio. Some representative branch losses are given in Table 4.

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[12, 13, 14, 15] of pressure changes, and pressure losses

TABLE 4. 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

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 expansion. Fig. 10 illustrates (a) abrupt enlargement and (b) abrupt contraction.

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

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

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.

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

$$H_{ge} = C_r\left(\frac{V_1 - V_2}{4005}\right)^2 = C_rC_1\left(\frac{V_1}{4005}\right)^2 = C_rC_2\left(\frac{V_2}{4005}\right)^2 \qquad (9)$$

where

H_{ge} = pressure loss due to gradual enlargement, inches of water.

C_r = coefficient of loss, as ratio of loss to loss for abrupt expansion, dependent upon the total angle included between the sides of the duct.

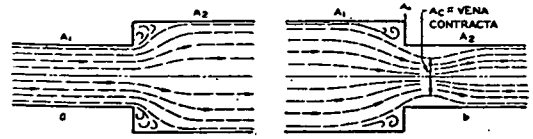


FIG. 10. AIR FLOW AT ABRUPT ENLARGEMENT OR CONTRACTION OF AIR STREAM