Equation 4 has been developed under the assumption that the temperature of the supply air is the same as the temperature of the room air. It applies only to straight flow outlets with aspect ratios less than 16.

Equation 5 for the performance of straight flow outlets evolved from research[1] allows the calculation of the maximum residual velocity at any distance perpendicular to the outlet face. It applies for aspect ratios up to 50.

$$V_r = K\,\frac{V_1\sqrt{A_1}}{X} = K\,\frac{Q_1}{X\sqrt{A_1}} \qquad (5)$$

where

- V_r = maximum residual velocity in air stream, i.e., the highest maintained velocity at the given cross section in the room, feet per minute.
- V_1 = average initial velocity across outlet, feet per minute.
- K = Constant of proportionality.
- A_1 = effective outlet area in square feet = (gross measured area) x (percentage of free area/100) x (discharge coefficient).
- X = Normal distance from outlet face, feet.

Equation 5 together with Equation 6 (which reduces to Equation 7 if the jet angle is 20 deg) for the entrainment ratio,

$$\text{Entrainment Ratio} = \frac{0.785\,K}{R\,X\sqrt{A_1}}\left(\sqrt{\frac{A_1}{0.785}} + 2\,X\tan\frac{\Theta}{2}\right)^2 - 1 \qquad (6)$$

where

- R = ratio of maximum residual velocity to average residual velocity.
- Θ = jet angle or spread angle in degrees.

$$\underset{\text{(20 deg jet angle)}}{\text{Entrainment Ratio}} = \frac{0.785\,K}{R\,X\sqrt{A_1}}\left(\sqrt{\frac{A_1}{0.785}} + 0.35\,X\right)^2 - 1 \qquad (7)$$

has been used to develop charts[3] which provide the graphical solution of problems involving the determination of the throw of air from slots and jets, the residual velocity, and the size of openings. (See Figs. 2 and 3). The charts apply only to *air discharging into room air of same temperature as the stream.* They can be used to determine the throw of air and entrainment ratios up to 40:1 with initial velocities of 1000 to 6000 fpm and with residual velocities of 100 to 1000 fpm. The charts furthermore are for use with sharp-edged orifices or slots, and *include the coefficient of discharge.* If air is discharged from an orifice with a well-rounded entrance or from a length of straight duct, the coefficient of discharge is unity and the actual area of the opening is the effective area. For such rectangular openings the effective diameter is the diameter of a circle with an area equal to the actual area of the rectangle. The following examples will illustrate the use of the charts:

Example 1: Air is delivered to a cooler through independent slots each 24 in. x 2 in. with an initial velocity of 2000 fpm. Determine the maximum residual velocity and the entrainment ratio at a distance of 15 ft from the slot.

From Fig. 3 the effective diameter = 6.2 in. = 0.52 ft. The number of effective diameters in 15 ft = 15/0.52 = 28.8.

From Fig. 2 at 2000 ft initial velocity read entrainment ratio = 6.6 and maximum residual velocity = 390 fpm. From tests it has been shown that the *average* residual velocity may be taken as ⅓ of the *maximum* or 130 fpm in this case.

Example 2: Using the data from *Example 1* determine the distance at which the maximum residual velocity will be 150 fpm.

From Fig. 2 at V_1 = 2000 and V_r = 150, the number of effective diameters is read directly as 73 and the throw of the air is therefore 73 x 0.52 = 38 ft.

Example 3: Air issues from a round orifice plate with an initial average velocity of 4000 fpm. It is to have a maximum residual velocity of 400 fpm at a distance of 30 ft from the opening. Calculate the size of the opening required and the entrainment ratio.

On Fig. 2 at the intersection of the curve of 4000 fpm, the entrainment ratio is read directly as 15 and the effective diameters of throw = 55.

Since 55 effective diameters are equal to 30 ft as required, 1 effective diameter = $\frac{30}{55}$ = 0.545 ft or 6.56 in.

On Fig. 3 vertically below intersection of 6.56 in. effective diameter line and equivalent round opening line read 8.5 in. in lower margin.

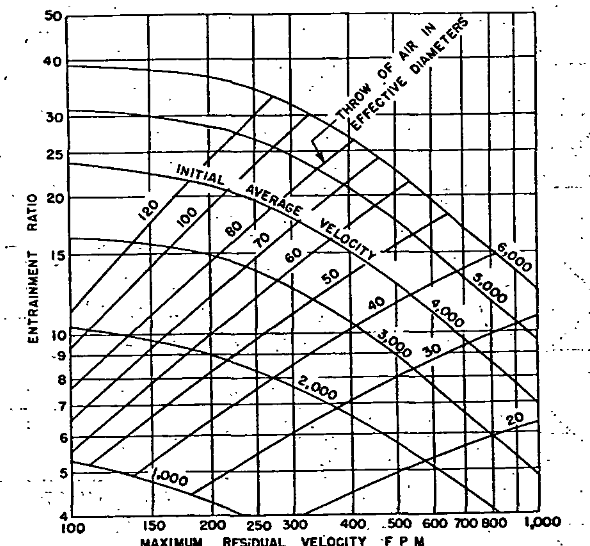

Fig. 2. Relation Between Initial Velocity, Residual Velocity, Entrainment Ratio and Throw of Air from Jets and Slots

Example 4: A jet of air issues from a pipe or from air orifice having a well-rounded entrance (coefficient of discharge = 1.0) and delivers air with the same velocities and with the same throw as in *Example 3.* What is the required diameter?

In this case since the coefficient of discharge is unity, the effective diameter of the jet is the actual diameter of the pipe or orifice, or 6.56 in., as obtained in *Example 3.*

Spread

The induction effect results in the spreading of the air stream. The total angle included by the air stream from straight flow outlets has been measured and found to be between 14 and 25 deg. The angle will depend on the type of approach, type of outlet and velocity.

The effect of vertical bars placed in the face of the outlet to increase the spread, may also be deducted from the momentum theory. Assuming that there are no horizontal deflecting bars and that the air spreads vertically through a total angle of 14 deg; that a uniform velocity exists at any section of the air stream; and that the conservation of momentum