little effect on the jet pattern or velocities at some distance from the plaque.[1]

For a basic equation for radial flow outlets resulting from the air distribution research at Case Institute of Technology see Jet Velocities from Radial Flow Outlets, by Alfred Koestel (ASHAE TRANSACTIONS, Vol. 63, 1957, p. 505).

Discharge from a Long Slot

When a long slot receives its air supply from one end only, the important design factor is the ratio of the area of the slot to the area of the supply duct, and both the air stream profiles and the duct pressure requirements are determined by this

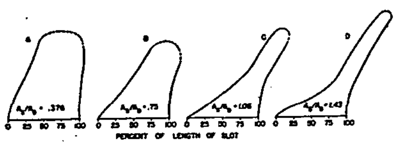


Fig. 5.... Shape of Air-Stream Envelopes as Slot Area is Increased

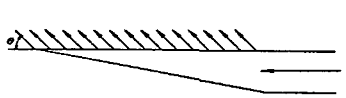
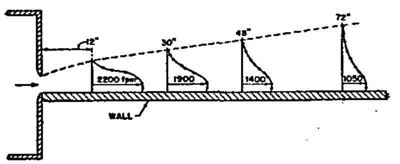


Fig. 6.... Uniform Air Flow from a Slot Supplied by a Tapered Duct



(V_0 = 2260, A = 0.10, C_d = 0.78)

Fig. 7.... Jet Velocity Patterns for a Square Outlet Discharging along Wall or Ceiling

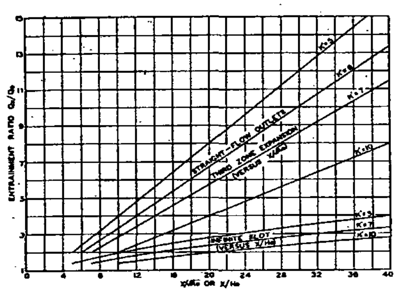


Fig. 8.... Entrainment Ratios for Straight-Flow Outlets

ratio.[9] Fig. 5 shows the changing profile as the slot area is increased for a rounded entrance slot (C_d = 0.93) with constant duct cross-section.

The air discharge from a slot in a tapered duct will be uniform (Fig. 6) for a relationship between discharge angle and slot-duct dimensions[9]

$$\cot \theta = \frac{A_s C_d}{A_d} \qquad (6)$$

where

θ = discharge angle, degrees.
A_s = slot area, square feet.
A_d = duct cross-sectional area at upstream end, square feet.
C_d = coefficient of discharge.

Perforated Panels

When air is discharged from perforated panels of relatively large sizes the constant velocity core formed by the coalescence of the individual jets extends a considerable distance from the panel face. In this Zone 1 region the proportionality constants K and K' do not apply. Therefore, the proportionality constants given in Table 1 should be used only when the ratio (Distance from panel/$\sqrt{\text{Panel area}}$) is larger than 5. When the ratio is less than 5, the equation

$$V_x = V_0 \cdot 1.2\sqrt{C_d \times R_{fa}} \qquad (7)$$

should be used for estimating centerline velocities.[10]

Effect of Walls and Ceilings

Jets discharging parallel to a wall with one edge of the outlet coinciding with the wall, take the form of one-half of an axial jet discharging from an outlet twice as large, similar to radial jets from ceiling plaques. Entrainment takes place practically only along the surface of a half cone and the maximum velocity remains close to the wall.[1] (See Fig. 7.) Values of K and K' are approximately those for a free jet multiplied by $\sqrt{2}$, that is to say, the normal maximum of 7.0 for K' for free jets becomes 9.9 for a similar jet adjacent to, and discharged parallel to, a wall, and in Fig. 2, $\frac{X}{\sqrt{2A_0}}$ should be used in place of $\frac{X}{\sqrt{A_0}}$

When a jet is discharged parallel to, but at some distance from a wall, its expansion in the direction of the wall is reduced and entrained air must be obtained by recirculation from the jet itself instead of from ambient air.[6, 11] The jet expands normally to within a short distance from the wall, which nearer to the outlet only affects velocity distribution in the outer shell of the jet, but further on also affects centerline velocities. This happens at some distance from a plane where the jet outline becomes parallel to the wall, and where the jet enters its fourth or terminal zone. Few engineering data are available on this important phase of jet expansion.[5]

Effect of Resistance on Return Path of Jet Air

Laboratory experiments on jets usually involve recirculated air with negligible resistance to flow on the return path of the jet air. Experience and experiments in tunnels of small cross-sectional area in mines, where considerable resistance is offered to the return flow of jet air to outlets, show that the expansion of the jet terminates abruptly at a distance that is independent of velocity of discharge and but slightly affected by size of outlet. Such distances are determined primarily by size and

length of return path. In a long 5 ft x 6 ft tunnel, a jet may not travel more than 25 ft whereas in a relatively short opening, 25 by 60 ft, it may travel more than 250 ft. Few engineering data are available on this phase of jet expansion but it can be of great practical importance.[5]

Entrainment Ratios

Equations for the entrainment of circular jets and of jets from long slots have been mathematically derived.[12] They are:

For third zone expansion of circular jets,

$$\frac{Q_x}{Q_0} = \frac{2}{K'} \cdot \frac{X}{\sqrt{A_0}} \qquad (8)$$

For a long slot

$$\frac{Q_x}{Q_0} = \sqrt{\frac{2}{K'}} \cdot \sqrt{\frac{X}{H_0}} \qquad (8a)$$

where

Q_x = total volume flow rate at distance X from face of outlet, cubic feet per minute.
Q_0 = discharge from outlet, cubic feet per minute.
X = distance from face of outlet, feet.
K' = proportionality constant.
A_0 = effective area of stream at discharge from an open-end duct or at a contracted section, square feet.
H_0 = width of slot, feet.

Equations 8 and 8a have been used in plotting Fig. 8 for entrainment ratios.

OUTLET PERFORMANCE

The air distribution research sponsored by the AMERICAN SOCIETY OF HEATING AND AIR-CONDITIONING ENGINEERS has proved that the phenomena of room distribution are amenable to scientific research and rational interpretation, and has now reached a stage where a definite technique of experimentation in combination with semi-empirical theories can be of great help in the design of air outlets.

Practical room air distribution, however, is still predominantly an art, where decisions depend on isolated tests and judgments must be based on the accumulated experience of the behavior of outlets in the laboratory and in the field. Manufacturers' literature is available to provide data for the performance and application of various outlets. In designing a satisfactory air distribution system, the engineer must make use of this material, and weigh the different factors of the outlet performance which place considerable limitations on his proceedings. A short discussion follows regarding some of these factors which are: (1) jet pattern, (2) capacity, (3) temperature differential, (4) room air motion, (5) permissible noise level, and (6) smudging.

Jet Pattern

Refer to section Ventilating Jets in Air Distribution for a general discussion of the jet pattern. In selecting the *throw* and *drop* of outlets the following considerations are important: (1) throw, (2) effect of vanes, (3) effect of type of outlet, and (4) drop.

1. *Throw.* The throw of a wall outlet must be sufficient to produce satisfactory conditions over the area to be conditioned. Underblowing may cause heated air to rise too rapidly above the occupied zone and thus create excessive vertical temperature variation (stratification); in cooling operation it may cause cold air to drop into the occupied zone before supply and room air are mixed sufficiently, and thereby create a condition of acute discomfort (draft). On the other hand, overblowing will result in objectionable downdrafts from any surface the primary air stream may strike.

On the average, it is considered most practicable to select a throw which is three-fourths of the distance toward an exposed wall or window, as shown in diagram A of Fig. 9. However, structural characteristics, mounting height of outlet, temperature differential, and resultant drop or rise, or location of greatest heating or cooling loads strongly affect the selection of the optimum throw. In spaces with beamed ceilings, the outlets should be located below the bottom of the lowest beam level, and preferably low enough so that an upward or arched blow may be employed. The blow should be arched sufficiently to miss the beams and, at the same time, in such a manner as to prevent the primary or induced air stream from striking furniture and obstacles, and producing objectionable drafts.

2. *Effect of Vanes.* Vanes affect grille performance if their depth corresponds at least to the distance between the vanes. If the *vane ratio* is less than unity, effective control of the air stream discharged from the grille by means of the vanes is impossible. If it is higher than two, further improvement is slight.

A grille discharging air uniformly forward (vertical vanes in straight position), will have a *spread* of 14 to 24 degrees, depending on type of outlet, duct approach, and discharge velocity. Turning of the vanes will influence the direction and the throw of the discharged air stream.

A grille with *diverging vanes* (vertical vanes with uniformly increasing angular deflection to a maximum at each end of 45 deg) will have a spread of approximately 60 deg and the throw will be reduced considerably. With increasing divergence the quantity of air handled by the grille for a given duct static pressure will decrease.

A grille with *converging vanes* (vertical vanes with uniformly decreasing angular deflection) will have a slightly higher throw than a grille with straight vanes, but the spread will be the same for both settings. The air stream will converge slightly for a short distance in front of the outlet, and then spread somewhat more than the air discharged from a grille with straight vanes.

In addition to vertical vanes which normally spread the air horizontally, horizontal vanes may be used to spread the air vertically. However, spreading the air vertically entails the risk of hitting beams or other obstructions, or of blowing primary air at excessive velocities into the occupied zone.

3. *Effect of Type of Outlet.* Ceiling diffusers distribute the air with a horizontal spread of 360 deg and also have a downward air motion. Therefore, both throw (radius of diffusion) and mounting height are important and interdependent factors. Due to the 360 deg spread, the rate of induction is higher and the throw shorter than that for a wall grille handling the same air quantity at the same outlet velocity. Therefore, ceiling diffusers will frequently permit the use of higher air velocities than wall outlets, and consequently may be sized smaller to handle the same air volumes. If ceiling outlets are installed flush with the ceiling, impingement of the air stream along the ceiling surface restricts induction of secondary air, and the throw is increased approximately 40 percent above that of an unrestricted air stream. (Refer to Radial Jets and Effect of Walls and Ceilings in section Ventilating Jets in Air Distribution.)

Slotted outlets, due to their high aspect ratio, have higher induction than comparable round or square vaned outlets of