ble to answer the following questions about a jet discharged from any air supply outlet:

1. What is the shape of the jet (spread or coverage)?
2. How can the velocity at any selected point within the jet be determined?
3. How far does the jet travel or what is its throw?

A *free jet* is a straight-flow jet, free from pulsations or helical flow, which is discharged into a large open room in which no surfaces, objects, or convection currents interfere with the formation of the natural flow pattern.

Most of the available data refer to isothermal jets. Information given herein refers to this type unless otherwise noted.

Types of Outlets

Two general classes of outlets have been the subject of experimental study:

Class 1. Straight-flow devices, such as ducts, nozzles, orifices, slots, straight-flow grilles and multiple openings located close together, perforated panels being an extreme example.

Class 2. Annular outlets including ceiling plaques, but not including diffusers.

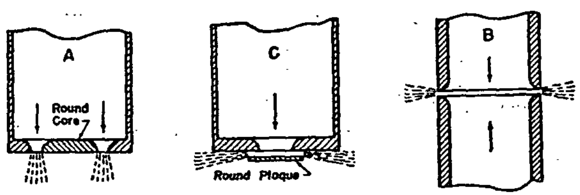

FIG. 1. CROSS-SECTIONS OF ROUND DUCTS WITH THREE BASIC TYPES OF ANNULAR OUTLETS

Fig. 1 shows three basic types of annular outlets. Outlet A is a circular slot in a wall or ceiling, and produces a jet similar to straight-flow jets. Outlet B discharges the jet radially from the axis of the approach duct, and also produces a jet quite similar to straight-flow jets. Outlet C, usually called a ceiling plaque, is a radial outlet with a plane boundary extending from one edge, but it cannot readily be correlated with outlet B.

Shape of Axial Jets

A surprising similarity between the shape of the jets exists at a short distance from the outlet face, whether the outlet is round, rectangular, grille-like, or a perforated panel. Even in the case of wide-angle grilles or annular outlets, the similarities are such as to permit the same analysis of performance.

The jet discharged from a round opening forms an expanding cone; whereas jets from rectangular outlets rapidly pass from rectangular to elliptical cross-sectional shape at a short distance from the outlet face, and then to a circular shape, at a rate depending primarily on the aspect ratio.

The angle of divergence is very definite close to the outlet face, but the boundary contours are somewhat billowy and are easily affected by external influences. Here, as in air distribution generally, room air movement is replete with local eddies, vortices, and surges, which are manifestations

of unbalance in the forces acting within the air stream. These internal forces govern the air motion, yet they are extremely delicate.

Measured angles of divergence (spread) for discharge into large open spaces have usually ranged from 20 to 24 deg with an average of 22 deg. Coalescing jets for closely spaced multiple outlets expand at somewhat smaller angles, averaging 18 deg, and jets discharging into relatively small spaces show even smaller angles of expansion.[8] Tests indicate that in cases where the outlet area itself is small compared to the dimensions of the space normal to the jet, the jet may be considered free as long as

$$X \leq 1.5\sqrt{A_R}$$

where

X = distance from face of outlet, feet.
A_R = cross-sectional area of the confined space, square feet.

Four Zones in Jet Expansion

In analyzing the performance of jets, four major zones can be distinguished. They may be roughly defined in terms of the maximum or centerline velocity existing at the cross section being considered:

Zone 1: A short zone, extending about 4 diameters or widths from the outlet face (or vena contracta for orifice discharge), in which the maximum velocity of the air stream remains practically unchanged.

Zone 2: A transition zone, extending to about 8 diameters for round outlets, or for rectangular outlets of small aspect ratio, over most of which maximum velocities vary inversely as the square root of the distance from the outlet. For rectangular outlets of large aspect ratio, this zone is elongated and extends from about 4 widths to a distance approximately equal to the width multiplied by four times the aspect ratio.

Zone 3: A long zone, of major engineering importance, in which the maximum velocity varies inversely as the distance from the outlet. This zone is often called the zone of fully *established turbulent flow* and may be 25 to 100 diameters long (or equivalent diameters of equal areas), depending on the shape and area of the outlet, the initial velocity, and the dimensions of the space into which the outlet discharges.

Zone 4: A terminal zone in which, in the case of confined spaces, the maximum velocity decreases at an increasing rate, or, in the case of large spaces free from wall effects, the maximum velocity decreases rapidly in a few diameters to the velocity range below 50 fpm which is usually regarded as *still air*.

Centerline Velocity in Zone 3

Research has shown that maximum or centerline velocities in Zone 3 of straight flow isothermal jets can be determined with good engineering accuracy from

$$\frac{V_x}{V_0} = \frac{KD_0}{X} = \frac{K'\sqrt{A_0}}{X} \tag{1}$$

$$V_x = \frac{K'V_0\sqrt{A_0}}{X} = \frac{K'Q}{X\sqrt{A_0}} \tag{2}$$

$$= \frac{K'Q}{X\sqrt{A_0} \times C_d \times R_{fa}} \tag{2a}$$

where

V_x = centerline velocity, feet per minute.

$V_0 = \dfrac{V_c}{C_d \times R_{fa}}$ = average initial velocity at discharge from open-end duct or across contracted stream at vena contracta of orifice or multiple-opening outlet, feet per minute.