The loss for a sudden symmetrical contraction can be expressed as

$$H_c = C_2\left(\frac{V_2}{4005}\right)^2 = C_1\left(\frac{V_1}{4005}\right)^2 = C_0\left(\frac{V_0}{4005}\right)^2 \quad (10)$$

where

H_c = pressure loss due to sudden contraction (Fig. 10b)

C_0 = loss coefficient based on orifice area A_0

V_0 = velocity of air through orifice, feet per minute.

The loss for a gradual symmetrical contraction can be similarly expressed as

$$H_{gc} = C_2\left(\frac{V_2}{4005}\right)^2 \quad (11)$$

where the coefficient of loss, C_2, depends on the included angle of the sides of the duct and the sharpness of the edges at the junction of taper to following duct section.

Pressure loss data for a variety of duct elements are given in Table 3.

DUCT DESIGN

The following discussion refers to ducts for commercial and industrial heating, ventilating, and air conditioning systems of the central station type. The design procedures given yield the static pressure required to overcome the resistance of the ductwork, including the supply outlets and return intakes. The fan selected for the duct system must not only produce this pressure but also the additional pressure required by the central equipment such as washers or spray chambers, heating or cooling coils, and filters. Pressure losses of these components should be obtained from the manufacturers' catalogs.

Special duct design procedures for heating ducts used in residences can be found in Chapter 19, Warm Air Heating Systems. The design of ducts in industrial exhaust systems is discussed in Chapter 45.

General rules which should be followed in the design are:

1. The air should be conveyed as directly as possible at the permissible velocities to obtain the desired results with minimum noise and greatest economy of power, material and space.

2. Sudden changes in the direction or velocity of the air should be avoided. When sudden changes are necessary at bends, turning vanes should be used to minimize the pressure loss.

3. Diverging transition pieces should be made as gradual as practicable. As shown in the section on area changes, losses in abrupt enlargements are high and therefore such transitions should be avoided. The included angle of divergence for enlargement should not exceed 20 deg. Losses in contractions are low but the included angle of convergence should not be greater than 60 deg.

4. Where the greatest air carrying capacity per square foot of sheet metal is desired, rectangular ducts should be made as nearly square as possible. Aspect ratios (ratio of width to depth) greater than 10 to 1 should be avoided.

5. Ducts should be constructed of smooth material, such as steel or aluminum sheet metal. For ducts made from other materials, proper allowance for the change in roughness should be made.[3]

6. Through the design procedures which follow, a reasonably precise estimate of the flow resistances offered by the system can be obtained. However, it should be recognized that in actual installations, resistances may vary considerably from the calculated values because of variation in the smoothness of materials, types of joints used, and the ability of workmen to fabricate the system in accordance with the design. Fans and motors should therefore be selected to provide at least a slight factor of safety, and dampers should be installed in each branch outlet for balancing the system.

Procedure for Duct Design

The general procedure is as follows:

1. Study the plan of the building and arrange the positions of the supply outlets to provide proper distribution of air within each space. Select outlet sizes from manufacturers' catalog data.

2. Draw a sketch of the most convenient system of ductwork, connecting the supply outlets and return intakes with the central station apparatus, taking cognizance of the building construction, avoiding all obstructions in steel work and equipment, and at the same time maintaining a simple design.

3. Calculate the sizes of all main and branch ducts by one of the procedures given in the following section.

4. Determine the total pressure requirement of the supply and return duct systems. Although the loss in total pressure of each duct run connecting the fan and each supply outlet (or return intake) should be calculated and made the same for all runs, ordinarily only the pressure loss of the duct run apparently having the greatest resistance is referred to as the pressure loss of the duct system. Dampers are relied upon for balancing the system.

Table 5. Recommended and Maximum Duct Velocities

Designation	Recommended Velocities, fpm			Maximum Velocities, fpm		
	Residences	Schools, Theaters, Public Buildings	Industrial Buildings	Residences	Schools, Theaters, Public Buildings	Industrial Buildings
Outside Air Intakes[a]	500	500	500	800	900	1200
Filters[a]	250	300	350	300	350	350
Heating Coils[a]	450	500	600	500	600	700
Air Washers	500	500	500	500	500	500
Suction Connections	700	800	1000	900	1000	1400
Fan Outlets	1000–1600	1300–2000	1600–2400	1700	1500–2200	1700–2800
Main Ducts	700–900	1000–1300	1200–1800	800–1200	1100–1600	1300–2200
Branch Ducts	600	600–900	800–1000	700–1000	800–1300	1000–1800
Branch Risers	500	600–700	800	650–800	800–1200	1000–1600

[a] These velocities are for total face area, not the net free area; other velocities in table are for net free area

Design Velocities

It is not possible to give specific rules for selecting duct velocities. Since the fan horsepower increases approximately as the square of the velocity, and noise generation increases with static pressure, velocities should be kept low for quiet and economical operation. On the other hand, from Equation 3, at a given flow rate the duct size increases with decreasing velocity. For multi-story buildings, it is sometimes possible to reduce the height between floors by using very small ducts, thereby effecting a considerable reduction in building investment cost. Velocities as high as 6000 fpm in main ducts have been used in *high-velocity* duct systems. Special outlets for such systems have recently been marketed; they incorporate a device for reducing the pressure and attenuating the noise before introducing the supply air into the conditioned space. High-velocity duct sys-