where

h_r = regain in static pressure, feet of fluid flowing.
v_1 and v_2 = mean velocities in inlet and outlet duct sections, respectively, feet per second.

The static pressure regain in a gradually expanding transition, followed by an after section, may be expressed as:

$$h_r = \left[\frac{v_1^2}{2g} - \frac{v_2^2}{2g}\right] - \left[\frac{c_1(v_1 - v_2)^2}{2g}\right] \tag{15}$$

or

$$h_r = \frac{v_1^2 - v_2^2 - c_1(v_1 - v_2)^2}{2g} \tag{16}$$

where

c_1 = an experimentally determined constant depending on nature of construction.

Curves have been developed showing the static pressure regain and the *theoretical* efficiency of conversion in abrupt expansion, and in diverging sections in smooth circular ducts.[13,14]

DUCT DESIGN

The discussion of duct design in this chapter refers to ducts in fan systems for central heating, ventilating and air conditioning systems. Additional data for heating ducts used in residences are to be found in Chapter 18 (Gravity Warm Air Systems) and Chapter 19 (Mechanical Warm Air Systems). The design of ducts in industrial exhaust systems is discussed in Chapter 45.

The following general rules should be followed in design:

1. The air should be conveyed as directly as possible at the permissible velocities to obtain the desired results with greatest economy of power, material and space.
2. Sharp elbows and bends should be avoided. Carefully designed splitters and turning vanes should be used to reduce the elbow or outlet pressure loss.
3. Diverging transformation pieces should be made as long as practicable. As shown in the section on area changes, losses in sudden enlargements are high, and abrupt enlargements should be avoided. The included angle of divergence for enlargements should not exceed 20 deg. Losses in contractions are low, but the included angle of convergence should not be larger than 60 deg.
4. Special care should be taken to avoid restriction of flow in elbows or transformation pieces.
5. Rectangular ducts should be made as nearly square as possible. Good practice limits the ratio between the long side and the short side 3 to 1. In no case should this ratio exceed 10 to 1.
6. Ducts should be constructed of smooth material, such as steel or aluminum sheet metal. For ducts made from other materials, for example masonry, proper allowance for the surface friction coefficient should be made.

Procedure for Duct Design

The general procedure for design is outlined as follows:

1. Study the plan of the building and draw in roughly the most convenient system of ducts, taking cognizance of the building construction, avoiding all obstructions in steel work and equipment, and at the same time maintaining a simple design.
2. Arrange the positions of duct outlets to insure the proper distribution of air.
3. Divide the building into zones and proportion the volume of air necessary for each zone.
4. Determine the size of each outlet, based on the volume as obtained in the preceding paragraph, for the proper outlet velocity and throw. In case of some ceiling diffusers, determine size of outlet for proper throat velocity and radius of diffusion.
5. Calculate the sizes of all main and branch ducts by one of the three methods of sizing air supply systems in common use, the velocity reduction method, the equal friction method or the static regain method.
6. Calculate the losses for the duct offering the greatest resistance to the flow of air, using the A.S.H.V.E. Friction Charts, Figs. 1 and 2, and the other data given in this chapter.

Recommended Design Velocities

The air velocities given in Table 4 have been found to give satisfactory results in engineering practice. Where the higher velocities are used, the ducts should be cross-braced to prevent breathing, buckling or vibration, and should be constructed of heavier gage metal. At the higher velocities, it is particularly important to design the ducts for minimum resistance. As high velocities at one point offset the effect of proper design in all other parts of the system, emphasis should be placed on the importance of air velocities, elbow design, location of dampers, fan connections, grille and register approach connections, and similar details. For industrial buildings, noise is seldom given much consideration, and main duct velocities as high as 2800 or 3000 fpm are sometimes used, but when these velocities are used due consideration should be given to duct design, resistance pressure, fan efficiencies and motor horsepower. For department stores and similar buildings, 2000 to 2200 fpm are sometimes used in main ducts where noise is not objectionable and space conditions warrant it.

TABLE 4. 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.

Where high velocity diffusing outlets are used, the duct velocity should be, if possible, equal to, or somewhat lower than the throat (neck) velocity of the diffuser, in order to utilize the effect of higher static pressure in the duct for equalization of air discharge.

The velocities in main ducts, and particularly in branch ducts and branch risers, should be correlated to the throat (neck) velocity of the air outlets, and manufacturers' data should be consulted for permissible throat velocity for the particular type of application.

If it is necessary to use a duct velocity that is twice the velocity for an outlet mounted on the side of the duct, a collar with directing vanes should