Table 5 . . . . Ratio of Pressure Loss to Branch Velocity Pressure

Take-off Angle	Ratio of Velocity in Branch to Velocity in Main Duct						
	0.4	0.6	0.8	1.0	1.5	2.0	3.0
90-deg	6.5	3.1	2.0	1.5	0.95	0.74	0.62
60-deg	5.0	2.2	1.3	0.77	0.47	0.47	0.58
45-deg	3.5	1.3	0.64	0.43	0.40	0.45	0.54

where

H_{ge} = pressure loss due to gradual enlargement, inches of water.

C_r = coefficient of loss, as ratio of loss to loss for abrupt expansion, dependent upon the total angle included between the sides of the duct.

The loss for a sudden symmetrical contraction can be expressed as:

$$H_e = C_2\left(\frac{V_2}{4005}\right)^2 = C_1\left(\frac{V_1}{4005}\right)^2 = C_e\left(\frac{V_e}{4005}\right)^2 \qquad (10)$$

where

H_e = pressure loss due to sudden contraction (Fig. 11).
C_e = loss coefficient based on orifice area A_e.
V_e = velocity of air through orifice, feet per minute.

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

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

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 the following duct section.

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 methods 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 7, Warm Air Heating Systems, of the 1964 Guide And Data Book. The design of ducts in industrial exhaust systems is discussed in Chapter 35 of the 1964 Guide And Data Book.

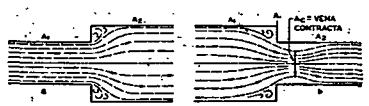

Fig. 11 . . . . Air Flow at Abrupt Enlargement or Contraction of Air Stream

General rules which should be followed in the design of ducts 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 8 to 1 should be avoided. Where possible, a ratio of 4 to 1 or less should be maintained.
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.
7. Avoid obstructing ducts with piping, conduits, or structural members. Unavoidable duct obstructions must be streamlined with an *easement* or a *tear-drop*, the length of which should be at least three times the thickness of the tear-drop.

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 duct system, 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 methods given in the following section.
4. Determine the total pressure requirement of the supply and return duct systems. Although the loss in total presssure 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.
5. However, the more self-balancing the duct system is, the less expensive in the long run is the overall system from the standpoint of engineering, duct fabrication and installation, and balancing of the duct system.
6. *If* the ducts are of recommended construction and are airtight, one can assume that approximately 75 percent of the difference between the initial and final velocity heads will be available for conversion to static pressures. This applies to duct systems designed by any of the three methods described in this chapter.

Design Velocities

It is not possible to give specific rules for selecting duct velocities, but the velocities listed in Table 6 have given satisfactory results in designing conventional systems. 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, as evident from Equation 3, at a given flow rate, the duct size increases with decreasing velocity. For multistory 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. The various space-saving systems which are becoming increasingly numerous are discussed in Chapters 2, 3, and 4 of the 1964 Guide And Data Book. The design of high-velocity ducts is discussed briefly in a later section, Design of High-Velocity Ducts, in this chapter.

Table 6 . . . . Recommended and Maximum Duct Velocities for Conventional Systems

Designation	Residences	Schools, Theaters, Public Buildings	Industrial Buildings
	Recommended Velocities, Fpm		
Outdoor Air Intakes[a]	500	500	600
Filters[a]	250	300	350
Heating Coils[a,b]	450	500	600
Cooling Coils[a]	450	500	600
Air Washers[a]	500	500	500
Fan Outlets	1000–1600	1300–2000	1600–2400
Main Ducts[b]	700–900	1000–1300	1200–1800
Branch Ducts[b]	600	600–900	800–1000
Branch Risers[b]	500	600–700	800
	Maximum Velocities, Fpm		
Outdoor Air Intakes[a]	800	900	1200
Filters[a]	300	350	350
Heating Coils[a,b]	500	600	700
Cooling Coils[a]	450	500	600
Air Washers[a]	500	500	500
Fan Outlets	1700	1500–2200	1700–2800
Main Ducts[b]	800–1200	1100–1600	1300–2200
Branch Ducts[b]	700–1000	800–1300	1000–1800
Branch Risers[b]	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.
[b] For low velocity systems only. For recommendations on high velocity systems, see section on design of high velocity ducts in this chapter, and see Table 2 in Chapter 2 of the 1964 Guide And Data Book.

DESIGN METHODS

In the design of air duct systems, three methods are employed: (1) *velocity-reduction*, (2) *equal-friction*, and (3) *static-regain*. The three methods and their refinements represent different design levels of accuracy and complexity, and they should be selected to suit the application. Simple duct systems may be designed as quickly and easily as possible. For large installations, the system static-pressure requirement must be determined as precisely as possible.

It should be borne in mind that none of the three duct design methods will automatically produce the most economical duct system for all conditions. A careful evaluation and balancing of all cost variables entering into design of a duct system should be made with each design method if maximum economy is to be achieved. The main variables affecting the the owning cost of a duct system are: cost of the ductwork, duct insulation, fan horsepower, space requirements, and cost of provisions for sound attenuation.

Velocity-Reduction Method

This method consists of selecting the velocity at the fan discharge and designing for progressively lower velocities in the main at each branch duct. For the selected velocities and known air-flow rates, the various duct diameters may be read directly from Figs. 2 or 3, and the equivalent rectangular sizes are obtained from Table 2. The pressure loss of the run having apparently the highest resistance is determined by adding the straight pipe, elbow, and transition losses; this total value represents the fan static pressure required for the supply-duct system. The return-air system is sized similarly, starting with the lowest velocities at the return intakes and increasing them progressively in the direction of the fan inlet. Dampers are relied upon for balancing the system.

A refinement of this method involves sizing the branch ducts to dissipate the pressure available at the entrance to each. The pressure loss of the ductwork between the fan and first branch take-off is subtracted from the now known fan static pressure to obtain the available pressure at each junction. By trial and error, a branch velocity is found that results in the branch pressure loss being equal to, or somewhat less than, that available. The procedure is repeated for each branch.

If the fan is specified so that the static pressure available for the ductwork is known, the method consists of finding, by trial and error, the velocities in the main duct that will result in a pressure loss equal to the pressure available. The branch ducts are then sized as previously explained.

The merits of the *velocity-reduction* method are: (1) duct sizes are determined very easily, and (2) velocities can be limited to those known to be safe from causing noise problems. Its disadvantages are: (1) proper choice of velocities requires experience and judgment, and (2) the designer cannot always determine by inspection which run may have the highest resistance.

Equal-Friction Method

The principle of this method is to make the pressure loss per foot of length the same for the entire system. Little balancing is required for symmetrical layouts in which all runs have about the same resistance. For layouts having both short and long runs, the shortest run will require considerable dampering.

A modification of this method would include designing the longest run at two or more different friction rates. If, due to space limitations, a relatively high friction rate must be used on the upstream side of the duct system, this rate can be reduced when space conditions become less critical on the downstream of the system.

Usual practice is to select the velocity in the main duct near the fan to provide a satisfactory noise level for the particular application. Since the flow rate (cfm) is known, this establishes a value of friction loss per 100 ft of duct in Fig. 2 or 3. This same friction loss value is maintained throughout the design. For example, the flow rate in the main after the first branch take-off is reduced by that handled by the branch. Therefore, proceed vertically downward in Fig. 2 or 3 to the new flow rate value, and read the velocity and diameter. Note that the velocity is reduced. An advantage of this method is that it *automatically* reduces the duct velocities in the direction of flow, thereby reducing noise problems. The equivalent rectangular size of any diameter is obtained from Table 2. By continuing the procedure, the designer may size all sections, including branch ducts, from Figs. 2 and 3 at the same friction loss per foot of actual length.

After sizing the system, the designer should calculate the pressure loss of the run which apparently has the highest resistance. The pressure losses of all elbows and transitions are included, and expressed in terms of *equivalent length* of straight pipe.