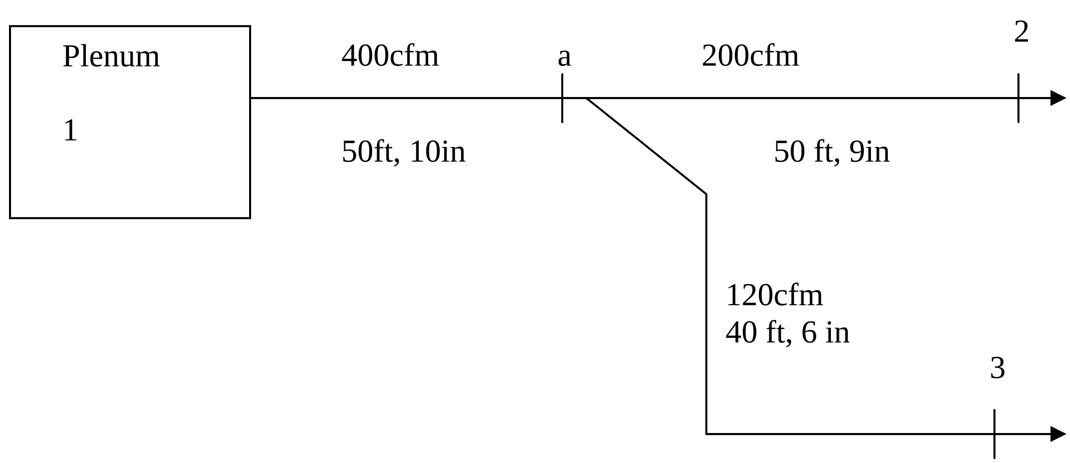
To find pressure loss

1. duct size is known.
2. flow rate is known.

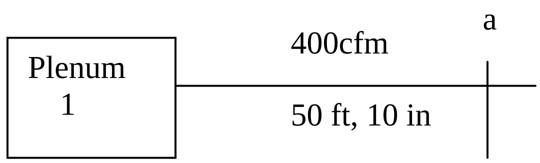
S.1 Compute the loss pressure for each branch of simple Duct system shown in figure using *loss coefficient method.*

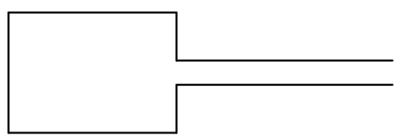


Solution:

For section 1-a

(i) for plenum exit loss





C = 0.85 (from T-4)

$$\overline{V_u} = \frac{Q_u}{A_u} = \frac{400}{(\pi/4)(10/12)^2} = 733.385 \text{ ft/min}$$

$$H_{1-a} = C\left[\frac{\overline{V_u}}{4000}\right]^2 = 0.85\left[\frac{733.385}{4000}\right]^2$$

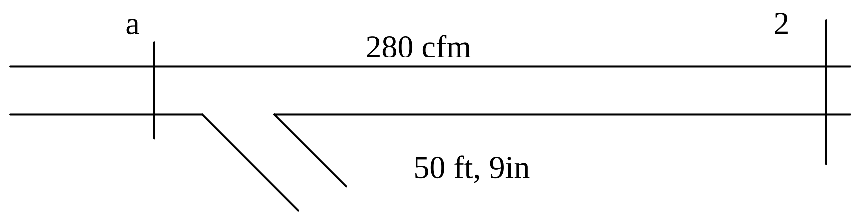
For straight line 1-a (50 ft)

$$\begin{bmatrix} 400\text{cfm} \\ 10\text{ in} \end{bmatrix} \rightarrow \left(\frac{\Delta P}{L}\right) = \frac{0.09}{100}$$

$$(\Delta P)_{1-a} = \frac{0.09}{100} \times 50 = 0.045 \text{ in of water}$$

$$\text{total pressure loss for Run } 1 - a = 0.045 + 0.0285 = 0.0735 \text{ in of water}$$

<u>section a- 2</u>



$$\overline{V_d} = \frac{Q_d}{A_d} = \frac{280}{\left(\pi/4\right)\left(9/12\right)^2} = 633.79 \text{ ft/min}$$

$$\begin{bmatrix} \overline{V_u} = 733.385 \text{ ft/min} \\ \overline{V_d} = 633.79 \text{ ft/min} \end{bmatrix} \Rightarrow \Delta P_{fit} = 0.002 \text{ in of water}$$

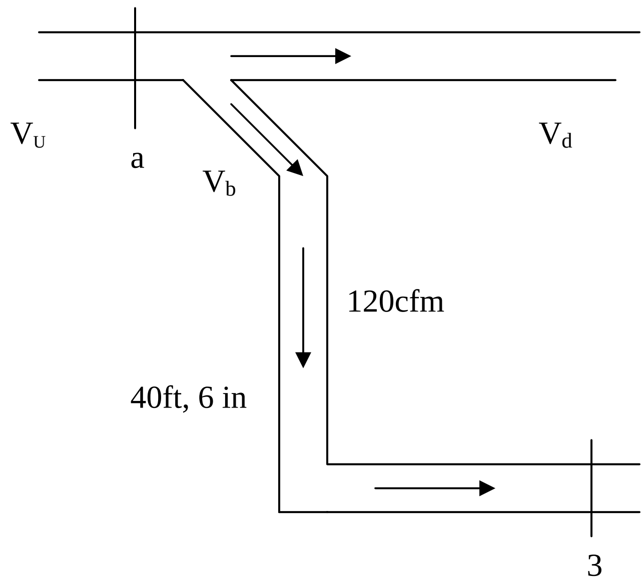
For straight run

$$\begin{bmatrix} 280\text{cfm} \\ 9 \text{ in} \end{bmatrix} \Rightarrow \frac{\Delta P}{L} = \frac{0.08}{100} \text{ in of water}$$

$$\Delta P_{st} = \frac{0.08}{100} \times 50 = 0.04 \text{ in of water}$$

$$\text{total pressure loss for Run a - 2} = 0.04 + 0.002 = 0.042 \text{ in of water}$$

Section a-3



$$\overline{V_b} = \frac{Q_b}{A_b} = \frac{120}{\left(\pi/4\right)^2\left(6/12\right)^2} = 611.154 \text{ ft/min}$$

$$\left[\begin{array}{l} \dfrac{\overline{V_b}}{\overline{V_u}} = \dfrac{611.154}{733.385} = 0.833 \\ \text{(branch loss)} \quad 45^\circ \text{ take off} \end{array}\right] \Rightarrow \quad C_b = 0.48$$

$$(i) \qquad H_b = C_b\left[\frac{\overline{V_u}}{4000}\right]^2 = 0.48\left[\frac{733.385}{4000}\right]^2 = 0.0161 \text{ in of water}$$

(ii) 45° elbow loss

$$C = 0.37 \quad (\text{assume } R/D = 1 \quad \Leftarrow \quad \text{from } T-2)$$

$$H_e = 0.37\left[\frac{\overline{V_b}}{4000}\right]^2 = 0.37\left[\frac{611.154}{4000}\right]^2 = 0.0086 \text{ in of water}$$

(iii) 90° elbow loss

$$H_e = 0.0086 \quad \text{in of water}$$

(iv) Straight Run loss (40 ft)

$$\begin{bmatrix} 120 \text{ cfm} \\ 6 \text{ in} \end{bmatrix} \Rightarrow \left(\frac{\Delta P}{L}\right) = \frac{0.12}{100} \quad \text{in of water}$$

$$(\Delta P)_{st} = \frac{0.12}{100} \times 40 = 0.048 \text{ in of water}$$

$$\text{total pressure loss for Run a-3} = 0.0161 + 0.0086 + 0.0086 + 0.048$$
$$= 0.0813 \text{ in of water}$$

total pressure loss for section 1-2 is

$$\Delta P_{1\text{-}2} = 0.0735 + 0.042 = 0.1155 \text{ in of water } 0 = 28.7595 \text{ pa}$$

Total pressure loss for section 1-3 is

$$\Delta P_{1=3} = 0.0735 + 0.0813 = 0.1548 \text{ in of water } = 38.54 \text{ pa}$$

+============================+

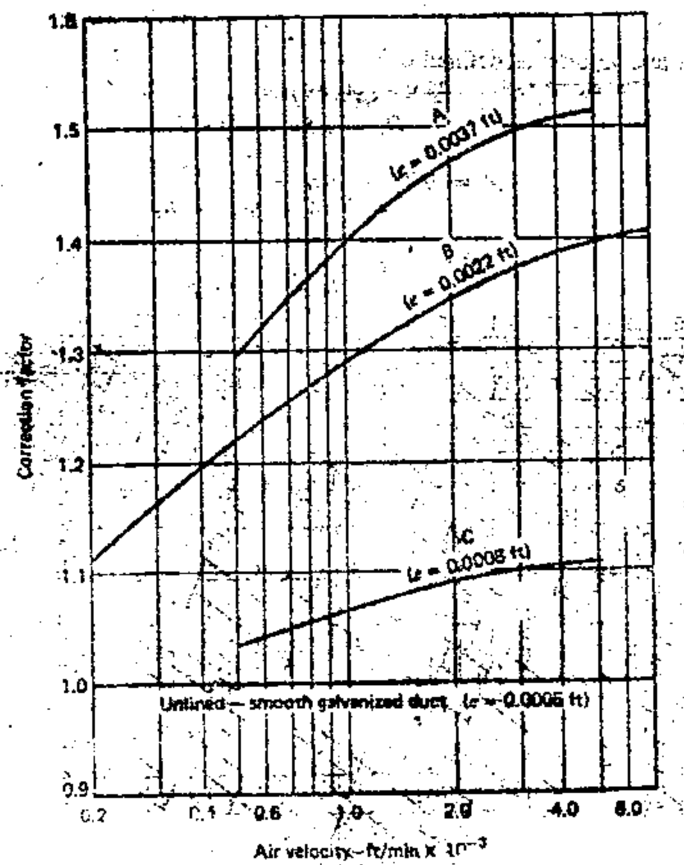


Figure A-5 Range of roughness correction factors for commercially available duct liners..

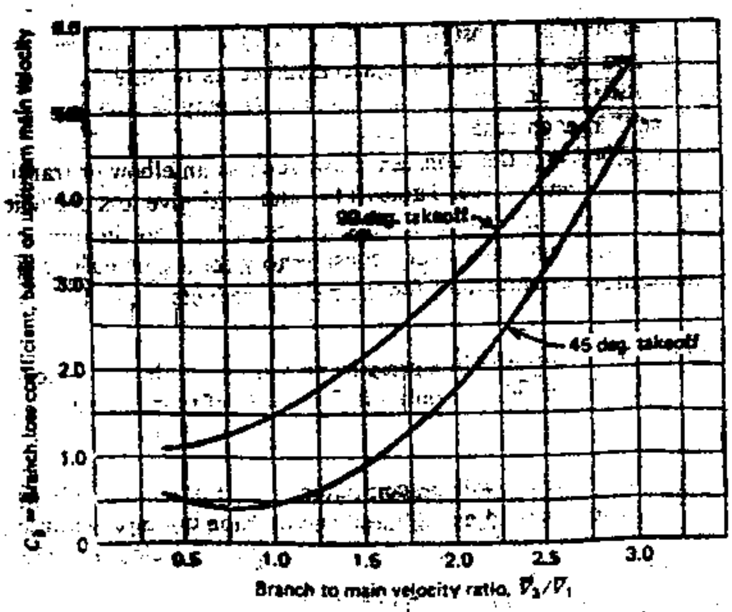


Figure A-6 Branch loss coefficient vs. velocity ratio.

Table T-4 Loss Coefficients for Area Changes

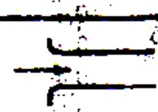
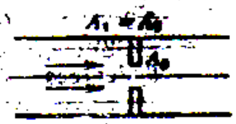
Type	Illustration	Conditions	Loss Coefficient
Duct entrance			C
		$A = \infty$	0.85
Formed entrance			C
		$A \infty$	0.03
		A_0/A	C_0
Square-edge orifice in duct		0.0	2.50
		0.2	1.86
		0.4	1.21
		0.6	0.64
		0.8	0.20
		1.0	0.0

Table T-5 Loss in Total Pressure for Transition Fittings
In. of water (in. x 25.4 = mm and in. of water x 249 = Pa)

Upstream Velocity $\bar{V}_u$	Downstream Velocity $\bar{V}_d$, fpm 600	800	1000	1200	1400	1600	1800	2000
600	0.001	0.003	0.004					
800	0.003	0.002	0.008	0.010	0.010			
1000	0.004	0.003	0.003	0.005	0.010	0.010		
1200	0.007	0.006	0.005	0.005	0.010	0.010	0.011	0.012
1400	0.010	0.010	0.008	0.008	0.006	0.010	0.011	0.013
1600	0.017	0.015	0.014	0.010	0.008	0.012	0.011	0.013
1800	0.022	0.020	0.018	0.012	0.011	0.012	0.012	0.013
2000	0.027	0.020	0.019	0.018	0.017	0.017	0.015	0.010

Upstream Velocity $\bar{V}_u$	Downstream Velocity $\bar{V}_d$, fpm 2000	2500	3000	3500	4000	4500	5000
2000	0.010	0.020	0.030				
2500	0.030	0.020	0.030	0.040			
3000	0.040	0.030	0.030	0.040	0.050		
3500	0.060	0.050	0.040	0.040	0.050	0.060	0.070
4000	0.090	0.090	0.080	0.060	0.050	0.060	0.070
4500	0.120	0.110	0.100	0.090	0.070	0.060	0.070
5000	0.140	0.140	0.130	0.100	0.100	0.080	0.070

Table T-3 Loss Coefficients for Area Changes

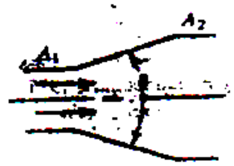
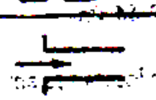
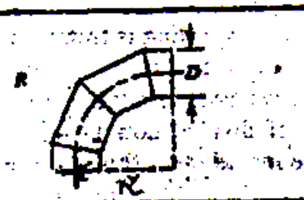
Type	Illustration	Conditions	Loss Coefficient	
		A_1/A_2	C_1	C_2
Abrupt expansion		0.1	0.81	81
		0.2	0.64	15
		0.3	0.49	5
		0.4	0.36	2.25
		0.5	0.25	1.00
		0.6	0.16	0.45
		0.7	0.09	0.18
		0.8	0.04	0.06
		0.9	0.01	0.01
		θ, degrees	C_r	
Gradual expansion*		5	0.17	
		7	0.22	
		10	0.28	
		20	0.45	
		30	0.59	
		40	0.73	
		A_2/A_1	C_2	
Abrupt contraction square edge		0.0	0.34	
		0.2	0.32	
		0.4	0.25	
		0.6	0.16	
		0.8	0.06	
		θ, degrees		
Gradual contraction		30	0.02	
		45	0.04	
		60	0.0[illegible]	
Equal area transformation		$A_1 = A_2$	C	
		$\theta \leq 14$	0.15	
Franged entrance			C	
		$A \approx \infty$	0.3[illegible]	

Table T-1 Circular Equivalents of Rectangular Ducts for Equal Friction and Capacity.

Side Rectangular Duct	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	22	24
6	6.6																
7	7.1	7.7															
8	7.5	8.2	8.8														
9	8.0	8.6	9.3	9.9													
10	8.4	9.1	9.8	10.4	10.9												
11	8.8	9.5	10.2	10.8	11.4	12.0											
12	9.1	9.9	10.7	11.3	11.9	12.5	13.1										
13	9.5	10.3	11.1	11.8	12.4	13.0	13.6	14.2									
14	9.8	10.7	11.5	12.2	12.9	13.5	14.2	14.7	15.3								
15	10.1	11.0	11.8	12.6	13.3	14.0	14.6	[illegible]	15.8	[illegible]							
16	10.4	11.4	12.2	13.0	13.7	14.4	15.1	15.7	16.3	16.9	17.5						
17	10.7	11.7	12.5	13.4	14.1	14.9	15.5	16.1	16.8	17.4	18.0	18.6					
18	11.0	11.9	12.9	13.7	14.5	15.3	16.0	16.6	17.3	17.9	18.5	19.1	19.7				
19	11.2	12.2	13.2	14.1	14.9	15.6	16.4	17.1	17.8	18.4	19.0	19.6	20.2	20.8			
20	11.5	12.5	13.5	14.4	15.2	15.9	16.8	[illegible]	18.2	[illegible]	19.5	20.1	20.7	21.3	21.9		
22	12.0	13.1	14.1	15.0	15.9	16.7	17.6	18.3	19.1	19.7	20.4	21.0	21.7	22.3	22.9	24.1	
24	12.4	13.6	14.6	15.6	16.6	17.5	18.3	19.1	19.8	20.6	21.3	21.9	22.6	23.2	23.9	25.1	26.2
26	12.8	14.1	15.2	16.2	17.2	18.1	19.0	19.8	20.6	21.4	22.1	22.8	23.5	24.1	24.8	[illegible]	27.2
28	13.2	14.5	15.6	16.7	17.7	18.7	19.6	20.5	21.3	22.1	22.9	23.6	24.4	25.0	25.7	[illegible]	28.2
30	13.6	14.9	16.1	17.2	18.3	19.3	20.2	21.1	22.0	22.9	23.7	24.4	25.2	25.9	26.7	28.0	29.3
32	14.0	15.3	16.5	17.7	18.8	19.8	20.8	21.8	22.7	23.6	24.4	25.2	26.0	26.7	27.5	28.9	30.1
34	14.4	15.7	17.0	18.2	19.3	20.4	21.4	22.4	23.3	24.2	25.1	25.9	26.7	27.5	28.3	20.7	31.0
36	14.7	16.1	17.4	18.6	19.8	20.9	21.9	23.0	23.9	24.8	25.8	26.6	27.4	28.3	29.0	30.5	37.0
38	15.0	16.4	17.8	19.0	20.3	21.4	22.5	23.5	24.5	25.4	26.4	27.3	28.1	29.0	29.8	31.4	32.8
40	15.3	16.8	18.2	19.4	20.7	21.9	23.0	24.0	25.1	26.0	27.0	27.9	28.8	29.7	30.5	32.1	33.6

Table T-2 Total Pressure Losses Due to Elbows

Type	Illustration	Conditions	Loss Coefficient C
90 degree round 4 piece		R/D = 0.75 1.0 1.5 2.0	0.50 0.37 0.27 0.24
90 degree round		Miter	1.2
Miter with turning vanes		Plate Formed None	0.20 0.15 1.20

*Reprinted by permission from ASHRAE Handbook of Fundamentals, 1977.

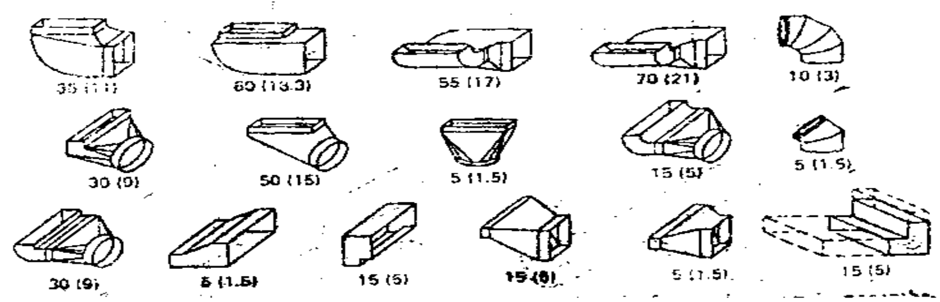


Figure A-7 Equivalent lengths of some plenum and branch fittings in feet and meters in parentheses.

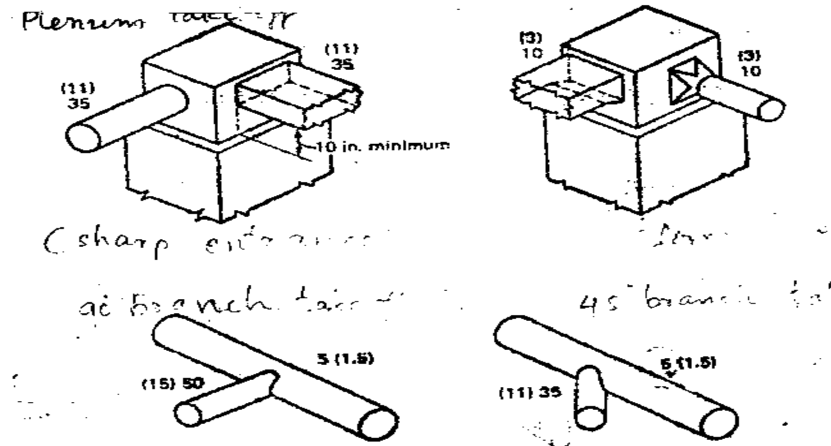
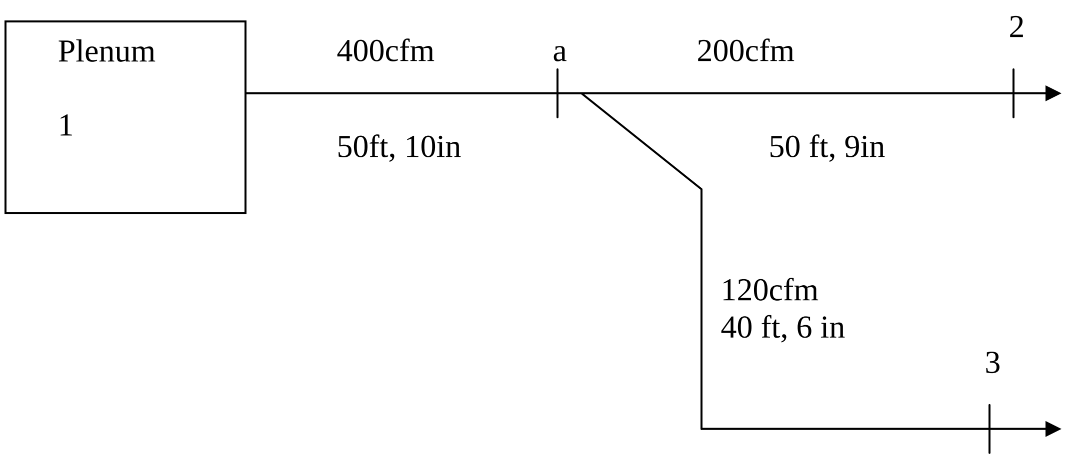


Figure A-8 Equivalent length of common duct fittings in feet and meters in parentheses.

Equivalent Length Method

S.2 Compute the loss pressure for each branch of simple duct system shown in figure using *Equivalent Length* approach.



<u>Section 1-a</u>

$$L_{1-a} = 50 + (35) = 85 \text{ ft}$$

$$\begin{bmatrix} 400 \text{ cfm} \\ \text{dia} := 10 \text{ in} \end{bmatrix} \Rightarrow \left(\frac{\Delta P}{L}\right) = 0.09 \text{ in of water/100 ft}$$

$$\Delta P = \left(\frac{\Delta P}{L}\right) \times L_{1\text{-a}} = \frac{0.09}{100} \times 85 = 0.0765 \text{ in of water}$$

Section a-2

$$L_{a\text{-}2} = 50 + (5) = 55 \text{ ft}$$

$$\begin{bmatrix} 200 \text{ cfm} \\ \text{dia} := 9 \text{ in} \end{bmatrix} \Rightarrow \left(\frac{\Delta P}{L}\right) = \frac{0.08}{100} \text{ in of water}$$

$$\Delta P_{a\text{-}2} = \frac{0.08}{100} \times 55 = 0.044 \text{ in of water}$$

Section a-3

$$L_{a\text{-}3} = 40 + (35) + (5) + (10) = 90 \text{ ft}$$

$$\begin{bmatrix} 120 \text{ cfm} \\ \text{dia} := 6 \text{ in} \end{bmatrix} \Rightarrow \left(\frac{\Delta P}{L}\right) = 0.12 \text{ in of water}$$

$$\Delta P_{a=3} = \frac{0.12}{100} \times 90 = 0.108 \text{ in of water}$$

The pressure loss for section 1 to 2 is

$$\Delta P_{1\text{-}2} = \Delta P_{1\text{-}a} + \Delta P_{a\text{-}2} = 0.0765 + 0.044 = 0.1205 \text{ in of water}$$
$$= 30.00 \text{ Pa}$$

The pressure loss for section 1 to 3 is

$$\Delta P_{1\text{-}3} = \Delta P_{1\text{-}a} + \Delta P_{a=3} = 0.0765 + 0.108 = 0.1845 \text{ in of water}$$
$$= 45.9 \text{ pa}$$

+========================+

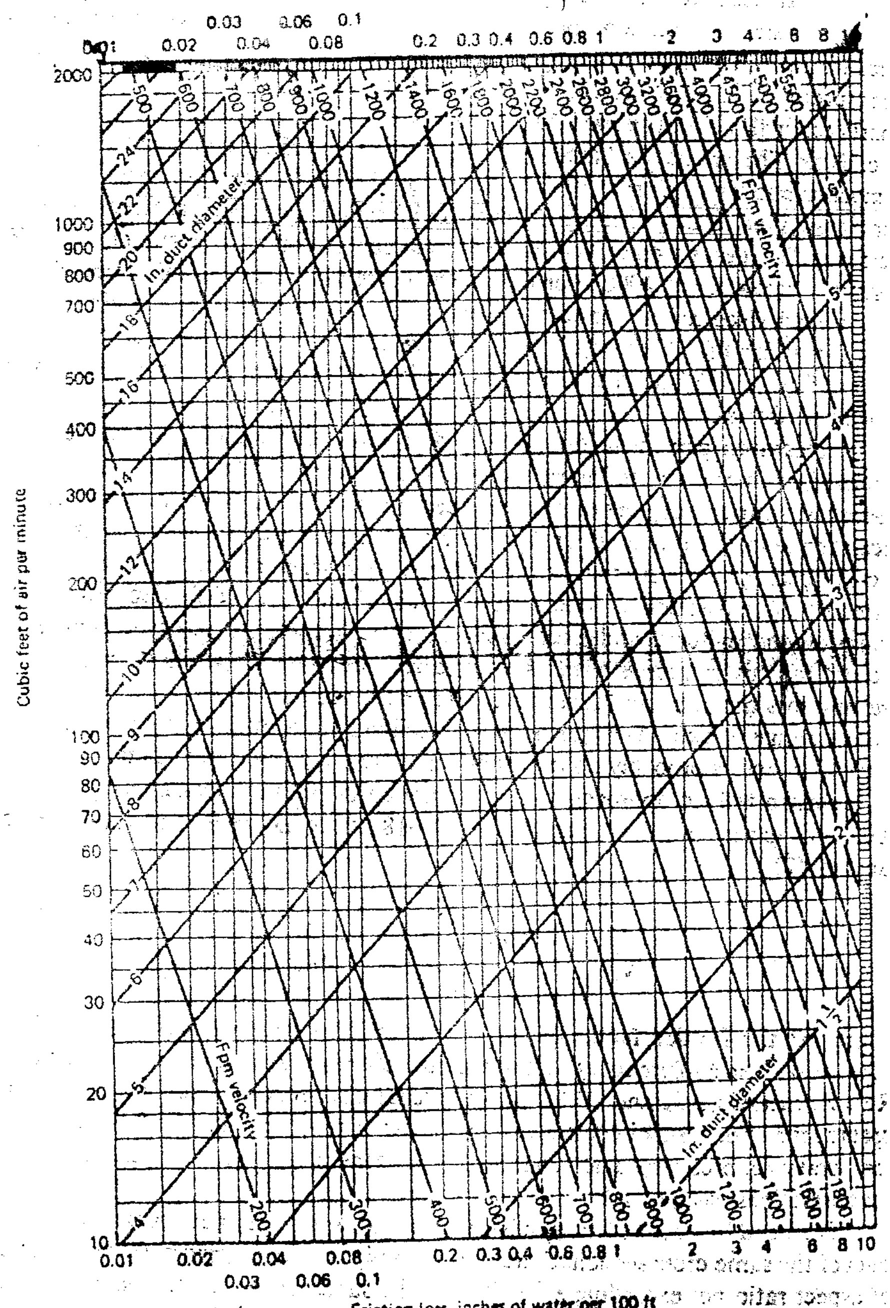
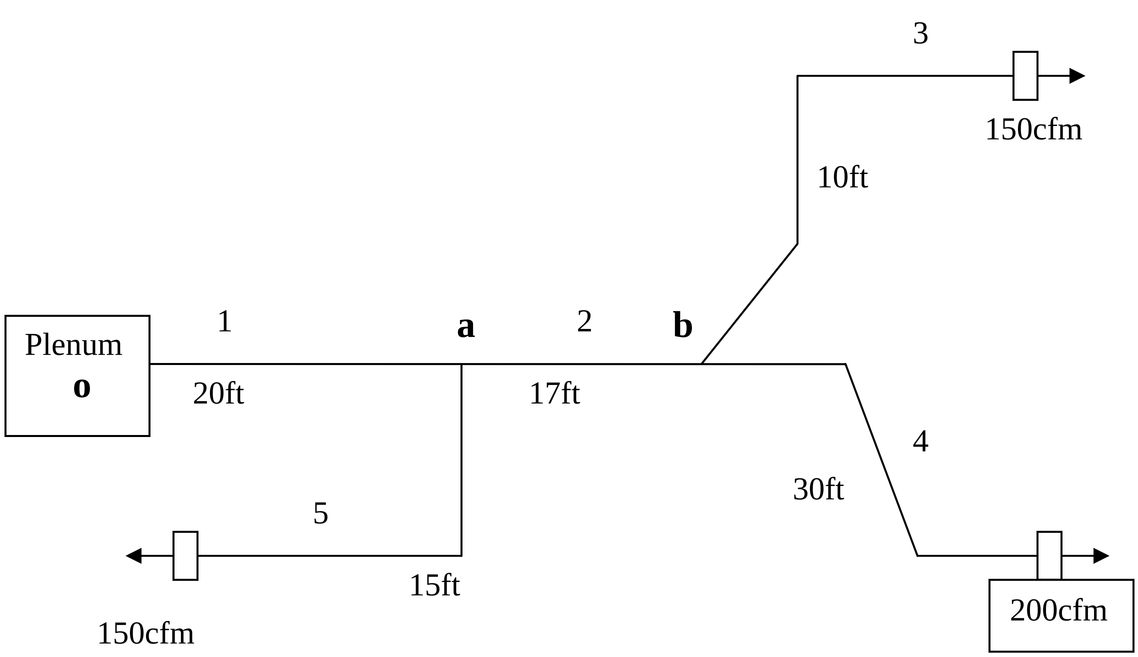


Figure 11-18. Lost-head due to friction for galvanized steel ducts. (Reprinted by permission from *ASHRAE Handbook of Fundamentals*, 1977.)

TO FIND DUCT SIZE

Equal Friction Method

S-3 Select duct sizes for the simple duct system of shown in figure using Equal Friction Method. The system is for a residence. The total pressure for the duct system is 0.12 in of water and the loss in total pressure for each diffuser at the specified flow rate is 0.02 in of water.



$$L_{e123} = 20+17+10+(35+5+35+5+10+30) = 167\ \text{ft}$$

$$L_{e124} = 20+17+30+(35+5+5+5+5+30) = 152\ \text{ft}$$

$$L_{e15} = 20+15+(35+50+10+30) = 160\ \text{ft}$$

L_{e123} is design line.

$$\Delta P = 0.12 - 0.02 = 0.1 \quad \text{in of water}$$

$$\left(\frac{\Delta P}{L}\right)_{123} = \left(\frac{\Delta P}{L}\right)_{design} = \frac{0.1}{167} = 0.000598 = 0.598\times 10^{-3} \ \text{in of water/ft}$$

$$cfm_1 = 150+200+150 = 500\ \text{cfm}$$

$$cfm_2 = 150+200 = 350\ \text{cfm}$$

$$\left(\frac{\Delta P}{L}\right)_{design} = 0.0598\ \text{in of water}/100\ \text{ft} \ \text{is equal for all of line.}$$

$cfm_1 = 500\ \text{cfm} \Rightarrow D_1 = 11.9\ \text{in}, \quad V_1 = 660\ \text{ft/min}$

$cfm_2 = 350\ \text{cfm} \Rightarrow D_2 = 10.2\ \text{in}, \quad V_2 = 600\ \text{ft/min}$

$cfm_3 = 150\ \text{cfm} \Rightarrow D_3 = 7.5\ \text{in}, \quad V_3 = 490\ \text{ft/min}$

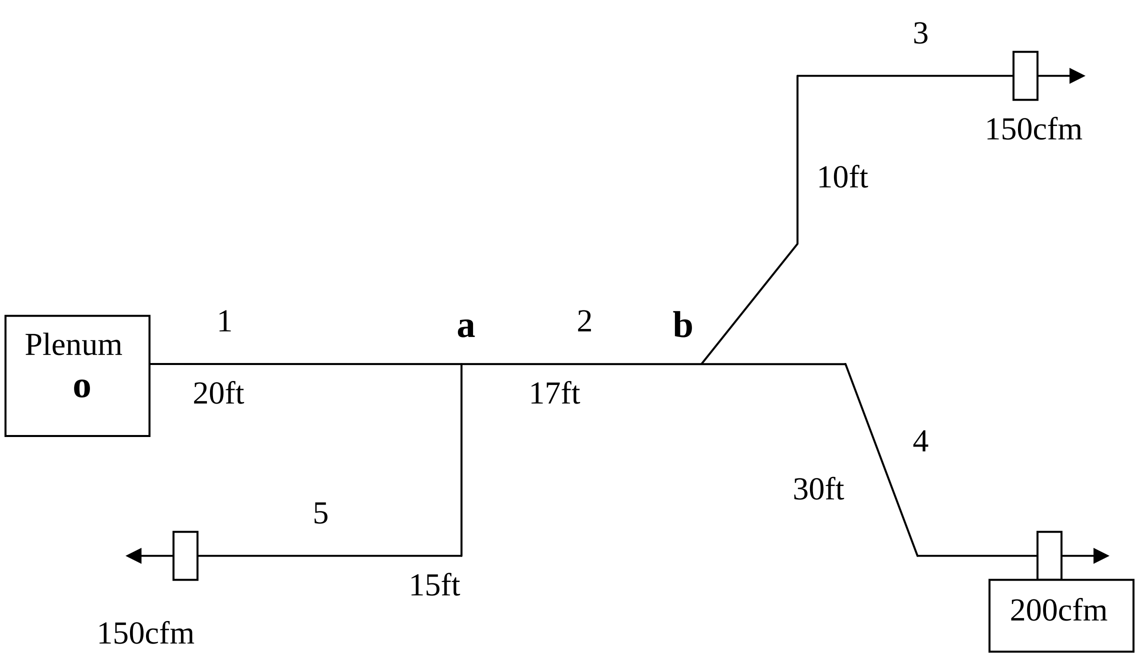
$cfm_4 = 200\ \text{cfm} \Rightarrow D_4 = 8.4\ \text{in}, \quad V_4 = 525\ \text{ft/min}$

$cfm_5 = 150\ \text{cfm} \Rightarrow D_5 = 7.5\ \text{in}, \quad V_5 = 490\ \text{ft/min}$

+============================+

Balance Capacity Method

S-4 Select duct sizes for the simple duct system of shown in figure using Balance Capacity Method. The system is for a residence. The total pressure for the duct system is 0.12 in of water and the loss in total pressure for each diffuser at the specified flow rate is 0.02 in of water.



$$L_{e123} = 20+17+10+(35+5+35+5+10+30) = 167\ \text{ft}$$

$$L_{e124} = 20+17+30+(35+5+5+5+5+30) = 152\ \text{ft}$$

$$L_{e15} = 20+15+(35+50+10+30) = 160\ \text{ft}$$

L_{e123} is design line.

$$\Delta P = 0.12 - 0.02 = 0.1 \quad \text{in of water}$$

$$\left(\frac{\Delta P}{L}\right)_{123} = \left(\frac{\Delta P}{L}\right)_{design} = \frac{0.1}{167} = 0.000598 = 0.598\times10^{-3} \ \text{in of water/ft}$$

$$cfm_1 = 150+200+150 = 500\ \text{cfm}$$

$$cfm_2 = 150+200 = 350\ \text{cfm}$$

$$\left(\frac{\Delta P}{L}\right)_{design} = 0.0598\ \text{in of water}/100\ \text{ft is design line for line 1, 2,3.}$$

$$cfm_1 = 500\ \text{cfm} \Rightarrow D_1 = 11.9\ \text{in}, \quad V_1 = 660\ \text{ft/min}$$

$$cfm_2 = 350\ \text{cfm} \Rightarrow D_2 = 10.2\ \text{in}, \quad V_2 = 600\ \text{ft/min}$$

$$cfm_3 = 150\text{cfm} \Rightarrow D_3 = 7.5\ \text{in}, \quad V_3 = 490\ \text{ft/min}$$

According to the theory, the pressure of all line are equal.

$$\Delta P_3 = \Delta P_4$$

$$L_{e3} = 10+(35+5+10+30) = 90\ \text{ft}$$

$$\Delta P_3 = \left(\frac{\Delta P}{L}\right)_{design} \times 90 = 0.05038\ \text{in of water}$$

$$L_{e4} = 30+(5+5+5+30) = 75\ \text{ft}$$

$$\left(\frac{\Delta P}{L}\right)_4 = \frac{0.0538}{75} = 0.7176\times10^{-3} \text{ in of water} = 0.07176 \text{ in of water/100 ft}$$

$$\begin{bmatrix}\left(\frac{\Delta P}{L}\right)_4 = 0.07176 \text{ in of water/100ft} \\ cfm_4 = 200\end{bmatrix} \Rightarrow D_4 = 8.1 \text{ in}, \quad V_4 = 560 \text{ ft/min}$$

<u>Section a-5</u>

$$\Delta P_{o5} = \Delta P_{o4} \quad \ldots\ldots \quad \text{equ:(1)}$$

$$\Delta P_{oa} + \Delta P_{a5} = \Delta P_{oa} + \Delta P_{ab} + \Delta P_{b4}$$

$$\Delta P_{a5} = \Delta P_{ab} + \Delta P_{b4} \quad \ldots\ldots \quad \text{equ:(2)}$$

$$L_{b4} = L_4 = 75 \text{ ft}$$

$$L_{ab} = L_2 = 17 + 5 = 22 \text{ ft}$$

$$\Delta P_{ab} = \Delta P_2 = \left(\frac{\Delta P}{L}\right)_2 \times L_2 = 0.598\times10^{-3}\times 22 = 0.01315 \text{ in of water}$$

$$\Delta P_{b4} = \Delta P_4 = \left(\frac{\Delta P}{L}\right)_4 \times L_4 = 0.7176\times10^{-3}\times 75 = 0.0538 \text{ in of water}$$

$$\Delta P_5 = \Delta P_{a5} = 0.0538 + 0.01315 = 0.0669 \text{ in of water}$$

$$L_{a5} = 15 + (50 + 10 + 30) = 105 \text{ ft}$$

$$\left(\frac{\Delta P}{L}\right)_5 = \frac{\Delta P_{a5}}{L_{a5}} = \frac{0.0669 \text{ in of water}}{105 \text{ ft}} = 0.637\times10^{-3} \text{ in of water/ft}$$

$$\left[\left(\frac{\Delta P}{L}\right) = 0.0637 \text{ in of water/100 ft}, \quad cfm = 150\right] \Rightarrow D_5 = 7.5 \text{ in}, \; V_5 = 489 \text{ ft/min}$$

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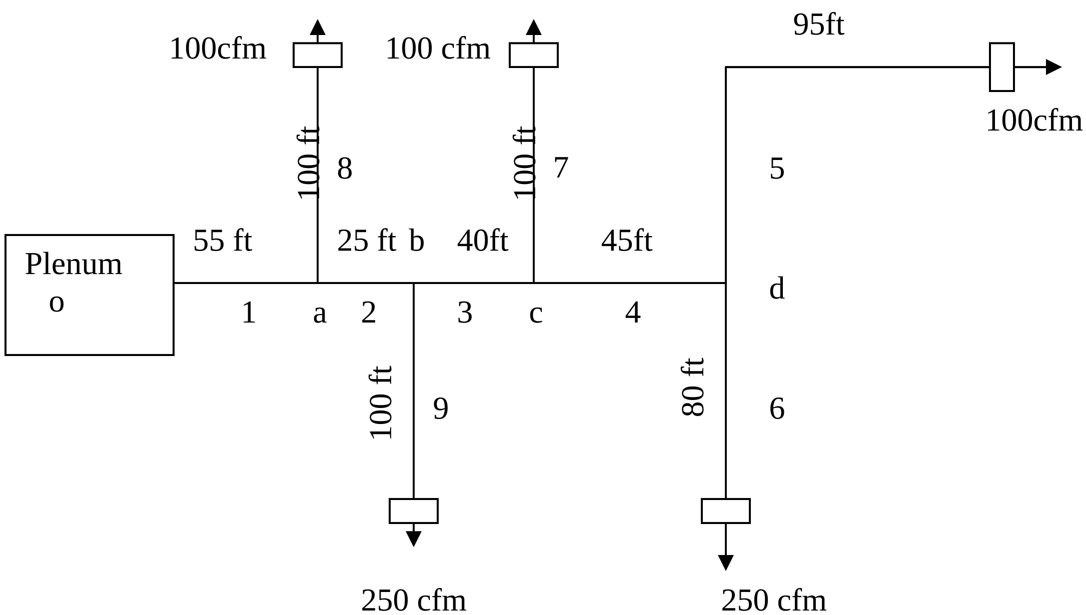
S-5 Design the duct system of shown in figure by using the equal friction method. The velocity in the duct attached to the plenum must not exceed 900 ft/min and the overall loss in total pressure should not exceed about 0.32 in of water. Total pressure losses for the diffusers are all equal to 0.04 in of water. The lengths shown are the total equivalent length of each section. Use English unit.



For main duct velocity = 900 ft/min

cfm_1 = 100+250+250+100+100 =800

from chart,

$$\begin{bmatrix} \text{main duct velocity} \\ \text{cfm}_1 \end{bmatrix} \Rightarrow \quad D_1 = 12.9\ \text{in}, \quad V_1 = 890\ \text{ft/min}$$

$$\left(\frac{\Delta P}{L}\right)_{\text{design}} = 0.096\ \text{in of water/100ft}$$

$\left(\frac{\Delta P}{L}\right)_{\text{design}}$ is equal for all lines.

From chart,

$$\text{cfm}_2 = 250 + 250 + 100 + 100 = 700 \Rightarrow \quad D_2 = 12.2\ \text{in}, \quad V_2 = 870\ \text{ft/min}$$

$$\text{cfm}_3 = 100 + 100 + 250 = 450 \Rightarrow D_3 = 10.4\ \text{in}, \quad V_3 = 780\ \text{ft/min}$$

$$\text{cfm}_4 = 100 + 250 = 350 \quad \Rightarrow \quad D_4 = 9.5\ \text{in}, \quad V_4 = 700\ \text{ft/min}$$

$$\text{cfm}_5 = 100 \quad \Rightarrow \quad D_5 = 5.9\ \text{in}, \quad V_5 = 530\ \text{ft/min}$$

$$\text{cfm}_6 = 250 \quad \Rightarrow \quad D_6 = 8.2\ \text{in}, \quad V_6 = 660\ \text{ft/min}$$

$$\text{cfm}_7 = 100 \quad \Rightarrow \quad D_7 = 5.9\ \text{in}, \quad V_7 = 530\ \text{ft/min}$$

$$\text{cfm}_8 = 100 \quad \Rightarrow \quad D_8 = 5.9\ \text{in}, \quad V_8 = 530\ \text{ft/min}$$

$$\text{cfm}_9 = 250 \quad \Rightarrow \quad D_9 = 8.2\ \text{in}, \quad V_9 = 660\ \text{ft/min}$$

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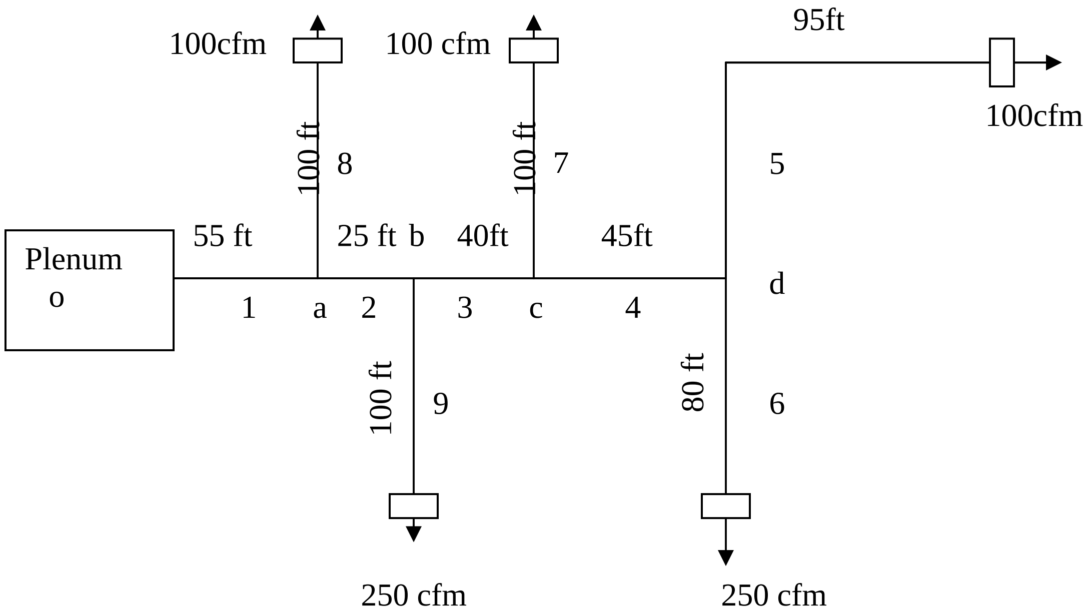
S-6 Design the duct system of shown in figure by using balance capacity method. The velocity in the duct attached to the plenum must not exceed 900 ft/min and the overall loss in total pressure should not exceed about 0.32 in of water. Total pressure losses for the diffusers are all equal to 0.04 in of water. The lengths shown are the <u>total equivalent length</u> of each section. Use English unit.



For main duct velocity = 900 ft/min

cfm_1 = 100+250+250+100+100 =800

from chart,

$$\begin{bmatrix} \text{main duct velocity} \\ \text{cfm}_1 \end{bmatrix} \Rightarrow \quad D_1 = 12.9\text{ in}, \quad V_1 = 890\text{ ft/min}$$

$$\left(\frac{\Delta P}{L}\right)_{\text{design}} = 0.096 \text{ in of water/100ft}$$

$$L_{e12345} = 55 + 25 + 40 + 45 + 95 = 260 \text{ ft}$$

$$L_{e12346} = 55 + 25 + 40 + 45 + 80 = 245 \text{ ft}$$

$$L_{e1237} = 55 + 25 + 40 + 100 = 220 \text{ ft}$$

$$L_{e129} = 55 + 25 + 100 = 180 \text{ ft}$$

$$L_{e18} = 55 + 100 = 155 \text{ ft}$$

$$\Delta P_{o\text{-}5} = \frac{0.096}{100} \times 260 = 0.2496 \text{ in of water}$$

$$\Delta P_{o\text{-}5} = \Delta P_{o\text{-}6}$$

$$\Delta P_{o\text{-}d} + \Delta P_{d\text{-}5} = \Delta P_{o\text{-}d} + \Delta P_{d\text{-}6}$$

$$\Delta P_{d\text{-}5} = \left(\frac{\Delta P}{L}\right)_{\text{design}} \times L_5 = \frac{0.096}{100} \times 95 = 0.0912 \text{ in of water}$$

$$\Delta P_{d\text{-}6} = \Delta P_{d\text{-}5} = 0.0912 \text{ in of water}$$

$$\left(\frac{\Delta P}{L}\right)_6 = \frac{\Delta P_{d\text{-}6}}{L_6} = \frac{0.0912}{80} = 1.14 \times 10^{-3} \text{ in of water}$$

$$\begin{bmatrix} \left(\frac{\Delta P}{L}\right)_6 \Big/ 100\text{ ft} = 0.114 \\ \text{cfm}_6 = 250 \end{bmatrix} \Rightarrow \quad D_6 = 8.2 \text{ in}, \quad V_6 = 690 \text{ ft/min}$$

$$\Delta P_{o\text{-}6} = \Delta P_{o\text{-}7}$$

$$\Delta P_{o\text{-}c} + \Delta P_{c\text{-}4\text{-}d} + \Delta P_{d\text{-}6} = \Delta P_{o\text{-}c} + \Delta P_{c\text{-}7}$$

$$\Delta P_{c\text{-}4\text{-}d} = \left(\frac{\Delta P}{L}\right)_{design} \times L_4 = \frac{0.096}{100} \times 45 = 0.0432 \text{ in of water.}$$

$$\Delta P_{d\text{-}6} = \Delta P_6 = 0.0912 \text{ in of water}$$

$$\Delta P_{c\text{-}7} = \Delta P_{c\text{-}4\text{-}d} + \Delta P_{d\text{-}6} = 0.0432 + 0.0912 = 0.1344 \text{ in of water}$$

$$\left(\frac{\Delta P}{L}\right)_7 = \left(\frac{\Delta P_{c\text{-}7}}{L_{c\text{-}7}}\right) = \frac{0.1344}{100} = 1.344 \times 10^{-3}$$

$$\begin{bmatrix} \left(\frac{\Delta P}{L}\right)_7 \Big/ 100\text{ ft} = 0.1344 \\ \text{cfm}_7 = 100 \end{bmatrix} \Rightarrow D_7 = 5.6 \text{ in}, \quad V_7 = 600 \text{ ft/min}$$

$$\Delta P_{o\text{-}7} = \Delta P_{o\text{-}9}$$

$$\Delta P_{o\text{-}b} + \Delta P_{b\text{-}9} = \Delta P_{o\text{-}b} + \Delta P_{b\text{-}c} + \Delta P_{c\text{-}7}$$

$$\Delta P_{b\text{-}9} = \Delta P_{b\text{-}c} + \Delta P_{c\text{-}7}$$

$$\Delta P_{b\text{-}c} = \left(\frac{\Delta P}{L}\right)_{design} \times L_3 = \frac{0.096}{100} \times 40 = 0.0384 \text{ in of water}$$

$$\Delta P_9 = \Delta P_{b\text{-}9} = \Delta P_{b\text{-}c} + \Delta P_{c\text{-}7} = 0.0384 + 0.1344 = 0.1728 \text{ in of water}$$

$$\left(\frac{\Delta P}{L}\right)_9 = \frac{0.1728}{150} = 1.152 \times 10^{-3} \text{ in of water /ft}$$

$$\begin{bmatrix} \left(\frac{\Delta P}{L}\right)_9 \Big/ 100\text{ ft} = 0.1152 \\ \text{cfm}_9 = 250 \end{bmatrix} \Rightarrow D_9 = 8.0 \text{ in}, \quad V_9 = 700 \text{ ft/min}$$

$$\Delta P_{o\text{-}8} = \Delta P_{o-9}$$

$$\Delta P_{o\text{-}a} + \Delta P_{a\text{-}8} = \Delta P_{o\text{-}a} + \Delta P_{a\text{-}b} + \Delta P_{b=9}$$

$$\Delta P_{a\text{-}8} = \Delta P_{a\text{-}b} + \Delta P_{b\text{-}9}$$

$$\Delta P_{a-b} = \left(\frac{\Delta P}{L}\right)_{design} \times L_2 = \frac{0.096}{100} \times 25 = 0.024 \text{ in of water}$$

$$\Delta P_{a\text{-}8} = 0.024 + 0.1728 = 0.1968 \text{ in of water}$$

$$\left(\frac{\Delta P}{L}\right)_{a\text{-}8} = \frac{0.1968}{100} = 1.968 \times 10^{-3} \text{ in of water /ft}$$

$$\begin{bmatrix} \left(\frac{\Delta P}{L}\right)_8 \Big/ 100\text{ ft} = 0.1968 \text{ in of water/100ft} \\ \text{cfm}_8 = 100 \end{bmatrix} \Rightarrow \quad D_8 = 5.2 \text{ in}, \quad V_8 = 700 \text{ ft/min}$$

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