INSTRUCTION MANUAL - DUCT DESIGN PROGRAM

The design of a system of ducts is a tedious job requiring repetitive computations and is ideally suited for computers. The requirement that the designer make certain critical decisions about duct length, transport velocity, etc., must be preserved but computer programs can facilitate acquiring loss coefficients, processing numerical data and conduct repetitive calculations as designers make different design decisions. Several duct design computer programs are available for purchase from the ACGIH. What follows is the description of how to use an uncomplicated program written for personal computers (Clap D. E., Groh D. J. and Nenadic C. M., "Ventilation Design by Microcomputers", *Am. Ind. Hyg. Assoc. J,* Vol 21, No 7, 691-697, 1987). More elaborate proprietary duct design programs contain loss coefficients for a larger number of fittings and perform many decisions automatically based on some optimization algorithm built into the program and are faster and better suited for complex duct systems. From an instructional point of view, the elementary program is preferable because by asking users to make key decisions, they become intimately involved in the design and their understanding is improved.

The computer program, "Duct Design Program", should be downloaded from the web page for the text, **http://www.MNE.psu.edu/Cimbala/indoor** to an individual personal computer. Do not use the program directly from the internet. The program is designed to operate in a single personal computer with its own printer and users should follow this advice for their own peace of mind! If a number of personal computers are combined in a network, users may not be able to print their results. If this happens, a computer specialist will be needed to intervene to enable the results of your computations to be printed on a common printer. The program is driven by a menu in which questions appear on the screen and users reply. In the material that follows, the questions and answers will be denoted by underlined phrases.

The program contains 16 options that enable users to compute the pressure drop in a branch and tabulate, transfer, cancel data until satisfactory performance is achieved.

Option 1 - Determines pressure losses in a branch
Option 2 - Balances all branches at a junction
Option 3 - Determine a fan's static pressure requirements
Option 4 - List of branches and their losses
Option 5 - List of the branches' velocities, total losses, design Q's & duct diameters
Option 6 - Print branch data on printer
Option 7 - Determine the static pressure losses/gains through an expansion contraction
Option 8 - Calculate the pressures at a point
Option 9 - Calculate the velocity of air for a certain duct size
Option 10 - Clear current data file
Option 11 - Pack current data file
Option 12 - Delete a branch
Option 13 - Rename a branch
Option 14 - Duplicate a branch
Option 15 - Redetermine a branch's static pressure loss
Option 16 - Load a different data file

If users become muddled progressing through any option they can always press the ESC key which returns them to the menu where they can sort things out. To clear erroneous data from a data file, Option 10 should be used. To delete an actual data file, users should use the DEL key.

The program opens with Option 1 that computes the pressure drop in a branch. Users should compute the pressure drop for the branch furthest from the fan. Worksheets show data users provide and what the program computes. The program asks users to input data followed by striking the "carriage return, or enter key". In the material that follows such steps will be noted by underlining the input data and the symbol "CR" for the carriage return. At the end of the computation the user is asked "is this satisfactory" at which time the duct diameter is either changed and the computation in Option 1 repeated or if answered affirmatively, the list of the 16 options appears and users select what they want. The program requires users to designate the starting and ending points of a segment of the duct system by symbols composed of no more than three alpha-numeric symbols in which the first letter must adhere to the following:

Hoods - each hood inlet must begin with "H"
Junctions - a junction is a fitting with two or more inlets or two or more outlets, each junction must begin with "J"
Fan - each fan must begin with "F"
Points - points in the duct system in which there is a single inlet and a single outlet must be designated by an integer, they must not start with H, J or F

The program uses a mixture of duct design conventions. The pressure drop through a slot(s) is computed as the product of the a "slot entry loss coefficient" (C_s, input by the user), times the velocity pressure through the slot VP_s computed by the program. The pressure drop through a hood is computed as the product of a "hood entry loss coefficient" (C_h, input by the user) times the velocity pressure in the duct leaving the hood VP_d computed by the program. In the case of elbows, an *equivalent length* procedure is used. If users prefer to compute the pressure drop through a fitting as the product of a head loss coefficient times the duct velocity pressure, they should compute these losses by hand and introduce the pressure drop as a separate entity in Option 1.

Individuals learn how to use computer programs by reading written instructions and a great deal of "hacking". They learn by doing, much as one learns how to ride a bicycle, get on, fall off, get on again, fall off, etc. After a few bumps and bruises, they learn. The following illustrative problem shows how the different options of the program are used. It is suggested that users repeat the steps shown below, and use input data and arrive at a new solution.

Illustrated Example – **Ventilation Duct System For A Foundry**

A small foundry casts gray iron gear blanks and other small castings for an agricultural equipment manufacturer. The foundry uses scrap steel and iron from an automotive scrap operation they run adjacent to the property. The foundry has recently been cited by the state air pollution control agency and OSHA for excessive dust emissions to the environment and excessive silica concentrations in the workplace. The foundry operation has been redesigned to capture particles from key parts of the process.

The layout of the plant makes it necessary to connect each of the processes to single ducts of increasing diameter that carry the dusty air to the fan and fabric filter before being discharged to the atmosphere. The location of the ducts has been selected by the plant engineer but the diameters of each of the branches, the main duct and the fan pressure drop have to be computed.

+++++++++ INSERT FIGURE 6.25, p 345, of PIV, 1991 +++++++++++++++++++++

Figure Caption

BH - Baghouse   BG - Blast Gate
F - Fan   DB - Downdraft Grinding Bench
C - Cyclone   SE - Shakeout Enclosure
PS - Pouring Station

Elbow centerline radius/Duct diameter (r/D) = 2
Slot velocity = 2,000 FPM
Maximum velocity entering fan = 1,500 FPM
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The electric arc melting furnace is equipped with its own air pollution control system and is not part of the redesign. The molds are filled at a pouring station and vapors are collected by a side-draft hood similar to Fig 1.16. After the castings have cooled, they are removed from their sand molds by a shake-out machine contained in a (15' x 15' x 10') shakeout enclose (SE). The flasks holding the sand molds enter and leave the enclosure on a conveyor that passes through two narrow openings. The molding sand falls to the floor below where it is reprocessed for future use. The castings leave the shake-out enclosure (SE) and have their sprues and risers removed. The pressure drop through the shakeout enclosure (SE) is equal to the hood entry loss coefficient (C_h) times the duct velocity pressure VP_d. All air enters the shake-out enclosure through the two openings surrounding the conveyor and leaves through an opening in the ceiling of the enclosure that is connected to the main duct leading to the bag house (BH). A cyclone collector (C), Fig 9.2, with a pressure drop of 4 inches of water removes particles of sand before the air enters the main duct. The casting sprues and risers are removed by workers on two downdraft grinding benches (DB) similar to Fig 1.28. Any surface imperfections are ground-off on these downdraft benches (DB). The total pressure drop through the pouring station is equal to the slot entry loss coefficient (C_s) times the slot velocity pressure VP_s plus the hood loss coefficient (C_h) times the duct velocity pressure VP_d. The pressure drop through the downdraft grinding booth (DB) is equal to the hood loss coefficient (C_h) times the duct velocity pressure VP_d.

Ventilation air from each device (pouring station, two downdraft grinding benches and shakeout enclosure) is collected by a common duct and the particles removed by a baghouse (BH) fabric filter before being discharged to the atmosphere. Each device is connected to the common duct by branch ducts of smaller diameter. Each branch contains a blast gate (BG) that can be closed to prevent air from being drawn through the device when the device is not in use. Air is withdrawn through the entire system by an exhaust fan (F) whose pressure drop has to be computed. The fan manufacturer requires

that air approaches the fan (F) at a velocity of 1,500 FPM. Thus a 30-degree expansion section must be installed between point 4 and the fan.

Selecting the individual ventilation systems (hoods), deciding the needed volumetric flow rates and duct transport velocities, slot velocity, entry loss coefficients, etc. has been performed using ASHRAE and ACGIH and manufacturer's literature and are summarized in Worksheet 1.

Worksheet No 1 - Components

Device	CFM	Slot FPM	Loss Coefficients		δP (in H2O)
			Slot	Hood	
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shake-out	6,000	N/A	N/A	0.5	to be found
downdraft					
bench	4,200	N/A	N/A	0.25	to be found
pouring					
slot hood	15,000	2000	1.78	0.25	to be found
cyclone	6,000	N/A	N/A	N/A	4.0
blast gates	4,200	N/A	N/A	N/A	1.5
baghouse	to be found	N/A	N/A	N/A	10.0
expansion	to be found	N/A	N/A	N/A	to be found

Step 1 Booting The Disk (John is everything in Step 1 necessary ???)

Make a backup copy of the program. Add the DOS System utility to this backup copy if it is not already contained in the program. Boot the computer with a DOS version 3.00 or higher, having SYS.COM. Type SYS x: CR where x: is the drive containing the copy of the ventilation duct design program. Finally type COPY COMMAND.COM x: CR to complete the process.

To run the program, place the disk in Drive A, type A: followed by CR, then type VENT followed by CR. A display will appear containing prompts at the bottom of the screen that need to be answered. At the command Enter [Drive:] [Path] of data files type CR. To the question Enter name of file to read/create, OR <CR> to re-enter path type a name for a new data file followed by CR. Alternatively you may read an existing file created at an earlier time by typing its name. The file extension ".dat" will be input automatically. If an existing file was chosen the screen will display the 16 options listed above. To begin select Option 1. If a new file name was entered, the program goes immediately to Option 1.

Step 2 Pressure Drop Between HS And J1

Begin by computing the pressure drop for the branch furthest from the fan. In this problem the furthest is the shake-out enclosure. The prompt enter starting point appears on the screen. Type HS followed by CR. The prompt enter end point appears to which users answer J1 followed by CR. The prompt enter design Q (CFM) appears, to which

users enter 6000 followed by CR. The prompt transport velocity (FPM) appears to which 4000 and CR is entered. The program computes the duct diameter (rounded off to commercial diameters) and recomputes the actual duct transport velocity and duct velocity pressure (VP). On the screen will appear,

Duct diam	16.00 in
Duct area	1.40 ft^2
Act. duct vel.	4297.18 FPM
Duct vel. pres.	1.15 inches of H20

The question are there any hood entry losses ? [Y/N] appears next. Answer Y, no carriage return is needed. This question pertains to losses due to slots, plenum chambers, diffusers etc. in the hood. Worksheet 1 contains the data, if the information is not available, users will be obliged to estimate slot loss factors and hood entry loss factors from experiment or approximate them from hoods of similar design. Since there are no slots for the shake-out enclosure, the only loss to report will be hood entry loss factor (C_h) equal to 0.5. To the question are there any slots ? answer N. To the question enter hood entry loss factor answer 0.5 followed by CR. The program will display the hood entry loss in the units of inches of water. The screen will now display the following additional information,

Add acceleration factor to	
Entry loss factor	1.5
Hood entry loss	1.73 inches of H20

To the question are there any duct losses ? [Y/N], users should reply with Y. To the question length (feet), one replies 52 followed by CR. The screen will now display the following additional information,

Friction loss/100 ft	1.49 in H20
Duct losses	0.77 in H20

To the question are there any fittings ? [Y/N] answer Y. The question are there any elbows [Y/N] is answered in the affirmative by striking Y. The program now asks the question centerline radius (duct diameters) 1.5, 2, or 2.5 (i.e. elbow radius/duct diameter). It will be assumed that long-radius elbows will be used and the answer 2 followed by CR should be entered. A series of prompts appear to which the following answers are given. Number of 90 elbows, type 2 followed by CR. Number of 60 elbows, type 0 followed by CR. Number of 45 elbows, type 0 followed by CR. Number of 30 elbows, type 0 followed by CR. The screen now displays the following additional information,

Equiv. lengths	47.43 ft
Elbow losses	0.70 inches of H20

The question are there any branching entry losses ? [Y/N] refers to the presence of branches shown in the figure in addition to those that enter the main duct between HS and J1. Since the volumetric flow rate through the branch HS-J1 is 6000 CFM and larger than through the other two branches, it will be presumed that branch HS-J1 is the main duct to which branches HB1-J1 and HB2-J1 are added. Thus there are no branching entries in HS-J1, and users should type N. The program then prompts enter other losses

(i.e. evases, collectors, etc...) in H20 which refer to the pressure drop produced by any devices in the branch between the end points HS and J1. Since the sketch shows that there is a cyclone that produces a pressure drop of 4 inches of water, users type the number 4 followed by CR. The program computes the total branch loss between HS and J1 and displays the prompt total branch losses (in H2O) = 7.204. The program screen also displays the question Is this satisfactory ?. The question is important in future steps to be taken, but for now users should reply in the affirmative by striking Y. The menu now appears listing the 16 options and users select one of the options for whatever they wish to compute next. Select Option 1 by typing 1 followed by CR to compute the pressure drop in branch HB1-J1.

Step 3 Pressure Drop Between HB1 and J1

Data from Worksheets 1 and 2 are entered in a fashion similar to step 1. The figure above shows that the branch enters the larger duct by an entry that is inclined to the duct by 30 degrees. Thus to the question are there branching entry losses ?, answer Y. The prompt then asks Angle of entry [A = 45, B = 30], answer B. The prompt then asks Enter other losses (i.e. evases, collectors, etc.) in H2O. Enter 1.5 for the blast gate. At the end of the option the statement is displayed total branch losses (in H2O) = 3.789 Is this satisfactory ? to which the answer Y is given. Users are again asked to select an option. Since branch HB2-J1 is identical to HB1-J1, users should enter 14 followed by CR to calculate the initial pressure drop in the branch.

Step 4 Pressure Drop Between HB2 and J1

Option 14 begins with the prompt enter original starting point, to which users answer HB1, followed by CR. Users are next asked enter new starting point, to which they answer HB2 followed by CR. To the prompt enter original ending point, users answer J1 followed by CR. Lastly the question enter new ending point, is answered by J1, followed by CR. When the list of options is displayed on the screen, users should enter 5 to display a summary of the pressure drops from each of the three branches that join at junction J1. The following are the results.

Start	End	Vel	Losses	Q	Diam
HS	J1	4297.18	7.204	6000	16.00
HB1	J1	3928.85	3.789	4200	14.00
HB2	J1	3928.85	3.789	4200	14.00

Step 5 Tabulation of Pressure Drops at Junction J1

A balanced system is one in which the static pressure drop between the atmosphere and point J1 is the same for each of the three branches that meet at junction J1. If the computed pressure drop for each branch shown when Option 5 is selected are not the same, users must select other duct diameters, repeat steps 1 to 3, enter data as above and compute a new branch pressure drop. The process must be repeated until the pressure drop in each of the three branches is the same within at least 20%. It must be remembered that the pressure drop is proportional to the square of the velocity and the velocity is inversely proportional to the square of the diameter. **Thus the pressure drop is inversely proportional with the fourth power of the duct diameter**. Thus to reduce

the pressure drop, the duct diameter should be increased. Users must be careful not to increase the diameter by too large an amount or else the transport velocity will become too small and gravimetric settling will become a problem.

To reconsider a previous branch and to change its diameter so as to change its pressure drop, select Option 15 by typing 15 followed by CR. The question enter starting position and ending point appear on the screen and users enter the end points of whichever branch they wish to modify. The question duct diameter (inches), appears to which users type a value X larger or smaller value than before followed by CR. Other questions will be asked as per step 1 and users enter the appropriate values. Each branch that is to be reconsidered requires the use of Option 15. Even if one reconsidered a branch that is identical to another, each branch should be reconsidered using Option 15 rather than Option 14. At the end of the computation, Option 5 should be selected to display the pressure drop in each of the branches. Only the latest values will be shown, so if former values of diameter and pressure drop are needed by users they must record them separately (on paper). The pressure drop in each of the three branches can be brought into agreement within 20% in a few iterations. Shown below are these final values.

Start	End	Vel	Losses	Q	Diam
HS	J1	3395.31	5.955	6000	18
HB1	J1	5347.61	5.852	4200	12
HB2	J1	5347.61	5.852	4200	12

Step 6 Junction Balance

Once the pressure drop for the three branches is within 20% of each other users should select Option 2 to modify the volumetric flow rates and bring about equality of the pressure drop at a junction. Type 2 followed by CR. The question name of junction to be balanced will appear to which the answer J1 followed by CR should be given. The volumetric flow rate in the branch with the lowest volumetric flow rate will be increased to a value "CFM_{cor}",

$$CFM_{cor} = CFM_{design} \text{ [highest SP branch/lowest SP branch]}^{1/2}$$

If the user was lucky and selected duct diameters in which the pressure drops at the junction J1 were within 5%, Option 2 will not adjust the volumetric flow rate of the lowest value. To see the new volumetric flow rates in the three branches, type 5 followed by CR. No attempt should be made to correct for the larger diameter at the exit of junction J1. The equation computing the pressure drop for the entries used in Option 1 will include this effect automatically. The user will see that the three branches have also been reported as a single straight duct with approximately the same pressure drop but volumetric flow rate equal to the sum of the volumetric flow rates of the three separate branches. The program also automatically defines the starting and end points of this new effective branch with new nomenclature in which the starting point is called HJ and ending point is defined as @1. Users can should use these terms in future calculations.

HS-J1   5.95 in H2O

HB1-J1   5.85 in H2O
HB2-J1   5.85 in H2O
HJ-@1   5.96 in H2O

Users may find it helpful to print the results of steps 1-6. Select Option 6 to print a summary of what has been shown on the screen plus a summary of the individual pressure drops through a slot, hood, duct, elbows and branching entries. Select Option 8 to determine the pressure at any point, such as @1. Use Option 11 to reassemble data and eliminate data discarded as a result of using Option 15.

Step 7 Pressure Drop In a Straight Duct

The pressure drop between @1 and J2 should be computed using Option 1. The entry of branch HP-J2 should be ignored for the moment since it will be addressed in the next step. By typing @1 and indicating the that the starting and end points are @1 and J2 respectively, the program will automatically use the corrected total flow rate and transport velocity from step 6. Users can override this and input another transport velocity by typing in the value followed by CR. Even though points @1 and J2 are junctions at which fittings with entries exist, users should not include them in Step 7. The fittings at @1 were noted as entries in the previous steps and the entry at J2 will be included in Step 9.

Step 8 Cumulative Pressure Drop

The pressure drop between the entry of the pouring station and junction J2 must be equal to the cumulative pressure drop in the duct between points HB1, HB2 HS and junction J2. To find the cumulative pressure drop, select Option 8 by typing 8 followed by CR. Input the end point J2 followed by CR and the cumulative static pressure drop, velocity pressure and total pressure at point J2 will be shown. These values (plus or minus 20%) become the performance requirements for the branch HP and J2 which will be computed next.

Step 9 Pressure Drop In Branch HP-J2

The pressure drop in branch HP-J2 is computed using Option 1 following decisions similar to those discussed in Step 1. Since the pouring station has a hood with slots, answer Y to the question are there any slots ?. Input 2000 to the question slot velocity (FPM). To the prompt enter slot entry loss factor, type 1.78. To the prompt are there any branching entries ? [Y/N] answer Y and to the prompt angle of entry [A = 45, B = 30] answer B. Be sure to include the pressure drop of 1.5 in H2O for the blast gate. At the end of Option 1, the prompt appears total branch losses (in H2O) = 3.783 Is this satisfactory ? Answer Y.

Some amount of iteration using Option 15 will have to be performed to bring the pressure drop to within 20% (or less) of the cumulative pressure drop in Step 8. Since the pressure drop is only 3.783 in H2O for a duct 26 inches in diameter, select a smaller duct, such as 20 inches in diameter and a transport velocity of 6876 FPM. A final balancing should be performed using Option 2 as per Step 7. The following are the results of the first and last steps in the iteration. Note that point J2 will hereafter be called @2.

Start	End	Vel	Losses	Q	Diam
HJ	@1	4314.04	5.955	14,400	24.74
@1	J2	3905.61	0.951	14,400	26
HP	J2	4068.34	3.783	15,000	26
HP	J2	6876	7.346	15,000	20
HJ	@2	5523	7.346	29,400	31.24

Step 10 Pressure Drop Between Points @2 And 3

The pressure drop in the duct between points @2 and 3 is computed in the same fashion as Step 7. Use the volumetric flow rate of 29,400 CFM and a transport velocity of 5523 FPM that appears on the display. A total branch loss of 1.5 in H2O is computed. To the question Is this satisfactory ? answer Y. Use Option 8 to show that the static pressure at point 3 is -9.181 in H2O.

Step 11 Pressure Drop Between Point 4 and the Fan

Before computing the pressure recovery in the expansion, users must compute the pressure drop between points 4 and the fan (denoted as F) by using Option 1. It will be presumed that 29,400 CFM must enter the fan at a transport velocity of 1500 FPM, a velocity which is lower than the transport velocity at point 3.

Step 12 Pressure Rise In Expansion Fitting Between Point 3 and 4

The pressure increase from an expansion fitting is calculated by Option 7. To the question is it an (E)xpansion or (C)ontraction [E/C] type E followed by CR since it is an expansion fitting. Input the starting and end points 3 and 4 respectively. The prompt enter taper angle (degrees) appears and a total (included) angle 30 is entered followed by CR. The question is the expansion within 150 inches of a disturbance ? is asked because the program computes the pressure recovery lessened by an amount depending on the proximity of any upstream disturbance. The sketch should be consulted and an appropriate Y/N given followed by CR. It should be noted that to gain full value of an expansion, it is to the designers advantage to locate the expansion at least 5 duct diameters downstream of any other fitting, junction, fan discharge, hood, etc. Since there is 15 feet of duct upstream of the expansion and 10 feet of duct downstream of the expansion answer N. Using Option 5 the following data appear.

Start	End	Vel	Losses	Q	Diam
HS	J1	3,395.31	5.955	6,000	18.0
HB1	J1	5,347.61	5.852	4,200	12.0
HB2	J1	5,347.61	5.852	4,200	12.0
HJ	@1	4,314.04	6.105	14,400	24.7
@1	J2	4,583.66	7.129	14,400	24.0
HP	J2	6,875.49	7.346	15,000	20.0
HJ	@2	5,522.94	7.681	29,400	31.2
@2	3	5,989.32	1.500	29,400	30.0
3	4	1,497.33	- 0.844	29,400	60.0

Step 13 Pressure Drop Downstream Of The Fan

Computing the fan performance properties is the last calculation to be made. Prior to performing it, the pressure drop between the point F and HE must be computed. Option 1 should be selected with the 10 inches of water pressure drop for the fabric filter used in answer <u>enter the losses (evases, collectors, etc..) in H2O</u>. Use the same duct diameter and transport velocity between points 4 and F as was used between points 3 and F.

Step 14 Fan Requirements

Select Option 3 and define F as the fan location. The program computes the fan static pressure requirement. Shown below are the results,

Fan static pressure difference = 18.21 in H2O
Fan design flow rate= 29,400 CFM
Intake duct diameter = 60 in.
Output duct diameter = 60 in.

Use Option 6 to print Worksheet 2 that summarizes the results of the entire analysis including the fan requirements.

Worksheet No 2 - Duct Parameters

Points	CFM	Duct FPM*	Length	Elbows	Entries	other δP (inches H20)
HS-J1	6,000	4,000	52	2-90	0	4.0
HB1-J1	4,200	4,000	30	1-90, 1-45	30	1.5
HB2-J1	4,200	4,000	30	1-90, 1-45	30	1.5
J1-J2	14,400	4,000	100	0	0	0
HP-J2	15,000	4,000	27	1-45	30	1.5
J2-3	29,400	4,000	65	1-90	0	0
3-4	29,400	1,500	10	0	0	0
4-F	29,400	1,500	10	0	0	0
F-HE	29,400	1,500	10	0	0	10.0

* initial value of duct transport velocity