# COMPUTER AIDED OPTIMAL DESIGN

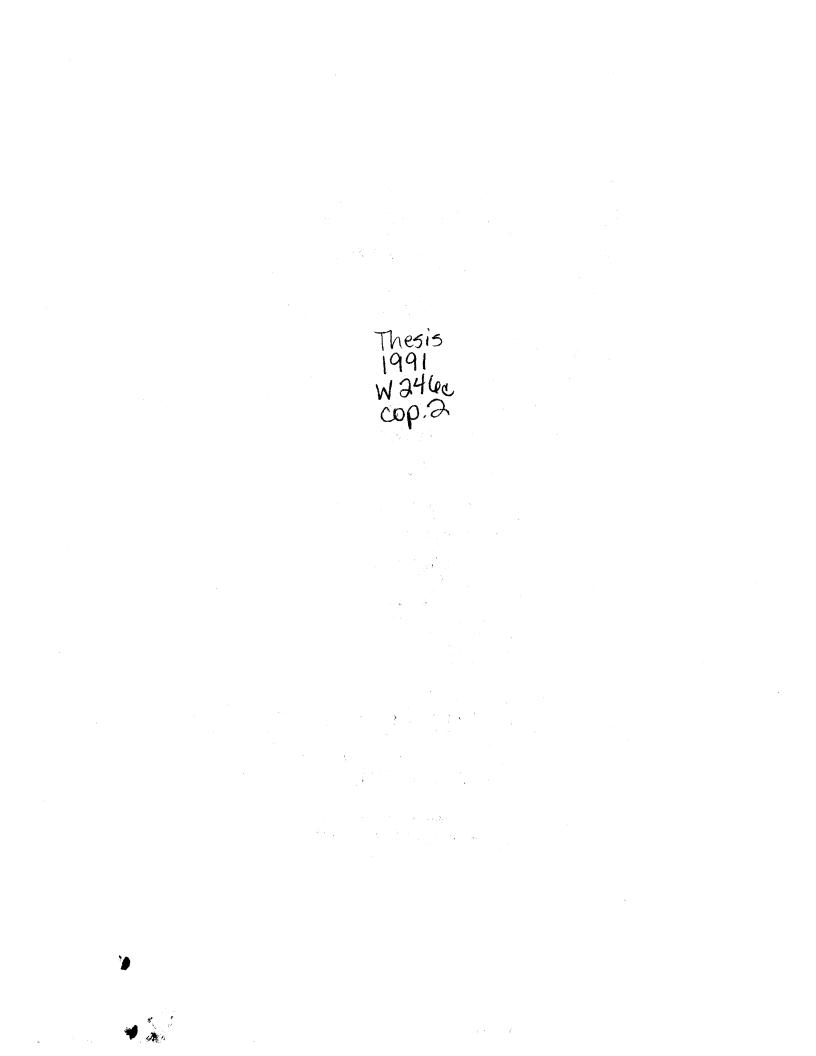
### OF DUCT SYSTEMS

By

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Thesis Approved:

Thesis Adviser of the Graduate College Dean

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### CHAPTER I

### INTRODUCTION

### General

One of the important problems related to the design of any ventilating or air conditioning system is being able to provide the best duct work. In order to achieve maximum energy efficiency and minimal duct material cost, the best design methods have to be chosen carefully. There are three methods described by the ASHRAE Handbook of Fundamentals (ASHRAE 1989) -- equal friction, static regain, and the T-method. Other methods mentioned by McQuiston (1989) are the balanced capacity and the velocity reduction methods. Among these standard methods, the T-method is the only method that claims to provide the optimal duct design.

The optimized duct design concept is based on minimizing the life cycle cost of the duct system. The duct system optimal design is a form of large scale optimization problem. There are several ways to solve this kind of multi-dimensional problem, but most of them cannot always find the globally optimal point. The T-method uses the ideas of dynamic programming optimization method. If used properly, the dynamic programming method has a good chance of

finding the global minimum. Much research related to duct design has been done before by using the dynamic programming method (Shitzer 1979).

The method of simulated annealing (Kirkpatrick, 1983) is a relatively new general-purpose method of very large scale optimization, which has been attracting significant attention recently. It offers the possibility of finding the global optimal point. This method has been reported to be used in power distribution systems (Chiang et al., 1990), optical areas (Kim, 1990), image processing areas (Carnevali, 1985), electronics (Kirkpatrick, 1983), and biochemistry areas (Prabhakaran, 1985). It was reported to have solved the travelling salesman problem, and the global wiring problem of silicon chips successfully (Kirkpatrick, 1983).

Although the T-method has successfully optimized duct network problems, it is unusual for one optimization method to work well for all problems. Also, the T-method has some limitations. For example, the T-method cannot solve problems with the velocity limit constraints and the static pressure limit constraints. This is one of the important reasons to look for alternatives to the Tmethod.

The purpose of this study is to apply the modified simulated annealing method to the duct system optimization problem and compare its results to the T-method. It is therefore necessary to implement the T-method.

#### **Technical Background**

A literature survey was done in the areas of duct design technology and large scale optimization.

#### Duct Design Methods

The equal friction method (McQuiston, 1988) is based on making the pressure loss per foot of duct length the same for the entire system. This method will produce a well balanced duct system if all runs of duct are the same. In most practical systems, this is not the case. The short runs will have to be damped to increase the resistance, which will result in a waste of energy. The balanced capacity method (McQuiston, 1988) involves making the total pressure loss of each path the same under design flow rates. In general, this means that the longest path is sized first, and then the other paths are sized to have the correct pressure loss to match the total pressure at each junction. It is a natural law that all duct systems will balance themselves. The dampers may have to be installed to insure correct flow rates. The system will not be the optimal.

In 1940 Carrier et al. (Tsal, 1988) recommended the static regain duct design method. They thought that this method would be better than the equal friction and the velocity reduction methods. The static regain method saves energy by converting "kinetic energy" into static pressure. The duct section nearest the fan is sized first

by using some additional criteria, and the remaining ducts are sized to have the same total pressure. McQuiston (1988) classified this method as a high velocity duct design method. This method is based on the Bernoulli-Borda equation below:

$$\Delta P = \left(\frac{V_1^2}{C} - \frac{V_2^2}{C}\right) - \left(\frac{k(V_1 - V_2)^2}{C}\right)$$
(1.1)  

$$V_1, V_2 --- \text{ velocity of air in the duct (m/s).}$$
  

$$C --- \text{ fitting coefficient.}$$
  

$$k --- \text{ gradual/abrupt expansion loss ratio}$$

This method was critiqued by Tsal et al. (1988). Other disadvantages were discussed by McQuiston (1988).

The velocity reduction method (Tsal, 1986) can be represented below:

$$V_{j+1} = u V_j, \quad j = 1, 2, ..., n-1$$
 (1.2)

u --- Reduction factor.

V --- Velocity of the air (m/s).

j --- The number of duct section.

The velocity reduction method is used primarily for variable air volume systems (VAV), which depends on the VAV boxes to balance the system pressure loss. It consisted practically of making sure that the duct closest to the fan has acceptable velocity, and then reducing the velocities of the downstream ducts so that the velocities are reduced gradually. This method is some what heuristic and requires a sound background of duct design experience.

The constant velocity method (Tsal, 1986) is a special case of the velocity reduction method, where the reduction factor is 1.0 The velocities of the whole system remain the same. The T-method's starting point is based on this method.

#### T-method

The T-method is a special method for duct network optimal design. It uses the ideas of dynamic programming. Because of the complexity of the duct network and its constraints, most of the methods mentioned above are not capable of finding the global minimum of the duct network cost (Tsal, 1987). Dynamic programming has a better chance to find the global minimum.

The first trial of using dynamic programming in duct system design optimization was by Tsal et al. in 1968 (Tsal, 1987). Arkin and Shitzer had also published their works about using dynamic programming design of the duct system (Arkin, 1979). Tsal et al. tried to optimize the velocity of the duct by dynamic programming (1986). They took the first partial derivatives of the objective function, which is always the life cycle cost of the duct network, with respect to velocity for each section of the duct network (Tsal, 1986, Equation 20) to form several equations. They calculated the optimum air velocity of each duct section by solving these partial derivative equations.

In 1989 when the T-method was introduced, the optimum pressure loss ratio is calculated by taking the partial derivatives of the objective function with respect to pressure losses (Tsal, 1989, Equation 1.24). The system is balanced when the fan pressure is distributed optimally by the ratios of T factors which are calculated by using the partial derivatives of the objective function. T factors are the fan pressure distribution factors introduced by Tsal. T factors are calculated by condensing the system into one node. After the fan is selected the fan pressure is distributed by expanding the system. If the system is not balanced, the iteration is needed. This method seems to find the global minimum of the life cycle cost of the duct network. More detailed discussions are made in the following chapter.

#### Other Optimization methods

There are several ways to optimize the duct network which have been tried before--the Coordinate Descent Method (Tsal, 1987), Lagrange Multipliers Method (Tsal, 1987), Reduced Gradient Method (Abadie,1969), Quadratic Search Method (Leah, 1987), and Dynamic Programming (Bellman, 1957). These methods were well explained by Tsal and Adler (1987).

<u>Simulated Annealing Method.</u> Kirkpatrick (1983) developed a stochastic optimization procedure which is analogous to the statistical thermodynamics of the annealing process of the heated metal with the optimization methods. First, the system is

heated up, then cooled down, and then the temperature is kept at the annealing point for a long time, so that the atoms will line themselves up to form a pure crystal. The pure crystal often contains less energy and has less defects.

By simulating the thermodynamics problem, the introduced pseudo-temperature is the control parameter of the process. When the temperature is high, atoms move in all directions. When the iteration begins, the objective function is allowed to go uphill. The lower the temperature, the longer the iteration will last. Therefore, there is less chance for the system to go in an uphill direction. The possibility for the objective function to go uphill is controlled by the Metropolis Monte Carlo function. The new move is accepted or not with the possibility that its objective function is lower than before, or with the probability  $exp(-\Delta E/T)$  if the objective function is higher than before. Simulated annealing provides the possibility of finding the global minimum.

### CHAPTER II

### **T-METHOD IMPLEMENTATION**

#### Introduction

The T-method is an optimal fan pressure distribution method. The pressure ratio of two duct sections connected in series are calculated by taking the partial derivative of the objective function with respect to pressure losses.

### **Objective** function

Tsal (1989) uses life cycle cost as his objective function.

$$E = E_p * (PWEF) + E_s$$
 (2.1)

where

E = life cycle cost of the duct system (\$).

 $E_p$  = annual electric energy cost (\$).

 $\{E_S = \text{Initial cost of the duct system ($)}.$ 

PWEF = present worth escalation factor. Electric energy cost:

$$E_{p} = \underbrace{Q_{fan}}_{---} \frac{(E_{c}) Y + E_{d}}{10^{5} \eta_{f} \eta_{e}} P_{fan}$$
(2.2)

where

 $Q_{fan} = total air flow rate(m^3/s)$ .

 $E_{C}$  = unit energy cost (\$/kWh).

Y = system operation time (hr/year).

 $E_d$  = energy demand cost (\$/kWh).

 $P_{fan} = Fan pressure (Pa.).$ 

 $\eta_f$  = fan total efficiency.

 $\eta_e$  = motor total efficiency.

Initial Cost:

 $E_{S} = S_{d} \pi D L$  (Round ducts) (2.3)

$$E_s = 2 S_d (H+W) L$$
 (Rectangular ducts) (2.4)

where

 $Sd = unit duct work cost (\$/m^2).$ 

Present Worth Escalation Factor:

$$PWEF = \frac{[(1+AER)/(1+AIR)]^{a} - 1}{1 - [(1+AIR)/(1+AER)]}$$
(2.5)

AER = annual escalation rate.

AIR = average interest rate.

a = amortization period.

The objective function can be written in the form of coefficient K, which is the duct characteristic defined by Tsal (1989).

The duct characteristic coefficient K can be calculated by  $K = n (\mu)^{0.2} Q^{0.4} L$  (2.6)

n parameter is

$$n=1$$
 (Round) (2.7)

$$n = \frac{1+r}{(\pi r)^{0.5}}$$
(2.8)

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where

$$r = \frac{\text{Height}}{\text{Width}}$$
(2.9)

 $\mu = f L + C D \text{ (round)}$   $\mu = (\frac{f L}{D_f} + C) D_v \text{ (Rectangular)}$ (2.10)

where

L = length of the duct (m).

C = fitting coefficient.

f = friction coefficient.

 $Q = air flow volume(m^3/s).$ 

r = aspect ratio for rectangular duct.

Df ---- equivalent-by-friction diameter (m).

$$D_f = \frac{2 H W}{H + W}$$
(2.11)

Dv ---- equivalent-by-velocity diameter (m)

$$D_V = 1.128 (H^*W)^{1/2}$$
 (2.12)

where

H = height of the rectangular duct (m).

W = width of the rectangular duct (m).

From the above equation Tsal found the final objective function. (Tsal, 1989).

$$E=z_1(P_{fan}) + z_2 K (\Delta P)^{-0.2}$$
 (2.13)

K ---- duct characteristic coefficient z<sub>1</sub>,z<sub>2</sub>---- Intermediate variable z<sub>1</sub>,z<sub>2</sub>:

$$z_1 = Qfan \frac{(E_c) Y}{10^5 \eta_e \eta_f}$$
 (PWEF) (2.14)

$$z_2 = 0.959 \pi \left(\frac{\rho}{g}\right)^{0.2} S_d$$
 (2.15)

T-method's objective function is reasonable, clear, easy to understand, and easy to take the partial derivatives.

#### T Factor

The T-method uses the ideas of the dynamic programming optimization method and other traditional optimization methods. Its optimization relies on the partial derivatives of the objective function. The T-method's objective function can be written as follows, if the duct system has two duct sections connected in series:

$$E = E_1 + E_2$$
 (2.16)

 $E_1, E_2$  = the life cycle cost of each section.

The relationship of pressure losses is

$$\Delta P = \Delta P_1 + \Delta P_2 \tag{2.17}$$

 $\Delta P_1, \Delta P_2$  = pressure loss of each section (Pa.).

In order to calculate the optimal fan pressure distribution factor, the partial derivative of the objective function is taken with respect to  $\Delta P_1$  and  $\Delta P_2$ , and set equal to zero.

$$\frac{\partial E}{\partial (\Delta P_1)} = z_1 - 0.2 \ z_2 \ K_1 \ (\Delta P_1)^{-1.2} = 0$$

$$\frac{\partial E}{\partial (\Delta P_2)} = z_1 - 0.2 \ z_2 \ K_2 \ (\Delta P_2)^{-1.2} = 0$$
(2.18)

where

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K<sub>1</sub>, K<sub>2</sub> --- intermediate variables (duct characteristic coefficient).

From the partial derivative equations above, we can get the optimal pressure loss ratio of two sections connected in series.

$$\frac{\Delta P_1}{\Delta P_2} = \left(\frac{K_1}{K_2}\right)^{0.833}$$
(2.19)

Take the reciprocal of each side and add 1 to each side of equation (2.19).

$$\frac{\Delta P_2}{\Delta P_1} + 1 = \left(\frac{K_2}{K_1}\right)^{0.833} + 1$$
(2.20)

From equation (2.20)

$$\Gamma = \frac{\Delta P_1}{\Delta P_1 + \Delta P_2} = \left(\frac{K_1^{0.833}}{K_1^{0.833} + K_2^{0.833}}\right)$$
(2.21)

T = T factor of T-Method, the optimal ratio of the pressure losses for two duct sections.

The T factor is calculated by taken the partial derivatives of the objective function. It is the heart of the T-method, which is the optimal fan pressure distribution factor of the two sections or

equivalent sections connected in series. T factor is calculated by finding the K coefficients of every duct sections.

Pressure loss is calculated by the Darcy-Weisbach equation for round and rectangular ducts.

Round:

$$\Delta P = \left(\frac{fL}{D} + C\right) \frac{V^2 \rho}{2 g}$$
(2.22)

Rectangular:

$$\Delta P = \left(\frac{f \ L}{D_{\rm f}} + C\right) \frac{V^2 \ \rho}{2 \ \rm g}$$
(2.23)

$$\rho$$
 = Air density (kg/m<sup>3</sup>).  
g = constant (1.0 kg-m/(N-s<sup>2</sup>).

Using  $\mu$  coefficient:

Round: 
$$\Delta P = 0.811 \text{ g}^{-1}\mu \rho Q^2 D^{-5}$$
 2.24)

Rectangular:  $\Delta P = 0.811 \text{ g}^{-1} \mu \rho Q^2 D_v^{-5}$  (2.25)

To express the diameter in terms of a pressure loss:

$$D_{v} = 0.959(\mu \rho)^{0.2} Q^{0.4} (g \Delta P)^{-0.2}$$
(2.26)

If two duct sections are connected in parallel, there is no pressure distribution problem, just is a balancing problem. T-method just set the pressure losses of these two sections equal.

From previous equations, the equivalent-by-cost diameter  $D_0$  can be calculated for rectangular duct section.

$$D_0 = 2(H+W)/\pi$$
 (2.27)

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So

$$D_o = \frac{1+r}{\sqrt{\pi r}} D_v = n * D_v$$
 (Round n=1) (2.28)

The initial cost of duct E is

$$E_{S} = \pi * D * L * S_{d}$$
  
= 0.959(\mu \rho)^{0.2} \* Q^{0.4} \* (g \Delta P)^{-0.2} n L (2.29)

Then, the K coefficient can be calculated alternately:

$$K = n \,\mu^{0.2} \,Q^{0.4} \,L \tag{2.30}$$

K factor or coefficient of each duct section can be calculated by condensing the whole system into one node.

### Condensing

Next is the process of condensing two duct sections connected in series into one node.

$$K_{1-2} = (K_1^{0.833} + K_2^{0.833})^{1.2}$$
 (2.31)

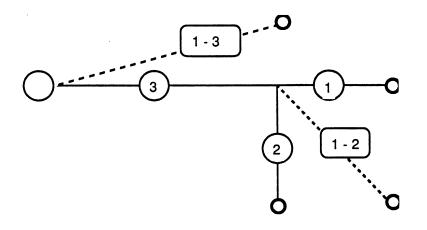


Figure 1. Condensing a tee.

Condensing a tee is shown in Figure 1 which contains one node, two children in parallel, and one parent in series:

$$K_{1-3} = (K_{1-2}^{0.833} + K_3^{0.833})^{1.2}$$
(2.32)

$$=[(K_1 + K_2)^{0.833} + K_3^{0.833}]^{1.2}$$
(2.33)

From equation 2.33

$$E = z_1(P_{fan}) + z_2 K (\Delta P)^{-0.2}$$
(2.34)

The optimum fan pressure can be calculated by taking the derivative of Equation 2.34 with respect to  $\Delta P$ , setting to zero, and solving for pressure loss.

$$P_{fan(opt)} = 0.26 \left(\frac{z_2}{z_1} \kappa\right)^{0.833} + \Delta Pmax$$
 (2.35)

 $\Delta P_{max}$  ----- Maximum additional pressure loss (Pa.).

If fan and motor are preselected, the existing fan pressure is treated as optimum.

### Expansion

This step distributes fan pressure through the system proportional to the T coefficients or T factors.

Duct pressure loss

$$\Delta \mathsf{P}_{i} = (\mathsf{P}_{i})\mathsf{T}_{i} \tag{2.36}$$

0 0 2 2

Tee coefficient 
$$T = \left(\frac{K_i}{K_{i-1}}\right)^{0.833}$$

 $K_i = K_S$  at duct section #i. So  $K_S = K_i$ 

We call  $K_{1-i}$  of node #i  $K_t$ .  $K_t$  is the K for condensed node.

$$T = \left(\frac{K_s}{K_t}\right)^{0.833}$$
(2.38)

So we can calculate the pressure loss for each node.

$$\Delta P = P * T \tag{2.39}$$

P is the pressure at that node. By knowing  $\Delta P$ , we can find out the optimized duct diameter:

$$D = 0.959 \ (\mu \ \rho)^{0.2} \quad Q^{0.4} \ (g \ \Delta P)^{-0.2} \tag{2.40}$$

(2.37)

$$\frac{2(H+W)}{\pi} = D \quad \text{for rectangular duct.}$$
(2.41)

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After the D is calculated, the pressure loss of each duct is calculated, then the pressure loss of each path is calculated. If the maximum pressure loss of every path is greater than 4 percent different (Tsal, 1989) (or the other percentage) from the fan pressure, iteration is needed. Using the duct diameter D estimated by previous function, the previous calculation can be done again and again until the pressure loss is balanced.

#### CHAPTER III

### NUMERICAL STUDY OF DUCT DESIGN METHOD

#### Introduction

As discussed before, when air flow of each duct section is specified, the duct design involves two major problems. When two duct sections are <u>connected in parallel</u>, there is a pressure balancing problem. When two duct sections are connected in series (Figure 2), there is a pressure distribution problem. Almost all the duct design methods are concerned with these two problems. The way to calculate the pressure distribution ratios in each method is different and is not always obviously observed. The following paragraphs are going to discuss how the pressure distribution ratios are calculated by different duct design methods.

#### **Two Sections Connected in Series**

Fan pressure can be distributed by introducing the fan pressure distribution factor (FPDF). If two ducts are connected in series (Figure 2), the pressure ratio of these two duct sections can be represented below

$$\frac{\Delta P_1}{\Delta P_2} = FPDF$$
  
or  
$$\frac{\Delta P_1}{\Delta P_1 + \Delta P_2} = FPDF^*$$
  
(3.1)

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These two FPDFs are different in number but are the same in meaning.

where

 $\Delta P_1$  = pressure loss of first section (Pa.).  $\Delta P_2$  = pressure loss of second section (Pa).

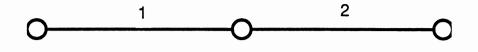


Figure 2. Two duct sections connected in series.

Total pressure loss:

$$\Delta P = \Delta P_1 + \Delta P_2 \tag{3.2}$$

## Two Sections Connected in Parallel

 $\sqrt{If}$  there are only these two sections in the system, their pressure losses have to be the same (Figure 3).

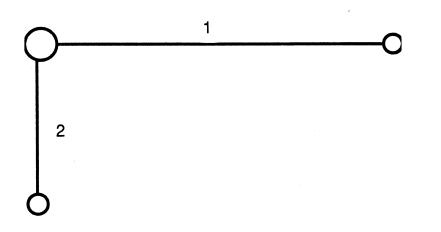


Figure 3. Two duct sections connected in parallel.

$$\Delta \mathsf{P} = \Delta \mathsf{P}_1 = \Delta \mathsf{P}_2 \tag{3.3}$$

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The concept of the imaginary section is based on the idea that one subtree of ducts can be viewed as one large imaginary duct section.

The following sections will try to collapse the existing duct design methods, or duct optimization methods into one formula.  $\int \sqrt{}$ 

#### **T-Method**

T-method is an optimization method which uses the T factor. T factor is the fan pressure distribution factor. The fan pressure distribution factor (FPDF<sup>\*</sup>) can have any value between zero and one, and the system will still be balanced. The T-method has its own way to calculate the fan pressure distribution factor, given by equation (2.21). In this section, it will be shown that the T-method for determining the T-factor can also be cast as a method which sets the fan pressure distribution factor equal to a ratio of initial costs.

$$FPDF^* = T = \frac{\Delta P_1}{\Delta P_1 + \Delta P_2} = \frac{E_{s1}}{E_{s1} + E_{s2}}$$
(3.4)

Using the technique shown in equations (2.19) through (2.21)

$$\frac{\Delta P_1}{\Delta P_2} = \frac{Es_1}{Es_2} \tag{3.5}$$

The mathematical analysis is shown below.

The initial cost of one duct section is

 $E_{S} = \pi * D * L * Sd$ 

$$= 0.959 \ (\mu \ \rho)^{0.2} * Q^{0.4} * (g \ \Delta P)^{-0.2} n \ L$$
(3.6)

Substituting (3.6) into (3.5) yields

$$\frac{\Delta P_1}{\Delta P_2} = \frac{E_{s1}}{E_{s2}} \frac{0.959 \ (\mu_1 \rho)^{0.2} \ Q_1^{0.4} \ (g \ \Delta P_1)^{-0.2} \ n_1 \ L_1}{0.959 \ (\mu_2 \rho)^{0.2} \ Q_2^{0.4} \ (g \ \Delta P_2)^{-0.2} \ n_2 \ L_2}$$
(3.7)

. .

 $\Delta P_1, \Delta P_2$  --- Optimal pressure drops of two duct

sections connected in series.

Equation (3.7) simplifies to

$$\frac{\Delta P_1}{\Delta P_2} = \frac{n_1(\mu_1)^{0.2} Q_1^{0.4} (\Delta P_1)^{-0.2} L_1}{n_2(\mu_2)^{0.2} Q_2^{0.4} (\Delta P_2)^{-0.2} L_2}$$
(3.8)

solving (3.8)

$$\frac{\Delta P_1}{\Delta P_2} = \left(\frac{n_1 \ (\mu_1)^{0.2} \ Q_1^{0.4} \ L_1}{n_2 \ (\mu_2)^{0.2} \ Q_2^{0.4} \ L_2}\right)^{0.833} \tag{3.9}$$

from equation (2.30)

$$K = n\mu^{0.2} Q^{0.4} L$$
 (3.10)

Substitute equation (3.10) into equation (3.9)

$$\frac{\Delta P_1}{\Delta P_2} = \left(\frac{K_1}{K_2}\right)^{0.833} \tag{3.11}$$

Using the technique shown in equations (2.19) through (2.21)

$$FPDF^* = T = \frac{\Delta P_1}{\Delta P_1 + \Delta P_2} = \left(\frac{K_1^{0.833}}{K_1^{0.833} + K_2^{0.833}}\right) = \frac{E_{s1}}{E_{s1} + E_{s2}}$$
(3.12)

Therefore, we reach T-Method's result. Thus, the assertion that the T-factor can also be represented as a ratio of the initial costs is true. This ratio will control the fan pressure distribution to each duct section.

### Equal Friction Method

This method is purely a duct design method without involving any optimization method. The FPDF of this method is equal to the ratio of lengths of two sections connected in series.

This method is based on sizing each duct so that the pressure loss per unit total length is constant.

$$\frac{\Delta P_1}{L_1} = \frac{\Delta P_2}{L_2} = \dots = \frac{\Delta P_n}{L_n}$$
(3.13)

From the formula above, the fan pressure distribution factor of section one can be calculated as

$$FPDF^{*} = \frac{\Delta P_{1}}{\sum_{i=1}^{n} \Delta P_{i}} = \frac{L_{1}}{\sum_{i=1}^{n} L_{i}}$$
(3.14)

This means the equal friction method can be represented in the FPDF\* factor.

### **Balanced Capacity Method**

Balanced Capacity Method is similar to the equal friction method. The difference is that fan pressure distribution factors (FPDF\*) are calculated by the longest equivalent length of the subtree.

$$FPDF^* = \frac{L_1}{Longest (path1, path2, ..., pathj)}$$
(3.15)

### Velocity Reduction Method

The velocity is reduced by the u factor.

$$\frac{V_1}{V_2} = u \tag{3.16}$$

Recall Darcy-Weisbach equation

$$\Delta P = f \frac{Le V^2}{D} \frac{\rho}{2g}$$
(3.17)

Le --- Equivalent length (m).

From equation 3.16 and 3.17, we get

$$\frac{\Delta P_1}{\Delta P_2} = \frac{f_1 * Le_1 * \frac{(V_1)^2}{(D_1 * 2g)} \rho}{f_2 * Le_2 * \frac{(V_2)^2}{(D_2 * 2g)} \rho}$$
(3.18)

or

$$\frac{\Delta P_1}{\Delta P_2} = \frac{\frac{f_1 * Le_1 *}{(D_1)}}{\frac{f_2 * Le_2 *}{(D_2)}} * \left(\frac{V_1}{V_2}\right)^2$$
(3.19)

Equation 3.19 can be written this way

$$\frac{\Delta P_1}{\Delta P_2} = \frac{\frac{f_1 * Le_1}{(D_1 1)}}{\frac{f_2 * Le_2}{(D_2)}} * (u)^2$$
(3.20)

This means that the velocity reduction method can be described by using the FPDF factor.

### Conclusion

Most of the duct design method can be represented in the calculation of fan pressure distribution factor. The different methods have different FPDF factors. Therefore, they have different results.

### CHAPTER IV

# NUMERICAL PROCEDURE AND ANALYSIS OF OPTIMAL PRESSURE DISTRIBUTION METHOD

(Duct system optimization methods should be capable of finding) the minimum of the system cost, balancing the system, selecting the fan, and distributing the fan pressure to the system properly.

The basic idea of optimal pressure distribution (OPD) method Jalance the duct network pressure losses of each path, 2) to select the optimal fan pressure, and 3) to distribute the fan pressure in the proportion of the optimal pressure distribution ratio. The optimal pressure distribution ratios are chosen by the modified simulated annealing method rather than calculated by T-method.

#### **OPD** Factor

We borrowed the T-Method's ideas of optimizing the ratios of the pressure losses of the duct sections instead of optimizing the velocities or the pressure losses directly. We call these ratios Fan Pressure Distribution Ratios. Although the purpose of duct optimization is to find the optimal duct sizes, we cannot optimize the duct sizes explicitly. The sizes of duct sections are dependent on each other because the pressure losses of each paths have to be

balanced. In order to provide simulated annealing method independent variables, the OPD factor is introduced. OPD factor is the ratio of pressure losses of two duct sections or one duct section and a duct subtree.

Consider a two sections duct system where the fan pressure has already been selected. If two ducts are in parallel, there is a balancing problem. These two sections have to have the same pressure losses. There is no optimization problem if the fan pressure has already been chosen. If two ducts are in series, there is no balancing problem, but there is a pressure distribution problem. The cost of the system is related to how the fan pressure is distributed. This is an optimization problem.

In OPD method, the optimum pressure ratio is

$$\frac{\Delta P_1}{\Delta P_2 + \Delta P_1} = OPDF$$
(4.1)

where

 $\Delta P_1$ ,  $\Delta P_2$  -- The pressure losses of first and second section in series (Pa.).

OPDF -- Optimal Pressure Distribution Factor.

The fan pressure can be calculated as

 $P_{fan} = \Delta P_1 + \Delta P_2$ 

If there are only two duct sections or one duct and one subtree of ducts in the system. We borrowed T-method's objective function, for the purpose of comparison. The objective function includes the initial cost and the energy cost of the system.

The objective function is

$$E = E_{p} (PWEF) + E_{S}$$
(4.2)

Electric energy cost:

$$E_{p} = Q_{fan} \frac{(E_{c}) Y + E_{d}}{10^{5} \eta_{f} \eta_{e}} P_{fan}$$

$$(4.3)$$

Present Worth Escalation Factor (PWEF):

$$PWEF = \frac{[(1+AER)/(1+AIR)]^{a} - 1}{1 - [(1+AIR)/(1+AER)]}$$
(4.4)

AER = annual escalation rate (%).
AIR = annual interest rate (%).
a = amortization period (year).

The initial cost (Es) can be calculated as

$$E_{\rm S} = S_{\rm d} \pi D L \qquad (Round) \tag{4.5}$$

 $E_s = 2 S_d (H+W) L$  (Rectangular) (4.6) where

D = duct diameter (m).

H = duct height (m). W = duct width (m).  $\eta_{f} = fan efficiency (\%).$   $\eta_{e} = fan motor efficiency (\%).$   $P_{fan} = fan pressure (Pa.).$   $Q_{fan} = fan flow rate (m<sup>3</sup>/s).$ 

The related economic factors can be estimated from the following sources (Tsal, 1989):

Duct price per unit (Sd)---"Sheet Metal Estimating" Annual escalation rate (AER)---"Utility Costs Forecasting" Amortization period (a) --- Expected Life time of duct system.

Energy demand cost (Ed) --- "Electric Power Annual" Energy unit cost (Ec) --- "Electric Power Annual"

The life cycle cost E is calculated one by one of each duct section. The total cost is calculated by adding all the  $E_s$  together. The fitting cost, fan cost, heating and cooling coil cost are considerate as constant, and not included in the objective function.

### **Fundamental Equations**

The basic equation is the Darcy-Weisbach Equation. The total pressure loss of the flow in closed duct can be calculated as follows: (Wright, 1945)

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$$\Delta P = f \frac{L}{D} \frac{V^2}{2g} \qquad (4.7)$$

where

 $\Delta P$  = head loss due to friction (Pa.).

L = conduit length (m).

D = conduit inside diameter (m).

V = fluid velocity (m/s).

g = acceleration due to gravity (1.0 kg-m/N-s<sup>2</sup>).

 $\rho$  = air density (kg/m<sup>3</sup>)

f = friction factor.

Because the air velocity is relatively low, the air flow rate can be calculated as

$$Q = V * A \tag{4.8}$$

Q = air flow rate  $(m^3/s)$ . A = area of the duct cross-section  $(m^2)$ .

From equation 4.8, the following relationship can be found:

$$V = \frac{4}{\pi} \frac{Q}{D^2}$$
 (4.9a)  
 $V = Q/(H * W)$  (4.9b)

For rectangular ducts, the duct width can be interpreted in terms of an equivalent-by-velocity diameter by equating Equations 4.9a and 4.9b. From 4.7 and 4.9, the equivalent-by-velocity diameter can be calculated

$$D_{v} = \left(\left(\frac{4}{\pi}\right)^{2} f Le * \rho \left(2g \Delta P\right)^{-1} Q^{2}\right)^{1/5}$$
(4.10)

where

 $D_V$  = equivalent-by-velocity diameter (m). Le = equivalent length (m).  $\Delta P$  = pressure loss of this duct section (Pa).  $\pi$  = 3.1415926535898

For the rectangular duct

$$V = Q / (H * W)$$
 (4.11)

From equation 4.9 and 4.11, we can get the equivalent velocity diameter  $D_V$  of the rectangular duct section:

$$D_{v} = \sqrt{((\frac{4}{\pi}) * H * W)}$$
(4.12)

and the equivalent-by-friction diameter for the rectangular duct is:

$$D_f = 2 * (\frac{H * W}{H + W})$$
 (4.13)

We can also find the following relationship.

$$W = \pi \frac{D^2}{4 H}$$
(4.14)

Reynold's number is

$$Re = \frac{D_f * V}{\mu}$$
(4.15)

where

 $\mu$  = viscosity.

By using Altshul's equation (Tsal,1989), we can calculate friction factor

$$f = 0.11 \left(\frac{\varepsilon}{D_f} + \frac{68}{Re}\right)$$
 (4.16)

 $\varepsilon$  = roughness of the duct material.

Pressure balancing is a natural law of all duct systems. If the designers do not balance the system, the system will balance itself. In which case the air flow of each duct will be different than the designed flow rate. Some room probably has too much of a supply of air, but some room does not have enough supply of air.

If the system (Figure 4) is balanced, three equations have to be satisfied (ASHRAE, 1989).

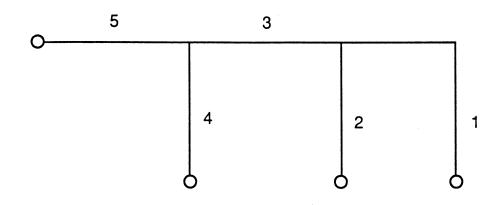


Figure 4. Five duct sections system.

$$\Delta P_1 = \Delta P_2$$
$$\Delta P_4 = \Delta P_3 + \Delta P_2$$
or
$$\Delta P_4 = \Delta P_3 + \Delta P_1$$

Kr Y

$$P_{fan} = \Delta P_5 + \Delta P_3 + \Delta P_1$$

or  $P_{fan} = \Delta P_5 + \Delta P_3 + \Delta P_2$ 

or  $P_{fan} = \Delta P_4 + \Delta P_5$ 

The optimal system should not rely on the damper to balance the pressure. The ducts should be sized properly in order to have the appropriate pressure losses.

The fan pressure is distributed as the ratios of optimal pressure distribution factor (OPDF), where the OPD factor is selected by simulated annealing method.

$$\Delta P_i = OPDF_i \ (P_{fan} - \sum_{Root}^{Present \ section} \Delta P)$$
(4.17)

i = the duct section number of each path.  $\Delta P_i$  = the pressure losses of each section.

The optimal pressure distribution factor is first calculated by

$$OPDF_{i} = \frac{Le_{i}}{\underset{Present}{\sum}} Le$$
(4.18)

Le<sub>i</sub> = equivalent length of number i section.  $\sum$  Le = the longest equivalent length of the tree.

Because of the definitions above, all OPDFs are independent themselves. If you change one, the rest do not have to change, and the system will still be balanced. So the simulated annealing method is able to change the OPD factor without unbalancing the system.

The total equivalent length equals

Le = L + D \* C / f (4.19)

Le = equivalent length (m).

D = diameter of the duct (m).

C = loss coefficient.

f = friction factor.

L = the original length of the duct (m).

### **Optimization Procedure**

OPD method's optimization procedure is much different than the T-method. It starts from choosing the OPDF factors of the duct system. The computer uses a random number generator to determine which OPDF factors should be changed, and which directions the OPDF should change. If the OPDF picked by computer cannot be changed (Terminal node, presized section or the other constraints) or the direction of the change is wrong, another set of random numbers will be needed. After the OPDF is changed, new duct sizes are calculated, and a new life cycle cost of the duct system is calculated. If this new life cycle cost is lower than the previous one, the change will be kept. If the new life cycle cost is higher than the previous one, the change is kept with the possibility of exp(-  $\Delta E/T$ ). T is the pseudo-temperature introduced by simulated annealing method. T will become smaller and smaller until there are no more changes being accepted. The final life cycle cost of the system is the result.

### Fan Pressure Optimization

The fan pressure is calculated differently than the T-method. The fan pressure is not calculated by simulated annealing also. It is calculated by one dimensional minimization method called the Golden Search Method. The relationship between fan pressure and the system life cycle cost is different than the duct sizes. So one dimensional optimization procedure is used to find out the optimal fan pressure. The golden search is used to find out the optimum fan pressure. If the fan has already selected, the fan should work at the maximal efficient point, that pressure should be the optimum fan pressure. If the fan pressure is given by the user, it will not be changed during the optimization.

### CHAPTER V

### DUCT TREE DATA STRUCTURE

The optimal fan pressure distribution method was calculated in C computer language. C gives more feasibility to design those very complex and very large systems. The tree structure programmed in C makes the programming much more logical than the spread sheet.

### Tree presentation

The tree like duct system can be presented in tree data structure. The physical connection between two duct sections can be represented in logical connection between two data structures. So a tree structure of duct network can be exactly duplicated in the machine memory. This will benefit the simulation of duct system.

### Data Structure of "DUCT TREE"

The data structure of one duct section is represented as below.

typedef struct duct\_section {
 double V,L,Q,DPz,Dz,C,Df,Dv,D;
 double f,DP,DPmax;
 double Pup,Pdn,DPt,DPr,DPp;

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double Le,OPDF; double H,W; int ch1,ch2,presized; } duct\_section;

It contains most of the important information of this duct section for further calculation or output.

Also there is a shell or connecter for this duct section data structure.

typedef struct node { int i; (duct\_section \*D;) struct node \*prev; struct node \*ch1; struct node \*ch2; } node;

It contains a pointer to the duct section, a duct number, a pointer to the previous duct section, and two pointers to the child sections.

### **Traversal of Duct Tree**

Theoretically, traverse of the tree can be done in two ways: depth first traverse and breadth first traverse. Breadth first traverse searches the node in a certain depth --- a certain number of layers. This has nothing to do with the physical duct system. So we use the other way, depth first traverse. It depends on if the children are processed first, or parents are processed first. The depth first traversal of duct tree can be classified in preorder, inorder, and postorder. Preorder traversal of the tree precesses the parent node first, and then goes to the children node. Postorder is the reverse of the preorder. The parent node is processed last, the child nodes are processed first. The inorder traversal of the data structure tree processes the nodes from left to right (or from right to left). If the calculation starts from fan to terminals, the preorder traversal of the duct tree is the best choice. If the calculation starts from terminal to fan, the postorder traversal of the duct tree is needed.

Recursion, which uses the hardware stack, is faster than the iteration method, and the source code is shorter also. Therefore we used the recursive function to traverse the duct tree.

### Preorder Traversal

The fan pressure should be distributed from the duct section closest to the fan to the terminal or from root to leaf. A preorder traversal of the duct tree is needed. A preorder traversal example shown below is a function called recursive which calculates the pressure loss of each duct section.

```
dstri_pres(H,Pfan)
node *H;
double Pfan;
{
double Dv5,f,Q,Le,dP;
```

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```
if(H == NULL)
    return;
 if(H->D->presized != TRUE)
     H->D->DP = Pfan * H->D->OPDF;
 f = H -> D -> f;
 Le = H \rightarrow D \rightarrow Le;
 Q = H -> D -> Q;
 dP = H \rightarrow D \rightarrow DP - H \rightarrow D \rightarrow DPz;
 if(dP <= 0.0)
    dP = 0.01;
  Dv5 = 16./(PI * PI) * f * Le
       * DENSITY * (Q * Q)/(2. * GC * dP);
  if(H->D->presized == FALSE)
    H \to D \to Dv = pow(Dv5,0.2);
  dstri_pres(H->ch1,(Pfan - H->D->DP));
  dstri_pres(H->ch2,(Pfan - H->D->DP));
}
```

# Postorder Traversal

The biggest pressure loss of each path of the duct network should be calculated from the terminal to fan or from leaf to root. A postorder traversal of the duct tree network is used. This function is a recursive function and returns a value of biggest pressure loss of the whole duct network.

```
double calc_DP(H,DP,biggest)
node *H;
double DP,biggest;
{
    if(H == NULL)
        return(max(biggest,DP));
    biggest = calc_DP(H->ch1,H->D->DP + DP,biggest);
    biggest = calc_DP(H->ch2,H->D->DP + DP,biggest);
    if((H->ch1 == NULL)&&(H->ch2 == NULL))
        biggest = max(biggest, DP);
        return(biggest);
}
```

# CHAPTER VI

### **RESULTS, DISCUSSIONS AND CONCLUSIONS**

The mathematical model developed in this work was programmed using C language. The computer program worked under both DOS and UNIX system, on both IBM 386 and RISC System 6000. This program is capable of minimizing the life cycle cost of both rectangular and round duct systems. Another program was developed to implement the T-method for comparison.

Both of these two programs can solve the supply-return system problems. Both programs have solved the example problem in the ASHRAE Handbook of Fundamental 1989 and Tsal's Five duct sections example problem. The computer output can be found in the Appendix.

### **Results of Simulated Annealing**

From Figure 5 to Figure 8, the plots show how the simulated annealing method worked to minimize the life cycle cost of the ASHRAE example problem. The modified simulated annealing method started from the results of balanced capacity method. The air velocities shown on the figures are the air velocities of the longest paths of the system.

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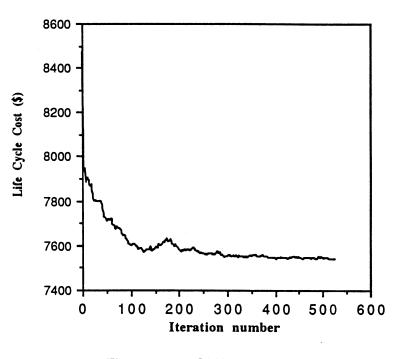


Figure 5. ASHRAE Example (V=7.5 m/s)

In ASHRAE example, because the fan is preselected both the life cycle cost of the duct system and the total duct surface areas can be the objective function. They have a constant relation.

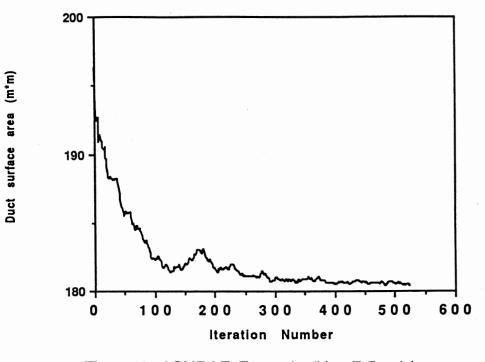
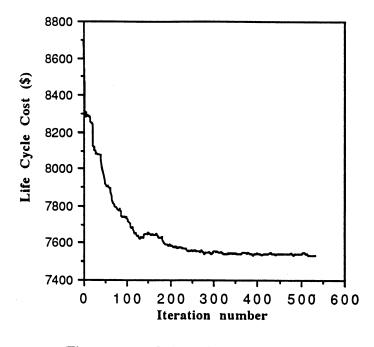
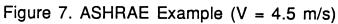


Figure 6. ASHRAE Example (V = 7.5 m/s)

A different starting point was used to test if the lowest life cycle cost of the duct system has any relationship with the starting point.





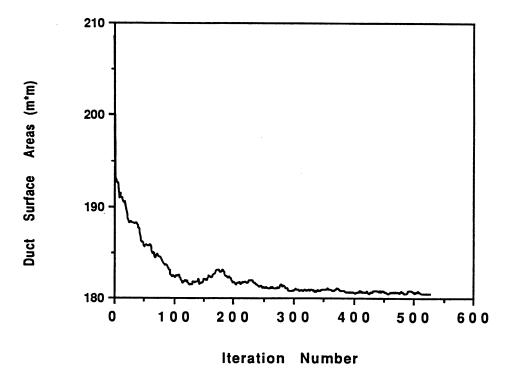


Figure 8. ASHRAE Example (V = 4.5 m/s)

We found that the lowest cost has nothing to do with the starting point. The objective function started from different starting points and terminated at the same result.

We observed the significant changes of the total duct surface areas, of the ASHRAE example (Figure 5 and Figure 7). And also we found that the objective function and the total duct surface areas has a very close relationship. Because the fan pressure is preselected, the duct surface areas are actually the objective function.

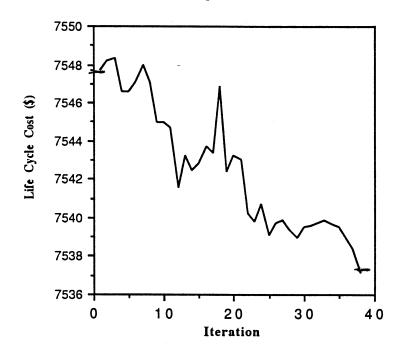


Figure 9. ASHRAE Example Final Calculation (V = 7.5 m/s)

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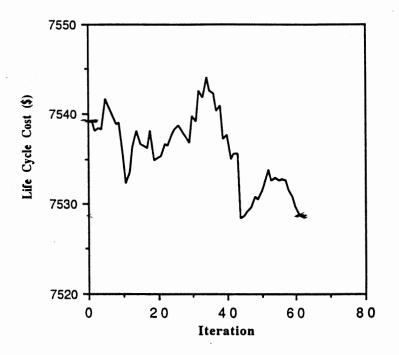


Figure 10. ASHRAE Example Final Calculation (V=4.5m/s)

Figure 9 and Figure 10 are the detailed analyses of the annealing procedures. We can see that the objective function oscillated violently even at the final stage of the calculation. Perspectively, the objective function moved towards the global minimum. It started at \$8692 and ended at \$7528. The duct surface area reduced from 211 square meters to 180.12 square meters. The surface area is 14.8% smaller than the ASHRAE handbook example (211 square meters).

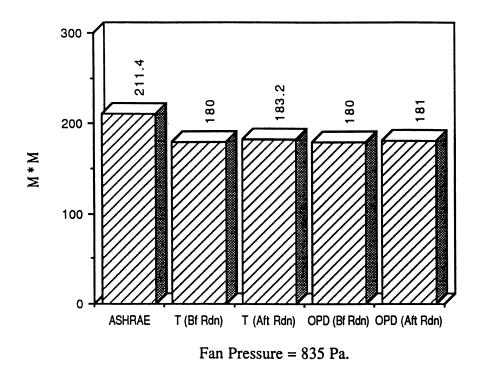


Figure 11. Duct Surface Area of Different Design Method.

Figure 11 shows the comparison of the OPD method, the Tmethod and the ASHRAE example. Because the fan pressures used by different methods are the same, the duct surface areas can represent the cost of the system, which is the objective function. "Aft Rd" and "Bf Rd" stand for "After rounding" and "Before Rounding". We noticed the size rounding does not make too much difference of the total duct surface area.

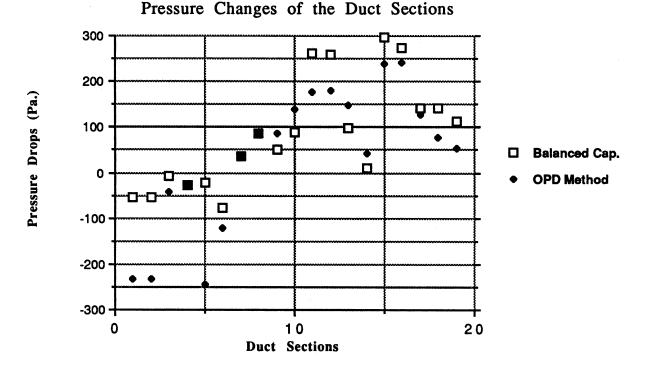


Figure 12. Pressure Changes of the Duct Sections.

Figure 12 shows the changes of pressure loss of each duct section. The OPD method is compared with the equal capacity method which is the starting point of the OPD method. The negative pressure losses refer to the return duct sections. The preselected duct sections' pressure losses are kept the same during the calculation.

# **Results of Golden Search Method**

The golden search method was used to find out the optimum fan pressure. It solved an example problem given by Tsal (1989). The result is presented in Figure 13 and Figure 14. The life cycle cost went down quickly and stopped at the bottom of the objective function while the fan pressure changed.

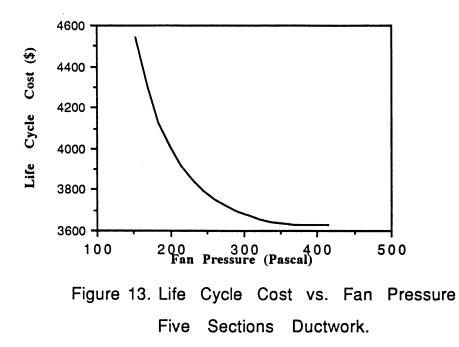


Figure 13 shows when the fan pressure increases the objective function goes down hill. But from a detailed look of the iteration, we will find that the objective function will goes uphill if we continue to increase the fan pressure (Figure 14).

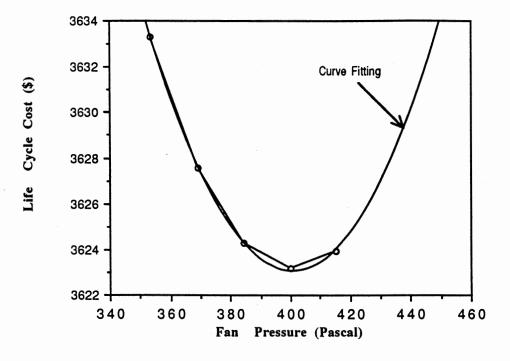


Figure 14. Details of Cost vs. Fan Pressure Five Section Ductwork.

The computer program stopped at the lowest point of the pressure-cost curve. In this Five Duct Sections problem, if we continue to increase fan pressure, the life cycle cost of the duct system will increase rapidly.

### **Comparison of Pressure Losses**

Without changing the fan pressure, how is the duct material saved? The answer is the fan pressure distributed more optimally. The pressure saved by the shorter duct sections which have the

relatively high fitting resistance is used to shrink the longer duct sections' diameters. We can find the significant duct diameter changes are made by the computer programs in Figure 15.

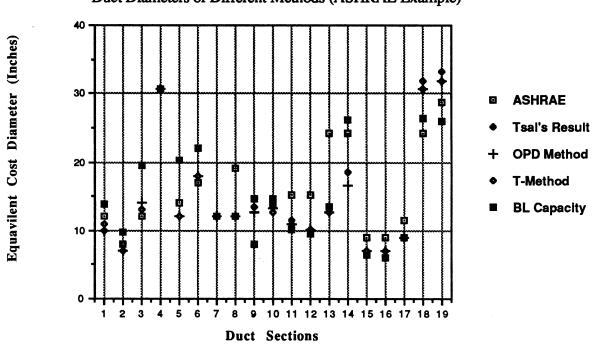


Figure 15. Duct Diameters of Different Methods ASHRAE Example

The ASHRAE example problem was solved by T-method and the OPD method. We got little different results from Tsal's (1989) because we used different computer methods than Tsal. There is a round off error. There is a small difference between the T-method's results and OPD method's results. But they got the similar total duct surface areas (Figure 12). From Figure 15 we can see that the

Duct Diameters of Different Methods (ASHRAE Example)

biggest pressure changes happened in the return duct sections. Most of the return duct sections have long lengths but less fitting frictions in ASHRAE example. An increase in the velocities of these duct sections can decrease the cross-sections of the ducts; therefore, the surface areas of the duct system will decrease. However, the increase of the pressure loss of the return system will decrease the velocity of the supply system, because the fan is fixed. We can see from Figure 15 that most of the duct pressure losses are reduced. Also we can find that not all of the duct pressure losses decreased. Sections 13 and 14 have relatively low fitting frictions compared to their lengths; therefore their pressure losses increase to reduce the surface area. Sections 18 and 19 have large fitting resistance but relatively short lengths; therefore the pressure losses at these two sections decline to save the energy for the other duct sections.

### **Comparison to T-Method**

Both the T-Method and the OPD method can find the global minimum of the objective function. Their results validated each other. The T-Method has less iterations but relies on the partial derivatives of the objective function, and hence requires an objective function with analytically differentiable partial derivatives. The OPD method has more calculations but is more flexible to add constraints to without changing the mathematics model too much. Besides the constraints the T-Method can solve, the OPD method can solve the additional constraints, like air velocity limit, and static pressure limit or the other critical constraints. The changes required to add the new constraints to the software are small. It is more flexible to meet the future challenge of the new constraints brought by new control technology and the VAV system. Another improvement which the OPD method made is that the OPD method's objective function can be life cycle cost, or something else. Many kinds of economic analysis models can be used as the objective function. This gives the OPD method great advantage over T-method in business application.

### **Different Starting Point**

We have tried to work on the same problem from different starting points. The results (Figure 5 and Figure 7) show that the simulated annealing method is able to reach the same answer (global minimum) from two different starting points.

### Conclusions

Based on this study, the following conclusions have been developed:

(1) Both the OPD method and the T-method find essentially the same minimum of the objective function. The closeness of the minimum points strongly suggests that both methods have found the global minimum.

(2) As described by Tsal, the T-method has not been shown able to incorporate constraints such as air velocity limits or static pressure limits. Further more, it seems unlikely that such constraints can be incorporated without fundamentally changing the method. The addition of a penalty function would add multiple singularities to the objective function, rendering the analytical partial derivatives indeterminate. On the other hand, the OPD method can easily incorporate such constraints.

(3) The OPD method's objective function is not limited to life cycle cost. It can be modified without changing the method itself. For example, the objective function could be the first cost of the system, including the fan.

(4) Most of the existing duct design methods can be cast as methods for determining the fan pressure distribution ratios of the ducts. This might be useful for future studies.

(5) The OPD method is a good alternative to the T-method.

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### REFERENCES

Abadie, J.; Carpentier, J. 1969. "Generalization of the Wolfe Reduced Gradient Method to the Case of Nonlinear Constrains". <u>Optimization</u>, by Fletcher ed. New York: Academic Press.

Arkin, Hillel and Shitzer, Avraham 1979 "Computer Aided Optimal Life-Cycle Design of Rectangular Air Supply Duct System." <u>ASHRAE</u> <u>Transactions</u>, Vol. 85, Part I, pp197-213.

Arkin, Hillel and Shitzer, Avraham 1979 "Study of Economic and Engineering Parameters Related to The Cost of an Optimal Air Supply Duct System." <u>ASHRAE Transactions</u>, Vol. 85, Part II, pp 363-374.

ASHRAE 1989. <u>ASHRAE handbook--1989 fundamentals</u>, Chapter 32, "Duct design." Atlanta: American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc.

Bellman, R.E. 1957 <u>Dynamic programming</u>. New York: Princeton University Press.

Chiang, Hsiao-Dong, et al. 1990 "Optimal Network Reconfigurations in Distribution Systems: Part 2: Solution Algorithms and Numerical Results" IEEE Transactions on Power Delivery, Vol 5,No. 3, July 1990, pp 1568-1574.

Carnevali, P., et al. 1985 "Image processing by simulated annealing", <u>IBM Journal of Research and Development</u>, Vol 29 pp569-579.

Kim, Myung Soo; Guest, Clark C. 1990, "Simulated annealing algorithm for binary phase only filters in pattern classification" <u>Applied Optics</u> v29 pp1203-1208.

Kirkpatrick, S., Gelatt, C.D., and Vecchi, M.P. 1983, "Optimization by Simulated Annealing" <u>Science</u>, Vol. 220 pp. 671-680

Ide, Hideo and Matsumura, H 1990 "Frictional Pressure losses of Two-Phase Gas-Liquid Flow in Rectangular Channels." <u>Experimental Thermal and Fluid Science</u> 3:362-372.

Lafore, Robert 1990 <u>The Waite Group's Microsoft C Programming for</u> the PC. Howard W. Sams & Company.

Leah, R.L.; Pedersen, C.O.; and Liebman, J.S. 1987. "Optimization Using Quadratic Search - A case Study of a Chilled Water System." <u>ASHRAE</u> <u>Transactions</u>, Vol. 93, Part 2.

McQuiston, F.C. and Parker, J.D., 1988 <u>Heating. Ventilating. and Air</u> conditioning analysis and design. John wiley & sons.

Scott, K.S., 1986 "Don't Ignore Duct Design For Optimized HVAC Systems." <u>Specifying Engineer</u> Vol. 55, pp 62-64.

Tremblay, Jean-Paul and Sorenson, Paul G. 1984 <u>An Introduction to</u> <u>Data Structures with Applications</u>. McGRAW-HILL Book Company.

Tsal, R.J.and Adler, M.S. 1987 "Evaluation of numerical methods for ductwork and pipeline optimization." <u>ASHRAE Transactions</u>, Vol.93, Part I, pp.17-34.

Tsal, R.J.and Behls, H.F. 1986 "Evaluation of Duct Design Methods." <u>ASHRAE Transactions</u>, Vol.92, Part IA, pp.347-361.

Tsal, R.J.and Behls, H.F. 1988 "Fallacy of The Static Regain Duct Design Method" <u>ASHRAE Transactions</u>, Vol.94, Part II, pp.76-89.

Tsal, R.J. and R.Mangel. 1988 "T-method duct design. Part I: Optimization theory" and "Part II: Calculation procedure and economic analysis." <u>ASHRAE Transactions</u>, Vol 94, Part II.

Tsal, R.J., Behls, H.F., Mangel, R. 1990 "T-method duct design. Part III: Simulation." Presented at ASHRAE's Annual Meeting. St.Louis, Missouri, June 23-26

Vecchi, M.P. and Kirkpatrick, S. 1983 "Global Wiring by Simulated Annealing" <u>IEEE Transactions on Computer Aided Design</u>, Vol. CAD-2, p.215.

Piccioni, Mauro 1991 "A Combined Multistart-Annealing Algorithm for Continuous Global Optimization" <u>Computers and Mathematics</u> <u>Applications</u>, Vol 21, No. 6/7, pp173-179.

Prabhakaran, M.; Harvey, Stephen C. 1985 "Molecular dynamics anneals large-scale deformations of model macromolecules: stretching the DNA double helix to form an intercalation site" <u>The</u> <u>Journal of Physical Chemistry</u> v89 pp5767-5769.

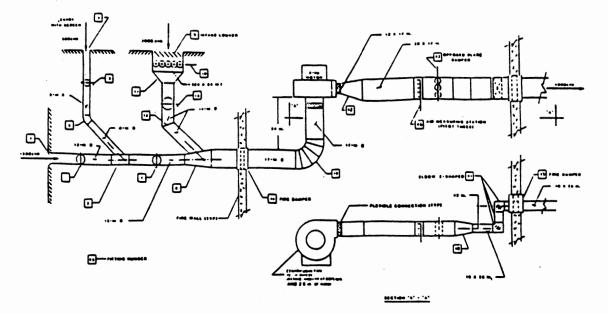
Press, W.H., et al 1990 <u>Numerical Recipes in C</u>. New York: Cambridge University Press.

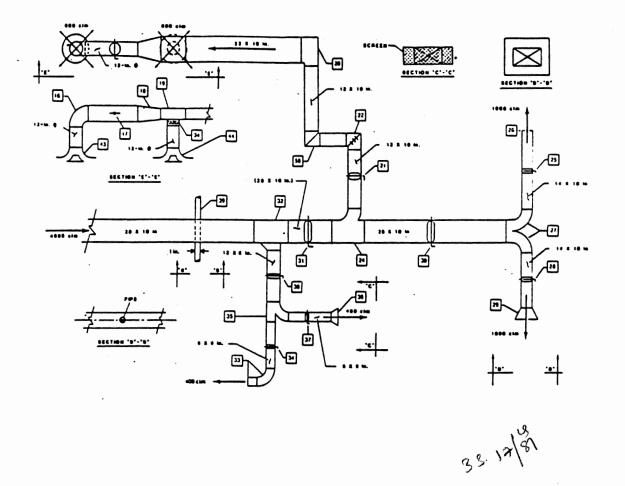
Wright, D.K.Jr. 1945 "A New Friction Chart For Round Ducts" <u>ASHVE</u> <u>Transactions</u> Vol. 51, pp 303-316. APPENDIXES

### APPENDIX A

### ASHRAE EXAMPLE SCHEMATIC

### 1989 Fundamentals Handbook





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# APPENDIX B

### ASHRAE EXAMPLE COMPUTER OUTPUT

OPD METHOD

#### ASHRAE Exemple (OPD Method)

T = 999.00000	10. I		1			T			······	
Made										
	1	2	3	4	5	6				
V	7.269	4.909	4.909	2.526	4.504	7.640				
OPDF	1	1	0.133	0	0.385	0.576				
<u> </u>	28.294	40.597	13.31	17.107	48.13	10.101				
L	24.38	23.77	7.31	1.52	20.42	11.89				
0	0.71	0.24	0.84	0.84	0.94	1.88				
OPz	0	0	0	25	0	56				
Dat	0	0	0.24	0.52	1.06	0.24				
C Di	0.23	0.26	0.494	0.61	0.616	0.669				
DV	0.363	0.25	0.494	0.688	0.516	0.559				
1	0.021	0.023	0.02	0.02	0.02	0.018				
0P	52.706	55.113	7.698	27.185	22.406	77.145				
OPmex	0	0	0	27.185	27.145	82.185				
chi	0	0	1	0	4	3				
chiết	0	0	2	0	0	5				
D	0.363	0.25	0.494	0	0.516	0.559				
н	0	0	0	0.61	0	0				
W	0	0	0	0.61	0	0				
Plan = 43	5.000 E = 46	82.5684 A -	215.012798							
T = 999.0000	00									
Note	7		9	10	11	12	13	14	15	
V	3.832	3.832	6.750	6.759	12.277	14.298	13.044	7.544	12.153	
OPDF	0	0	0.159	0.218	1	16 200	0.214	0.018	1	
<u></u>	18,110	71.798	23.996	42.183	23.67	16.298	12.177	<u>5.33</u> 4.67	15.73	
<u> </u>	4.27	1.22	7.62	13.72	0.10	<u>6.71</u> 0.47	10.67 0.94	4.67	9.75	
O DPz	0.28	0.28	0.56	0.56	0.47	0.47	0.94	1.51	0.19	
Oz Oz	0.305	0.305	0	0				0	0	
C C	1.04	5.3	1.26	2.19	1.78	1.19	0.12	0.04	1.27	
ă	0.305	0.305	0.286	0.286		0.171		0.384	0.123	
- DV	0.305	0.305	0.325	0.325	0.221	0.205	0.303	0.505	0.141	
1	0.023	0.023	0.022	0.022	0.023	0.024	0.021	0.02	0.026	
0P	36.99	45.012	50.601	88.953	263.316	260.015	99.016	9.579	296	
OPmex	36.99	85.012	85.012	85.012		0			0	
ch1	0	0	7	9	0	0		10	0	
ch2	0	0	8	0	0	0	12	13	0	
D	0.305	0.305	0	0	0	0	0	0	0	
н	0	0	0.254	0.254	0.254	0.254	0.254	0.254	0.152	
W	0			0.326	0.151	0.129	0.284	0.788	0.103	
Pien = 83	6.000 E = M	192.5884 A -	215.012798							
L	1									
T = 999.0000	00									
Node	16	17	18	19 7.258						
OPDF	13.552	12.256	6.976	0.169						
Le	10.851	11.625	122.833	\$4.386						
L.	6.1		7.01	3.66		<u> </u>				
1 à	0.19	0.38	1.88	1.88						
DPz	0		10							
Da				12.5			1			
	0		0	12.5						
c	0	0		0		• • • • • • • • • • •				
		0 0.34	0	0 3.06						
C	1.09 0.115 0.134	0 0.34 0.174 0.199	0 4.28 0.512 0.586	0 3.06 0.501 0.574						
	1.09 0.115 0.134 0.026	0 0.34 0.174 0.199 0.024	0 4.28 0.512 0.586 0.019	0 3.06 0.501 0.574 0.019						
C Dr Dv 1 DP	1.08 0.115 0.134 0.028 274.329	0 0.34 0.174 0.199 0.024 143.365	0 4.28 0.512 0.580 0.019 142.524	0 3,06 0.501 0.574 0.019 113.596						
C DI DV I DP DPmax	1.08 0.115 0.134 0.026 274.329 0	0 0.34 0.174 0.199 0.024 143.365 0	0 4.28 0.512 0.586 0.019 142.524 95.012	0 3,06 0.501 0.574 0.019 113.596 107.512						
C Dr Dv t DP DP max ch1	1.09 0.115 0.134 0.026 274.329 0 0	0 0.34 0.174 0.199 0.024 143.365 0 15	0 4.28 0.512 0.580 0.019 142.524 95.012 14	0 3.06 0.501 0.574 0.019 113.596 107.512						
C Dr Dv t DP DP max ch1 ch2	1.09 0.115 0.134 0.026 274.329 0 0 0	0 0.34 0.174 0.024 143.365 0 15	0 4.28 0.512 0.580 0.019 142.524 95.012 14 17	0 3.06 0.501 0.574 0.019 113.596 107.512 18 0						
C Df Dv 1 DP DP DP DP mas ch1 ch2 D	1.00 0.115 0.134 0.026 274.320 0 0 0 0 0 0	0 0.34 0.174 0.099 0.024 143.365 0 15 15 16	0 4.28 0.512 0.580 0.019 142.524 95.012 14 17 0	0 3.06 0.501 0.574 0.019 113.596 107.512 107.512 0 0						
C Df Dv t DPmax Ch1 ch1 ch2 D H	1.00 0.115 0.134 0.026 274.320 0 0 0 0 0 0 0 0 0 0 0 0 0 0 152	0.34 0.174 0.174 0.024 143.365 0 15 15 0 0 0 0.203	0 4.28 0.512 0.586 0.019 142.524 95.012 14 17 0 0	0 3.06 0.501 0.574 0.019 113.596 107.512 10 0 0 0 0 0.61						
C Dr Dr DP DP DP max ch1 ch2 D H W	1.00 0.116 0.026 274.320 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	0 0.34 0.174 0.199 0.024 143.365 0 0 15 15 16 0 0.203 0.153	0 4.28 0.512 0.580 0.019 142.524 95.012 14 17 0 0.011 0.0412	0 3.06 0.501 0.574 0.019 113.596 107.512 107.512 0 0 0 0 0.61						
C Dr Dv r OP DP dn1 dn2 D H	1.00 0.116 0.026 274.320 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	0.34 0.174 0.174 0.024 143.365 0 15 15 0 0 0 0.203	0 4.28 0.512 0.580 0.019 142.524 95.012 14 17 0 0.011 0.0412	0 3.06 0.501 0.574 0.019 113.596 107.512 10 0 0 0 0 0.61						
C DI DV 1 DP DPmax ch1 ch2 D D H H W Pten = 83	1.09 0.115 0.134 0.026 274.329 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	0 0.34 0.174 0.199 0.024 143.365 0 0 15 15 16 0 0.203 0.153	0 4.28 0.512 0.580 0.019 142.524 95.012 14 17 0 0.011 0.0412	0 3.06 0.501 0.574 0.019 113.596 107.512 10 0 0 0 0 0.61						
C Dr Dr DP DP DP max ch1 ch2 D H W	1.09 0.115 0.134 0.026 274.329 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	0 0.34 0.174 0.199 0.024 143.365 0 0 15 15 16 0 0.203 0.153	0 4.28 0.512 0.580 0.019 142.524 95.012 14 17 0 0.011 0.0412	0 3.06 0.501 0.574 0.019 113.596 107.512 10 0 0 0 0 0.61						
C Of Dv f OP OP OP OP OP OP OP OP OP OP	1.09 0.115 0.134 0.026 274.329 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	0 0.34 0.174 0.199 0.024 143.365 19 0 0.153 0.153 0.203 0.153 0.203 0.203	0 4.28 0.512 0.546 0.019 142.524 95.012 14 17 0 0 0.661 0.442 215.012788	0 3.06 0.501 0.574 0.019 113.596 107.512 107.512 0 0 0 0.61 0.425						
C Of Dv r OPmas ofil ofi2 D Pian = 83 T = 0.000000 Node	1.09 0.115 0.326 274.329 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	0 0.34 0.174 0.174 0.024 143.365 15 15 0 0 0.203 0.153 0.153 0.553 0.153	0 4.28 0.512 0.586 0.019 142.524 95.012 14 17 0 0 0.61 0.442 215.012796	0 3.06 0.501 0.574 0.019 113.596 107.612 0 0 0 0.61 0.425	5	  12 104				
C Df Dv 1 Df Df Df df df 2 Df Max df 2 D 1 df 2 DF 2 D	1.00 0.115 0.134 0.028 274.320 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	0 0.34 0.174 0.199 0.024 143.365 0 143.365 0 153 0.203 0.153 0.153 0.25384 A 4 0 0.203 0.153 0.204 0.153 0.25484 A 4 0.154 0.055 0.054 0.055 0.054 0.054 0.054 0.054 0.054 0.054 0.055 0.054 0.054 0.054 0.054 0.055 0.054 0.054 0.055 0.054 0.054 0.054 0.055 0.055 0.055 0.055 0.055 0.055 0.055 0.055 0.055 0.055 0.055 0.055 0.055 0.055 0.055 0.056 0.055 0.056 0.055 0.056 0.0	0 4.28 0.512 0.546 0.010 142.524 95.012 14 17 0 0.642 215.012706	0 3.06 0.501 0.574 0.019 113.596 107.512 107.512 0 0 0 0.0 1 0.425	5 12.920	12.104				
C Of Dv f OPmax dh1 dr2 D H W Plan = 83 T = 0.000000 Node V OPDF	1.09 0.115 0.134 0.026 274.329 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	0 0.34 0.174 0.199 0.024 143.365 19 0 0.153 0.203 0.153 502.5844 A -	0 4.28 0.512 0.546 0.019 142.524 95.012 14 17 0 0 0.611 0.442 2 215.012788	0 3.06 0.501 0.574 0.019 113.596 107.512 107.512 0 0 0 0.61 0.425	5 12.929 0.995	12.104				
C Of Dv f OPmax ch1 ch2 D D H W W Plan = 83 T = 0.000000 Node V CPDF La	1.09 0.115 0.134 0.026 274.329 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	0 0.34 0.174 0.174 0.024 143.365 0 0 15 16 0 0.203 0.153 0.153 0.25384 A. 2 9.068 1 1 35.644	0 4.28 0.512 0.586 0.019 142.524 95.012 14 17 0 0 0.61 0.442 215.012796	0 3.06 0.501 0.574 0.019 113.596 107.612 0 0 0.61 0.425 0 0 0.425 0 0 0.61 0.425 0 0 0.17.107	5 0.995 38.005	12.104 0.207 17.541				
C Of Dv f OPmax dh1 dr2 D H W Plan = &3 T = 0.000000 Node V OPDF	1.00 0.115 0.134 0.028 274.320 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	0 0.34 0.174 0.199 0.024 143.365 0 0 15 0 0.203 0.153 0.25384 A 0 0.203 0.153 0.25384 A 1 35.844 A 1 35.844 A 22.77	0 4.28 0.512 0.549 0.019 142.524 95.012 14 0.42 215.012706 0.442 215.012706	0 3.06 0.501 0.574 0.019 113.566 107.512 107.512 107.512 0 0 0 0.0425 0 0 0 0.425 0 0 0 0.425 0 0 0 0 17.107 1.528	5 12.929 0.995 36.005 20.42	12.104 0.207 17.541 11.89				
C Dr Dr DP DPmax ch1 ch2 D DPmax th2 T = 0.000000 T = 0.000000 T = 0.000000 V CPDF La L	1.09 0.115 0.134 0.026 274.329 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	0 0.34 0.174 0.199 0.024 143.365 0 0 15 0 0.203 0.153 002.5844 A 0 2 9.068 1 35,844 23.77 0.24	0 4.28 0.512 0.546 0.019 142.524 95.012 14 0.442 • 215.012788 	0 3.06 0.501 0.574 0.019 113.596 107.512 107.512 107.512 0.00 0.01 0.425 0.0252 0.0250	5 12.929 0.995 36.0045 20.42 0.94	12.104 0.207 17.541 11.89 1.88				
C Of DV 1 OP 0 0 0 0 0 0 0 0 0 0 0 0 0	1.09 0.115 0.134 0.026 274.329 0 0 0 0 0 0 0 0 0 0 0 0 0	0 0.34 0.174 0.199 0.024 143.365 0 0 15 16 0 0.203 0.153 0.203 0.203 0.203 0.552 592.5884 A c	0 4.28 0.512 0.566 0.019 142.524 95.012 14 17 0 0.61 0.442 215.012708 10.142 215.012708	0 3.06 0.501 0.574 0.015 113.566 107.512 10 0 0 0.61 0.425 0.425 0.425 0.425 0.425 0.425 0.425 0.526 0.17.107	5 12.920 0.995 30.005 20.42 0.94	12.104 0.207 17.541 11.89 1.88 55				
C Of Dv f OPmax dh1 df2 D H W Plan = 83 T = 0.000000 Node V OPDF Le L O	1.09 0.115 0.134 0.026 274.329 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	0 0.34 0.174 0.199 0.024 143.365 0 0 153 00.203 0.153 00.25384 0.203 0.153 00.25384 1 1 35.844 23.77 0.24 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	0 4.28 0.512 0.549 0.019 142.524 95.012 14 17 0 0 0.42 215.012798 0 10.183 10.18 0.153 11.351 7.31 0.944 0.044	0 3.06 0.501 0.574 0.019 113.596 107.512 107.512 107.512 0.0 0 0 0.0 0 0 0 0 0.425 0 0 0 17.107 1.52 0.94 2.252 0.04	5 12.929 0.995 36.005 20.42 0.94	12.104 0.207 17.541 11.89 1.80 55				
C Dr Dr DP DP DP dn1 dn2 D DP H W Plan = 83 T = 0.000000 T = 0.000000 V OPDF L O DP D D D D D D D D D D D D D	1.00 0.115 0.134 0.028 274.320 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	0 0.34 0.174 0.199 0.024 143.365 0 0 15 16 0 0.203 0.153 592.5884 A 2 9.088 1 1 35.844 23.77 0.24 0 0 0.153 0.158 0.158 0.158 0.158 0.158 0.158 0.158 0.158 0.158 0.158 0.158 0.174 0.175 0.174 0.174 0.174 0.174 0.174 0.174 0.175	0 4.28 0.512 0.546 0.019 142.524 95.012 14 17 0 0.61 0.442 215.012706 0.61 0.442 215.012706 0.63 10.16 0.153 11.351 7.31 0.94 0.024 0.243	0 3.06 0.501 0.574 0.015 113.566 107.512 10 0 0 0 0.61 0.425 0.425 0.425 0.425 0.425 0.61 0.520 0.520 0.520 0.520 0.520 0.520 0.520 0.520 0.520 0.520 0.520 0.5210000000000000000000	5 12.920 0.995 36.005 20.42 0.94 0.995 1.06 0.304	12.104 0.207 17.541 11.89 1.84 55 55 0 0 0.24				
C Of Dv f DP DP DP DP dr1 dr2 D H W T = 0.000000 T = 0.000000 V OPDF Le L OP DP DP D D D D D D D D D D D D D	1.00 0.115 0.134 0.028 274.320 0 0 0 0 0 0 0 0 0 0 0 0 0	0 0.34 0.174 0.199 0.024 143.365 0.024 143.365 0.025 0.203 0.153 0.203 0.153 502.5884 A - 2 9.088 1 1 35.844 23.77 0.24 0 0 0.24 0.203 1.55 0.24 0.083 0.183 0.185 0.185 0.185 0.185	0 4.28 0.512 0.549 0.019 142.524 95.012 14 17 0 0 0.42 215.012798 10.183 10.18 0.153 11.351 7.31 0.944 0.0440 0.0440 0.0440 0.0440 0.04400000000	0 3.00 0.501 0.574 0.019 113.596 107.612 107.612 107.612 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	5 12.929 0.995 38.005 20.42 0.94 0.94 0.304 0.304	12.104 0.207 17.541 11.89 1.86 55 0 0 0.24 0.445 0.445				
C Of DV f DP DP DP DP DP DP DP DP DP DP	1.09 0.115 0.134 0.026 274.329 0 0 0 0 0 0 0 0 0 0 0 0 0	0 0.34 0.174 0.199 0.024 143.365 0.024 143.365 0.020 0.153 502.5844 A 0.023 502.5844 A 0.153 0.2544 0.23.77 0.24 0.048 0.153 0.163 0.163 0.024	0 4.28 0.512 0.546 0.019 142.524 95.012 14 0.442 • 215.012708 	0 3.06 0.501 0.574 0.019 113.596 107.512 107.512 107.512 0.00 0.01 0.01 0.0250	5 12.929 0.995 36.0045 20.42 0.944 0.044 0.044 0.044 0.044 0.304 0.304 0.304 0.304	12.104 0.207 17.541 11.00 1.00 55 0 0.24 0.445 0.445 0.011				
C Of DV 1 OP 0 0 0 0 0 0 0 0 0 0 0 0 0	1.09 0.115 0.134 0.026 274.329 0 0 0 0 0 0 0 0 0 0 0 0 0	0 0.34 0.174 0.199 0.024 143.365 0 0 15 16 0 0.203 0.153 502.5484 A 2 9.088 1 1 35.844 23.77 0.24 2 9.088 1 1 35.844 0.183 0.183 0.183 0.183 0.185 0.085 0.185 0.085 0.185 0.085 0.185 0.085 0.185 0.085 0.085 0.085 0.085 0.085 0.085 0.085 0.085 0.085 0.085 0.085 0.085 0.085 0.085 0.085 0.095 0.085 0.0	0 4.28 0.512 0.546 0.019 142.524 95.012 14 17 0 0.61 0.442 215.012766 0.442 215.012766 0.442 215.012766 0.442 0.442 0.153 11.351 0.944 0.024 0.343 0.0343 0.0343 0.0343	0 3.00 0.501 0.574 0.019 113.596 107.512 107.512 0.0 0 0.61 2.522 0.0 17.107 1.52 0.0425 0.0 17.107 1.52 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0	5 12.929 0.995 38.005 20.42 0.94 0.005 00000000	12.104 0.207 17.541 11.00 55 0 0.24 0.445 0.445 0.011 120.484				
C Of DV 1 DPmas ch1 ch2 D DPmas ch1 ch2 D D T = 0.000000 T = 0.000000 V C DDF D D D D D D D D D D D D D	1.00 0.115 0.134 0.028 274.320 0 0 0 0 0 0 0 0 0 0 0 0 0	0 0.34 0.174 0.199 0.024 143.365 0.024 143.365 0.00 0.203 0.153 0.153 0.153 592.5884 A - 2 9.088 1 1 35.844 23.77 0.24 0 0 0 1.58 0.183 0.183 0.183 0.183 0.183 0.185 0.224 0.22 0.22 0.22 0.22 0.22 0.22 0.2	0 4.28 0.512 0.549 0.019 142.524 95.012 14 0.442 215.012798 0.442 215.012798 0.442 0.153 10.183 0.153 0.153 0.153 0.153 0.04400000000	0 3.06 0.501 0.574 0.019 113.596 107.512 107.512 107.612 0.0 0 0 0 0 0 0 0 0 0 0 0 0 0	5 12.929 0.995 38.005 20.42 0.94 0.304 0.304 0.304 0.304 0.304 2.7.185	12.104 0.207 17.541 11.89 1.84 55 0 0 0.24 0.445 0.445 0.014 120.444 82.185				
C Of DV f DP DP DP DP DP DP DP DP DP DP	1.09 0.115 0.134 0.026 274.329 0 0 0 0 0 0 0 0 0 0 0 0 0	0 0.34 0.174 0.199 0.024 143.365 0.024 143.365 0.020 0.153 502.5844 A - 0.153 502.5844 A - 2 9.068 1 35.444 23.77 0.24 0 0 0.153 0.183 0.024 232.432 0.024	0 4.28 0.512 0.546 0.019 142.524 95.012 14 0.442 • 215.012708 	0 3.06 0.501 0.574 0.019 113.596 107.512 107.512 107.512 107.512 107.512 107.512 107.512 107.512 107.512 0.04 0.0425 0.04 0.0425 0.04 0.052 0.054 0.054 0.055 0.054 0.055 0.054 0.055 0.055 0.055 0.055 0.055 0.055 0.057 0.	5 12.929 0.995 36.0045 20.42 0.944 0.304 0.304 0.304 0.304 0.304 0.304 0.304 0.304 0.304 0.304 0.304 0.304 0.4 0.4 0.4 0.4 0.4 0.4 0.4 0.4 0.4 0	12.104 0.207 17.541 11.80 1.80 0.24 0.24 0.445 0.011 120.454 82.165 33				
C Of DV 1 OP DP 0 0 0 0 0 0 0 0 0 0 0 0 0	1.09 0.115 0.134 0.026 274.329 0 0 0 0 0 0 0 0 0 0 0 0 0	0 0.34 0.174 0.199 0.024 143.365 0 0 153 0.203 0.153 0.203 0.153 0.203 0.153 0.203 0.153 0.203 0.153 0.203 0.153 0.203 0.153 0.203 0.153 0.204 0.203 0.153 0.204 0.153 0.024 0.0000000000	0 4.28 0.512 0.546 0.019 142.524 95.012 95.012 95.012 0.442 215.012798 310.18 0.442 215.012798 0.442 0.442 0.442 0.442 0.442 0.442 0.0343 0.024 0.0343 0.034	0 3.06 0.501 0.574 0.019 113.566 107.512 107.512 107.512 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.	5 12.929 0.995 20.42 0.944 0.00 0.00 0.00 0.00 0.00 0.00 0.0	12.104 0.207 17.541 11.80 1.80 0.24 0.445 0.445 0.445 0.445 0.445 0.445 0.445 0.445 0.445 0.445 0.445 0.215 0.215 0.225 0.225 0.225 0.225 0.227 0.227 0.207				
C D? D? DP DP DP DP DP DP DP DP DP D D D D D D D D D D D D D	1.00 0.115 0.134 0.028 274.329 274.329 0 0 0 0 0 0 0 0 0 0 0 0 0	0 0.34 0.174 0.199 0.024 143.365 0.024 143.365 0.00 0.203 0.153 0.153 0.153 592.5884 A - 22 9.088 1 1 35.844 23.77 0.24 23.77 0.24 0 0 0.153 0.183 0.183 0.183 0.183 0.024 0.024 0.00 0.155 0.274 0.275 0.277 0.275 0.275 0.275 0.275 0.275 0.275 0.277 0.275 0.2777 0.2777 0.2777 0.2777 0.27777 0.277777 0.27777777777	0 4.28 0.512 0.549 0.019 142.524 95.012 14 17 0 0.00 0.42 215.012798 0.442 0.153 10.18 0.153 11.351 7.31 0.944 0.024 0.343 0.022 41.810 0.023	0 3.06 0.501 0.574 0.019 113.596 107.512 107.512 107.612 0.0 0 0 0 0 0 0 0 0 0 0 0 0 0	5 12.929 0.995 38.005 20.42 0.94 0.304 0.304 0.304 0.304 2.27.185 4 0.304 0.304	12.104 0.207 17.541 11.60 0.624 0.445 0.445 0.044 120.444 82.185 3 5 0.445				
C D7 D7 D7 D7 D7 D7 D7 D7 D7 D7	1.09 0.115 0.134 0.026 274.329 0 0 0 0 0 0 0 0 0 0 0 0 0	0 0.34 0.174 0.199 0.024 143.365 0.024 143.365 0.024 0 0 0.203 0.153 00.2535 0.0153 00.25354 1 35.25454 23.77 0.24 0 0 0.203 0.183 0.183 0.024 232.432 0 0 0 0.183 0.024	0 4.28 0.512 0.546 0.019 142.524 95.012 14 0.442 215.012798 10.442 215.012798 10.153 10.16 0.453 10.183 0.153 11.351 0.343 0.024 0.24 0.343 0.343 0.02 41.919 0 1 1 2 2 2 3 3 0.24 0.24 0.24 0.24 0.24 0.24 0.24 0.24	0 3.00 0.501 0.574 0.019 113.596 107.512 107.512 107.512 107.512 107.512 107.512 107.512 107.512 0.04 2.526 0.04 0.0425 0.04 0.0425 0.04 0.0425 0.04 0.0425 0.04 0.0425 0.04 0.0425 0.04 0.0425 0.04 0.0425 0.04 0.045 0.05	5 12.929 0.995 38.005 20.42 0.946 0.304 0.	12.104 0.207 17.541 11.80 0.445 0.445 0.445 0.445 82.185 3 5 5 0.445 0.455 0.4				
C Of DV 1 DPmax ch1 ch2 D DPmax V Phen = 83 T = 0.000000 V T = 0.000000 V C DDF DDF La L OF DF DF DF DF DF DF DF DF DF D	1.09 0.115 0.134 0.026 274.329 0 0 0 0 0 0 0 0 0 0 0 0 0	0 0.34 0.174 0.199 0.024 143.365 0.024 143.365 0.020 0.153 0.203 0.153 0.203 0.153 0.203 0.153 0.203 0.153 0.203 0.153 0.203 0.153 0.203 0.153 0.203 0.153 0.204 0.000 0.163 0.024 0.000 0.163 0.024 0.025 0.025 0.025 0.025 0.024 0.024 0.024 0.024 0.024 0.024 0.024 0.025 0.025 0.025 0.024 0.000 0.000 0.0000 0.0000000000	0 4.28 0.512 0.546 0.010 142.524 95.012 14 0.442 215.012796 31 0.442 215.012796 0.442 0.042	0 3.00 0.501 0.574 0.019 113.596 107.512 107.512 107.512 107.512 107.512 107.512 107.512 107.512 0.04 2.526 0.04 0.0425 0.04 0.0425 0.04 0.0425 0.04 0.0425 0.04 0.0425 0.04 0.0425 0.04 0.0425 0.04 0.0425 0.04 0.045 0.05	5 12.929 0.995 38.005 20.42 0.946 0.304 0.	12.104 0.207 17.541 11.80 0.445 0.445 0.445 0.445 82.185 3 5 5 0.445 0.455 0.4				
C Of DV 1 OP 0 0 0 0 0 0 0 0 0 0 0 0 0	1.09 0.115 0.134 0.026 274.329 0 0 0 0 0 0 0 0 0 0 0 0 0	0 0.34 0.174 0.199 0.024 143.365 0.024 143.365 0.020 0.153 0.203 0.153 0.203 0.153 0.203 0.153 0.203 0.153 0.203 0.153 0.203 0.153 0.203 0.153 0.203 0.153 0.204 0.000 0.163 0.024 0.000 0.163 0.024 0.025 0.025 0.025 0.025 0.024 0.024 0.024 0.024 0.024 0.024 0.024 0.025 0.025 0.025 0.024 0.000 0.000 0.0000 0.0000000000	0 4.28 0.512 0.546 0.010 142.524 95.012 14 0.442 215.012796 31 0.442 215.012796 0.442 0.042	0 3.00 0.501 0.574 0.019 113.596 107.512 107.512 107.512 107.512 107.512 107.512 107.512 107.512 0.04 2.526 0.04 0.0425 0.04 0.0425 0.04 0.0425 0.04 0.0425 0.04 0.0425 0.04 0.0425 0.04 0.0425 0.04 0.0425 0.04 0.045 0.05	5 12.929 0.995 38.005 20.42 0.946 0.304 0.	12.104 0.207 17.541 11.80 0.445 0.445 0.445 0.445 82.185 3 5 5 0.445 0.455 0.4				
C Of Of Dv I OPmas OPmas of OPmas OPmas V OPDF La L OPz OF OF OF OF OF DF DF DF DF DF OF OF OF OF OF OF OF OF OF O	1.09 0.115 0.134 0.026 274.329 0 0 0 0 0 0 0 0 0 0 0 0 0	0 0.34 0.174 0.199 0.024 143.365 0.024 143.365 0.020 0.153 0.203 0.153 0.203 0.153 0.203 0.153 0.203 0.153 0.203 0.153 0.203 0.153 0.203 0.153 0.203 0.153 0.204 0.000 0.163 0.024 0.000 0.163 0.024 0.025 0.025 0.025 0.025 0.024 0.024 0.024 0.024 0.024 0.024 0.024 0.025 0.025 0.025 0.024 0.000 0.000 0.0000 0.0000000000	0 4.28 0.512 0.546 0.010 142.524 95.012 14 0.422 215.012798 31 0.442 - 215.012798 - - - - - - - - - - - - -	0 3.00 0.501 0.574 0.019 113.596 107.512 107.512 107.512 107.512 107.512 107.512 107.512 107.512 0.04 2.526 0.04 0.0425 0.04 0.0425 0.04 0.0425 0.04 0.0425 0.04 0.0425 0.04 0.0425 0.04 0.0425 0.04 0.0425 0.04 0.045 0.05	5 12.929 0.995 38.005 20.42 0.946 0.304 0.	12.104 0.207 17.541 11.80 0.445 0.445 0.445 0.445 82.185 3 5 5 0.445 0.455 0.4				
C Of DV 1 OP 0 0 0 0 0 0 0 0 0 0 0 0 0	1.09 0.115 0.134 0.026 274.329 0 0 0 0 0 0 0 0 0 0 0 0 0	0 0.34 0.174 0.199 0.024 143.365 0.024 143.365 0.020 0.153 0.203 0.153 0.203 0.153 0.203 0.153 0.203 0.153 0.203 0.153 0.203 0.153 0.203 0.153 0.203 0.153 0.204 0.000 0.163 0.024 0.000 0.163 0.024 0.025 0.025 0.025 0.025 0.024 0.024 0.024 0.024 0.024 0.024 0.024 0.025 0.025 0.025 0.024 0.000 0.000 0.0000 0.0000000000	0 4.28 0.512 0.546 0.010 142.524 95.012 14 0.422 215.012798 31 0.442 - 215.012798 - - - - - - - - - - - - -	0 3.06 0.501 0.574 0.019 113.596 107.512 107.512 107.512 107.512 107.512 107.512 107.512 107.512 0.641 0.425 0.044 0.0425 0.044 0.0425 0.044 0.044 0.052 0.052 0.052 0.052 0.054 0.054 0.051 0.052 0.051 0.052 0	5 12.929 0.995 38.005 20.42 0.946 0.304 0.	12.104 0.207 17.541 11.80 0.445 0.445 0.445 0.445 82.185 3 5 5 0.445 0.455 0.4				

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#### ASHRAE Exemple (OPD Method)

T = 0.000000			1	I		I	T	T		
- No da	7									
Node	3.832	3.832	9	10	11	12	13	14	11.089	
OPOF	0	0	0.994	0.616	1	1	0.467	0.156	1	
<u> </u>	18.110	71.798	22.006	38.447	26.47	16.394	12.049	5.186	16.111	
	0.28	0.28	7.62	13.72	9.16	<u> </u>	10.67	4.57	9.75	
OPz	25	37.6	0	0	0	0	0	0	0	
De	0.306	0.305	0	0	0	0	0	0	0	
	0.306	5.3 0.305	1.26	2.19	1.78	1.19	0.12	0.04	1 27	
DV I	0.306	0.305	0.288	0.294	0.241	0.222	0.24	0.364	0.129	
1	0.023	0.023	0.022	0.022	0.023	0.023	0.022	0.02	0.026	
OP	36.99	85.012	85.806	137.884	176.383	179.582	146.441	42.489	237.307	
OPmes ch1	36.99	<b>85.012</b>	45.012	86.012	0	0	0	85.012	0	
dhit	ő	ő		0			12	13		
0	0.306	0.305	0	0	0	0	0	0	0	
H W	0	0	0.264	0.254	0.264	0.254	0.254	0.254	0.152	
Pien - 436		102.5484 A .	180.114962	0.266	0.18	0.162	0.243	0.41	0.113	
		1								
1 = 0.000000										
Node	16	17	18	19						
V	12.829	11.704	4.974	4.748						
OPOF	1	0.351	0.201	0.114						
Le	11.048	11.7	147.913	106.81						
	6.1 0.19	9.14	7.01	3.66						
DPz	0.10	0.30	10	12.5						
Oz	0	0	0	0	t.					
C C	1.09	0.34	4.28	3.06						
Or Dv	0.119	0.179	0.615	0.629						
1	0.026	0.024	0.019	0.019						
DP	240.607	127.716	76.706	56.362						
DPmax ch1	0	0	95.012	107.512 18						
chill	0		14	0					+	
D	0	0	0	0						
н	0.152		0.61	0.61						
W Plen = 836	0.097	0.16 02.5664 A =	0.62	0.649						
T = 777.00000	00									
Node	1		3	4	6					
V	13.202	9.088	10.18	2.526	12.929	12.104				
OPOF	1	1	0.153	0	0.995	0.207				
-	27.184		11.361	17.107	36.005	17.541				
	24.38	23.77	7.31	1.52	20.42	11.89				
DPz	0	0	0	25	0	55				
Dz	0		0	0	0	0				
C D	0.23		0.24	0.52	1.06	0.24				
DV	0.262		0.343	0.688	0.304	0.445				
1	0.021	0.024	0.02	0.02	0.021	0.019				
OP	233.160		41.919	27.185	245.62	120.484				
OPmex ch1	0	the second s	0	<b>27.185</b> 0	27.185	82.185				
dh2		. V			ا ۾					•
		0	2		4	3				
0	0.254	0.178	2 0.356	0	0 0.305	3 5 0.457				
н	0.254	0.178	2 0.356 0	0 0 0.61	0 0.305 0	3 5 0.457 0				
H W	0.254	0.178 0 0	2 0.356 0 0	0 0 0.61	0 0.305	3 5 0.457				
H W Plan = 39	0.254 0 0 5.063 E = 7	0.178 0 0	2 0.356 0 0	0 0 0.61	0 0.305 0	3 5 0.457 0				
H W	0.254 0 0 5.063 E = 7	0.178 0 0	2 0.356 0 0	0 0 0.61	0 0.305 0	3 5 0.457 0				
H W Plan = 39 T = 777.0000	0.254 0 0 5.063 E = 7	0.178 0 0 563.0100 A -	2 0.356 0 180.652796	0 0.61 0.61	0 0.305 0 0	3 5 0.457 0 0				
H W Plan = 39	0.254 0 0 5.063 E = 7 00 7	0.178 0 0 553.0100 A -	2 0.356 0 0 180.652769	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	0 0.305 0 0 0 1 11	3 5 0.457 0 0 0	13	14		
H W Plen = 391 T = 777.0000 Node	0.254 0 5.053 E = 7 00 7 3.832 0	0.178 0 553.0100 A - 6 3.832 0	2 0.356 0 180.852799 8.623 0.994	0 0.61 0.61 0.61 0.61 0.615	0 0.305 0 0 0 0 0 0	3 5 0.457 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	15.257 0.457	14.488 0.155	11.089	
H W Plan = 39 T = 777.0000 Node V OPOF Le	0.254 0 0 5.063 E = 7 00 7 3.832 0 18.110	0.178 0 0 553.0100 A = 3.632 0 71.798	2 0.356 0 180.652780 0 8.623 0.994 22.095	0 0.61 0.61 0.61 0.61 0.615 39.447	0 0.305 0 0 0 11 10.284 1 25.47	3 0.467 0 0 0 0 0 0 0 0 12 12 12 12 12 12 12 12 12 12 12 12 12	15.257 0.457 12.049	14.488 0.155 5.185	11.089 1 16.111	
H W Plan = 391 T = 777.0000 Node V OPDF Le L	0.254 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	0.178 0 0 553.0100 A - - - - - - - - - - - - - - - - - - -	2 0.356 0 180.552700 8.623 0.994 22.096 7.62	0 0.61 0.61 0.61 0.61 0.616 0.616 0.616 0.616 0.616 0.616 0.616 0.616 0.617 0.617 0.617 0.617 0.617 0.61 0.61 0.61 0.61 0.61 0.61 0.61 0.61	0 0.305 0 0 11 10.284 11 10.284 11 25.47 9.16	3 6 0.457 0 0 0 0 12 12.180 1 18.394 6.71	15.257 0.457 12.049 10.67	14.488 0.155 5.185 4.57	11.089 1 16.111 9.75	
H W Plan = 39 T = 777.0000 Node V OPOF Le	0.254 0 0 5.063 E = 7 00 7 3.832 0 18.110	0.178 0 0 553.0100 A = 553.0100 A = 553.0100 A = 0 71.798 1.22 0.28	2 0.356 0 0 180.552709 8.623 0.994 22.096 7.62 0.56	0 0.61 0.61 10 4.276 0.616 39.447 13.72 0.66	0 0.305 0 0 0 0 1 1 1 25.47 8.16 0.47	3 6 6 0.457 0 0 0 0 0 0 0 1 12 12 12 12 12 12 13 9 4 1 1 6.394 6.71 0.47	15.257 0.457 12.049 10.67 0.94	14.488 0.155 5.185	11.089 1 16.111	
H W Pten = 394 T = 777.0000 Node V OPOF L G C DF L O DZ	0.254 0 0 5.053 E = 7 0 3.832 0 0 18.110 4.27 0.28 25 0.305	0.178 0 0 553.0100 A 3.632 0 71.798 1.22 0.28 37.5 0.305	2 0.356 0 0 0 0 140.652700 0 0.994 22.096 7.62 0.994 0.994 0.994 0.994 0.55 0.55	0 0 0.61 0.61 0.61 0.61 0.61 0.615 0.615 0.615 0.656 0 0 0	0 0.305 0 0 0 11 11 10.284 1 25.47 9.16 0.47 0.047	3 5 0.457 0 0 0 0 0 0 0 12 12.180 11 15.380 11 16.394 6.71 0.47 0 0 0	15.257 0.457 12.049 10.67 0.94 0 0	14.488 0.155 5.185 4.57 1.51 0	11.089 1 16.111 9.75 0.19 0	
H W Plen = 39 T = 777.0000 Node V OPDF Le L C DPz Oz C	0.254 0 5.053 E = 7 00 7 3.832 0 18.119 4.27 0.28 2.5 0.305 1.04	0.178 0 0 553.0100 A = 3.832 0 71.798 1.22 0.28 37.5 0.305 5.3	2 0.356 0 0 180.552709 8.623 0.984 22.096 7.62 0.584 0 0 0 0 0 0 0 0	0 0.61 0.61 0.61 0.616 3.8.447 13.72 0.616 3.8.447 13.72 0.58 0 0 0 0 0 0 0 0 2.19	0 0.305 0 0 0 0 0 0 0 0 0 0 0.284 1 1 25.47 8.16 0.47 0 0 0 0 0	3 5 6 0.457 0 0 0 0 0 12 12 12 12 12 12 13 14 394 6.71 0.47 0 0 0 1.19 0 0 0 0 0 0 0 0 0 0 0 0 0	15.257 0.457 12.049 10.67 0.94 0 0 0	14.488 0.155 5.185 4.57 1.51 0 0 0.04	11.089 1 16.111 9.75 0.19 0 0 1.27	
H W Plen = 39 T = 777.0000 Node V OPOF Le L L C DFz Dz C C Df	0.254 0 5.053 E = 7 00 7 3.832 0 18.119 4.27 0.28 25 0.305 1.04 0.305	0.178 0 0 0 0 0 0 0 71.798 0.28 0.28 0.28 0.28 0.305 0.305	2 0.356 0 0 0 0 0 0 0 180.452706 9 8.623 0.994 22.096 7.62 0.56 0 0 0 0 0 0.1.26	0 0 0.61 0.61 0.61 0.61 0.616 0.616 3.9.447 13.72 0.616 0.916 0.916 0.916 0.2.19	0 0.306 0 0 0 0 0 0 0 0 0.284 1 1 1 0.284 7 0.284 0.47 0.1.76 0.0 0 1.76 0.211	3 5 0.457 0 0 0 0 0 0 12 12 12 12 12 12 12 12 13 14 1 1 16 394 6.71 0 0 0 0 1.19 0 0.19	15.257 0.457 12.049 10.67 0.94 0 0 0 0 0 0 0 0 0.12	14.488 0.155 5.185 4.57 1.51 0 0 0 0.04 0.314	11.089 1 16.111 9.75 0.19 0 0 0 1.27 0.129	
H W Plen = 39 T = 777.0000 Node V OPDF Le L C DPz Oz C	0.254 0 5.053 E = 7 00 7 3.832 0 18.119 4.27 0.28 2.5 0.305 1.04	0.178 0 0 0 553.0100 A 3.832 0 71.768 1.22 0.28 37.5 0.305 5.3 0.305 0.305 0.305	2 0.356 0 0 0 140.652700 0 0.994 22.096 7.62 0.994 0.994 0.994 0.994 0.994 0.994 0.994 0.994 0.0256 0.288	0 0 0.61 0.61 0.61 0.61 0.61 0.61 0.61 0	0 0.305 0 0 0 0 0 0 0 0 0 11 1 1 10.284 1 125.47 0.16 0 0 0 0 1.78 0.211 0.241	3 5 0.457 0 0 0 0 0 12 12.180 12 12.180 11 16.394 6.71 0.47 0 0 0 1.19 0.10 0.222	15.257 0.457 12.049 10.67 0.94 0 0 0	14.488 0.155 5.185 4.57 1.51 0 0 0 0.04 0.314 0.364	11.089 1 16.111 9.75 0.19 0 0 1.27 0.129 0.148	
H W Plen = 39 T = 777.0000 Node V OPDF Le L DFz Dz C C DFz Dz C DF DF DF DF	0.254 0 5.053 E = 7 00 7 3.832 0 18.119 4.27 0.28 1.04 0.305 1.04 0.305 0.023 34.69	0.178 0 0 0 0 0 0 0 553.0100 A = 8 3.832 0 0 71.788 1.22 0.28 0.28 0.28 0.305 6.33 0.305 0.023 8.6.012	2 0.356 0 0 0 0 0 0 180.852706 9 8.623 0.984 22.096 7.62 0.86 0 0 0 0 0 0 1.26 0.256 0.288 0.022 8 8.605	0 0 0.61 0.61 0.61 0.61 0.61 0.616 0.616 0.616 0.916 0.276 0.0 0 0.2.10 0.204 0.022 137.094	0 0.306 0 0 0 0 0 0 0 111 10.284 1 11 10.284 0 0 0 0 0 0.1.76 0.211 0.221 10.221 10.221 10.221	3 5 0.457 0 0 0 0 0 12 12 12 12 12 12 12 12 12 12 12 12 12	15.257 0.457 12.040 10.67 0.044 0 0 0 0.12 0.248 0.288 0.288 0.022 148.441	14.488 0.155 5.185 4.57 1.51 0 0 0.04 0.314 0.384 0.324 0.02 42.489	11.089 1 16.111 9.75 0.19 0 1.27 0.129 0.148 0.026 237.307	
H W Plan = 39 7 = 777.0000 Node V OPDF Le Le L DFz Dz C Df DV f DP DP DP DP DP DP DP DP DP	0.254 0 0 5.053 E = 7 0 5.053 E = 7 0 3.832 0 0 18.119 4.27 0.28 0.305 1.04 0.305 0.305 0.305 0.336 0.	0.178 0 0 0 0 0 0 0 0 553.0100 A 0 0 0 71.768 1.22 0.28 0.71.768 1.22 0.28 0.306 0.306 0.306 0.023 0.023 0.6.012 0.86.012	2 0.356 0 0 140.652706 8.623 0.994 22.096 7.62 0.566 0.256 0.256 0.288 0.022 6.602	0 0 0.61 0.61 0.61 0.61 0.61 0.61 0.61 0	0 0.305 0 0 0 0 0 0 0 11 1 1 10.284 1 125.47 0.16 0 0 0 0 1.78 0.211 0.221 1 0.023 176.383 0 0	3 5 0.457 0 0 0 0 12 12.180 1 1 1 5.394 5.71 0.47 0 0 0 1.19 0.222 0.023 170.642 0 0 0	15.287 0.467 12.040 10.67 0.94 0 0 0 0 0.12 0.248 0.22 0.228 0.022 146.441 146.441	14.488 0.155 5.185 4.57 1.51 0 0 0.04 0.314 0.384 0.02 42.489 85.012	11.089 1 16.111 9.75 0.19 0 0 0 0 0 1.27 0.129 0.148 0.026 237.307 0 0	
H W Plen = 39 T = 777.0000 Node V OPDF Le L DFz Dz C C DFz Dz C DF DF DF DF	0.254 0 5.053 E = 7 00 7 3.832 0 18.119 4.27 0.28 1.04 0.305 1.04 0.305 0.023 34.69	0.178 0 0 553.0100 A • 553.0100 A • 553.0100 A • 553 0.28 0.28 0.28 5.3 0.305 5.3 0.305 0.305 0.223 85.012 0.023	2 0.356 0 0 0 0 0 0 140.652706 0 .954 0.954 0.954 0.954 0.954 0.256 0.256 0.256 0.258 0.022 8.605 8.5.012	0 0.0.61 0.61 0.61 0.61 0.61 0.61 0.61 0	0 0.305 0 0 0 0 0 0 0 11 0.284 1 1 0.284 1 0.284 0 0 0 0 0.211 0.221 1 0.223 176.383 0 0 0 0	3 5 6 0.457 0 0 0 0 12 12 12 12 12 12 12 12 12 12	15.287 0.467 12.040 10.67 0.94 0.0 0 0.12 0.248 0.022 146.441 10 11	14.488 0.155 5.185 4.57 1.51 0 0 0.04 0.314 0.384 0.02 42.489 85.012 10	11.089 1 16.111 9.75 0.19 0 0 1.27 0.120 0.148 0.026 237.307 0 0 0	
H W Plan = 39 T = 777.0000 Node V V CPOF Le L OP DF C DF C DF C DF C DF C C C DF C C C DF C C C DF C C C DF C C C DF C C C DF C C C DF C C C DF C C C DF C C C DF C C C DF C C C C DF C C C C DF C C C C C C C C C C C C C	0.254 0 0 0 0 0 0 0 0 0 0 0 0 0	0.178 0 0 553.0100 A = 3.432 0 71.768 1.22 0.28 37.5 0.306 0.306 0.306 0.023 45.012 85.012 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	2 0.356 0 0 0 0 0 0 0 140.652706 7 8 0.596 0.596 0.256 0.256 0.256 0.288 0.022 6 5.012 7 7 8 0.022 6 5.012 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	0 0 0.61 0.61 0.61 0.61 0.61 0.616 0.616 0.616 0.616 0.616 0.204 0.022 137.944 0.022 137.944 85.012 9 0.0000000000000000000000000000000000	0 0.305 0 0 0 0 0 0 0 0 1 11 1 0.284 1 0.284 1 0.284 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	3 5 6 0.457 0 0 0 0 1 12 12.160 1 13.160 1 16.394 6.71 0.47 0 0 0 1.16 0.47 0 0 0 0 0 0 0 0 0 0 0 0 0	15.257 0.457 12.049 10.67 0.044 0.00 0.12 0.248 0.022 146.441 10 0 11 12	14.488 0.155 5.185 4.57 1.51 0 0 0.04 0.314 0.384 0.02 42.489 85.012 10	11.089 1 16.111 9.75 0.19 0 0 0 1.27 0.128 0.148 0.026 237.307 0 0 0 0 0 0 0 0 0 0 0 0 0	
H W Plan = 39 7 = 777.0000 V V CPOF Le L OP DF DF DF DF C DF C DF DF DF DF DF DF DF DF DF DF	0.254 0 0 5.053 E = 7 0 5.053 E = 7 0 5.053 E = 7 0 0 1 8.119 1 8.129 0.28 0.305 0.305 0.305 0.305 0.305 0.305 0.305 0.305 0.023 34.99 0.0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	0.178 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	2 0.356 0 180.552700 0 0.180.552700 0 0.054 0.054 0.256 0.224 0.022 0.56 0.225 0.022 0.022 0.022 0.022 0.022 0.022 0.022 0.022 0.022 0.022 0.022 0.022 0.022 0.022 0.022 0.025 0.022 0.025 0.022 0.025 0.022 0.025 0.022 0.025 0.025 0.025 0.022 0.025 0.050 0.020	0 0 0.61 0.61 0.61 0.61 0.61 0.61 0.61 0	0 0.305 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	3 6 6 0.457 0 0 0 0 0 12 12 12 12 12 12 12 12 12 12	15.287 0.467 12.040 10.67 0.94 0.04 0.0 0 0.12 0.248 0.022 146.441 145.441 11 12 0 0.254	14.488 0.155 5.185 4.57 1.51 0 0 0.04 0.314 0.354 40.02 42.489 85.012 10 13 0 0.254	11.089 1 16.111 9.75 0.19 0 0 1.27 0.129 0.148 0.026 237.307 0 0 0 0 0 0 0 0 0 0 0 0 0	
H W Plen = 39 T = 777.0000 Node V OPOF Le L C OPF DF DF DF DF DF DF DF DF DF D	0.254 0 0 0 0 0 0 0 0 0 0 0 0 0	0.178 0 0 0 0 0 0 0 553.0100 A = 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	2 0.356 0 0 0 0 0 0 0 0 0 0.862 7.62 0.994 22.096 7.62 0.56 0.056 0.256 0.256 0.256 0.2264 0.022 85.012 7 85.012 85.012 0.254 0.254 0.254 0.254	0 0 0.61 0.61 0.61 0.61 0.616 0.616 0.616 0.616 0.616 0.0.616 0.0.616 0.0.204 0.204 0.204 0.204 0.204 0.204 0.204 0.0040000000000	0 0.305 0 0 0 0 0 0 0 0 0 0 0 0.211 0.211 0.221 0.211 0.223 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	3 6 6 0.457 0 0 0 0 0 12 12 12 12 12 12 12 12 12 12	15.287 0.487 12.049 10.67 0.04 0.0 0 0.242 0.248 0.022 0.248 0.022 0.022 0.022 0.022 0.022 0.022 0.022 0.022 0.022 0.022 0.022 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.000000	14.488 0.155 5.185 4.57 1.51 0 0 0.04 0.314 0.354 40.02 42.489 85.012 10 13 0 0.254	11.089 1 16.111 9.75 0.19 0 0 1.27 0.129 0.148 0.026 237.307 0 0 0 0 0 0 0 0 0 0 0 0 0	
H W Plen = 39 7 = 777.0000 Node V OPOF Le L OP DPz Oz C C DPz Oz C C DP DP DP DP Mass c C DP H W	0.254 0 0 5.053 E = 7 0 5.053 E = 7 0 5.053 E = 7 0 0 1 8.119 1 8.129 0.28 0.305 0.305 0.305 0.305 0.305 0.305 0.305 0.305 0.023 34.99 0.0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	0.178 0 0 0 0 0 0 0 553.0100 A = 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	2 0.356 0 180.552700 0 0.180.552700 0 0.054 0.054 0.256 0.224 0.022 0.56 0.225 0.022 0.022 0.022 0.022 0.022 0.022 0.022 0.022 0.022 0.022 0.022 0.022 0.022 0.022 0.022 0.025 0.022 0.025 0.022 0.025 0.022 0.025 0.022 0.025 0.025 0.025 0.022 0.025 0.050 0.020	0 0 0.61 0.61 0.61 0.61 0.61 0.61 0.61 0	0 0.305 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	3 6 6 0.457 0 0 0 0 0 12 12 12 12 12 12 12 12 12 12	15.287 0.467 12.040 10.67 0.94 0.04 0.0 0 0.12 0.248 0.022 146.441 145.441 11 12 0 0.254	14.488 0.155 5.185 4.57 1.51 0 0 0.04 0.314 0.354 40.02 42.489 85.012 10 13 0 0.254	11.089 1 16.111 9.75 0.19 0 0 1.27 0.129 0.148 0.026 237.307 0 0 0 0 0 0 0 0 0 0 0 0 0	
H W Plen = 39 7 = 777.0000 Node V OPOF Le L OP DPz Oz C C DPz Oz C C DP DP DP DP Mass c C DP H W	0.254 0 0 0 0 0 0 0 0 0 0 0 0 0	0.178 0 0 0 0 0 0 0 553.0100 A = 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	2 0.356 0 0 0 0 0 0 0 0 0 0.862 7.62 0.994 22.096 7.62 0.56 0.056 0.256 0.256 0.256 0.2264 0.022 85.012 7 85.012 85.012 0.254 0.254 0.254 0.254	0 0 0.61 0.61 0.61 0.61 0.61 0.61 0.61 0	0 0.305 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	3 6 6 0.457 0 0 0 0 0 12 12 12 12 12 12 12 12 12 12	15.287 0.467 12.040 10.67 0.94 0.04 0.0 0 0.12 0.248 0.022 146.441 145.441 11 12 0 0.254	14.488 0.155 5.185 4.57 1.51 0 0 0.04 0.314 0.354 40.02 42.489 85.012 10 13 0 0.254	11.089 1 16.111 9.75 0.19 0 0 1.27 0.129 0.148 0.026 237.307 0 0 0 0 0 0 0 0 0 0 0 0 0	
H W Plen = 399 T = 777.0000 V V OPOF Le L C DPz Oz C C DF DPz Oz C C DF DF DF DF DF DF DF DF DF DF	0.254 0 0 0 0 0 0 0 0 0 0 0 0 0	0.178 0 0 0 0 0 0 0 553.0100 A = 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	2 0.356 0 0 0 0 0 0 0 0 0 0.862 7.62 0.994 22.096 7.62 0.56 0.056 0.256 0.256 0.2264 0.022 85.012 7 85.012 85.012 85.012 0.254 0.254	0 0 0.61 0.61 0.61 0.61 0.61 0.61 0.61 0	0 0.305 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	3 6 6 0.457 0 0 0 0 0 12 12 12 12 12 12 12 12 12 12	15.287 0.467 12.040 10.67 0.94 0.04 0.0 0 0.12 0.248 0.022 146.441 145.441 11 12 0 0.254	14.488 0.155 5.185 4.57 1.51 0 0 0.04 0.314 0.354 40.02 42.489 85.012 10 13 0 0.254	11.089 1 16.111 9.75 0.19 0 0 1.27 0.129 0.148 0.026 237.307 0 0 0 0 0 0 0 0 0 0 0 0 0	

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### ASHTAE Exemple (OPD Method)

= 777.0000	000				 			
Node	16	17	18	19	 1			
V	12.829	11.704	4.974	4.748				
OPDF	1	0.361	0.201	0.114				
6	11.042	11.7	147.013	106.81				
L	6.1	9.14	7.01	3.66				
0	0.10	0.38	1.88	1.88				
DPz	0	0	10	12.5				
Oz	0	0	0	0				
C	1.09	0.34	4.28	3.06				
Di	0.110	0.179	0.615	0.629				
DV	0.137	0.203	0.684	0.71				
1	0.026	0.024	0.019	0.019				
0P	240.507	127.716	76.706	55.362				
OPmex	0	0	95.012	107.512				
ch1	0	16	14	18				
chiế	0	16	17	0			1	
D	0	0	0	0				1
н	0.162	0.203	0.61	0.61				
W	0.127	0.152	0.61	0.66				1
Plan a 83		3.0100 A .	180.852790			1	1	1

### APPENDIX C

### FIVE DUCT SECTION PROBLEM COMPUTER OUTPUT

OPD METHOD

#### Five Dust Sealen Problem (OPD Method)

T = 999.0000	00				T	
Node	1	2	3	- 4	5	
V	5.639	4.001	10.756	8.771	4.001	
OPDF	1	1	0	1	0.373	
6	26.452	19.284	10.898	24.015	73.728	
L	14	12		16	19.81	
0	0.7	0.22	0.02	0.5	1.42	
DPz	26	37.8	0.33	0	37.6	
Dz	0.8	0.65	0.18	0.66	1.5	
	0.334	0.265	0.33	0.269	0.672	
 Dv	0.398	0.265	0.33	0.269	0.672	
1	0.021	0.024	0.02	0.022	0.018	
DP	57.423	54.024	46.98	49.848	57.196	
DPmex	25	37.6	84.48	0	121.98	
chi	0	0	1	0	3	
chill	0	0	2	0	4	
D	0	0.265	0.33	0.269	0.672	
н	0.264	0	0	0	0	
w	0.489	0	0	0	0	
Plan - 15	3.762 E = 43	64.5429 A -	94.446611			
	L					
	<b> </b>					
T = 0.000000	<b> </b>					
Mada	ł,ł	2	3	4		
Node	13.214	11.136	10.756	13.014	8.11	
OPOF	13.214	11.130	10.750	1	0.329	
Le	22.258	16.198	10.899	22.176	56.892	
	14	12	10.000	16	19.81	
	0.7	0.22	0.92	0.5	1.42	
OFI	25	37.6	0	0	37.6	
Dat	0	0	0.33	0	0	
C	0.8	0.65	0.18	0.65	1.5	
Of	0.229	0.159	0.33	0.214	0.472	
Dv	0.26	0.159	0.33	0.214	0.472	
1	0.022	0.025	0.02	0.023	0.010	
DP	250.902	224.127		271.116	128.316	
DPmex	26	37.5		0	121.98	
dh1	0	0		0	3	
chill	0	0	2	0		
D					4	
	0	0.169	0.33	0.214	0.472	
н	0.254	0	0.33	0.214	0.472	
H W	0 0.254 0.200	0	0.33	0.214	0.472	
н	0 0.254 0.200	0	0.33	0.214	0.472	
H W	0 0.254 0.200	0	0.33	0.214	0.472	
H W	0 0.254 0.200	0	0.33	0.214	0.472	
H W Plan = 39	0 0.254 0.209 0.761 E = 36	0	0.33	0.214	0.472	
H W	0 0.254 0.209 0.761 E = 36	0	0.33	0.214	0.472	
H W Plan = 39 T = 777.0000	0 0.254 0.209 0.781 E = 30	0 0 18.1754 A •	0.33 0 67.361296	0.214	0.472	
H W Plan = 39	0 0.254 0.200 0.761 E = 30 000 1	0	0.33 0 67.361296	0.214	0.472	
H W Plan = 39 T = 777.0000 Node	0 0.254 0.209 0.781 E = 30	0 0 18.1754 A -	0.33 0 67.361296 57.361296 3 10.756	0.214 0 0 0	0.472 0 0	
H W Plan = 36 T = 777.0000 Node V	0 0.254 0.200 0.781 E = 36 000 1 13.214	0 0 18.1754 A - 2 11.136	0.33 0 67.361296 57.361296 3 10.756	0.214 0 0 0	0.472 0 0 0 0	
H W Plan = 29 T = 777.0000 Node V OPDF	0 0.254 0.200 0.200 0.200 0.200 0.200 0.200 0.200 0.200 0.200 0.200 0.200 0.200 0.200 0.200 0.254 0.254 0.254 0.254 0.254 0.254 0.254 0.254 0.254 0.254 0.200 0.254 0.200 0.254 0.200 0.254 0.200 0.254 0.200 0.254 0.200 0.200 0.200 0.254 0.200000000	0 0 18.1754 A • 11.136 1	0.33 0 67.361296 3 10.756 0 10.690 8	0.214 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	0.472 0 0 0	
H W Plan = 38 T = 777.0000 Node V OPDF Le	0 0.254 0.209 0.781 E = 30 0.781 E = 30 1 1 1 1 1 2 22.258	0 0 18.1754 A 4 11.136 1 1 16.198	0.33 0 67.361296 3 10.756 0 10.809 8	0.214 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	0.472 0 0 0 0	
H W Pten = 20 T = 777.0000 Node V OPDF Le L C DPz	0 0.254 0.209 0.751 E = 30 0.751 E = 30 1 1 1.3.214 1 22.258 14 0.7 25	0 0 18.1754 A • 11.136 1 1.150 1 1 0.22 37.5	0.33 0 0 0.31296 0 0.0256 0 10.756 0 10.899 0 0 0 0 0 0	0.214 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	0.472 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	
H W Plan = 36 T = 777.0000 Node V OPDF Le L C Q DFZ DZ	0 0.254 0.200 0.781 E = 36 0.781 E = 36 1.214 1.3.214 1.3.214 1.3.215 1.2.256 1.4 0.7 2.55 0.0	0 0 18.1754 A 2 11.136 14.190 12 0.22 37.8 0 0	0.33 0 67.361296 3 10.756 0 0 10.699 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	0.214 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	0.472 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	
H W Plan = 20 T = 777.0000 Node V OPDF Le L L C DFZ C C	0 0.254 0.209 0.761 E = 36 000 1 13.214 1 22.258 1 0.7 2.5 0 0 0 0 0 0 0 0	0 0 18.1754 A 2 11.136 1 1.136 1 1 1.136 1 2 0.22 37.5 0 0 0.656	0.33 0 0 67.361226 3 10.756 0 0 10.696 0 0.62 0 0 0.33 0.116	0.214 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	0.472 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	
H W Plan = 36 Y = 777.0000 Node V OPDF Le L OP DF Dz C Of	0 0.254 0.209 0.761 E = 36 0.761 E = 36 0.000 1 1 1.3.214 1 22.256 1 4 0.0 2 8 0.0 8 0.226	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	0.33 0 0 67.361298 3 10.756 0 0 10.899 0 0 0.032 0.18 0 0 0.33	0.214 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	0.472 0 0 0 0 0 0 0 0 0 0 0 0.320 56.692 19.61 1.42 37.6 0.5 0.472	
H W Pfen = 36 F = 777.0000 Node V OPDF L C OPDF L C C Dz C C Dz C C Dz Dz C C	0 0.254 0.209 0.781 E = 30 0.781 E = 30 1 1 13.214 1 1 22.258 1 4 0.0 0 0.229 0.229 0.220	0 0 18.1754 A 2 11.136 1 14.190 12 0.22 37.5 0 0.66 0.155	0.33 0 0 0 0 0 0 0 0 10.756 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	0.214 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	0.472 0 0 0 0 0 0 0 0 0.11 0.320 18.81 1.42 37.6 0 0 1.5 0.472 0.472	
H W Plan = 26 T = 777.0000 Node V OPDF Le L C DPz Dz C C DF Dv f 1	0 0.254 0.209 0.761 E = 36 0.000 1 13.214 1 1 22.258 14 0.7 25 0 0 0 0.228 0.228 0.228 0.228	0 0 18.1754 A 2 11.136 1 14.199 12 0.22 37.6 0.22 0.156 0.156 0.022	0.33 0 0 67.361226 3 10.756 0 0 10.699 0 0 0.33 0.18 0.33 0.33 0.02	0.214 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	0.472 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 472 0.472 0.472 0.010	
H W Plan = 38 Plan = 38 V Node V OPDF L OP DF DF DF DF DF DF DF DF DF DF	0 0.254 0.209 0.761 E = 30 0.761 E = 30 1 1 1 3.214 1 22.256 1 4 0.22 5 0.08 0.220 0.220 0.220 0.220 0.220	0 18.1754 A 0 11.1754 A 0 11.136 11.136 11.136 12 0.22 37.5 0.055 0.055 0.055 0.052 224.122	0.33 0 0 0 0 0 0 0 0 10.756 0 10.899 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	0.214 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	0.472 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	
H W Plan = 36 Plan = 36 V CPOF L COP L C C C DF DZ C C DF DF DF DF DF DF DF DF DF DF	0 0.254 0.209 0.761 E = 30 0.761 E = 30 0.761 E = 30 0.761 E = 30 0.761 E = 30 1 1 1 3.214 1 22.258 1 4 1 22.258 0 0 0 0.28 0 0.220 0 0.28 0 0.220 0 0.28 0 0.220 2 50.022 2 50.022	0 0 0 0 0 0 0 0 18.1754 A 0 0 1 1 1 1.136 1 1 1 6.190 0 12 0.22 37.5 0 0.155 0.022 224.127 37.0	0.33 0 0 0 0 0 0 0 0 10.756 0 0 10.556 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	0.214 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	0.472 0 0 0 0 0 0 0 0 0 0.11 0.320 0 0.472 0.472 0.472 0.472 0.019 128.316 121.88	
H W Plan = 26 T = 777.0000 Node V OPDF Le L Q OPDF Le L Q DPZ DZ C C DZ C DF DP DP DP Maximum ( DP DP DP DP DP DP DP DP DP DP	0 0.254 0.209 0.761 E = 30 000 1 13.214 1 1 22.258 1 4 1 0.07 2 5 0 0 0 0 2 5 0 0 2 5 0.220 0.220 0.220 0.220 0.220 0.220 0.220 0.220 0.250 0.220 0.2500 0.2500 0.2500 0.2500 0.2500 0.2500 0.2500 0.2500 0.2500 0.250000000000	0 0 18.1754 A 2 11.136 1 1 18.196 12 0.22 37.5 0.22 0.66 0.155 0.021 224.122 37.6 0.22 0.22 0.22 0.22 0.22 0.22 0.22 0.	0.33 0 0 67.361226 3 10.756 0 10.699 0 0 0.33 0.18 0.33 0.33 0.33 0.32 0.41 9 0.41 9 0.41 9 10.756 1	0.214 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	0.472 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	
H W Pfen = 38 F = 777,0000 Node V OPDF L OP L OP DP DP DP DP DP DP DP DP DP D	0 0.254 0.209 0.761 E = 30 0.761 E = 30 0.000 1 1 1.3.214 1 22.256 1 4 0.0 2 5 0.228 0.228 0.228 0.228 0.228 0.228 0.228 0.228 0.228 0.228 0.228 0.228 0.228 0.228 0.228 0.250 0.254 0.250 0.254 0.250 0.254 0.250000000000	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	0.33 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	0.214 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	0.472 0 0 0 0 0 0 0 0 0 0.320 56.692 19.61 1.42 37.6 0.010 5.0.472 0.472	
H W Pfen = 36 Pfen = 36 Pfen = 36 V OPDF L OPDF L OPDF L OPDF L OPDF L OPDF L OPDF L OPDF L OPDF DF DF DF DF DF DF DF DF DF	0 0.254 0.209 0.761 E = 30 0.761 E = 30 0.761 E = 30 0.761 E = 30 0.761 E = 30 0 0.220 0.2000 0.200 0.200 0.2000 0.2000 0.200000000	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	0.33 0 0 0 0 0 0 0 0 10.756 0 10.599 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	0.214 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	0.472 0 0 0 0 0 0 0 0 0 0.11 0.320 0.56.892 19.81 1.42 3.7.6 0.010 1.5.0 0.472 0.472 0.472 0.472 0.472 0.472 0.472	
H W Plan = 26 Plan = 26 V Node V OPDF Le L O OPDF Le L C OPDF Le L O OPDF Le L O OPDF Le L O OPDF Le L O OPDF DF DF DF DF DF DF DF DF DF	0 0.254 0.200 0.761 E = 36 0.000 1 13.214 1 1 22.258 1 4 1 22.258 0 0 0 0 0.228 0.228 0.228 0.228 0.228 0.228 0.228 0.228 0.228 0.229 0.022 0.254 0.022 0.025 0.00	0 0 18.1754 A 2 11.136 1 16.196 12 0.22 37.5 0.22 0.66 0.155 0.026 0.155 0.024 224.127 37.6 0.025 0.026 0.155 0.026 0.0000000000	0.33 0 0 67.361226 3 10.756 0 10.699 0 0 0.33 0.18 0.02 0.02 0.03 0.03 0.03 0.03 0.03 0.03	0.214 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	0.472 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	
H W Pien = 38 F = 777,0000 Node V OPDF L OPF L OPF D2 C C D7 D7 D7 D7 D7 D7 D7 D7 D7 D7	0 0.254 0.200 0.761 E = 30 0.761 E = 30 0.761 E = 30 0.254 14 13.214 122.256 14 0.225 0.022 250.002 250.002 250.002 250.002 0.025 0.0254 0.0254	0 18.1754 A 2 11.136 11.136 11.136 11.136 0.155 0.055 0.	0.33 0 0 67.361226 3 10.756 0 10.699 0 0 0.33 0.18 0.02 0.02 0.03 0.03 0.03 0.03 0.03 0.03	0.214 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	0.472 0 0 0 0 0 0 0 0 0 0.11 0.320 0.56.892 19.81 1.42 3.7.6 0.010 1.5.0 0.472 0.472 0.472 0.472 0.472 0.472 0.472	

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### APPENDIX D

# ASHRAE EXAMPLE COMPUTER OUTPUT

T-METHOD

	liseries.									
	heration	<u> </u>		1						
Node: 1	21	3	41	5	6					
V: 7.500	7.5	7.6	2.526	7.5	7.5					
L: 24.380	23.77	7.31	1.52	20.42	11.89					
Q: 0.710	0.24	0.84	0.94	0.94	1.84					
DPz: 0.00	0	0	25	0	55					
De: 0.000	0	0.24	0.52	0	0					
C: 0.230 Df: 0.347	0.202	0.390	0.61	0.399	0.24					
Dv: 0.244	0.183	0.336	0.688	0.314	0.457					
r: 0.010	0.010	0.019	0.019	0.019	0.019					
DP: 52.80	128.864	19.838	27.172	68.666	78.601					
mu: 0.544	0.77	0.235	0.39	0.811	0.361					
Ka: 18.81	12.749	5.337	0	19.105	12.487					
KE 18.81	12.749	40.361	0	19.105	79.396					
T: 1.000	1	0.185	0	1	0.214					
OPmax: 0.0	0	0	27.172	27.172	82.172					
Pup: 208.01	208.038	256.341	27.172	266.341	372.487					
Pdn: 0.004	0	208.038	0 27.172	27.172	266.341					
DPt: 208.0	208.038	47.303	0.1	228.168	<u>117,146</u> 62,146					
ch1; 0	208.038			4	3					
che: 0	ő	2	ő	0	5					
DPp: 140.2	226.303	96.439	172.338	146.166	76.601					
DPes: 223.2	147.184	0	200.149	0	0					
D: 0.264	0.163	0.336	0	0.314	0.457					
H: 0.000	0	0	0.61	0	0					
W: 0.000	0	0	0.61	0	0					
DPerman = 22		1519.761480								
		7141.746 E2 =								
Node: 7		9	10							
Node: 7	3.832	7.5	7.6	7.5	<u> </u>	13	7.5	15	16	
L: 4.270	1.22	7.62	13.72	9.16	6.71	10.67	4.57	9.75	6.1	
0: 0.290	0.28	0.56	0.56	0.47	0.47	0.84	1.51	0.19	0.19	
DP2: 25.00	37.6	0	0	0	0	0	0	0	0	
Dz: 0.306	0.305	0	0	0	- 0	0	0	0		
C: 1.040	5.3	1.26	2.19	1.78	1.19	0.12	0.04	1.27	1.09	
Df: 0.306	0.306		0.273	0.26	0.25	0.335	0.386	0.159	0.159	
Dv: 0.30	0.306	0.291	0.29	0.246	0.228	0.281	0.388	0.151	0.142	
t: 0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	
DP: 36.50	84.876	60.455	106.106	83.642	67.363	24.462	8.967	82.185		
mu: 0.304	1.64	0.552	0.07	0.699	0.48	0.289	0.134	0.437	0.327	
Ka: 0.000	0	6.071	18.234	7.114	4.834	0.675 24.816	4./48 54.068	4.803	2.835	
T: 0.000	0	1	0.642	7.114	1	0.456	0.132			
OPmax: 36.	84.875	84.875	84.875	Ó	ó	0	\$4.875	0	ö	
Pup: 84.87	84.875	165.252	309.379	168.254	168.254	300.379	343.435	195.443	195.443	
Pdn: 44.38	0	\$4.875	165.252	0	0	168.254	309.379	0	0	
DPt: 36.50	84.875	80.377	144.127	168.254	168.254	141.125	34.056	195.443	195.443	
DPT: 38.50	0.1	80.377	144.127	168.254	168.254	141.125	34.066	195.443	195.443	
ch1: 0	0	7	•	0	0	11	10	0	0	
ch2: 0	0	4	0	0	0	12	13	0	0	
DPp: 496.2	544.661	459.776	390.321			317.578	293.126	403.996	383.2	
DPex: -33.7	-82.138	0	0	61.394	\$7.583	0	0	58.617	79.313	
D: 0.306 H: 0.000	0.305		0.254			0.254	0.254	0 160	0.160	
W: 0.000	0		0.294			0.493	0.793	0.152	0.152	
DPeamer = 22					0.07/		0.703	0.107	0.107	
		7141.746 E2								
T										
Neration	0									
Node: 17	18									
V: 7.500	7.6									
L: 9.140	7.01				<b>├</b>					
Q: 0.380 DPz: 0.00	1.88				┝━━━━━┥					
Dz: 0.000	0									
C: 0.340	4.28				·					
Dr: 0.224	0.491								1	1
Dv: 0.183	0.677									
f: 0.019	0.019	0.019								[
DP: 37.65	163.604									
mu: 0.281	2.57									
Ka: 5.471	12.530								ļ	
Kt: 16.02	89.544								ļ	ļ
T: 0.431	0.194				<u> </u>					
Pup: 343.43	415.795				┝────┤				<b> </b>	<u> </u>
Pdn: 196.44	343.435				<u> </u>				<u> </u>	
DPL 147.9	72.361								I	
DPr: 147.8	62.361								1	<u> </u>
ch1: 15	14									İ
ch2: 16	17	0								
DPp: 321.8	284.159									
	0	0								
DPest: 0.00										
D: 0.000	0				••••••••••••••••••••••••••••••••••••••					
D: 0.000 H: 0.203	0 0.61	0.61								
D: 0.000 H: 0.203 W: 0.250	0 0.61 0.411	0.61		049						
D: 0.000 H: 0.203 W: 0.250 DPoxmax = 22	0 0.61 0.411 23.240 Ep	0.61 0.411 1519.761480	Es - 5621.964							
D: 0.000 H: 0.203 W: 0.250 DPeames = 22	0 0.61 0.411 23.240 Ep	0.61	Es - 5621.964							

	Neration	•			· · · · · · · · · · · · · · · · · · ·	T		r		
Node: 1	2	3	4	5	6					
V: 12.97	9.042	10.616		12.13	11.444					
L: 24.360	23.77	7.31	1.52	20.42	11.80					
Q: 0.710	0.24		0.84	0.94	1.88					
DP2: 0.00	0									
Dz: 0.000	0	0	0							
C: 0.230	1.58	0.24	0.62		0.24					
Df: 0.264	0.183	0.336	0.61	the second s	0.467					
Dv: 0.267	0.187	0.335	0.688	0.300	0.451					
t: 0.021	0.024		0.02		0.019					
DP: 223.31	238.103		27.191	211.801	112.297					
mu; 0.581	0.86			The second s						
Ka: 19.084	13.033		0		12.287					
KE: 19.08	13.033	40.908	0		79.405				l	
T: 1.000		0.183	0 27.191		0.211					
DPmax: 0.0	209.766									
Pup: 200.76 Pdn: 0.006	200.700	209.766	0		256.600					
DPt 200.7	209.766		the second s							
DPT: 200.7	209.766		0.1		61.423					
ch1: 0	0				3					
dhet: 0	0				š					
DPp: 281.0				the second s						
DPes: 4.8	-17.654									
D: 0.267	0.187									
H: 0.000	0				0					
W: 0.000					Ő					
		1519.761480							·	
		7128.474 E2								r
Node: 7	8	9				13	14	15	16	
V: 3.832							12.795			
L: 4.270		7.62	13.72	9.16	6.71	10.67	4.67	9.75		
Q: 0.290	0.28	0.56			0.47	0.94	1.51	0.19	0.19	
DPz: 25.00	37.6					0				
Dz: 0.306	0.305		and the second se			0	0		0	
C: 1.040	6.3					0.12	0.04			
Df: 0.306	0.306					0.249	0.328	0.133	0.124	
Dv: 0.30	0.306					0.284	0.389			
t: 0.023	0.023				0.023	0.022	0.02			
DP: 36.99	85.012					143.306				
mu: 0.418	1.644					0.294	0.126			
Ks: 0.000	0					9.194	4.197			
Kt: 0.000	0				4.002	24.372	52.764			
T: 0.000						0.444				
DPmax: 36.	85.012						85.012			
Pup: 86.01										
Pdn: 48.02	0					172.506				
DPt 36.98							31.076			
DPT: 38.90					the second s	137.661	31.076			the second data was a
ch1: 0	0		9			11	10			
		the state of the second se		the second se						
DPp: 434.3 DPet: 27.6										
D: 0.306										
H: 0.000										the second s
W: 0.000										
		1519.761480			0.10	0.246	0.465	0.110	0.105	<u> </u>
		7128.474 E2								
					1				<u> </u>	+
Heration	n 1	<u>†</u>	<u> </u>		t				<u> </u>	t
1	ř	1	1	1	1			t		<u> </u>
Node: 17	18	19	1	1	1			1	<u> </u>	t
V: 12.97				1	1			1		t
L: 9.140				1				1		1
Q: 0.300										[
DPz: 0.00								1		
Dz: 0.000										
C: 0.340		3.06		I	1					
Df: 0.100		0.63								
Dv: 0.196	0.698									
f: 0.024	0.019									L
DP: 166.47										
mu: 0.317										
Ka: 5.646				L						
Kt: 15.43					L				L	
T: 0.432					ļ					
DPmax: 0.0				ļ	ļ			ļ		
Pup: 341.2				ļ	ļ		L		L	
Pdn: 193.64				<b> </b>	ļ				J	L
DPt: 147.5							L	L	L	
DPT: 147.5				L	ļ			L	L	
ch1: 15				ļ	ļ				L	
ch2: 16				ļ	L				L	
DPp: 304.4					<u> </u>				<b></b>	<u> </u>
DPet: 0.00				l	l			ļ	Į	Į
	0			<u> </u>	<u> </u>				<b> </b>	<u> </u>
D: 0.000								1	1	1
H: 0.203				+	·			1		
H: 0.203 W: 0.144	0.589	0.651		467						
H: 0.203 W: 0.144 DPermax =	0.589 56.068 Ep -	0.651	Es = 5608.712							
H: 0.203 W: 0.144 DPermax =	0.589 56.068 Ep -	0.651	Es = 5608.712							

	Neration	2	1	1	1		T	1		
Node: 1	2	3	4	5	6					
V: 12.661 L: 24.380	8.72	10.664	2.529	12.52	11.764					
Q: 0.710	0.24	0.84	0.94	20.42	11.89			+		
DPT: 0.00	0	0	25	0						
Dz: 0.000	0	0	0	0	0					
C: 0.230	1.58	0.24	0.52	1.06	0.24					
Dr: 0.267 Dv: 0.267	0.187	0.335	0.61	0.309	0.461					
f: 0.021	0.024	0.02	0.02	0.021	0.451					
DP: 200.54	210.765	46.782	27.191	227.95	116.181					
mu: 0.584	0.865	0.23	0.393	0.749	0.332					
Ka: 19.084	13.047	5.314	0	18.804	12.279					
KE 19.00	13.047	40.92	0	18.804	79.385					
T: 1.000		0.182	27.191	27.191	0.211					
Pup: 209.61	209.611	256.4	27.101	256.4	372.741					
Pdn: 0.004	0	209.611	0	27.101	256.4					
OPt 200.61	209.611	46.788	27.191	229.209	116.342					
DPT: 200.6	209.611	46.788	0.1	229.209	61.342					
ch1: 0	0		0	4	3					
chill: 0 DPp: 372.6	373.728	2 162.963	0 371.381	0	116 161					
DPer: 0.22	-0.986	0	1.48	<b>344,131</b> 0	116.161		<u>├</u>			
D: 0.267	0.187	0.336	0	0.309	0.461					
H: 0.000	0	0	0.61	0	0					
W: 0.000	0	0	0.609	0	0					
Plan = 436.0		1519.761480 7133.794 E2 -								
		/133./84 E2 0					├ <del> </del>			
Node: 7		9	10		the second s	13	14	15	16	
V: 3.832	3.832	8.386	8.467	10.156	11.941	14.887	12.697	10.205	11.725	
L: 4.270	1.22	7.62	13.72	9.16	6.71	10.67	4.57	9.75	6.1	
Q: 0.280 DPz: 25.00	0.28	0.56	0.56	0.47	0.47	0.94	1.51	0.19	0.19	
Dz: 0.300	0.305	ő	0	0		0	0	0	0	
C: 1.040	5.3	1.26	2.19	1.78	1.19	0.12	0.04	1.27	1.09	
Df: 0.306	0.305	0.258	0.257	0.212		0.261	0.329	0.136	0.125	
Dv: 0.306	0.305	0.292	0.291	0.243	0.224	0.284	0.389	0.154	0.144	
t. 0.023	0.023	0.022	0.022	0.023	0.023	0.022	0.02	0.026	0.026	
DP: 36.99	45.012	80.712 0.558	144.682 0.979	171.522	<u>171.31</u> 0.448	137.652	<u>31.125</u> 0.125	194.648	194.163 0.338	
Ka: 0.000	0	6.069	12.226	7.167		9.193	4.203	4.917	2.897	
KE: 0.000	0	6.069	20.812	7.167	4.914	24.389	52.784	4.917	2.897	
T: 0.000	0	1	0.642	1	1	0.443	0.121	1	1	
DPmax: 38.5	85.012	\$5.012	85.012	0		0	85.012	0	0	
Pup: 86.01	85.012	166.663	309.94	172.486		309.84	341.01	193.724	193.724	
Pdn: 48.02 DPt: 36.99	85.012	85.012 80.541	165.563	0 172.486	172.486	172.486	309.94	0 193.724	0 193.724	
DPr: 38.94	85.012	80.541	144.387	172.486		137.464	31.07	193.724	193.724	
ch1: 0	0	7	9	0		11	10	0	0	
ch2: 0	0	8	0	0	0	12	13	0	0	
DPp: 417.5	466.552	380.54	299.828			292.798	156.146	466.086	465.601	
DPer: 44.7 D: 0.305	-3.294	0	0			0	0	-3.827	-3.342	
H: 0.000						<b>A</b>	i ni	0	0	
W: 0.000	0	0.254	0.254	0.254	0.254	0.254	0.254	0 0,152	0,152	
OPezmax = 4	0	0.254	0.254	0.182		0 0.254 0.249		0 0.152 0.122	0 0.152 0.107	
	0 4.728 Ep =	0.254 0.263 1519.761489	0.254 0.261 Es = 5614.032	0.182	the state of the s	0.254	0.254	0.152	0.152	
	0 4.728 Ep =	0.254	0.254 0.261 Es = 5614.032	0.182	the state of the s	0.254	0.254	0.152	0.152	
Pten = 835.	0 4.725 Ep = D00 E1 =	0.254 0.263 1519.761489	0.254 0.261 Es = 5614.032	0.182	the state of the s	0.254	0.254	0.152	0.152	
	0 4.725 Ep = D00 E1 =	0.254 0.263 1519.761489	0.254 0.261 Es = 5614.032	0.182	the state of the s	0.254	0.254	0.152	0.152	
Pten = 835.	0 4.725 Ep = D00 E1 =	0.254 0.263 1519.761489 7133.794 E2	0.254 0.261 Es = 5614.032 7609.243 A	0.182	the state of the s	0.254	0.254	0.152	0.152	
Ptan = 435.0 Neration Node: 17 V: 12.39	0 4.728 Ep = 2000 E1 = 2 18 4.917	0.254 0.263 1519.761489 7133.794 E2 19 4.377	0.254 0.261 Es = 5614.032 - 7609.243 A	0.182	the state of the s	0.254	0.254	0.152	0.152	
Ptan = \$35.0 Node: 17 V: 12.39 L: 0.140	0 4.728 Ep = 2000 E1 = 2 18 4.917 7.01	0.254 0.263 1519.761489 7133.794 E2 19 4.377 3.66	0.254 0.261 Es = 5614.032 - 7609.243 A	0.182	the state of the s	0.254	0.254	0.152	0.152	
Ptan = 635.0 Node: 17 V: 12.390 L: 9.140 Q: 0.380	0 4.728 Ep = 000 E1 = 2 18 4.917 7.01 1.88	0.254 0.263 1519.751480 7133.794 E2 - 19 4.377 3.66 1.88	0.254 0.261 Es = 5614.032 7609.243 A	0.182	the state of the s	0.254	0.254	0.152	0.152	
Ptan = 435.0 Node: 17 V: 12.39 L: 0.140	0 4.728 Ep = 2000 E1 = 2 18 4.917 7.01	0.254 0.263 1519.751480 7133.794 E2 - 19 4.377 3.66 1.88	0.254 0.261 Es = 5614.032 - 7608.243 A	0.182	the state of the s	0.254	0.254	0.152	0.152	
Ptan = 435.0 Node: 17 V: 12.390 L: 9.140 Q: 0.380 DPz: 0.00	0 4.728 Ep = 2000 E1 = 2 18 4.917 7.01 1.88 10	0.254 0.263 1519.761480 7133.794 E2 - 19 4.377 3.66 1.88 12.6 0	0.254 0.261 Es = 6614.002 - 7600.243 A	0.182	the state of the s	0.254	0.254	0.152	0.152	
Ptan = 436. Neration V: 12.394 L: 9.140 O: 0.380 DPz: 0.000 Dz: 0.000 C: 0.340 Df: 0.173	0 4.728 Ep = 000 E1 = 2 18 4.917 7.01 1.88 10 0 0 4.28 0.618	0.254 0.263 1519.761440 7133.794 £2 19 4.377 3.66 1.84 12.6 0.3.06 0.654	0.254 0.261 Es = 5614.002 7609.243 A	0.182	the state of the s	0.254	0.254	0.152	0.152	
Ptan = 636.           Reration           Node:         17           V:         12.398           L:         9.140           O:         0.380           DPz:         0.000           Dz:         0.000           Dz:         0.000           Dz:         0.000           D:         0.173           Dv:         0.194	0 4.728 Ep = 0000 E1 = 2 18 4.917 7.01 1.86 10 0 4.28 0.618 0.701	0.254 0.263 1519.751430 7133.794 £2 19 4.377 3.56 1.88 12.5 0 3.06 0.664 0.744	0.254 0.261 55 - 5614.002 - 7609.243 A	0.182	the state of the s	0.254	0.254	0.152	0.152	
Ptan = 435. Node: 17 V: 12.398 L: 0.140 O: 0.380 DPI: 0.000 DI: 0.073 DU: 0.198 F. 0.024	0 4.728 Ep = 2000 E1 = 2 18 4.917 7.01 1.88 10 0 0 4.28 0.618 0.701 0.019	0.254 0.263 1519.761460 7133.794 E2 19 4.377 3.66 1.86 1.86 1.86 0.654 0.306 0.654 0.744 0.744	0.254 0.261 Es = 6614.032 7800.243 A	0.182	the state of the s	0.254	0.254	0.152	0.152	
Ptan = 636.           Reration           Node:         17           V:         12.398           L:         9.140           O:         0.380           DPz:         0.000           Dz:         0.000           Dz:         0.000           Dz:         0.000           D:         0.173           Dv:         0.194	0 4.728 Ep = 0000 E1 = 2 18 4.917 7.01 1.86 10 0 4.28 0.618 0.701	0.254 0.263 1519.751440 7133.794 E2 19 4.377 3.66 1.84 12.6 0.3.06 0.654 0.744 0.019 4.8.676	0.254 0.261 5 = 5614.032 - 7609.243 A	0.182	the state of the s	0.254	0.254	0.152	0.152	
Ptan = 635.           Node:         17           V:         12.398           L:         9.140           OC:         0.380           DPr::         0.000           D::         0.173           Dr::         0.024           F:         0.024           DP:         147.41	0 4.728 Ep = 2000 E1 = 2 18 4.917 7.01 1.88 10 0 0 4.28 0.618 0.701 0.019 75.145	0.254 0.263 1519.751440 7133.794 E2 19 4.377 3.66 1.84 12.6 0.3.06 0.654 0.744 0.019 4.8.676	0.254 0.261 55 - 5614.002 - 7609.243 A	0.182	the state of the s	0.254	0.254	0.152	0.152	
Pten = 435. Node: 17 V: 12.396 L: 9.140 OP: 0.000 DP: 0.000 DP: 0.000 DP: 0.000 DP: 0.000 DP: 0.000 C: 0.340 DP: 0.173 DP: 0.173 DP: 0.174 Re: 5.624 Kc: 15.40	0 4.728 Ep = 2000 E1 = 2 18 4.917 7.01 1.88 10 0 0 4.28 0.618 0.701 0.019 75.145 3.135 12.797 8.8.84	0.254 0.263 1519.751440 7133.794 E2 19 4.377 3.66 1.88 12.6 0.654 0.744 0.010 4.8.676 2.341 6.316 10.8.72	0.254 0.261 0.261 0.261 0.261 0.261 0.254 0.254 0.254 0.254 0.254 0.254 0.254 0.254 0.254 0.254 0.254 0.254 0.261 0.261 0.261 0.264	0.182	the state of the s	0.254	0.254	0.152	0.152	
Ptan = 635. Node: 17 V: 12.398 L: 9.140 OP: 0.390 DP: 0.000 DE: 0.000 DE: 0.000 DE: 0.173 DV: 0.198 f: 0.024 DP: 147.41 rmu: 0.311 Ka: 5.624 K2: 15.401 T: 0.432	0 4.726 Ep = 2000 E1 = 2 16 4.917 7.01 1.86 10 0 0 4.26 0.618 0.701 0.019 76.146 3.135 12.797 48.964 0.199	0.254 0.263 1519.751430 7133.794 £2 · 119 4.377 3.56 1.88 12.5 0 0.654 0.654 0.744 0.019 46.876 2.341 6.318 100.872 0.069	0.254 0.261 Es = 6614.002 7600.243 A	0.182	the state of the s	0.254	0.254	0.152	0.152	
Ptan = 635. Node: 17 V: 12.398 L: 9.140 O: 0.380 DP:: 0.000 DP:: 0.000 C: 0.340 DP: 0.173 DV: 0.173 DV: 0.198 f: 0.024 DP: 147.41 mu: 0.316 Ka: 5.624 KC: 15.401 DP: 0.432 DP: 0.432	0 4.728 Ep = 2000 E1 = 2 18 4.917 7.01 7.01 1.88 0.019 0 4.28 0.618 0.701 0.019 75.145 3.135 3.135 3.135 3.135 0.199 95.012	0.254 0.263 1519.761480 7133.794 E2 - 19 4.377 3.66 1.64 1.64 1.65 0.654 0.744 0.744 0.744 0.744 0.744 0.744 0.318 100.872 0.009 107.612	0.254 0.261 Es = 5614.032 7808.243 A	0.182	the state of the s	0.254	0.254	0.152	0.152	
Pten = 435. Node: 17 V: 12.398 L: 9.140 OPz: 0.000 Dz: 0.000 Dz: 0.000 Dz: 0.000 D: 0.173 Dv: 0.198 f: 0.024 DP: 147.41 mu: 0.316 Ka: 5.620 T: 0.432 DPmax: 0.0 Pug: 341.0	0 4.728 Ep = 2000 E1 = 2 18 4.917 7.01 1.88 10 0 0 4.28 0.618 0.701 0.019 75.145 3.135 12.797 7.8.484 0.199 95.012 414.5	0.254 0.263 1519.751440 7133.794 E2 - 19 4.377 3.66 1.48 12.6 0.654 0.744 0.019 4.6.376 2.341 6.310 4.6.376 2.341 6.310 4.0.672 0.099 107.612 4.42.259	0.254 0.261 0.261 56 - 5614.002 - 7609.243 A	0.182	the state of the s	0.254	0.254	0.152	0.152	
Ptan = 635. Node: 17 V: 12.398 L: 9.140 O: 0.380 DP:: 0.000 DP:: 0.000 C: 0.340 DP: 0.173 DV: 0.173 DV: 0.198 f: 0.024 DP: 147.41 mu: 0.316 Ka: 5.624 KC: 15.401 DP: 0.432 DP: 0.432	0 4.728 Ep = 2000 E1 = 2 18 4.917 7.01 7.01 1.88 0.019 0 4.28 0.618 0.701 0.019 75.145 3.135 3.135 3.135 3.135 0.199 95.012	0.254 0.263 1519.751440 7133.794 E2 - 19 4.377 3.66 1.48 12.6 0.654 0.744 0.019 4.6.376 2.341 6.310 4.6.376 2.341 6.310 4.0.672 0.099 107.612 4.42.259	0.254 0.261 55 - 5614.002 - 7609.243 A	0.182	the state of the s	0.254	0.254	0.152	0.152	
Ptan = 635. Node: 17 V: 12.396 L: 9.140 OPz: 0.000 DPz: 0.000 DF: 0.173 DF: 0.173 DF: 0.174 DF: 147.41 rul: 0.316 Ka: 5.624 KC: 15.401 T: 0.432 DPmax: 0.0 Pup: 341.0 Pdr: 193.75	0 4.726 Ep = 2000 E1 = 2 16 4.917 7.01 1.86 0.10 0 0 4.28 0.618 0.618 0.701 0.019 75.145 3.135 12.797 48.864 0.199 95.012 414.5 3.41.01	0.254 0.263 1519.761489 7133.794 E2 - 19 4.377 3.66 1.48 12.5 0 0 3.06 0.554 0.544 0.744 0.744 0.744 0.019 45.876 2.341 100.872 0.009 107.512 442.259 414.5 47.758	0.254 0.261 Es = 5614.032 7808.243 A	0.182	the state of the s	0.254	0.254	0.152	0.152	
Pten = 635. Node: 17 V: 12.396 L: 9.140 OPz: 0.000 DPz: 0.000 DP: 0.196 f: 0.024 DP: 147.41 rul: 0.316 Ka: 5.624 KC: 15.401 T: 0.432 DPmaz: 0.0 Pup: 341.01 Pdr: 193.72 DPt: 147.22 ch1: 15	0 4.728 Ep = 2000 E1 = 2 16 4.917 7.01 1.86 0.019 0.019 75.145 12.797 8.964 0.199 95.012 414.5 3.411 73.491 63.491 14	0.254 0.263 1519.751430 7133.794 £2 · 199 4.377 3.56 1.48 12.5 0.0 3.06 0.654 0.744 0.019 46.876 2.341 6.318 100.872 0.099 107.512 462.259 414.5 47.758 35.256 18	0.254 0.261 55 - 5614.002 - 7609.243 A	0.182	the state of the s	0.254	0.254	0.152	0.152	
Ptan = 635. Node: 17 V: 12.398 L: 9.140 O: 0.380 DP: 0.000 DP: 0.000 C: 0.340 DP: 0.000 C: 0.340 DP: 147.41 DP: 147.45 DP: 147.45 DP: 147.45 DP: 147.45 DP: 147.45 DP: 147.45 DP: 147.25 DP: 147	0 4.728 Ep = 2000 E1 = 2 18 4.917 7.01 1.88 100 0 4.28 0.618 0.701 0.019 75.145 3.135	0.254 0.263 1519.761480 7133.794 E2 - 19 4.377 3.66 1.84 1.84 1.85 0.054 4.376 0.054 4.074 0.744 0.019 4.876 2.341 6.316 100.872 0.099 107.512 442.259 107.512 442.258 18 35.258 18 0 0 0	0.254 0.261 Es = 5614.032 7808.243 A	0.182	the state of the s	0.254	0.254	0.152	0.152	
Ptan = 635. Node: 17 V: 12.398 L: 9.140 OPz: 0.000 D2: 0.000 D2: 0.000 D2: 0.000 D2: 0.000 D2: 0.173 D0: 0.173 D0: 0.173 D0: 0.198 f: 0.024 DP: 147.41 mu: 0.316 Kt: 15.401 T: 0.432 DPmax: 0.0 P4m: 193.72 DP: 147.22 DP: 147.22 DP: 147.23 DP: 147.23 DP: 147.24 DP: 147.24	0 4.728 Ep = 000 E1 = 2 18 4.917 7.01 1.88 0.010 0 0 0 4.28 0.616 0.701 0.019 75.145 3.135 12.797 48.964 0.199 95.012 414.5 3.41.01 73.491 14.5 3.401 14.5 3.401 14.5 3.401 14.5 3.401 14.5	0.254 0.263 1519.751440 7133.794 E2 - 19 4.377 3.66 1.48 12.8 0.0 3.06 0.654 0.744 0.744 0.010 4.6.376 2.341 6.316 0.054 0.054 0.054 0.054 0.054 0.054 0.054 0.054 0.054 0.054 0.055 1.45 0.099 107.612 2.341 6.316 0.099 107.612 2.341 6.316 0.099 107.512 0.099 10.	0.254 0.2610	0.182	the state of the s	0.254	0.254	0.152	0.152	
Pten = 635. Node: 17 V: 12.398 L: 0.140 OPz: 0.000 DPz: 0.000 DP: 0.173 DV: 0.196 f: 0.024 DP: 147.41 rul: 0.316 Ka: 5.824 KC: 15.401 T: 0.432 DPmaz: 0.0 Pup: 341.0 Pdr: 193.72 DPt: 147.22 ch1: 15 ch2: 16 DPs: 271.4 DPs: 271.4 DPs: 20.00	0 4.728 Ep = 2000 E1 = 2 16 4.917 7.01 1.88 100 0 4.28 0.618 0.701 0.019 75.145 12.797 48.864 0.199 95.012 414.5 3.411 73.491 63.491 14 17 124.021 0 0 0 0 0 0 0 0 0 0 0 0 0	0.254 0.263 1519.751430 7133.794 £2 · 199 4.377 3.56 1.48 12.5 0.0 3.06 0.654 0.744 0.019 46.876 2.341 6.318 100.872 0.099 107.512 462.259 414.5 47.758 35.258 18 0.0 9 414.6 76 0.0 9 18 18 0.0 9 18 18 0.0 9 18 18 0.0 9 19 19 19 10 19 10 10 10 10 10 10 10 10 10 10 10 10 10	0.254 0.261 55 - 5614.002 7809.243 A	0.182	the state of the s	0.254	0.254	0.152	0.152	
Ptan = 635. Node: 17 V: 12.308 L: 9.140 O: 0.380 DP2: 0.000 D2: 0.000 D2: 0.000 D2: 0.000 C: 0.340 DP: 147.41 DP: 147.41 DP: 147.41 DP: 147.42 DPmax: 0.0 Fug: 341.0 Pdn: 193.72 DP1: 147.22 DPmax: 0.0 Pdn: 193.72 DP1: 147.22 DPmax: 0.0 Pdn: 193.72 DP1: 147.22 DPmax: 0.0 Pdn: 193.72 DP1: 147.22 DPT: 147.22 DPT: 147.22 DPT: 147.23 DP1: 147.	0 4.728 Ep = 2000 E1 = 2 18 4.917 7.01 7.01 1.88 0.019 0 4.28 0.618 0.701 0.019 75.145 3.135 3.135 3.135 3.135 3.135 3.135 3.135 3.145 3.145 3.145 3.141 0.199 95.012 4.14.5 3.4101 7.7491 6.3.491 1.77 7.124.021 0 0 0 0	0.254 0.263 1519.751440 7133.794 £2 19 4.377 3.66 1.84 12.6 0.3.06 0.654 0.744 0.014 0.044 0.044 0.044 0.0572 0.099 107.512 462.259 414.6 7.758 35.256 18 0 0 44.876 0 0 44.876	0.254 0.261 0.261 55 - 5614.032 - 7609.243 A	0.182	the state of the s	0.254	0.254	0.152	0.152	
Ptan = 635. Node: 17 V: 12.398 L: 9.140 OPz: 0.000 DPz: 0.000 DF: 0.173 DF: 0.173 DF: 0.173 DF: 0.174 DF: 147.41 rul: 0.316 Ka: 5.624 KC: 15.401 T: 0.432 DPrmax: 0.0 Pup: 341.0 Pdr: 193.72 DPt: 147.22 ch1: 15 ch2: 16 DPs: 271.4 DPs: 271.4 DPs: 0.000	0 4.728 Ep = 2000 E1 = 2 16 4.917 7.01 1.88 100 0 4.28 0.618 0.701 0.019 75.145 12.797 48.864 0.199 95.012 414.5 3.411 73.491 63.491 14 17 124.021 0 0 0 0 0 0 0 0 0 0 0 0 0	0.254 0.263 1519.751430 7133.794 E2 - 119 4.377 3.66 1.48 12.6 0.654 0.744 0.019 4.6.317 2.341 6.318 100.672 0.099 107.612 4.42.259 4.14.5 4.7.75 3.5.258 18 0.099 0.099 107.612 0.099 10.000 0.000000000000000000000000	0.254 0.261 0.261 5 - 5614.032 - 7609.243 A	0.182	the state of the s	0.254	0.254	0.152	0.152	
Ptan = 435. Node: 17 V: 12.398 L: 9.140 OP: 0.000 DP: 0.000 DP: 0.000 DP: 0.000 DP: 0.000 DP: 0.000 DP: 0.024 Pro: 0.173 DP: 0.173 DP: 0.173 DP: 0.173 DP: 147.41 mu: 0.314 Ks: 5.624 KC: 15.401 T: 0.432 DPms: 0.00 Pup: 341.0 Pdn: 193.72 DP: 147.22 ch1: 157 DP: 147.22 ch1: 157 DP: 147.22 ch1: 157 DP: 147.23 DP: 147.24 DP: 1	0 4.728 Ep = 2000 E1 = 2 18 4.917 7.01 1.88 0.018 0.701 0.019 75.145 3.135 3.491 1.145 3.491 1.15 3.15	0.254 0.263 1519.751440 7133.794 £2 19 4.377 3.66 1.84 12.6 0.3.06 0.654 0.744 0.019 4.8.676 2.341 6.318 100.872 0.099 4.4.876 4.7.758 35.258 18 0 0 4.4.876 0 0 0 0 4.4.876 0 0 0 0 0 0 0 107.512 35.258 18 0 0 0 0 0 0 0 0 0 0 0 10.512 18 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	0.254 0.261 0.261 7609.243 A	0.142	the state of the s	0.254	0.254	0.152	0.152	
Ptan = 435. Node: 17 V: 12.398 L: 9.140 OP: 0.000 DP: 0.000 DP: 0.000 DP: 0.000 DP: 0.000 DP: 0.000 DP: 0.024 Pro: 0.173 DP: 0.173 DP: 0.173 DP: 0.173 DP: 147.41 mu: 0.314 Ks: 5.624 KC: 15.401 T: 0.432 DPms: 0.00 Pup: 341.0 Pdn: 193.72 DP: 147.22 ch1: 157 DP: 147.22 ch1: 157 DP: 147.22 Ch1: 157 DP: 147.23 DP: 147.24 DP: 1	0 4.728 Ep = 2000 E1 = 2 18 4.917 7.01 1.88 0.018 0.701 0.019 75.145 3.135 3.491 1.145 3.491 1.15 3.15	0.254 0.263 1519.751430 7133.794 E2 - 1519.751430 7133.794 E2 - 1519.751430 1.33.66 1.48 1.25 0.0 0.454 0.744 0.019 4.6.76 2.341 6.318 100.872 0.099 414.5 47.758 35.258 148.676 0.0 0 0.01 18.00 0.01 0.01 0.01 0.01 0.	0.254 0.261 0.261 7609.243 A	0.142	the state of the s	0.254	0.254	0.152	0.152	
Ptan = 435. Node: 17 V: 12.398 L: 9.140 OP: 0.000 DP: 0.000 DP: 0.000 DP: 0.000 DP: 0.000 DP: 0.000 DP: 0.024 Pro: 0.173 DP: 0.173 DP: 0.173 DP: 0.173 DP: 147.41 mu: 0.314 Ks: 5.624 KC: 15.401 T: 0.432 DPms: 0.00 Pup: 341.0 Pdn: 193.72 DP: 147.22 ch1: 157 DP: 147.22 ch1: 157 DP: 147.22 Ch1: 157 DP: 147.23 DP: 147.24 DP: 1	0 4.728 Ep = 2000 E1 = 2 18 4.917 7.01 1.88 0.018 0.701 0.019 75.145 3.135 3.491 1.145 3.491 1.15 3.15	0.254 0.263 1519.751440 7133.794 £2 19 4.377 3.66 1.84 12.6 0.3.06 0.654 0.744 0.019 4.8.676 2.341 6.318 100.872 0.099 4.4.876 4.7.758 35.258 18 0 0 4.4.876 0 0 0 0 4.4.876 0 0 0 0 0 0 0 107.512 35.258 18 0 0 0 0 0 0 0 0 0 0 0 10.512 18 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	0.254 0.261 0.261 7609.243 A	0.142	the state of the s	0.254	0.254	0.152	0.152	

	Iteration 3									
Node: 1	2	3	4	5						
V: 12.64	8.696	10.66	2.529	12.646	11.772					
L: 24.380	23.77	7.31	1.52	20.42	11.89					
Q: 0.710 DPz: 0.00	0.24	0.84	0.94	0.94	1.88					
Dz: 0.000	0	0	0	0	0					
C: 0.230	1.58	0.24		1.06	0.24					
Dt: 0.267 Dv: 0.267	0.187	0.336		0.309	0.461					
f: 0.021	0.024	0.02		0.021	0.019					
OP: 200.41	209.428	46.746		229.003	116.286					
mu: 0.565 Ks; 19.06	0.865	0.23	0.393	0.748	0.332					
Kt: 10.00	13.048	40.921	0	18.802	79.384					
T: 1.000	1	0.182		1	0.211					
DPmax: 0.0 Pup: 208.5	209.673	256.362		27.191	82.181 372.68					
Pdn: 0.00	0	209.673	0	27.191	256.362					
DPt: 200.5	209.573 209.573	46.779	27.101	229.161 229.161	116.328					
ch1: 0	0	1		4	3					
chel: 0	0	2		0	6					
DPp: 372.4	372.46	163.032		346.288	116.286					
D: 0.257	0.187	0.336			0.451					ŀ
H: 0.000	0	0	0.61	0	0					
W: 0.000	0 47.895 En a	0	0.809 Es = 5616.419	0	0					
Plan = 43	.000 E1 -	7136.181 E2	- 7615.640 A	- 182.730160						
the second se		the second distance of								
Node: 7	3.832	<b>8.378</b>		11	11.978	13	14	15	16	
L: 4.270	1.22	7.62	13.72	9.16	6.71	10.67	4.57	9.75	6.1	
O: 0.280 DPz: 25.00	0.28	0.56		0.47	0.47	0.94	1.61	0.19	0.19	
Dz: 0.306	0.305	0		0	0	0	0		0	
C: 1.040	5.3	1.26	2.19	1.78	1.19	0.12	0.04	1.27	1.09	<u> </u>
Df: 0.306	0.305			0.212	0.192	0.251	0.329	0.136	0.125	
Dv: 0.300 f: 0.023	0.023	0.292		0.242	0.224	0.284	0.389	0.154	0.144	
DP: 36.99	86.012	80.554	144.41	172.529			31.076	193.76	193.76	
mu: 0.411	1.644	0.668		0.672	0.448	0.294	0.125		0.338	
Ka: 0.000				7.168	4.916	9,193 24.301	4.203	4.017	2.897	
T: 0.000	0	1	0.642	1	1		0.121	1	1	
DPmax: 36.	\$5.012	86.012		0		The second s	45.012	the second s	0	
Pup: 86.01 Pdn: 44.08	<b>35.012</b> 0			172.474	172.474		340.968	193.698	193.698	
DPt: 36.96	85.012	80.527	144.362	172.474	172.474	137.428	31.066	193.698		
DPr: 38.84 ch1: 0	0.1	\$0.527		172.474			31.066	193.698	193.698	
ch1: 0 ch2: 0		the second s					10		0	
DPp: 414.4	462.447	377.434	296.881	462.471	462.471	289.842			462.472	
DPex: 47.8 D: 0.306	-0.126			-0.151	-0.151	the second s			-0.152	
H: 0.000				0.254	0.254		0.254	0.152	0.152	
W: 0.000										
Plan = 831			Es = 5615.419 7615.640 A							
		/130.101 EE		- 142.730100						
Iteration 3										
Node: 17	18	19	<u> </u>							
V: 12.30	the second s					L	1			<u> </u>
L: 9.140	7.01									ļ
Q: 0.380 DPz: 0.00										
DE: 0.000	0	0					<u> </u>		<u>.</u>	<u> </u>
C: 0.340										
Dt: 0.173 Dv: 0.196										
t: 0.024							<u> </u>		<u>.</u>	
DP: 147.31										
mu: 0.310 Ka: 5.634										
KE 15.40	88.99									
T: 0.432										
DPmax: 0.0 Pup: 340.9										
Pdn: 183.64	340.968	414.512								
	73.644			ļ						
DPt: 147.2										
DPT: 147.2	63.544		1				L			
DPr: 147.2 ch1: 15 ch2: 16	63.544 14 17	18								
DPr: 147.2 ch1: 15 ch2: 16 DPp: 268.7	63.544 14 17 121.395	18 0 47.824								
DPr: 147.2 ch1: 15 ch2: 16 DPp: 266.7 DPest: 0.00	63.544 14 17 121.395 0	18 0 47.824 0								
DPr: 147.2 ch1: 15 ch2: 16 DPp: 286.7 DPet: 0.000 D: 0.000 H: 0.203	63.544 14 17 121.395 0 0	18 0 47.824 0 0 0.61								
DPr: 147.2 ch1: 15 ch2: 16 DPp: 268.7 DPet: 0.00 D: 0.000 H: 0.203 W: 0.151	63.544 14 17 121.395 0 0 0 0.61	18 0 47.824 0 0 0 0.61 0.714								
DPr: 147.2' ch1: 15 ch2: 16 DPp: \$6.7 DPet: 0.000 D: 0.000 H: 0.203 W: 0.151 DPetrans •	63.544 14 17 121.395 0 0 0 0.61 0.634 47.595 Ep	18 0 47.824 0 0 0.61 0.714 1519.761480	Es = 5615.419							
DPr: 147.2 ch1: 15 ch2: 16 DPp: 286.7 DPes: 0.00 D: 0.000 H: 0.203 W: 0.151	63.544 14 17 121.395 0 0 0 0.61 0.634 47.595 Ep	18 0 47.824 0 0 0.61 0.714 1519.761480								

	heration	177		1	T		T			
I										
Node: 1	2	3	4	5	6					
V: 12.64	1.696	10.66	2.529	12.546	11.772					
L: 24.340	23.77	7.31	1.52	20.42	11.89					
0: 0.710 DPz: 0.00	0.24	0.84	0.84	0.94	1.88					
De: 0.000	ő	0			55					
C: 0.230	1.58	0.24	0.62	1.06	0.24					
Of: 0.267	0.187	0.335	0.61	0.309	0.461					
Dv: 0.267	0.187	0.335	0.688	0.309	0.451					
f: 0.021	0.024	0.02	0.02	0.021	0.019					
DP: 200.44	209.427	46.746	27.101	229.001	116.285					
mu: 0.561	0.865	0.23	0.383	0.749	0.332					
Ka: 19.084	13.048	5.314	0	18.802	12.270					
Kt: 19.000	13.048	40.921	0	18.802	79.384					
T: 1.000	1	0,182	0	1	0.211					
DPmax: 0.0	0 209.673	0 256.352	27.101	27.191	82.191					
Pup: 208.51 Pdn: 0.000	200.073		0	256.352	372.68					
DPt 200.51	209.673	46.779	27.191	229.161	116,328					
DPr: 200.5	209.573	44.779	0.1	229.161	61.328					
ch1; 0	0		0	4	3					
chet: 0	0	2	0	0	6					
DPp: 372.4	372.46	163.032	372.479	345.288	116.286					
DPes: 0.22	0.219	0	0.201	0	0					
D: 0.279	0.203		0	0.305	0.467					
H: 0.000	0		0.61	0	0					
W: 0.000	0		0.61	0	0					
		1519.761480			<b>-</b>					
		7136.181 E2			<b>├</b>					
Node: 7	8	9	10		12	13	14	15	16	
V: 3.432	3.832			10.183	11.978	14.879	12.688	10.185	11.714	
L: 4.270	1.22		13.72	9.16	6.71	10.67	4.67	9.75	6.1	
Q: 0.280	0.28		0.56	0.47	0.47	0.94	1.51	0.19	0.19	and the second se
DPz: 25.00	37.6	0	0	0	0	0	0	0	0	
Dz: 0.30	0.306		the second s	the second s	0	0	0	0	0	
C: 1.040	5.3	1.26	2.10	1.78	1.19	0.12	0.04	1.27	1.09	the second s
Df: 0.306	0.305	the second s	0.267	0.212	0.192	0.251	0.329	0.136	0.125	
Dv: 0.305 f: 0.023	0.306	0.292	0.291	0.242	0.224	0.284	0.389	0.154	0.144	<u> </u>
t: 0.023	85.012	80.653	144.408	178.529	0.023	0.022	0.02	0.026	0.020	
mu: 0.41	1.644	0.558	0.98	0.672	0.448	0.284	0.125	193.759	<u>193.759</u> 0.338	
Ka: 0.000	1.044		12.227	7.158	4.916	9.193	4.203	4.917	2.897	<u> </u>
Kt: 0.000			20.813		4.016	24.301	52.798	4.917	2.897	l
T: 0.000			0.642	<u> </u>		0.443	0.121		2.007	
DPmax: 36.	\$5.012		\$6.012	0	Ó	0	85.012	0	ö	1
Pup: 86.01	85.012					309.902	340.968	193.698		1
Pdn: 48.02	0		165.54	0	0	172.474	309.902	0	0	
DPt: 36.98	85.012		144.362	172.474	172.474	137.428	31.066	193.698	193.698	
DPT: 36.96	0.1		144.362	172.474	the second s	137.428	31.066	193.698		
ch1: 0	0			0		11	10	0		
d12: 0	0 462.447		0 296.881			12	13	0		the second s
DPp: 414.4 DPet: 47.8	-0.126		200.001	462.471	462.471	289.942	152.471	462.472		
D: 0.305	0.305		0		0	0	0	0.152	-0.152	
H: 0.000	0		0.254		0.254	0.254	0.254	0.152	0.152	
W: 0.000	Ó				0.152	0.254	0.483	0.127	0.127	
DPermer =	47.896 Ep =	1519.761480	Es = 5615.419	180						
		7136.181 E2								[
iteration	n 777									·····
l Neder										<u> </u>
Node: 17					<u> </u>					ł
V: 12.38	7.01								h	
Q: 0.300	1.88			1	<u> </u>					t
DPz: 0.00	10								t	+
Dz: 0.000									1	1
C: 0.340	4.28	3.06								
Df: 0.173										[
Dv: 0.198	0.702									
f: 0.024	0.019								l	ļ
DP: 147.31	73.646									ļ
mu: 0.310	3.163								<u> </u>	+
Ka: 5.624 Ki: 15.401	12.813			h						+
T: 0.432									t	<u> </u>
DPmax: 0.0	95.012								t	
Pup: 340.9									t	1
Pdn: 193.66	340.968									1
DPt: 147.2	73.544	47.809								
DPT: 147.2	63.644									
ch1: 15										
dh2: 16	17								L	
DPp: 268.7				<b> </b>						L
DPex: 0.00				<b> </b>					<u>↓</u>	<b> </b>
D: 0.000 H: 0.203					h					<u> </u>
H: 0.203					<u> </u>					t
DPermax =		1519.761489							ł	<u> </u>
		7135.181 E2							1	1
									•	A

# APPENDIX E

### FIVE DUCT SECTION PROBLEM COMPUTER OUTPUT

T-METHOD

#### Five Duct Section Problem (T-Method)

Interation 0         Image: 0								
v         7.6         7.6         7.6         7.6         7.6         7.6           0         0.7         0.22         0.82         0.5         1.42           0         0         0.33         0         0         0.33         0.76           0         0.33         0.193         0.33         0.281         0.461         0.461           0         0.23         0.193         0.33         0.281         0.461         0.461           0         0.23         0.193         0.33         0.281         0.461         0.461           0         0.2428         0.2411         0.2411         0.2428         0.232.88         0.221         0.243           0         0.101         0.441         0.344         0.411         0.441         0.441         0.441         0.441         0.441         0.441         0.441         0.441         0.441         0.441         0.441		heration 0						
L 14 12 8 16 16 16 16 17 17 17 16 17 16 17 16 17 17 16 17 17 16 17 17 16 17 17 16 17 17 16 17 17 16 17 17 17 17 17 17 17 17 17 17 17 17 17	Node	1	2	3	4	5		
L 14 14 12 8 16 19.41 0 0 07 022 0.92 0.92 0.5 142 0 0 0 0.33 0 0 77.8 0 0 0.23 0.193 0.33 0.291 0.401 Dr 0.228 0.193 0.33 0.221 0.442 Dr 0.228 0.193 0.33 0.221 0.445 Dr 0.228 0.193 0.39 0.291 0.491 Dr 0.228 0.193 0.39 0.291 0.491 Dr 0.228 0.193 0.295 0.427 Dr 0.228 0.193 0.295 0.291 0.292 0.442 Dr 0.292 0.295 0.295 0.291 0.292 0.442 Pr 12.497 0.518 0.716 0.292 0.292 0.242 Pr 12.497 0.019 0.011 0.0428 0.292 0.245 Pr 190.411 0.0411 0.0428 0.292 0.245 Pr 190.411 100.411 0.022 0.118 0.728 Dr 190.411 100.411 0.234 4.472 234.483 128.602 Dr 190.411 100.411 0.234 4.472 1234.483 128.602 Dr 190.411 100.411 4.472 1234.483 128.602 Dr 190.411 100.411 4.472 1234.883 128.602 Dr 190.411 12 0.00 0.00 Dr 190.411 12 0.30 0.220 0.442 H 0.02 0.01 0.00 Dr 190.411 12 0.33 0.22 0.442 H 0.02 0.01 0.00 Dr 190.411 12 0.33 0.22 0.442 H 0.02 0.00 0.00 Dr 190.013 0.02 0.00 Dr 190.013 0.02 0.00 Dr 190.013 0.02 0.00 Dr 190.013 0.02 0.00 Dr 190.013 0.22 0.442 Dr 10.028 0.00 0.00 Dr 20.008 0.00 0.00	V	7.6	7.6	10.756	7.5	7.5		
DPr         26         07.6         0         37.6           Dg         0         0         0.33         0         0           C         0.3         0.163         0.33         0.281         0.401           Dw         0.2728         0.161         0.33         0.281         0.401           Dw         0.2728         0.161         0.333         0.221         0.442           T         0.161         0.343         0.281         0.442         1.113           Ka         12.4427         5.316         0         10.524         5.328           T         1         1         0         1         0.643         5.328           CPrma         24.326         23.7.6         5.316         10         0.224.433         402.143           DPr         190.411         190.411         0.244.433         402.1463         10.472         244.433         402.1463           DPr         190.411         190.411         0         234.433         402.1463         10.730         10.472           DPr         190.411         190.411         0.233         0.210.130         0.231         0.442         10.730         11.42         10.730	L	14	12		16			
DPr         28         37.6         0         0         37.6           DQ         0         0.33         0.281         0.481         0.481           DV         0.274         0.161         0.33         0.281         0.481           DV         0.274         0.161         0.33         0.281         0.483           DV         0.274         0.161         0.33         0.221         0.443           DP         A1.686         0.9264         44.472         5.716         114         0.063           DP         A1.686         0.9264         44.472         5.716         116         0.483         1.131           Ka         12.467         5.316         0.107.21         0.1622         6.8264           T         1         1         0         1         0.648         2.24.833         167.302           DPm         106.411         106.411         4.472         224.833         167.302         0.442           DPm         106.411         106.414         4.772         224.833         167.302           DPm         10.628         10.717172         1172         114.672         0.463           DPm         10.628	0	0.7	0.22	0.92	0.5	1.42		
Dg         0         0.33         0         0           C         0.3         0.183         0.33         0.281         0.442           Dv         0.278         0.181         0.33         0.228         0.442           I         0.018         0.019         0.019         0.019         0.019         0.019           DP         0.184         0.354         0.311         0.433         1.113           CP         81.886         0.284         0.315         0.116.284         2.3285           R         12.487         6.319         0.116.284         2.3285           R         12.487         6.319         0.116.472         0.4433         118.472           DPm         100.411         0.324.483         124.483         124.433         124.433           DPm         100.411         0.324.483         124.433         124.433         124.433           DPm         100.411         0.324.433         124.433         124.433         124.433           DPm         0.240.266         257.744         158.473         171.72         14.407           DPm         0.240.266         257.746         124.477         234.483         124.692	OPz	25	37.5	0				
C         0.8         0.18         0.88         0.19         11         0.16         0.13         0.16         0.18 <th0.18< th="">         0.18         0.18<!--</td--><td></td><td>0</td><td></td><td></td><td></td><td></td><td></td></th0.18<>		0						
Dr         0.3         0.193         0.281         0.491           Dr         0.278         0.161         0.33         0.22         0.442           I         0.018         0.019         0.019         0.019         0.019         0.019           DP         81.848         0.8264         44.472         67.165         114.006           mu         0.561         0.316         0.411         0.6284         23.286           R         12.497         5.319         17.115         10.528         68.284           T         1         1         0         1         64.59           Pray         140.411         190.411         44.472         234.683         102.116           Dr         160.411         144.472         234.683         128.023         128.023           Dr*         160.411         152.111         44.472         234.683         128.023         0.442           D         0         0         0         234.683         128.023         0.442           D         0         0         0         0         0         0         0           Dr         160.411         152.1741         154.774         134.7								
Dr         0.278         0.161         0.33         0.22         0.442           I         0.019         0.019         0.019         0.019         0.019         0.019           DP         81.888         0.211         0.243         0.143         0.143         0.143         0.143         0.105         23.285           Na         12.487         5.319         0         10.528         52.850         7         1         0         1         0.463         1.113           Na         12.487         5.316         0         10.528         52.850         7         0         10.443         23.483         0.061.163         0.443         10.441         0.442         10.441         0.444         0.234.83         0.07.183         0.02.180         0.733         0.116.10         0.33         0.116.10         0.33         0.116.10         0.33         0.116.10         0.33         0.12         0.442         0.03         0.041         0.03         0.041         0.044.11         0.044.11         0.044.11         0.044.11         0.044.11         0.044.11         0.044.11         0.044.11         0.044.11         0.044.11         0.046.10         0.33         0.022         0.442         0.040.10						the second s		
1         0.018         0.018         0.018         0.018         0.018           DP         81.848         09.254         0.211         0.463         1.113           Ka         12.497         5.318         0.1522         5.322.85           R         12.497         5.319         0.16.524         5.22.85           R         12.497         5.319         0.16.524         5.22.85           Pm         19.0411         10.4172         0.1423         5.22.85           DPmm         190.411         10.4172         10.453         67.83           Pep         190.411         10.4472         234.883         107.803         107.83           DPT         196.411         100.411         44.72         234.883         127.803         67.83           Oth         0         0         0         11.000         0         11.000         10.011         0.013         0.02         0.014           DPm         240.346         237.412         3.44         6         6           DPm         240.345         237.412         3.44         6         0.016           DPm         240.347         0.00         0         0         0.016								
DP         81.840         08.286         44.472         67.186         114.006           Ru         0.641         0.354         0.211         0.463         1.113           Ka         12.497         5.319         0         10.524         62.2286           T         1         0         1         0.466         0.271         0.118.472           Pup         160.411         120.411         234.483         402.165         0.766           Prime         166.411         150.411         4.472         234.483         167.303           DPr         166.411         152.911         44.472         234.483         167.303           DPr         166.411         152.911         44.472         234.483         167.303           DPr         166.411         152.917         14.006         0         0         0           OPre         161.819         144.472         234.483         167.303         0         0           DPr         161.819         144.35002         0         0         0         0         0         0         0           DPr         1.469         0.231         0.10         0         0         0         0	DV			0.33	0.22	0.442		
mu         0.841         0.344         0.211         0.463         1.113           Ks         12.497         5.319         0         10.623         69.23.66           P         1         1         0         10.463         69.24.64           Pm         25         37.6         8.1972         0         119.472           Pm         0         0         190.411         234.483         062.165         07.165           Pm         190.411         190.411         234.483         128.003         07.167         0.33         07.234.483         128.003           OH         190.411         190.411         190.411         190.411         190.411         190.403         0.03         0.03         0.03         0.03         0.03         0.03         0.03         0.03         0.03         0.03         0.03         0.03         0.03         0.03         0.03         0.03         0.03         0.03         0.04         0.03         0.03         0.03         0.04         0.04         0.04         0.05         0.04         0.05         0.04         0.05         0.04         0.05         0.04         0.05         0.04         0.05         0.05         0.05	1	0.019	0.019	0.019	0.019	0.019		
mu         0.841         0.344         0.211         0.463         1.113           Ka         12.497         6.319         17.416         10.428         52.285           T         1         1         0         10.428         52.285           T         1         1         0         10.428         52.285           DPmm         25         37.5         81.972         0         119.472           Pep         180.411         152.483         234.883         107.303         17.303           DPr         186.411         152.811         44.472         234.883         127.803         127.803           Ott         0         0         1         14.472         234.883         128.003           Ott         10         0         0         1         12.483         127.172         114.006           OPm         161.819         144.439         0         231.013         0         0           OPm         240.364         52.774         18.478         70.304         6           MW         2347         0         0         0         0         0           O         0.51         14.44         12	DP	81.888	99.268	44.472	67.165	114.006		
Ka         12.497         5.318         0         1         0.428         22.285           Y         1         1         0         1         0.428         59.266           Y         1         1         0         1         0.428         59.266           Pup         190.411         120.4483         224.483         002.168         199.411         0         234.683           DPr         190.411         152.411         44.472         234.483         197.503         197.633	mu	0.681	0.354	the second s		the second s		
Ng         12.497         6.319         7.416         10.458         6.928           DPmm         28         37.5         6.1972         0         119.472           Pape         190.411         100.411         234.483         062.165           DPr         190.411         102.411         0         234.483         107.303           DPr         196.411         102.411         0         234.483         107.303           DPr         196.411         102.211         44.472         234.483         107.403           DPr         196.411         102.211         44.472         234.483         107.403           DPr         196.411         102.711         114.009         0         3           DPr         240.346         287.746         10.44.439         0         231.013         0           DPr         240.346         287.745         0.22         0.442         0         0         0           DPr         240.346         287.745         0.22         0.442         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0 </td <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td>								
T         1         0         1         0         1         0         1         0         1         0         1         0         1         0         1         0         1         0         1         0         1         0         0         1         0         0         0         1         0         0         0         0         1         0				the second s				
DPmm         28         37.6         11.972         0         11.6.772           Pap         190.411         104.411         234.683         107.03           DPr         190.411         192.411         234.683         107.03           DPr         196.411         192.411         44.472         234.683         107.03           DPr         196.411         192.401         44.472         234.683         107.03           OT         0         2         0         3         3           OP         181.419         144.428         158.478         11.40.04           DP         0.240         0.161         0.32         0.22         0.442           M         0.247         0.6         0         0         0           DP         0.247         0.6         0         0         0           Max         231.013         6         0         0         0         0           Par         240.34         62         37.6         0         0         0           Max         11         2         3         4         5         1.42           DP         11.1.262         1.107.66         1.107 <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td>								
Pup         190.411         124.443         234.443         00.21.463           DPr         190.411         10.411         4.472         234.443         167.503           DPr         166.411         152.911         4.472         234.483         167.503           OPr         166.411         152.911         4.472         234.483         128.603           OPr         240.346         27.746         158.478         171.172         114.005           DPsu         181.819         144.439         0.23         0.24         0.442           H         0.214         0.23         0.22         0.442           H         0.214         0.23         0.22         0.442           H         0.214         0.244330029         0.00         0           Prant -402.106.61         3144.453.622         3.74.112 A = 70.305118         1.42           DPrant -402.10.776         10.766         13.107         9.266           L         14         12         8         16         19.41           O         0.7         0.22         0.5         1.42         0.77           Dr         0.4247         0.156         0.33         0.22         0.442								
Pen         0         0         190.411         0         234.483         167.803           DPr         166.411         152.811         44.472         234.483         129.603           Oft         0         0         1         2.0         3           Off         0         0         1         1.0         3           Off         0         0         2         0         3           Off         240.346         287.764         0         231.013         0           D         0         0         0         0         0         0         0           D         0.2177         0         0         0         0         0         0           V         11.62         2.3         4         6         5           Pran< 402.186	DPmes			81.972	0	119.472		
DPr         190.411         194.412         234.843         167.303           drit         0         0         1         0         3         129.603           drit         0         0         2         0         4           DPp         240.366         287.746         158.478         171.172         114.009           DPm         161.619         144.435         0.23         0.22         0.442           M         0.2647         0         0         0         0         0           H         0.2647         0         0         0         0         0           Premare         201.013         5g.e         722.005414         5g.e         204.44.33029         0         0         0           Premare         202.105         5g.e         77.617         0         0         27.6         0         0         27.6         0         0         27.6         0         0         27.6         0         0         27.6         0         0         27.6         0         0         27.6         0         0         27.6         0         0         27.6         0         0         27.6         0         0	Pup	190.411	190.411	234.883	234.883	402.185		
DPr         180.411         190.411         44.472         234.483         167.303           ch1         0         0         1         0         3         128.603         128.603           ch1         0         0         1         0         3         128.603         148.478         171.172         114.069           CMP         161.619         144.439         0         231.013         0	Pdn	0	0	190.411	0	234.883		
DPr         166.411         152.011         44.472         234.843         172.803           cfm         0         0         2         0         4           DPm         161.619         144.439         0         231.013         0.42           DPm         161.619         144.439         0         231.013         0.42           DPm         0.254         0         0         0         0         0           W         0.254         0         0         0         0         0         0           Pran = 402.185         E1 =         3146.45         E2 =         377.112 A = 70.305186         1         1           Node         1         2         3         4         6         1         1         2         3         4         6           V         11.648         10.776         10.765         13.197         9.265         1.42           DPran = 402.185         C1 =         37.6         0         0         37.6           D         0.7         0.22         0.22         0.42         0.442         16.15         15.142           DPran = 402.185         C1 =         0.33         0.22         0.4	DPt	190.411	190.411	44.472	234.883	167.303		
chi         0         0         1         0         11         0         11         0         11         11         0         11	DPT	165.411	152.911	44.472	234.883			
check         0         2         0         4           DPm         161.619         144.439         0         231.013         0.42           DPm         0         245.40         0         0         0         0           D         0.254         0         0         0         0         0           W         0.247         0         0         0         0         0           Pfan         402.145         E1         3144.45         E2         374.112.A         70.306160           Pfan         402.145         E1         314.45.45.42         20.55         1.142           Node         1         1         2         3         4         6           V         11.409         10.776         10.765         13.197         9.265           L         14         12         6         16         142           DPz         26         37.5         0         0         37.5           Dz         0.65         0.16         0.456         1.6         0.5           Dr         0.224         0.161         0.33         0.22         0.442           Dr         0.245								
OPp         240.346         287.746         158.478         171.172         114.006           OPeat         191.619         144.439         0         231.013         0           M         0         2847         0         0         0         0           M         0         2847         0         0         0         0         0           M         0         2847         0         0         0         0         0         0         0           Marmater         22.008214         Es = 24144.334029         0         0         0         0         0           Pran = 402.186         E1 = 3144.43         2         3         4         6         6           V         11         2         3         4         6         6         0         0         0         2.26         0         2.26         0         0         0         2.26         0         2.26         0         2.26         0.22         0.22         0.22         0.22         0.22         0.22         0.22         0.22         0.22         0.22         0.22         0.443         0         0         0         0         0         0		the second s						
OPear         101.418         14.438         0         231.013         0           D         0         0.161         0.33         0.22         0.442           H         0.2541         0         0         0         0           W         0.367         0         0         0         0           Pran = 402.186         E1 = 3146.483         E2 = 377.112         A = 70.206186         0           Note         1         2         3         4         6           V         11.408         10.776         10.756         13.197         2.265           L         14         12         6         16         19.8.41           O         0.7         0.22         0.22         0.42         0.5           C         0.4         0.65         0.3         0.22         0.427           O         0.247         0.161         0.33         0.22         0.427           Dr         0.262         0.028         0.022         0.427         15           Dr         0.247         0.161         0.33         0.22         0.427           Dr         0.264         0.024         0.028         0.68.05						the state of the s		
D         0         0.161         0.33         0.22         0.442           W         0.267         0         0         0         0           DPsuma_         23.013         E_s         232.00514         E_s         2414 330029           Pran<         402.186         E1         3146 443         E2         3141         E         3141           Notice         1         2         3         4         6           Notice         1         2         3         4         6           V         11.408         10.776         10.766         13.197         9.266           D         0         0.77         0.22         0.92         0.5         142           DP         2         2         37.5         0         0         37.5           Dz         0         0.33         0.22         0.442         0.442           DW         0.274         0.161         0.33         0.22         0.442           DW         0.274         0.164         0.33         0.22         0.442           DW         0.274         0.164         0.33         0.22         0.442           DW								
H         0.284         0         0         0         0           DPsuma_ = 231.013         6g = 732.008514         Es = 2414.838029         0         0           Pian = 402.186         E1 = 3146.443         E2 = 3774.112         A = 70.206186           Martisen 1         Image: Comparison of the		161.819			231.013	0		
W         0.347         0         0         0         0         0           Pren = 402.103         Ep = 722.00516         E = 2414.30629	0			0.33	0.22	0.442		
W         0.347         0.0         0.0         0.0         0.0           Pran = 402.1015         Ep = 722.00516         E = 2414.30629	н	0.254	0	0	0	0		
DP=mmax         231.013         Ep         722.004514         Ex         274.112         A 70.206198           Node         1         2         3         4         6           Node         1         2         3         4         6           V         11.498         10.776         10.756         13.197         0.265           L         14         12         4         16         19.41           O         0.7         0.22         0.62         0.5         1.42           DPz         26         37.6         0         0.33         0         0           C         0.8         0.66         0.18         0.456         1.5           Dr         0.224         0.166         0.33         0.22         0.442           Dr         0.221         0.022         0.022         0.022         0.022           T         10.501         22.845         5.444         0         10.563         22.846           R         12.245         5.444         0         10.563         23.8.03           T         1         1         0         10.663         56.813           T         1	W		0		0			
Pres         402.188         E1 =         3146.454         E2 =         3774.112 A = 70.306196           Node         1         2         3         4         6           Node         1         2         3         4         6           V         11.498         10.776         10.756         13.197         9.265           U         141         12         8         16         11.8.1           O         0.77         0.222         0.62         0.5         1.42           Dr         0.86         0.18         0.66         1.63         0.22         0.442           Dr         0.874         0.166         0.33         0.22         0.442           Dr         0.877         0.399         0.223         0.602         1.044           Dr         1.022.426         6.448         0         121.98         164.458           Res         12.246         6.448         0         121.98         164.458           Pag         190.018         190.018         236.999         136.218         165.228           Dr         0.64         132.198         40.228.999         165.228 <t< td=""><td>the second s</td><td></td><td></td><td></td><td>20</td><td></td><td></td></t<>	the second s				20			
Node         1         2         3         4         6           V         11.498         10.776         0.756         13.197         9.265           L         14         12         4         16         19.41           O         0.77         0.22         0.92         0.5         1.42           DPz         26         37.6         0         0.33         0         0           Dz         0         0.03         0         37.5         0.166         0.33         0.22         0.442           Dr         0.274         0.161         0.33         0.22         0.442         156.175           mu         0.67         0.386         0.423         0.602         1.644           Ka         12.2445         5.446         7.984         10.563         52.849           Mu         0.57         0.386         0.223         0.602         1.643           Ka         12.2445         5.446         7.994         10.563         58.613           T         1         1         0         1         0.467         1.85           Pap         190.018         190.018         236.899         128.428								
Nersten 1         2         3         4         5           V         11.408         10.776         10.756         13.107         0.266           V         11.408         10.776         10.756         13.107         0.266           C         14         12         4         16         18.61           O         0.7         0.22         0.92         0.5         1.42           Dr         0.8         0.65         0.18         0.65         1.5           Dr         0.2247         0.161         0.33         0.22         0.442           Dr         0.274         0.165         0.33         0.22         0.442           Dr         0.270         0.390         0.223         0.602         0.022         0.016           DP         187.306         208.841         46.84         238.642         156.176           Mu         0.57         0.390         0.223         0.6502         1.044           Ks         12.245         6.449         0         10.653         228.699           Pag         180.018         190.018         236.999         128.428         0           DP         190.018 <t< td=""><td></td><td></td><td></td><td></td><td></td><td></td><td></td></t<>								
Nodes         1         2         3         4         5           V         11.498         10.776         10.756         13.197         9.265           L         14         12         4         16         19.81           O         0.7         0.22         0.82         0.5         1.42           DPz         25         37.5         0         0         33.0         0         0           Cz         0.8         0.65         0.16         0.65         1.5         0         0         0         0.33         0.22         0.442         0.442         0.442         0.442         0.442         0.442         0.442         0.442         0.22         0.022         0.022         0.042         0.443         0         10.563         22.849         10.445         10.445         10.445         10.444         10.451         15.444         10.451         10.452         10.445         10.4451         10.453         10.4451         10.453         10.451         10.453         10.451         10.453         10.451         10.451         10.451         10.451         10.451         10.451         10.451         10.451         10.451         10.451         10.451								
Node         1         2         3         4         6           V         11.468         10.776         10.756         13.197         0.265           L         14         12         4         16         18.81           Q         0.7         0.22         0.82         0.5         1.42           DPr         26         37.6         0         0         33         0         0           C         0.8         0.65         0.18         0.33         0.22         0.442           DV         0.278         0.165         0.33         0.22         0.442           DV         0.278         0.165         0.33         0.22         0.442           DP         187.304         208.41         46.96         238.942         159.175           mu         0.67         0.390         0.223         0.502         10.461           Ka         12.245         6.449         0         16.643         22.849           Re         12.245         6.449         0         16.543         22.849           Re         12.456         1.448         0         121.98         Pa           Pap         1			l	l				
V         11.488         10.776         10.766         13.197         0.286           L         14         12         8         16         19.41           Q         0.7         0.22         0.82         0.5         1.42           DPr         226         37.6         0         0         37.6           Dr         0.847         0.161         0.33         0.22         0.442           Dr         0.227         0.165         0.23         0.22         0.442           Dr         0.227         0.165         0.23         0.22         0.442           Dr         0.228         0.028         0.022         0.022         0.016           Dr         0.677         0.389         0.223         0.692         1.044           Dr         0.677         0.389         0.223         0.692         1.044           T         1         1         0         1         0.643         56.813           T         1         1         0         1         0.463         56.813           T         1         1         0         1         0.463         56.813           T         1 <t< td=""><td></td><td></td><td></td><td></td><td></td><td></td><td></td></t<>								
L         14         12         6         16         19.81           OP2         0.5         0.62         0.6         1.42           DP2         28         37.6         0         0         37.6           Dz         0         0.66         0.18         0.65         1.6           Dr         0.247         0.161         0.33         0.22         0.442           Dr         0.221         0.025         0.02         0.022         0.442           Dr         0.022         0.025         0.02         0.022         0.442           Dr         0.022         0.025         0.02         0.022         0.442           Dr         0.022         0.023         0.602         1.76           mu         0.57         0.390         0.223         0.623         1.64           Ka         12.245         5.449         17.694         10.653         58.813           T         1         1         0         1         0.457         236.999         123.699           DPmax         235.991         126.992         128.994         124.828         124.828         124.828           DPn         190.018					4	5		
L         14         12         6         16         19.81           OP2         0.5         0.62         0.6         1.42           DP2         28         37.6         0         0         37.6           Dz         0         0.66         0.18         0.65         1.6           Dr         0.247         0.161         0.33         0.22         0.442           Dr         0.221         0.025         0.02         0.022         0.442           Dr         0.022         0.025         0.02         0.022         0.442           Dr         0.022         0.025         0.02         0.022         0.442           Dr         0.022         0.023         0.602         1.76           mu         0.57         0.390         0.223         0.623         1.64           Ka         12.245         5.449         17.694         10.653         58.813           T         1         1         0         1         0.457         236.999         123.699           DPmax         235.991         126.992         128.994         124.828         124.828         124.828           DPn         190.018	V	11.498	10.776	10.756	13.197	9.266		
O         0.7         0.22         0.82         0.5         1.42           DP         25         37.6         0         0         37.6           DZ         0         0.86         0.18         0.46         1.6           DY         0.847         0.191         0.33         0.22         0.442           DV         0.276         0.026         0.02         0.022         0.442           DP         10.022         0.026         0.02         0.022         0.442           DP         10.022         0.026         0.02         0.022         0.043           DP         10.022         0.026         0.022         0.022         0.043           Mu         0.57         0.389         0.323         0.562         1.648           Max         12.245         6.449         17.894         10.683         22.869           Na         12.245         6.449         17.894         0.1683         22.869           Pap         190.018         190.018         236.998         236.998         236.989           DP         190.018         190.018         6.842         236.989         128.426           DP         190.0	the second se							
DPr         25         37.5         0         0         37.5           Dz         0         0.83         0         0         0           C         0.8         0.65         0.18         0.65         0.16           Dr         0.247         0.161         0.33         0.22         0.447           P         0.022         0.026         0.02         0.022         0.016           DP         167.306         200.851         46.65         238.642         156.176           DP         167.306         200.851         46.65         238.642         156.176           DP         167.308         0.223         0.502         1.044           Ka         12.246         5.449         17.984         10.863         58.813           T         1         1         0         128.899         168.602         128.891           DPm         190.018         190.018         238.899<					the second s		· · · · · · · · · · · · · · · · · · ·	
Dr.         O         0.33         0         0           C         0.8         0.65         0.18         0.65         1.6           Dr         0.247         0.161         0.33         0.22         0.442           Dr         0.274         0.165         0.33         0.22         0.442           Dr         187.306         209.881         44.88         238.642         159.175           T         0.57         0.389         0.223         0.602         0.024         0.021           Ma         0.57         0.389         0.223         0.602         0.024         0.623           Ka         12.245         5.449         17.494         10.653         58.813           T         1         1         0         1         0.433         0.236.999         402.1285           Pap         190.018         190.018         236.999         236.999         121.98           Pah         0         0         0         0         0         33         0.22         0         4           DPr         190.018         190.918         44.98         236.999         128.428           DPr         190.018         190.								
C         0.8         0.95         1.5           Dr         0.247         0.161         0.33         0.22         0.442           Dv         0.027         0.166         0.33         0.22         0.442           1         0.022         0.026         0.02         0.022         0.018           DP         167.306         209.881         44.96         238.642         1561.75           mu         0.57         0.389         0.223         0.602         1.044           Ka         12.245         5.449         0         10.563         22.886           V         12.345         5.449         0         10.643         22.886           Pag         160.018         190.018         0         236.999         402.926           Pdn         0         0         190.018         0         236.999         128.426           Ch1         0         0         1         0         3         46.98         236.999         128.426           Ch1         0         0         1         0         3         46.92         0         0         46.92           DP         190.018         46.98         236.999	and the second s							
DI         0.247         0.161         0.33         0.22         0.442           Dv         0.278         0.166         0.33         0.22         0.447           T         0.022         0.022         0.016         0.427         0.166         0.33         0.22         0.447           DP         187.306         200.881         44.98         238.642         156.175           T         0.57         0.399         0.223         0.602         1.028           Ka         12.245         5.449         17.644         10.663         58.013           T         1         1         0         1         0.467           DPmax         225         37.5         84.48         0         121.98           Pup         190.018         190.018         236.999         128.426           DPr         190.018         190.018         46.98         236.999         128.426           DPr         166.018         152.618         44.98         236.999         128.426           DPr         166.018         152.618         46.98         236.999         128.426           DPr         166.018         152.618         46.98         236.999						the second s		
Dv         0.274         0.165         0.33         0.22         0.437           f         0.022         0.026         0.02         0.022         0.018           DP         187.306         208.41         46.96         238.442         156.176           mu         0.67         0.399         0.223         0.502         1.044           Ks         12.246         6.449         0         10.663         22.846           R2         12.246         6.449         0         1         0.467           DPmax         25         37.5         44.46         0         121.946           Pap         190.018         190.018         236.999         236.999         128.426           Ph         190.018         190.018         0         236.999         128.426           Ch1         0         0         1         0         3         40.236.999           DP         165.018         152.518         44.98         236.999         128.426           Ch1         0         0         0         0         3         41.22           DP         393.461         416.037         206.155         397.817         159.176								
f         0.022         0.022         0.019           DP         187.306         200.481         44.68         238.442         158.175           mu         0.67         0.389         0.323         0.602         1.044           Ks         12.245         5.449         0         10.663         22.889           R2         12.245         5.449         0         10.663         22.889           R2         12.245         5.449         0         10.663         22.889           R2         12.245         5.449         0         12.198           Pap         190.018         190.018         236.999         236.999         236.999           Ph         190.018         190.018         0         236.999         165.928           DPr         190.018         190.018         0         236.999         186.928           Ch1         0         0         1         0         3         3           DPr         190.018         190.918         97.817         159.176           DPr         393.461         416.937         206.185         397.817         159.176           DPr         393.461         416.937         20	01		0.161	0.33	0.22	0.442		
DP         187.305         209.881         44.98         238.442         159.175           mu         0.67         0.399         0.223         0.602         1.044           Ks         12.245         6.449         0         10.663         22.989           R2         12.245         6.449         17.694         10.563         58.813           T         1         0         1         0.467           DPmax         226         37.5         84.44         0         121.98           Pup         190.018         190.018         0         236.999         402.925           Pdn         0         0         190.018         0         236.999         128.426           DP         196.018         152.518         46.98         236.999         128.426           DP         393.461         416.037         206.155         397.617         159.175           DPax         0.464         -13.112         0         6.107         0         0           D         0         0.165         0.301.64         0         0         0         0           D         0.224         0         0         0         0         0<	8	0.278	0.165	0.33	0.22	0.437		
DP         187.306         209.881         46.98         238.442         159.176           Mu         0.67         0.399         0.223         0.602         1.044           K6         12.246         6.449         0         10.663         22.989           R2         12.246         6.449         17.694         10.663         58.813           T         i         1         0         1         0.467           DPmax         226         37.5         84.44         0         121.98           Pup         190.018         190.018         236.999         402.925           Pdn         0         0         190.018         0         236.999         128.426           DPr         165.018         152.518         44.98         236.999         128.426           DPr         165.018         152.518         45.98         236.999         128.426           DPr         165.018         152.518         46.98         236.999         128.426           DPr         165.018         152.518         45.98         236.999         128.426           DPr         393.461         41.9.37         206.155         37.617         10.756	1							
mu         0.67         0.399         0.223         0.502         1.044           Kg         12.246         6.449         0         10.663         52.896           N2         12.246         6.449         10.663         58.013         T           T         1         0         1         0.457         10.6451         58.013           DPmax         25         37.6         84.44         0         121.96         10.457           Pag         190.018         190.016         236.999         236.999         128.999         128.999         128.999         128.251           Pdn         0         0         190.016         46.86         236.999         128.426           DPr         190.016         190.016         48.86         236.999         128.426           Ch1         0         0         1         0         3         3           drig         0         0         1         0         3         3         3           DPr         192.461         416.037         206.155         397.617         156.176         0           DPacex         9.464         -13.112         0         5.107         0 <td< td=""><td></td><td></td><td></td><td></td><td></td><td></td><td></td></td<>								
Ks         12.245         6.449         0         10.662         22.080           R         12.245         6.449         17.684         10.663         52.080           T         1         1         0         1         0.467           DPmax         25         37.5         84.48         0         121.98           Pup         190.018         190.018         0         236.999         236.999         166.926           DPr         190.018         190.018         48.98         236.999         166.926           DPr         165.018         152.618         48.98         236.999         166.926           DPr         165.018         152.618         49.92         0         4           DPs         393.461         416.037         206.155         397.617         159.176           DPs         393.461         418.037         206.155         397.617         159.176           DPs         393.461         418.037         206.155         397.617         159.176           DPs         0.226         0         0         0         0         0           DPs         393.461         418.037         206.833314         0	and the second se							
R2         12.245         5.449         17.694         10.663         54.013           T         i         1         0         1         0.467           Pmp         190.018         190.018         236.999         236.999         402.925           Pdn         0         0         190.018         236.999         402.925           Pdn         0         0         190.018         0         236.999         128.426           DPr         195.018         192.518         44.98         236.999         128.426           DPr         195.018         152.518         44.98         236.999         128.426           DPr         195.018         152.518         45.98         236.999         128.426           DPr         393.461         416.037         206.155         397.617         159.176           DPe         393.461         416.037         206.155         397.617         159.176           DP         0         0.166         0.33         0.22         0.437           H         0.254         0         0         0         0           O         0.464         13.112         0         6.107         0								
T         1         1         0         1         0.467           DPmax         26         37.5         64.44         0         121.96           Pup         190.018         190.018         236.999         236.999         402.25           Pdn         0         0         190.018         236.999         236.999         402.25           DPn         190.018         190.016         46.89         236.999         126.426           Ch1         0         0         1         0         3           drf2         0         0         1         0         3           drf2         0         0         1         0         3           DPs         393.461         416.037         206.155         397.617         159.175           DPex         9.464         -13.112         0         6.107         0           D         0.264         0         0         0         0         0           W         0.236         E1 = 3128.946         E2 = 346.633314         0         0           Pfen = 402.825         E1 = 3128.946         E2 = 3416.319 A = 66.904270         0           Node         1         2 <td></td> <td></td> <td></td> <td></td> <td>10.563</td> <td>22.989</td> <td></td>					10.563	22.989		
DPmax         26         37.5         84.48         0         121.98           Pup         190.018         190.018         236.999         236.999         436.999           DPt         190.018         190.018         44.88         236.999         166.926           DPt         190.018         190.018         44.88         236.999         166.926           DPt         190.018         190.018         44.88         236.999         166.926           DPt         190.018         152.518         44.89         236.999         166.926           OPt         190.018         152.518         44.89         236.999         166.926           OPt         190.018         152.518         44.89         236.999         166.926           OPt         190.018         12.20         10         5         10         7           DPs         393.461         418.037         206.155         397.617         159.176           DPs         0         0.254         0         0         0         0           DPs         393.352712         Es = 2396.633314         0         0         0           Pfan = 402.825         13.157         9.464         1 </td <td>R</td> <td>12.246</td> <td>5.449</td> <td>17.694</td> <td>10.563</td> <td>58.813</td> <td></td>	R	12.246	5.449	17.694	10.563	58.813		
DPmax         26         37.5         64.48         0         121.98           Pup         190.018         190.018         236.999         236.999         432.825           Pun         0         0         190.018         190.018         0         236.999         128.999           DPr         190.018         190.018         44.98         236.999         128.426           DPr         165.018         152.518         44.98         236.999         128.426           OPr         165.018         152.518         44.98         236.999         128.426           OPr         165.018         152.518         44.98         236.999         128.426           OPr         393.461         418.037         206.155         397.617         159.176           DPs         393.461         418.037         206.155         397.617         159.176           DPs         0.254         0         0         0         0         0         0           DPs         393.362712         Es = 2396.633314         0         0         0         0           W         0.226         E1 = 3128.986         E2 = 3815.319.4         66.804270         0           W </td <td>T</td> <td>1</td> <td>1</td> <td>0</td> <td>1</td> <td>0.467</td> <td></td>	T	1	1	0	1	0.467		
Np         190.018         190.018         236.999         236.999         402.925           Pdn         0         0         190.018         236.999         145.925           DPr         190.018         190.018         44.98         236.999         186.926           DPr         195.018         152.518         44.98         236.999         128.426           Ch1         0         0         1         0         3           dril         0         0         2         0         4           DPp         393.461         416.037         206.155         397.617         159.176           DPex         9.464         -13.112         0         6.107         0           D         0         0.254         0         0         0         0         0           W         0.24         0         0         0         0         0         0           W         0.24         0         0         0         0         0         0           DP         31.12         2         31.61         1         1         0         0           W         0.245         10.258         10.756         1	OPmex	25	37.5	84.48	0			
Pdn         0         0         190.018         0         236.099           DPn         190.018         190.018         46.84         236.099         126.626           DPr         165.018         152.518         46.98         236.099         126.426           ch1         0         0         1         0         3           ch2         0         0         2         0         4           DPp         393.461         416.037         206.155         397.617         159.175           DPex         9.464         -13.112         0         5.107         0         0           D         0         0.665         0.33         0.22         0.437         0           W         0.264         0         0         0         0         0         0           W         0.265         E1 = 3128.946         E2 = 3416.319 A = 64.904270         0         0         0           Pten = 402.825         E1 = 3128.946         E2 = 3416.319 A = 64.904270         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0 <td< td=""><td></td><td></td><td></td><td></td><td></td><td></td><td></td></td<>								
DPt         190.016         190.016         44.86         236.999         166.926           DPv         165.018         152.518         44.98         236.999         128.426           OH         0         0         1         0         3           ch2         0         0         2         0         4           DPp         393.461         418.037         206.155         397.617         159.176           DPex         9.464         -13.112         0         5.107         0         0           DPex         9.464         -13.112         0         6.107         0								
DPr         165.018         152.518         44.08         236.000         128.428           ch1         0         0         1         0         3           ch2         0         0         2         0         4           DPp         393.461         416.037         206.155         397.617         159.176           DPex         0.464         -13.112         0         6.107         0           D         0         0.166         0.33         0.22         0.437           H         0.254         0         0         0         0         0           W         0.24         0         0         0         0         0         0           DPstmax         13.112         Ep         733.352712         Es = 2366.633314								
chi         0         0         1         0         3           chi         0         0         2         0         4           DPp         393.461         416.037         206.155         397.617         159.175           DPex         9.464         -13.112         0         \$.107         0           D         0         0.166         0.33         0.22         0.437           H         0.2544         0         0         0         0         0           W         0.24         0         0         0         0         0           W         0.244         0         0         0         0         0           Marsten         13.112         Ep = 733.352712         Es = 2366.633314         0         0           DPramax         13.112         Ep = 733.352712         Es = 3416.310 A = 64.604270         0           Node         1         2         3         4         6           V         11.678         10.256         13.157         9.464           L         14         12         8         16         18.11           Q         0.77         0.22         0.82								
ch2         0         0         2         0         4           DPp         393.461         418.037         208.155         397.617         159.176           DPex         9.464         418.037         208.155         397.617         159.176           D         0         0.165         0.33         0.22         0.437           H         0.254         0         0         0         0         0           W         0.224         0         0         0         0         0           DPexmax =         13.112         Ep = 733.352712         Es = 2395.633314		165.018		46.08	236.999	128.426		
DPp         393.461         416.037         206.155         397.817         159.175           DPext         0.464         -13.112         0         6.107         0           D         0         0.165         0.33         0.22         0.437           H         0.254         0         0         0         0         0           W         0.24         0         0         0         0         0           Pfen         13.112         Ep         733.362712         Es         2395.63314         0         0           Pfen         402.825         E1         3128.946         E2         3615.319 A         66.604270         0         0           Termenter         Termenter           Termenter         Termenter           Termenter         Termenter           Termenter         1         2           Node         1         2         3         4         6           V         11.576         13.157         9.464           L         14         12         6         16         16.5 <td colspa<="" td=""><td></td><td>0</td><td>0</td><td>1</td><td>0</td><td>3</td><td></td></td>	<td></td> <td>0</td> <td>0</td> <td>1</td> <td>0</td> <td>3</td> <td></td>		0	0	1	0	3	
DPex         9.464         -13.112         0         \$.107         0           D         0         0.165         0.33         0.22         0.437           H         0.254         0         0         0         0         0           W         0.24         0         0         0         0         0           Pten = 402.926         E1 = 3128.946         E2 = 3815.319 A = 66.904270	ch2	0	0	2	0	4		
DPex         9.464         -13.112         0         5.107         0           D         0         0.165         0.33         0.22         0.437           H         0.254         0         0         0         0         0           W         0.24         0         0         0         0         0           DPsymax         13.112         Ep         733.352712         Es         2366.633314         -           Pfen         402.825         E1         3 128.996         Es         2366.633314         -         -            -         -         -         -         -         -         -            -         -         -         -         -         -         -            -	DPp	393.461	416.037	206.155	397.817	159.175		
D         0         0.166         0.33         0.22         0.437           H         0.254         0         0         0         0         0           W         0.24         0         0         0         0         0           DPesmax         13.112         Ep = 733.352712         Es = 2395.633314         0         0         0           DPesmax         0.245         E1 = 3128.986         E2 = 3615.319 A = 66.804270         0         0         0           Reration 2		9.464	-13,112		the second s			
H         0.264         0         0         0         0           W         0.24         0         0         0         0         0         0           OPstmax         13.112         Ep         733.352712         Es         2395.63314         0           Pfen         402.825         E1         3128.946         E2         3 615.318         A         66.604270           Interston 2         Interston 2         Interston 2           Interston 2         Interston 2         Interston 2           Interston 2         Interston 2         Interston 2         Interston 2         Interston 2           Node         1         Interston 2         Interston 2         Interston 2         Interston 2         Interston 2           Node         1         Interston 2         Interston 2         Interston 2           Node         1         Interston 2         Interston 2         Interston 2           Interston 2         Interston 2         Interston 2	and the second se							
W         0.24         0         0         0         0           DPstmax = 13.112         Ep = 733.352712         Es = 2366.633314         -         -         -           Pfen = 402.825         E1 = 3128.996         E2 = 3416.319.A = 64.904270         -         -         -           Rention 2         316.319         A = 64.904270         -         -         -           Node         1         2         3         4         6         -           V         11.576         10.256         10.756         13.157         9.464           L         14         12         6         16         19.61           Q         0.77         0.22         0.92         0.5         1.42           DPz         26         37.6         0         0         33         0         0           CC         0.6         0.65         0.18         0.65         1.5         0           DFz         0.221         0.165         0.33         0.222         0.437           DF         0.2217         0.165         0.33         0.222         0.447           DF         0.222         0.024         0.02         0.022         0.016								
DPostmax         13.112         Ep         733.352712         Es         2366.633314           Pfen         402.825         E1         3128.946         E2         3615.319         A         64.804270           Reration 2								
Pfen = 402,825         E1 = 3128,846         E2 = 3815.318 A = 46.804270           Remetion 2           Node         1         2           Node         1         2           Node         1         2           Node         1         2           V         11.57         9.464           L         6         16         19.61           V         11.57         9.464           L         6         16         19.61           U         0          0 <th colspa<="" td=""><td></td><td></td><td></td><td></td><td></td><td>0</td><td></td></th>	<td></td> <td></td> <td></td> <td></td> <td></td> <td>0</td> <td></td>						0	
Node         1         2         3         4         5           V         11.578         10.258         10.756         13.157         9.444           L         11.578         10.258         10.756         13.157         9.444           Q         0.77         0.22         0.82         0.5         1.42           DPz         28         37.5         0         0         33.0         0         0           C         0.8         0.65         0.18         0.85         1.5         0 </td <td>DPexmax =</td> <td>13.112 Ep = 1</td> <td>733.362712 E</td> <td><u>s = 2366.63331</u></td> <td>4</td> <td></td> <td></td>	DPexmax =	13.112 Ep = 1	733.362712 E	<u>s = 2366.63331</u>	4			
Node         1         2         3         4         5           V         11.578         10.258         10.756         13.157         9.444           L         11.578         10.258         10.756         13.157         9.444           Q         0.77         0.22         0.82         0.5         1.42           DPz         28         37.5         0         0         33.0         0         0           C         0.8         0.65         0.18         0.85         1.5         0 </td <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td>1</td>							1	
Reration 2         Image: Constraint of the second sec								
Node         1         2         3         4         5           V         11.576         10.258         10.756         13.157         9.464           L         14         12         6         16         19.61           Q         0.7         0.22         0.92         0.5         1.42           DPz         26         37.5         0         0         37.6           DZ         0         0         33         0         0           C         0.8         0.65         0.18         0.665         1.5           DZ         0         0.33         0.22         0.437           DV         0.277         0.165         0.33         0.22         0.437           DV         0.277         0.166         0.33         0.22         0.437           DP         189.911         100.564         48.82         236.609         185.03           mu         0.656         0.401         0.223         0.502         1.037           K6         12.244         5.454         0         10.563         22.96           K2         12.244         5.454         0         10.563         22.96			1	I			t	
Node         1         2         3         4         5           V         11.576         10.258         10.756         13.157         9.444           L         114         12         6         16         19.61           Q         0.7         0.22         0.82         0.5         1.42           DPz         26         37.6         0         0         37.6           Dz         0         0         0.33         0         0         0           C         0.8         0.65         0.18         0.65         1.5         1.5           Dr         0.246         0.165         0.33         0.22         0.437           f         0.022         0.024         0.02         0.022         0.019           Dr         0.656         0.401         0.22         0.602         1.037           Ma         0.569         0.401         0.22         0.602         1.037           Ma         12.244         5.454         0         10.663         22.96           Q         12.244         5.454         0         10.563         5.784           Np         190.037         190.037			1		J	<u>.</u>	t	
V         11.576         10.258         10.756         13.157         9.464           L         14         12         6         16         19.61           Q         0.7         0.22         0.92         0.5         1.42           DPz         26         37.5         0         0         37.5           Dz         0         0.33         0         0         0           C         0.8         0.65         0.18         0.65         1.5           Dr         0.227         0.165         0.33         0.22         0.437           Dv         0.277         0.166         0.33         0.22         0.437           Dr         0.221         0.016         0.223         0.602         1.037           Mu         0.569         0.401         0.223         0.503         2.266           R         12.244         5.454         0         10							l	
L         14         12         6         16         18.81           Q         0.7         0.22         0.92         0.5         1.42           DPr         226         37.5         0         0         37.5           Dr         0         0.33         0         0         0           G         0.8         0.65         0.18         0.465         1.5           Dr         0.245         0.165         0.33         0.22         0.437           Dv         0.277         0.165         0.33         0.22         0.437           Dv         0.227         0.165         0.33         0.22         0.437           Dv         0.221         0.024         0.02         0.022         0.437           DP         189.911         190.544         48.98         236.999         186.03           mu         0.566         0.401         0.222         0.502         1.037           Ks         12.244         5.454         0         10.663         58.784           T         1         1         0         1         0.457           DPmax         255         37.5         64.46         0								
O         0.7         0.22         0.82         0.5         1.42           DPz         26         37.5         0         0         37.5           Dz         0         0         0         0.33         0         0           C         0.8         0.65         0.18         0.85         1.5           Dr         0.246         0.165         0.33         0.22         0.437           Dv         0.246         0.165         0.33         0.22         0.447           Dv         0.277         0.165         0.33         0.22         0.447           f         0.022         0.024         0.02         0.022         0.016           DP         189.911         190.564         48.98         236.898         185.03           mu         0.569         0.401         0.223         0.602         1.037           Ks         12.244         5.454         0         10.663         22.96           lq         12.244         5.454         0         10.563         52.784           lq         190.037         190.037         237.017         237.017         20.467           Pup         190.037								
DPz         26         37.5         0         0         37.5           Dz         0         0         0.33         0         0         0           C         0.8         0.65         0.18         0.65         1.5         0         0         0           Dr         0.246         0.165         0.33         0.22         0.437         0<								
Dz         0         0.33         0         0           G         0.8         0.66         0.18         0.66         1.5           Df         0.246         0.165         0.33         0.22         0.437           Dv         0.277         0.166         0.33         0.22         0.437           f         0.022         0.024         0.02         0.022         0.437           DP         189.911         190.564         46.98         236.999         186.03           mu         0.566         0.401         0.223         0.502         1.037           Ks         12.244         5.454         0         10.663         58.784           it         1         0         1         0.467           DPmas         255         37.6         64.46         0         121.96           Pup         190.037         190.037         237.017         402.408           Pup         190.037         190.037         0         237.017         402.408           Pup         190.037         190.037         0         237.017         402.408           Pup         190.037         190.037         46.98         237.017								
C         0.8         0.65         0.18         0.65         1.5           Dr         0.246         0.165         0.33         0.22         0.437           Dv         0.277         0.165         0.33         0.22         0.437           1         0.022         0.024         0.02         0.022         0.016           DP         188.911         190.564         46.98         236.896         166.03           DP         188.911         190.564         46.98         236.896         10.37           Ma         0.569         0.401         0.223         0.502         1.037           Ka         12.244         5.454         0         10.663         22.96           RQ         12.244         5.454         0         10.563         52.784           RQ         12.244         5.454         0         10.563         52.784           DPmax         25         37.6         84.46         0         121.98           Pup         190.037         190.037         237.017         237.017         402.808           DPr         190.037         190.037         46.98         237.017         165.791           DPr	DPz			0	0	37.6		
C         0.8         0.45         0.18         0.65         1.5           Di         0.244         0.165         0.33         0.22         0.437           Dv         0.277         0.165         0.33         0.22         0.437           f         0.022         0.024         0.02         0.022         0.016           DP         188.911         190.564         48.98         236.699         165.03           Dmu         0.669         0.401         0.223         0.602         1.97           Max         12.244         5.454         0         10.663         22.96           NQ         12.244         5.454         0         10.663         22.96           NQ         12.244         5.454         0         10.663         22.96           NQ         12.244         5.454         0         10.663         22.96           Np         190.037         190.037         237.017         237.017         402.808           Pdm         0         0         190.037         0.27.017         237.017         237.017           DPr         190.037         190.037         46.98         237.017         165.791	Dz		0	0.33	0	0		
Of         0.248         0.165         0.33         0.22         0.437           Dv         0.277         0.166         0.33         0.22         0.437           f         0.022         0.024         0.02         0.022         0.019           DP         189.911         190.564         44.98         238.699         165.03           mu         0.569         0.401         0.223         0.602         1.037           Ka         12.244         5.454         0         10.563         22.96           R         12.244         5.454         0         10.563         28.784           T         1         0         1         0.457           DPmax         28         37.6         44.44         0         121.96           Pup         190.037         190.37         0         237.017         0         237.017           DPr         190.037         190.37         237.017         0         237.017         0           DPr         190.037         190.37         46.98         237.017         165.761           DPr         196.037         190.37         45.98         237.017         128.291           ch	C	0.6	0.65	0.18	0.65	1.5		
Dv         0.277         0.165         0.33         0.22         0.437           f         0.022         0.024         0.02         0.022         0.143           DP         189.911         190.544         44.98         238.899         166.03           mu         0.569         0.401         0.223         0.602         1.037           Ka         12.244         5.454         0         10.663         52.96           Ka         12.244         5.454         0         10.663         52.96           Ka         12.244         5.454         0         1         0.457           DPmas         25         37.5         84.46         0         121.98           Pup         190.037         190.037         237.017         237.017         402.808           Pup         190.037         190.037         46.98         237.017         165.791           DPr         190.037         190.037         46.98         237.017         128.201           DPr         190.037         190.037         46.98         237.017         165.791           DPr         190.037         190.037         46.98         237.017         168.791 <tr< td=""><td></td><td></td><td></td><td></td><td></td><td>and the second se</td><td></td></tr<>						and the second se		
f         0.022         0.024         0.02         0.022         0.016           DP         188.911         190.554         48.98         238.896         185.03           mu         0.656         0.401         0.223         0.602         1.037           Ks         12.244         5.454         0         10.563         22.96           NQ         12.244         5.454         0         10.563         22.96           NQ         12.244         5.454         0         10.563         22.96           NQ         12.244         5.454         0         10.563         22.96           T         1         1         0         1         0.457           DPmax         25         37.5         84.46         0         121.98           Pup         190.037         190.037         237.017         237.017         402.806           DPr         190.037         190.037         46.98         237.017         165.791           DPr         190.037         152.537         46.98         237.017         128.291           drif         0         0         1         0         3         22         4								
DP         189.911         190.564         44.98         238.999         166.03           mu         0.569         0.401         0.223         0.602         1.037           Ka         12.244         5.454         0         10.563         22.96           RQ         12.244         5.454         0         10.563         22.96           RQ         12.244         5.454         0         1         0.467           DFmax         25         37.6         84.44         0         121.96           Pup         190.037         190.037         237.017         237.017         402.808           Pdn         0         0         190.037         0         237.017         140.2.808           Pdn         0         0         190.037         237.017         126.7017         165.701           DPr         190.037         190.037         46.98         237.017         128.291           DPr         195.037         152.537         44.98         237.017         128.291           DPr         165.037         152.537         45.98         237.017         128.291           ChT         0         0         0         0         3 </td <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td>								
mu         0.569         0.401         0.223         0.502         1.037           Ka         12.244         5.454         0         10.663         22.96           IQ         12.244         5.454         0         10.563         58.784           T         1         1         0         1         0.457           DPmax         25         37.6         84.44         0         121.98           Pup         190.037         190.037         237.017         237.017         402.806           Pdn         0         0         190.037         0.237.017         402.806           Pdn         0         0         190.037         190.037         0.237.017         402.806           Pdn         0         0         190.037         46.98         237.017         165.791           DPr         185.037         152.537         48.98         237.017         128.291           OH         0         0         1         0         3         3           ch2         0         0         2         0         4         4           DPp         401.921         402.574         212.01         401.928         196.03								
Ka         12.244         5.454         0         10.663         22.96           NQ         12.244         5.454         17.697         10.563         52.784           T         1         1         0         1         0.467           DPmas         25         37.5         64.46         0         121.98           Pup         190.037         190.037         237.017         237.017         202.006           Pdm         0         0         190.037         0         237.017         237.017           DPr         180.037         190.037         46.98         237.017         165.791           DPr         180.037         152.537         44.98         237.017         128.291           ch1         0         0         1         0         3           ch2         0         0         2         0         4           DPp         401.921         402.574         212.01         401.928         196.03           DPex         0.887         0.235         0         0.88         0         0           DPp         0.165         0.33         0.22         0.437         0								
IQ         12.244         6.464         17.697         10.563         58.784           T         1         1         0         1         0.467           DPmas         25         37.6         84.46         0         121.98           Pup         190.037         190.037         237.017         237.017         402.808           Pdn         0         0         190.037         0         237.017           DPr         190.037         190.037         46.98         237.017         165.701           DPr         196.037         190.37         46.98         237.017         128.291           ch1         0         0         1         0         3           ch2         0         0         2         0         4           DPp         401.921         402.574         212.01         401.928         166.03           DPp         0.887         0.235         0         0.88         0         0           DPp         0.165         0.33         0.22         0.437         0         0								
T         1         1         0         1         0.467           DPmax         26         37.6         64.44         0         121.68           Pup         190.037         190.037         237.017         237.017         402.406           Pdn         0         0         190.037         0         237.017         165.791           DPr         190.037         152.537         46.98         237.017         165.791           DPr         165.037         152.537         40.98         237.017         165.791           DPr         165.037         152.537         40.98         237.017         165.791           DPr         100         0         1         0         3         3           drig         0         0         0         2         0         4           DPp         401.92         402.574         212.01         401.928								
DPmax         25         37.5         64.46         0         121.98           Pup         190.037         190.037         237.017         237.017         402.806           Pdn         0         0         190.037         0         237.017         237.017           DPt         190.037         190.037         46.98         237.017         165.791           DPr         196.037         152.537         46.98         237.017         128.291           dh1         0         0         1         0         3           cht2         0         0         2         0         4           DPp         401.921         402.574         212.01         401.928         196.03           DPex         0.887         0.235         0         0.88         0         0           DPp         401.921         402.574         212.01         401.922         146.03           DPex         0.887         0.235         0         0.88         0           D         0         0.165         0.33         0.22         0.437			5.454		10.563	58.784		
DPmas         25         37.5         64.48         0         121.98           Pup         190.037         190.037         237.017         237.017         402.804           Pdn         0         0         190.037         0         237.017         402.804           Pdn         0         0         190.037         0         237.017         165.701           DPr         190.037         190.037         46.98         237.017         165.701           DPr         165.037         152.537         46.98         237.017         128.291           dh1         0         0         1         0         3         dr2         0         4           DPp         401.921         402.574         212.01         401.928         196.03         0         4           DPp         401.921         402.574         212.01         401.928         196.03         0         0         0         0         0         6.86         0         0         0         0         0         0         4         0         196.03         0         0         0         0         0         0         0         0         0         0         0         <	T	11		0	1	0.457		
Pup         190.037         190.037         237.017         237.017         402.808           Pdn         0         0         190.037         0         237.017         402.808           DPr         190.037         190.037         46.98         237.017         165.701           DPr         196.037         152.537         46.98         237.017         128.291           Ch1         0         0         1         0         3           Ch2         0         0         2         0         4           DPp         401.921         402.574         212.01         401.928         166.03           DPex         0.887         0.235         0         0.88         0           D         0         0.165         0.33         0.22         0.437	DPmax	25	37.6	84.48	0			
Pdn         0         0         190.037         0         237.017           DPt         190.037         190.037         46.98         237.017         165.791           DPr         165.037         152.537         46.98         237.017         165.791           DPr         165.037         152.537         46.98         237.017         128.291           dh1         0         0         1         0         3           dh2         0         0         2         0         4           DPp         401.921         402.574         212.01         401.928         165.03           DPex         0.687         0.235         0         0.68         0           D         0         0.165         0.33         0.22         0.437								
DPt         190.037         190.037         46.98         237.017         165.791           DPr         166.037         152.537         44.98         237.017         128.291           dh1         0         0         1         0         3           dh2         0         0         2         0         4           DPp         401.921         402.574         212.01         401.928         166.03           DPex         0.887         0.235         0         0.86         0           D         0         0.165         0.33         0.22         0.437								
DPr         165.037         152.537         46.98         237.017         128.291           ch1         0         0         1         0         3           ch2         0         0         2         0         4           DPp         401.921         402.574         212.01         401.928         166.03           DPex         0.687         0.235         0         0.88         0           D         0         0.165         0.33         0.22         0.437								
ch1         0         0         1         0         3           ch2         0         0         2         0         4           DPp         401.921         402.574         212.01         401.928         185.03           DPex         0.687         0.235         0         0.68         0           D         0         0.166         0.33         0.22         0.437								
ch2         0         0         2         0         4           DPp         401.921         402.574         212.01         401.928         165.03           DPex         0.687         0.235         0         0.68         0           D         0         0.165         0.33         0.22         0.437								
DPp         401.921         402.574         212.01         401.928         166.03           DPex         0.687         0.235         0         0.88         0           D         0         0.165         0.33         0.22         0.437		0	0	1	0	3		
DPp         401.921         402.574         212.01         401.928         166.03           DPex         0.687         0.235         0         0.88         0           D         0         0.165         0.33         0.22         0.437	ch2	0	0	2	0	4		
DPex         0.887         0.235         0         0.88         0           D         0         0.166         0.33         0.22         0.437								
D 0 0.165 0.33 0.22 0.437								
	н	0.254		0	0	0		
W 0.238 0 0 0 0	the second s					0	l	
DPexmax = 0.887 Ep = 733.141026 Es = 2304.581517								
Man = 402.808 E1 = 3127.723 E2 = 3612.158 A = 66.536100	Plan = 40						1	

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lede	1	2	3	4	6	
٧	11.541	10.241	10.756	13,156	9.484	
L	14	12		16	19.81	
0	0.7	0.22	0.92	0.6	1.42	
OPI	25	37.6	0	0	37.6	
De	0	0	0.33	0	0	
C	0.8	0.65	0.18	0.65	1.5	
01	0.246	0.165	0.33	0.22	0.437	
Dv	0.277	0.165	0.33	0.22	0.437	
1	0.022	0.024	0.02	0.022	0.019	
0P	190.079	189.953	46.98	236.864	165.622	
mu	0.649	0.401	0.223	0.602	1.036	
Ka	12.243	5.464	0	10.563	22.957	
R	12.244	6.464	17.607	10.643	58.784	
1	1	1	0	1	0.457	
Pmex	25	37.5	84.48	0	121.98	
<u>No</u>	190.037	190.037	237.017	237.017	402.808	
Pan	0	0	190.037	0	237.017	
DPt	190.037	190.037	46.98	237.017	166.791	
OPT	166.037	162.637	46.98	237.017	128.291	
chi	0	0	1	0	3	
chil	0	0	2	0	4	
DPp	401.921	402.674	212.01	401.928	166.03	
DPes	0.887	0.236	0	0.88	0	
0	0	0.178	0.33	0.220	0.432	
н	0.254	0	0	0	0	
W	0.254	0	0	0	0	
Perman =			- 2394.581517			
Plan = 4	02.806 E1 = 3	127.723 E2 -	3657.738 A	67.589473		
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### VITA

#### Fan Wang

### Candidate for the Degree of

### Master of Science

Thesis: COMPUTER AIDED OPTIMAL DESIGN OF DUCT SYSTEMS

Major Field: Mechanical Engineering

Biographical:

Personal Data: Born in Beijing, P.R. China, January 30, 1965 the son of Mr. Geng Wang and Mrs. Min Wen.

- Education: Graduated from High School Attached to Beijing University, Beijing, P.R.China, September, 1982; received the Bachelor of Science in Aerospace Engineering degree from Beijing University of Aeronautics and Astronautics, Beijing, P.R.China, 1986; completed the requirements for the Master of Science degree at Oklahoma State University, July, 1991.
- Professional Experience: Design Engineer, QingYun Instrument Factory, Department of Aerospace of China, Beijing, P.R.China, 1986-1989; Research Assistant, Oklahoma State University, Stillwater, Oklahoma, 1989-1991;