air movement in buildings

Computerprograms calculating air pressures and air flows in buildings in which a fire is simulated

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SUMMARY

Three computerprograms calculating air pressures and air flows in buildings have been developed.
These computer programs consist of a network of non-linear equations. The IWIS libraryprocedure KNEWTØN is used in the iteration process which finds the solution of the system of nonlinear equations. Rooms in which several air flows come together are called junctions (for instance a corridor, a central hall or a staircase).
The first program is suited for a model with one junction, the second one for a model with one junction and a room in which a fire can be simulated. With the third program it is possible to calculate flows and pressures in a model with one fireroom and nineteen junctions.

1. INTRODUCTION

In order to deal with the smokeproblem in buildings in case of fire, one has to get a better understanding of the importance of the different factors determining the spread of smoke through the building.
These factors are:
1. the windpressure around the building
2. the air leakage of the facade and inner walls (i.e. windows, doors and other openings)
3. the temperature differences (i.e. caused by the fire)
4. mechanical ventilation
5. smokeproduction

These factors can serve as input data for a computerprogram as air flows, air pressures, pressuredifferences and air leakage coefficients (C-values).
In the ventilation technique it is common use to approximate the air flow through a gap or a crack with the equation:

$$I_m = C_m \cdot (\Delta p)^{1/n} \qquad (1)$$

where I_m = air mass flow [kg.s^{-1}]

C_m = air mass leakage [kg.s^{-1}] at 1 [Pa]

Δp = pressure difference across the gap [Pa]

n = exponent between 1 and 2

laminar flow, n = 1

turbulent flow, n = 2

The model of a building can be very extensive and complex. Often one is not interested in each individual flow and pressure. In that case it may be useful to simplify the model. This is possible by calculating the substitute for serial and parallel branches.
The smoke problem is a dynamic one.
By calculating the proposed model at several thermal pressure differences one can obtain a sufficient approximation of the dynamic process. Because of the breaking of window panes during the fire the C-values will have a very discontinuous course.

2. CONCLUSION

These computer programs are a very useful tool to obtain information about a large scope of proposed systems or situations of buildings in which a fire may cause spread of smoke. Though buildings can be more complex than indicated in these programs, we think that the most important influences on the spread of smoke can be calculated if the right simplifications are made.

3. THE COMPUTERPROGRAMS

3.1 Computer language

The programs have been written in FØRTRAN 4 for the CDC 6000 computer. In order to use the computerprogram the following group of cards has to be inserted in the card reader:

Example: <u>First program.</u>

```
JOBNAME, T40, IØ40, CM 52000. ---. ← your name
ACCØUNT,  ------   ← your computer account number
REWIND, ØUTPUT.
FTN.
LGØ
7/8/9     ←  end of record
             PROGRAM JA (INPUT, OUTPUT)        } the text of
             CØMMON // Y, C(10,3)              } this program
               .
               .

7/8/9     ←  e.o.r.
               .                               } input data
               .
               .
6/7/8/9   ←  end of
```

<u>Second and third program</u>

```
JOBNAME, T .., IØ..., CM....                    Name
ACCØUNT, ....
REWIND, ØUTPUT
ATTACH, FILE, ACCULIB, ID = PSL, MR = 1
LIBRARY, FILE
FTN
LGØ
7/8/9
```

and further identical to the first program.

3.2.1 One Junction

The first problem was

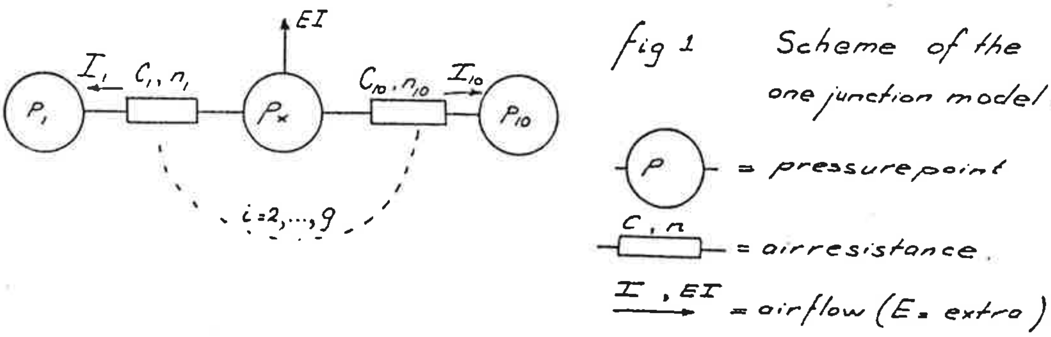


fig 1 Scheme of the one junction model.

A model with one junction with an unknown pressure p_x and a maximum of ten flows coming together in the junction. As mentioned in the introduction one flow can be represented by a simple equation.

$$I_i = C_i * (p_x - p_i)^{1/n_i} \quad , \; i = 1, \ldots, 10 \ldots \qquad (2)$$

The pressure p_x can be calculated by the equation

$$\sum_{i=1}^{10} C_i * (p_x - p_i)^{1/n_i} + EI = 0 \qquad (3)$$

This equation is nonlinear in the pressure p_x and p_i.
EI is a flow caused by the mechanical ventilation.
If $p_x - p_i$ is negative we must write (2):

$$\sum_{i=1}^{10} \text{sign}\,(p_x - p_i) * C_i * (\text{abs}(p_x - p_i))^{1/n_i} + EI=0 \qquad (4)$$

The only unknown variable is p_x
A short computerprogram finds the solution of this equation with a given tolerance EPS.
The iteration process in the program is based upon the bisection method.

3.2.2 Input data

The input data are:

N - the number of flows

AO, BO - the interval in which the right value of p_x lies

EPS - the tolerance.

C(i,k) - i = 1, ..., N 10   the array of C-values, pressures and
k = 1, 2, 3   exponents of the branches around the junction.

Example of the array C(i,k)

	1	2	3
1	c_1	p_1	n_1
2	c_2	p_2	n_2
. . .			
10≥N	c_N	p_N	n_N

3.2.3 Preparing of input data

The first four inputdata are read from one input card by the statement:

```
READ 100, N, AO, BO, EPS, EI
100 FØRMAT (I2, 2F6.1, F6.4, F6.1)
```

An example of a card is:

```
 3 100.  100.  0.0001  10.0
I2 F6.1 F6.1   F6.4    F6.1
```

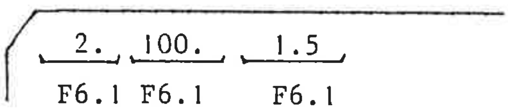
After this READ statement the values of the variables will be:

```
  N =  3
 AO = -100.0
 BO =  100.0
EPS =    0.0001
 EI =   10.0
```

The next N cards, in this example the next 3, are read by the statement:

```
    READ 102,( C (K,L), L = 1,3), K = 1,N)
102 FØRMAT (3 F6.1)
```

Each card must be prepared in this way:



For example:

```
C (1,1) =   2.0
C (1,2) = 100.0
C (1,3) =   1.5
```

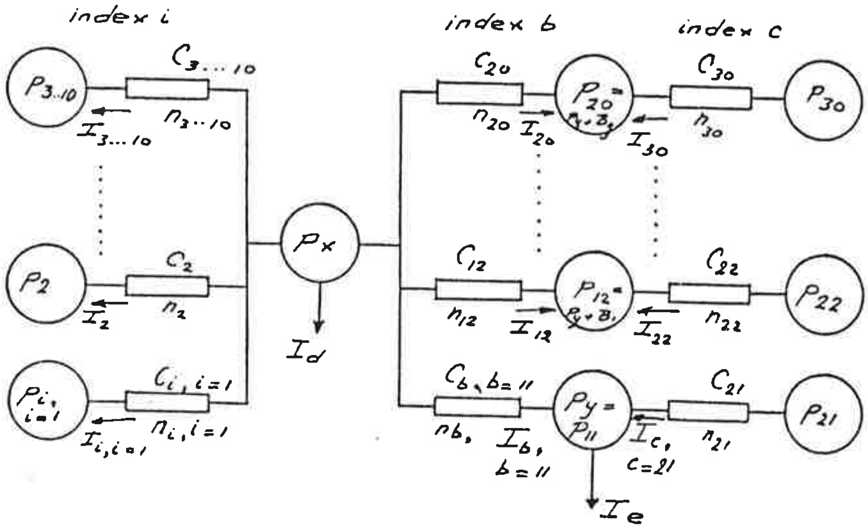
3.2.4 Output

The output values are:

- the pressure in the junction p_x
- the values of the flows around the junction.

3.3.1 Two Junctions

The second problem was



Two junctions with unknown pressures p_x and p_y and three groups of flows:

I_i $\quad i = 1, \ldots, 10$

I_b $\quad b = 11, \ldots, 20$

I_c $\quad c = 21, \ldots, 30$

where:

$$I_i = C_i * (p_x - p_i)^{1/n_i} \quad ; \; i = 1, \ldots, 10 \qquad (5)$$

$$I_b = C_b * (p_x - p_b)^{1/n_b} \quad ; \; b = 11, \ldots, 20 \text{ and } p_{11} = p_y \qquad (6)$$

$$I_c = C_c * (p_c - p_b)^{1/n_c} \quad ; \; c = 21, \ldots, 30 \qquad (7)$$

$$\begin{aligned} p_{11} &= p_y + B0 \text{ where } B0 = 0 \\ p_{12} &= p_y + B1 \\ &\vdots \\ p_{20} &= p_y + B9 \end{aligned} \qquad (8)$$

C_i, C_b, C_c, p_i, p_c, n_i, n_b, n_c and the differences between p_{11} and $p_{12,\ldots,20}$ (B0,...,B9) are known.
For this problem two nonlinear equations are valid:

$$\left.\begin{array}{l} \sum\limits_i I_i + \sum\limits_b I_b + EI(1) = 0 \\ \sum\limits_b I_b + \sum\limits_c I_c + EI(2) = 0 \end{array}\right\} \qquad \ldots\ldots (9)$$

In pressure, C-values and exponents:

$$\sum_{i=1}^{N} \text{sign}\,(p_x-p_i) * C_i * (\text{abs}(p_x-p_i))^{1/n_i} \sum_{b=11}^{10+K} \text{sign}(p_x-p_y-B_{b-11})*C_b*$$

$$(\text{abs}(p_x-p_y-B_{b-11}))^{1/n_b} + EI(1) = 0$$

$$\sum_{b=11}^{10+K} \text{sign}\,(p_x-p_y-B_{b-11})*C_b*(\text{abs}(p_x-p_y-B_{b-11}))^{1/n_b} + \sum_{C=21}^{20+M} \text{sign}(p_c-p_y-B_{c-21})*C_c* \qquad (10)$$

$$(\text{abs}(p_c-p_y-B_{c-21}))^{1/n_c} - EI(2) = 0$$

Again, the only unknown variables are p_x and p_y.
The program uses the library procedure KNEWTØN of IWIS-TNO for the iteration process. This procedure computes the solution of this system of two nonlinear equations with two unknown variables by the method secant.
The procedure KNEWTØN calls the other procedures:
- F (2,X,Y) which calculates the left hand side of both equations. The first value of them is placed in Y(1) and the second in Y(2)
- CHECK (2,X,Y,K) which uses the results in array X and Y and stops the iteration process when the solution has been sufficiently approximated.

3.3.2 Input data

N the number of flows I_i
K " " " " I_b
M " " " " I_c
EPS-the tolerance
EI (1)-the extra flow to the first junction

EI (2)-the extra flow to the second junction

C(i,1)	i = 1,..., N 1 = 1,2,3	The values of C, p and n (equation 1) at I_i
B(i,1)	i = 1,..., K 1 = 1,2,3	The values of C, B and n at I_n
A(i,1)	i = 1,..., M 1 = 1,2,3	The values of C, p and n at I_c

3.3.3 Preparing of input data

The first six input data are read by the statements

```
        READ 1000, N, K, M, EPS, EI(1), EI(2)
   1000 FØRMAT (3I2, F10.4, 2F10.2)
```

Example.

3	4	3	0.01	-10.00	200.00
I2	I2	I2	F10.4	F10.2	F10.2

After this:

N = 3, K = 4, M = 3, EPS = 0.01, EI (1) = -10.0, EI (2) = 200.0

The next N, K and M cards are read by:

```
        READ 1002, (( C(I,L), L = 1,3), I = 1,N)
        READ 1002, (( B(I,L), L = 1,3), I = 1,K)
        READ 1002, (( A(I,L), L = 1,3), I = 1,M)
   1002 FØRMAT, (3 F10.3)
```

Example of one card, say the fifth card of the first group:

47.0	-23.1	1.7
F10.3	F10.3	F10.3

After this: C (5,1) = C_5 = 47 [kg.s^{-1}] at 1[Pa]

C (5,2) = p_5 =-23.1 [Pa]

C (5,3) = n_5 = 1.7

3.3.4 Output

The output values are:

p_x and p_y

Flow I1, ..., N.

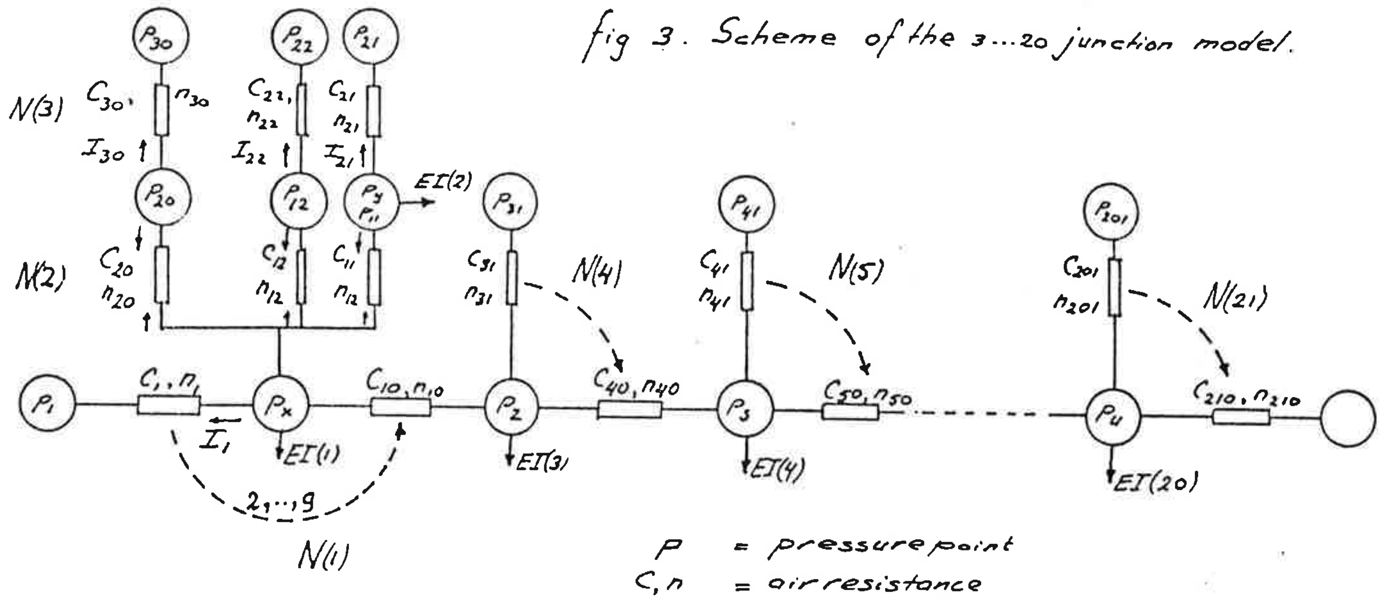
Flow B1, ..., K.

Flow C1, ..., M.

3.4.1 Two and more junctions

The third problem to study was:

fig 3. Scheme of the 3...20 junction model.



P = pressure point
C, n = airresistance
I, EI = airflow (E = extra)
N = group of flows of one junction.

There are NN junctions, 2 ≤ NN ≤ 20, with NN unknown pressures p_x, p_y, p_z, ..., p_u and (NN+1) flow groups ΣI1, ΣI2, ..., ΣI(NN), ΣI (NN+1).

These flowgroups are described by NN nonlinear equations:

$$\left.\begin{array}{l}
\sum_{i=1}^{N(1)} I1_i + \sum_{i=1}^{N(2)} I2_i + EI(1) = 0 \\
\sum_{i=1}^{N(2)} -I2_i + \sum_{i=1}^{N(3)} I3_i + EI(2) = 0 \\
\sum_{i=1}^{N(4)} I4_i + EI(3) - I1_{N(1)} = 0 \\
\sum_{i=1}^{N(5)} I5 + EI(4) - I4_{N(4)} = 0 \\
\cdot \\
\cdot \\
\cdot \\
\sum_{i=1}^{N(NN)} I(NN) + EI(NN-1) - I(NN-1)_{N(NN-1)} = 0 \\
\sum_{i=1}^{N(NN+1)} I(NN+1)_i + EI(NN) - I(NN)_{N(NN)} = 0
\end{array}\right\} \quad (11)$$

where:

$$I1_i = C_i * (p_x - p_i)^{1/n_i} \qquad i = 1, \ldots, 10$$

$$I2_i = C_i * (p_x - B_{i-11} - p_y)^{1/n_i} \qquad i = 11, \ldots, 20$$

$$I3_i = C_i * (p_y + B_{i-22} - p_y)^{1/n_i} \qquad i = 21, \ldots, 30$$

$$I4_i = C_i * (p_z - p_i)^{1/n_i} \qquad i = 31, \ldots, 40$$

$$I5_i = C_i * (p_s - p_1)^{1/n_i} \qquad i = 41, \ldots, 50$$

$$\vdots$$

$$I21_i = C_i * (p_u - p_i)^{1/n_i} \qquad i = 201, \ldots, 210$$

Exactly:

(Note: The notation of the pressure differences should be like in equation (4) and (10)).

$$\sum_{i=1}^{N(1)-1} C_i*(p_x-p_i)^{1/n_i} + C_{N(1)}*(p_x-p_z)^{1/n_{N(1)}} +$$

$$\sum_{i=1}^{N(2)} C_i *(p_x-B_{i-11}-p_y)^{1/n_i} + EI(1) = 0$$

$$\sum_{i=1}^{N(2)} C_i *(B_{i-11}-p_y-p_x)^{1/n_i} + \sum_{i=1}^{N(3)} C_i* (B_{i-11}+p_y-p_i)^{1/n_i} + EI(2) = 0$$

$$\sum_{i=1}^{N(4)-1} C_i*(p_z-p_i)^{1/n_i} + C_{N(4)}* (p_z-p_s)^{1/n_{N(4)}} + C_{N(1)} *(p_z-p_x)^{1/n_{N(1)}} +$$

$$+ EI(3) = 0 \quad ...(12)$$

$$\sum_{i=1}^{N(NN+1)} C_i*(p_u-p_i)^{1/n_i} + C_{N(NN)}* (p_u-p_w)^{1/n_{N(NN)}} + EI(NN) = 0$$

The computerprogram solves this system with the aid of some subroutines.

The job consists of:

- main program ELA
- subroutine F
- subroutine CHECK.

In the mainprogram input data are read and X1(NN) is given the value of the maximum of the known pressures and X2(NN) the minimum of them. X1(NN) and X2(NN) act as start vectors of the solution. They contain the pressures p_x, p_y, p_z, ..., p_u. In the main program the maximum number of iterations is set to 500 and KNEWTØN is called, in which KNEW does the iteration process after CHECK has been called.
In CHECK and KNEW F is used. F calculates the left hand side of the equations (12) in the points X1 (NN) and X2 and puts those values to Y1(NN) and Y2 (NN). CHECK stops the iteration process if all absolute values of $|Y1(i)|_{i=1,...,NN}$ or those of $|Y2(i)|_{i=1, ..., NN}$ are less than EPS. If not the program is set to KNEW for a new iteration step. Further more KNEWTØN uses DECOMP and SOLVE for matrix operations.

3.4.2. Input data

NN - number of junctions + 1

EPS - tolerance of the solution

N(NN) - the number of flows around each junction

EI(NN-1) - the extra flows (mech. ventilation or smoke production)

A(NN,10,3) - the values of C, p and n for all flows.

These data are read by

```
      READ 1001, NN, EPS
1001  FØRMAT (I3, F10.4)
      READ 1002, (N(I), I + 1,NN)
1002  FØRMAT (21I3)
      READ 1006,(EI(J), J + 1,NN)
1006  FØRMAT (8F 10.3)
      READ 1003,(A(I, J, KM),KM + 1,3), J = 1, NA)for I =1,NN
1003  FØRMAT (3 F10.3)
```

Note that array A(I, J, K) contains all known C-values, pressures or pressure differences and exponents.

I is the number of the flowgroup (fig. 3).

J is the number of the flow in the flow group.

K = 1,3 (1 = C-value; 2 = pressure and 3 = exponent).

At the place of an unknown pressure (usually on the last card of a group of flows) can be any value, for it will not be read. Those values for the unknown pressures are generated in the iteration subroutines of the program. In the second group of flows the pressure differences between the first pressure-point of the second group and the concerning pressure-point are written at the second place (K = 2) on the card.

3.4.3. Example of input data

card 1 :	7	0.01					
	I3						
variable :	NN	EPS					
card 2 :	4	4	3	4	4	4	4
	I3	I3	I3	I3	I3	I3	I3
variable :	N(1)	N(2)	N(3)	N(4)	N(5)	N(6)	N(7) = N(NN)
card 3 :	100.0	-500.0	125.0	25.0	125.0		
	F10.3	F10.3	F10.3	F10.3	F10.3		
variable :	EI(1)	EI(2)	EI(3)	EI(4)	EI(5)		

8 times F10.3

All next cards are written in FØRMAT (3 F10.3)

variable :	C-value	pressure	exponent	
card 4 :	1.0	50.0	1.5	A (1,J,K) I = 1 2)
card 5 :	1.5	-20.0	1.7	
:	1.2	-30.0 1)	1.7	
:	1000.0	[0.0]	2.0	
	1000.0	0.0	2.0	A (2,J,K) I = 2
	1000.0	2.0	2.0	
	1000.0	5.0	2.0	
	0.0	8.0	2.0	
	500.0	-10.0	2.0	A (3,J,K) I = 3
	500.0	-10.0	2.0	
	500.0	-10.0	2.0	
	1.5	70.0	1.5	A (4,J,K) ,,
	2.0	-25.0	1.7	
	1.0	-25.0	1.6	
	1000.0	[0.0]	2.0	
	200.0	75.0	2.0	A (5,J,K)
	1.5	-30.0	1.5	
	1.7	-35.0	1.5	
	1000.0	[0.0]	2.0	
	1.3	75.0	1.5	A (6,J.K)
	1.5	-30.0	1.8	
	1.7	-30.0	1.6	
	1000.0	[0.0]	2.0	
	1.2	80.0	1.5	A (7,J,K)
	200.0	-35.0	2.0	
	1.5	-40.	1.5	
	50.0	-50.0	1.8	

1) [0.0] unknown pressures, data is not necessary.

2) J and K are described in [illegible]

3.4.4. Output

The sequence of the output is:

1) estimates of the start values of the unknown pressures
2) calculated pressures
3) calculated flows.

For further details see appendix program 3.

3.5.1. Final

More information about the operation of the CDC system (about using any program) can be found in the book: SCØPE [1]. Complete information about the language Fortran 4 is given in the book : FØRTRAN REFERENCE MANUAL [2] . Both books are at the IWIS terminal.

4. NOMENCLATURE

A	=	array
B	=	thermal pressure difference [Pa]
AO, BO	=	pressure interval
C	=	C-value = air leakage coefficient [$kg.s^{-1}$] at 1 [Pa]
EI	=	extra flow (mechanical ventilation/smokegasgeneration)
EPS	=	tolerance in the solution
I	=	mass flow of air [kg/s]
I,J,K,M,N	=	index
N,NN	=	maximum value of an index
n	=	exponent (see (1))
p	=	pressure [Pa]

5. REFERENCES

[1] SCOPE REFERENCE MANUAL. Models 72, 73, 74 version 3.4 6000 version 3.4. Corporate Headquarters 8100 34th Ave. SO. Minneapolis, Minn. 55440.

[2] FORTRAN VERSION 4 REFERENCE MANUAL. Revised vision 8100 34th Ave. SO. Minneapolis, Minn. 55440.

PROGRAM JA 73/72 OPT=1 FTN 4.6+433

```
      PROGRAM JA(INPUT,OUTPUT)
      COMMON//C(10,3),J,EI
      DIMENSION A(500),B(500)
      READ 100,J,A0,B0,EPS,EI
      READ 102,((C(K,L),L=1,3),K=1,J)
      PRINT  104
      PRINT  106,((C(K,L),L=1,3),K=1,J)
      I=1
      A(I)=A0
      B(I)=B0
      F1=FUN(A(I))
      F2=FUN(B(I))
      IF(F1*F2.GT.0) GOTO 50
    5 F=FUN((A(I)+B(I))/2)
      PRINT 108,I,A(I),B(I),F
      IF(ABS(F).LE.EPS)GOTO 30
      IF(F.GT.0) GOTO 10
      A(I+1)=(A(I)+B(I))/2
      B(I+1)=B(I)
      GOTO  20
   10 A(I+1)=A(I)
      B(I+1)=(A(I)+B(I))/2
   20 I=I+1
      GOTO 5
   30 PAR=(A(I)+B(I))/2
      PRINT 110,PAR
      DO 40 L=1,J
      F=C(L,1)*(ABS(PAR-C(L,2)))**(1/C(L,3))
      IF(PAR.LT.C(L,2)) F=-F
      PRINT 112,L,F
   40 CONTINUE
      GOTO 60
   50 CONTINUE
      PRINT 114,A0,B0
   60 CONTINUE
  100 FORMAT(12,2F5.1,F6.4,F10.2)
  102 FORMAT(3F6.1)
  104 FORMAT(* CONTROL DATA *)
  106 FORMAT(1H ,3F6.1)
  108 FORMAT(1H ,I5,3F10.4)
  110 FORMAT(* VALUE OF PRESSURE IS= *,F10.4)
  112 FORMAT(2H 1,12,2H =,F10.4)
  114 FORMAT(* BAD INITIAL PARAMETERS A0=*,F6.1,* B0=*,F6.1)
      STOP
      END
```

```
FUNCTION FUN          73/72    OPT=1                                    FTN 4.6+433

          REAL FUNCTION FUN(PAR)
          COMMON//C(10,3),J,EI
          F=0.0
          K=1
          DO 10 L=1,J
          IF(PAR.LT.C(L,2)) K=-1
          F=F+K*C(L,1)*(ABS(PAR-C(L,2)))**(1/C(L,3))
       10 K=1
          FUN=F+EI
          RETURN
          END
```

```
CONTROL DATA
    2.0 100.0     1.5
    1.0 -80.0     1.7
    4.0-100.0     2.0
     1 -100.0000  100.0000   10.0776
     2 -100.0000    0.0000  -20.7836
     3  -50.0000    0.0000   -4.7971
     4  -25.0000    0.0000    2.7222
     5  -25.0000  -12.5000   -1.0114
     6  -18.7500  -12.5000     .8612
     7  -18.7500  -15.6250    -.0736
VALUE OF PRESSURE IS=   -17.1875
I 1 =   -47.8943
I 2 =    11.4202
I 3 =    36.4005
```

```
PROGRAM ELA            73/72    OPT=1                                    FTN 4.6+433

              PROGRAM ELA(INPUT,OUTPUT)
              COMMON//J,C(10,3),K,B(10,3),M,A(10,3),EI(2),EPS
              COMMON/NUM/LICZ
              INTEGER R
              REAL MIN,MAX,EI(2),X1(2),X2(2)
              EXTERNAL KNEWTON,KNEW,DECOMP,SOLVE,F,CHECK
              NN=2
              N=500
              LICZ=0
              READ 1000,J,K,M,EPS,(EI(R),R=1,2)
              READ 1002,((C(I,L),L=1,3),I=1,J)
              READ 1002,((B(I,L),L=1,3),I=1,K)
              READ1002,((A(I,L),L=1,3),I=1,M)
              PRINT 1001,J,K,M,EPS,(EI(R),R=1,2)
              PRINT 1004,((C(I,L),L=1,3),I=1,J)
              PRINT 1004,((B(I,L),L=1,3),I=1,K)
              PRINT 1004,((A(I,L),L=1,3),I=1,M)
        C
        C-------MIN I MAX OF PRESSURE
        C
              MIN=MAX=0.0
              DO 10 I=1,J
              IF(C(I,2).LT.MIN)MIN=C(I,2)
              IF(C(I,2).GT.MAX)MAX=C(I,2)
           10 CONTINUE
              DO 20 I=1,M
              IF(A(I,2).LT.MIN)MIN=A(I,2)
              IF(A(I,2).GT.MAX)MAX=A(I,2)
           20 CONTINUE
              X1(1)=2*MIN
              X1(2)=2*MAX
              X2(1)=MIN
              X2(2)=MAX
              PRINT 1005,(X1(KK),KK=1,2)
              PRINT 1006,(X2(KK),KK=1,2)
              CALL KNEWTON(NN,X1,X2,F,CHECK,N)
         1000 FORMAT(3I2,F10.4,2F10.2)
         1002 FORMAT(3F10.3)
         1001 FORMAT(1H ,3I2,F10.4,2F10.2)
         1004 FORMAT(1H ,3F10.3)
         1005 FORMAT(* FIRST ESTIMATIONS OF SOLUTION IS *,2F10.3)
         1006 FORMAT(* SECOND ESTIMATIONS OF SOLUTION IS *,2F10.3)
              STOP
              END
SUBROUTINE F           73/72    OPT=1                                    FTN 4.6+433

              SUBROUTINE F(K1,X1,X2)
              COMMON//J,C(10,3),K,B(10,3),M,A(10,3),EI(2),EPS
              INTEGER R
              REAL EI(2)
              REAL X1(2),X2(2)
              FU=0.
              N=1
```

```
      DO 10  I=1,J
      N=1
      IF((X1(1)-C(I,2)).LT.0)N=-1
   10 FU=FU+N*C(I,1)*(ABS(X1(1)-C(I,2)))**(1/C(I,3))
      GU=0.
      DO 20 I=1,K
      N=1
      IF((X1(1)-X1(2)-B(I,2)).LT.0)N=-1
      GU=GU+N*B(I,1)*(ABS(X1(1)-X1(2)-B(I,2)))**(1/B(I,3))
   20 FU=FU+N*B(I,1)*(ABS(X1(1)-X1(2)-B(I,2)))**(1/B(I,3))
      X2(1)=FU+EI(2)
      DO 30 I=1,M
      N=1
      IF((X1(2)+B(I,2)-A(I,2)).GT.0)N=-1
   30 GU=GU+N*A(I,1)*(ABS(X1(2)+B(I,2)-A(I,2)))**(1/A(I,3))
      X2(2)=GU+EI(1)
      RETURN
      END
```

SUBROUTINE CHECK   73/72   OPT=1   FTN 4.6+433

```
      SUBROUTINE CHECK(N1,X1,X2,K1)
      COMMON//J,C(10,3),K,B(10,3),M,A(10,3),EI(2),EPS
      COMMON/NUM/LICZ
      INTEGER R
      REAL X1(2),X2(2),Y1(2),Y2(2)
      LICZ=LICZ+1
      CALL F(2,X1,Y1)
      CALL F(2,X2,Y2)
      IF(ABS(Y1(1)).LT.EPS.AND.ABS(Y1(2)).LT.EPS)GOTO 50
      PRINT 2,(X1(KK),KK=1,2),(Y1(KK),KK=1,2)
    2 FORMAT(* VARIABLES *,2F20.10,*  VALUES *,2F20.10)
      IF(ABS(Y2(1)).LT.EPS.AND.ABS(Y2(2)).LT.EPS)GOTO 60
      PRINT 2,(X2(KK),KK=1,2),(Y2(KK),KK=1,2)
      RETURN
   50 CONTINUE
      PRINT 1,(X1(J),J=1,2)
      X=X1(1)
      Y=X1(2)
    1 FORMAT(*  VALUE OF PRESSURE IS X=... ; Y=... ;   *,2F20.10)

      GOTO 70
   60 X=X2(1)
      Y=X2(2)
      PRINT 1,(X2(J),J=1,2)
   70 DO 80 I=1,J
      N=1
      IF((X-C(I,2)).LT.0)N=-1
      FI=N*C(I,1)*(ABS(X-C(I,2)))**(1/C(I,3))
      PRINT 3,I,FI
   80 CONTINUE
      DO 90 I=1,K
      N=1
      IF((X-Y-B(I,2)).LT.0)N=-1
      FB=N*B(I,1)*(ABS(X-Y-B(I,2)))**(1/B(I,3))
      PRINT 4,I,FB
   90 CONTINUE
      DO 100 I=1,M
      N=1
      IF((Y+B(I,2)-A(I,2)).LT.0)N=-1
      FC=N*A(I,1)*(ABS(Y+B(I,2)-A(I,2)))**(1/A(I,3))
      PRINT 5,I,FC
  100 CONTINUE
```

```
    3   FORMAT(* FLOW    I*,I2,* = *,F20.10)
    4   FORMAT(* FLOW    B*,I2,* = *,F20.10)
    5   FORMAT(* FLOW    C*,I2,* = *,F20.10)
        PRINT 6,LICZ
    6   FORMAT(* NUMBER OF ITERATIONS IS *,I4)
        K1=0
        RETURN
        END

  6 4 4      .0100       0.00       0.00
        2.100      2.160      1.500
        1.100     -3.240      1.500
       27.900     -3.240      1.700
        2.700     -2.380      1.500
        5.700     -2.380      1.800
        1.500     -3.240      1.500
      122.000      0.000      2.000
       85.000      3.200      2.000
      129.000      6.400      2.000
        0.000      9.600      1.000
        0.000      2.160      1.000
      517.000      2.150      2.000
      382.000      2.150      2.000
      506.000      2.160      2.000
FIRST ESTIMATIONS OF SOLUTION IS       -6.480      4.320
SECOND ESTIMATIONS OF SOLUTION IS      -3.240      2.160

     VALUE OF PRESSURE IS X=... ; Y=... ;

     -1.1730652396         -4.2462557940

  FLOW   I 1 =          -4.6857803253
  FLOW   I 2 =           1.7848856216
  FLOW   I 3 =          42.7651908378
  FLOW   I 4 =           3.0606903050
  FLOW   I 5 =           6.3278251967
  FLOW   I 6 =           2.4339349388
  FLOW   B 1 =         213.8722827467
  FLOW   B 2 =         -30.2688651579
  FLOW   B 3 =        -235.2901456175
  FLOW   B 4 =           0.0000000000
  FLOW   C 1 =           0.0000000000
  FLOW   C 2 =        -925.7412732112
  FLOW   C 3 =         -30.2137466393
  FLOW   C 4 =         904.2751143765
  NUMBER OF ITERATIONS IS     9
```

```
FLA3I,IC100,T100,CM52000.          WIL.
ACCOUNT,16.00000001,50.
REWIND,OUTPUT.
ATTACH,FILE,ACCULIB,ID=PSL,MR=1.
LIBRARY,FILE.
FTN.
LGO.
?
      PROGRAM FLA(INPUT,OUTPUT)
      COMMON//NN,N(21),A(21,10,3),EPS,EI(20)
      COMMON/NUM/LIC7,K
      REAL MIN,MAX
      DIMENSION X1(20),X2(20)
      EXTERNAL KNEWTON,KNEW,DECOMP,SOLVE,F,CHECK
      READ 1001,NN,EPS
      PRINT 1001,NN,EPS
      IF(NN.GT.2.AND.NN.LT.22) GOTO 10
      PRINT 1000
      STOP
   10 READ 1002,(N(I),I=1,NN)
      PRINT 1002,(N(I),I=1,NN)
      NNN=NN-1
      READ 1006,(EI(J),J=1,NNN)
      PRINT 1006,(EI(J),J=1,NNN)
      DO 20 I=1,NN
      NA=N(I)
      READ 1003,((A(I,J,KM),KM=1,3),J=1,NA)
      PRINT 1003,((A(I,J,KM),KM=1,3),J=1,NA)
   20 CONTINUE
C
C.......MIN AND MAX OF PRESSURE
C
      MIN=MAX=0.
      DO 40 I=1,NN
      IF(I.EQ.2) GOTO 40
      NA=N(I)
      DO 30 J=1,NA
      IF(A(I,J,2).LT.MIN) MIN=A(I,J,2)
      IF(A(I,J,2).GT.MAX) MAX=A(I,J,2)
   30 CONTINUE
   40 CONTINUE
      DO 50 I=1,NNN
      X1(I)=MAX
   50 X2(I)=MIN
      PRINT 1004,(X1(I),I=1,NNN)
      PRINT 1005,(X2(I),I=1,NNN)
      K=500
      LIC7=0
C
C....... START TO ITERATIONS PROCESS
C
      CALL KNEWTON(NNN,X1,X2,F,CHECK,K)
 1000 FORMAT(* SORRY, YOU WANT TO SOLVE MORE THEN 20 OR LESS THEN 2
     CNONLINEAR EQUATIONS *)
 1001 FORMAT(I3,F10.4)
 1002 FORMAT(21I3)
 1003 FORMAT(3F10.3)
 1004 FORMAT(* FIRST ESTIMATIONS OF SOLUTION IS*,10F10.3,/,34X,10F10.3)
 1005 FORMAT(* SECOND ESTIMATIONS OF SOLUTION IS*,10F10.3,/,34X,10F10.3)
 1006 FORMAT(8F10.3)
      STOP
      END
```

```
      SUBROUTINE F(LN,X1,X2)
      COMMON//NN,N(21),A(21,10,3),EPS,ET(20)
      DIMENSION X1(20),X2(20)
      FU=0.
      NA=N(1)
      IF(NN.GT.3) NA=NA-1
      DO 10 J=1,NA
      M=1
      IF((X1(1)-A(1,J,2)).LT.0)M=-1
   10 FU=FU+M*A(1,J,1)*(ABS(X1(1)-A(1,J,2)))**(1/A(1,J,3))
      IF(NN.EQ.3) GOTO 20
      M=1
      IF((X1(1)-X1(3)).LT.0)M=-1
      FU=FU+M*A(1,N(1),1)*(ABS(X1(1)-X1(3)))**(1/A(1,N(1),3))
   20 GU=0.
      NA=N(2)
      DO 30 J=1,NA
      M=1
      IF((X1(1)-X1(2)-A(2,J,2)).LT.0)M=-1
      GU=GU-M*A(2,J,1)*(ABS(X1(1)-X1(2)-A(2,J,2)))**(1/A(2,J,3))
   30 FU=FU+M*A(2,J,1)*(ABS(X1(1)-X1(2)-A(2,J,2)))**(1/A(2,J,3))
      X2(1)=FU+ET(1)
      NA=N(3)
      DO 40 J=1,NA
      M=1
      IF((X1(2)+A(2,J,2)-A(3,J,2)).LT.0)M=-1
   40 GU=GU+M*A(3,J,1)*(ABS(X1(2)+A(2,J,2)-A(3,J,2)))**(1/A(3,J,3))
      X2(2)=GU+ET(2)
      IF(LN.EQ.2)RETURN
      DO 100 J=4,NN
      NA=N(J)-1
      M=1
      IF(J.EQ.4)GOTO50
      SROD=X1(J-1)-X1(J-2)
      IF(SROD.LT.0)M=-1
      FU=M*A(J-1,N(J-1),1)*ABS(SROD)**(1/A(J-1,N(J-1),3))
      GOTO 60
   50 SROD=X1(3)-X1(1)
      IF(SROD.LT.0)M=-1
      FU=M*A(1,N(1),1)*ABS(SROD)**(1/A(1,N(1),3))
   60 DO 70 I=1,NA
      M=1
      SROD=X1(J-1)-A(J,I,2)
      IF(SROD.LT.0)M=-1
   70 FU=FU+M*A(J,I,1)*ABS(SROD)**(1/A(J,I,3))
      IF(J.LT.NN)GOTO 80
      M=1
      SROD=X1(J-1)-A(J,N(J),2)
      IF(SROD.LT.0)M=-1
      FU=FU+M*A(J,N(J),1)*ABS(SROD)**(1/A(J,N(J),3))
      X2(J-1)=FU+ET(J-1)
      RETURN
   80 M=1
      SROD=X1(J-1)-X1(J)
      IF(SROD.LT.0)M=-1
      FU=FU+M*A(J,N(J),1)*ABS(SROD)**(1/A(J,N(J),3))
  100 X2(J-1)=FU+ET(J-1)
      RETURN
      END
```

```
      SUBROUTINE CHECK(LN,X1,Y2,K)
      COMMON//NN,N(21),A(21,10,3),EPS,EI(20)
      COMMON/NUM/LICZ,K1
      DIMENSION X1(20),X2(20),Y1(20),Y2(20),X(20)
      LICZ=LICZ+1
      CALL F(LN,X1,Y1)
      IF(LICZ.GT.50)GOTO 8
      PRINT 2,(Y1(J),J=1,LN)
    8 DO 10 J=1,LN
      IF(ABS(Y1(J)).GT.EPS)GOTO 140
   10 CONTINUE
      DO 20 J=1,LN
   20 X(J)=X1(J)
   30 PRINT 1
      PRINT 2,(X(J),J=1,LN)
      NA=N(1)
      MM=1
      IF(NN.GT.3)NA=NA-1
      DO 40 J=1,NA
      M=1
      SROD=X(1)-A(1,J,2)
      IF(SROD.LT.0)M=-1
      FU=M*A(1,J,1)*ABS(SROD)**(1/A(1,J,3))
      PRINT 3,MM,J,FU
   40 CONTINUE
      IF(NN.EQ.3)GOTO 50
      M=1
      SROD=X(1)-X(3)
      IF(SROD.LT.0)M=-1
      FU=M*A(1,N(1),1)*ABS(SROD)**(1/A(1,N(1),3))
      PRINT 3,MM,N(1),FU
   50 NA=N(2)
      MM=2
      DO 60 J=1,NA
      M=1
      SROD=X(1)-X(2)-A(2,J,2)
      IF(SROD.LT.0)M=-1
      FU=M*A(2,J,1)*ABS(SROD)**(1/A(2,J,3))
      PRINT 3,MM,J,FU
   60 CONTINUE
      NA=N(3)
      MM=3
      DO 70 J=1,NA
      M=1
      SROD=X(2)+A(2,J,2)-A(3,J,2)
      IF(SROD.LT.0)M=-1
      FU=M*A(3,J,1)*ABS(SROD)**(1/A(3,J,3))
      PRINT 3,MM,J,FU
   70 CONTINUE
      IF(NN.EQ.3)GOTO 130
      JED=1
      DO 120 J=4,NN
      NA=N(J)-1
      MM=J
      M=1
   90 DO 100 I=1,NA
      M=1
      SROD=X(J-1)-A(J,I,2)
      IF(SROD.LT.0)M=-1
      FU=M*A(J,I,1)*ABS(SROD)**(1/A(J,I,3))
      PRINT 3,MM,I,FU
  100 CONTINUE
```

```
      M=1
      IF(J.LT.NN)GOTO 110
      SROD=X(J-1)-A(J,N(J),2)
      IF(SROD.LT.0)M=-1
      FU=M*A(J,N(J),1)*ABS(SROD)**(1/A(J,N(J),3))
      PRINT 3,MM,N(J),FU
      GOTO 130
  110 SROD=X(J-1)-X(J)
      IF(SROD.LT.0)M=-1
      FU=M*A(J,N(J),1)*ABS(SROD)**(1/A(J,N(J),3))
      PRINT 3,MM,N(J),FU
  120 CONTINUE
  130 PRINT 4,LICZ
      K=0
      RETURN
  140 CALL F(LN,X2,Y2)
      IF(LICZ.GT.50)GOTO 145
      PRINT 2,(Y2(J),J=1,LN)
  145 DO 150 J=1,LN
      IF(ABS(Y2(J)).GT.EPS)GOTO 160
      X(J)=X2(J)
  150 CONTINUE
      GOTO 30
  160 IF(LICZ.LT.K1)RETURN
      PRINT 5
      K=0
    1 FORMAT(* VALUES OF PRESSURES *)
    2 FORMAT(1H ,(5F20.10))
    3 FORMAT(* FLOW    I*,2I2,* = *,F20.10)
    4 FORMAT(* NUMBER OF ITERATIONS IS *,I4)
    5 FORMAT(* SORRY. THIS SYSTEM OF NONLINNEAR EQUATIONS HAVE NO
     CSOLUTION *)
      RETURN
      END
?
```

```
 7       .01
 4   4   3   4   4   4   4
  100.      -500.      125.      125.      125.      140.
    1.        50.        1.5
    1.5      -20.        1.7
 1500.       -30.        2.
 1000.         0.        2.
 1000.         0.        2.
 1000.         2.        2.
 1000.         5.        2.
    0.         8.        2.
  500.       -10.        2.
  500.       -10.        2.
  500.       -10.        2.
    1.5       70.        1.5
    2.       -25.        1.7
    1.       -25.        1.6
 1000.         0.        2.
  200.        75.        2.
    1.5      -30.        1.5
    1.7      -35.        1.5
 1000.         0.        2.
    1.3       75.        1.5
    1.5      -30.        1.8
    1.7      -30.        1.6
 1000.         0.        2.
    1.2       80.        1.5
  200.       -35.        2.
    1.5      -40.        1.5
   50.       -50.        1.8
?
```

```
VALUES OF PRESSURES
      -19.7786259659        -19.4210373698        -19.5926700191
      -19.3070231693        -20.9068450562
      -22.2413552230
 FLOW    I 1 1 =        -16.9491637353
 FLOW    I 1 2 =           .6179339571
 FLOW    I 1 3 =       4795.6325757720
 FLOW    I 1 4 =       -431.2259810409
 FLOW    I 2 1 =       -597.9870366703
 FLOW    I 2 2 =      -1535.4440712790
 FLOW    I 2 3 =      -2314.6465164309
 FLOW    I 2 4 =          0.0000000000
 FLOW    I 3 1 =      -1534.6854213355
 FLOW    I 3 2 =      -1362.0790514723
 FLOW    I 3 3 =      -1051.3131514728
 FLOW    I 4 1 =        -30.0335206830
 FLOW    I 4 2 =          5.3975464890
 FLOW    I 4 3 =          2.8715362007
 FLOW    I 4 4 =       -534.4593996263
 FLOW    I 5 1 =      -1942.2360636060
 FLOW    I 5 2 =          7.2804296484
 FLOW    I 5 3 =         10.6557938620
 FLOW    I 5 4 =       1264.8406567440
 FLOW    I 6 1 =        -27.2380756735
 FLOW    I 6 2 =          5.1134083522
 FLOW    I 6 3 =          6.7553140047
 FLOW    I 6 4 =       1155.2100098111
 FLOW    I 7 1 =        -26.2380956561
 FLOW    I 7 2 =        714.3849040115
 FLOW    I 7 3 =         10.2101269835
 FLOW    I 7 4 =        316.8530749667
 NUMBER OF ITERATIONS IS    14
```

Simplified Flow diagram