Numerical Heat Transfer

(数值传热学)

Chapter 10 General Code for 2D Elliptical Fluid Flow and Heat Transfer (2)

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Chapter 10 General Code for 2D Elliptical Fluid Flow and Heat Transfer Problems (2)

10.6 Methods of application and explanation of Main Program

10.6.1 Methods of Code application

10.6.2 Explanation of Main Program

10.6.2.1 MODULE START_L

10.6.2.2 PROGRAM MAIN

10.6.2.3 SUBROUTINE DIFLOW

10.6.2.4 SUBROUTINE SOLVE

10.6.2.5 SUBROUTINE SETUP

10.6.2.6 SUBROUTINE SUPPLY

10. 6 Methods of Application and Explanation of Main Program

10.6.1 Methods of Code application

1.Establishing complete mathematical formulation and comparing with the standard equation:

$$\frac{\partial(\rho^{*}\phi)}{\partial t}+div(\rho^{*}\vec{u}\phi)=div(\Gamma_{\Phi}grad\phi)+S_{\phi}^{*}$$

Determine S_{ϕ}^{*}, Γ_{ϕ}, and ρ_{ϕ}^{*}

2.Calling（调用） a USER(will be taught in Chapter 11) similar to the problem studied, retaining MODULE part, modifying other part and saving with a new name;

3. Using a few nodes, 5～7 in each direction, and setting a small value of LAST, say 3－5, to go through grammatical examination; Then gradually increasing the complexity. For example, for turbulent heat transfer simulation, computing laminar flow first .

4. Making correspondent modifications for the six-ENTRY in USER, according to the problem studied, especially for following parts:

(1) **LSOLVE(NF)**—for variable NF to be solved setting：

.TRUE.

(2) **LPRINT(NF)**—for variable NF to be printed out setting:

.TRUE.

(3) **TITLE(NF)**—for variable NF to be printed out specifying its title (within eight letters).

(4) **LBLK(NF)**—for variable NF to be solved by block correction setting: .TRUE., otherwise .FALSE., Its default value is .T. .

(5) **LAST**—Given iteration times, default values is 5.

(6) **NTIMES(NF)**—Default value equals 1; for steady nonlinear one setting: 1 to 2; unsteady linear: 5 to 6

(7) **DT**—Time step, default value is 10^{30}

For fully implicit scheme, in the b-term there is a term of $a_P^0 = \rho \Delta V / \Delta t$, if $\Delta t \to \infty, a_P^0 \to 0$, leading to steady state results. Default value is for steady case.

(8) RELAX(NF)—**Default value is 1.**

(9) IPREF, JPREF: i, j **of pressure reference point , their default values are 1,1;**

5 Defining a new dependent variable, say *C*(*i*,*j*) ,as follows:

First defining C(NI,NJ),

then using EQUIVALENCE:

EQUIVALENCE (F(1,1,5), C(1,1)).

10-6-2 Explanation of Main programs

```
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C  This computer program was copied from the graduate student course
C  program of the University of Minnesota.  Part of it was re-formulated
C  to meet the local computational environment.  Some inappropriate
C  expressions were also corrected. The program is used only for the
C  teaching purpose.  No part of it may be published. You may use it as a
C  frame to re-develop your own code for research purpose.
C --------Instructor of Numerical Heat Transfer, XJTU,2013.---------------
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C  The current version of the program was updated from Fortran 77 to
C  Fortran 95  by Dr. Yu-Tong Mu , Dr. Li Chen and  Dr.Kong Lin of NHT
C  group of XJTU during 2013.01-04
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C******************************************************************
```

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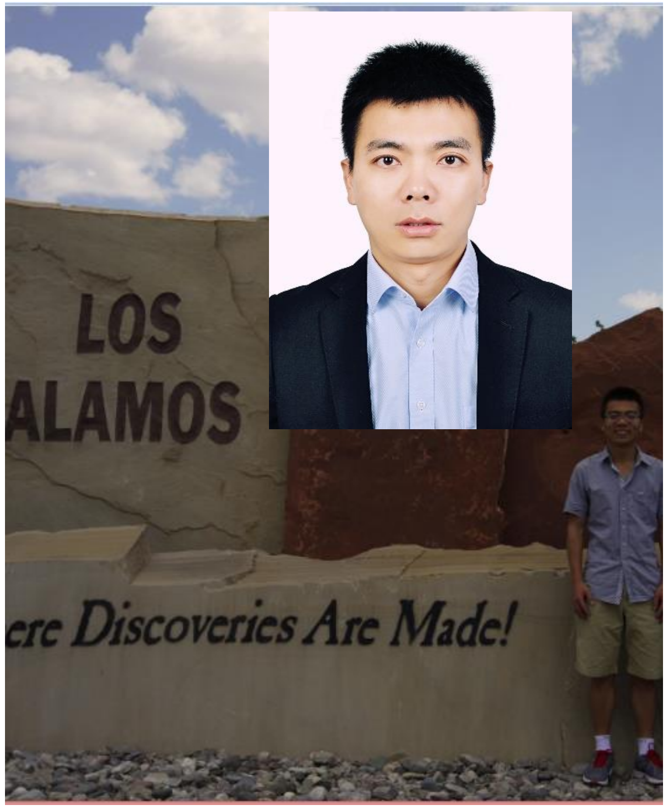

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8.6.2.1 MODULE START_L

(1)-Explained in detail

```
MODULE START_L
n  PARAMETER (NI=100,NJ=200,NIJ=NI,NFMAX=10,NFX4=NFMAX+4)
C*****************************************
   CHARACTER*8 TITLE(NFX4)
   LOGICAL LSOLVE(NFX4),LPRINT(NFX4),LBLK(NFX4),LSTOP
   REAL*8,DIMENSION(NI,NJ,NFX4)::F    ! One 3D function
   REAL*8,DIMENSION(NI,NJ,6)::COF,COFU,COFV,COFP   ! Four 3D functions
   REAL*8,DIMENSION(NI,NJ)::P,RHO,GAM,CP,CON,AIP,AIM,AJP,AJM,AP
   REAL*8,DIMENSION(NI):: U,V,PC,T,DU,DV,UHAT,VHAT
   REAL*8,DIMENSION(NI):: X,XU,XDIF,XCV,XCVS,XCVI,XCVIP
   REAL*8,DIMENSION(NJ)::Y,YV,YDIF,YCV,YCVS,YCVR,YCVRS,ARX,ARXJ,
  1    ARXJP,R,RMN,SX,SXMN
   REAL*8,DIMENSION(NI)::FV,FVP,FX,FXM
   REAL*8,DIMENSION(NJ)::FY,FYM
   REAL*8,DIMENSION(NIJ)::PT,QT
   REAL*8 RELAX(NFX3),TIME,DT,XL,YL,RHOCON
   INTEGER*4 NF,NP,NRHO,NGAM,NCP,L1,L2,L3,M1,M2,M3,
  1    IST,JST,ITER,LAST,MODE,NTIMES(NFX4),IPREF,JPREF
    REAL*8 SMAX,SSUM
    REAL*8 FLOW,DIFF,ACOF
```

Sc or b

a_e, a_w, a_n, a_s, a_p

For TDMA in Block correction

(1) Packaging data (封装数据);

(2) Initializing data (数据初始化);

(3) Declaring type of data (声明数据类型).

```
C******************************************
 EQUIVALENCE(F(1,1,1),U(1,1)),(F(1,1,2),V(1,1)),(F(1,1,3),PC(1,1))
1, (F(1,1,4),T(1,1))
 EQUIVALENCE(F(1,1,11),P(1,1)),(F(1,1,12),RHO(1,1)),(F(1,1,13)
1,GAM(1,1)),(F(1,1,14),CP(1,1))
 EQUIVALENCE(COF(1,1,1),CON(1,1)),(COF(1,1,2),AIP(1,1)),
1(COF(1,1,3),AIM(1,1)),(COF(1,1,4),AJP(1,1)),
2(COF(1,1,5),AJM(1,1)),(COF(1,1,6),AP(1,1))
 REAL*8,DIMENSION(NI)::TH,THU,THDIF,THCV,THCVS
 REAL*8 THL
 EQUIVALENCE(X,TH),(XU,THU),(XDIF,THDIF),(XCV,THCV),
1(XCVS,THCVS),(XL,THL)
  DATA LSTOP,LSOLVE,LPRINT/.FALSE.,NFX4*.FALSE., NFX4*.FALSE./
  DATA LBLK/NFX4*.TRUE./
  DATA MODE,LAST,TIME,ITER/1,5,0.,0/
  DATA RELAX,NTIMES/NFX4*1.,NFX4*1/
  DATA DT,IPREF,JPREF,RHOCON,CPCON/1.E+30, 1,1,1.,1./
  END MODULE
```

Default value!!

```
MODULE module_name
••••••
••••••
••••••
END MODULE
```

Module name is composed of two parts, with a hyphen(-) at bottom in between.

(1) Packaging data (封装数据);
(2) Initializing data (数据初始化);
(3) Declaring type of data (声明数据类型).

Some explains to this most important module

REAL*8,DIMENSION(NI,NJ,NFX4)::F

Real variable 3-D array, array title F， F(NI,NJ,NFX4);
Variable number in three coordinates are NI,NJ and NFX4 respectively;
:: ---is the symbol for separation, separator, to make the declaration of variable type clear;

REAL*8 SMAX,SSUM

Real variable of SMAX and SSUM, with length of eight digits;

INTEGER*4 NF,NP,NRHO

Integral variable of NF,NP,NRHO, with length of four digits;

EQUIVALENCE(F(1,1,1),U(1,1)),(F(1,1,2),V(1,1))

Making the 1st variable of the 3D array F identical to the 2D array U; the same for (F（1,1,2），V(1,1)))

10.6.2.2 PROGRAM MAIN

(2)-Explained in detail

```
C*****************************************************************
C----------------------------------------MAIN -----------------------------------
C*****************************************************************
```

Calling Module

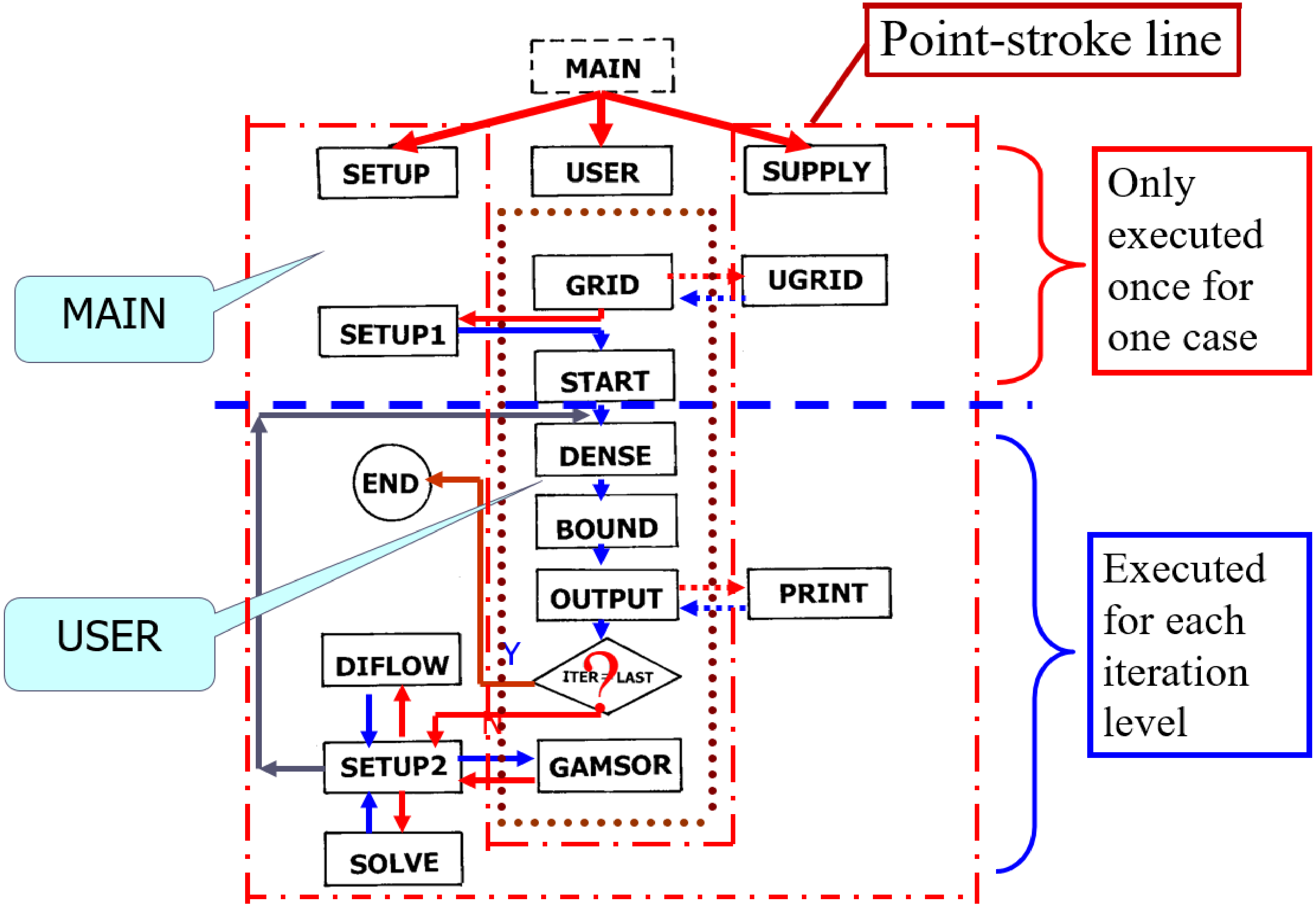
```
      PROGRAM MAIN !Name of subroutine
      USE START_L      Share the variables defined in the MODULE
      IMPLICIT NONE
C****************************************************************
```

Only Executed once

```
      OPEN(8,FILE='RESULT.txt')  ! Result file for output
      CALL GRID       !Grid generation (setup interface positions)
      CALL SETUP1     !Set up 1-D array not changed in iteration
      CALL START      !Set up initial field
     DO WHILE (.NOT.LSTOP）!  If LSTOP is .F., the NOT .F. is .T., following
                                               four CALLs are executed
```

Executed Many times

```
      CALL DENSE       !Set up fluid density
      CALL BOUND       !Set up boundary condition
      CALL OUTPUT      !Print out present results
      CALL SETUP2      !Key module: set coefficients and solve ABEqs.
      ENDDO
      CALL OUTPUT !Print out some results
      CLOSE(8)   !Simulation completed  close file RESULT.TXT in Channel 8
      STOP       !Terminate computation
      END      !End of subroutine
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
```



Flow-chart of teaching code

These parts will be explained in detail.

1. MODULE START_L
2.---------------------MAIN ------------------
3. SUBROUTINE DIFLOW
4. Structure of SOLVE
5. Block correction
6. Structure of SETUP
7. MODE execution
8. Determination of neighbor coefficients
9. Determination of AP coefficients
10. Structure of SIMPLER
11. Temporal storage of coefficients for of SIMPLER
12. Accumulated addition
13. Storage of coefficients of p-equation
14. Nominal density for temperature
15. Iteration=Marching forward
16. Data Format for print out
17. Stream function computation
18. Data print out procedure

10.6.2.3 SUBROUTINE DIFLOW

(3)-Explained in detail

CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC

SUBROUTINE DIFLOW ! Determine $D\bullet A(|P_\Delta|)$ of power law scheme

Calling Module

USE START_L ! Share the variables defined in the MODULE START_L

IMPLICIT NONE !The input variables are DIFF and FLOW

REAL*8 TEMP ! Declaration of a temporal real variable TEMP

C**

ACOF=DIFF ! $D\bullet A(|P_\Delta|)=D$（ACOF finally represents $D\bullet A(|P_\Delta|)$ ）

! 1st return for diffusion case

IF(FLOW== 0.) RETURN ! No flow, only diffusion

TEMP=DIFF-ABS(FLOW)*0.1 ! $D-0.1|F|=D(1-0.1|P_\Delta|)$

ACOF=0. ! $\{A(|P_{\Delta e}|)=\max[0,(1-0.1|P_{\Delta e}|)^5]\begin{cases}0 & |P_{\Delta e}|>10\\(1-0.1|P_{\Delta e}|)^5 & |P_{\Delta e}|<10\end{cases}$

! 2nd return for $|P_{\Delta e}|>10$

IF(TEMP.<= 0.) RETURN ! $|P_{\Delta e}|>10$

TEMP=TEMP/DIFF ! $1-0.1|P_{\Delta e}|$

! 3rd return for $|P_{\Delta e}|<10$

ACOF=DIFF*TEMP5** ! $D\cdot(1-0.1|P_{\Delta e}|)^5=D\bullet A(|P_{\Delta e}|)$

RETURN

END !In SETUP2: $a_E=D_eA(|P_{\Delta e}|)+[0,-F_e]$

CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC

10.6.2.4 SUBROUTINE SOLVE

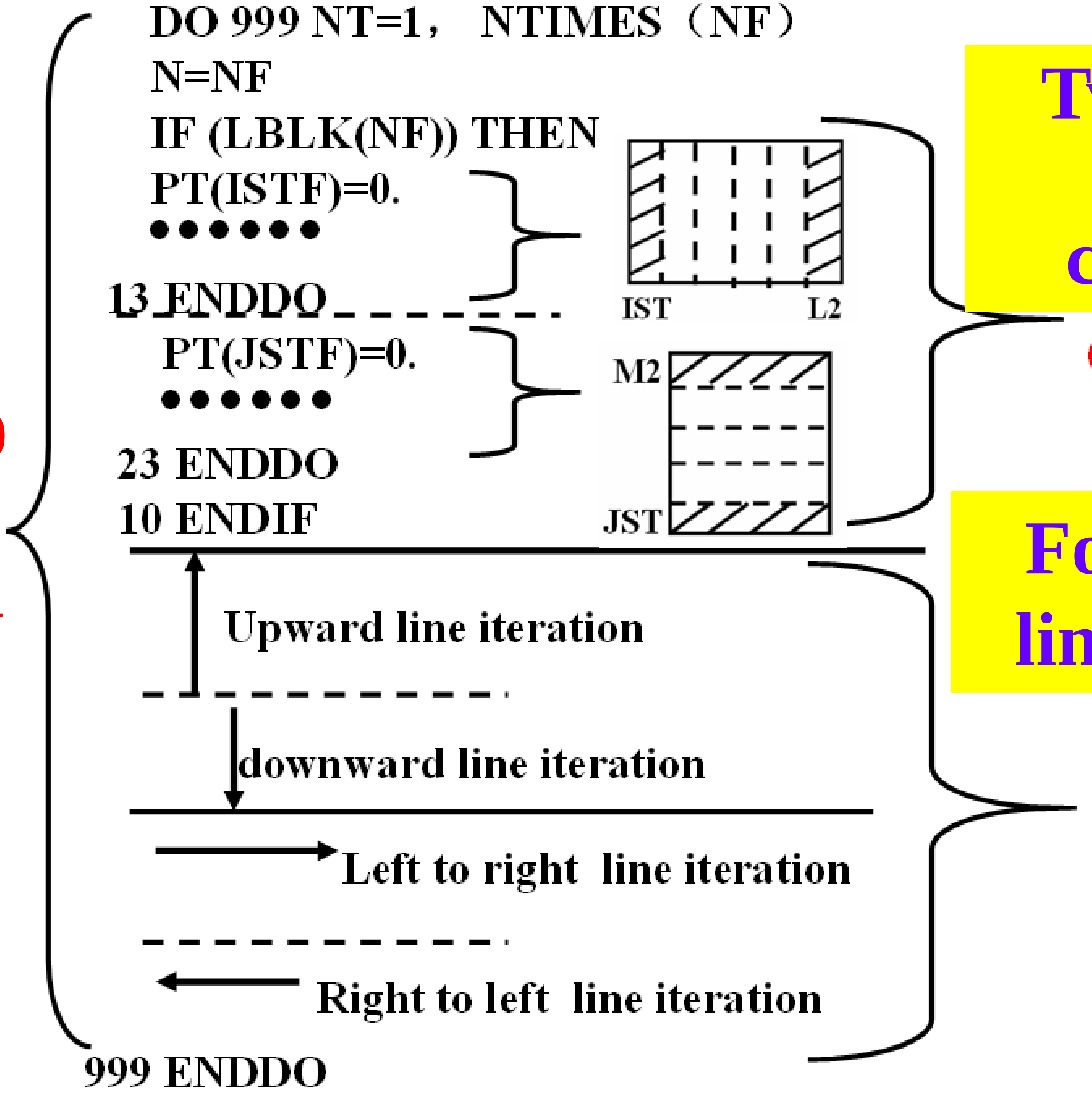
Calling Module

Declaration of variable type

```
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
    SUBROUTINE SOLVE   !ADI  line iteration＋Block correction
    USE START_L
    IMPLICIT NONE
    INTEGER*4 ISTF, JSTF, IT1, IT2, JT1, JT2, NT, N,I,J,II,JJ
    REAL*8 BL, BLP, BLM,  BLC, DENOM, TEMP
C*****************************************************************
```

Structure of SOLVE

AD---alternative direction



S O L V E

```
DO 999 NT=1， NTIMES（NF）
N=NF
IF (LBLK(NF)) THEN
PT(ISTF)=0.
••••••
13 ENDDO
 PT(JSTF)=0.
 ••••••
23 ENDDO
10 ENDIF
```

Upward line iteration

downward line iteration

Left to right line iteration

Right to left line iteration

```
999 ENDDO
```

Two times of block corrections

Correction

Fore times of line iterations

AD line Iteration

(4)-Explained in detail

Review on block correction

(5)-Explained in detail

$$(BL)\bar{\phi}'_i = (BLP)\bar{\phi}'_{i+1} + (BLM)\bar{\phi}'_{i-1} + BLC, i = IST, ...L2$$

$$BL = \sum_{j=JST}^{M2}(AP) - \sum_{j \neq M2}(AJP) - \sum_{j \neq JST}(AJM) \qquad BLP = \sum_{j=JST}^{M2}(AIP)$$

$$BLM = \sum_{j=JST}^{M2}(AIM) \qquad BLC = \sum_{j=JST}^{M2} CON + \sum_{j=JST}^{M2}(AJP)\phi^*_{i,j+1} + \sum_{j=JST}^{M2}(AJM)\phi^*_{i,j-1}$$

$$+ \sum_{j=JST}^{M2}(AIP)\phi^*_{i+1,j} + \sum_{j=JST}^{M2}(AIM)\phi^*_{i-1,j} - \sum_{j=JST}^{M2}(AP)\phi^*_{i,j}$$

$$\boxed{\begin{array}{c} BL = A, BLP = B, \\ BLM = C \end{array}}$$

$$A_i\bar{\phi}'_i = B\bar{\phi}'_{i+1} + C_i\bar{\phi}'_{i-1} + D_i, \ i = 1,2,.....M1 \rightarrow \bar{\phi}'_{i-1} = P_{i-1}\bar{\phi}'_i + Q_{i-1}$$

$$P_i = \frac{B_i}{\underline{A_i - C_i P_{i-1}}}; \quad Q_i = \frac{D_i + C_i Q_{i-1}}{\underline{A_i - C_i P_{i-1}}}; \qquad P_1 = \frac{B_1}{A_1}; \quad Q_1 = \frac{D_1}{A_1}$$

DENOM=BL-PT(I-1)*BLM

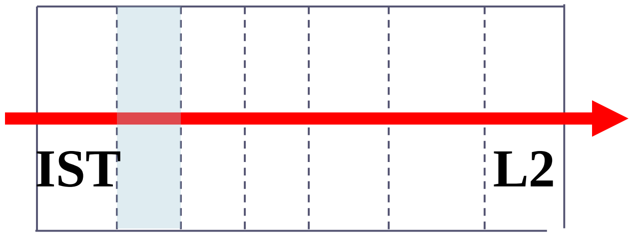
DENOM

Very small DENOM makes a too large correction which may inundate(淹没） the existing solution!

```
C********************************************************************
    ISTF=IST-1
    JSTF=JST-1
    IT1=L2+IST
    IT2=L3+IST
    JT1=M2+JST
    JT2=M3+JST
C********************************************************************
    DO 999  NT=1,NTIMES(NF) ! Solution of algebraic equation
    N=NF  !  NF: 1＝U， 2＝V， 3＝P， ……….
C------------------------------------------------------------------------------
   IF(LBLK(NF)) THEN !When LBLK is true, execute Block-correction
   PT(ISTF)=0.   !  Coefficient in TDMA   $P_{IST-1}$
   QT(ISTF)=0.   !  Constant in TDMA      $Q_{IST-1}$
   DO 11 I=IST,L2
   BL=0.     !Initial value in B-correction
   BLP=0.    !Initial value in B-correction
   BLM=0. ! Initial value in B-correction
```

!Temporal integral variables for 1st variable or starting point of DO-loop

I –direction B.Correction.



(5)- Explained in detail

In discussion of TDMA: A B C D

$$(BL)\bar{\phi}'_i = (BLP)\bar{\phi}'_{i+1} + (BLM)\bar{\phi}'_{i-1} + BLC, i = IST,..L2$$

Coefficients calculation

```
 BLC=0. !Initial value
 DO  12 J=JST,M2
 BL=BL+AP(I,J)
IF(J /= M2)  BL=BL-AJP(I,J)
IF(J /= JST) BL=BL-AJM(I,J)
BLP=BLP+AIP(I,J)
BLM=BLM+AIM(I,J)
BLC=BLC+CON(I,J)+AIP(I,J)*F(I+1,J,N)+AIM(I,J)*F(I-1,J,N)
1   +AJP(I,J)*F(I,J+1,N)+AJM(I,J)*F(I,J-1,N)-AP(I,J)*F(I,J,N)

12 ENDDO
```

$$BL = \sum_{j=JST}^{M2}(AP) - \sum_{j\neq M2}(AJP) - \sum_{j\neq JST}(AJM)$$

$$BLP = \sum_{j=JST}^{M2}(AIP)$$

$$BLM = \sum_{j=JST}^{M2}(AIM)$$

$$\boxed{\begin{aligned}BLC = &\sum_{j=JST}^{M2} CON + \sum_{j=JST}^{M2}(AJP)\phi^*_{i,j+1} + \sum_{j=JST}^{M2}(AJM)\phi^*_{i,j-1}\\ &+ \sum_{j=JST}^{M2}(AIP)\phi^*_{i+1,j} + \sum_{j=JST}^{M2}(AIM)\phi^*_{i-1,j} - \sum_{j=JST}^{M2}(AP)\phi^*_{i,j}\end{aligned}}$$

$$A_i\bar{\phi}'_{\text{i}} = B\bar{\phi}'_{\text{i+1}} + C_i\bar{\phi}'_{\text{i-1}} + D_i$$

$$\bar{\phi}'_{i-1} = P_{i-1}\bar{\phi}'_i + Q_{i-1}$$

$$P_i = \frac{B_i}{A_i - C_iP_{i-1}}; \quad Q_i = \frac{D_i + C_iQ_{i-1}}{\underline{A_i - C_iP_{i-1}}};$$

DENOM

Elimination (消元)

```
 DENOM=BL-PT(I-1)*BLM
 IF(ABS(DENOM/BL) <1.E-10) DENOM=1.E25
 PT(I)=BLP/DENOM
 QT(I)=(BLC+BLM*QT(I-1))/DENOM
11 ENDDO
```

!Ensure a meaningful correction

Back substitution (回代)

BL=0. （Initial set up)

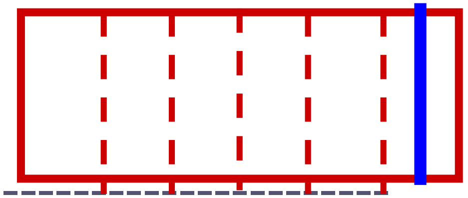
```
      BL=0.
      DO 13 II=IST,L2
      I=IT1-II
      BL=BL*PT(I)+QT(I)
      DO 14 J=JST,M2
      F(I,J,N)=F(I,J,N)+BL!
   14 ENDDO
   13 ENDDO
C-----------------------------------------------------------------------
      PT(JSTF)=0.
      QT(JSTF)=0.
      DO 21 J=JST,M2
      BL=0.
      BLP=0.
      BLM=0.
      BLC=0.
      DO 22  I=IST,L2
      BL=BL+AP(I,J)
      IF(I /= L2) BL=BL-AIP(I,J)
      IF(I /= IST) BL=BL-AIM(I,J)
      BLP=BLP+AJP(I,J)
```

IT1=L2+IST

I=IT1-II＝L2＋IST-IST＝L2-**Begin**

I=IT1-II＝L2＋IST-L2＝IST-**End**

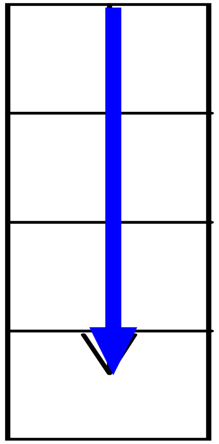
Correcting by BL for the same column



$$T_{i-1} = P_{i-1}T_i + Q_{i-1}$$

BL=BL*PT(I)+QT(I)

TDMA: from L2 to IST



$$(BL)\bar{\phi}'_j = (BLP)\bar{\phi}'_{j+1} + (BLM)\bar{\phi}'_{j-1} + BLC, J = JST,....M2$$

Y –direction

B-correction

```
       BLM=BLM+AJM(I,J) !
       BLC=BLC+CON(I,J)+AIP(I,J)*F(I+1,J,N)+AIM(I,J)*F(I-1,J,N)
     1 +AJP(I,J)*F(I,J+1,N)+AJM(I,J)*F(I,J-1,N)-AP(I,J)*F(I,J,N)
  22 ENDDO
       DENOM=BL-PT(J-1)*BLM  !
       IF(ABS(DENOM/BL)<1.E-10) DENOM=1.E25
       PT(J)=BLP/DENOM  !
       QT(J)=(BLC+BLM*QT(J-1))/DENOM
   21 ENDDO
        BL=0.
        DO  23 JJ=JST,M2
        J=JT1-JJ
        BL=BL*PT(J)+QT(J)
        DO 24 I=IST,L2
        F(I,J,N)=F(I,J,N)+BL !Correcting by BL for the same block
   24 ENDDO
   23 ENDDO
   10 ENDIF
  C―――――――――――――――――――――――――――――
  !  Above is block correction, following is ADI line iteration
```

Solving in I-direction，scanning in J direction, SLUR

$$AP\phi_{i,j}^{n}=AIP\phi_{i+1,j}^{n}+AIM\phi_{i-1,j}^{n}+b+AJP\phi_{i,j+1}^{n-1}+AJM\phi_{i,j-1}^{n-1};\quad i=IST\ldots L2$$

```
C------------------------------------------------------------------------------
    DO 90 J=JST,M2
    PT(ISTF)=0.          ! PT=0，QT=given boundary value, 1st kind boundary condition
    QT(ISTF)=F(ISTF,J,N)
    DO 70 I=IST,L2
    DENOM=AP(I,J)-PT(I-1)*AIM(I,J)
    PT(I)=AIP(I,J)/DENOM
    TEMP=CON(I,J)+AJP(I,J)*F(I,J+1,N)+AJM(I,J)*F(I,J-1,N)
    QT(I)=(TEMP+AIM(I,J)*QT(I-1))/DENOM
  70 ENDDO
    DO 80 II=IST,L2
    I=IT1-II  !Recursive
    F(I,J,N)=F(I+1,J,N)*PT(I)+QT(I)
  80 ENDDO
  90 ENDDO
C------------------------------------------------------------------------------
```

Elimination (消元): DO 70 … QT(I)

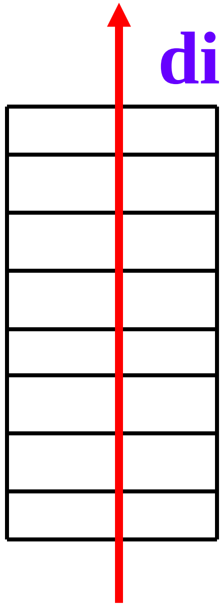
Back substitution (回代): DO 80 … F(I,J,N)

$$P_i=\frac{B_i}{A_i-C_iP_{i-1}};$$

$$Q_i=\frac{D_i+C_iQ_{i-1}}{A_i-C_iP_{i-1}};$$

$$b+AJP\phi_{i,j+1}^{n-1}+AJM\phi_{i,j-1}^{n-1}$$

$$T_{i-1}=P_{i-1}T_i+Q_{i-1}$$



Scanning direction

```
C-------------------------------------------------------------------------------------
       DO 190 JJ=JST,M3 ！ Solving in I-direction， scanning from t
       J=JT2-JJ  !Starting from JT2 ,rather than from JT1
       PT(ISTF)=0.
       QT(ISTF)=F(ISTF,J,N)
       DO 170 I=IST,L2
       DENOM=AP(I,J)-PT(I-1)*AIM(I,J)
       PT(I)=AIP(I,J)/DENOM
       TEMP=CON(I,J)+AJP(I,J)*F(I,J+1,N)+AJM(I,J)*F(I,J-1,N)
       QT(I)=(TEMP+AIM(I,J)*QT(I-1))/DENOM
    170 ENDDO
       DO 180 II=IST,L2
       I=IT1-II  !Recursive solution
       F(I,J,N)=F(I+1,J,N)*PT(I)+QT(I)
    180 ENDDO
    190 ENDDO
C-------------------------------------------------------------------------------------
```

For executing 1st kind B.C.

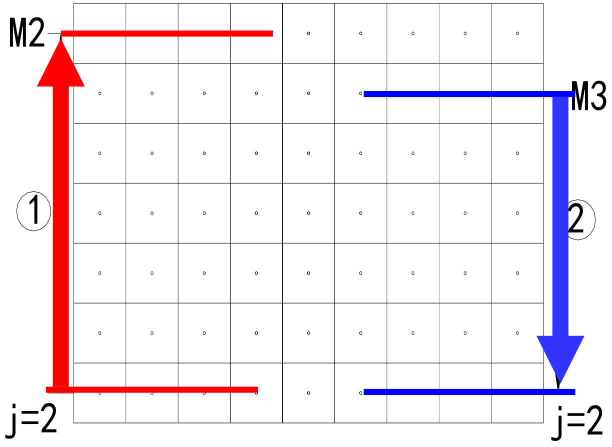
Elimination
(消元)

Back substitution
(回代)

$$P_i = \frac{B_i}{A_i - C_i P_{i-1}};$$

$$b + AJP\phi_{i,j+1}^{n-1} + AJM\,\phi_{i,j-1}^{n-1}$$

$$Q_i = \frac{D_i + C_i Q_{i-1}}{A_i - C_i P_{i-1}};$$



```
C-----------------------------------------------------------------------
   DO 290 I=IST,L2！ Solving in J-direction, scanning from left to right
   DO 270 J=JST,M2
   DENOM=AP(I,J)-PT(J-1)*AJM(I,J)
   PT(J)=AJP(I,J)/DENOM
   TEMP=CON(I,J)+AIP(I,J)*F(I+1,J,N)+AIM(I,J)*F(I-1,J,N)
   QT(J)=(TEMP+AJM(I,J)*QT(J-1))/DENOM  ！
 270 ENDDO
   DO 280 JJ=JST,M2
   J=JT1-JJ  !Recursive solution
   F(I,J,N)=F(I,J+1,N)*PT(J)+QT(J)  ！ P100(a)，
 280 ENDDO
 290 ENDDO
C-----------------------------------------------------------------------
```

```
C-----------------------------------------------------------------------------------
    DO 390 II=IST,L3  !  Solving in J-direction, scanning from right to left
    I=IT2-II
    PT(JSTF)=0.
    QT(JSTF)=F(I,JSTF,N)
    DO 370 J=JST,M2
    DENOM=AP(I,J)-PT(J-1)*AJM(I,J)
    PT(J)=AJP(I,J)/DENOM ,
    TEMP=CON(I,J)+AIP(I,J)*F(I+1,J,N)+AIM(I,J)*F(I-1,J,N)
    QT(J)=(TEMP+AJM(I,J)*QT(J-1))/DENOM
 370 ENDDO
    DO 380 JJ=JST,M2
    J=JT1-JJ  !Recursive solution
    F(I,J,N)=F(I,J+1,N)*PT(J)+QT(J)  !  P100(a),
 380 ENDDO
 390 ENDDO
C*****************************************************************
```

```
C**************************************************************
 999 ENDDO    ！（End of solution of ABEqs )

     ENTRY RESET  ！（CON， AP are accumulatively used, should be reset）
     DO 400 J=2,M2
     DO 401 I=2,L2
     CON(I,J)=0.
     AP(I,J)=0.
 401 ENDDO
 400 ENDDO
     RETURN
     END

CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
```

10.6.2.5 SUBROUTINE SETUP

```
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
  SUBROUTINE SETUP
C**********************************************************************************
   USE START_L
   IMPLICIT NONE
   INTEGRER*4 I, J,K,N
   REAL*8  REL, FL, FLM, FLP, GM, GMM, VOL, APT, AREA, SXT,
  1 SXB, ARHO
C***************************************************************************************
```

```
C************************************************************************
  1 FORMAT(//15X,'COMPUTATION  IN  CARTESIAN  COORDINATES‘
        !  Print out title for Cartesian coordinate
  2 FORMAT(//15X,'COMPUTATION FOR AXISYMMETRIC SITUATION')
        !  Print out title for cylindrical coordinate
  3 FORMAT(//15X,'COMPUTATION   IN   POLAR   COORDINATES')
        !  Print out title for polar coordinate
  4 FORMAT(14X,40(1H*),//)

C--------------------------------------------------------------------------------------------------------------
```

(6)-Explained in detail

Structure of SETUP

ENTRY SETUP1

- Setup 28 one dimensional geometric parameters;
- Setup initial values

RETURN

ENTRY SETUP2

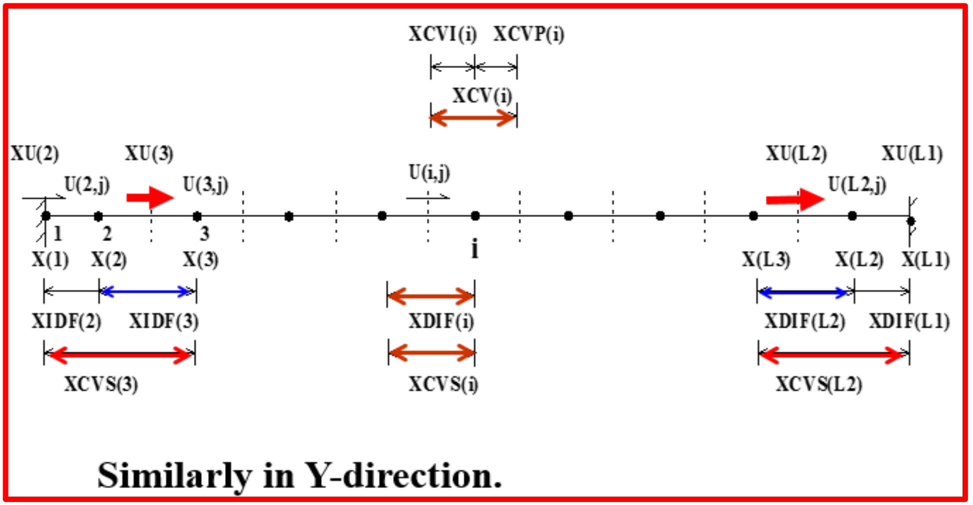
- Coefficient for u equation
- Coefficient for v equation
- Calculate UHAT and VHAT
- Coefficient for pressure equation and solve pressure
- Solve u equation and v equation.
- Coefficient for pressure correction equation and solve it.
- Correction velocity
- Coefficient for other equation and solve it (from NF=5 to 10 in order)

RETURN

SIMPLER

S E T U P

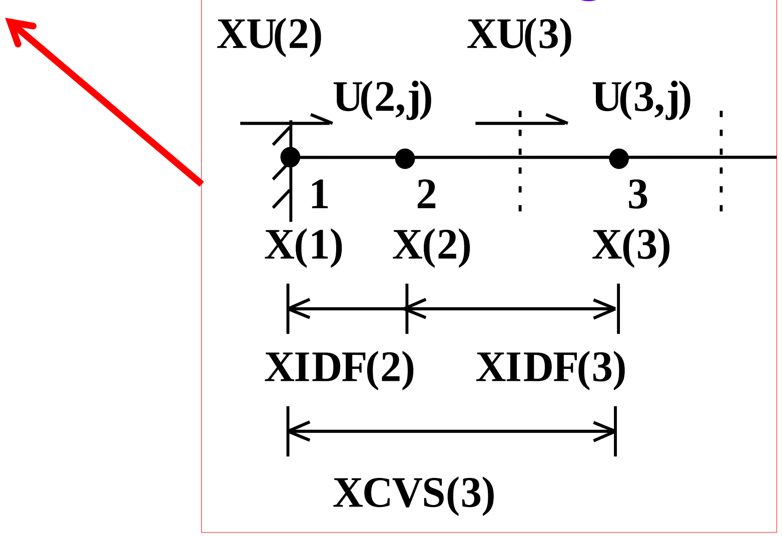
```
C-------------------------------------------------------------------------------
    ENTRY SETUP1 !Set up 1D arrays not changed  during iteration
    NP=NFMAX+1  ! NFMAX=10，NP＝11
    NRHO=NP +1  ! NRHO＝12
    NGAM=NRHO+1  ! NGAM＝13
    NCP=NGAM+1  ! NCP＝14
    L2=L1-1        ! Set up L2,L3,M2,M3
    L3=L2-1
    M2=M1-1
    M3=M2-1
    X(1)=XU(2)  ! X(1)＝XU(2)＝0
    DO 5 I=2,L2
    X(I)=0.5*(XU(I+1)+XU(I))
  5 ENDDO
    X(L1)=XU(L1)
    Y(1)=YV(2)              !Y(1)=YV(2)＝0
    DO 10 J=2,M2
    Y(J)=0.5*(YV(J+1)+YV(J)) !Practice B
 10 ENDDO
```



Similarly in Y-direction.

**! Practice B:
XU(I) has been
set in GRID**

```
      Y(M1)=YV(M1)
      DO 15 I=2,L1
      XDIF(I)=X(I)-X(I-1)
15 ENDDO
      DO 18 I=2,L2
      XCV(I)=XU(I+1)-XU(I)
18 ENDDO
      DO 20 I=3,L2
      XCVS(I)=XDIF(I)     ! Width of CV U (I,J) in x direction
20 ENDDO
      XCVS(3)=XCVS(3)+XDIF(2)!  Width of CV U connected with left boundary
      XCVS(L2)=XCVS(L2)+XDIF(L1) !  Width of CV U with right boundary
      DO 22 I=3,L3
      XCVI(I)=0.5*XCV(I)    !  $(\delta x)_{e^-}$
      XCVIP(I)=XCVI(I)       !  $(\delta x)_{e^+}$
22 ENDDO
      XCVIP(2)=XCV(2)
      XCVI(L2)=XCV(L2)
      DO 35 J=2,M1
      YDIF(J)=Y(J)-Y(J-1)
35 ENDDO
```



(7a)---Explained in detail

```
      DO 40 J=2,M2
      YCV(J)=YV(J+1)-YV(J)  !Width of main CV in y-direction
   40 ENDDO
      DO 45 J=3,M2
      YCVS(J)=YDIF(J)   ! Width of V (I,J) in y-direction
   45 ENDDO
      YCVS(3)=YCVS(3)+YDIF(2)
      YCVS(M2)=YCVS(M2)+YDIF(M1)
      IF(MODE= =1) THEN
      DO 52 J=1,M1
      RMN(J)=1.0    ! Nominal radius=1
      R(J)=1.0        ! for Cartesian coordinate
   52 ENDDO
      ELSE
      DO 50 J=2,M1          !Cylindrical and polar coordinates
      R(J)=R(J-1)+YDIF(J)  !R(1) has defined
   50 ENDDO
      RMN(2)=R(1)
      DO 60 J=3,M2
   60 RMN(J)=RMN(J-1)+YCV(J-1)   ! Radius of position of V(I,J)
   60 ENDDO
      RMN(M1)=R(M1)
      ENDIF
```

R＝1 for both nodes and interfaces in Cartesian coordinate

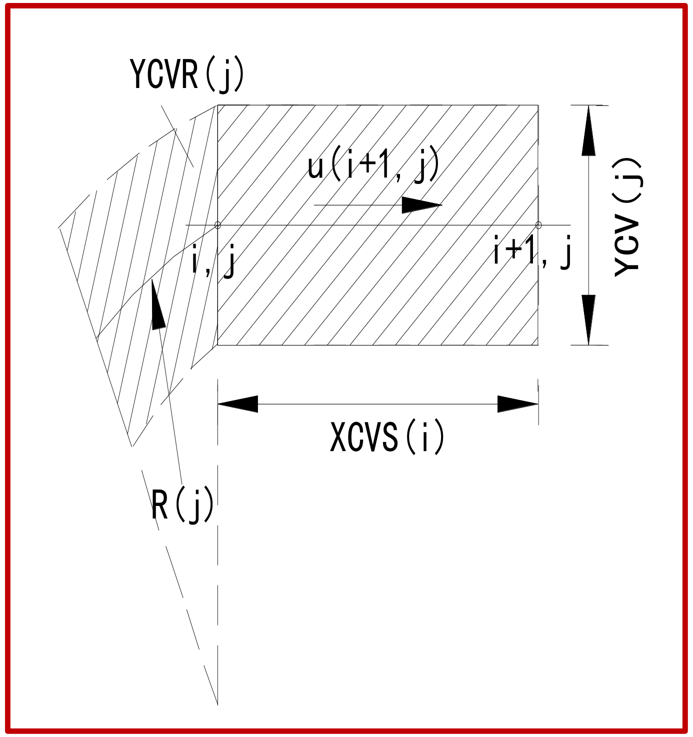
(7b)---Explained in detail

```
   DO 57 J=1,M1
   SX(J)=1.
   SXMN(J)=1.
   IF(MODE.== 3) THEN
   SX(J)=R(J)
   IF(J /= 1) SXMN(J)=RMN(J)
   ENDIF
57 ENDDO
   DO 62 J=2,M2
   YCVR(J)=R(J)*YCV(J)
   ARX(J)=YCVR(J)
   IF(MODE = = 3) THEN
   ARX(J)=YCV(J)
62 ENDDO
```

Set up scaling Factor for polar coordinate

Interface starts from J=2

!E-W conduction area of CV for three cases, for Cartesian R=1



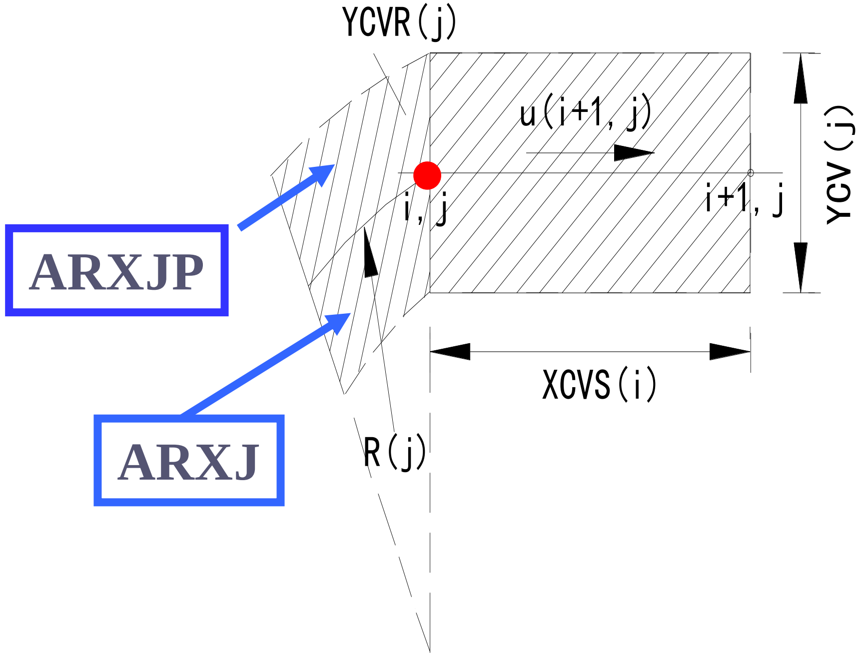
(7c)--- Explained in detail

```
      DO 64 J=4,M3
      YCVRS(J)=0.5*(R(J)+R(J-1))*YDIF(J)
   64 ENDDO
      YCVRS(3)=0.5*(R(3)+R(1))*YCVS(3)
      YCVRS(M2)=0.5*(R(M1)+R(M3))*YCVS(M2)
      IF(MODE = = 2) THEN
      DO 65 J=3,M3
      ARXJ(J)=0.25*(1.+RMN(J)/R(J))*ARX(J)
      ARXJP(J)=ARX(J)-ARXJ(J)
   65 ENDDO
      ELSE
      DO 66 J=3,M3
      ARXJ(J)=0.5*ARX(J)
      ARXJP(J)=ARXJ(J)
   66 ENDDO
      ENDIF
      ARXJP(2)=ARX(2)
      ARXJ(M2)=ARX(M2)
```

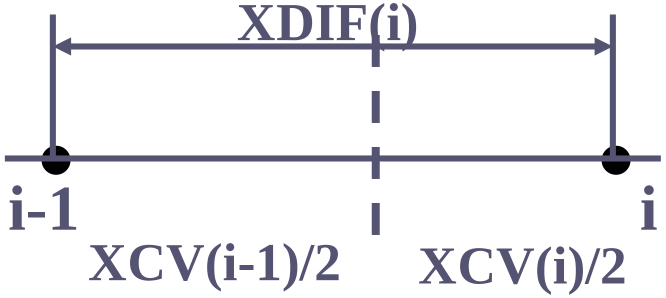
$$ARXJ(J)=\frac{1}{2}(R(j)+RMN(j))\bullet\frac{YCV(j)}{2}=$$

$$0.25[1+\frac{RMN(j)}{R(j)}]\bullet\underline{R(j)\bullet YCV(j)}=$$

$$0.25[1+\frac{RMN(j)}{R(j)}]\bullet\underline{ARX(j)}$$



```
      DO 70 J=3,M3
      FV(J)=ARXJP(J)/ARX(J)
      FVP(J)=1.-FV(J) !Interpolation coefficient
   70 ENDDO
      DO 85 I=3,L2
      FX(I)=0.5*XCV(I-1)/XDIF(I) !Interpolation  in x-direction
      FXM(I)=1.-FX(I)
   85 ENDDO
      FX(2)=0.
      FXM(2)=1.
      FX(L1)=1.
      FXM(L1)=0.
      DO 90 J=3,M2
      FY(J)=0.5*YCV(J-1)/YDIF(J) ! Interpolation in y-direction
      FYM(J)=1.-FY(J)
   90 ENDDO
      FYM(2)=1.
      FY(M1)=1.
      FYM(M1)=0.
CON,AP,U,V,RHO,PC AND P ARRAYS ARE INITIALIZED HERE
```



$$\boxed{\begin{aligned}\phi_{i-1/2} &= \phi_{i-1}\frac{\text{XCV(i)/2}}{\text{XDIF(i)}} + \phi_i\frac{\text{XCV(i-1)/2}}{\text{XDIF(i)}} \\ &= \phi_{i-1}FXM(i) + \phi_i FX(i)\end{aligned}}$$

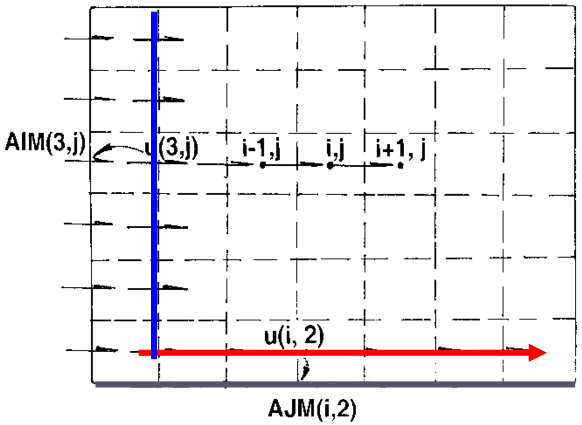
The first letter C is also used to indicate that this is an explanation line

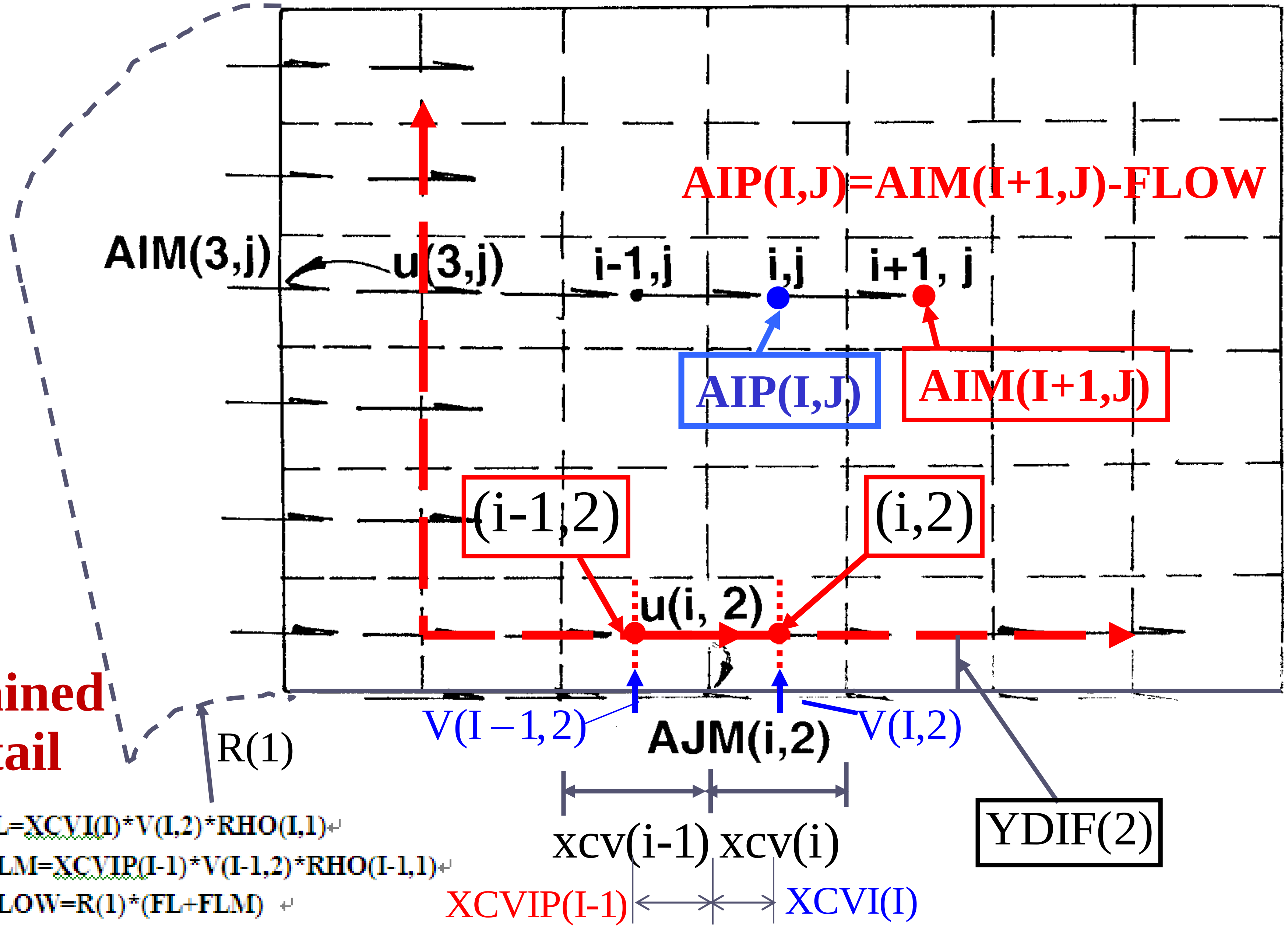
```
      DO 96 J=1,M1
      DO 95 I=1,L1
      PC(I,J)=0.
      U(I,J)=0.
      V(I,J)=0.
      CON(I,J)=0.
      AP(I,J)=0.
      RHO(I,J)=RHOCON
      CP（I,J)=CPCON
      P(I,J)=0.
95    ENDDO
96    ENDDO
      IF(MODE= =1) PRINT 1
      IF(MODE= =1) WRITE(8,1)
      IF(MODE= =2) PRINT 2
      IF(MODE= =2) WRITE(8,2)
      IF(MODE= =3) PRINT 3
      IF(MODE= =3) WRITE(8,3)
      PRINT 4
      WRITE(8,4)
      RETURN
```

Set up initial fields for iteration

Print out coordinate title of out put data

```
C-----------------------------------------------------------------------------
  ENTRY SETUP2
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
COEFFICIENTS FOR THE U EQUATION
     NF=1  ! NF=1:  U;  NF=2:  V;  NF=3:  P', P;  NF=NP:  P
     IF(LSOLVE(NF)) THEN      !
     IST=3
     JST=2
     CALL GAMSOR
     REL=1.-RELAX(NF) ! （U） underrelaxation
     DO 102 I=3,L2  !Coefficient of south boundary
     FL=XCVI(I)*V(I,2)*RHO(I,1)
     FLM=XCVIP(I-1)*V(I-1,2)*RHO(I-1,1)
     FLOW=R(1)*(FL+FLM) ! Flow rate through south interface
     DIFF=R(1)*(XCVI(I)*GAM(I,1)+XCVIP(I-1)*GAM(I-1,1))/YDIF(2)
     CALL DIFLOW !With DIFF and FLOW at hand CALL DIFLOW to get D.A(|P|);
     AJM(I,2)=ACOF+AMAX1(0.,FLOW)    Coefficient a_S
102 ENDDO
```





(8)---Explained in detail

```
FL=XCVI(I)*V(I,2)*RHO(I,1)
FLM=XCVIP(I-1)*V(I-1,2)*RHO(I-1,1)
FLOW=R(1)*(FL+FLM)
DIFF=R(1)*(XCVI(I)*GAM(I,1)+XCVIP(I-1)*GAM(I-1,1))/YDIF(2)
```

Explanation of DIFF(Diffusion conductance)

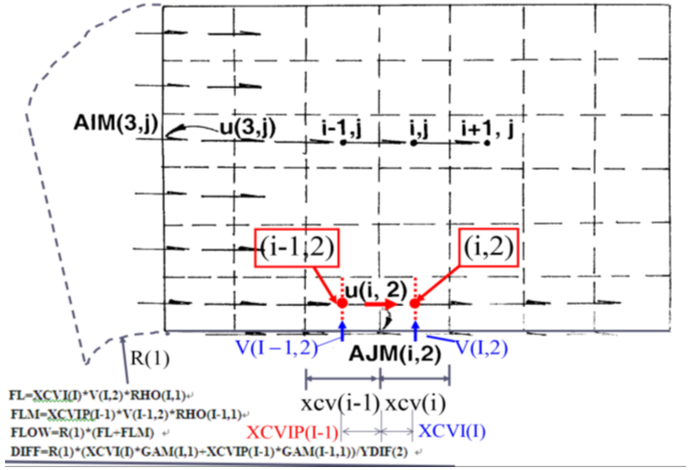
DIFF=R(1)*(XCVI(I)*GAM(I,1)+XCVIP(I-1)*GAM(I-1,1))/YDIF(2)

For Cartesian coordinates:

$$D_{n-e}=\frac{(\delta x)_{e^-}}{\dfrac{(\delta y)_n}{\Gamma_n}}+\frac{(\delta x)_{e^+}}{\dfrac{(\delta y)_n}{\Gamma_{ne}}}=\frac{(\delta x)_{e^-}\Gamma_n+(\delta x)_{e^+}\Gamma_{ne}}{(\delta y)_n}$$

For Cylindrical coordinates:

$$D_{n-e}=\mathrm{R1}[\frac{(\delta x)_{e^-}\Gamma_n+(\delta x)_{e^+}\Gamma_{ne}}{(\delta y)_n}]$$



```
FL=XCVI(I)*V(I,2)*RHO(I,1)
FLM=XCVIP(I-1)*V(I-1,2)*RHO(I-1,1)
FLOW=R(1)*(FL+FLM)
DIFF=R(1)*(XCVI(I)*GAM(I,1)+XCVIP(I-1)*GAM(I-1,1))/YDIF(2)
```

```
DO 103 J=2,M2
FLOW=ARX(J)*U(2,J)*RHO(1,J)
DIFF=ARX(J)*GAM(1,J)/(XCV(2)*SX(J))
CALL DIFLOW        ! Get A(|P|)
AIM(3,J)=ACOF+AMAX1(0.,FLOW)  !Coefficient aW
DO 104 I=3,L2
IF(I = = L2) THEN
FLOW=ARX(J)*U(L1,J)*RHO(L1,J)
DIFF=ARX(J)*GAM(L1,J)/(XCV(L2)*SX(J)) ! DW
ELSE
FL=U(I,J)*(FX(I)*RHO(I,J)+FXM(I)*RHO(I-1,J))
FLP=U(I+1,J)*(FX(I+1)*RHO(I+1,J)+FXM(I+1)*RHO(I,J))
FLOW=ARX(J)*0.5*(FL+FLP)
DIFF=ARX(J)*GAM(I,J)/(XCV(I)*SX(J))
ENDIF
CALL DIFLOW  !  A(|P|)
AIM(I+1,J)=ACOF+AMAX1(0.,FLOW)
AIP(I,J)=AIM(I+1,J)-FLOW  ! Relationship between coefficients
```

$$D \bullet A(|P_\Delta|) + \quad 0, F$$

```
 IF(J = = M2) THEN
 FL=XCVI(I)*V(I,M1)*RHO(I,M1)
 FLM=XCVIP(I-1)*V(I-1,M1)*RHO(I-1,M1)
 DIFF=R(M1)*(XCVI(I)*GAM(I,M1)+XCVIP(I-1)*GAM(I-1,M1))/YDIF(M1)
 ELSE
 FL=XCVI(I)*V(I,J+1)*(FY(J+1)*RHO(I,J+1)+FYM(J+1)*RHO(I,J))
 FLM=XCVIP(I-1)*V(I-1,J+1)*(FY(J+1)*RHO(I-1,J+1)+FYM(J+1)*
1 RHO(I-1,J))
  GM=GAM(I,J)*GAM(I,J+1)/(YCV(J)*GAM(I,J+1)+YCV(J+1)*GAM(I,J)+
1 1.0E-30)*XCVI(I)
  GMM=GAM(I-1,J)*GAM(I-1,J+1)/(YCV(J)*GAM(I-1,J+1)+YCV(J+1)*
1 GAM(I-1,J)+1.E-30)*XCVIP(I-1)
  DIFF=RMN(J+1)*2.*(GM+GMM)
  ENDIF
  FLOW=RMN(J+1)*(FL+FLM)
  CALL DIFLOW  !  A(|P|)
 AJM(I,J+1)=ACOF+AMAX1(0.,FLOW)
 AJP(I,J)=AJM(I,J+1)-FLOW   !Relationship between coefficients
```

(9)--- Explained in detail

```
 VOL=YCVR(J)*XCVS(I)        !Volume of velocity CV
 APT=(RHO(I,J)*XCVI(I)+RHO(I-1,J)*XCVIP(I-1))
1/(XCVS(I)*DT)  ! Unsteady term ρ/△t;   DT---△t;
 AP(I,J)=AP(I,J)-APT  ! AP (I,J)  at right side is SP
 CON(I,J)=CON(I,J)+APT*U(I,J)
 AP(I,J)=(-AP(I,J)*VOL+AIP(I,J)+AIM(I,J)+AJP(I,J)+AJM(I,J))
1/RELAX(NF) !Underrelaxation is organized during solution procedure
 CON(I,J)=CON(I,J)*VOL+REL*AP(I,J)*U(I,J) !  REL＝1－α
 DU(I,J)=VOL/(XDIF(I)*SX(J))  !  To get flow area
 DU(I,J)=DU(I,J)/AP(I,J) !  de in velocity correction
104 ENDDO
103 ENDDO
```

$$a_P^0 = \frac{\rho_P \Delta V}{\Delta t}$$

$$!\, d_e = A_e / a_e$$

$$\boxed{b = S_c \Delta V + a_p^0 \phi_p^0 + (1-\alpha)\frac{a_P}{\alpha}\phi_P^0}$$

$$\boxed{a_p = \left(\sum a_{nb} + \rho_P \Delta V/\Delta t - S_p \Delta V\right)/\alpha}$$

! Come here we have finished the coefficients calculation for u velocity and should store them temporary to leave COF empty for calculation coefficients for velocity v.

----------Review of SIMPLER algorithm-------------

(10)---Explained in detail

1. **Assuming initial fields， determine coefficients of discretized *u, v* eqs.;**
2. **Calculating pseudo-velocity** $u,\tilde{v}$;

$$\boxed{a_e u_e = \sum a_{nb} u_{nb} + b + A_e(p_P - p_E)}$$

$$u_e = \sum \frac{a_{nb}u_{nb}+b}{a_e} + \frac{A_e}{a_e}(p_P - p_E) \longrightarrow$$

$$u_e = \tilde{u}_e + \frac{A_e}{a_e}(p_P - p_E) = \tilde{u}_e + d_e(p_P - p_E); v_n = \tilde{v}_e + d_n(p_P - p_N)$$

and Solving pressure equation， obtaining p^* ;

$$\boxed{a_P p_P = a_E p_E + a_W p_W + a_N p_N + a_S p_S + b}$$

$$b = \frac{(\rho_P^0 - \rho_P)\Delta x \Delta y}{\Delta t} + [(\rho u)_w - (\rho u)_s]A_e + [(\rho\tilde{v})_s - (\rho\tilde{v})_n]A_n$$

$$a_P = a_E + a_W + a_N + a_S$$

$$a_E = d_e A_e \rho_e \quad a_W = d_w A_w \rho_w \quad a_n = d_n A_n \rho_n \quad a_S = d_s A_s \rho_s$$

$$\boxed{a_E = \rho(\frac{A_e}{a_e})\Delta y}$$

$$\boxed{a_N = \rho(\frac{A_n}{a_n})\Delta x}$$

Coefficients of *u*,*v* momentum equations are needed for determining coefficients of pressure equation.

3. Solving momentum equations based on p^* , obtaining u^*, v^*

4. Solving pressure correction equation based on u^*, v^* , obtaining p'

In pressure equation: $$b = [(\rho u)_w - (\rho u)_s]A_e + [(\rho \tilde{v})_s - (\rho \tilde{v})_n]A_n$$

In pressure correction equation: $$b = [(\rho u^*)_w - (\rho u^*)_s]A_e + [(\rho v^*)_s - (\rho v^*)_n]A_n$$

For boundary CV velocities take the specified values.

5. **Correcting velocity** $u = u^* + u^{'}; v = v^* + v^{'}$**, where** $u^{'}$ and $v^{'}$ **are determined based on** $p^{'}$

6. **Taking the updated velocity , repeating steps 1-6, until convergence is reached.**

```
    MODULE START_L
    PARAMETER (NI=100,NJ=200,NIJ=NI,NFMAX=10,NFX4=NFMAX+4)
C******************************************
    CHARACTER*8 TITLE(NFX4)
    LOGICAL LSOLVE(NFX4),LPRINT(NFX4),LBLK(NFX4),LSTOP
    REAL*8,DIMENSION(NI,NJ,NFX4)::F
    REAL*8,DIMENSION(NI,NJ,6)::COF,COFU,COFV,COFP
    REAL*8,DIMENSION(NI,NJ)::P,RHO,GAM,CP,CON,AIP,AIM,AJP,AJM,AP
    REAL*8,DIMENSION(NI):: U,V,PC,T,DU,DV,UHAT,VHAT
    REAL*8,DIMENSION(NI):: X,XU,XDIF,XCV,XCVS,XCVI,XCVIP
    REAL*8,DIMENSION(NJ)::Y,YV,YDIF,YCV,YCVS,YCVR,YCVRS,ARX,ARXJ,
   1   ARXJP,R,RMN,SX,SXMN
    REAL*8,DIMENSION(NI)::FV,FVP,FX,FXM
    REAL*8,DIMENSION(NJ)::FY,FYM
    REAL*8,DIMENSION(NIJ)::PT,QT
```

```
C*******************************************
  EQUIVALENCE(F(1,1,1),U(1,1)),(F(1,1,2),V(1,1)),(F(1,1,3),PC(1,1))
 1, (F(1,1,4),T(1,1))
  EQUIVALENCE(F(1,1,11),P(1,1)),(F(1,1,12),RHO(1,1)),(F(1,1,13)
 1,GAM(1,1)),(F(1,1,14),CP(1,1))
  EQUIVALENCE(COF(1,1,1),CON(1,1)),(COF(1,1,2),AIP(1,1)),
 1(COF(1,1,3),AIM(1,1)),(COF(1,1,4),AJP(1,1)),
 2(COF(1,1,5),AJM(1,1)),(COF(1,1,6),AP(1,1))
  REAL*8,DIMENSION(NI)::TH,THU,THDIF,THCV,THCVS
  REAL*8 THL
  EQUIVALENCE(X,TH),(XU,THU),(XDIF,THDIF),(XCV,THCV),
 1(XCVS,THCVS),(XL,THL)
   DATA LSTOP,LSOLVE,LPRINT/.FALSE.,NFX4*.FALSE., NFX4*.FALSE./
   DATA LBLK/NFX4*.TRUE./
   DATA MODE,LAST,TIME,ITER/1,5,0.,0/
   DATA RELAX,NTIMES/NFX4*1.,NFX4*1/
   DATA DT,IPREF,JPREF,RHOCON,CPCON/1.E+30, 1,1,1.,1./
   END MODULE
```

----------End of Review of SIMPLER algorithm-------------

```
COFU(IST:L2, JST:M2, 1:6)=COF(IST:L2,JST:M2,1:6) ! Transfer the coefficients
! Store coefficients of U temporary as follows:
```

COF(I,J,1)	COF(I,J,2)	COF(I,J,3)	COF(I,J,4)	COF(I,J,5)	COF(I,J,6)
CON（I,J）	AIP(I,J)	AIM(I,J)	AJP(I,J)	AJM(I,J)	AP(I,J)

Explain

```
!  In SIMPLER to solve pressure eq., coefficients of both u eq.and
!  v-eq. are needed. Only u-coefficients are not enough. Thus
!  u-coefficients  are temporary stored, and v-eq. coefficients
!  are computed by using array COF(I,J)
```

COEFFICIENTS FOR THE V EQUATION-（Determine coefficients of V

```
NF=2          !
CALL RESET  !Set zero values for AP(I,J),CON(I,J)
IST=2
JST=3
CALL GAMSOR
REL=1.-RELAX(NF)
```

(11)---Explained in detail

```
   DO 202 I=2,L2
   AREA=R(1)*XCV(I)
   FLOW=AREA*V(I,2)*RHO(I,1)
   DIFF=AREA*GAM(I,1)/YCV(2)
   CALL DIFLOW
   AJM(I,3)=ACOF+AMAX1(0.,FLOW)  ! a_S
202 ENDO
   DO 203 J=3,M2
   FL=ARXJ(J)*U(2,J)*RHO(1,J)
   FLM=ARXJP(J-1)*U(2,J-1)*RHO(1,J-1)
   FLOW=FL+FLM
   DIFF=(ARXJ(J)*GAM(1,J)+ARXJP(J-1)*GAM(1,J-1))/(XDIF(2)*SXMN(J))
   CALL DIFLOW
   AIM(2,J)=ACOF+AMAX1(0.,FLOW) ! a_W
   DO 204 I=2,L2
   IF(I.E= = L2) THEN
   FL=ARXJ(J)*U(L1,J)*RHO(L1,J)
   FLM=ARXJP(J-1)*U(L1,J-1)*RHO(L1,J-1)
   DIFF=(ARXJ(J)*GAM(L1,J)+ARXJP(J-1)*GAM(L1,J-
  1 1))/(XDIF(L1)*SXMN(J))
```

```
  ELSE
  FL=ARXJ(J)*U(I+1,J)*(FX(I+)*RHO(I+1,J)+FXM(I+1)*RHO(I,J))
  FLM=ARXJP(J-1)*U(I+1,J-1)*(FX(I+1)*RHO(I+1,J-1)+FXM(I+1)*RHO(I,J-1))
  GM=GAM(I,J)*GAM(I+1,J)/(XCV(I)*GAM(I+1,J)+XCV(I+1)*GAM(I,J)+
1 1.E-30)*ARXJ(J)
  GMM=GAM(I,J-1)*GAM(I+1,J-1)/(XCV(I)*GAM(I+1,J-1)+XCV(I+1)*
1 GAM(I,J-1)+1.0E-30)*ARXJP(J-1)
  DIFF=2.*(GM+GMM)/SXMN(J)
  ENDIF
  FLOW=FL+FLM
  CALL DIFLOW
  AIM(I+1,J)=ACOF+AMAX1(0.,FLOW)        ! a_W
  AIP(I,J)=AIM(I+1,J)-FLOW!Relationship between coefficients
  IF (J= =M2) THEN
  AREA=R(M1)*XCV(I)
  FLOW=AREA*V(I,M1)*RHO(I,M1)
```

```
DIFF=AREA*GAM(I,M1)/YCV(M2)
ELSE
AREA=R(J)*XCV(I)
FL=V(I,J)*(FY(J)*RHO(I,J)+FYM(J)*RHO(I,J-1))*RMN(J)
FLP=V(I,J+1)*(FY(J+1)*RHO(I,J+1)+FYM(J+1)*RHO(I,J))*RMN(J+1)
FLOW=(FV(J)*FL+FVP(J)*FLP)*XCV(I)
DIFF=AREA*GAM(I,J)/YCV(J)
ENDIF
CALL DIFLOW
AJM(I,J+1)=ACOF+AMAX1(0.,FLOW) ! a_S
AJP(I,J)=AJM(I,J+1)-FLOW          !Relationship
VOL=YCVRS(J)*XCV(I)         !Volume of V- CV
SXT=SX(J)
```

```
      APT=(ARXJ(J)*RHO(I,J)*0.5*(SXT+SXMN(J))+ARXJP(J-1)*RHO(I,J-1)*
     10.5*(SXB+SXMN(J)))/(YCVRS(J)*DT)
      AP(I,J)=AP(I,J)-APT
      CON(I,J)=CON(I,J)+APT*V(I,J)
      AP(I,J)=(-AP(I,J)*VOL+AIP(I,J)+AIM(I,J)+AJP(I,J)+AJM(I,J))
     1/RELAX(NF)
      CON(I,J)=CON(I,J)*VOL+REL*AP(I,J)*V(I,J)
      DV(I,J)=VOL/YDIF(J)
      DV(I,J)=DV(I,J)/AP(I,J)
  204 ENDDO
  203 ENDDO
      COFV(IST:L2,JST:M2,1:6)=COF(IST:L2,JST:M2,1,6)
     !  Store   coefficients of V-eq. to compute coefficients of P-equation
  CALCULATE UHAT AND VHAT !
      DO 150 J=2,M2
      DO 151 I=3,L2
      UHAT(I,J)=(COFU(I,J,2)*U(I+1,J)+COFU(I,J,3)*U(I-1,J)+COFU(I,J,4)
     1 *U(I,J+1)+COFU(I,J,5)*U(I,J-1)+COFU(I,J,1))/COFU(I,J,6)
```

! Compute $u, \tilde{v}$

$$\boxed{\bar{u}_e = \sum \frac{a_{nb}u_{nb}+b}{a_e}}$$

```
151 ENDDO
150 ENDDO
      DO 250 J=3,M2
      DO 251 I=2,L2
      VHAT(I,J)=(COFV(I,J,2)*V(I+1,J)+COFV(I,J,3)*V(I-1,J)+COFV(I,J,4)
     1 *V(I,J+1)+COFV(I,J,5)*V(I,J-1)+COFV(I,J,1))/COFV(I,J,6)
251 ENDDO\
250 ENDDO
```

COEFFICIENTS FOR THE PRESSURE EQUATION-----------------------------

```
      NF=3
      CALL RESET
      IST=2
      JST=2
      CALL GAMSOR
```

!In the discretized pressure equation the source term is

! $b=[(\rho u)_w-(\rho u)_e]A_e+[(\rho\tilde{v})_s-(\rho\tilde{v})_n]A_n$

!This term has to be computed for every interface of a CV!

```
      DO 410 J=2,M2,
      DO 411 I=2,L2
      VOL=YCVR(J)*XCV(I)
      CON(I,J)=CON(I,J)*VOL
411 ENDDO
410 ENDDO
```

!Volume of main CV.

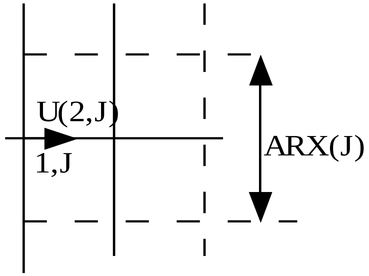
!Pressure has no inherent source term, here setting this
!operation just for general purpose .Usually COM(I,J)=0

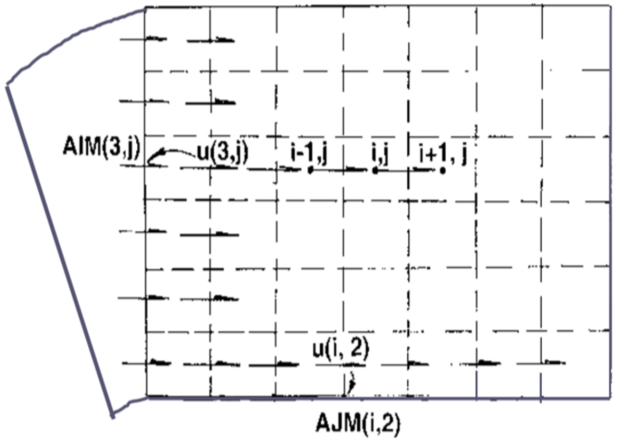
(12) Explained in detail

! For boundary actual velocity is used.

累加

```
DO 402 I=2,L2
ARHO=R(1)*XCV(I)*RHO(I,1)
CON(I,2)=CON(I,2)+ARHO*V(I,2) ! Accumulative add
AJM(I,2)=0  !a_S =0，  Adiabatic boundary
402 ENDDO
DO 403 J=2,M2
ARHO=ARX(J)*RHO(1,J)
CON(2,J)=CON(2,J)+ARHO*U(2,J) ! Accumulative additio
AIM(2,J)=0. ! a_W =0，  Adiabatic  boundary
DO 404 I=2,L2
IF(I= =L2) THEN !For the last CV the given velocity is used
ARHO=ARX(J)*RHO(L1,J)
CON(I,J)=CON(I,J)-ARHO*U(L1,J) ! Accumulative addition
AIP(I,J)=0.  !a_E=0
ELSE
ARHO=ARX(J)*（FX(I+1)*RHO(I+1,J)+FXM(I+1)*RHO(I,J))
```





$$! \quad b = [(\rho u)_w - (\rho u)_e] A_e + [(\rho \tilde{v})_s - (\rho \tilde{v})_n] A_n$$

```
FLOW=ARHO*UHAT(I+1,J) !   ! For inner CV  UHAT is used.
CON(I,J)=CON(I,J)-FLOW
CON(I+1,J)=CON(I+1,J)+FLOW !
AIP(I,J)=ARHO*DU(I+1,J)    ! aE
AIM(I+1,J)=AIP(I,J) !Relationship between （aW） and (aE)i+1
ENDIF
IF(J= =M2) THEN
ARHO=RMN(M1)*XCV(I)*RHO(I,M1)
CON(I,J)=CON(I,J)-ARHO*V(I,M1) ! Accumulative addition
AJP(I,J)=0. !  North coefficient of M2
ELSE
ARHO=RMN(J+1)*XCV(I)*(FY(J+1)*RHO(I,J+1)+FYM(J+1)*RHO(I,J))
FLOW=ARHO*VHAT(I,J+1)      ! For inner CV  VHAT is used.
CON(I,J)=CON(I,J)-FLOW
CON(I,J+1)=CON(I,J+1)+FLOW
AJP(I,J)=ARHO*DV(I,J+1)
AJM(I,J+1)=AJP(I,J) !Relationship between coefficients
ENDIF
```

```
      AP(I,J)=AIP(I,J)+AIM(I,J)+AJP(I,J)+AJM(I,J)
404 ENDDO
403 ENDDO
      DO 421 J=2,M2
      DO 422 I=2,L2
      AP(I,J)=AP(I,J)/RELAX(NP)  ! Pressure underrelaxation
      CON(I,J)=CON(I,J)+(1.0-RELAX(NP))*AP(I,J)*P(I,J)
422 ENDDO
421 ENDDO
      COFP(IST:L2,JST:M2,2:5)=COF(IST:L2,JST:M2,2:5)
```

(13) Explained in detail

!Store a_E,a_W,a_N,a_S for p-correction equation

! while CON（b）and AP (a_P) are not stored； Because AP has been
!underrelaxed, and the velocity in b term of p-correction eq. is different.

```
    NF=NP !NFMAX+1; P(I,J) is one member of F(I,J,NF)
    CALL SOLVE  !  Solving P-equation
```

```
COMPUTE U AND V！ Pressure has been solved
      NF=1
      IST=3
      JST=2
      COF(IST:L2,JST:M2,1:6)=COFU(IST:L2,JST:M2,1:6)！ Coefficients of U
      DO 551 J=JST,M2
      DO 552 I=IST,L2
      CON(I,J)=CON(I,J)+DU(I,J)*AP(I,J)*(P(I-1,J)-P(I,J))
522 ENDDO
521 ENDDO
      CALL SOLVE  !Solving U equation
C--------------------------------------------------------------------------------
      NF=2
      IST=2
      JST=3
      COF(IST:L2,JST:M2,1:6)=COFV(IST:L2,JST:M2,1:6) !Coefficients of V
      DO 553 J=JST,M2
      DO 554 I=IST,L2
      CON(I,J)=CON(I,J)+DV(I,J)*AP(I,J)*(P(I,J-1)-P(I,J))
```

```
      CON(I,J)=CON(I,J)+DV(I,J)*AP(I,J)*(P(I,J-1)-P(I,J))
554 ENDDO
553 ENDDO
      CALL SOLVE  !  Solving V-equation. Such U V are temporary, need to be
   ! improved
COEFFICIENTS FOR THE PRESSURE CORRECTION EQUATION
      NF=3       !  P-correction equation
      CALL RESET     !  Zero of CON(I,j)  and AP(i,j)
      IST=2
      JST=2
      COF(IST:L2,JST:M2,2:5)=COFP(IST:L2,JST:M2,2:5)
   !  Transfer coefficients of P-eq. to P-correction equation.
      CALL GAMSOR
      SMAX=0.
      SSUM=0.
```

$$! \quad b=[(\rho u^*)_w-(\rho u^*)_e]A_e+[(\rho v^*)_s-(\rho v^*)_n]A_n$$

! The velocities just solved are u* and v*

```
      DO 510 J=2,M2
      DO 511 I=2,L2
      VOL=YCVR(J)*XCV(I)        !  Volume of PCV
      CON(I,J)=CON(I,J)*VOL
511 ENDDO
510 ENDDO
      DO 502 I=2,L2
      ARHO=R(1)*XCV(I)*RHO(I,1)
      CON(I,2)=CON(I,2)+ARHO*V(I,2)  !  Source term b
502 ENDDO
      DO 503 J=2,M2
      ARHO=ARX(J)*RHO(1,J)
      CON(2,J)=CON(2,J)+ARHO*U(2,J)
      DO 504 I=2,L2
      IF(I= =L2) THEN
      ARHO=ARX(J)*RHO(L1,J)
      CON(I,J)=CON(I,J)-ARHO*U(L1,J)  !  Calculate b-term
      ELSE

      ARHO=ARX(J)*(FX(I+1)*RHO(I+1,J)+FXM(I+1)*RHO(I,J))
      FLOW=ARHO*U(I+1,J)  !  Adopt U*,V* to solve P’
      CON(I,J)=CON(I,J)-FLOW
      CON(I+1,J)=CON(I+1,J)+FLOW
```

Do loop 502－504 for mass source of each CV

```
      ENDIF
      IF(J= =M2) THEN
      ARHO=RMN(M1)*XCV(I)*RHO(I,M1)
      CON(I,J)=CON(I,J)-ARHO*V(I,M1
      ELSE
      ARHO=RMN(J+1)*XCV(I)*(FY(J+1)*RHO(I,J+1)+FYM(J+1)*RHO(I,J))
      FLOW=ARHO*V(I,J+1)
      CON(I,J)=CON(I,J)-FLOW
      CON(I,J+1)=CON(I,J+1)+FLOW
      ENDIF
      AP(I,J)=AIP(I,J)+AIM(I,J)+AJP(I,J)+AJM(I,J)
      PC(I,J)=0.  !  Initial field
      SMAX=AMAX1(SMAX,ABS(CON(I,J)))  !  Take the maximum
      SSUM=SSUM+CON(I,J)  !  Summation of b
  504 ENDDO
  503 ENDDO
      CALL SOLVE  !  Solving p-correction equation
```

For AP

```
COME HERE TO CORRECT THE VELOCITIES
      DO 521 J=2,M2
      DO 522 I=2,L2
      IF(I/=2) U(I,J)=U(I,J)+DU(I,J)*(PC(I-1,J)-PC(I,J)) !  Correcting velocity u
      IF(J/=2) V(I,J)=V(I,J)+DV(I,J)*(PC(I,J-1)-PC(I,J)) !  Correcting velocity v
522 ENDDO
521 ENDDO
500 ENDIF
COEFFICIENTS FOR OTHER EQUATIONS----------------------------------------
      IST=2
      JST=2
      DO 600 N=4,NFMAX  !NF>=4
      NF=N
      IF(LSOLVE(NF)) THEN
      CALL GAMSOR
      IF(LSOLE(4)) THEN
      DO I=1,L1
      DO J=1,M1
      RHO(I,J)=RHO(I,J)*CP(I,J)    !  This is the temperature
      ENDDO
      ENDDO
      REL=1.-RELAX(NF)
```

(14) Explain in detail

```
DO 602 I=2,L2
AREA=R(1)*XCV(I)
FLOW=AREA*V(I,2)*RHO(I,1)
DIFF=AREA*GAM(I,1)/YDIF(2)
CALL DIFLOW
AJM(I,2)=ACOF+AMAX1(0.,FLOW)
602 ENDDO
DO 603 J=2,M2
FLOW=ARX(J)*U(2,J)*RHO(1,J)
DIFF=ARX(J)*GAM(1,J)/(XDIF(2)*SX(J))
CALL DIFLOW
AIM(2,J)=ACOF+AMAX1(0.,FLOW)
DO 604 I=2,L2
IF(I= =L2) THEN
FLOW=ARX(J)*U(L1,J)*RHO(L1,J)
DIFF=ARX(J)*GAM(L1,J)/(XDIF(L1)*SX(J))
ELSE
FLOW=ARX(J)*U(I+1,J)*(FX(I+1)*RHO(I+1,J)+FXM(I+1)*RHO(I,J))
DIFF=ARX(J)*2.*GAM(I,J)*GAM(I+1,J)/((XCV(I)*GAM(I+1,J)+
```

```
1 XCV(I+1)*GAM(I,J)+1.0E-30)*SX(J))
  ENDIF
  CALL DIFLOW
  AIM(I+1,J)=ACOF+AMAX1(0.,FLOW)
  AIP(I,J)=AIM(I+1,J)-FLOW
  AREA=RMN(J+1)*XCV(I)
   IF(J= = M2) THEN
   FLOW=AREA*V(I,M1)*RHO(I,M1)
   DIFF=AREA*GAM(I,M1)/YDIF(M1)
   ELSE
   FLOW=AREA*V(I,J+1)*(FY(J+1)*RHO(I,J+1)+FYM(J+1)*RHO(I,J))
   DIFF=AREA*2.*GAM(I,J)*GAM(I,J+1)/(YCV(J)*GAM(I,J+1)+
 1 YCV(J+1)*GAM(I,J)+1.0E-30)
   ENDIF
   CALL DIFLOW
```

(15)---Explained in detail

```
          AJM(I,J+1)=ACOF+AMAX1(0.,FLOW)
          AJP(I,J)=AJM(I,J+1)-FLOW
          VOL=YCVR(J)*XCV(I)
          APT=RHO(I,J)/DT  ! Transient term ρ/△t without volume
          AP(I,J)=AP(I,J)-APT
          CON(I,J)=CON(I,J)+APT*F(I,J,NF)
          AP(I,J)=(-AP(I,J)*VOL+AIP(I,J)+AIM(I,J)+AJP(I,J)+AJM(I,J))
        1/RELAX(NF)
           CON(I,J)=CON(I,J)*VOL+REL*AP(I,J)*F(I,J,NF)
604 ENDO
603 ENDO
           CALL SOLVE !
           IF（LSLVE(4)) THEN ! If the temp. eq. is solved ,them Reset density back to rho
           DO I=I,L1
           DO J=1,M1
           RHO(I,J)=RHO(I,J)/CP(I,J)  ! Reset density back to rho
           ENDDO
           ENDDO
           ENDIF
           ENDIF
600 ENDDO（End of the solving process）
           TIME=TIME+DT  ！ Forward time
           ITER=ITER+1   !Increase the indicator
           IF(ITER>= LAST) LSTOP=.TRUE. RETURN
           END
```

$$a_p = \left(\sum a_{nb} + \rho_P \Delta V/\Delta t - S_p \Delta V\right)/\alpha$$

$$b = S_c \Delta V + a_p^0 \phi_p^0 + (1-\alpha)\frac{a_P}{\alpha}\phi_P^0$$

Transient,
Linear----
Steady,
nonlinear

10.6.2.6 SUBROUTINE SUPPLY

```
      SUBROUTINE SUPPLY
C************************************************************************
      USE START_L
      IMPLICIT NONE
      REAL*8 DX,DY,RHOM,PREF
      INTEGER*4 I,J,N,JJ,IEND,JEND,IBEG,JBEG,IFST,JFST,JFL
C************************************************************************
```

```
C*****************************************************************
  10 FORMAT(1X,26(1H*),3X,A10,3X,26(1H*))
  20 FORMAT(1X,4H I =,I6,6I9)
  30 FORMAT(1X,' J')
  40 FORMAT(1X,I3,2X,1P7E9.2)
  50 FORMAT(1X,1H )
  51 FORMAT(2X,'I =',2X,7(I4,5X))
  52 FORMAT(2X,'X =',1P7E9.2)
  53 FORMAT(1X,' TH =',1P7E9.2)
  54 FORMAT(2X,'J =',2X,7(I4,5X))
  55 FORMAT(2X,'Y =',1P7E9.2)
C*****************************************************************
     ENTRY UGRID
     XU(2)=0.
     DX=XL/FLOAT(L1-2)
     DO 1 I=3,L1
     XU(I)=XU(I-1)+DX
   1 ENDDO
     YV(2)=0.
     DY=YL/FLOAT(M1-2)

      DO 2 J=3,M1
      YV(J)=YV(J-1)+DY
    2 ENDDO
      RETURN
```

!1P7E9.2

!1P---1 integral digit of each data;

!7E---7 data in scientific expression

! 9.2---Each data contains 9 places, and there are two decimal places (小数2位)

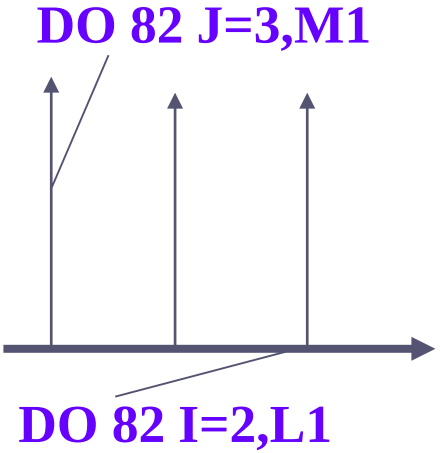
```
2.00E+00 2.30E+00 2.90E+00 3.50E+00 4.10E+00 4.70E+00 5.00E+00
1.80E+00 2.08E+00 2.64E+00 3.20E+00 3.76E+00 4.32E+00 4.60E+00
1.40E+00 1.64E+00 2.12E+00 2.60E+00 3.08E+00 3.56E+00 3.80E+00
1.00E+00 1.20E+00 1.60E+00 2.00E+00 2.40E+00 2.80E+00 3.00E+00
6.00E-01  7.60E-01 1.08E+00 1.40E+00  1.72E+00 2.04E+00 2.20E+00
2.00E-01  3.20E-01 5.60E-01  8.00E-01   1.04E+00 1.28E+00 1.40E+00
0.00E+00 1.00E-01 3.00E-01  5.00E-01   7.00E-01  9.00E-01  1.00E+00
```

(16)---Explained in detail

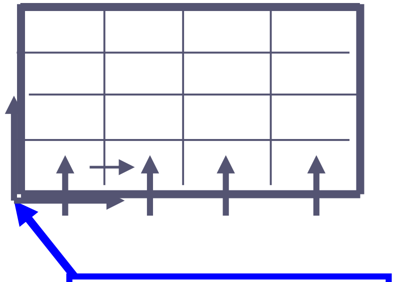
(17)---Explained in detail

```
C****************************************************
      ENTRY PRINT
      IF(LPRINT(3)) THEN
CALCULATE THE STREAM FUNCTION
      F(2,2,3)=0.
      DO 81 I=2,L1
      IF(I.NE.2) F(I,2,3)=F(I-1,2,3)-RHO(I-1,1)*V(I-1,2)
     1*R(1)*XCV(I-1)  ! I＝2， F(2,2,3)=0;
      DO 82 J=3,M1
      RHOM=FX(I)*RHO(I,J-1)+FXM(I)*RHO(I-1,J-1)
      F(I,J,3)=F(I,J-1,3)+RHOM*U(I,J-1)*ARX(J-1) !
 82   ENDDO
 81   ENDDO
```

! For print out， NF=3 represents stream function


DO 82 J=3,M1

DO 82 I=2,L1


F(2,2,3)=0

$$\rho ur = \frac{\partial \psi}{\partial y}; \rho vr = -\frac{\partial \psi}{\partial x} \quad \psi = -\int \rho vr dx \quad \psi = \int \rho ur dy$$

For bottom, from left to right $\psi_{i,2} = \psi_{i-1,2} - \sum_{i=3} \rho_{i-1,1} v_{i-1,2} r(1) \Delta x_i$

For vertical, from bottom to top $\psi_{i,j} = \psi_{i,j-1} + \rho_m u_{i,j-1} r(j) \Delta y_j$

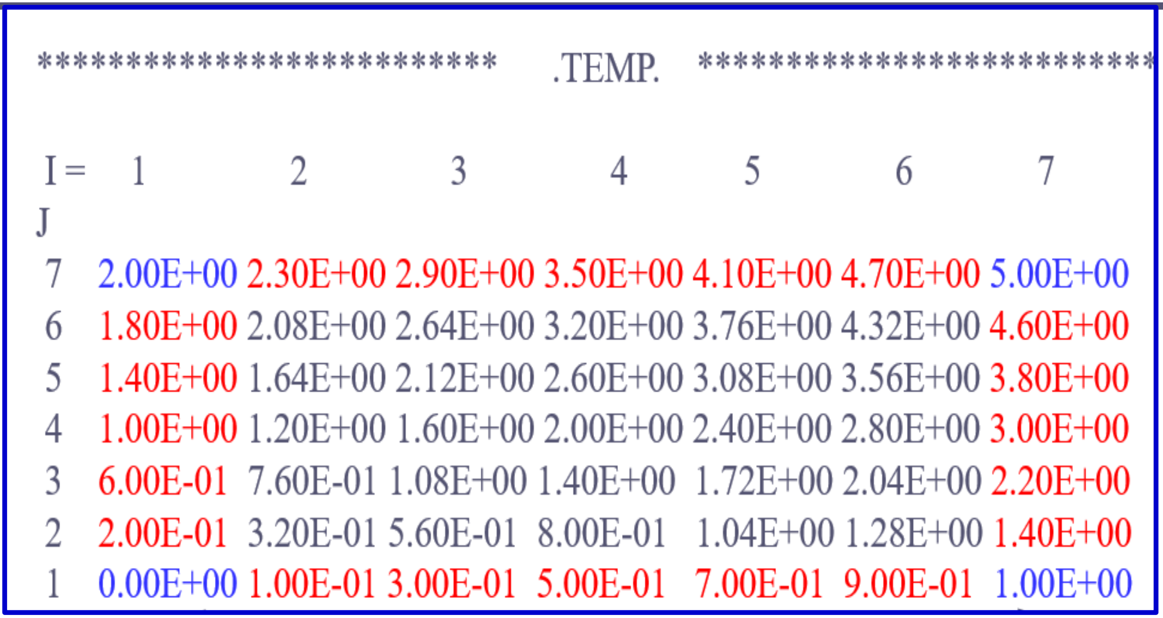
```
     IF(LPRINT(NP)) THEN
CONSTRUCT BOUNDARY PRESSURES BY EXTRAPOLATION
     DO 91 J=2,M2
     P(1,J)=(P(2,J)*XCVS(3)-P(3,J)*XDIF(2))/XDIF(3)
     P(L1,J)=(P(L2,J)*XCVS(L2)-P(L3,J)*XDIF(L1))/XDIF(L2)
 91 ENDDO
     DO 92 I=2,L2
     P(I,1)=(P(I,2)*YCVS(3)-P(I,3)*YDIF(2))/YDIF(3)
     P(I,M1)=(P(I,M2)*YCVS(M2)-P(I,M3)*YDIF(M1))/YDIF(M2)
 92 ENDDO
     P(1,1)=P(2,1)+P(1,2)-P(2,2)
     P(L1,1)=P(L2,1)+P(L1,2)-P(L2,2)
     P(1,M1)=P(2,M1)+P(1,M2)-P(2,M2)
     P(L1,M1)=P(L2,M1)+P(L1,M2)-P(L2,M2)
     PREF=P(IPREF,JPREF) ! Reference point of pressure
     DO 93 J=1,M1
     DO 93 I=1,L1
     P(I,J)=P(I,J)-PREF ! Relative pressure
  94ENDDO
  93ENDDO
      ENDIF
```

(17a)---Explained in detail

```
PRINT 50 ！ Print out to screen
WRITE(8,50) ！ Output into file
IEND=0
DO WHILE (IEND/=L1)
IBEG=IEND+1
IEND=IEND+7  ！ !7 data in each line
IEND=MIN0(IEND,L1) ！ Take minimum
PRINT 50
WRITE(8,50)
PRINT 51,(I,I=IBEG,IEND) !From IBEG too IEND for printing
WRITE(8,51) (I,I=IBEG,IEND)
IF(MODE/=3) THEN
PRINT 52,(X(I),I=IBEG,IEND)
WRITE(8,52) (X(I),I=IBEG,IEND)
ELSE                           ! Print out x-coordinates
PRINT 53,(X(I),I=IBEG,IEND)
WRITE(8,53) (X(I),I=IBEG,IEND)
ENDIF
ENDDO
IF(IEND= =L1) THEN
```

```
JEND=0
PRINT 50
WRITE(8,50)
DO WHILE(JEND/=M1) THEN
JBEG=JEND+1
JEND=JEND+7
JEND=MIN0(JEND,M1)
PRINT 50
WRITE(8,50)
PRINT 54,(J,J=JBEG,JEND)
WRITE(8,54) (J,J=JBEG,JEND)
PRINT 55,(Y(J),J=JBEG,JEND)  ! Print out y-coordinates
WRITE(8,55) (Y(J),J=JBEG,JEND) GO TO 311
ENDDO
ENDIF
```

```
                          ! NCP has been defined as 14 in SETUP1, in
DO 999 N=1,NCP            Page 31 of the PPT
NF=N
IF(LPRINT(NF)) THEN             ! Print out F(I,J,NF) field
PRINT 50
WRITE(8,50)
PRINT 10,TITLE(NF)
WRITE(8,10) TITLE(NF)            ! Print out title of variable F(I,J,NF)
IFST=1
JFST=1
IF(NF==1.OR.NF==3) IFST=2
IF(NF==2.OR.NF==3) JFST=2
IBEG=IFST-7
DO WHILE（IEND<L1.OR.IBEG== -5.OR.IBRG== -6)
IBEG=IBEG+7  ！ Starting point for each line (7data)
IEND=IBEG+6  ！ Ending point of the line
IEND=MIN0(IEND,L1)
PRINT 50 WRITE(8,50)
```



```
************************      .TEMP.     ************************

 I =   1         2         3         4         5         6         7
 J
 7   2.00E+00 2.30E+00 2.90E+00 3.50E+00 4.10E+00 4.70E+00 5.00E+00
 6   1.80E+00 2.08E+00 2.64E+00 3.20E+00 3.76E+00 4.32E+00 4.60E+00
 5   1.40E+00 1.64E+00 2.12E+00 2.60E+00 3.08E+00 3.56E+00 3.80E+00
 4   1.00E+00 1.20E+00 1.60E+00 2.00E+00 2.40E+00 2.80E+00 3.00E+00
 3   6.00E-01 7.60E-01 1.08E+00 1.40E+00 1.72E+00 2.04E+00 2.20E+00
 2   2.00E-01 3.20E-01 5.60E-01 8.00E-01 1.04E+00 1.28E+00 1.40E+00
 1   0.00E+00 1.00E-01 3.00E-01 5.00E-01 7.00E-01 9.00E-01 1.00E+00
```

(17b)—Explained in detail

```
      PRINT 20,(I,I=IBEG,IEND)
      WRITE(8,20) (I,I=IBEG,IEND)
      PRINT 30
      WRITE(8,30)
      JFL=JFST+M1  .
      DO 115 JJ=JFST,M1
      J=JFL-JJ
      PRINT 40, J, (F(I,J,NF),I=IBEG,IEND)
      WRITE(8,40) J,(F(I,J,NF),I=IBEG,IEND)
115   ENDDO
      ENDDO
      ENDIF
999   END
```

（End of print do-loop）

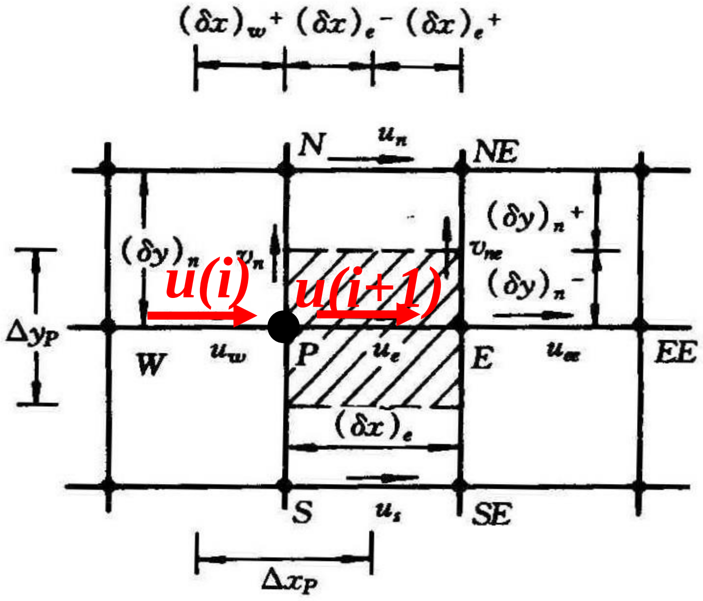
Transformation of data format for Tecplot

```
OPEN(9,FILE=″RESULT.DAT″)
      WRITE(9,’(″VARIABLES=X,Y″,$)’)
       DO NF=1,NCP
       IF(LPRINT(NF)) WRITE(9,’(″,″,A7,$)’) TITLE(NF)
       ENDDO
      WRITE(9,’(/,″ZONE I=″,I4,″,J=″,I4,″,T=T″,$)’) L1,M1
      DO J=1,M1
      DO I=1,L1
       WRITE(9,’(/,E11.3,E11.3,$)’) X(I),Y(J)
      DO NF=1,NCP
       IF(LPRINT(NF)) THEN
      FSHOW=F(I,J,NF)
      IF(NF==1) THEN
        IF(I==1) FSHOW=U(2,J)
        IF(I>=2.AND.I<=L2)  FSHOW=(U(I,J)+U(I+1,J))/2
        IF(I==L1) FSHOW=U(L1,J)
      ENDIF
```

Data format of TECPLOT

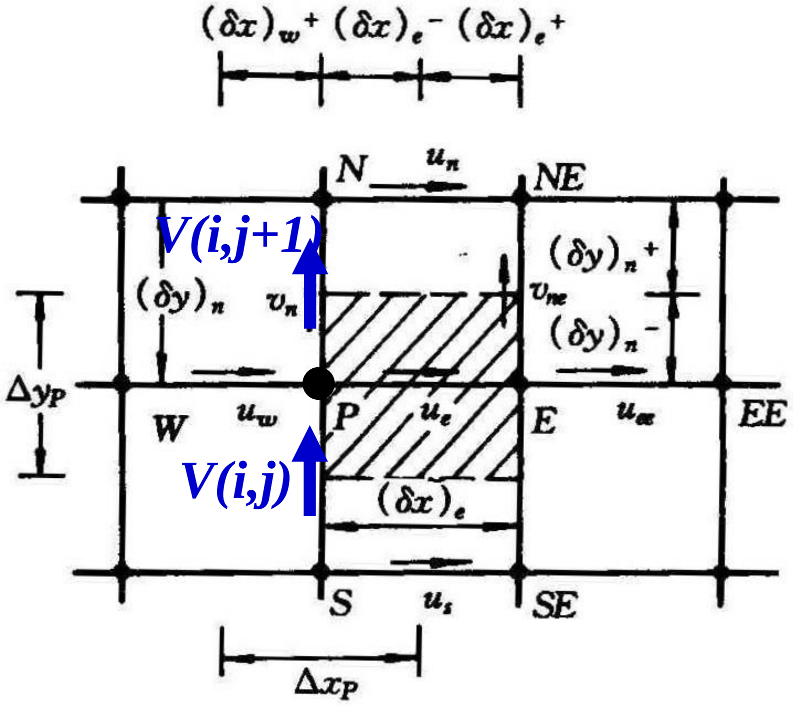
Data format of TECPLOT

For u



```
IF(NF==2) THEN
  IF(J==1) FSHOW=V(I,2)
  IF(J>=2.AND.J<=M2) FSHOW=(V(I,J)+V(I,J+1))/2
  IF(J==M1) FSHOW=V(I,M1)
ENDIF
WRITE(9,'(E11.3,$)') FSHOW
ENDIF
ENDDO
 ENDDO
ENDDO
CLOSE(9)
RETURN
END
```

For v



Comments and Recommendations for Teaching Code Study

1.It is the students' responsibility to study the code line by line to completely understanding the function of each line and the numerical techniques included.

You should understand every detail included in each line, for example:

```
IF(MODE.== 3) THEN
SX(J)=R(J)
IF(J /= 1) SXMN(J)=RMN(J)
ENDIF
```

why here J=1 should not be included?

2.You can understand a numerical algorithm, say SIMPLER, completely only when you know how to implementing the algorithm by code.

3.If you meet some difficulty in understanding the teaching code you may contact me by email (wqtao@mail.xjtu.edu.cn) at any time. I will be happy to communicate with you.

4.Our teaching assistants will give the instruction on how to run the code.

Computer-Aided Project of 2022 Numerical Heat Transfer
Xi’an Jiaotong University

We present three computer-aided projects: one is to be solved by our teaching code (**Project 1**），the 2nd and 3rd ones are to be solved by FLUENT (**Fundamental , Project 2**, **Intermediate Project 3**) . Every student can choose one project according to your interest and condition.

For the first project the self-developed computer code should attached in your final report.

For the second and third project Class F and Class I will have different projects. The instructors will assign the project at the end of the lecture.

Computer-Aided Project (1) of NHT-2022, Xi’an Jiaotong University

-----Laminar forced convection in a converge-diverge tube

1.Engineering problem

Periodic-fully developed laminar heat transfer in a converging-diverging tube

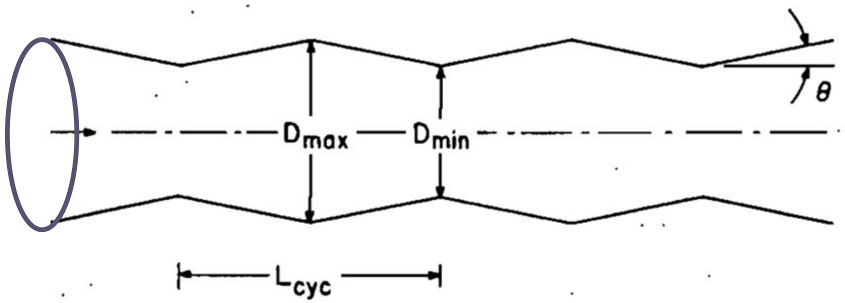


Fig.1

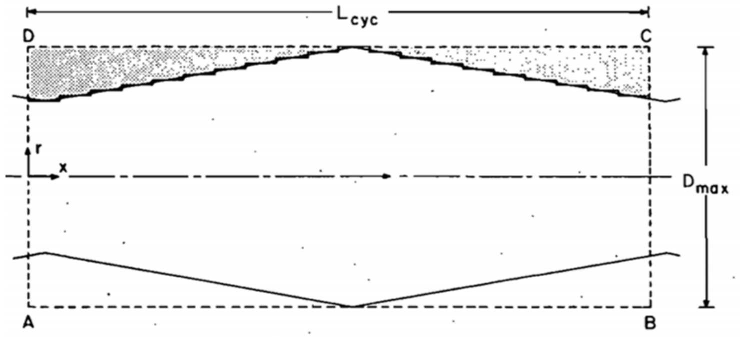


Fig.2

2. Simplification Assumptions:

(1) Flow and heat transfer are in steady state and laminar;

(2) Wall temperature and physical properties of fluid are constant;

3. Given conditions

(1) $L_{cyc} / D_{\max} = 1.51, 2.29;$ (2) $\theta = 10^{\circ}, 14.8^{\circ}$

(3) Fluid Pr=0.7, 5.0 (4) Fluid Re=100,600,1000

4. Find

The Nusselt numbers of one cycle (Fig.2) at three Reynolds numbers for a selected value of $L_{cyc} / D_{\max}$, θ and Pr.

5. Suggestions

(1) The domain-extension method may be adopted to deal with the irregular domain （axi-symmetrical cylindrical coordinate）；

(2) For the numerical method of periodic fully developed flow and heat transfer Section11.2.1 and 11.2.2.2 of the Textbook may be consulted;

(3) A domain a bit larger than one cycle is recommended for the simulation (Fig. 3), so that the periodic boundary condition can be implemented easily. That is, the results at AA and BB sections are exchanged each other, and the same for CC-DD .

(4) Reference length is defined as $D_{eq} = A_{cyc} / \pi L_{cyc}$

A_{cyc} is the heat transfer area per cycle.

(5) Your results are compared with reference [1].

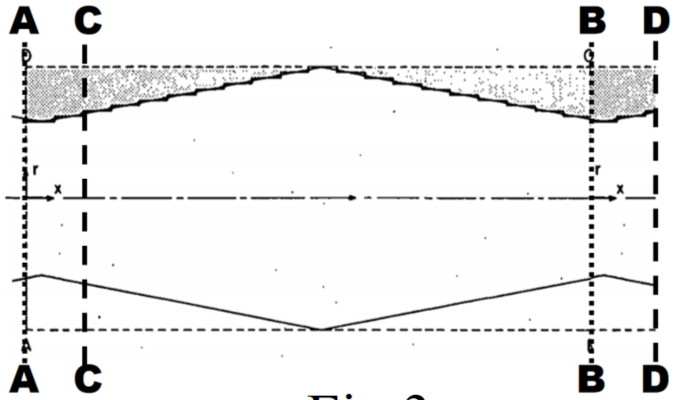


Fig.3

6. References

[1] E M Sparrow, A R Prata. Numerical solutions for laminar flow and heat transfer in a periodically converging-diverging tube, with experimental confirmation. Numerical Heat Transfer, Numerical Heat Transfer, vol. 6, pp. 441-461,1983

[2] 陶文铨编著. 数值传热学（第二版）.西安：西安交通大学出版社，2001. pp.488-492

6. Requirements

The project report should be written in the format of the Journal of Xi’an Jiaotong University. Both Chinese and English can be accepted.

Please submit in the USER part developed by yourself for solving the problem.

The project report should be due in before April 30, 2023 to room 1-6072 of Giant No.1.

本组网页地址：http://nht.xjtu.edu.cn　欢迎访问！

Teaching PPT will be loaded on ou website

同舟共济

渡彼岸！

People in the same boat help each other to cross to the other bank, where….