Numerical Heat Transfer

(数值传热学)

Chapter 8 General Code for 2D Elliptical FF & HT Problems of Discretized Equations（Cd）

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Xi'an, 2018-Nov.-07

8. 6 Methods of application and explanation of MAIN

8.6.1 Methods of Code application

8.6.2 Explanation of MAIN Program

8.6.2.1 MODULE START_L

8.6.2.2 PROGRAM MAIN

8.6.2.3 SUBROUTINE DIFLOW

8.6.2.4 SUBROUTINE SOLVE

8.6.2.5 SUBROUTINE SETUP

8.6.2.6 SUBROUTINE SUPPLY

8. 6 Methods of Application and Explanation of MAIN

8.6.1 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 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:

.TRUE.

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

.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: .TRUE., otherwise .FALSE., Its default value is .T. .

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

(6) NTIMES(NF)—Default values equals 1; for steady nonlinear : 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 $a_P^0 = \frac{\rho \Delta V}{\Delta t}$, if $\Delta t \rightarrow \infty, a_P^0 \rightarrow 0$, 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 , default values are 1,1;

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

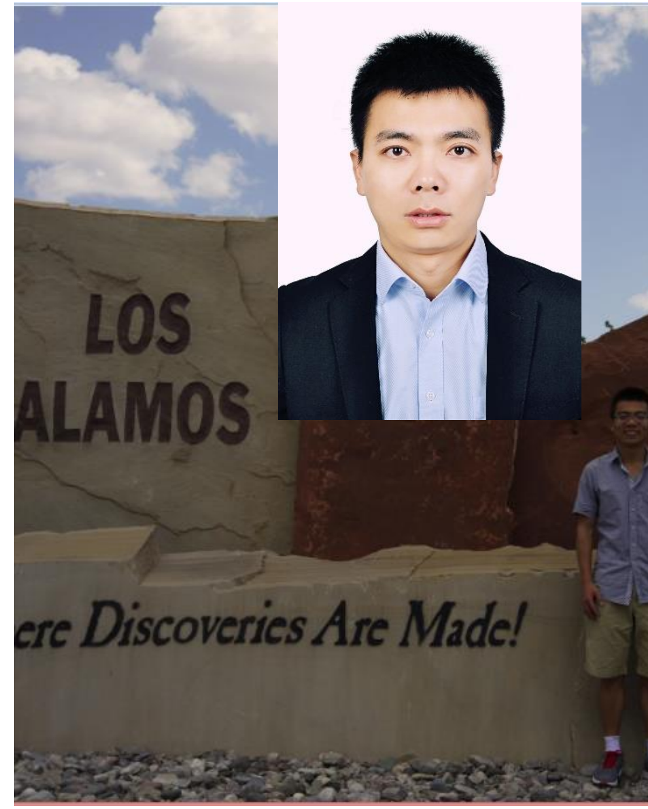
First defining C(NI,NJ),

then using EQUIVALENCE:

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

8-6-2 Explanation of MAIN programs

```
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
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 microcomputer 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
C  as a frame to re-develop your own code for research purpose.
C --------Instructor of Numerical Heat Transfer, XJTU,2013.18---------------
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
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
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C*****************************************************************
```



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8.6.2.1 MODULE START_L

(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).

```
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      ! 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   For TDMA in Block correction
 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
```

CON → Sc or b

AIP,AIM,AJP,AJM,AP → Ae,Aw,An,As, Ap

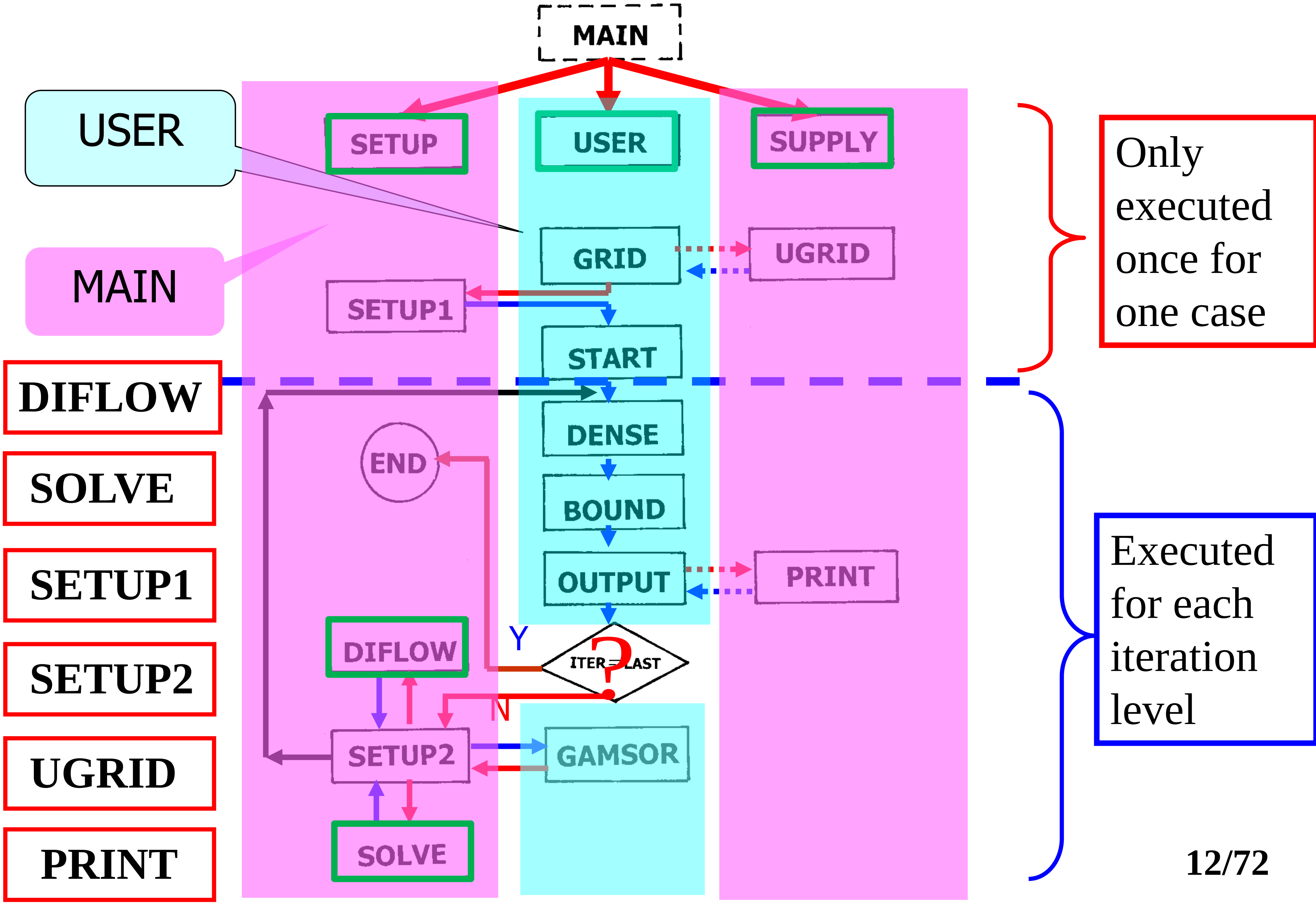
```
C****************************************
 EQUIVALENCE(F(1,1,1),U(1,1)),(F(1,1,2),V(1,1)),(F(1,1,3),PC(1,1))
1, (F(1,1,4),T(1,1))
 EQUIVALENCE(F(1,1,11),P(1,1)),(F(1,1,12),RHO(1,1)),(F(1,1,13)
1,GAM(1,1)),(F(1,1,14),CP(1,1))
 EQUIVALENCE(COF(1,1,1),CON(1,1)),(COF(1,1,2),AIP(1,1)),
1(COF(1,1,3),AIM(1,1)),(COF(1,1,4),AJP(1,1)),
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!!

(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).

8.6.2.2 PROGRAM MAIN

```
C*****************************************************************
C----------------------------MAIN PROGRAM---------------------------------
C*****************************************************************
    PROGRAM MAIN
    USE START_L          Share the variables defined in the MODULE
    IMPLICIT NONE
C*****************************************************************
    OPEN(8,FILE='RESULT.txt')  ! Result file for output
    CALL GRID        !Grid generation(setup interface postions)
    CALL SETUP1      !Set up 1-D array not changed in iteration
    CALL START       !Set up initial field
   DO WHILE (.NOT.LSTOP）    ! Controlled by ITER
    CALL DENSE       !Set up fluid density
    CALL BOUND       !Set up boundary condition
    CALL OUTPUT      !Print out
    CALL SETUP2      !Key module: set coefficients and solve ABEqs.
    ENDDO
    CALL OUTPUT !Print out some results
    CLOSE(8)     !Simulation completed close file RESULT.TXT
    STOP         !Terminate computation
    END
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
```


MAIN
USER
SETUP
USER
SUPPLY
MAIN
GRID
UGRID
SETUP1
START
DIFLOW
SOLVE
SETUP1
SETUP2
UGRID
PRINT
DENSE
END
BOUND
OUTPUT
PRINT
Y
ITER=LAST
N
DIFLOW
SETUP2
GAMSOR
SOLVE
Only executed once for one case
Executed for each iteration level

8.6.2.3 SUBROUTINE DIFLOW

```
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      SUBROUTINE DIFLOW
      USE START_L
      IMPLICIT NONE
      REAL*8 TEMP
C*****************************************************
      ACOF=DIFF
      IF(FLOW== 0.) RETURN
      TEMP=DIFF-ABS(FLOW)*0.1
      ACOF=0.
      IF(TEMP.<= 0.) RETURN
      TEMP=TEMP/DIFF
      ACOF=DIFF*TEMP**5
      RETURN
      END
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
```

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

USE START_L — Share the variables defined in the MODULE

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

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

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

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

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

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

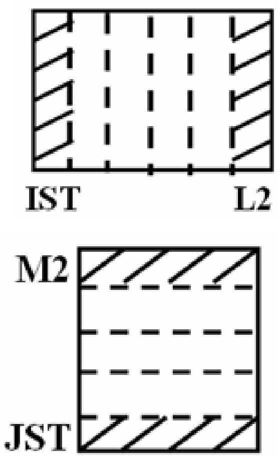
8.6.2.4 SUBROUTINE SOLVE

```
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

SOLVE

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



2 times B.C.
AD Block Correction

Upward line iteration

downward line iteration

Left to right line iteration

Right to left line iteration

4 times L.I.
AD line Iteration

999 ENDDO

Review on block correction

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

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

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

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

$BL = A, BLP = B,$
$BLM = C$

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

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

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

DENOM

```
C*****************************************************************
      ISTF=IST-1
      JSTF=JST-1
      IT1=L2+IST    ! SOLVE-temporary
      IT2=L3+IST    ! SOLVE-temporary
      JT1=M2+JST    ! SOLVE-temporary
      JT2=M3+JST    ! SOLVE-temporary
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
     QT(ISTF)=0.   ! Constant in TDMA
     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
```

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

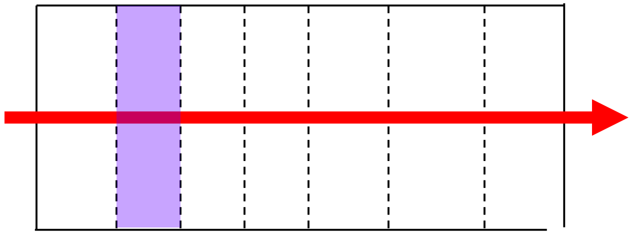
$$A_i\phi_i = B\phi_{i+1} + C_i\phi_{i-1} + D_i, \ i = IST,.....L2$$

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

P_{IST-1}

Q_{IST-1}

I –direction B.Correction.



A B C D

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

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

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

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

$$BLC = \sum_{j=JST}^{M2} CON + \sum_{j=JST}^{M2} (AJP)\phi_{i,j+1}^{*} + \sum_{j=JST}^{M2} (AJM)\phi_{i,j-1}^{*} + \sum_{j=JST}^{M2} (AIP)\phi_{i+1,j}^{*} + \sum_{j=JST}^{M2} (AIM)\phi_{i-1,j}^{*} - \sum_{j=JST}^{M2} (AP)\phi_{i,j}^{*}$$

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

DENOM

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

TDMA: $\overline{\phi}_{i-1}^{'} = P_{i-1}\overline{\phi}_i^{'} + Q_{i-1}$

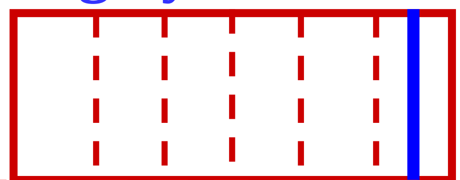
```
BL=0.    (Initial set up)
DO 13 II=IST,L2
I=IT1-II
BL=BL*PT(I)+QT(I)
DO 14 J=JST,M2
F(I,J,N)=F(I,J,N)+BL!
14 ENDDO
13 ENDDO
C-----------------------------------------------------------------------------
PT(JSTF)=0.
QT(JSTF)=0.
DO 21 J=JST,M2
BL=0.
BLP=0.
BLM=0.
BLC=0.
DO 22  I=IST,L2
BL=BL+AP(I,J)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

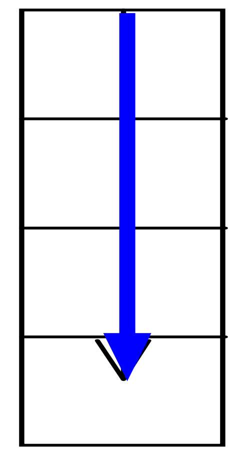
Correcting by BL for the same column



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

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

TDMA: from L2 to IST



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

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

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

$$i = IST \ldots L2$$

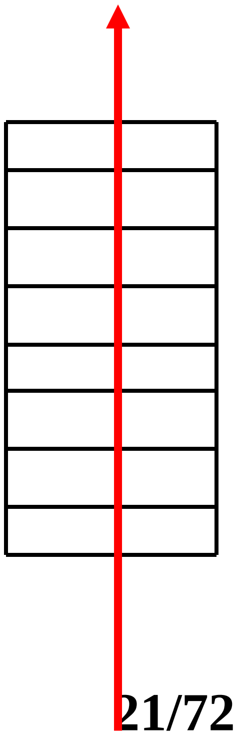
```
C-------------------------------------------------------------------------------
      DO 90 J=JST,M2
      PT(ISTF)=0.
      QT(ISTF)=F(ISTF,J,N)      ! ISTF=IST-1
                                ! PT=0,  QT=given boundary value
      DO 70 I=IST,L2
      DENOM=AP(I,J)-PT(I-1)*AIM(I,J)
      PT(I)=AIP(I,J)/DENOM
      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-------------------------------------------------------------------------------
```

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

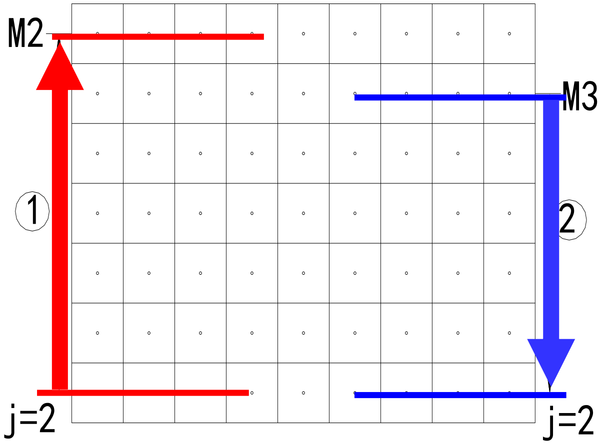
$$Q_i = \frac{D_i + C_i Q_{i-1}}{A_i - C_i P_{i-1}};$$

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

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



```
C------------------------------------------------------------------------
    DO 190 JJ=JST,M3 ! Solving in I-direction, scanning from top to bottom
    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------------------------------------------------------------------------
```



```
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
```

8.6.2.5 SUBROUTINE SETUP

```
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
   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----------------------------------------------------------------------
```

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.

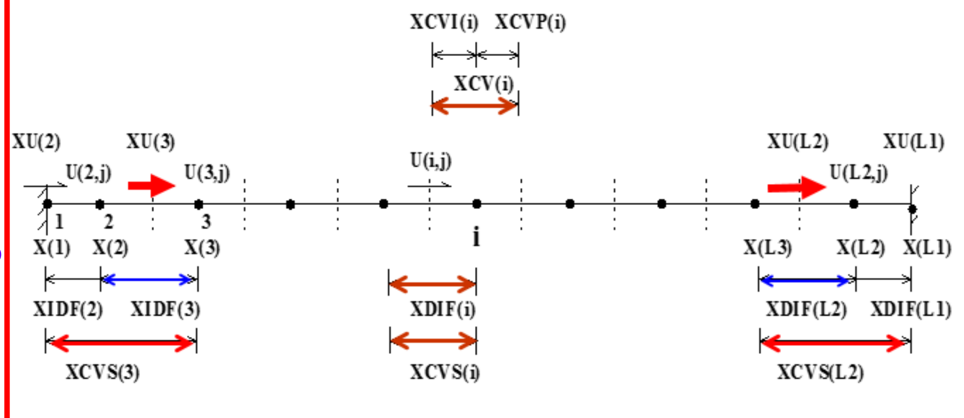
Correction velocity

Coefficient for other equation and solve it (from NF=5 to 10 in order)

RETURN

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
```



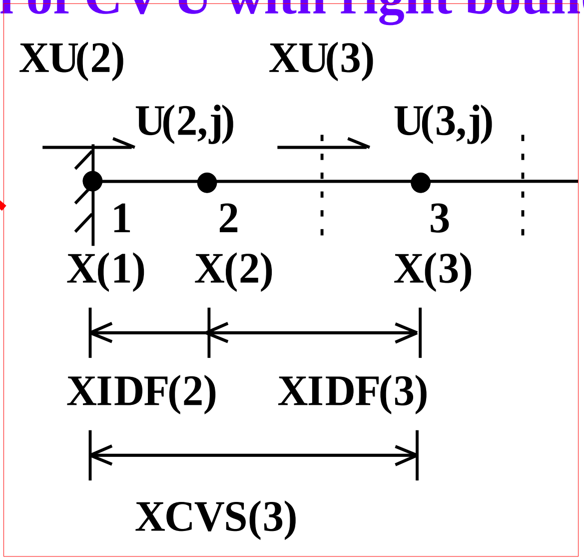
Similarly in Y-direction.

! 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)   !
    XCVIP(I)=XCVI(I)      !
22 ENDDO
    XCVIP(2)=XCV(2)
    XCVI(L2)=XCV(L2)
    DO 35 J=2,M1
    YDIF(J)=Y(J)-Y(J-1)
35 ENDDO
```

$(\delta x)_{e^-}$

$(\delta x)_{e^+}$



```
      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 Cartesian coordinate

```
    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

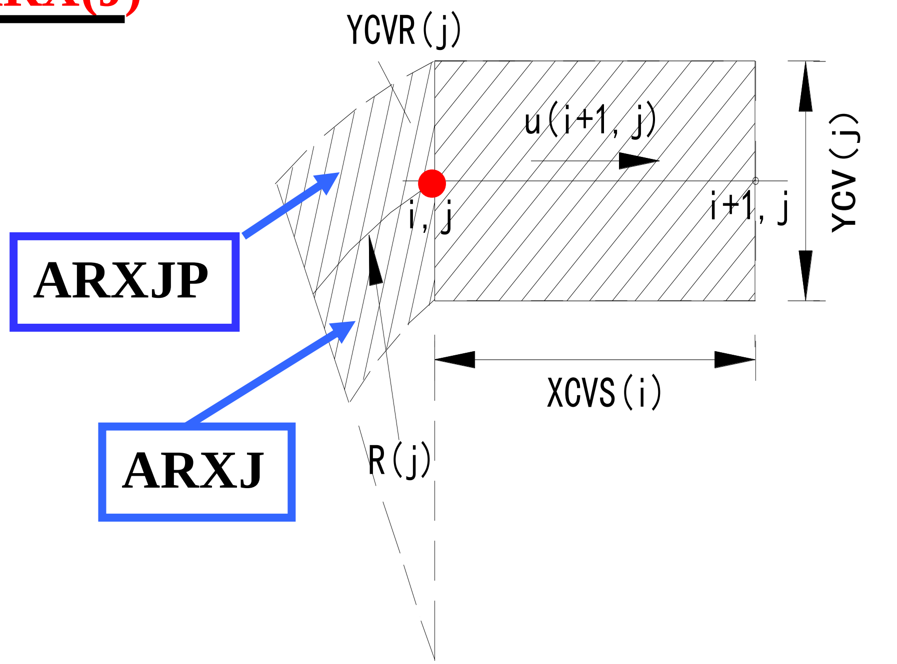
E-W conduction area of CV for three cases, for Cartesian R=1

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

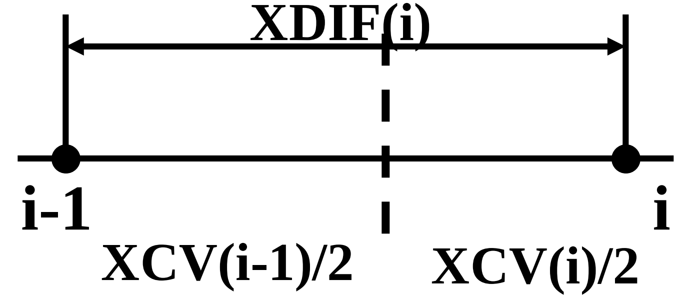
$$0.25[1+\frac{RMN(j)}{R(j)}]\bullet \underline{R(j)\bullet YCV(j)}=$$

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

```
    DO 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)
```



```
    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
```



$$\phi_{i-1/2} = \phi_{i-1}\frac{\text{XCV(i)/2}}{\text{XDIF(i)}} + \phi_i\frac{\text{XCV(i-1)/2}}{\text{XDIF(i)}}$$

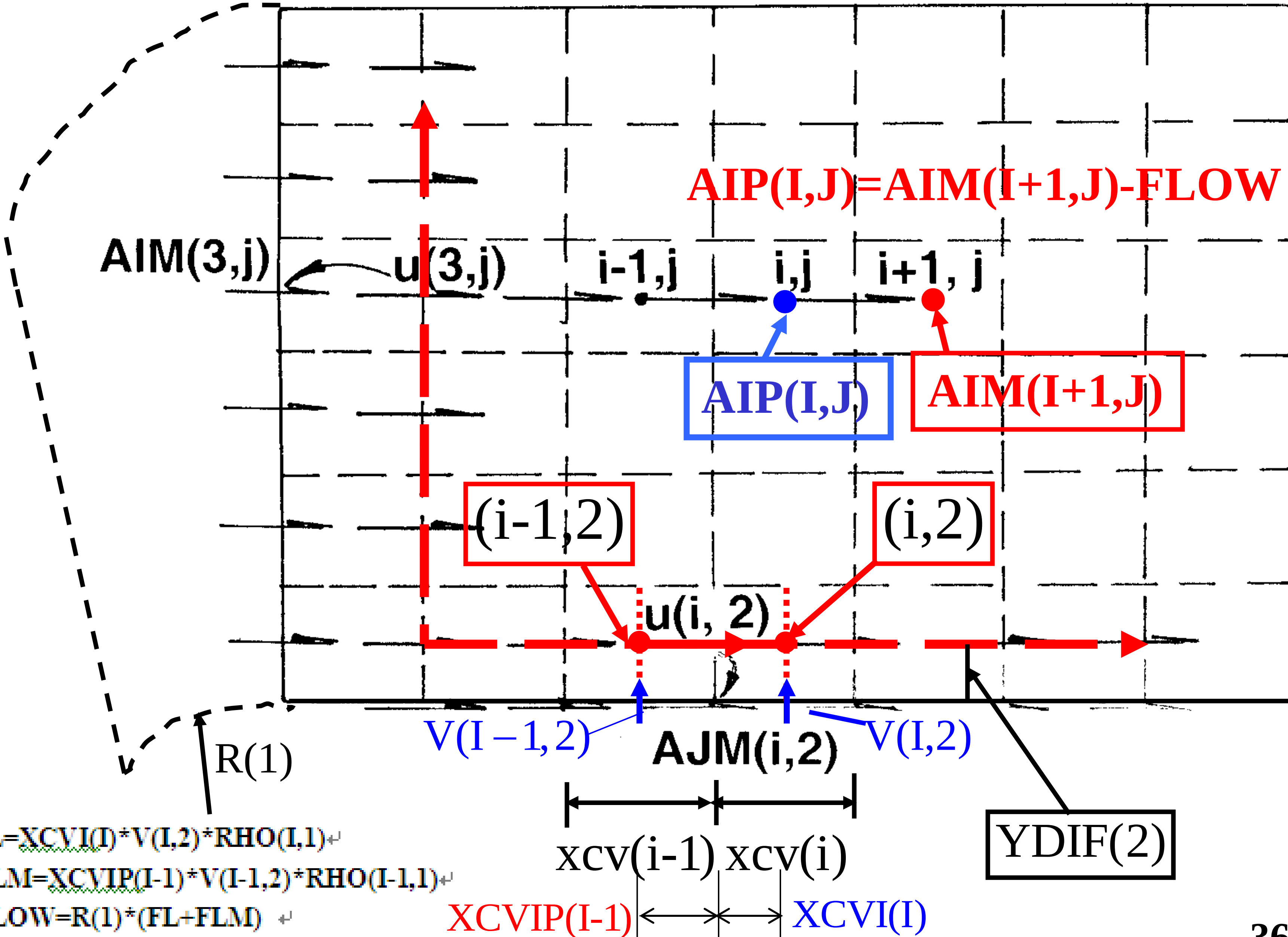
$$= \phi_{i-1}FXM(i) + \phi_i FX(i)$$

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)（20151216）
RETURN
C-------------------------------------------------------------------
```

Set up initial fields for iteration

Print out coordinate title of out put data



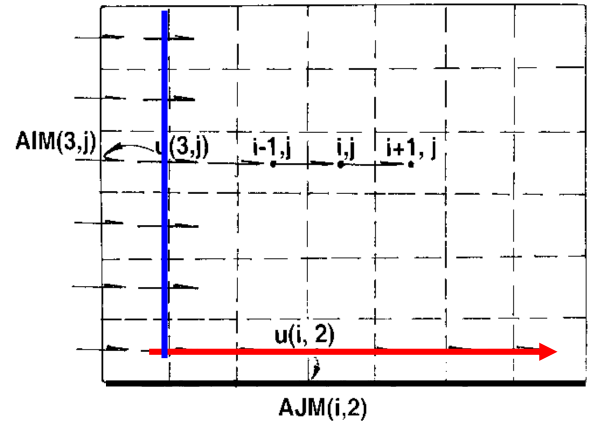
FL=XCVI(I)*V(I,2)*RHO(I,1)

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)

```
C-----------------------------------------------------------------------------------
  ENTRY SETUP2
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
COEFFICIENTS FOR THE U EQUATION
    NF=1  ! NF=1:  U;  NF=2:  V;  NF=3:  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 !Get D.A(|P|);
    AJM(I,2)=ACOF+AMAX1(0.,FLOW)    Coefficient a_S
102 ENDDO
```



```
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
```

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

```
 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
```

```
 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
```

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

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

$$\frac{A_e}{a_e}$$

$$a_p = \left(\sum a_{nb} + a_p^0 - S_p \Delta V\right)/\alpha$$

Review of SIMPLER algorithm

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

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

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

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

and Solving pressure equation， obtaining p^* **;**

$$a_P p_P = a_E p_E + a_W p_W + a_N p_N + a_S p_S + b$$

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

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

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

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

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

Review of SIMPLER algorithm

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

Boundary 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.

(1) Asuuming initial field u^0, v^0**, determining coefficient, b and pseudo-velocity** $\tilde{u}, \tilde{v}$ **;**

(2) Solving pressure equations, and taking the results as p^***;**

(3) Solving discretized momentum equations ,and taking the results as u^*, v^***;**

(4) Solving pressure correction equations, yielding p'**;**

(5) Correcting velocity from p' **, yielding** u', v'**;**

(6) Taking $(u^*+u'), (v^*+v')$ **as the flow solution of the present level and starting iteration for next level.**

```
COFU(IST:L2, JST:M2, 1:6)=COF(IST:L2,JST:M2,1:6)
! 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)

```
!  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
```

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)
```

```
     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 !
```

! Compute $\tilde{u}, \tilde{v}$

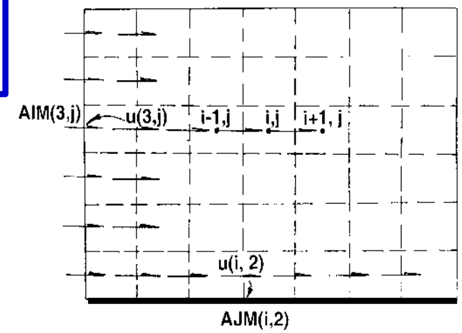
$$\bar{u}_e = \sum \frac{a_{nb}u_{nb} + b}{a_e}$$

```
  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)
```

```
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 pressure equation no source term for the generality
      DO 410 J=2,M2    ! source term is still computed.
      DO 411 I=2,L2
      VOL=YCVR(J)*XCV(I)        !Volume of main CV.
      CON(I,J)=CON(I,J)*VOL
411 ENDDO
410 ENDDO
```

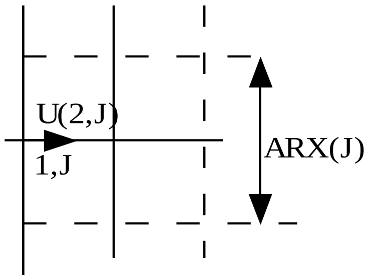
! $b=[(\rho u)_w-(\rho u)_s]A_e+[(\rho\tilde{v})_s-(\rho\tilde{v})_n]A_n$

! For bounndary actual velocity is used.




```
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
```

累加




```
DO 403 J=2,M2
ARHO=ARX(J)*RHO(1,J)
CON(2,J)=CON(2,J)+ARHO*U(2,J) ! Accumulative addition
AIM(2,J)=0. ! a_W =0， Adiabatic  boundary
DO 404 I=2,L2
IF(I= =L2) THEN
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))
```

$$\begin{cases} \Delta X \cdot 1 \quad r=1 \quad \text{Cartesian} \\ r\cdot\theta(\theta=1)\cdot\Delta x \ \text{Cylindrical} \\ r\Delta\theta\cdot 1 \ \text{Polar} \end{cases}$$

```
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)    ! a_E
AIM(I+1,J)=AIP(I,J) !Relationship between (a_W) and (a_E)_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)
```

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

! while CON（b）and AP (aP) are not stored； Because AP has been
!underelaxed, and the veloity in 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.
```

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

! 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)      <-- For AP
 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
```

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)
```

```
      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
```

```
      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
      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
```

$$b = S_C \Delta V + a_P^0 \phi_P^0$$

$$a_P = a_E + a_W + a_N + a_S + a_P^0 - S_P \Delta V$$

Transient, Linear---- Steady, nonlinear

CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC

8.6.2.6 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

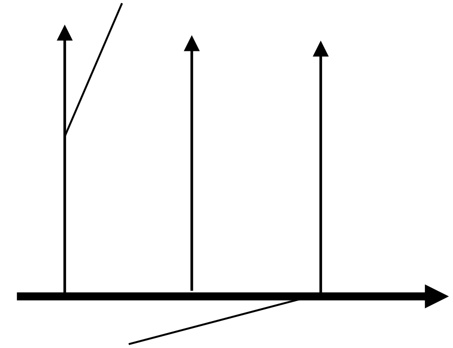
!1P---1 integral digit of each data;

!7E---7 data in scientific expression

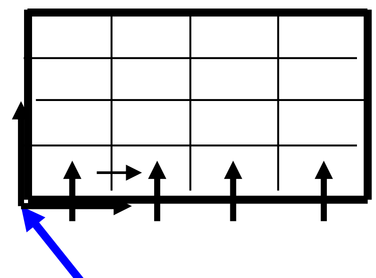
! 9.2---Each data contains 9 places, and there are two decimal places (小数2位)

```
C*************************************************
      ENTRY PRINT              ! For print out， NF=3 represents stream function
      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
```

DO 82 J=3,M1



DO 82 I=2,L1



F(2,2,3)=0

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

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
```

```
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)   ! Print out x-coordinates
ELSE
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
```

```
DO 999 N=1,NCP                ! NCP has been defined as 14 in SETUP1, in Page 29 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)
```

```
    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

！ WRITE(8,10) TITLE(NF) ！ 10 FORMAT(1X,26(1H*),3X,A10,3X,26(1H*))

```
**************************   .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
```

！ 40 FORMAT(1X,I3,2X,1P7E9.2)

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)**

同舟共济
渡彼岸!