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# SOLAR VENTILATION AND AIR-CONDITIONING SYSTEM INVESTIGATION USING THE FINITE ELEMENT METHOD

by

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## CHAPTER 7

## PROGRAM DESCRIPTION


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### 7.1.1 Introduction

The finite element coding for solving the Navier Stokes, continuing, and general energy equations may be subdivided into a number of subroutines each of which may be further reduced into subsections. Before discussing the code details on a subroutine basis, the overall solution strategy may be seen in the skeleton flow chart of Figure 2.2. The actual code comprises many local loops/branches, however these are highlighted by comment statements in the program listings.

### 7.1.2 Master (Main) Segment

This is the program master segment and is used to call the various subroutines in the relevant order.

## 7.2 Subroutine DATAG

This subroutine is called from the MASTER segment and is primarily intended for initialising control variables and arrays. Input and the associated variable name has received detailed coverage in user report, Ref. (1), however knowledge of the following variables is important.

| | |
|---|---|
| ND1(=4) | declared channel for eliminated equations, appears and used in FRUNT, FRONTA and BACSUB, BACSUBA, RESOL |
| NTR | the iteration counter |

NTRA — coded 1 on first entry to FRONT, Ø after - used to code nodal number negative on last appearance in the mesh

MWGA — a non-zero value indicates a single nodal degree of freedom for single equation solution; zero indicates multiple degrees-of-freedom for coupled solution in FRONT, FRONTA.

## Vectors

NOPP(I) — the vector NOPP holds the location in the solution vector (VARI) of the first degree-of-freedom for the node I, typically. NOPP(4) holds the location in VARI of $U_4$ in {u p v} calculations. When used in conjunction with the vector MDF(I) the location of $p_i$, $v_i$ etc. may be found in VARI, generally in the program the procedure in {u p v} solution is

```
M1 = NOPP(I)
M2 = M1+1                  at corner nodes
M3 = M1 + MDF(I) - 1

M1 = NOPP(I)               at midside nodes
M3 = M1 + MDF(I) - 1
```

then

$U_i$ = VARI(M1)

$P_i$ = VARI(M2)

$v_i$ = VARI(M3)

| | |
|---|---|
| TEMP(I) | the vector of nodal temperatures in uncoupled solution, TEMP(I) holds the temperature at node I. |
| LPR(I) | holds the side code for gradient boundary evaluation associated with element I, this is used in VARCALC in calculating the vector of right hand sides |
| VARI(I) | the solution vector which holds the calculated field and is set up after solution in VARCALC |
| VARA(I) | may be used to hold a relaxed field for accelerating solution convergence rates. |

## 7.3 Subroutine DIAG1[7]

This subroutine checks the overall control parameters which govern the number of nodes, number of elements, initial conditions, and boundary conditions for the problem being investigated. If an error is detected it is associated with a specific number NEROR, and an appropriate message is output. Since control parameters are mnemonic, the errors appearing in the program listing are self-explanatory.

| Error Number | Type of Error |
|---|---|
| 1 | If total number of nodes, (NH), is specified as less than or equal to zero. |
| 2 | If the number of data lines referring to nodal points coordinates, (NNP) is less than or equal to zero or greater than total number of nodal points (NH). |
| 3 | If total number of elements, (NE), is less than or equal to zero. |
| 4 | If the total number of node points, (NH), is greater than the product of the total number of elements and the number of nodes per element. |
| 5 | If the number of essential type boundary conditions to be specified, (NB), is greater than the total number of possible degrees of freeom. |
| 6 | If the total number of initial conditions, ICOND, to be specified is greater than the total number of possible degrees of freedom for MARK≠3. |
| 7 | If the number of elements which contain a gradient type boundary condition, (NRT), is greater than the total number of elements, (NE). |
| 8 | If the number of gradient type boundary conditions, (IRT), is greater than the total number of possible degrees of freedom (variables), (NP). |
| JEROR | Local error indicator. |

Vectors

| | |
|---|---|
| NECHO(80) | Array used to store remaining data temporarily. |
| NEROR(8) | Error indicating array. |

If any check fails the data which had not been read to that point will be read and printed.

## 7.4 Subroutine DIAG2[7]

If the checks on the control data prove to be satisfactory then the remaining data is checked using this subroutine. The main sources of error are usually associated with either the coordinates or in defining element topology i.e. (geometric data errors). NEROR is used again as an indicator for particular checks.

Error Number

| | |
|---|---|
| 9 | If the fluid density or the fluid molecular viscosity is less than or equal to zero. |
| 10 | If there are two or more nodal points with identical coordinates. |
| 11 | If a node number appears more than once in any element. |
| 12 | If a node number is outside the permissible bounds. |
| 13 | If the number of initial conditions specified as input is greater than the total number of variables for MARK=3. |

The variable JEROR, and the vectors NECHO and NEROR are exactly the same as in subroutine DIAG1. Similarly, should any check fail, the data which had not been read to that point will be read and printed.

## 7.5 Subroutine CORDGEN

This is called from the routine DATAG and is primarily intended to set up element geometry.

| | |
|---|---|
| NBN(=8) | holds the number of element nodes |
| NCN | holds the total degrees of freedom (dof) per element (20 for upv, 28 for upvθ) |
| NDF | holds the dof at corner nodes (3 for upv, 4 for upvθ) |

Vectors

| | |
|---|---|
| MDF(I) | holds the degrees of freedom associated with node I |
| NDN(I) | holds the number of nodes associated with element I |

## 7.6 Subroutine ELGEN[8,9]

Subroutine ELGEN can be called from CORDGEN and is used for mesh generation using the isoparametric concept. It can deal with mesh generation for domains with complex shapes and for multiply-connected domains. This routine is self-explanatory in the listing.

| | |
|---|---|
| NXL | Number of elements in the ($\xi$) direction |
| NYL | Number of elements in the ($\eta$) direction |
| NN | First node number |
| ND | Direction parameter |
| | = 0, elements are numbered sequentially along lines of constant ($\eta$) |
| | = 1, elements are numbered sequentially along lines of constant ($\xi$) |

Vectors

| | |
|---|---|
| XM(8) | holds X-coordinates of master nodes |
| YM(8) | holds Y-coordinates of master nodes |
| XPT(I) | total number of X-coordinate points in the mesh |
| YPT(I) | total number of Y-coordinate points in the mesh |
| NS(I) | stores a list of node numbers of ($\xi$= -1) for all mesh points |
| SHP(8) | shape functions for ($\xi,\eta$) coordinates of each generated node for each element |
| XX(8) | ($\xi$) coordinate of the master nodes |
| YY(8) | ($\eta$) coordinate of the master nodes |

## 7.7 Subroutine WRITELP

This routine is generally called from VARCALC and is used for printing the initial state and the iteration results. Where output is large this routine may only be called every i.nth iteration and on convergence of the solution.

## 7.8 Subroutine DATAK

Subroutine DATAK is called from the MASTER segment and is used to read in and assign coding to the boundary condition vectors.

NBV — this holds the number of constrained values in coupled solution where care must be taken not to duplicate boundary value prescription, the variable is used in BACSUB, the backsubstitution routine.

Vectors

NCOD(I) — given a code 1 for constrained dof I where I is calculated using NOPP and MDF vectors, typically let $v_4$ be a constrained value, then

M3 = NOPP(4) + MDF(4) - 1

NCOD(M3) = 1

NCOD is zero for an unknown global value and is used in FRONT

BC(I) — is the prescribed value associated with NCOD(I) as defined above

| | |
|---|---|
| NODV(I) | can be used to hold the global location in NCOD of the ith (as read in) dof typically if $v_4$ was the 10th constrained value read then NODV(10) = M3 this can be used where solution requires iteration between coupled and single equations where vectors NCOD, BC are also set to hold the constrained values in the single equation solution. |
| VALV(I) | the boundary value in association with NODV(I). |

## 7.9 Subroutine VARCALC

This is the routine called from the MASTER segment which is used for setting up the vector of right hand sides (RHS) to which the element vectors q (see Section 2.3) contribute and also in calling the solution routine, testing for convergence and printing results.

| | |
|---|---|
| ERA | sets the convergence tolerance on the velocity field for successive iterations |
| RMAX | the greatest relative change in any computed velocity, thus RMAX less than ERA denotes satisfactory convergence |
| ITERNAN | a marker for uncoupled solution global iteration. |

Vectors

| | |
|---|---|
| R2(I) | this is used in PRESCR to set up the vector of RHS where prescribed gradient values are supplied as input to the program |
| SK(I) | this holds the problem solution as returned from the frontal solution procedure FRONT where 'I' is as defined for the vector NCOD |
| AVARI(I) | holds a relaxed value of the solution field, for the case shown as under relaxation, over relaxation may be used too, typically in the loop DO 15 AVARI(I) $= \alpha$ SK(I) + $(1-\alpha)$ VARI(I) where $\alpha(>1)$ is an over-relaxation constant. In this work $\alpha = 0.5$. |
| UPVBC(I) | holds the boundary condition values for (u,p,v) in the uncoupled solution for the next global iteration solving (N-S) equations |
| NCODV(I) | holds the coded (dof) as boundary conditions for (u,p,v) in the uncoupled solution for the next global iteration, solving (N-S) equations |
| TBC(I) | holds the boundary condition values for temperature ($\theta$) in the uncoupled solution for the next global iteration, solving the energy equation |
| NCODT(I) | holds the coded (dof) as boundary conditions for temperature ($\theta$) in the uncoupled solution for the next global iteration, solving the energy equation |

## 7.10 Subroutine TEMPCAL

This routine is called from VARCALC and is used to control solution of the temperature equations, notably it is used for reading in boundary conditions, setting up vectors NCOD and BC and in extracting the solution for storage in the vector TEMP.

| | |
|---|---|
| NBT | holds the total temperature boundary conditions and is used in the routine BACSUB |
| NF | provides temporary storage for NP the total degrees of freedom for upv calculation |
| NV | provides temporary storage for NDF |
| LQ | provides temporary storage for NCN |

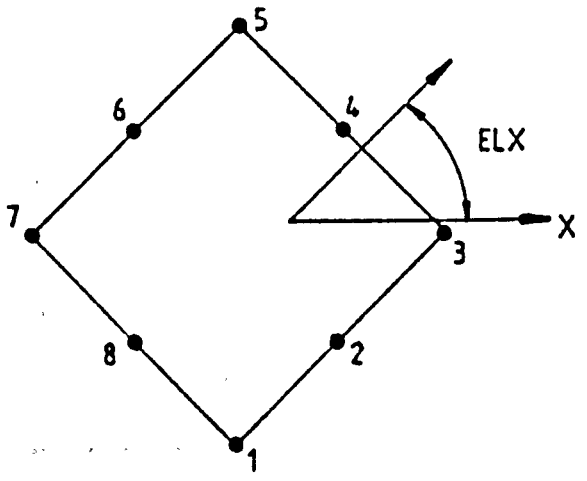
NP, NDF and NCN are then assigned values (NH, 1, NBN respectively) in readiness for solving the energy equation using FRONT with MWGA=-1. Before returning to VARCALC, NP, NDF and NCN are reassigned. Further should it be necessary to solve the uncoupled equation iteratively then directory vectors need to be set up to hold boundary values, here UPVBC(I), NCODV(I), TBC(I) and NCODT(I) are used as explained in Section 7.9.

## 7.11 Subroutine HCOEF

A routine called from either VARCALC or TEMPCAL where boundary temperature gradients require evaluation subsequent to obtaining a converged solution.

TESTX, TESTY, TESTS — these are used to test integration and for an edge integration TESTX and TESTY should nearly reflect the change in X and Y over the side of the element, TESTS = $\sqrt{(TESTX^2 + TESTY^2)}$

ELX — the cosine of the angle between the outward pointing normal on the element side and the x axis (see the figure below)




ELY — as ELX but in the Y direction

Arrays

B(1,I) — the gradient $\partial N_i/\partial X$ at node I evaluated at the gaussian point IG (IG = 1 to 3)

B(2,I) — the gradient $\partial N_i/\partial y$

## 7.12 Subroutine PRESCR

This routine is called from VARCALC when non-zero boundary prescriptions need evaluation. The routine integrates over the element sides/faces and assembles the elemental vectors {q} into a

global RHS vector R2. Further the routine may be developed and called iteratively to update non-zero gradient/stress boundary conditions, see Section 7.33.

## 7.13 Subroutine SURFINT

Subroutine SURFINT is called from PRESCR and HCOEF and is used for integration over an element side/face according to the variable NSID/NFACE (see Refs. 1, 7, 12).

| | |
|---|---|
| GPG = -1.0 | this corresponds to the element side/face at the parametric coordinate $\xi$ = - 1.0 integration is carried out in the direction $\eta$(GPH(I) where I=1 to NGAUSS) the number of gaussian points for integration. Similarly GPG = 1.0 corresponds to $\xi$ = + 1.0 while GPH = 1.0 or -1.0 refers to edges at $\eta = \pm 1.0$ and integration in direction $\xi$(GPG(I), I = 1 to NGAUSS). |
| DETJ | this is the determinant of the Jacobian matrix [J] and is used for obtaining $[J]^{-1}$ to form the global shape function derivatives[2] |
| DX, DY, DS | these are the components of elemental edge increments over which integration has occurred, then $TESTX = \sum_{i=1}^{i=NGAUSS} DX_i$ etc. |

Arrays

| | |
|---|---|
| CJ(1,1) | this is the contribution $\partial x/\partial \xi$ to the Jacobian matrix |
| CJ(1,2) | the contribution $\partial y/\partial \xi$ |
| CJ(2,1) | the contribution $\partial x/\partial \eta$ |
| CJ(2,2) | the contribution $\partial y/\partial \eta$ |
| CJI(1,1) | the inversion $\partial x/\partial \xi$ |
| CJI(1,2) | the inversion $\partial x/\partial \eta$ |
| CJI(2,1) | the inversion $\partial y/\partial \xi$ |
| CJI(2,2) | the inversion $\partial y/\partial \eta$ |
| DEL(1,I) | the element shape function derivative $\partial N_i/\partial \xi$ |
| DEL(2,I) | the derivative $\partial N_i/\partial \eta$ |

These in conjunction with the inversion CJI(L,M) are used to form the elemental shape function derivatives with respect to the global coordinate systems which are stored in vectors B(L,M) as defined in Section 7.11. To save on computer space many of these arrays associated with forming shape function derivatives are equivalenced

to the SK vector (primarily used in the solution routine) and thus inter-routine data transfer economically effected.

## 7.14 Subroutine DIRECS

The purpose of this routine is to evaluate the direction cosines ELX, ELY and is called from routine SURFINT. The values of the array CJ are also generated in this routine as they are necessary in calculating ELX, ELY.

## 7.15 Subroutine ABFIND

This routine is called from FRONT and is used for calling the appropriate element matrix assembly procedure.

## 7.16 Subroutine DERIV

This routine is called from the MASTER segment and from VARCALC when upwind weighting is employed. The function of the routine is to calculate nodal shape functions at the integration Gauss points for each element and to store these on peripheral storage in readiness to assemble the elemental stiffness matrices.

| | |
|---|---|
| NGAUSS | the number of integration Gauss points in one direction |

Vectors

| | |
|---|---|
| XG(I) I=1,3 | the parametric coordinate of the Gauss point |
| CG(I) I=1,3 | the associated integration weight coefficient |
| DDA(I) | the area increment (analogous to DX, DY) associated with the Gauss point where a variable TESTDA may be used such that for an element |

$$\text{TESTDA} = \sum_{i=1}^{i=NGauss^2} \text{DDA(I)}$$

then TESTDA should closely represent element area and is useful for debugging as this checks out the entire shape function-derivative routines

| | |
|---|---|
| P(I) | the value of the shape function at node I evaluated at the Gauss point |
| WP(I) | as for P(I) except for the upwind shape function |
| DP(I) | the vector containing all the P(I) for the element which is written onto peripheral store through channel 10 |
| DWP(I) | as DP(I) for upwind shape functions, but written to channel 8 |
| CP(I) | as DP(I) for superparametric element, stored on channel 10. |

Arrays

| | |
|---|---|
| WDEL(I,J) | the derivative of the upwind shape function at node J with respect to I(I=1=$\xi$, I=2=$\eta$) and evaluated at the Gauss point |
| DB(L,I) | this contains all the arrays B(L,J) evaluated at Gauss points and is written to storage through channel 10 |
| DWB(L,I) | as DB(L,I) but for upwind shape functions, written for channel 8 |
| CB(L,I) | as DB(L,I) for the superparametric element, stored on channel 10. |

## 7.17 Subroutine ABFORM1

This is called by ABFIND (called by FRONT) and is the assembly routine for the element stiffness matrix (for normal velocity gradients). The procedure is that element shape functions and derivatives are read off channels 10 (and 8 where appropriate) and the elemental matrices are formulated where with the exception of body force terms all matrix contributions occur on the left hand side (LHS), and even those can be taken to the LHS.

Vectors

| | |
|---|---|
| AT1(I) | holds the RHS evaluation of $q_1$ at element node I |
| AI2(I) | holds the RHS evaluation of $q_3$ at element node I |
| PP(I) | holds the superparametric shape function for weighting the continuity equation at node I (=1,3,5,7). |

Arrays

| | |
|---|---|
| BB(I,J) | holds the derivatives of the superparametric element (I=1 =x etc) at node J and is used in evaluating pressure gradient terms in the momentum equations |
| AA(I,J) | holds the element stiffness matrix and is equivalenced to ESTIFM for transfer of data to the global assembly procedure in FRONT,FRONTA. |

## 7.18 Subroutine ABFORM2

This is called by ABFIND and is the assembly routine for stress boundary prescription. The structure is identical to ABFORM1.

## 7.19 Subroutine EFVISC

This routine evaluates effective viscosity, effective conductivity by first calculating the length scale and kinetic energy of turbulence.

| | |
|---|---|
| ZLX1, ZLX2 | distances of a point from the parallel wall to the x-direction respectively |
| ZLY1, ZLY2 | distances of a point from the parallel walls perpendicular to the y-direction respectively |
| ZPT1, ZPT2 | distances of a point from the parallel walls perpendicular to the z-direction respectively |
| ZLLX | length scale of turbulence ($\ell_\mu$) for the part of the domain under consideration |

| | |
|---|---|
| TINS | turbulence intensity in the part of the domain being considered |
| UV | absolute, normalised velocity vector |
| SQK | $\sqrt{K}$, is square root of kinetic energy of turbulence |
| VKIN | holds original value of kinematic viscosity ($\nu$) |
| VKON | holds original value of thermal conductivity (K) |
| IWTS | holds original value of upwinding choice indicator (IUPWIN) |

Vectors

| | |
|---|---|
| VKINM(I) | holds original laminar kinematic viscosity for each element in the mesh |
| VMUDYN(I) | holds original laminar molecular viscosity for each element in the mesh |
| VCOND(I) | holds original laminar thermal conductivity for each element in the mesh |
| EMUT(8) | holds current element nodal turbulent dynamic viscosity |
| EMUE(8) | holds current element nodal effective dynamic viscosity |
| CONDFT(8) | holds current element nodal turbulent thermal conductivity |
| CONDFE(8) | holds current element nodal effective thermal conductivity |

Vectors UU(I), VV(I) and the array DIS(3,I) are fully explained in WYSET (7.25).

## 7.20 Subroutine TLSKIN

Is called from EFVISC to store and transfer via COMMON/TLSKIN1/, TLSKIN2/, the element nodal values of length scale of turbulence, turbulent kinetic energy, turbulent viscosity and turbulent conductivity. These are printed by VARCALC after solution convergence.

Vectors

| | |
|---|---|
| TLS(I) | holds length scale of turbulence value for each point in the mesh |
| EKE(I) | holds kinetic energy of turbulence value for each point in the mesh |
| TRMU(I) | holds turbulent dynamic viscosity value for each point in the mesh |
| TRCOND(I) | holds turbulent thermal conductivity value for each point in the mesh. |

## 7.21 Subroutine FVPROP[10,11]

This routine evaluates the molecular and kinematic ($\mu$,$\nu$) viscosity, thermal conductivity (K), coefficient of thermal expansion ($\beta$), specific heat capacity for constant pressure (CP) and the nodal fluid density ($\rho$) on the basis of variable property constants dependent on the temperature ($^{o}$K). It has to be called for each element for laminar flow only, in a similar manner as calling EFVISC.

| | |
|---|---|
| $T\phi$ | initial or fluid bulk reference temperature |

Vectors

| | |
|---|---|
| DVISC(8) | holds newly formed current element nodal molecular viscosity |
| EKFON(8) | holds newly formed current element nodal thermal conductivity |
| STEMP(8) | holds the current element nodal temperature values ($^{o}K$) from last iteration |

The above routine can be used with both coupled and uncoupled solutions.

7.22 Subroutine ABFORM5

Again called by ABFIND contains the formulation for free or mixed convection.

Vector

| | |
|---|---|
| A13(I) | this holds the elemental RHS contribution $q_4$ at element node I and comprises contributions from the Newton-Raphson algorithm. |

7.23 Subroutine TEMPM

Called from ABFIND, this routine assembles the elemental matrix entries for the decoupled energy equation.

## 7.24 Subroutine SFR

SFR is called by either DERIV or SURFINT and contains the elemental shape functions and derivatives for both parabolic and linear elements, the latter used to assemble the superparametric element for pressure interpolation. The routine also contains the upwind weighting functions and their derivatives.

## 7.25 Subroutine WYSET

This routine is called by DERIV and SURFINT and evaluates the optimised parameters $\alpha$ and $\beta$ for the upwind weighting functions.

A1 = $\alpha_1$ (see References 1, 3, 4, 9 and 12)

AA1 = $\beta_1$

A2 = $\alpha_3$

AA2 = $\beta_3$

B1 = $\alpha_2$

BB1 = $\beta_2$

B2 = $\alpha_4$

BB2 = $\beta_4$

### Vectors

| | |
|---|---|
| UAVE(1) | average velocity along element side 3,1 (= $\bar{U}_{31}$) |
| UAVE(2) | = $\bar{U}_{57}$ |
| VAVE(1) | = $\bar{V}_{53}$ |
| VAVE(2) | = $\bar{V}_{71}$ |
| UU(I) | = u velocity component at current element node I |
| VV(I) | = v velocity component at current element node I |

Arrays

| | |
|---|---|
| DIS(1,I) | the u component of velocity at node I |
| DIS(2,I) | the v component of velocity at node I |
| DIS(3,I) | (T) - temperature at node I |

## 7.26 Subroutine FRONT, FRONTA

This is the global matrix assembly and elimination routine and is called by VARCALC, TEMPCAL, PSICALC and WCALC. Details of the structure of this routine may be found in Ref. (5). However the present version is more efficient due to implementation of work done by Walters in Ref. (6). Three errors regarding NCRIT and NMAX sizes, and element matrix singularity or ill-conditioning are self-explanatory once they occur.

## 7.27 Subroutine BACSUB, BACSUBA

This is a backsubstitution routine and is called by FRONT subsequent to completing the elimination phase of solution.

## 7.28 Subroutine RESOL[5]

This routine provides a re-solution facility, where it can compute corrections to the equations system depending on their residuals.

## 7.29 Subroutine PSICALC[1,12,13]

This subroutine calculates stream function ($\psi$) from a known velocity field.

| | |
|---|---|
| IAUTO | = 0, specify stream function values at every node on the boundaries |
| | = 1, subroutine AUTOBC called to compute stream function values at the boundaries |
| NB | total number of boundary nodes |
| NOD | node number for boundary conditions |
| VAL | stream function boundary condition value. |

Vectors

| | |
|---|---|
| PSI(I) | holds each nodal ($\psi$) value in the mesh |
| NODP(I) | holds boundary node numbers in the mesh |
| VALP(I) | holds boundary node ($\psi$) value in the mesh |

Certain temporary variables storage similar to Section 7.10 is necessary before their original values are reassigned. This is straightforward and can be followed very easily in the listing.

## 7.30 Subroutine WCALC[1,12,13]

This subroutine calculates vorticity ($\omega$) field from a known velocity field.

| | |
|---|---|
| NB, NOD, VAL | similar as in Section 7.29 |

Vectors

| | |
|---|---|
| NODW(I) | holds each nodal ($\omega$) value in the mesh |
| VALW(I) | holds boundary node numbers in the mesh |
| R2(I) | holds boundary node ($\omega$) value in the mesh |

7.31 Subroutine AUTOBC[1,12]

This routine determines boundary values for the stream function field (Cartesian coordinates only).

| | |
|---|---|
| KINL | number of elements on inlet boundary |
| KOUT | number of elements on outlet boundary |
| PSIF | ($\psi$) value on fixed boundary (specified as datum boundary) |
| NLB | total number of boundary nodes on fixed boundary |
| NOD | node number |
| NUB | total number of boundary nodes not on fixed boundary |

Vectors

| | |
|---|---|
| ALEN(I) | holds length of elements side for inlet boundary |
| BLEN(I) | holds length of elements side for outlet boundary |
| KINZ(I) | holds element numbers for inlet boundary |
| KOUZ(I) | holds element numbers for outlet boundary |

## 7.32 Subroutine ABFORM6[1,12]

Element assembling routine to be called from the frontal solution routine for stream function or vorticity.

JAY = 0, for Cartesian coordinates
= 1, for axisymmetric case.

The vectors have the same meanings as in Section 7.17 as well as the overall structure.

## 7.33 Procedure for Updating Nonzero Gradient/Stress Boundary Prescriptions

The routine PRESCR is used to assemble non-zero gradient/stress boundary conditions into the global RHS vector. It may also be used with little modification to update unknown gradient/stress values during each iteration of calculation. This may be achieved in the manner outlined below:

i) Call PRESCR iteratively from VARCALC with the appropriate NSID/NFACE code

ii) For gradient values form in loop DO20 (see Appendix II) the appropriate linearised values $\frac{\partial \bar{u}}{\partial x}$, $\frac{\partial \bar{v}}{\partial x}$ etc. which may be achieved typically at the edge Gauss points

```
G1=0.0
G2=0.0
DO 20 L=1, NBN
```

```
NN=IABS(NOP(NELL,L))
M1=NOPP(NN)
M3=M1+MDF(NN)-1
G1=G1+VAR1(M1)*B(1,L)    (∂u/∂x)
G2=G2+VAR1(M3)*B(1,L)    (∂v/∂x)
20 CONTINUE
```

iii) For stress values a similar procedure may be used except p is evaluated from the superparametric interpolation

iv) The gradient/stresses, evaluated at the edge Gauss points may then be assembled into the RHS vector in the loop DO 60 which needs small changes, typically

$$R2(M1)=R2(M1)+H1*V*\left|\frac{\partial \bar{u}}{\partial x}\ DY + \frac{\partial \bar{u}}{\partial y}\ DX\right|$$

$$R2(M3)=R2(M3)+H1*V*\left|\frac{\partial v}{\partial x}\ DY + \frac{\partial v}{\partial y}\ DX\right|$$

etc.

## 7.34 References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# APPENDIX I

## PROGRAM DIMENSIONING AND USERS INSTRUCTIONS


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## AI.1 Introduction

The following are program instructions in full details, reporting the problem types which may be tackled using the two dimensional and axisymmetric version option. Hence this can be regarded as an instruction manual for running the program.

The finite element algorithms utilise the eight-noded, quadrilateral, isoparametric elements (Serendipity family) and are structured to solve four different problem types:

1. Isothermal - (laminar),
2. Forced convection - (laminar),
3. Free or mixed convection - (laminar), and
4. Buoyant, recirculating free or mixed convection (turbulent or mixed).

For problem types 1 and 2, formulations are included for solving the Navier Stokes equations (see Schlichting, reference 1) in both Cartesian (x-y) and axisymmetric (r-z) form. Further, for these two equation sets, the algorithm caters for boundary conditions of the following form:

a) prescribed
b) normal velocity gradients (n.v.g)
c) stress (see reference 1).

The nondissipative energy equation (see reference 1) is also solved for problems of category 2 after having first obtained a

converged velocity field. However such a procedure is only acceptable where fluid properties are largely independent of temperature. Solution of the uncoupled equations in both Cartesian and axisymmetric form is effected only for prescribed values and zero temperature gradients on the domain boundary.

Natural convection occurs when density changes occur in the fluid. For this reason, the energy equation is linked to the right hand side of the Navier-Stokes equations for the uncoupled solution, where each time the Navier-Stokes equations are solved, the resulting velocities are used to solve the energy equation until overall convergence is achieved. Another formulation for this problem type is included where the energy equation is coupled into the velocity field calculation and solution for temperature differences with respect to a reference value effected through the domain. This procedure is subject to both prescribed and gradient boundary conditions.

## AI.2 Implementation on Different Computer Systems

This program is written to conform to the American National Standard FORTRAN 77 (ansi 77) and is set up to run on the Honeywell Multics (DPS8/M) operating system. Different computers have different operating systems and thus some guidance on implementation is warranted.

Input to the program is effected through channel NCR (=5) whereas line printer output is directed to channel NLP (=9).

The program may also require two further channels for input/output. Channel NCP (=1) - (file CPØ), for dumping or reading in initial conditions (e.g. extrapolated values) and channel (2) - (file ed1), which is used for dumping data for use in restart should there be insufficient time available to complete the computer run in one attempt. Further, working space is required by the program in order that excessive storage is not consumed. For this purpose, scratch discs need to be assigned to channels 10, 8 and 4, the former two are used in assembly of the element stiffness matrices and appear in subroutines

DERIV

ABFORM1

ABFORM2

ABFORM5

ABFORM6

and TEMPM

The discs are written to/read from SEQUENTIALLY and having been read from require REWIND. However not all compilers feature these instructions and may require conversion of these files to DIRECT ACCESS form, the declaration of which depends on the computer operating system.

Scratch disc 4 is encountered in the solution procedure and holds the reduced equations on channel ND1 (=4), this is also written to in a SEQUENTIAL manner and occurs in subroutines:

FRONT, FRONTA

and BACSUB, BACSUBA

A further feature of the program is the system clock function calling subroutine (TIMER). This function occurs in many places throughout the program and it is suggested that either a dummy routine is inserted or a routine which calls the clock function of the particular operating system using a subroutine such as ours:

```
      SUBROUTINE TIMER (K1)
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
C     Call system clock function (in seconds)
      X=QMILL(I)
      K1=X
      RETURN
      END
```

For the Honeywell Multics system a [PL/1] program had to be written to define the above [QMILL(I)] for the system and to return it in seconds.

## AI.3 Arrays and their Dimensioning

### AI.3.1 Arrays in COMMON/GEP/

The numbers shown are the ones used in this thesis:

| | | | | | |
|---|---|---|---|---|---|
| NOP(a,8) | (122,8) | R1(c) | (1553) | NODV(d) | (550) |
| NDN(a) | (122) | R2(c) | (1553) | VALV(d) | (550) |
| LPR(a) | (122) | VARI(c) | (1553) | | |
| TEMP(b) | (461) | VARA(c) | (1553) | | |
| CORD(b,2) | (461,2) | NCOD(c) | (1553) | | |
| RSPEC(b,6) | (461,6) | BC(c) | (1553) | | |
| NOPP(b) | (461) | AVARI(c) | (1553) | | |
| MDF(b) | (461) | | | | |

The value of 'a' must be at least equal to the number of elements in the problem, while entry 'b' needs to be at least the number of nodes in the overall mesh. The value of 'c' must be at least the total number of degrees of freedom (dof) in the mesh, while 'd' must be at least the number of constrained degrees of freedom for the problem. Some knowledge of these values is necessary 'a priori' - estimation of which is best illustrated by example as shown in the mesh below, Figure AI.1:

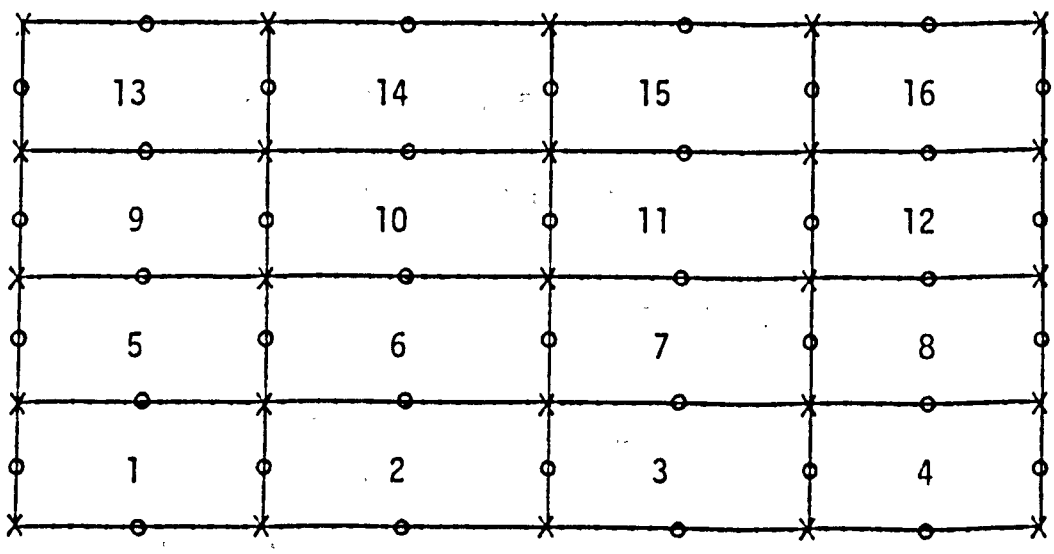



FIGURE AI.1

Clearly there are 16 elements, then a $\geqslant 16$, there are 65 nodes, hence b $\geqslant$ 65. The number of dof requires further calculation. For the velocity and pressure field, velocity is interpolated quadratically while pressure is subject to linear interpolation, thus the x (or z) velocity component 'u', pressure 'p' and y (or r) component 'v' are solved at nodes 'X' while only u and v are solved at nodes 'o'. Thus for the mesh the total degrees of freedom is given by

$$25 \times 3 + 40 \times 2 = 155$$

thus $$c \geqslant 155$$

When the temperature field is solved for a coupled equation set, temperature is quadratically interpolated and thus the variables u, p, v, $\theta$ are solved at corner nodes and u, v, $\theta$ at midside nodes. For a particular problem, the number of dof associated with an element is echoed as the variable NCN and the total dof for the problem is output against the name NP.

AI.3.2 <u>Arrays in COMMON/GUARD/</u>

The numbers shown are the ones used in this thesis:

| | | |
|---|---|---|
| SK(p) | (40000) | NMAX = 200 |
| ESTIFM(q,q) | (28,28) | NCRIT = 80 |
| GISH(r) | (600) | |
| INTEG(s) | (2700) | |

The values of p, r and s are the most difficult to estimate, 'q' must be at least the number of dof associated with each element, when solving for u, p, v, θ - q ⩾ 28. The value of p has a minimum value as in certain subroutines, local arrays are equivalenced to SK to save space, for the present p⩾40000. The maximum value of p, r and s are solely dependent on a developed form of Hood's frontal solution routine (see references 2 and 3) as the global stiffness array is equivalenced to it in the solution procedure, thus some knowledge of solution 'frontwidth' is required.

An estimate of this value may be obtained again with reference to the example mesh, Figure AI.2 below:

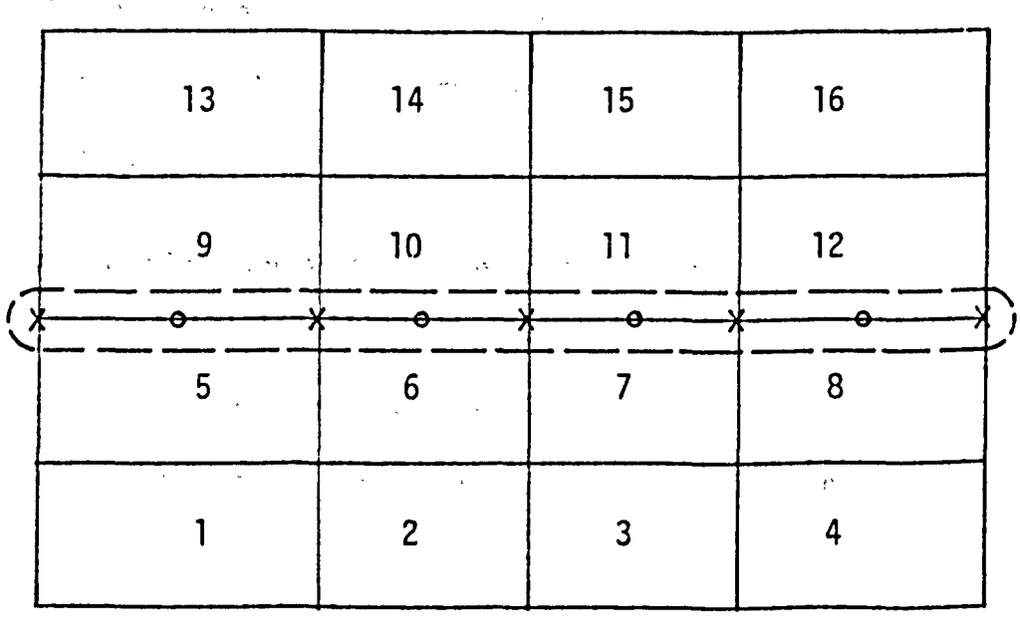



FIGURE AI.2

Solution proceeds with ascending element numbers, at a particular solution stage eight elements have been processed resulting in a

front of partially assembled equations as shown (contributions from elements 9 to 12 are required to fully assemble the matrix on the 'front'). The total number of partially assembled equations for u, p, v solution are;

$$5 \times 3 + 4 \times 2 = 23$$

plus space to assemble the next element

$$= 23 + 20 = 43$$

Therefore for the unsymmetric matrix, the storage required is $(43)^2$.

Estimation of the value of NMAX is also subject to boundary prescription and thus its precise value is difficult to evaluate beforehand.

The estimation of NMAX controls the value of 'p' which is now set such that $p \geqslant (NMAX)^2$, whereas $r \geqslant NMAX$. The INTEG array is formed by equivalencing integer arrays in FRONT and BACSUB, FRONTA BACSUBA, these arrays are shown together with the numbers used in this thesis:

| | |
|---|---|
| LDEST(x)(28) | LHED(y)(200) |
| KDEST(x)(28) | KHED(y)(200) |
| NK(x)(28) | LPIV(y)(200) |
| EQ(y,y)(200,200) | KPIV(y)(200) |
| | JMOD(y)(200) |

The value of 'x' must be at least the total number of dof for an element (28 for u, p, v, θ), whereas y ⩾ NMAX. However, should there be any underestimate of NMAX the solution routine will stop and the appropriate diagnostic message printed.

A further local array which may need redimensioning occurs in subroutines (WYSET) and (EFVISC) under the name DISC(3,e) where e should be chosen to be the same as 'b' in Section AI.3.1 i.e. e = 461 as in this work.

## AI.4 Program Input

The following section describes program input data including the program variable name and the format through which it is read. Reference will be made to data line sets, these may constitute a single line of input or many lines.

1 TITLE (12A6)

TITLE (3) lines of input to describe the purpose of the computer run (2 lines could be left empty).

2 MARK, NAX1, NEWTON, IUPWIN, ITURB, (5I5)

MARK=1 Normal Velocity Gradients (nvg) boundary specification

MARK=2 Stress boundary specification

MARK=3 Free or mixed convection formulation, nvg's or u,p,v; gradient or prescribed value on θ

MARK=4 Forced or mixed convection, nvg boundary prescription on u,p,v

MARK=5 Forced convection, stress boundary prescription on u,p,v.

| | |
|---|---|
| NAX1=0 | x-y coordinate system |
| NAX1=1 | z-r coordinate system |
| NEWTON=0 | standard iteration procedure |
| NEWTON=1 | Newton-Raphson iteration procedure (should yield higher convergence rates for laminar flow only) |
| IUPWIN=0 | no upwinding, i.e. weighting functions equals the shape functions |
| IUPWIN=1 | upwinding applied to the temperature equation in free or mixed convection problems |
| IUPWIN=2 | upwind weighting applied on the momentum equations in advection dominated problems |
| ITURB=0 | laminar flow only |
| ITURB=1 | partially turbulent or fully turbulent flows. |

This calls subroutine (EFVISC) in which effective viscosity and effective conductivity are evaluated for each element. This subroutine should be adjusted for each individual problem. For isothermal studies proceed to card set 4.

3. CONDF, BETA, CPF (3F20.10)

CONDF = thermal conductivity of the working fluid

BETA = coefficient of cubical expansion

CPF = specific heat capacity at constant pressure

4. EMU, RHO, X, Y (4F20.10)

EMU = dynamic viscosity

RHO = density

X = x component of body force

Y = y component of body force

5 NH(I5)

NH = number of nodes in the mesh

6 MTRD(I5)

MTRD=0 no restart input required on channel (2) namely [edl] file

MTRD=1 input required on channel 2 for restart

7 NCARDS(I5)

NCARDS=0 no output of converged field for post processing (plotting, extrapolation for restart etc).

NCARDS=1 output of converged velocity-temperature fields on convergence on channel NCP(=1), namely [cpØ] file.

8 MTRIT(I5)

MTRIT=0 no dump of unconverged calculations onto channel 2 for restart

MTRIT=1 dump of unconverged calculations onto channel 2 for restart

9 LTIM(I5)

LTIM = duration of program execution before dump for restart if MTRIT=1, otherwise execution stops, the variable

LTIM is compared against the argument derived from the system clock using SUBROUTINE TIMER.

10 NNP(I5)

NNP = the number of nodal points input to the program - nodal coordinates need only be supplied at element corners, interpolation of midside nodes occurring automatically where element sides are straight

For NNP=0, go to card set 14.

11 N, CORD(N,1), CORD(N,2) (I19,2F15,10)

N = node number

CORD(N,1) = x(or z) coordinate of the node

CORD(N,2) = y(or r) coordinate of the node

There should be 'NNP' lines of data to input the coordinate system.

12 NE (I5)

NE = the number of elements in the mesh

13 N,NOP(N,1) ....., NOP(N,8) (2I8, 7I5)

N = element number

NOP(N,1) = global node number corresponding to the 'element' node number 1 of element N as shown in Figure AI.3 below:

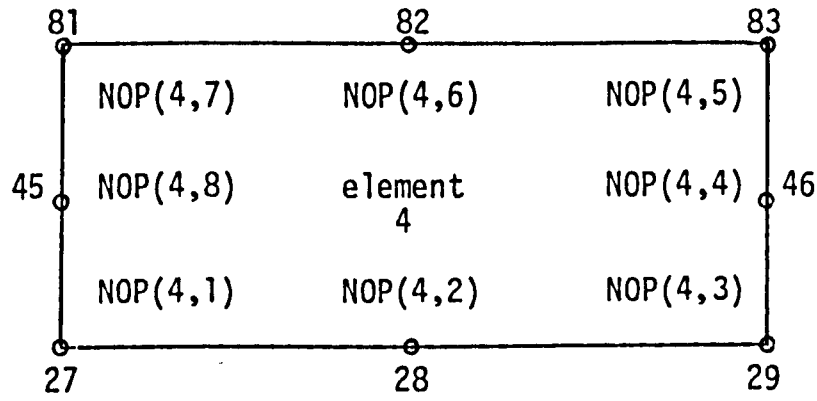



FIGURE AI.3

Then for element four the input line is

4 27 28 29 46 83 82 81 45

N.B. (a) counterclockwise nodal numbering

(b) there should be NE lines of element data.

If NNP≠0 go to card set 16

14 (i) IMESH(I5)

IMESH=1, Arbitrary or complex mesh generation.

Now go to 15

IMESH=0, Equidistance (equispaced) mesh generation.

Carry on

(ii) NROWS, NCOLS (2I5)

NROWS = number of elements rows

NCOLS = number of elements columns

(iii) DX,DY (2F20.10)

DX = element X increment

DY = element Y increment

Go to 16

15 i) NXL, NYL, NN, ND (4I10)

NXL = total number of elements in the ($\xi$) direction

NYL = total number of elements in the ($\eta$) direction

NN = first node number of the mesh

ND = 0, sequential numbering of elements along lines of constant ($\eta$)

ND = 1, sequential number of elements along lines of constant ($\xi$)

ii) (XM(I), YM(I), I=1,8) (2F10.3)

Reads in (8) cards for the x,y coordinates of the master nodes of the mesh, on the basis of 8-noded isoparametric quadrilateral element mesh blocks.

The procedure (15-i)→(15-ii) can be repeated for as many mesh blocks as required, then these mesh blocks are interconnected to form the mesh.

16 ICOND (I10)

ICOND=0 pass to card set 18

ICOND = number of initial conditions on u,p,v,($\theta$) which have been extrapolated from previous runs or guessed, these are read off channel NCP(=1)

17 L,K,PHI (2I5, F20.10) in the file assigned for channel (1), namely [cpØ].

L = node number

K = dof number

K=1 for u or Vz

K=2 for p (only at corner nodes)

K=3 for v or Vr

K=4 for θ (temperature)

PHI = magnitude of the DOF

18 NRT (I5)

NRT = 0 pass to card set 22

NRT = number of elements on which gradient/stress boundary prescriptions are applied, however zero gradients are assumed and do not need explicit evaluation.

19 LE, NSID (2I5)

LE = element number

NSID = element side code (see Figure AI.4 below).

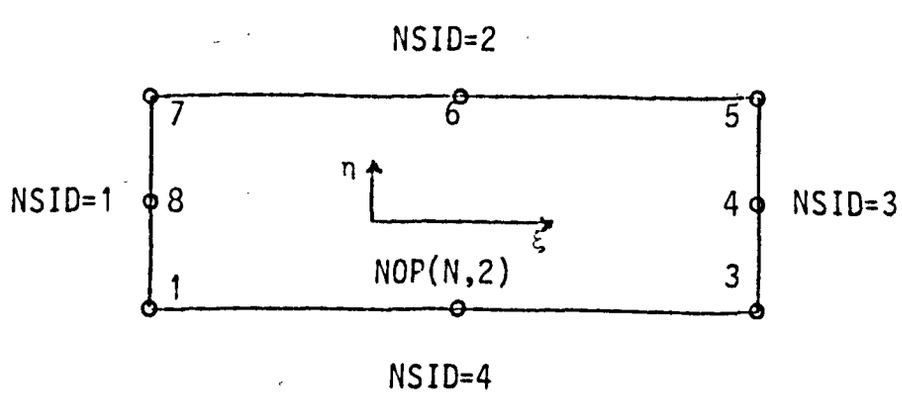



FIGURE AI.4

20 IRT (I5)

IRT = total number of gradient/stress boundary prescriptions

21 L, RSPEC(L,1) ..... RSPEC(L,2) (I10, 6F10.4)

L = node number

RSPEC(L,1) = $\partial u/\partial x$ for nvg formulation

RSPEC(L,1) = $\sigma_x$ for stress formulation

RSPEC(L,2) = $\partial u/\partial y$ for nvg formulation

RSPEC(L,2) = $\tau_{xy}$ for stress formulation

RSPEC(L,3) = $\partial v/\partial x$ for nvg formulation

RSPEC(L,3) = $\tau_{yx}$ for stress formulation

RSPEC(L,4) = $\partial v/\partial y$ for nvg formulation

RSPEC(L,4) = $\sigma_y$ for stress formulation

RSPEC(L,5) = $\partial\theta/\partial x$ for free or mixed laminar and/or turbulent convection

RSPEC(L,6) = $\partial\theta/\partial y$ for free or mixed laminar and/or turbulent convection

In cylindrical coordinate systems

$$\frac{\partial}{\partial x} = \frac{\partial}{\partial z}; \quad \frac{\partial}{\partial y} = \frac{\partial}{\partial r}; \quad \sigma x = \sigma z;$$

$$\tau_{xy} = \tau_{zr}; \quad \tau_{yx} = \tau_{rz}; \quad \sigma y = \sigma r$$

22 NB (I5)

NB = number of constrained degrees of freedom, care must be taken to avoid duplication as this affects the solution procedure

23 NOD, MDEG, VAL (2I5, F20.10)

NOD = node number

MDEG = dof code (as K of 17)

VAL = prescribed boundary value

For isothermal data, input is now complete. For coupled free or mixed laminar and/or turbulent convection problems, go to card set 28. For uncoupled forced or mixed laminar and/or turbulent convection only, continue.

24 NB (I5)

NB = number of prescribed temperature values, again taking care to avoid duplication

25 NOD, VAL (I5, 5X, F20.10)

NOD = node number

VAL = prescribed temperature value

26 NHEAT (I5)

NHEAT= 0

This ends input data for uncoupled forced or mixed laminar and/or turbulent convection problems.

NHEAT= number of elements on which heat transfer coefficients need calculating

27 NELL, NSID 2I5)

NELL = element number

NSID = element side code (see 19)

This completes input data for uncoupled forced or mixed laminar and/or turbulent convection problems. Go to 30.

28 NHEAT (I5)

Used in coupled free or mixed laminar and/or turbulent convection problems, but has the same function as card set 26.

NHEAT = 0 completes input data for free or mixed convection problems.

Go to 30.

29 NELL, NSID (2I5)

As card set 27 and completes input for free or mixed laminar and/or turbulent convection problems. Go to 30.

30 IPSW (I5)

IPSW=0 this indicates that stream function and vorticity values calculations are not required and ends input data for either forced or free convection, or any other case.

IPSW=1 program goes on to calculate stream function and vorticity values from known velocity fields using the (FEM), and hence following data is required.

31 IAUTO (I5)

IAUTO=0 this means that stream function values at boundary nodes have to be specified, hence carry on to 32

IAUTO=1 subroutine "AUTOBC" is called to compute stream function values at boundaries. Go to 34.

32 NB (I5) Total number of boundary nodes for stream functions only.

33 NOD, VAL (I10, F20.10) as many data lines as (NB) in 32 above.

NOD = boundary node number

VAL = stream function value at this node.

Go to 43.

34 KINL (I5) Number of elements on inlet boundary, (for $\psi$)

35 KINZ, ALEN (I10, F20.10) as many data lines as (KINL) in 34 above.

KINZ = element number

ALEN = length of element side

36 KOUT (I5) Number of elements on outlet boundary.

37 KOUZ, BLEN (I10, F20.10) as many data lines as (KOUT) in 36 above.

KOUZ = element number

BLEN = length of element side

38 PSIF (F20.10) Value of stream function to be specified on datum boundary.

39 NLB (I5) Total number of boundary nodes on fixed boundary, for ($\psi$)

40 NOD (I5) Node number, as many data lines as (NLB) in 39 above, for ($\psi$)

41 NUB (I5) Total number of boundary nodes <u>not</u> on fixed boundary, for ($\psi$)

42 NOD (I5) Node number, as many data lines as (NUB) in 41 above, for ($\psi$)

43 NB (I5) Total number of boundary nodes for vorticity only. If (NB=0), this means no vorticity values calculations are required and hence, this ends the input data, otherwise, proceed.

44 NOD, VAL (I10, F20.10)

NOD = node number

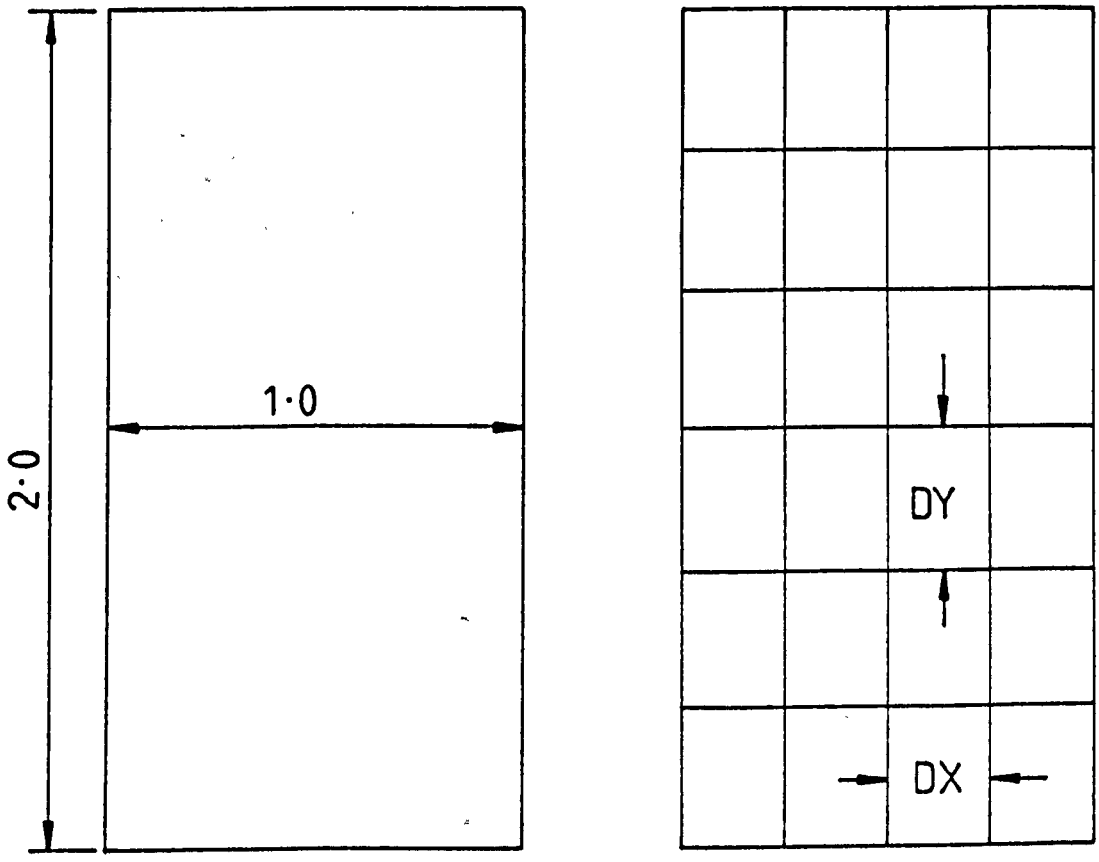
VAL = vorticity value

As many data lines as (NB) in 43 above.

## AI.5 Details of the Auto Mesh Generation Features

### AI.5.1 Equidistant (Equispaced) Mesh Generation (MESH=0)

This is a simple algorithm for auto generation of a REGULAR finite element mesh (see data set 14(ii), 14(iii) of Section AI.4). Input for this section is best illustrated by example shown below in Figure AI.5.




FLUID DOMAIN ELEMENT DISCRETISATION

FIGURE AI.5

For the problem there are 6 rows of elements (NROWS=6) and 4 columns (NCOLS=4), then for the geometry shown

$$DX = \frac{1.0}{4} = 0.25 \qquad DY = \frac{2.0}{6} = 0.67$$

AI.5.2 Arbitrary or Complex Mesh Generation (MESH=1)[4]

This is an algorithm which uses the isoparametric concept to deal with complex domains shapes and multiply connected domains.

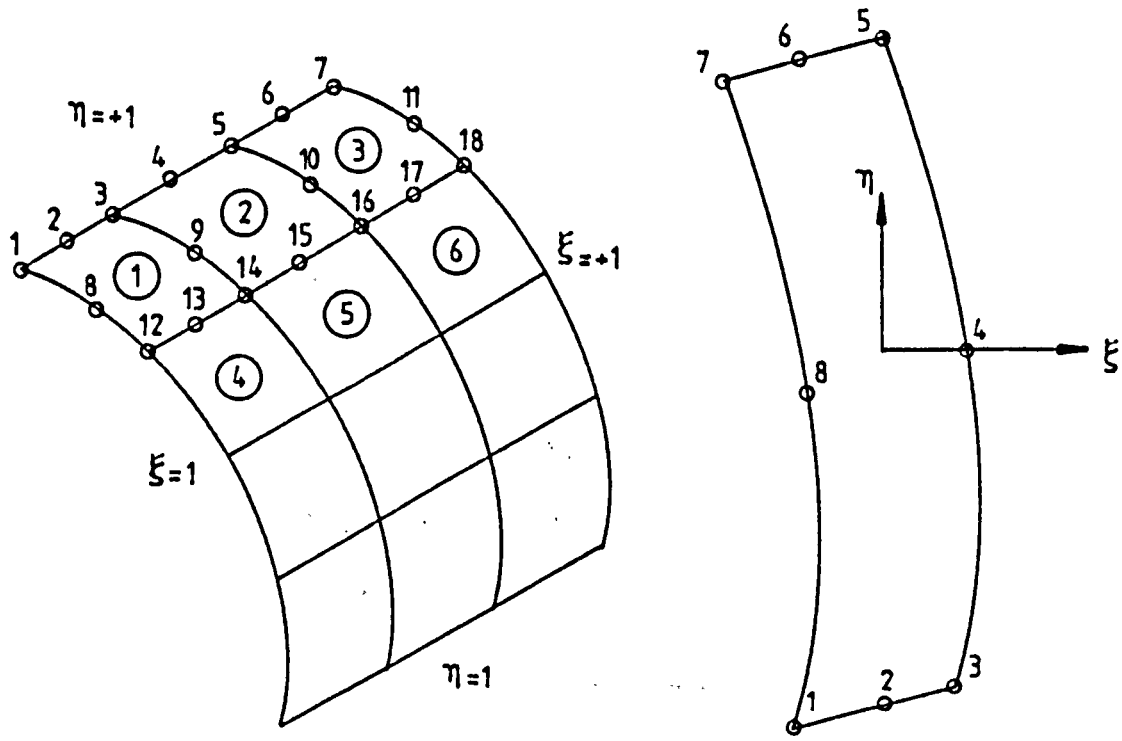


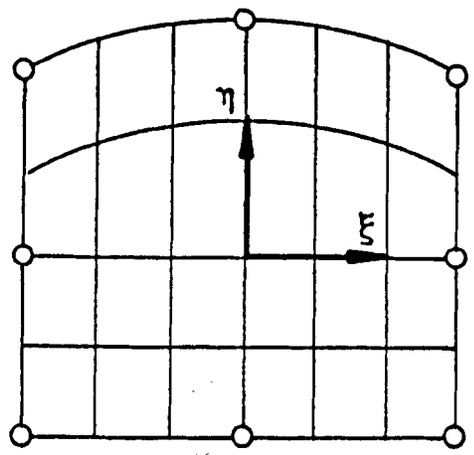

FIGURE AI.6: CURVED DOMAIN

Using the curved domain in Figure AI.6on the right hand side, it is regarded that the whole domain is one big isoparametric element and defined by the eight master nodes. A suitable mesh is obtained by using lines of constant ($\xi$) and ($\eta$), left hand side to divide the "large element" into (n) elements in the ($\xi$) direction and (m) elements in the ($\eta$) direction. The coordinates of any point (j) are given as: (4)

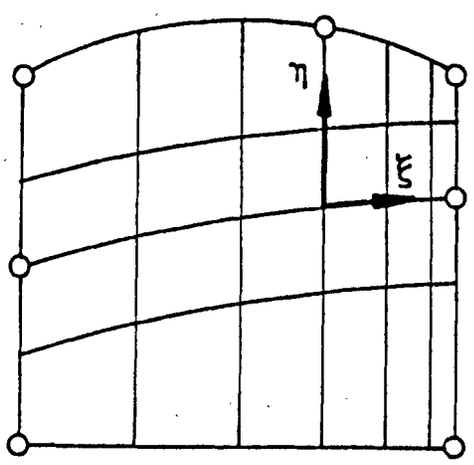
$$\left.\begin{aligned} x_j &= \sum_{i=1}^{8} N_i\,(\xi_j, \eta_j)\, x_i \\ y_j &= \sum_{i=1}^{8} N_i\,(\xi_j, \eta_j)\, y_i \end{aligned}\right\} \qquad (AI.1)$$

If grading of mesh is required, weighting factors can be introduced to create unequal dimensions inside a "large element". A simpler

way to shift the origin of $(\xi,\eta)$ axes towards the corner in which a denser mesh is desired is shown in Figure AI.7.




NORMAL MESH




GRADED MESH

FIGURE AI.7

For detailed examples and discussion see References 4 and 5.

## 6.6 References


1. *"Boundary Layer Theory"*, by H. Schlichting, McGraw-Hill, (1979).
2. Hood, P., *"Frontal Solution Program for Unsymmetric Matrices"*, Int. J. Num. Meth. Engng. Vol (10), pp(379-399) (1976), Erratum: Vol. 11, p. 1202, (1977).
3. Walters, Roy A., *"The Frontal Method in Hydrodynamics Simulations"*, Computers and Fluids, Vol. 8, pp. 265, 272, (1980).
4. Cheung, Y.K. and Yeo, M.F., *"A practical introduction to Finite Element analysis"*, Pitman, (1979).
5. Alghatam, M.J., *"An investigation into the use of the Finite Element method for certain continuum problems"*, MSc Thesis, Mech. Eng. Dept., University of Technology, Loughborough, England, UK (1979).
6. *Computer Program Report (NS2D)*, Department of Civil Eng., Univ. College, Swansea, Wales (1982).

# APPENDIX II

## PROGRAM LISTING

```
LOUGHBOROUGH UNIVERSITY

****    ***    **** *****
*   * *   * *      *
****  ***** * *** ****
*     *   * *   * *
*     *   *  **** *****

*****  ***  ****  *   *  ***  ***** ***** ***** ****
*     *   * *   * ** ** *   *   *     *   *     *   *
****  *   * ****  * * * ***** *     *   ****  ****
*     *   * *  *  *   * *   *  *     *   *     *  *
*       ***  *   * *   * *   *  *     *   ***** *   *

VERSION 4

FETHSOLVAC
----------

PROGRAMMER : Mohammed J. K. Alshatam
DATE       : 10 . 01 . 1985
TIME       : 10:59
```

TEXT BOUND INTO

THE SPINE

BEST COPY

AVAILABLE

Variable print quality

FETHSOLVAC

```
C*****************************************************************
C     FINITE ELEMENT PROGRAM IN INCOMPRESSIBLE VISCOUS          *
C     LAMINAR AND TURBULENT FLOW INCLUDING HEAT TRANSFER.       *
C                                                               *
C            ''''''''''''''''''''''''''''''''''''''''''''''''''  *
C            Programmer: Mohammed Jassim Alghatam               *
C            ''''''''''''''''''''''''''''''''''''''''''''''''''  *
C                                                               *
C                                                               *
C*****************************************************************
C                                                               C
C                                                               C
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      COMMON/CONTF/
     1 X,Y,V,CINDF,BETA,DPF,RHO,HCOFX,HCOFY,
     2 DFF,DF3,DF4,EMU,WG(3),D3(2),D5,DX,DY,
     3 NP,NH,NE,NE,NCF,NIN,NEW,IT1,YD1,ITRD
     4,NTIME,YPRA,YTR,LTIM,NTRIT,NCARDS,NSID,NAXI
     5,NRT,NWGF,NWF,NELL,NTFA,NGAUSS,NPR,NCR,NLF,NCF
     6,NCOFC,IG,MG,NEW,NET,NEWTON,ITURB,ICOND
      COMMON/GEF
     1 TEMP(4F...),COORD(461,2),RSPEC(461,6)
     2,P1(1553),P2(1553),VARI(1553),VARA(1553),BC(1553)
     3,VALN(560),AVARI(1553),NOF(122,8),NDN(122),LPR(122)
     4,NCPR(461),NOF(461),NCOD(1553),NODY(560)
      COMMON/DARC/
     1 BK(400PA),ESTIFM(28,28),DISH(600),INTEG(2700)
      COMMON/VPUIN/
     1 FFL,FFC,AL,A2,B61,B62,B1,B2,DIS,I,461)
     2,...(8),NDEL(1,2),UR(2,8),DWE(2,72),DWF(72),TT(8)
     3,CU(8),VV(9),UPVF(2),VAVE(2),IUPWIN,IWTS,VKIN,VKON

      OPEN(UNIT=1,FILE='CPB',FORM='FORMATTED')
      OPEN(UNIT=2,FILE='ADI',FORM='UNFORMATTED')
      OPEN(UNIT=3,FORM='UNFORMATTED',STATUS='SCRATCH')
      OPEN(UNIT=4,FORM='UNFORMATTED',STATUS='SCRATCH')
      OPEN(UNIT=5,FORM='UNFORMATTED',STATUS='SCRATCH')
      OPEN(UNIT=6,FORM='UNFORMATTED',STATUS='SCRATCH')
      OPEN(UNIT=7,FILE='INPUT',FORM='FORMATTED')
      OPEN(UNIT=8,FILE='OUTPUT',FORM='FORMATTED')

      NCR=0
      NLF=0
      NCF=1
      CALL TIMER(IT1)
      WRITE(NLF,101)
      CALL TIMER(IT2)
      ITIME1=IT2-IT1
      WRITE(NLF,101)ITIME1
      CALL DATA3
```

FETHSOLVAC (CONT )

```
      CALL TIMER(IT)
      ITIME=IT-IT1
      WRITE(NLP,120)ITIME
      CALL DERIV
      CALL TIMER(IT)
      ITIME=IT-IT1
      WRITE(NLP,122)ITIME
      CALL DATAK
      CALL VARCALC
      CLOSE(1,STATUS='KEEP')
      CLOSE(2,STATUS='KEEP')
      CLOSE(3,STATUS='DELETE')
      CLOSE(4,STATUS='DELETE')
      CLOSE(8,STATUS='DELETE')
      CLOSE(10,STATUS='DELETE')
      CLOSE(5,STATUS='KEEP')
      CLOSE(9,STATUS='KEEP')
  100 FORMAT(' FINITE ELEMENT PROGRAM IN INCOMPRESSIBLE VISCOUS'//
     -' LAMINAR AND/OR  TURBULENT FLOW INCLUDING HEAT TRANSFER.'//
     -' IT SOLVES N-S , CONTINUITY , AND THE GENERAL ENERGY '//
     -' EQUATIONS FOR STEADY STATES. IT ALSO CALCULATES VARIOUS'//
     -' FLUID FLOW AND HEAT TRANSFER PARAMETERS.'///
     -'XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX'//
     -' Programmer:  Mohamed Issia Alsouqar'//
     -'XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX'//)
  101 FORMAT(1H0,21H EXECUTION STARTED AT,I5,6H SECS //)
  120 FORMAT(/28H DATA GENERATION COMPLETE AT,I5,6H SECS.//)
  122 FORMAT(/49H JACOBIAN AND DERIVATIVE CALCULATIONS COMPLETE AT,I5,6H
     1 SECS.//)
      STOP
      END
C
C
C
C
C
C
C
C
C
C*****************************
      SUBROUTINE TIMER(K1)
C*****************************
C
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
C     CALL SYSTEM CLOCK FUNCTION (IN SECONDS)
      X=DMILL(I)
      K1=X
      RETURN
      END
```

FETHSOLVAC (CONT.)

```
C
C
C
C
C
C
C
C**********************
      SUBROUTINE DATPG
C**********************
C
C
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      COMMON/CONTP/
     1 X,Y,V,CONDF,BETA,CPF,RHO,HCOFX,HCOFY,
     2 GPF,GPG,GPH,EMU,XG(3),CG(3),DS,DX,DY,
     3 NP,NH,NE,NB,NDF,NCN,NBN,IT1,ND1,MTRD
     4,NTIME,MARK,NTR,LTIM,MTRIT,NCARDS,NSID,NAXI
     5,NRT,MWGA,NNP,NELL,NTRA,NGAUSS,NPR,NCR,NLP,NCP
     6,NCORD,IG,NG,NBV,NBT,NEWTON,ITURB,ICOND
      COMMON/GEP/
     1 TEMP(461),CORD(461,2),RSPEC(461,6)
     2,R1(1553),R2(1553),VARI(1553),VARA(1553),BC(1553)
     3,VALV(560),AVARI(1553),NOP(122,8),NON(122),LPR(122)
     4,NOPP(461),MDF(461),NCOD(1553),NODV(560)
      COMMON/GUARD/
     1 SK(40000),ESTIFM(28,28),GISH(600),INTEG(2700)
      COMMON/UPWIN/
     1 AR1,AR2,A1,A2,BB1,BB2,B1,B2,DIS(3,461)
     2,WP(8),WDEL(2,8),WB(2,8),DWB(2,72),DWP(72),TT(8)
     3,UU(8),VV(8),UAVE(2),VAVE(2),IUPWIN,IWTS,VKIN,VKON
      CHARACTER *120 TITLE
C
C******************
C     INITIAL DATA
C******************
C
      DO 7 IT=1,3
      READ(NCR,'(A)')TITLE
      WRITE(NLP,270)TITLE
    7 CONTINUE
      REWIND 2
      REWIND 4
      REWIND 10
      REWIND 8
      ND1=4
      NTR=1
      NTRA=1
      MWGA=0
C
```

FETHSOLVAC (CONT.)

```
C*******************************
C   READ IN CONTROL VARIABLES
C*******************************
C
      READ(NCR,102)MARK,NAXI,NEWTON,IUPWIN,ITURB
      WRITE(NLP,601)
      GO TO(20,22,24,26,28),MARK
   26 CONTINUE
      IF(NAXI.EQ.0) WRITE(NLP,213)
      IF(NAXI.EQ.1) WRITE(NLP,217)
      WRITE(NLP,250)
      READ(NCR,600)CONDF,BETA,CPF
      WRITE(NLP,600)CONDF,BETA,CPF
      GO TO 30
   20 CONTINUE
      IF(NAXI.EQ.0)WRITE(NLP,212)
      IF(NAXI.EQ.1)WRITE(NLP,216)
      GO TO 30
   22 CONTINUE
      IF(NAXI.EQ.0)WRITE(NLP,214)
      IF(NAXI.EQ.1)WRITE(NLP,215)
      GO TO 30
   24 CONTINUE
      IF(NAXI.EQ.0)WRITE(NLP,219)
      IF(NAXI.EQ.1)WRITE(NLP,221)
      WRITE(NLP,250)
      READ(NCR,600)CONDF,BETA,CPF
      WRITE(NLP,600)CONDF,BETA,CPF
      GO TO 30
   28 CONTINUE
      IF(NAXI.EQ.0) WRITE(NLP,224)
      IF(NAXI.EQ.1) WRITE(NLP,226)
      WRITE(NLP,250)
      READ(NCR,600) CONDF,BETA,CPF
      WRITE(NLP,600) CONDF,BETA,CPF
   30 CONTINUE
      WRITE(NLP,222)MARK,NAXI,NEWTON,IUPWIN,ITURB
      READ(NCR,114)EMU,RHO,X,Y
      V=EMU/RHO
      WRITE(NLP,252)EMU,RHO,X,Y,V
      WRITE(NLP,602)
   33 WRITE(NLP,110)
      READ(NCR,102)NH
      WRITE(NLP,204)NH
      DO 18 I=1,NH
      DO 18 J=1,2
   18 CORD(I,J)=0.
      READ(NCR,102)MTRD
      WRITE(NLP,210)MTRD
      READ(NCR,102)NCARDS
```

FETHSOLVAC (CONT.)

```
      WRITE(NLP,234)NCARDS
      READ(NCR,102)MTRIT
      WRITE(NLP,230)MTRIT
      READ(NCR,103)LTIM
      WRITE(NLP,228)LTIM
C
C*****************************************************
C   READ IN DATA OFF DISC FOR CALCULATION RESTART
C*****************************************************
C
      IF(MTRD.LE.0)GO TO 42
      READ(2)
    1 NP,NTR,(VARI(I),I=1,NP)
      REWIND 2
C
C*******************************
C     GENERATE NODAL COORDINATES
C*******************************
C
   42 CALL CORDGEN
C
C*************************************************************
C     NUMBER VARIABLE DEGREES OF FREEDOM
C     MDF=NUMBER OF DEGREES OF FREEDOM
C     NOPP=CODED NODE NUMBER OF FIRST DEGREE OF FREEDOM
C*************************************************************
C
      NOPP(1)=1
      DO 74 I=2,NH
   74 NOPP(I)=NOPP(I-1)+MDF(I-1)
      NP=NOPP(NH)+MDF(NH)-1
      WRITE(NLP,100)NP
C
      DO 13 I=1,NH
      TEMP(I)=0.0
   13 CONTINUE
      IF(MTRD.NE.0) GO TO 16
      DO 12 I=1,NP
      VARA(I)=0.
   12 VARI(I)=0.
   16 CONTINUE
C*****************************
C   READ IN INITIAL CONDITIONS
C*****************************
C
      READ(NCR,103)ICOND
      WRITE(NLP,232) ICOND
      IF(ICOND.EQ.0)GO TO 39
      DO 35 I=1,ICOND
      READ(NCP,118)L,K,PHI
```

FETHSOLVAC (CONT.)

```
      IF(MARK.EQ.3.AND.MDF(L).EQ.3.AND.K.EQ.3) K=2
      IF(MARK.EQ.3.AND.MDF(L).EQ.3.AND.K.EQ.4) K=3
      IF(MARK.NE.3.AND.MDF(L).EQ.2.AND.K.EQ.3) K=2
      IF(MARK.NE.3.AND.K.EQ.4) GO TO 34
      J=NOPP(L)+K-1
      VARI(J)=PHI
      GO TO 35
   34 CONTINUE
      TEMP(L)=PHI
   35 CONTINUE
      WRITE(NLP,200)
      CALL WRITELP
      IF(MARK.LT.4) GO TO 39
      WRITE(NLP,201)
      DO 38 I=1,NH
      WRITE(NLP,246)I,TEMP(I)
   38 CONTINUE
   39 CONTINUE
      WRITE(NLP,227)
      WRITE(NLP,105)(N,NOPP(N),(CORD(N,M),M=1,2),MDF(N),N=1,NH)
C
C*****************************************************************
C     READ IN SPECIFIED STRESS OR NORMAL DERIVATIVE VALUES
C*****************************************************************
C
      DO 80 L=1,NE
      LPR(L)=0
   80 CONTINUE
      DO 82 L=1,6
      DO 82 I=1,NH
      RSPEC(I,L)=0.
   82 CONTINUE
   83 CONTINUE
      READ(NCR,102)NRT
      WRITE(NLP,238)NRT
      IF(NRT.EQ.0)GO TO 50
      WRITE(NLP,274)
      DO 46 L=1,NRT
      READ(NCR,106)LE,NSID
      WRITE(NLP,108)LE,NSID
      LPR(LE)=NSID
   46 CONTINUE
      WRITE(NLP,242)
      READ(NCR,102)IRT
      WRITE(NLP,120)IRT
      WRITE(NLP,122)
      DO 85 JI=1,IRT
      READ(NCR,246)L,(RSPEC(L,I),I=1,6)
      WRITE(NLP,246)L,(RSPEC(L,I),I=1,6)
   85 CONTINUE
```

FETHSOLVAC (CONT.)

```
0301:    50 CONTINUE
0302:       IWTS=IUPWIN
0303:       VKIN=V
0304:       VKON=CONDF
0305:C
0306:C*****************************************
0307:C      CHECK INITIAL DATA
0308:C*****************************************
0309:C
0310:       CALL DIAG1(NB,NRT,NE,ICOND,IRT,NH,NNP,NDF,NP,MARK)
0311:C
0312:C
0313:C*********************************************
0314:C      CHECK NODAL CONNECTIONS AND COORDINATES
0315:C*********************************************
0316:C
0317:       CALL DIAG2
0318:C
0319:C
0320:   100 FORMAT(/4H NP=,I4)
0321:   102 FORMAT(5I5)
0322:   103 FORMAT(I10)
0323:   105 FORMAT(2I5,2F20.10,I5)
0324:   106 FORMAT(  25I5)
0325:   108 FORMAT(2I10,F20.10)
0326:   110 FORMAT(13H ELEMENT DATA)
0327:   114 FORMAT(4F20.10)
0328:   118 FORMAT(2I5,F25.20)
0329:   201 FORMAT(/40H INITIAL CONDITION STATE FOR TEMPERATURE/)
0330:   202 FORMAT(/5X,5H NODE,5X,12H TEMPERATURE/)
0331:   120 FORMAT(/5H IRT=,I5//)
0332:   122 FORMAT( 5X,5H NODE,3X,6H DU/DX,4X,6H DU/DY,4X,6H DV/DX
0333:      2,4X,6H DV/DY,4X,6H DT/DX,4X,6H DT/DY
0334:      3/14X,3H SX,7X,3H SY/)
0335:   200 FORMAT(/14H INITIAL STATE/)
0336:   204 FORMAT(4H NH=,I3)
0337:   210 FORMAT(6H MTRD=,I3)
0338:   212 FORMAT(1H 'STEADY STATE-CARTESIAN COORDINATES',/,
0339:      -'NORMAL VELOCITY GRADIENTS SPECIFIED'/)
0340:   213 FORMAT('  FORCED OR MIXED CONVECTION,CARTESIAN SYSTEM',/,
0341:      :'NORMAL VELOCITY GRADIENT BOUNDARY CONDITIONS',/)
0342:   217 FORMAT('  FORCED OR MIXED CONVECTION AXISYMMETRIC SYSTEM',/,
0343:      :' NORMAL VELOCITY GRADIENTS BOUNDARY CONDITIONS',/)
0344:   214 FORMAT(/'STEADY STATE-CARTESIAN COORDINATES',/,
0345:      :'SURFACE STRESSES SPECIFIED'/)
0346:   215 FORMAT(/'STEADY STATE-CYLINDRICAL COORDINATES',/,
0347:      :'AXISYMMETRIC SURFACE STRESSES SPECIFIED'/)
0348:   216  FORMAT(/'STEADY STATE-CYLINDRICAL COORDINATES',/,
0349:      :'AXISYMMETRIC NORMAL VELOCITY GRADIENTS SPECIFIED'/)
0350:   219 FORMAT('       FREE OR MIXED CONVECTION,  ',/,
```

FETHSOLVAC (CONT.)

```
     -            7X,'CARTESIAN COORDINATE SYSTEM.',/,
     : 'NORMAL VELOCITY GRADIENTS BOUNDARY CONDITIONS',/)
 221 FORMAT('  FREE OR MIXED CONVECTION AXISYMMETRIC FORMULATION',/,
     :'NORMAL VELOCITY GRADIENTS BOUNDARY CONDITIONS',/)
 222 FORMAT(7H  MARK=,I2,5X,5HNAXI=,I2,5X,7HNEWTON=,I2,5X,7HIUPWIN=,I2,
    -5X,8H  ITURB=,I2)
 224 FORMAT('  FORCED CONVECTION CARTESIAN COORDINATES'
     :,' STRESS BOUNDARY CONDITIONS',/)
 226 FORMAT('  FORCED CONVECTION AXISYMMETRIC COORDINATES'
     :,' STRESS BOUNDARY CONDITIONS',/)
 227 FORMAT('/'  NODE NOPP X OR Z-COORDINATE          Y OR R-COORDINATE'
     :' MDF',/)
 228 FORMAT(6H LTIM=,I5,5HSECS.)
 230 FORMAT(7H MTRIT=,I3)
 232 FORMAT(/7H ICOND=,I10)
 234 FORMAT(8H NCARDS=,I2)
 238 FORMAT(5H NRT=,I2)
 242 FORMAT(/39H SPECIFIED STRESS OR NORMAL DERIVATIVES/)
 246 FORMAT(I10,6F10.4)
 250 FORMAT(10X,6H CONDF,14X,5H BETA,15X,6H   CPF)
 252 FORMAT('  VISCOSITY=',E12.5,'  DENSITY=',E12.5,
     :'  X BODY FORCE=',E12.5,/,1H '  Y BODY FORCE=',E12.5,
     :'  KINEMATIC VISCOSITY=',E12.5,/)
 270 FORMAT(1H ,A119)
 274 FORMAT(/8H ELEMENT,5X,5H SIDE/)
 600 FORMAT(3F20.10)
 601 FORMAT(/,1H ,'CONTROL DATA AND PHYSICAL QUANTITIES :',///)
 602 FORMAT(/,1H ,'DENSITY=RHO=(kg/m**3)',/,1H ,
     :'SPECIFIC HEAT CAPACITY FOR CONSTANT PRESSURE=CPF=',/,1H ,
     :'CP=[w/sec/kgK (J/kgK)]',/,1H ,
     :'DYNAMIC VISCOSITY=MU=[kg/m sec(N sec/m**2)]',/,1H ,
     :'KINEMATIC VISCOSITY=NU=(m**2/sec)',/,1H ,
     :'THERMAL CONDUCTIVITY=CONDF=K=(w/mK)',/,1H ,
     :'COEFFICIENT OF CUBICAL EXPANSION=BETA=(m**3/K)',/,1H )
      RETURN
      END
C
C
C
C
C
C
C
C
C*********************************************************************
C
      SUBROUTINE DIAG1(NBCON,NEBCN,NELEM,NICON,NNBCN,NPOIN,NRPON,
     -NDF,NP,MARK)
C
C*********************************************************************
```

FETHSOLVAC (CONT.)

```
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      DIMENSION NECHO(80),NEROR(8)
C
C***  SCRUTINY OF CONTROL DATA
C
      IF(NRPON.EQ.0) NRPON=NPOIN-(NELEM*3)
      DO 10 IEROR=1,8
   10 NEROR(IEROR)=0
C
C***  SCRUTINISE CONTROL DATA AND PRINT ERROR MESSAGE
C
      IF(NPOIN.LE.0)                          NEROR(1)=1
      IF(NRPON.LE.0.OR.NRPON.GT.NPOIN)        NEROR(2)=1
      IF(NELEM.LE.0)                          NEROR(3)=1
      IF(NPOIN.GT.NELEM*8)                    NEROR(4)=1
      IF(NBCON.GT.NPOIN*NDF)                    NEROR(5)=1
      ERNE3=NPOIN+NP
      IF(MARK.NE.3.AND.NICON.GT.ERNE3)         NEROR(6)=1
      IF(NEBCN.GT.NELEM)                      NEROR(7)=1
      IF(NNBCN.GT.NP)                          NEROR(8)=1
C
C***  CHECK ON ERROR-IF UNITY PRINT
C
      JEROR=0
      DO 20 IEROR=1,8
      IF(NEROR(IEROR).EQ.0) GO TO 20
      JEROR=1
C
C***  WRITE OUT ERROR NUMBER
C
      WRITE(9,2000)IEROR
   20 CONTINUE
      IF(JEROR.EQ.0) RETURN
C
C***  LIST DATA REMAINING AFTER CONTROL PARAMETERS
C
      WRITE(9,2010)
   30 CONTINUE
      READ(5,1000) NECHO
      WRITE(9,2020) NECHO
      GO TO 30
 1000 FORMAT(80A1)
 2000 FORMAT(/,10X,33HCONTROL PARAMETER ERROR*****ERROR,I5)
 2010 FORMAT(/,10X,42HDATA FOLLOWING ERROR IN CONTROL DATA LINES/)
 2020 FORMAT(10X,80A1)
      END
C
C
C
C
```

FETHSOLVAC (CONT.)

```
0451:C
0452:C
0453:C
0454:
0455:C*********************************************************************
0456:C
0457:      SUBROUTINE DIAG2
0458:C
0459:C*********************************************************************
0460:      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
0461:      COMMON/CONTR/
0462:     1 X,Y,V,CONDF,BETA,CPF,RHO,HCOFX,HCOFY,
0463:     2 GPF,GPG,GPH,EMU,XG(3),CG(3),DS,DX,DY,
0464:     3 NP,NH,NE,NB,NDF,NCN,NBN,IT1,ND1,MTRD
0465:     4,NTIME,MARK,NTR,LTIM,MTRIT,NCARDS,NSID,NAXI
0466:     5,NRT,MWGA,NNP,NELL,NTRA,NGAUSS,NPR,NCR,NLP,NCP
0467:     6,NCORD,IG,NG,NBV,NBT,NEWTON,ITURB,ICOND
0468:      COMMON/GEP/
0469:     1 TEMP(461),CORD(461,2),RSPEC(461,6)
0470:     2,R1(1553),R2(1553),VARI(1553),VARA(1553),BC(1553)
0471:     3,VALV(560),AVARI(1553),NOP(122,8),NDN(122),LPR(122)
0472:     4,NOPP(461),MDF(461),NCOD(1553),NODV(560)
0473:      COMMON/GUARD/
0474:     1 SK(40000),ESTIFM(28,28),GISH(600),INTEG(2700)
0475:      COMMON/UPWIN/
0476:     1 AA1,AA2,A1,A2,BB1,BB2,B1,B2,DIS(3,461)
0477:     2,WP(8),WDEL(2,8),WB(2,8),DWB(2,72),DWP(72),TT(8)
0478:     3,UU(8),VV(8),UAVE(2),VAVE(2),IUPWIN,IWTS,VKIN,VKON
0479:      DIMENSION NECHO(80),NEROR(13)
0480:C
0481:      NTOTV=NP
0482:      DENSY=RHO
0483:      MELEM=NE
0484:      MPOIN=NH
0485:      NELEM=MELEM
0486:      NNODP=NBN
0487:      NPOIN=NH
0488:      VISCY=EMU
0489:C
0490:C***  SCRUTINISE ELEMENT AND NODAL POINT DATA
0491:C
0492:C
0493:C***  INITIALIZE ERROR ARRAY
0494:C
0495:      DO 10 IEROR=1,13
0496:      NEROR(IEROR)=0
0497:   10 CONTINUE
0498:C
0499:C***  CHECK PHYSICAL PROPERTIES
0500:C
```

FETHSOLVAC (CONT.)

```
      IF(DENSY.LE.0.0.OR.VISCY.LE.0.0) NEROR(9)=1
C
C***  CHECK NODAL COORDINATES
C***  CHECK FOR TWO IDENTICAL COORDINATES
C
      DO 40 IPOIN=2,NPOIN
      JPOIN=IPOIN-1
      DO 30 KPOIN=1,JPOIN
      IF(CORD(IPOIN,1).NE.CORD(KPOIN,1).OR.CORD(IPOIN,2).
     -NE.CORD(KPOIN,2)) GO TO 20
      NEROR(10)=1
   20 CONTINUE
   30 CONTINUE
   40 CONTINUE
C
C***  CHECK ELEMENT NODAL NUMBERS
C***  A - REPETITION OF A NODE NUMBER IN ONE ELEMENT
C***  B - NODE NUMBER OUTSIDE PERMISSIBLE BOUNDS
C
      DO 50 IPOIN=1,NPOIN
      DO 50 IELEM=1,NELEM
      LCONT=0
      DO 50 INODE=1,NNODP
      IF(NOP(IELEM,INODE).NE.IPOIN) GO TO 50
      LCONT=LCONT+1
      IF(LCONT.GT.1) NEROR(11)=1
   50 CONTINUE
      DO 60 IELEM=1,NELEM
      DO 60 INODE=1,NNODP
      IF(NOP(IELEM,INODE).LE.0.OR.NOP(IELEM,INODE).GT.NPOIN)
     -NEROR(12)=1
   60 CONTINUE
C
C***  CHECK ON NUMBER OF INITIAL CONDITIONS INPUT
C
      IF(ICOND.GT.NTOTV.AND.MARK.EQ.3) NEROR(13)=1
C
C***  WRITE OUT ERROR NUMBER
C
      JEROR=0
      DO 70 IEROR=9,13
      IF(NEROR(IEROR).EQ.0) GO TO 70
      JEROR=1
      WRITE(9,2000) IEROR
   70 CONTINUE
C
C***  DECIDE WHETHER TO CONTINUE OR ECHO DATA
C
      IF(JEROR.EQ.0) RETURN
C
```

FETHSOLVAC (CONT.)

```
C***  LIST REMAINING DATA
C
      WRITE(9,2010)
   80 CONTINUE
      READ(5,1000) NECHO
      WRITE(9,2020) NECHO
      GO TO 80
 1000 FORMAT(80A1)
 2000 FORMAT(/10X,10HDATA ERROR,I5)
 2010 FORMAT(/10X,14HREMAINING DATA)
 2020 FORMAT(10X,80A1)
      END
C
C
C
C
C
C
C
C*************************
      SUBROUTINE CORDGEN
C*************************
C
C****************************
C     GENERATE COORDINATES
C****************************
C
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      COMMON/CONTR/
     1 X,Y,V,CONDF,BETA,CPF,RHO,HCOFX,HCOFY,
     2 GPF,GPG,GPH,EMU,XG(3),CG(3),DS,DX,DY,
     3 NP,NH,NE,NB,NDF,NCN,NBN,IT1,ND1,MTRD
     4,NTIME,MARK,NTR,LTIM,MTRIT,NCARDS,NSID,NAXI
     5,NRT,MWGA,NNP,NELL,NTRA,NGAUSS,NPR,NCR,NLP,NCP
     6,NCORD,IG,NG,NBV,NBT,NEWTON,ITURB,ICOND
      COMMON/GEP/
     1 TEMP(461),CORD(461,2),RSPEC(461,6)
     2,R1(1553),R2(1553),VARI(1553),VARA(1553),BC(1553)
     3,VALV(560),AVARI(1553),NOP(122,8),NDN(122),LPR(122)
     4,NOPP(461),MDF(461),NCOD(1553),NODV(560)
      COMMON/GUARD/
     1 SK(40000),ESTIFM(28,28),GISH(600),INTEG(2700)
      COMMON/UPWIN/
     1 AA1,AA2,A1,A2,BB1,BB2,B1,B2,DIS(3,461)
     2,WP(8),WDEL(2,8),WB(2,8),DWB(2,72),DWP(72),TT(8)
     3,UU(8),VV(8),UAVE(2),VAVE(2),IUPWIN,IWTS,VKIN,VKON
C
      NBN=8
      NCN=20
```

FETHSOLVRC (CONT.)

```
      NDF=3
      IF(MARK.NE.3) GO TO 71
      NCN=28
      NDF=4
   71 CONTINUE
      READ(NCR,102)NNP
      WRITE(NLP,206)NNP
      DO 70 I=1,NH
   70 MDF(I)=NDF-1
      WRITE(NLP,202)NCN
      IF(NNP.EQ.0)GO TO 72
      WRITE(NLP,267)
C
C*************************
C     READ IN ELEMENT DATA
C*************************
C
      DO 16 L=1,NNP
      READ(NCR,103)N,(CORD(N,M),M=1,2)
   16 CONTINUE
      WRITE(NLP,264)
      READ(NCR,102)NE
      WRITE(NLP,208)NE
      WRITE(NLP,224)
      DO 10 L=1,NE
      NDN(L)=8
      READ(NCR,106) N,(NOP(N,M),M=1,NBN)
      WRITE(NLP,106)N,(NOP(N,M),M=1,NBN)
   10 CONTINUE
      GO TO 78
C
C*************************************************************
C     CALCULATE NODAL DATA FOR A AUTOGENERATING REGULAR MESH.
C*************************************************************
C
   72 CONTINUE
      READ(NCR,102)IMESH
      IF(IMESH.EQ.1) GO TO 77
      READ(NCR,102)NROWS,NCOLS
      WRITE(NLP,266)NROWS,NCOLS
      READ(NCR,114)DX,DY
      WRITE(NLP,268)DX,DY
      NU=3*NROWS+2
      NE=NROWS*NCOLS
      DO 76 I=1,NROWS
      DO 76 J=1,NCOLS
      N=NROWS*(J-1)+I
      NDN(N)=8
      NOP(N,1)=(J-1)*NU+2*I-1
      NOP(N,2)=J*NU+I-NROWS-1
```

FETHSOLVAC (CONT.)

```
      NOP(N,3)=J*NU+2*I-1
      NOP(N,4)=J*NU+2*I
      NOP(N,5)=J*NU+2*I+1
      NOP(N,6)=J*NU+I-NROWS
      NOP(N,7)=(J-1)*NU+2*I+1
      NOP(N,8)=(J-1)*NU+2*I
      CORD(NOP(N,1),1)=(J-1)*DX
      CORD(NOP(N,3),1)=J*DX
      CORD(NOP(N,5),1)=J*DX
      CORD(NOP(N,7),1)=(J-1)*DX
      CORD(NOP(N,1),2)=(I-1)*DY
      CORD(NOP(N,3),2)=(I-1)*DY
      CORD(NOP(N,5),2)=I*DY
      CORD(NOP(N,7),2)=I*DY
   76 CONTINUE
      WRITE(NLP,224)
      WRITE(NLP,106) (N,(NOP(N,M),M=1,NBN),N=1,NE)
      GO TO 78
   77 CALL ELGEN
      GO TO 94
C
C*****************************
C     GENERATE MIDSIDE NODES
C*****************************
C
   78 CONTINUE
      DO 54 N=1,NE
      J=NDN(N)-1
      DO 54 K=1,J,2
   54 MDF(NOP(N,K))=NDF
      DO 68 N=1,NE
      JDN=NDN(N)
      DO 65 I=2,JDN,2
      NN=NOP(N,I)
      L=I+1
      IF(I.EQ.NBN) L=1
      DO 63 J=1,2
      IF(CORD(NN,J).NE.0.0) GO TO 63
      CORD(NN,J)=(CORD(NOP(N,I-1),J)+CORD(NOP(N,L),J))/2.
   63 CONTINUE
   65 CONTINUE
   68 CONTINUE
   94 CONTINUE
  102 FORMAT(2I5)
  103 FORMAT(I10,2F15.10)
  106 FORMAT(  2I8,7I5)
  114 FORMAT(4F20.10)
  202 FORMAT(5H NCN=,I3)
  206 FORMAT(5H NNP=,I3)
  208 FORMAT(4H NE=,I3)
```

FETHSOLVAC (CONT.)

```
  224 FORMAT(//23H ELEMENT NODE NUMBERING//)
  264 FORMAT(//34H IRREGULAR MESH-READ IN NODAL DATA//)
  266 FORMAT(7H NROWS=,I2,7H NCOLS=,I2//49H REGULAR MESH-NODAL DATA CALC
     1ULATED AUTOMATICALLY//)
  267 FORMAT(//35H IRREGULAR COORDINATES-READ IN DATA//)
  268 FORMAT(26H ELEMENT SIDE X-DIRECTION=,F20.10,6H UNITS/
     1        26H ELEMENT SIDE Y-DIRECTION=,F20.10,6H UNITS/)
      RETURN
      END
C
C
C
C
C
C
C
      SUBROUTINE ELGEN
C
C*********************************************************************
C.... MESH GENERATION ROUTINE USING ISOPARAMETRIC CONCEPT.
C.... IT CAN DEAL WITH MESH GENERATION FOR DOMAINS WITH COMPLEX SHAPES
C.... AND FOR MULTIPLY-CONNECTED DOMAINS.
C*********************************************************************
C
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      COMMON/CONTR/
     1 X,Y,V,CONDF,BETA,CPF,RHO,HCOFX,HCOFY,
     2 GPF,GPG,GPH,EMU,XG(3),CG(3),DS,DX,DY,
     3 NP,NH,NE,NB,NDF,NCN,NBN,IT1,ND1,MTRD
     4,NTIME,MARK,NTR,LTIM,MTRIT,NCARDS,NSID,NAXI
     5,NRT,MWGA,NNP,NELL,NTRA,NGAUSS,NPR,NCR,NLP,NCF
     6,NCORD,IG,NG,NBV,NBT,NEWTON,ITURB,ICOND
      COMMON/GEP/
     1 TEMP(461),CORD(461,2),RSPEC(461,6)
     2,R1(1553),R2(1553),VARI(1553),VARA(1553),BC(1553)
     3,VALV(560),AVARI(1553),NOP(122,8),NDN(122),LPR(122)
     4,NOPP(461),MDF(461),NCOD(1553),NODV(560)
      COMMON/GUARD/
     1 SK(40000),ESTIFM(28,28),GISH(600),INTEG(2700)
      COMMON/UPWIN/
     1 AA1,AA2,A1,A2,BB1,BB2,B1,B2,DIS(3,461)
     2,WP(8),WDEL(2,8),WB(2,8),DWB(2,72),DWP(72),TT(8)
     3,UU(8),VV(8),UAVE(2),VAVE(2),IUPWIN,INTS,VKIN,VKON
      DIMENSION XM(8),YM(8),XPT(461),YPT(461),NS(200),SHP(8),XX(8),YY(8)
C
C*********************************************************************
C.... ZETA, ETA COORDINATES OF THE MASTER NODES.
C*********************************************************************
C
```

FETHSOLVAC (CONT.)

```
      DATA XX/-1.0,0.0,1.0,1.0,1.0,0.0,-1.0,-1.0/
      DATA YY/-1.0,-1.0,-1.0,0.0,1.0,1.0,1.0,0.0/
C*****************************************************************
C
C.... READ/PRINT CONTROL DATA:-
C.... NXL= NO. OF ELEMENTS IN THE ZETA DIRECTION,
C.... NYL= NO. OF ELEMENTS IN THE ETA DIRECTON,
C.... NN=FIRST NODE NUMBER,
C.... ND= DIRECTION PARAMETER.
C.... IF ND=1 THEN ELEMENTS ARE NUMBERED SEQUENCIALLY ALONG LINES OF
C.... CONSTANT ZETA.
C.... IF ND=0 THE SEQUENTIAL NUMBERING IS ALONG LINES OF CONSTANT ETA.
C
C*****************************************************************
      READ(5,1000)NXL,NYL,NN,ND
      WRITE(9,1001)NXL,NYL,NN,ND
      WRITE(9,1013)
      DO 5 I=1,NBN
C
C*****************************************************************
C.... READ/PRINT X,Y COORDINATES OF MASTER NODES.
C*****************************************************************
C
      READ(5,1002)XM(I),YM(I)
      WRITE(9,1003)I,XM(I),YM(I)
    5 CONTINUE
      II=0
      NSF1=2*NYL+1
      DO 50 I=1,NSF1
C
C*****************************************************************
C.... ETA COORDINATES OF EACH GENERATED NODE.
C*****************************************************************
C
      YL=-1.0+2.0*(I-1)/(2*NYL)
      II=II+1
C
C*****************************************************************
C.... NS( ) STORES A LIST OF NODE NUMBERS OF ZETA=-1.
C*****************************************************************
C
      NS(I)=NN
      IF(II.EQ.3) II=1
      NSF2=2*NXL+1
      DO 45 J=1,NSF2,II
C
C*****************************************************************
C.... ZETA COORDINATES OF EACH GENERATED NODE.
C*****************************************************************
C
```

FETHSOLVAC (CONT.)

```
      XL=1.0-2.0*(J-1)/(2*NXL)
      DO 25 IJ=1,8
C
C*****************************************************************
C.... CALCULATE THE SHAPE FUNCTIONS FOR ZETA,ETA COORDINATES OF
C.... EACH GENERATED NODE.
C*****************************************************************
C
      GO TO (10,10,10,10,20,15,20,15)IJ
   10 SHP(IJ)=0.25*(1.0+XL*XX(IJ))*(1.0+YL*YY(IJ))*(XL*XX(IJ)+YL*YY(IJ)-
     11.0)
      GO TO 25
   15 SHP(IJ)=0.5*(1.0+XL*XX(IJ))*(1.0-YL*YL)
      GO TO 25
   20 SHP(IJ)=0.5*(1.0+YL*YY(IJ))*(1.0-XL*XL)
   25 CONTINUE
C
C*****************************************************************
C.... CALCULATE THE X,Y COORDINATES OF EACH NODE FROM:
C.... COLUMN VECTOR (X)=CUMULATIVE   [N(I)*[XM(I)] FOR I=1,8.
C...                 (Y) SUM OF      [     [YM(I)].
C*****************************************************************
C
      XXX=0.0
      YYY=0.0
      DO 30 K=1,8
      XXX=XXX+SHP(K)*XM(K)
      YYY=YYY+SHP(K)*YM(K)
   30 CONTINUE
      XPT(NN)=XXX
      YPT(NN)=YYY
      NN=NN+1
   45 CONTINUE
   50 CONTINUE
      MAXNOD=NN-1
      NSS=NS(1)
      WRITE(9,1014)
C
C*****************************************************************
C .... PRINT OUT THE NODAL COORDINATES.
C*****************************************************************
C
      DO 60 NIC=NSS,MAXNOD
      WRITE(9,1020)NIC,XPT(NIC),YPT(NIC)
   60 CONTINUE
      NEL=1
C
C*****************************************************************
C.... NEL-THE INCREMENT IN THE ELEMENT NUMBERS IN ZETA DIRECTION.
C*****************************************************************
```

FETHSOLVAC (CONT.)

```
C
      MEL=NYL
      IF(ND.EQ.0) MEL=1
      DO 150 I=1,NYL
      IF(ND.EQ.1) NEL=I
      NSS=(I-1)*2+1
C
C*****************************************************************
C.... NODE NUMBERS ALONG EDGE ZETA=-1 FOR USE IN GENERATING THE FIRST
C.... ELEMENT DEFINETION OF A ROW OF ELEMENTS IN THE ZETA DIRECTION.
C*****************************************************************
C
      N1=NE(NSS)
      N2=NE(NSS+1)
      N3=NE(NSS+2)
      DO 140 J=1,NXL
C
C*****************************************************************
C.... NODE NUMBERS OF ELEMENTS ALONG A ROW OF ELEMENTS IN THE ZETA
C.... USING THE SEQUENTIAL NUMBERING OF THE NODES.
C*****************************************************************
C
      NOP(NEL,3)=N3   +(J-1)*2
      NOP(NEL,4)=N3-1+(J-1)*2
      NOP(NEL,5)=N3+1-(J-1)*2
      NOP(NEL,6)=N2-1+(J-1)
      NOP(NEL,7)=N1+2+(J-1)*2
      NOP(NEL,8)=N1+1+(J-1)*2
      NOP(NEL,1)=N1   +(J-1)*2
      NOP(NEL,2)=N2   +(J-1)
      NEL=NEL+MEL
  140 CONTINUE
  150 CONTINUE
      MAXNEL=NXL*NYL
      WRITE(9,1013)
      DO 170 NEL=1,MAXNEL
      WRITE(9,1010)NEL,(NOP(NEL,I),I=1,8)
  170 CONTINUE
 1000 FORMAT(4I10)
 1001 FORMAT(1H1,4X,'NUMBER OF DIVISIONS IN LOCAL X DIRECTION=',I3,//,5X
     1,'NUMBER OF DIVISIONS IN LOCAL Y DIRECTION=',I3,//,5X,'FIRST NODE
     2NUMBER=',I3,//,5X,'DIRECTION PARAMETER=',I3)
 1002 FORMAT(2F10.3)
 1003 FORMAT(1X,I5,4F10.3)
 1010 FORMAT(10X,I5,3X,'NOP=',8I5)
 1013 FORMAT(//////,5X,'MASTER NODAL CO-ORDINATES',//,
     12X,'NODE',9X,1HX,9X,1HY)
 1014 FORMAT(//////,5X,'NODAL CO-ORDINATES',//,
     1   7X,'NODE',9X,1HX,9X,1HY)
 1015 FORMAT(//////,5X,'ELEMENT DEFINITIONS')
```

FETHSOLVAC (CONT.)

```
0901: 1020 FORMAT(6X,I5,2F10.3)
0902:      DO 1022 INH=1,NH
0903:      CORD(INH,1)=XPT(INH)
0904:      CORD(INH,2)=YPT(INH)
0905: 1022 CONTINUE
0906:      RETURN
0907:      END
0908:C
0909:C
0910:C
0911:C
0912:C
0913:C
0914:C
0915:
0916:C*********************
0917:      SUBROUTINE WRITELP
0918:C*********************
0919:C
0920:C*************************************
0921:C     OUTPUT OF VELOCITY AND PRESSURES
0922:C*************************************
0923:C
0924:      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
0925:      COMMON/CONTP/
0926:     1 X,Y,V,CONDF,BETA,CPF,RHO,HCOFX,HCOFY,
0927:     2 GPF,GPG,GPH,EMU,XG(3),CG(3),DS,DX,DY,
0928:     3 NP,NH,NE,NB,NDF,NCN,NEN,IT1,ND1,MTRD
0929:     4,NTIME,MARK,NTP,LTIM,MTRIT,NCARDS,NSID,NAXI
0930:     5,NPT,MWGA,NMP,NELL,NTRA,NGAUSS,NPR,NCR,NLP,NCP
0931:     6,NCOFD,IG,NG,NBW,NBT,NEWTON,ITURB,ICOND
0932:      COMMON/GEF/
0933:     1 TEMP(461),CORD(461,2),RSPEC(461,6)
0934:     2,R1(1553),R2(1553),VARI(1553),VARA(1553),BC(1553)
0935:     3,VALV(560),AVARI(1553),NOP(122,8),NDN(122),LPR(122)
0936:     4,NOPP(461),MDF(461),NCOD(1553),NODV(560)
0937:      COMMON/GUARD/
0938:     1 SK(40000),ESTIFM(28,28),GISH(600),INTEG(2700)
0939:      COMMON/UPWIN/
0940:     1 AA1,AA2,A1,A2,BB1,BB2,B1,B2,DIS(3,461)
0941      2,WP(8),WDEL(2,8),WB(2,8),DWB(2,72),DWP(72),TT(8)
0942:     3,UU(8),VV(8),UAVE(2),VAVE(2),IUPWIN,IWTS,VKIN,VKON
0943:      IF(MARK.NE.3) WRITE(NLP,501)
0944:      IF(MARK.EQ.3) WRITE(NLP,500)
0945:      DO 15 L=1,NH
0946:      IDF=MDF(L)
0947:      J=NOPP(L)-1
0948:      IF(IDF.LT.NDF)GO TO 5
0949:      IF(NDF.EQ.2)GO TO 8
0950:      WRITE(NLP,505)L,(VARI(J+I),I=1,IDF)
```

FETHSOLVAC (CONT.)

```
      GO TO 15
    5 IF(IDF.EQ.1)GO TO 10
    8 WRITE(NLP,510)L,(VARI(J+I),I=1,IDF)
      GO TO 15
   10 WRITE(NLP,515)L,VARI(J+1)
   15 CONTINUE
  500 FORMAT(/5H NODE,4X,11H U-VELOCITY,8X,10H PRESSURES,7X,11H V-VELOCI
     1TY,6X,12H TEMPERATURE/)
  501 FORMAT(/5H NODE,4X,11H U-VELOCITY,8X,10H PRESSURES,7X,11H V-VELOCI
     :TY,/)
  505 FORMAT(I5,6E18.10)
  510 FORMAT(I5,E18.10,18X,2E18.10)
  515 FORMAT(I5,18X,E18.10)
      RETURN
      END
C
C
C
C
C
C
C
C
C*********************
      SUBROUTINE DATAK
C*********************
C
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      COMMON/CONTR/
     1 X,Y,V,CONDF,BETA,CFF,RHO,HCOFX,HCOFY,
     2 GPF,GPG,GPH,EMU,XG(3),CG(3),DS,DX,DY,
     3 NP,NH,NE,NS,NDF,NCN,NBN,IT1,ND1,MTRD
     4,NTIME,MARK,NTR,LTIM,MTRIT,NCARDS,NSID,NAXI
     5,NRT,MWGA,NNP,NELL,NTRA,NGAUSS,NPR,NCR,NLP,NCP
     6,NCORD,IG,NB,NBV,NBT,NEWTON,ITURB,ICOND
      COMMON/GEP/
     1 TEMP(461),CORD(461,2),RSPEC(461,6)
     2,R1(1553),R2(1553),VARI(1553),VARA(1553),BC(1553)
     3,VALV(560),AVARI(1553),NOP(122,8),NDN(122),LPR(122)
     4,NOPP(461),MDF(461),NCOD(1553),NODV(560)
      COMMON/GUARD/
     1 SK(40000),ESTIFM(28,28),GISH(600),INTEG(2700)
      COMMON/UPWIN/
     1 AA1,AA2,A1,A2,BB1,BB2,B1,B2,DIS(3,461)
     2,WP(8),WDEL(2,8),WB(2,8),DWB(2,72),DWP(72),TT(8)
     3,UU(8),VV(8),UAVE(2),VAVE(2),IUPWIN,IWTS,VKIN,VKON
C
C*************************
C     BOUNDARY CONDITIONS
C*************************
```

FETHEOLVAC (CONT.)

```
C
      DO 5 I=1,NP
      NCOD(I)=0
      BC(I)=0.
    5 CONTINUE
      READ(NCR,122) NB
      WRITE(NLP,116)NB
      NBV=NB
      DO 25 I=1,NB
      READ(NCR,124)NOD,MDEG,VAL
      MDFF=MDF(NOD)
      IF(MOD(I,5).EQ.0)WRITE(NLP,400)
      GO TO (8,10,12,14),MDEG
    8 WRITE(NLP,208)NOD,VAL
      GO TO 24
   10 WRITE(NLP,210)NOD,VAL
      GO TO 24
   12 WRITE(NLP,212)NOD,VAL
      GO TO 24
   14 WRITE(NLP,214)NOD,VAL
   24 CONTINUE
      IF(MDFF.EQ.NDF)GO TO 21
      IF(MDEG.GT.2)MDEG=MDEG-1
   21 CONTINUE
      NODE=NOPP(NOD)+MDEG-1
      NODV(I)=NODE
      VALV(I)=VAL
      NCOD(NODE)=1
      BC(NODE)=VAL
   25 CONTINUE
      GO TO 30
   26 CONTINUE
      DO 29 I=1,NBV
      NOD=NODV(I)
      NCOD(NOD)=1
      BC(NOD)=VALV(I)
   29 CONTINUE
   30 CONTINUE
      DO 32 I=1,NP
      IF(NCOD(I).EQ.0)GO TO 32
      VARI(I)=BC(I)
   32 CONTINUE
      DO 44 I=1,NP
   44 VARA(I)=VARI(I)
   48 CONTINUE
  116 FORMAT
     1(/I5,    20H BOUNDARY CONDITIONS//5H NODE,          3X,
     * 9H D.O.F. 1
     * ,6X,9H D.O.F. 2
     * ,6X,9H D.O.F. 3
```

FETHSOLVAC (CONT.)

```
      * ,6X,9H D.O.F.  4)
  122 FORMAT (I5)
  124 FORMAT(2I5,F20.10)
  208 FORMAT(I5,E15.7)
  210 FORMAT(I5,15X,E15.7)
  212 FORMAT(I5,30X,E15.7)
  214 FORMAT(I5,45X,E15.7)
  400 FORMAT(1X,68(1H-))
      RETURN
      END
C
C
C
C
C
C
C
C*************************
      SUBROUTINE VARCALC
C*************************
C
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      COMMON/CONTR/
     1 X,Y,V,CONDF,BETA,CPF,RHO,HCOFX,HCOFY,
     2 GPF,GPG,GPH,EMU,XG(3),CG(3),DS,DX,DY,
     3 NP,NH,NE,NB,NDF,NCN,NBN,IT1,ND1,MTRD
     4,NTIME,MARK,NTR,LTIM,MTRIT,NCARDS,NSID,NAXI
     5,NRT,MWGA,NNP,NELL,NTRA,NGAUSS,NPR,NCR,NLP,NCP
     6,NCORD,IG,NG,NEV,NET,NEWTON,ITURB,ICOND
      COMMON/GEP/
     1 TEMP(461),CORD(461,2),RSPEC(461,6)
     2,R1(1553),R2(1553),VARI(1553),VARA(1553),BC(1553)
     3,VALY(560),AVARI(1553),NOP(122,8),NDN(122),LPR(122)
     4,NOPP(461),MDF(461),NCOD(1553),NODV(560)
      COMMON/GUARD/
     1 SK(40000),ESTIFM(28,28),GISH(600),INTEG(2700)
      COMMON/UPWIN/
     1 AA1,AA2,A1,A2,BB1,BB2,B1,B2,DIS(3,461)
     2,WP(8),WDEL(2,8),WB(2,8),DWB(2,72),DWP(72),TT(8)
     3,UU(8),VV(8),UAVE(2),VAVE(2),IUPWIN,IWTS,VKIN,VKON
      COMMON/TLSKIN1/ TLS(461),EKE(461),TRMU(461),ITERNAN
      COMMON/TLSKIN2/ TRCOND(461)
      COMMON/ITRSTO/UPVBC(1553),NCODV(1553),TBC(1553),NCODT(1553)
C
C*********************************
C     SET UP AND SOLVE EQUATIONS
C*********************************
C
C
```

FETHSOLVAC (CONT.)

```
      ERA=0.100
    5 CONTINUE
      RMAX=0.000
      ITERNAN=0
      DO 10 I=1,NP
      R2(I)=0.
      R1(I)=0.
   10 CONTINUE
      IF(MARK.LT.4.OR.NTR.EQ.1) GO TO 12
      DO 11 I=1,NP
      BC(I)=UPVBC(I)
      NCOD(I)=NCODV(I)
   11 CONTINUE
   12 CONTINUE
C
C*****************************************************
C   CALCULATE ANY GRADIENT/STRESS BOUNDARY CONDITIONS
C*****************************************************
C
      DO 25 N=1,NE
      IF(LPR(N).EQ.0)GO TO 25
      IF(ITUPE.EQ.0)GO TO 24
      CALL EFWISC(N)
   24 CONTINUE
      CALL PRESCR
   25 CONTINUE
      DO 35 I=1,NP
      R1(I)=R2(I)
   35 CONTINUE
      CALL TIMER(IT)
      ITIME=IT-IT1
      WRITE(NLP,214)ITIME
      IF(MARK.LT.4.OR.NTR.GT.1) GO TO 290
      DO 28 N=1,NP
      UPVBC(N)=BC(N)
      NCODV(N)=NCOD(N)
   28 CONTINUE
  290 CONTINUE
C
C*********************************
C   CALL ASSEMBLY/SOLUTION ROUTINE
C*********************************
C
      CALL FRONT
      NTRA=0
      CALL TIMER(IT)
      ITIME=IT-IT1
      WRITE(NLP,216)ITIME
C
C**********************
```

FETHSOLVAC (CONT.)

```
C       CONVERGENCE TEST
C*********************
C
        DO 55 JN=1,NH
        IDF=MDF(JN)
        IF(IDF.EQ.1)GO TO 55
        J=NOPP(JN)
        DO 52 I=1,IDF
        N=J+I-1
        IF(ABS(SK(N)).LT.0.1D-05)GO TO 52
        IF(IDF.EQ.NDF AND. I.EQ.2)GO TO 52
        HR=ABS((VARI(N)-SK(N))/SK(N))
        IF(HR.GT.RMAX)RMAX=HR
   52 CONTINUE
   55 CONTINUE
        RLXFCT=0.500
        DO 15 N=1,NP
   15 AVARI(N)=RLXFCT*SK(N)+(1-RLXFCT)*VARI(N)
        WRITE(NLP,204)RMAX
        DO 27 N=1,NP
        VARI(N)=SK(N)
   27 CONTINUE
        WRITE(NLP,154)NTR
        CALL WRITELP
        CALL TIMER(IT4)
        ITIME3=IT4-IT1
        WRITE(NLP,100)NTR,ITIME3
        REWIND 10
        REWIND 8
        ITERNAN=1
        IF(ITUPB.EQ.0) GO TO 29
        IF(MARK.GE.4) CALL TEMPCAL(RMAX,ERA)
        GO TO 32
   29 CONTINUE
        IF(MARK.GE.4.AND.RMAX.LT.ERA) CALL TEMPCAL(RMAX,ERA)
   32 CONTINUE
        NTR=NTR+1
C
C*************************************************************
C   DISC OUTPUT FOR CONTINUING CALCULATION ON RESTART
C*************************************************************
C
        IF(ITIME3.LT.LTIM) GO TO 78
        IF(MTRIT.EQ.0)GO TO 79
        WRITE(2)
      1 NP,NTR,(VARI(I),I=1,NP)
   78 CONTINUE
   79 CONTINUE
        DO 45 N=1,NP
   45   VARI(N)=AVARI(N)
```

$$\left|\frac{\phi_o-\phi_n}{\phi_n}\right| < 0.01$$

$\alpha$

$$AVARI\left(\begin{matrix}\text{new relaxed}\\ \text{values}\end{matrix}\right) = \alpha * SK\left(\begin{matrix}\text{new}\\ \text{values}\end{matrix}\right) + (1-\alpha) * VARI\left(\begin{matrix}\text{old relaxed}\\ \text{values}\end{matrix}\right)$$

$$\tilde{\phi}_o = \phi_n$$

o = OLD
n = NEW
~ = RELAXED

$$\tilde{\phi}_n = \phi_n$$

FETHSOLVPC (CONT.)

```
      IF(ITIME3.GE.LTIM)GO TO 570
      IF(IUPWIN.GT.0 AND RMAX.GT.ERA)CALL DERIV
      IF(RMAX.GE.ERA) GO TO 5
      IF(MARK.NE.3)GO TO 40
      READ(NCR,101)NHEAT
      WRITE(NLP,102)NHEAT
      IF(NHEAT.EQ.0)GO TO 40
      WRITE(NLP,103)
      DO 2 I=1,NHEAT
      READ(NCR,101)NELL,NSID
      WRITE(NLP,104)NELL,NSID
    2 CALL HCOEF
      STOP
   40 CONTINUE
C
C*************************************************
C    OUPUT RESULTS FOR PLOTTING,EXTRAPOLATING,
C    OR TO USE THEM AS INITIAL CONDITION VALUES
C    .... ETC.
C*************************************************
C
      IF(NCARDS.EQ.0) GO TO 50
      DO 42 I=1,NH
      IDF=MDF(I)
      DO 42 K=1,IDF
      J=NOPP(I)+K-1
      KK=K
      IF(MARK.EQ.3.AND.IDF.EQ.3.AND.K.EQ.2) KK=3
      IF(MARK.EQ.3.AND.IDF.EQ.3.AND.K.EQ.3) KK=4
      IF(MARK.NE.3.AND.IDF.EQ.2.AND.K.EQ.2) KK=3
      WRITE(NCP,118)I,KK,VARI(J)
   42 CONTINUE
   50 CONTINUE
      IF(ITURB.EQ.0) GO TO 570
      WRITE(NLP,520)
      WRITE(NLP,530)(TLS(K),K=1,NH)
      WRITE(NLP,540)
      WRITE(NLP,530)(EKE(K),K=1,NH)
      WRITE(NLP,550)
      WRITE(NLP,530)(TRMU(K),K=1,NH)
      WRITE(NLP,560)
      WRITE(NLP,530)(TRCOND(K),K=1,NH)
  520 FORMAT(1H ,'LENGTH SCALE DISTRIBUTION')
  530 FORMAT(30X,E15.7)
  540 FORMAT(1H ,'KINETIC ENERGY DISTRIBUTION')
  550 FORMAT(1H ,'TURBULENT VISCOSITY DISTRIBUTION')
  560 FORMAT(1H ,'TURBULENT CONDUCTIVITY DISTRIBUTION')
  570 CONTINUE
      IF(RMAX.GT.ERA) GO TO 98
      GO TO 99
```

FETHSOLVAC (CONT.)

```
   98 WRITE(NLP,208)
      STOP
   99 CONTINUE
C
C*********************************************
C     CALCULATE STREAM FUNCTION AND VORTICITY
C     VALUES FROM KNOWN VELOCITY FIELD USING
C     THE (F.E.M.)
C*********************************************
C
      READ(5,*)IPSW
      WRITE(9,106)IPSW
      IF(IPSW.EQ.0) GO TO 999
      MARK=6
      CALL PSICALC
  999 CONTINUE
  100 FORMAT(14H ITERATION NO.,I3,21H FINISHED AT MILLTIME,I5,6H SECS.)
  101 FORMAT(2I5)
  102 FORMAT(/7H NHEPT=,I3)
  103 FORMAT(/43H CALCULATIONS OF HEAT TRANSFER COEFFICIENTS/)
  104 FORMAT(//6H NELL=,I3,6H NSID=,I3)
  106 FORMAT(1H ,6H IPSW=,I3)
  110 FORMAT(2I10,F20.10)
  118 FORMAT(2I5,F25.20)
  119 FORMAT(I10,E20.10)
  154 FORMAT(15H ITERATION NO.=,I2)
  204 FORMAT(//41H LARGEST RELATIVE CHANGE IN ANY VARIABLE=,E18.10/)
  208 FORMAT(//28H SOLUTION NOT YET CONVERGENT//)
  213 FORMAT(/28H SOLUTION ROUTINE ENTERED AT,I5,6H SECS.//)
  216 FORMAT(/30H EXIT FROM SOLUTION ROUTINE AT,I5,6H SECS.//)
      RETURN
      END
C
C
C
C
C
C
C
C
C*********************************
      SUBROUTINE TEMPCAL(RMAX,ERA)
C*********************************
C
C*************************************************************
C     CALCULATE TEMPERATURE FIELD FROM A VELOCITY FIELD.
C*************************************************************
C
C*********************************************************************
C     UNCOUPLING SOLUTION OF FLOW EQUATION FROM TEMPERATURE EQUATION.
```

FETHSOLVAC (CONT.)

```
C*****************************************************************
C
C
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      COMMON/CONTP/
     1 X,Y,V,CONDF,BETA,CPF,RHO,HCOFX,HCOFY,
     2 GPF,GPG,GPH,EMU,XG(3),CG(3),DS,DX,DY,
     3 NP,NH,NE,NB,NDF,NCN,NBN,IT1,ND1,MTRD
     4,NTIME,MARK,NTR,LTIM,MTRIT,NCARDS,NSID,NAXI
     5,NRT,MWGA,NNP,NELL,NTRA,NGAUSS,NPR,NCR,NLP,NCP
     6,NCORD,IG,NG,NBV,NBT,NEWTON,ITURB,ICOND
      COMMON/GEP/
     1 TEMP(461),CORD(461,2),RSPEC(461,6)
     2,R1(1553),R2(1553),VARI(1553),VARA(1553),BC(1553)
     3,VALV(560),AVARI(1553),NOP(122,8),NDN(122),LPR(122)
     4,NOPF(461),MDF(461),NCOD(1553),NODV(560)
      COMMON/GUARD/
     1 SK(40000),ESTIFM(28,28),GISH(600),INTEG(2700)
      COMMON/UPWIN/
     1 AA1,AA2,A1,A2,BB1,BB2,B1,B2,DIS(3,461)
     2,WP(8),WDEL(2,8),WB(2,8),DWB(2,72),DWP(72),TT(8)
     3,UU(8),VV(8),UAVE(2),VAVE(2),IUPWIN,IWTS,VKIN,VKON
      COMMON/ITRSTO/UPVBC(1553),NCODV(1553),TBC(1553),NCODT(1553)
C
      REWIND ND1
      IF(NTR.GT.1) GO TO 26
      DO 24 I=1,NH
      NCOD(I)=0
      NCODT(I)=0
      BC(I)=0.
      TBC(I)=0.
      R2(I)=0.
   24 R1(I)=0.
C
C*****************************************
C   READ IN TEMPERATURE BOUNDARY CONDITIONS
C*****************************************
C
      READ(NCR,122) NB
      WRITE(NLP,116)NB
      NBT=NB
      DO 25 I=1,NB
      READ(NCR,124)NOD,VAL
      WRITE(NLP,124)NOD,VAL
      NCOD(NOD)=1
      NCODT(NOD)=1
      BC(NOD)=VAL
      TBC(NOD)=VAL
   25 CONTINUE
   26 CONTINUE
```

FETHSOLVAC (CONT.)

```
      IF(MARK.LT.4.OR.NTR.EQ.1) GO TO 280
      DO 270 N=1,NP
      NCOD(N)=NCODT(N)
      BC(N)=TBC(N)
  270 CONTINUE
  280 CONTINUE
      NF=NP
      NV=NDF
      LQ=NCN
      NP=NH
      NDF=1
      NCN=NBN
      MWGA=-1
C
C*****************************
C   SET UP AND SOLVE EQUATIONS
C*****************************
C
      CALL FRONT
      REWIND 10
      WRITE(NLP,126)
      DO 40 N=1,NH
      NCOD(N)=0
      BC(N)=0.
      TEMP(N)=SK(N)
      WRITE(NLP,152)N,TEMP(N)
   40 CONTINUE
      CALL TIMER(IT)
      ITIME=IT-IT1
      WRITE(NLP,400)ITIME
C
C*************************************************
C     CALCULATIONS OF HEAT TRANSFER COEFFICIENTS
C*************************************************
C
      IF(RMAX.GE.ERA) GO TO 3
      READ(NCR,122)NHEAT
      WRITE(NLP,123)NHEAT
      IF(NHEAT.EQ.0)GO TO 3
      WRITE(NLP,125)
      DO 2 I=1,NHEAT
      READ(NCR,122)NELL,NSID
      WRITE(NLP,127)NELL,NSID
    2 CALL HCOEF
    3 CONTINUE
      REWIND 10
      REWIND 9
      NP=NF
      NDF=NV
      NCN=LQ
```

FETHSOLVAC (CONT.)

```
      MWGA=0
  116 FORMAT(I5,32H TEMPERATURE BOUNDARY CONDITIONS)
  122 FORMAT(2I5)
  123 FORMAT(/7H NHEAT=,I3)
  125 FORMAT(/43H CALCULATIONS OF HEAT TRANSFER COEFFICIENTS/)
  127 FORMAT(//6H NELL=,I3,6H NSID=,I3)
  124 FORMAT(I5,5X,F20.10)
  126 FORMAT(/,' NODAL TEMPERATURE VALUES',/)
  152 FORMAT(I5,6E18.10)
  204 FORMAT(//46H LARGEST RELATIVE CHANGE IN TEMPERATURE VALUE=,E18.10)
  400 FORMAT(' TEMPERATURE CALCULATIONS FINISHED AT ',I5,'SECS')
      RETURN
      END
C
C
C
C
C
C
C
C**********************
      SUBROUTINE HCOEF
C**********************
C
C*****************************************************************
C   CALCULATE WALL TEMPERATURE GRADIENTS AT GAUSS POINTS
C*****************************************************************
C
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      COMMON/CONTR/
     1 X,Y,V,CONDF,BETA,CPF,RHO,HCOFX,HCOFY,
     2 GPF,GPG,GPH,EMU,XG(3),CG(3),DS,DX,DY,
     3 NP,NH,NE,NB,NDF,NCN,NBN,IT1,ND1,MTRD
     4,NTIME,MARK,NTR,LTIM,MTRIT,NCARDS,NSID,NAXI
     5,NRT,MWGA,NNP,NELL,NTRA,NGAUSS,NPR,NCR,NLF,NCP
     6,NCORD,IG,NG,NBV,NBT,NEWTON,ITURB,ICOND
      COMMON/GEP/
     1 TEMP(461),CORD(461,2),RSPEC(461,6)
     2,R1(1553),R2(1553),VARI(1553),VARA(1553),BC(1553)
     3,VALV(560),AVARI(1553),NOP(122,8),NDN(122),LPR(122)
     4,NOPP(461),MDF(461),NCOO(1553),NOOV(560)
      COMMON/GUARD/
     1 SK(40000),ESTIFM(28,28),GISH(600),INTEG(2700)
      COMMON/UPWIN/
     1 AA1,AA2,A1,A2,BB1,BB2,B1,B2,DIS(3,461)
     2,WP(8),WDEL(2,8),WB(2,8),DWB(2,72),DWP(72),TT(8)
     3,UU(8),VV(8),UAVE(2),VAVE(2),IUPWIN,IWTS,VKIN,VKON
      DIMENSION
     1 P(8),DEL(2,8),B(2,8),CJ(2,2),CJI(2,2)
```

FETHSOLVAC (CONT.)

```
      2,PP(4),BB(2,4),CB(2,36),CP(36)
      3,DB(2,72),DP(72),DDA(9)
       EQUIVALENCE
      1 (SK(1),P(1)),(SK(10),DEL(1,1))
      2,(SK(30),B(1,1)),(SK(50),CJ(1,1))
      3,(SK(55),CJI(1,1)),(SK(60),PP(1))
      4,(SK(70),DDA(1)),(SK(80),CB(1,1))
      5,(SK(160),CP(1)),(SK(200),DB(1,1))
      6,(SK(350),DP(1)),(SK(430),ELX)
      7,(SK(431),ELY)
C
       N=NELL
       TESTX=0.0
       TESTY=0.0
       TESTS=0.0
       WRITE(NLP,500)N
       DO 10 IG=1,NGAUSS
       CALL SURFINT
       G1=0.0
       G2=0.0
       ELX=-ELX
       ELY=-ELY
       IF(MARK.NE.3)GO TO 15
       DO 5 L=1,NBN
       K=IABS(NOP(N,L))
       M4=NOPP(K)+MDF(K)-1
       G1=G1+B(1,L)*VARI(M4)
       G2=G2+B(2,L)*VARI(M4)
    5  CONTINUE
       GO TO 25
   15  DO 20 L=1,NBN
       K=IABS(NOP(N,L))
       G1=G1+B(1,L)*TEMP(K)
       G2=G2+B(2,L)*TEMP(K)
   20  CONTINUE
   25  CONTINUE
       TESTX=TESTX+DX
       TESTY=TESTY+DY
       TESTS=TESTS+DS
       WRITE(NLP,505) IG,G1,G2
   10  CONTINUE
       WRITE(NLP,510) TESTX,TESTY,TESTS
  500 FORMAT(/35H HEAT TRANSFER CALCULATIONS ELEMENT,I5/)
  505 FORMAT('  GAUSS POINT',I3,'  DT/DX=',E13.5,'  DT/DY=',E13.5,/)
  510 FORMAT('  INTEGRATION TEST TESTX=',E13.5,'  TESTY=',
     :E13.5,'  TESTS=',E13.5,/)
       RETURN
       END
C
C
```

FETHSOLVAC (CONT.)

```
C
C
C
C
C
C
C*********************
      SUBROUTINE PRESCR
C*********************
C
C*****************************************
C     CALCULATES PRESCRIBED SURFACE FUNCTIONS
C*****************************************
C
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      COMMON/CONTR/
     1 X, Y, V, CONDF, BETA, CPF, RHO, HCOFX, HCOFY,
     2 GPF, GPG, GPH, EMU, XG(3), CG(3), DS, DX, DY,
     3 NP, NH, NE, NB, NDF, NCN, NBN, IT1, ND1, MTRD
     4, NTIME, MARK, NTR, LTIM, MTRIT, NCARDS, NSID, NANI
     5, NRT, MWGA, NNP, NELL, NTRA, NGAUSS, NPR, NCR, NLP, NCP
     6, NCORD, IG, NG, NBV, NBT, NEWTON, ITURB, ICOND
      COMMON/GEP/
     1 TEMP(461), COPD(461,2), RSPEC(461,6)
     2, R1(1553), R2(1553), VARI(1553), VARA(1553), BC(1553)
     3, VALV(560), AVARI(1553), NOP(122,8), NDN(122), LPP(122)
     4, NOPP(461), MDF(461), NCOD(1553), NODV(560)
      COMMON/GUARD/
     1 SK(40000), ESTIFM(28,28), GISH(600), INTEG(2700)
      COMMON/UPWIN/
     1 AA1, AA2, A1, A2, BB1, BB2, B1, B2, DIS(3,461)
     2, WP(8), WDEL(2,8), WB(2,8), DWB(2,72), DWP(72), TT(8)
     3, UU(8), VV(8), UAVE(2), VAVE(2), IUPWIN, INTS, VKIN, VKON
      DIMENSION
     1 P(8), DEL(2,8), B(2,8), CJ(2,2), CJI(2,2)
     2, PP(4), BB(2,4), CB(2,36), CP(36)
     3, DB(2,72), DP(72), DDA(9)
      EQUIVALENCE
     1 (SK(1),P(1)),(SK(10),DEL(1,1))
     2, (SK(30),B(1,1)),(SK(50),CJ(1,1))
     3, (SK(55),CJI(1,1)),(SK(60),PP(1))
     4, (SK(70),DDA(1)),(SK(90),CB(1,1))
     5, (SK(160),CP(1)),(SK(200),DB(1,1))
     6, (SK(350),DP(1)),(SK(430),ELX)
     7, (SK(431),ELY)
C
      NSID=LPR(NELL)
      JA=1
      IF(MARK.EQ.3)JA=2
      N=NELL
```

FETHSOLVAC (CONT.)

```
      TESTX=0.
      TESTY=0.
      TESTS=0.
      DO 100 IG=1,NGAUSS
      CALL SURFINT
      ELX=-ELX
      ELY=-ELY
C
C*****************************************************************
C     SURFACE INTEGRALS FOR PRESCRIBED TRACTIONS AND VELOCITY
C     /THERMAL GRADIENTS
C*****************************************************************
C
      G1=0.
      G2=0.
      G3=0.
      G4=0.
      IF(MARK.EQ.2.OR.MARK.EQ.3) GO TO 30
      DO 20 L=1,NEN
      NN=IABS(NOP(N,L))
      G1=G1+W*P(L)*(RSPEED(NN,1)*ELX+RSPEED(NN,2)*ELY)
      G2=G2+CORD(NN,2)*P(L)
      G3=G3+W*P(L)*(RSPEED(NN,3)*ELX+RSPEED(NN,4)*ELY)
      G4=G4+CONDF/(RHO*CPF)*P(L)*(RSPEED(NN,5)*ELX+RSPEED(NN,6)*ELY)
   20 CONTINUE
      GO TO 50
   30 CONTINUE
      DO 40 L=1,NEN
      NN=IABS(NOP(N,L))
      G1=G1+P(L)*(RSPEED(NN,1)*ELX+RSPEED(NN,2)*ELY)/RHO
      G2=G2+CORD(NN,2)*P(L)
      G3=G3+P(L)*(RSPEED(NN,3)*ELX+RSPEED(NN,4)*ELY)/RHO
      G4=G4+CONDF/(RHO*CPF)*P(L)*(RSPEED(NN,5)*ELX+RSPEED(NN,6)*ELY)
   40 CONTINUE
   50 CONTINUE
C
C*****************************************
C    SET UP RIGHT HAND SIDE VECTOR
C*****************************************
C
      DO 60 K=1,NBN
      H1=P(K)
      H2=P(K)
      IF(IUPWIN.EQ.2) H1=WP(K)
      IF(IUPWIN.EQ.1) H2=WP(K)
      NN=IABS(NOP(N,K))
      M1=NOPP(NN)
      M3=M1+MDF(NN)-JA
      M4=M3+1
      R2(M1)=R2(M1)+H1*G1*DS
```

FETHEOLVAC (CONT.)

```
      R2(M3)=R2(M3)+H1*G3*DS
      R2(M4)=R2(M4)+H2*G4*DS
      IF(NAXI.EQ.1) R2(M1)=R2(M1)*G2
      IF(NAXI.EQ.1) R2(M3)=R2(M3)*G2
      IF(NAXI.EQ.1) R2(M4)=R2(M4)*G2
   60 CONTINUE
      TESTX=TESTX+DX
      TESTY=TESTY+DY
      TESTS=TESTS+DS
  100 CONTINUE
      WRITE(NLP,500)N,G1,G2,G3,G4
      WRITE(NLP,510)
      WRITE(NLP,520)TESTX,TESTY,TESTS,ELX,ELY
C
C*****************************
C     PRINT RIGHT HAND VECTORS
C*****************************
C
      WRITE(NLP,530)
      WRITE(NLP,600)
      DO 115 NN=1,NBN
      L=IABS(NOP(N,NN))
      IDF=MDF(L)
      J=NOPP(L)-1
      IF(IDF.LT.NDF)GO TO 105
      IF(NDF.EQ.2)GO TO 100
      WRITE(NLP,605)L,(R2(J+I),I=1,IDF)
      GO TO 115
  105 IF(IDF.EQ.1)GO TO 110
  100 WRITE(NLP,610)L,(R2(J+I),I=1,IDF)
      GO TO 115
  110 WRITE(NLP,615)L,R2(J+1)
  115 CONTINUE
  500 FORMAT(/124 ELEMENT NO.,I4,2X,9H G-VALUES/4E20.10)
  510 FORMAT(17H INTEGRATION TEST)
  520 FORMAT(5E20.10)
  530 FORMAT(1X,18H RIGHT HAND VECTOR/)
  600 FORMAT(/5H NODE,4X,11H U-VELOCITY,8X,10H PRESSURES,7X,11H V-VELOCI
     1TY,6X,12H TEMPERATURE/)
  605 FORMAT(I5,5E18.10)
  610 FORMAT(I5,E18.10,18X,2E18.10)
  615 FORMAT(I5,18X,E18.10)
      RETURN
      END
C
C
C
C
C
C
```

FETHSOLVAC (CONT.)

```
C
C*************************
      SUBROUTINE SURFINT
C*************************
C
C*****************************************
C     CALCULATE SURFACE INTEGRATION CONSTANTS
C*****************************************
C
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      COMMON/CONTR/
     1 X,Y,V,CONDF,BETA,CPF,RHO,HCOFX,HCOFY,
     2 GPF,GPG,GPH,EMU,XG(3),CG(3),DS,DX,DY,
     3 NF,NH,NE,NB,NCF,NCN,NBN,IT1,NO1,MTRD
     4,NTIME,MAPK,NTP,LTIM,MTRIT,NCARDS,NSID,NAXI
     5,NRT,MWGR,NNP,NELL,NTRA,NGAUSS,NPR,NCR,NLP,NCP
     6,NCORD,IG,NG,NBW,NET,NEWTON,ITURB,ICOND
      COMMON/GEP/
     1 TEMP(461),CORD(461,2),REFEC(461,6)
     2,R1(1553),R2(1553),VARI(1553),VARA(1553),BC(1553)
     3,WALV(560),AVARI(1553),NOP(122,8),NON(122),LPR(122)
     4,NOPP(461),MDF(461),NCOD(1553),NODV(560)
      COMMON/GUARD/
     1 SK(40000),ESTIFM(29,28),GISH(600),INTEG(2700)
      COMMON/UPWIN/
     1 AA1,AA2,A1,A2,BB1,BB2,B1,B2,DIS(3,461)
     2,WP(8),WDEL(2,8),WB(2,8),DWB(2,72),DWP(72),TT(8)
     3,UU(8),VV(8),UPWE(2),VPWE(2),IUPWIN,IWTS,VKIN,VKON
      DIMENSION
     1 P(8),DEL(2,8),B(2,8),CJ(2,2),CJI(2,2)
     2,PP(4),BE(2,4),CB(2,36),CP(36)
     3,DB(2,72),DP(72),DDA(9)
      EQUIVALENCE
     1 (SK(1),P(1)),(SK(10),DEL(1,1))
     2,(SK(30),B(1,1)),(SK(50),CJ(1,1))
     3,(SK(55),CJI(1,1)),(SK(60),PP(1))
     4,(SK(70),DDA(1)),(SK(80),CB(1,1))
     5,(SK(160),CP(1)),(SK(200),DB(1,1))
     6,(SK(350),DP(1)),(SK(430),ELX)
     7,(SK(431),ELY)
      GO TO (4,8,12,16),NSID
    4 GPG=-1.
      GPH=XG(IG)
      GO TO 20
    8 GPG=XG(IG)
      GPH=1.
      GO TO 20
   12 GPG=1.
      GPH=XG(IG)
```

FETHSOLVAC (CONT.)

```
      GO TO 20
   16 GPG=XG(IG)
      GPH=-1.
   20 CONTINUE
      IF(IUPWIN.NE.0) CALL WYSET(NELL)
      CALL SFR
      CALL DIRECS
C
C*************************
C     CALCULATE B-MATRIX
C*************************
C
      DETJ = CJ(1,1) * CJ(2,2) - CJ(1,2) * CJ(2,1)
      IF(DETJ)22,21,22
   21 WRITE(NLP,216)
      STOP
   22 CJI(1,1) =CJ(2,2)/DETJ
      CJI(1,2) =-CJ(1,2) / DETJ
      CJI(2,1) =-CJ(2,1) / DETJ
      CJI(2,2) = CJ(1,1) / DETJ
      DO 23 J=1,2
      DO 23 L=1,NBN
      B(J,L)=0.
      DO 23 K=1,2
   23 B(J,L)=B(J,L)+CJI(J,K)*DEL(K,L)
      GO TO (24,28,24,28),NSID
   24 DX=CJ(2,1)*CG(IG)
      DY=CJ(2,2)*CG(IG)
      GO TO 32
   28 DX=CJ(1,1)*CG(IG)
      DY=CJ(1,2)*CG(IG)
   32 CONTINUE
      DS=SQRT(DX*DX+DY*DY)
  216 FORMAT(/74H DETJ=0-PROGRAM HALTED IN SURFINT----CHECK MESH DATA AN
     1D COMMON STATEMENTS/)
      RETURN
      END
C
C
C
C
C
C
C
C
C*************************
      SUBROUTINE DIRECS
C*************************
C
C*****************************************************************
```

FETHSOLVAC (CONT.)

```
C      CALCULATE DIRECTION COSINES ELX,ELY OF ELEMENT INWARD NORMAL
C*****************************************************************
C
       IMPLICIT DOUBLE PRECISION (A-H,O-Z)
       COMMON/CONTR/
     1 X,Y,V,CONDF,BETA,CPF,RHO,HCOFX,HCOFY,
     2 GPF,GPG,GPH,EMU,XG(3),CG(3),DS,DX,DY,
     3 NP,NH,NE,NB,NDF,NCN,NEN,IT1,ND1,MTRD
     4,NTIME,MARK,NTP,LTIM,MTRIT,NCARDS,NSID,NAXI
     5,NRT,MWGA,NNP,NELL,NTPA,NGAUSS,NFR,NCR,NLF,NCP
     6,NCORD,IG,NG,NBV,NET,NEWTON,ITURB,ICOND
       COMMON/GEP/
     1 TEMP(461),CORD(461,2),RSPEC(461,6)
     2,R1(1553),P2(1553),VARI(1553),VARP(1553),BC(1553)
     3,VALV(560),AVARI(1553),NOP(122,8),NON(122),LPR(122)
     4,NOPP(461),MDF(461),NCOD(1553),NODV(560)
       COMMON/GUARD/
     1 SK(40000),ESTIFM(28,28),GISH(600),INTEG(2700)
       COMMON/UPWIN/
     1 AA1,AA2,A1,A2,BB1,BB2,B1,B2,DIS(3,461)
     2,WP(8),WDEL(2,8),WB(2,8),DWB(2,72),DWP(72),TT(8)
     3,UU(8),VV(8),UAVE(2),VPVE(2),IUPWIN,IWTS,VKIN,VKON
       DIMENSION
     1 P(8),DEL(2,8),B(2,8),CJ(2,2),CJI(2,2)
     2,PP(4),BB(2,4),CB(2,36),CP(36)
     3,DB(2,72),DP(72),DDA(9)
       EQUIVALENCE
     1 (SK(1),P(1)),(SK(10),DEL(1,1))
     2,(SK(30),B(1,1)),(SK(50),CJ(1,1))
     3,(SK(55),CJI(1,1)),(SK(60),PP(1))
     4,(SK(70),DDA(1)),(SK(80),CB(1,1))
     5,(SK(160),CP(1)),(SK(200),DB(1,1))
     6,(SK(350),DP(1)),(SK(430),ELX)
     7,(SK(431),ELY)
C
       N=NELL
       DO 4 J=1,2
       DO 4 L=1,2
       GUSH=0.
       DO 2 K=1,NEN
       NN=IABS(NOP(N,K))
     2 GUSH=GUSH+DEL(J,K)*CORD(NN,L)
     4 CJ(J,L)=GUSH
       A11=CJ(1,1)
       A12=CJ(1,2)
       A21=CJ(2,1)
       A22=CJ(2,2)
       GO TO(8,12,8,12),NSID
     8 MFAC=1
       IF(NSID.EQ.3)MFAC=-1
```

FETHSOLVAC (CONT.)

```
      DS=SQRT(A21*A21+A22*A22)
      ELX=MFAC*A22/DS
      ELY=-MFAC*A21/DS
      GO TO 16
   12 MFAC=1
      IF(NSID.EQ.4)MFAC=-1
      DS=SQRT(A11*A11+A12*A12)
      ELX=MFAC*A12/DS
      ELY=-MFAC*A11/DS
   16 RETURN
      END
C
C
C
C
C
C
C
C*************************
      SUBROUTINE ABFIND
C*************************
C
C*****************************************************************
C   CALLING ROUTINE FOR PERTINENT ELEMENT ASSEMBLY PROCEDURE
C*****************************************************************
C
      IMPLICIT DOUBLE PRECIEION (A-H,O-Z)
      COMMON/CONTR/
     1 X,Y,W,CONDF,BETA,CPF,RHO,HCOFY,HCOFY,
     2 GPF,GPG,GPH,EMU,XG(3),CG(3),DS,DX,DY,
     3 NP,NH,NE,NE,NDF,NCN,NBN,IT1,ND1,MTRD
     4,NTIME,MARK,NTR,LTIM,MTRIT,NCARDS,NSID,NAXI
     5,NRT,MWGA,NNP,NELL,NTRA,NGAUSS,NPE,NCR,NLP,NCP
     6,NCORD,IG,NG,NBV,NBT,NEWTON,ITURB,ICOND
      COMMON/GEP/
     1 TEMP(461),CORD(461,2),RSPEC(461,6)
     2,P1(1553),P2(1553),VARI(1553),VARA(1553),BC(1553)
     3,VALV(560),AVPRI(1553),NOP(122,8),NON(122),LPR(122)
     4,NOPP(461),MDF(461),NCOD(1553),NODV(560)
      COMMON/GUARD/
     1 SK(40000),ESTIFM(28,28),GISH(600),INTEG(2700)
      COMMON/UPWIN/
     1 AA1,AA2,A1,A2,BB1,BB2,B1,B2,DIS(3,461)
     2,WP(8),WDEL(2,8),WB(2,8),DWB(2,72),DWP(72),TT(8)
     3,UU(8),VV(8),UAVE(2),VAVE(2),IUPWIN,IWTS,VKIN,VKON
      IF(MARK.EQ.6)GO TO 3
      IF(ITURB.EQ.0)GO TO 3
      CALL EFVISC(NELL)
    3 CONTINUE
```

FETHSOLVAC (CONT )

```
      IF(MWGA.NE.0.AND.MARK.NE.6) GO TO 35
      GO TO(5,10,20,5,10,40),MARK
    5 CALL ABFORM1
      GO TO 90
   10 CALL ABFORM2
      GO TO 90
   20 CALL ABFORM5
      GO TO 90
   35 CONTINUE
      CALL TEMPM
      GO TO 90
   40 CALL ABFORM6
   90 CONTINUE
      RETURN
      END
C
C
C
C
C
C
C
C**********************
      SUBROUTINE DERIV
C**********************
C
C*****************************************
C       CALCULATE SHAPE FUNCTION DERIVATIVES
C*****************************************
C
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      COMMON/CONTR/
     1 X,Y,W,CONDF,BETA,CPF,RHO,HCOFX,HCOFY,
     2 GPF,GPG,GPH,EMU,XG(3),CG(3),DS,DX,DY,
     3 NP,NH,NE,NB,NDF,NCN,NBN,IT1,ND1,MTRD
     4,NTIME,MARK,NTP,LTIM,MTRIT,NCARDS,NSID,NAXI
     5,NET,MWGA,NNP,NELL,NTRA,NGAUSS,NPR,NCP,NLP,NCP
     6,NCORD,IG,NG,NBV,NBT,NEWTON,ITURB,ICOND
      COMMON/GEP/
     1 TEMP(461),CORD(461,2),RSPEC(461,6)
     2,R1(1553),R2(1553),VARI(1553),VARA(1553),BC(1553)
     3,WALV(560),AVARI(1553),NOP(122,8),NDN(122),LPR(122)
     4,NOPP(461),MDF(461),NCOD(1553),NODV(560)
      COMMON/GUARD/
     1 SK(40000),ESTIFM(28,28),GISH(600),INTEG(2700)
      COMMON/UPWIN/
     1 AA1,AA2,A1,A2,BB1,BB2,B1,B2,DIS(3,461)
     2,WP(8),WDEL(2,8),WB(2,8),DWB(2,72),DWP(72),TT(8)
     3,UU(8),VV(8),UAVE(2),VAVE(2),IUPWIN,IWTS,VKIN,VKON
      DIMENSION
```

FETHSOLWAC (CONT.)

```
      1 P(8),DEL(2,8),B(2,9),CJ(2,2),CJI(2,2)
      2,PP(4),BB(2,4),CB(2,36),CP(36)
      3,DB(2,72),DP(72),DDA(9)
       EQUIVALENCE
      1 (SK(1),P(1)),(SK(10),DEL(1,1))
      2,(SK(30),B(1,1)),(SK(50),CJ(1,1))
      3,(SK(55),CJI(1,1)),(SK(60),PP(1))
      4,(SK(70),DDA(1)),(SK(80),CB(1,1))
      5,(SK(160),CP(1)),(SK(200),DB(1,1))
      6,(SK(350),DP(1)),(SK(430),ELX)
      7,(SK(431),ELY)
C
       NGAUSS=2
       XG(1)=0.774596669200
       XG(2)=0.
       XG(3)=-XG(1)
       CG(1)=0.555555555600
       CG(2)=0.888888888900
       CG(3)=CG(1)
       DO 90 NELL=1,NE
       IF(IUPWIN.EQ.0)GO TO 40
       CALL WYSET(NELL)
   40  CONTINUE
       JDN=NDN(NELL)
       LL=0
       DO 85 IG=1,NGAUSS
       DO 85 JG=1,NGAUSS
       LL=LL+1
       GPG=XG(IG)
       GPH=XG(JG)
       CALL SFR
C
C*****************************************************
C      SETS DERIVATIVES AND JACOBIAN IN GLOBAL COORDINATES
C      (A) PARABOLIC ELEMENT
C*****************************************************
C
       DO 60 J=1,2
       DO 60 L=1,2
       GAS=0.
       DO 58 K=1,NBN
       NN=IABS(NOP(NELL,K))
   58  GAS  =GAS +DEL(J,K)*CORD(NN,L)
   60  CJ(J,L)=GAS
C
C*********************************
C TO FORM DETJ DETERMINANT OF CJ
C*********************************
C
       DETJ = CJ(1,1) * CJ(2,2) - CJ(1,2) * CJ(2,1)
```

FETHSOLVAC (CONT.)

```
      IF(DETJ)66,62,66
   62 WRITE(NLP,505)
      WRITE(NLP,500)NELL
      STOP
   66 CJI(1,1) =CJ(2,2)/DETJ
      CJI(1,2) =-CJ(1,2) / DETJ
      CJI(2,1) =-CJ(2,1) / DETJ
      CJI(2,2) = CJ(1,1) / DETJ
      DO 68 J=1,2
      DO 68 L=1,NBN
      B(J,L)=0.
      DO 68 K=1,2
   68 B(J,L)=B(J,L)+CJI(J,K)*DEL(K,L)
      IF(IUPWIN.EQ.0)GO TO 69
      DO 67 J=1,2
      DO 67 L=1,NBN
      WB(J,L)=0.
      DO 67 K=1,2
   67 WB(J,L)=WB(J,L)+CJI(J,K)*WDEL(K,L)
   69 CONTINUE
      DA=DETJ*CG(IG)*CG(JG)
      DDA(LL)=DA
      DO 72 I=1,NBN
      NJ=(LL-1)*NBN+I
      DP(NJ)=P(I)
      IF(IUPWIN.GT.0)DWP(NJ)=WP(I)
      DO 70 L=1,2
      IF(IUPWIN.GT.0)DWB(L,NJ)=WB(L,I)
   70 DB(L,NJ)=B(L,I)
   72 CONTINUE
C
C*****************************************************
C     (B) SUPERPARAMETRIC ELEMENT-LINEAR/PARABOLIC
C*****************************************************
C
      NBN=4
      CALL SFR
      DO 82 J=1,2
      DO 82 L=1,NBN
      B(J,L)=0.
      DO 82 K=1,2
   82 B(J,L)=B(J,L)+CJI(J,K)*DEL(K,L)
      DO 84 I=1,NBN
      NJ=(LL-1)*NBN+I
      CP(NJ)=P(I)
      DO 83 L=1,2
   83 CB(L,NJ)=B(L,I)
   84 CONTINUE
      NBN=8
   85 CONTINUE
```

FETHSOLVAC (CONT.)

```
      NG=LL*8
      NGG=LL*4
C
C*********************************************
C   WRITE ELEMENT DATA ON PERIPHERAL STORAGE
C*********************************************
C
      WRITE(10)
     1 NELL,NG,LL,((DB(L,I),L=1,2),DP(I),I=1,NG),(DDA(L),L=1,LL),NGG
     2,((CB(L,I),L=1,2),CP(I),I=1,NGG)
      IF(IUPWIN.NE.0) WRITE(8)
     1NELL,NG,LL,((DWB(L,I),L=1,2),DWP(I),I=1,NG)
   90 CONTINUE
      REWIND 10
      REWIND 8
  500 FORMAT(16H ELEMENT NUMBER=,I3)
  505 FORMAT(/74H DETJ=0-PROGRAM HALTED IN DERIV------CHECK MESH-DATA AN
     1D COMMON STATEMENTS)
  510 FORMAT(/5H DET=,F10.4,4H LL=,I3)
      RETURN
      END
C
C
C
C
C
C
C
C*************************
      SUBROUTINE ABFORM1
C*************************
C
C*********************************************************
C     NORMAL DERIVATIVES SPECIFIED
C     CARTESIAN COORDINATES NAXI=0
C     AXI-SYMMETRICAL CYLINDRICAL COORDINATES NAXI=1
C     USE ITERATION METHOD ONLY NEWON=0
C     USE NEWTON RAPHSON METHOD ,NEWTON=1
C*********************************************************
C
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      COMMON/CONTP/
     1 X,Y,W,CONDF,BETA,CPF,RHO,HCOFX,HCOFY,
     2 GPF,GPG,GPH,EMU,XG(3),CG(3),DS,DX,DY,
     3 NP,NH,NE,NB,NDF,NCN,NBN,IT1,ND1,MTRD
     4,NTIME,MARK,NTP,LTIM,MTRIT,NCARDS,NSID,NAXI
     5,NRT,MWGA,NNP,NELL,NTRA,NGAUSS,NPR,NCR,NLP,NCP
     6,NCORD,IG,NG,NBV,NBT,NEWTON,ITUPB,ICOND
      COMMON/GEP/
     1 TEMP(461),CORD(461,2),RSPEC(461,6)
```

FETHSOLVAC (CONT.)

```
      2,R1(1553),R2(1553),VARI(1553),VARA(1553),BC(1553)
      3,VALV(560),AVARI(1553),NOP(122,8),NON(122),LPR(122)
      4,NOPP(461),MDF(461),NCOD(1553),NODV(560)
       COMMON/GUARD/
      1 SK(40000),ESTIFM(28,28),GISH(600),INTEG(2700)
       COMMON/UPWIN/
      1 AA1,AA2,A1,A2,BB1,BB2,B1,B2,DIS(3,461)
      2,WP(8),WDEL(2,8),WB(2,8),DWB(2,72),DWP(72),TT(8)
      3,UU(8),VV(8),UPVE(2),VAVE(2),IUPWIN,IWTS,VKIN,VKON
       DIMENSION AI1(8),AI2(8),P(8),B(2,8)
       DIMENSION AA(29,29),PP(4),BB(2,4),CB(2,36),CP(36)
       DIMENSION DB(2,72),DP(72),DDA(9)
       EQUIVALENCE
      1 (ESTIFM(1,1),AA(1,1))
C
       ANWT=0
       IF(NTP GT 2)ANWT=FLOAT(NEWTON)
       JDN=NON(NELL)
       IM=4
       IF(JDN NE NGN)IM=3
       DO 2 J=1,JDN
       AI1(J)=0
     2 AI2(J)=0.
       DO 4 I=1,NCN
       DO 4 J=1,NCN
     4 AA(I,J)=0.
C
C*****************************************************
C    READ IN ELEMENT DATA FROM PERIPHERAL STORE
C*****************************************************
C
       READ(10)
      1 N,NG,LL,((DB(L,I),L=1,2),DP(I),I=1,NG),(DDA(L),L=1,LL),NGG
      2,((CB(L,I),L=1,2),CP(I),I=1,NGG)
       IF(IUPWIN EQ 2) READ(8)
      1 N,NG,LL,((DWB(L,I),L=1,2),DWP(I),I=1,NG)
       DO 20 NG=1,LL
       DA=DDA(NG)
       DO 8 I=1,JDN
       NJ=(NG-1)*JDN+I
       P(I)=DP(NJ)
       WP(I)=DP(NJ)
       IF(IUPWIN EQ 2) WP(I)=DWP(NJ)
       DO 6 L=1,2
       WB(L,I)=DB(L,NJ)
       IF(IUPWIN EQ 2) WB(L,I)=DWB(L,NJ)
     6 B(L,I)=DB(L,NJ)
     8 CONTINUE
       DO 10 I=1,IM
       NJ=(NG-1)*IM+I
```

FETHSOLVAC (CONT.)

```
      PP(I)=CP(NJ)
      DO 9 L=1,2
    9 BB(L,I)=CB(L,NJ)        ∂Mi/∂x , ∂Mj/∂y
   10 CONTINUE
      G1=0.
      G2=0.
      G4=0.
      G5=0.
      G6=0.
      G7=0.
      G8=0
      DO 12 L=1,JDN
      K=IABS(NOP(N,L))
      M1=NOPP(K)
      M3=M1+MDF(K)-1
      H4=P(L)
      G1=G1+VARI(M1)*H4   u.Vx
      G2=G2+COORD(K,2)*H4 y,r
      G4=G4+VARI(M3)*H4    v,Vr
      IF(ANWT.EQ.0.)GO TO 12
      G5=G5+VARI(M1)*B(1,L) ∂u/∂x , ∂Vz/∂z
      G6=G6+VARI(M1)*B(2,L) ∂u/∂y , ∂Vz/∂r
      G7=G7+VARI(M3)*B(1,L) ∂v/∂x , ∂Vr/∂z
      G8=G8+VARI(M3)*B(2,L) ∂v/∂y , ∂Vr/∂r
   12 CONTINUE
      IF(NTP.EQ.1) G1=0.0
      IF(NTP.EQ.1) G4=0.0
      G3=0.
      IF(NAXI.EQ.1)G3=1./G2
      IF(NAXI.EQ.1)DA=DA*G2
C
C*********************
C     RIGHT HAND SIDE
C*********************
C
      DO 14 I=1,JDN
      H1=WP(I)    Wi
      K=IABS(NOP(N,I))
      TEMPR=TEMP(K)
      IF(MARK.LT.3.OR.ICOND.EQ.0) TEMPR=1.0D0
      IF(ANWT.EQ.1.) GO TO 15
      AI1(I)=AI1(I)∓H1*DA*X*BETA*TEMPR   q1
      AI2(I)=AI2(I)∓H1*DA*Y*BETA*TEMPR   q3
      GO TO 14
   15 CONTINUE
      AI1(I)=AI1(I)∓H1*DA*X*BETA*TEMPR-H1*DA*(G1*G5-G4*G6)*ANWT
      AI2(I)=AI2(I)∓H1*DA*Y*BETA*TEMPR-H1*DA*(G1*G7-G4*G8)*ANWT
   14 CONTINUE
C
C**********************
```

FETHSOLVAC (CONT.)

```
C      FORM FLUID MATRIX
C*********************
C
      DO 18 I1=1,IM
      DO 18 I2=1,2
      J1=(I1-1)*5+3*I2-2
      J11=(I1-1)*5+2*I2+1
      K1=2*(I1-1)+I2
      H1=WP(K1)
      H2=WB(1,K1)
      H3=WB(2,K1)
      DO 18 L1=1,IM
      JJ=(L1-1)*5+2
C
C*************************************
C   PRESSURE TERM FOR MOMENTUM EQUATION
C*************************************
C
      AA(J1,JJ)=AA(J1,JJ)+H1*DA*SB(1,L1)/RHO
      AA(J11,JJ)=AA(J11,JJ)+H1*DA*SB(2,L1)/RHO
      DO 18 L2=1,2
      J2=(L1-1)*5+3*L2-2
      J22=(L1-1)*5+2*L2+1
      K2=2*(L1-1)+L2
      H4=P(K2)
      H5=B(1,K2)
      H6=B(2,K2)
      H7=DA*V*(H2*H5+H3*H6)
     1+H1*DA*(G1*H5+G4*H6)
      H8=H1*DA*H4*G3
C
C*********************************
C  ASSEMBLE SHEAR & ADVECTION TERM
C*********************************
C
      IF(ANWT.EQ.1.)GO TO 17
      AA(J1,J2)=AA(J1,J2)+H7
      AA(J11,J22)=AA(J11,J22)+H7+H8*G3*V
      GO TO 25
   17 CONTINUE
      AA(J1,J2)=AA(J1,J2)+H7+H1*DA*H4*G5*ANWT
      AA(J11,J22)=AA(J11,J22)+H7+H8*G3*V+H1*DA*H4*G5*ANWT
      AA(J1,J22)=AA(J1,J22)+H1*DA*H4*G6*ANWT
      AA(J11,J2)=AA(J11,J2)+H1*DA*H4*G7*ANWT
   25 CONTINUE
C
C*************************************************
C       IF THE BODY FORCES (X,Y) ARE TO BE INCLUDED
C       AS (L.H.S.) TERMS IN THE MATRIX [AA].
C       INSTEAD OF THE [R.H.S.] VECTOR (R1), IT IS
```

$$\begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix} =$$

$$\begin{bmatrix} J_1, J_2 & J_1, JJ & J_1, J_{22} \\ J_1+1, J_2 & J_1+1, JJ & J_1+1, J_{22} \\ J_{11}, J_2 & J_{11}, JJ & J_{11}, J_{22} \end{bmatrix}$$

$W_i$

$\partial W_i/\partial x$ , $\partial W_i/\partial z$

$\partial W_i/\partial y$ , $\partial W_i/\partial r$

$N_j$

$\partial N_j/\partial x$ , $\partial N_j/\partial z$

$\partial N_j/\partial y$ , $\partial N_j/\partial r$

$a_{12}$

$a_{32}$

$a_{11}$

$a_{33}$

$a_{11}$

$a_{33}$

$a_{13}$

$a_{31}$

FETHSOLVAC (CONT.)

```
C       HERE IN THE NEXT TWO STATEMENTS.
C       FOR G1 (not equal=0)  i.e. AFTER
C       THE FIRST ITERATION.
C*****************************************************
C
      KK2=IABS(NOP(N,K2))
      TEMPR=TEMP(K2)
      IF(MARK.LT.3.OR.ICOND.EQ.0) TEMPR=1.0D0
      IF(NTR.EQ.1) GO TO 26
C     AA(J1,J2)=AA(J1,J2)+H1*DA*X*BETA*TEMPR/G1*H4
C     AA(J11,J22)=AA(J11,J22)+H1*DA*Y*BETA*TEMPR/G4*H4
   26 CONTINUE
C
C*************************
C   CONTINUITY EQUATION
C*************************
C
      IF(I2.EQ.2)GO TO 16
      AA(J1+1,J2)=AA(J1+1,J2)+PP(I1)*DA*HE
      AA(J1+1,J22)=AA(J1+1,J22)+PP(I1)*DA*H4*GI
   16 CONTINUE
   18 CONTINUE
   20 CONTINUE
      DO 22 I=1,JDN
      K=IABS(NOP(N,I))
      M1=NOFF(K)
      M2=M1+MDF(K)-1
      R1(M1)=R1(M1)+RI1(I)
      R1(M2)=R1(M2)+RI2(I)
   22 CONTINUE
  500 FORMAT(/15H ELEMENT NUMBER,I4)
  505 FORMAT(9E12.4)
      RETURN
      END
C
C
C
C
C
C
C
C
C*************************
      SUBROUTINE ARFORMD
C*************************
C
C*****************************************************
C     TRACTIONS SPECIFIED AS NATURAL BOUNDARY CONDITIONS.
C     NAXI=0,CARTESIAN COORDINATES
C     NAXI=1,AXISYMMETRIC CYLINDRICAL COORDINATES.
C     NEWTON=0,USING ITERATION ONLY
```

FETHSOLVAC (CONT.)

```
C       NEWTON=1,USING NEWTON RAPHSON METHOD.
C*****************************************************************
C
C
        IMPLICIT DOUBLE PRECISION (A-H,O-Z)
        COMMON/CONTR/
       1 X, Y, V, CONDF, BETA, CPF, RHO, HCOFX, HCOFY,
       2 GPF, GPG, GPH, EMU, XG(3), CG(3), DS, DX, DY,
       3 NP, NH, NE, NB, NDF, NCN, NEN, IT1, ND1, MTRD,
       4,NTIME, MAFK, NTP, LTIM, MTFIT, NCARDS, NSID, NPXT
       5,NPT, MWGP, NMP, NELL, NTFA, NGAUSS, NPF, NCP, NLP, NCP
       6,NCOPD, IG, NG, NEW, NET, NEWTON, ITURB, ICONV
        COMMON/GEP/
       1 TEMP(481), COPD(481,2), RSPED(481,5)
       2,P1(1500), P2(1500), VAR1(1500), VAR2(1500), SC(1500)
       3, VALV(500), SWEPT(1500), NDP(122,6), NDN(122), LPP(122)
       4,NDPP(481), MDF(481), NCOD(1500), NCON(769)
        COMMON/GUARD/
       1 SK(4P000), ESTIFM(29,29), GIEH(800), IVTEB(2700)
        COMMON/UPWIN/
       1 AP1, AP2, A1, A2, BB1, BB2, B1, B2, DIE(2,481)
       2, WP(9), WDEL(2,9), WE(2,9), DWE(2,72), DIF(72), TT(9)
       3, UU(9), VV(9), UAWE(2), VAWE(2), IUPWIN, INTB, VKIN, VKON
        DIMENSION AI1(9), AI2(9), P(9), E(2,9)
        DIMENSION PA(29,29), FF(4), BB(2,4), CF(2,72), CP(16)
        DIMENSION DB(2,72), DP(72), DDP(9)
        EQUIVALENCE
       1 (ESTIFM(1,1),PA(1,1))
C
        ANWT=0.0
        IF(NTP.GT.2)ANWT=FLOAT(NEWTON)
        JDN=NDN(NELL)
        IM=4
        IF(JDN.NE.NEN)IM=3
        DO 2 J=1,JDN
        AI1(J)=0
      2 AI2(J)=0.
        DO 4 I=1,NCN
        DO 4 J=1,NCN
      4 PA(I,J)=0
C
C*****************************************************************
C  READ IN ELEMENT DATA FROM PERIPHERAL STORAGE
C*****************************************************************
C
        READ(10)
       1 N,NG,LL,((DB(L,I),L=1,2),DP(I),I=1,NG),(DDP(L),L=1,LL),NGG
       2,((CB(L,I),L=1,2),CP(I),I=1,NGG)
        IF(IUPWIN.EQ.2) READ(8)
       1 N,NG,LL,((DWB(L,I),L=1,2),DWP(I),I=1,NG)
```

FETHEOLVPC (CONT.)

```
      DO 20 NG=1,LL
      DP=DDP(NG)
      DO 8 I=1,JDN
      NJ=(NG-1)*JDN+I
      P(I)=DP(NJ)
      WP(I)=DP(NJ)
      IF(IUPWIN.EQ.2) WP(I)=DWP(NJ)
      DO 6 L=1,2
      WB(L,I)=DB(L,NJ)
      IF(IUPWIN.EQ.2) WB(L,I)=DWB(L,NJ)
    6 B(L,I)=DB(L,NJ)
    8 CONTINUE
      DO 10 I=1,IM
      NJ=(NG-1)*IM-I
      PP(I)=CP(NJ)
      DO 9 L=1,2
    9 BE(L,I)=CB(L,NJ)
   10 CONTINUE
      G1=0.
      G2=0.
      G4=0
      G5=0.0
      G6=0.0
      G7=0.0
      G8=0.0
      DO 12 L=1,JDN
      K=IABS(NDP(N,L))
      M1=NDPP(K)
      M3=M1+MDF(K)-1
      H4=P(L)
      G1=G1+VARI(M1)*H4
      G2=G2+CORD(K,2)*H4
      G4=G4+VARI(M3)*H4
      IF(ANWT.EQ.0.)GO TO 12
      G5=G5+VARI(M1)*B(1,L)
      G6=G6+VARI(M1)*B(2,L)
      G7=G7+VARI(M3)*B(1,L)
      G8=G8+VARI(M3)*B(2,L)
   12 CONTINUE
      IF(NTR.EQ.1) G1=0.0
      IF(NTR.EQ.1) G4=0.0
      G3=0.0
      IF(NAXI.EQ.1)G3=1./G2
      IF(NAXI.EQ.1)DA=DA*G2
C
C*********************
C     RIGHT HAND SIDE
C*********************
C
      DO 14 I=1,JDN
```

FETHSOLVAC (CONT.)

```
      H1=WP(I)
      IF(ANWT.EQ.1.)GO TO 15
      AI1(I)=AI1(I)+H1*DA*X
      AI2(I)=AI2(I)+H1*DA*Y
      GO TO 14
   15 CONTINUE
      AI1(I)=AI1(I)+H1*DA*X+H1*DA*(G1*G5+G4*G6)*ANWT
      AI2(I)=AI2(I)+H1*DA*Y+H1*DA*(G1*G7+G4*G8)*ANWT
   14 CONTINUE
C
C*************************
C     FORM FLUID MATRIX
C*************************
C
      DO 18 I1=1,IM
      DO 18 I2=1,2
      J1=(I1-1)*5+3*I2-2
      J11=(I1-1)*5+2*I2+1
      K1=2*(I1-1)+I2
      H1=WP(K1)
      H2=WB(1,K1)
      H3=WB(2,K1)
      DO 18 L1=1,IM
      JJ=(L1-1)*5+2
C
C*****************************************
C    PRESSURE TERM FOR MOMENTUM EQUATION
C*****************************************
C
      AA(J1,JJ)=AA(J1,JJ)-DA*H2*PP(L1)/RHO
      AA(J11,JJ)=AA(J11,JJ)-(G3*H1+H3)*DA*PP(L1)/RHO
      DO 18 L2=1,2
      J2=(L1-1)*5+3*L2-2
      J22=(L1-1)*5+2*L2+1
      K2=2*(L1-1)+L2
      H4=P(K2)
      H5=B(1,K2)
      H6=B(2,K2)
C
C*****************************************************
C   SHEAR & ADVECTION TERM FOR MOMENTUM EQUATION
C*****************************************************
C
      H7=H1*DA*(G1*H5-G4*H6)
      H8=H1*DA*H4*G3
      AA(J1,J2)=AA(J1,J2)+DA*V*(2.*H2*H5+H3*H6)+H7
     1+H1*DA*H4*G5*ANWT
      AA(J11,J22)=AA(J11,J22)+DA*V*(2.*H3*H6+H2*H5)+H7+2*V*H8*G3
     1+H1*DA*H4*G8*ANWT
      AA(J1,J22)=AA(J1,J22)+DA*V*H3*H5
```

FETHSOLVAC (CONT.)

```
     1+H1+DA*H4*G6+ANWT
      AA(J11,J2)=AA(J11,J2)+DA*V*H2*H6
     1+H1+DA*H4+G7*ANWT
C
C*************************
C   CONTINUITY EQUATION
C*************************
C
      IF(I2.EQ.2)GO TO 16
      AA(J1+1,J2)=AA(J1+1,J2)+DA*PP(I1)*H5
      AA(J1+1,J22)=AA(J1+1,J22)+DA*PP(I1)*H6+PP(I1)*DA*H4*G3
   16 CONTINUE
   18 CONTINUE
   20 CONTINUE
      DO 22 I=1,JDN
      K=IABS(NOP(N,I))
      M1=NOPP(K)
      M3=M1+MDF(K)-1
      R1(M1)=R1(M1)+RI1(I)
      R1(M3)=R1(M3)+RI2(I)
   22 CONTINUE
      RETURN
      END
C
C
C
C
C
C
C
C
      SUBROUTINE EFVISC(IELEM)
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      DIMENSION EMUT(8),EMUE(8),CONDFT(8),
     -CONDFE(8),VKINM(122),VMUDYN(122),VCOND(122)
      COMMON/CONTP/
     1 X,Y,W,CONDF,BETA,CPF,RHO,HCOFX,HCOFY,
     2 GPF,GPG,GPH,EMU,NG(3),CG(3),DS,DX,DY,
     3 NP,NH,NE,NB,NDF NCN,NEN,IT1,ND1,MTRD
     4,NTIME,MARK,NTP,LTIM,MTRIT,NCARDS,NSID,NPXI
     5,NPT,MWGP,NNP,NELL,NTPA,NGAUSS,NPR,NCR,NLP NCP
     6,NCOPD,IG,NG,NEW,NET,NEWTON,ITURB,ICOND
      COMMON/GEP/
     1 TEMP(461),CORD(461,2),RSPEC(461 6)
     2,F1(1553),R2(1553),VARI(1553),VARR(1553),BC(1553)
     3,VALV(560),AVARI(1552),NOP(122,8),NDN(122),LPR(122)
     4,NOPP(461),MDF(461),NCOD(1552),NODW(560)
      COMMON/GUARD/
     1 SK(40000),ESTIFM(28,28),GISH(600),INTEG(2700)
      COMMON/UPWIN/
     1 AA1,AA2,A1,A2,BB1,BB2,B1,B2,DIS(3,461)
```

FETHSOLVAC (CONT.)

```
      2, WP(8), WDEL(2,8), WB(2,8), DWB(2,72), DWP(72), TT(8)
      3, UU(8), VV(8), UAVE(2), VAVE(2), IUPWIN, INTS, VKIN, VKON
       COMMON/TLSKIN1/ TLS(461), EKE(461), TRMU(461), ITERNAN
       IF(MARK.EQ.3)GO TO 1
       DO 11 I=1,NH
       IDF=MDF(I)
       J=NOPP(I)
       IF(IDF.EQ.2) JJ=J+1
       IF(IDF.EQ.3) JJ=J+2
       DIS(1,I)=VARI(J)      U
       DIS(2,I)=VARI(JJ)     V   } uncoupled soln.
       DIS(3,I)=TEMP(I)      T
   11  CONTINUE
       GO TO 3
 1     CONTINUE
       DO 2 I=1,NH
       IDF=MDF(I)
       J=NOPP(I)
       IF(IDF.EQ.3)JJ=J+1
       IF(IDF.EQ.4)JJ=J+2
       DIS(1,I)=VARI(J)      U
       DIS(2,I)=VARI(JJ)     V   } coupled soln.
       DIS(3,I)=VARI(JJ+1)   T
 2     CONTINUE
 3     CONTINUE
       DO 10 I=1,NBN
       K=IABS(NOP(IELEM,I))
       UU(I)=DIS(1,K)  U
       VV(I)=DIS(2,K)  V   } Nodal values at element level.
       TT(I)=DIS(3,K)  T
   10  CONTINUE
C
C*****************************************************************
C***   SHOULD TURBULENCE OCCUR THEN EVALUATE
C***   EFFECTIVE VISCOSITY at each node ,
C***   ON THE BASIS OF THE FACTORS OF
C***   TURBULENCE INTENSITY, TURBULENCEE KINETIC ENERGY,
C***   AND THE LENGTH SCALE OF TURBULENCE , i.e.
C***   (Prandtl-Kolmogorov )  one equation
C***   model of Turbulence.
C***   THE ANALOGY BETWEEN THERMAL AND MOMENTUM DIFFUSIVITY
C***   IS BEING CALLED UPON , VIA THE Prandtl-Number ,
C***   WHERE EFFECTIVE CONDUCTIVITY IS DEDUCED USING THE
C***   CALCULATED EFFECTIVE VISCOSITY
C-****************************************************************
C
       IF(MARK.GE.4.AND.ITERNAN.EQ.1) GO TO 64
       IF(ICOND.NE.0) GO TO 12
       IF(NTR.EQ.1) GO TO 630
   12  CONTINUE
```

FETHSOLVAC (CONT.)

```
      VKINM(IELEM)=0.0      ν
      VMUDYN(IELEM)=0.0     μ
      VCOND(IELEM)=0.0      K
      DO 300 KVV=1,8
C
C*****************************************************
C-----LENGTH SCALE OF TURBULENCE FOR THE REGION OF
C-----THE INLET TO THE CONVECTIVE CHANNEL.
C*****************************************************
C
      IF(IELEM.LE.3.OR.(IELEM.GE.13.AND.IELEM.LE.15))THEN
      ZLY=CORD(IABS(NOP(IELEM,KVV)),2)
      ZLY2=0.05100-ZLY
      CMU=0.4400
      ZPT1=0.500
      ZPT2=ZPT1
      ZLLXT=2.0*CMU*ZLY*ZLY2*ZPT1*ZPT2
      ZLXB1=ZLY*ZPT1*SQRT(ZLY2**2.0+ZPT2**2.0)
      ZLXB2=ZLY*ZPT2*SQRT(ZLY2**2.0+ZPT1**2.0)
      ZLXB3=ZLY2*ZPT1*SQRT(ZLY**2.0+ZPT2**2.0)
      ZLXB4=ZLY2*ZPT2*SQRT(ZLY**2.0+ZPT1**2.0)
      ZLLXB=ZLXB1+ZLXB2+ZLXB3+ZLXB4
      ZLLX=ABS(ZLLXT/ZLLXB)
      TINS=20.000
      UV=(SQRT((UU(KVV)**2.000)+(VV(KVV)**2.000)))/DIS(1,4)
      SQK=SQRT(1.500)*TINS*UV
      ZLLY=ZLLX*ABS(SQK)
      ELSE IF((IELEM.GE.4.AND.IELEM.LE.10).OR.
     -(IELEM.GE.16.AND.IELEM.LE.22)) THEN
C
C*****************************************************
C-----LENGTH SCALE OF TURBULENCE FOR THE CONVECTIVE
C-----CHANNEL ITSELF.
C*****************************************************
C
      ZLX1=CORD(IABS(NOP(IELEM,KVV)),1)
      ZLX2=0.0900-ZLX1
      CMU=0.4400
      ZPT1=0.500
      ZPT2=ZPT1
      ZLLXT=2.0*CMU*ZLX1*ZLX2*ZPT1*ZPT2
      ZLXB1=ZLX1*ZPT1*SQRT(ZLX2**2.0+ZPT2**2.0)
      ZLXB2=ZLX1*ZPT2*SQRT(ZLX2**2.0+ZPT1**2.0)
      ZLXB3=ZLX2*ZPT1*SQRT(ZLX1**2.0+ZPT2**2.0)
      ZLXB4=ZLX2*ZPT2*SQRT(ZLX1**2.0+ZPT1**2.0)
      ZLLXB=ZLXB1+ZLXB2+ZLXB3+ZLXB4
      ZLLX=ABS(ZLLXT/ZLLXB)
      TINS=17.000
      UV=(SQRT((UU(KVV)**2.000)+(VV(KVV)**2.000)))/DIS(1,4)
      SQK=SQRT(1.500)*TINS*UV
```

Length scale of Turbulence $l_u$ = ZLLX.

Turbulence Intensity

$\sqrt{\text{Kinetic Energy}}$

FETHSOLVAC (CONT.)

```
      ZLLY=ZLLX*ABS(SQK)
      ELSE IF((IELEM.EQ.11.OR.IELEM.EQ.12).OR.
     -(IELEM.EQ.23.OR.IELEM.EQ.24).OR.
     -(IELEM.EQ.25.OR.IELEM.EQ.26).OR.
     -(IELEM.GE.35.AND.IELEM.LE.37).OR.
     -(IELEM.GE.46.AND.IELEM.LE.48)) THEN
C
C*****************************************************
C-----LENGTH SCALE OF TURBULENCE FOR THE COMMON
C-----CHIMNEY OUTLET.
C*****************************************************
C
      ZLX1=CORD(IABS(NOP(IELEM,KVV)),1)
      ZLX2=0.19800-ZLX1
      CMU=0.4400
      ZPT1=0.500
      ZPT2=ZPT1
      ZLLXT=2.0*CMU*ZLX1*ZLX2*ZPT1*ZPT2
      ZLXB1=ZLX1*ZPT1*SQRT(ZLX2**2.0+ZPT2**2.0)
      ZLXB2=ZLX1*ZPT2*SQRT(ZLX2**2.0+ZPT1**2.0)
      ZLXB3=ZLX2*ZPT1*SQRT(ZLX1**2.0+ZPT2**2.0)
      ZLXB4=ZLX2*ZPT2*SQRT(ZLX1**2.0+ZPT1**2.0)
      ZLLXB=ZLXB1+ZLXB2+ZLXB3+ZLXB4
      ZLLX=ABS(ZLLXT/ZLLXB)
      UV=(SQRT((UU(KVV)**2.000)+(VV(KVV)**2.000)))/DIS(1,4)
      TINS=19.000
      SQK=SQRT(1.500)*TINS*UV
      ZLLY=ZLLX*ABS(SQK)
      ELSE IF((IELEM.GE.27.AND.IELEM.LE.34).OR.
     -(IELEM.GE.38.AND.IELEM.LE.45).OR.
     -(IELEM.GE.49.AND.IELEM.LE.96)) THEN
C
C*****************************************************
C-----LENGTH SCALE OF TURBULENCE FOR THE ROOM.
C*****************************************************
C     **— TOTAL HORIZONTAL FLOW — **
C
      TINS=7.000
      ZLY=CORD(IABS(NOP(IELEM,KVV)),2)
      UV=(SQRT((UU(KVV)**2.000)+(VV(KVV)**2.000)))/DIS(1,4)
      ZLY2=1.023-ZLY
      CMU=0.4400
      ZPT1=0.500
      ZPT2=ZPT1
      ZLLXT=2.0*CMU*ZLY*ZLY2*ZPT1*ZPT2
      ZLXB1=ZLY*ZPT1*SQRT(ZLY2**2.0+ZPT2**2.0)
      ZLXB2=ZLY*ZPT2*SQRT(ZLY2**2.0+ZPT1**2.0)
      ZLXB3=ZLY2*ZPT1*SQRT(ZLY**2.0+ZPT2**2.0)
      ZLXB4=ZLY2*ZPT2*SQRT(ZLY**2.0+ZPT1**2.0)
      ZLLXB=ZLXB1+ZLXB2+ZLXB3+ZLXB4
      ZLLX1=ABS(ZLLXT/ZLLXB)
```

FETHSOLVAC (CONT.)

```
C
      ZLX1=CORD(IABS(NOP(IELEM,KWW)),1) *-TOTAL VERTICAL FLOW-*
      ZLX2=1.14800-ZLX1
      ZLLXT=2.0*CMU*ZLX1*ZLX2*ZPT1*ZPT2
      ZLXB1=ZLX1*ZPT1*SQRT(ZLX2**2.0+ZPT2**2.0)
      ZLXB2=ZLX1*ZPT2*SQRT(ZLX2**2.0+ZPT1**2.0)
      ZLXB3=ZLX2*ZPT1*SQRT(ZLX1**2.0+ZPT2**2.0)
      ZLXB4=ZLX2*ZPT2*SQRT(ZLX1**2.0+ZPT1**2.0)
      ZLLXB=ZLXB1+ZLXB2+ZLXB3+ZLXB4
      ZLLX3=ABS(ZLLXT/ZLLXB)
      ZLLX12=(ZLLX1+ZLLX2)*0.500
C
C*********************************
C-----ROOM INLET WALL JET FLOW
C*********************************
C
      ZLY2=ZLY-0.06900
      ZLLXT=2.0*CMU*ZLY*ZLY2*ZPT1*ZPT2
      ZLXB1=ZLY*ZPT1*SQRT(ZLY2**2.0+ZPT2**2.0)
      ZLXB2=ZLY*ZPT2*SQRT(ZLY2**2.0+ZPT1**2.0)
      ZLXB3=ZLY2*ZPT1*SQRT(ZLY**2.0+ZPT2**2.0)
      ZLXB4=ZLY2*ZPT2*SQRT(ZLY**2.0+ZPT1**2.0)
      ZLLXB=ZLXB1+ZLXB2+ZLXB3+ZLXB4
      ZLLX3=ABS(ZLLXT/ZLLXB)
C
C*********************************
C-----ROOM EXIT WALL JET FLOW
C*********************************
C
      ZLY2=ZLY1-0.15050
      ZLLXT=2.0*CMU*ZLY1*ZLY2*ZPT1*ZPT2
      ZLXB1=ZLY1*ZPT1*SQRT(ZLY2**2.0+ZPT2**2.0)
      ZLXB2=ZLY1*ZPT2*SQRT(ZLY2**2.0+ZPT1**2.0)
      ZLXB3=ZLY2*ZPT1*SQRT(ZLY1**2.0+ZPT2**2.0)
      ZLXB4=ZLY2*ZPT2*SQRT(ZLY1**2.0+ZPT1**2.0)
      ZLLXB=ZLXB1+ZLXB2+ZLXB3+ZLXB4
      ZLLX4=ABS(ZLLXT/ZLLXB)
      ZLLX34=ZLLX3+ZLLX4
C
C*****************************************
C-----THE FLOW UP THE BACK WALL (IN THE ROOM)
C*****************************************
C
      ZLX2=1.07200-ZLX1
      ZLLXT=2.0*CMU*ZLX1*ZLX2*ZPT1*ZPT2
      ZLXB1=ZLX1*ZPT1*SQRT(ZLX2**2.0+ZPT2**2.0)
      ZLXB2=ZLX1*ZPT2*SQRT(ZLX2**2.0+ZPT1**2.0)
      ZLXB3=ZLX2*ZPT1*SQRT(ZLX1**2.0+ZPT2**2.0)
      ZLXB4=ZLX2*ZPT2*SQRT(ZLX1**2.0+ZPT1**2.0)
      ZLLXB=ZLXB1+ZLXB2+ZLXB3+ZLXB4
      ZLLX5=ABS(ZLLXT/ZLLXB)
      ZLLX=ZLLX12+ZLLX34+ZLLX5
      SQK=SQRT(1.500)*TINS*UY
      ZLLY=ZLLX*ABS(SQK)
      ELSE IF(IELEM.GE.97.AND.IELEM.LE.100) THEN
```

FETHSOLVRC (CONT.)

```
      TINS=12.0D0
      ZLY=COORD(IABS(NOP(IELEM,KVV)),2)
      UV=(SQRT((UU(KVV)**2.0D0)+(VV(KVV)**2.0D0)))/DIS(1,4)
      ZLY2=0.0E9D0-ZLY
      CMU=0.44D0
      ZPT1=0.5D0
      ZPT2=ZPT1
      ZLLXT=2.0*CMU*ZLY*ZLY2*ZPT1*ZPT2
      ZLXB1=ZLY*ZPT1*SQRT(ZLY2**2.0+ZPT2**2.0)
      ZLXB2=ZLY*ZPT2*SQRT(ZLY2**2.0+ZPT1**2.0)
      ZLXB3=ZLY2*ZPT1*SQRT(ZLY**2.0+ZPT2**2.0)
      ZLXB4=ZLY2*ZPT2*SQRT(ZLY**2.0+ZPT1**2.0)
      ZLLXB=ZLXB1+ZLXB2+ZLXB3+ZLXB4
      ZLLY=ABS(ZLLXT/ZLLXB)
      SQK=SQRT(1.5D0)*TINS*UV
      ZLLY=ZLLY*ABS(SQK)
      ELSE
C
C*****************************************************
C-----LENGTH SCALE OF TURBULENCE FOR THE INLET
C-----CHANNEL IF NECESSARY.
C*****************************************************
C
C
C
C     ****************************************************
C     IF THE INLET CHANEL FLOW IS TURBULENT SUPPRESS
C     THE FOLLOWING STATEMENT I.E. (GO TO 52) WITH
C     A "C" IN COLUMN ONE.
C     ****************************************************
C
C
C     GO TO 52
      ZLX1=COORD(IABS(NOP(IELEM,KVV)),1)
      ZLX2=1.4409D0-ZLX1
      CMU=0.44D0
      ZPT1=0.5D0
      ZPT2=ZPT1
      ZLLXT=2.0*CMU*ZLX1*ZLX2*ZPT1*ZPT2
      ZLXB1=ZLX1*ZPT1*SQRT(ZLX2**2.0+ZPT2**2.0)
      ZLXB2=ZLX1*ZPT2*SQRT(ZLX2**2.0+ZPT1**2.0)
      ZLXB3=ZLX2*ZPT1*SQRT(ZLX1**2.0+ZPT2**2.0)
      ZLXB4=ZLX2*ZPT2*SQRT(ZLX1**2.0+ZPT1**2.0)
      ZLLXB=ZLXB1+ZLXB2+ZLXB3+ZLXB4
      ZLLY=ABS(ZLLXT/ZLLXB)
      TINS=5.0D0
      UV=(SQRT((UU(KVV)**2.0D0)+(VV(KVV)**2.0D0)))/DIS(1,4)
      SQK=SQRT(1.5D0)*TINS*UV
      ZLLY=ZLLY*ABS(SQK)
      END IF
      EMUT(KVV)=0.0 μt
      EMUE(KVV)=0.0 μe
      CONDFT(KVV)=0.0 Kt
      CONDFE(KVV)=0.0 Ke
      EMUT(KVV)=RHO*ABS(ZLLY)
      EMUE(KVV)=VKIN*RHO+EMUT(KVV)
      CONDFT(KVV)=(0.7E9D0*EMUT(KVV))*VKON)/VKIN*RHO
      CONDFE(KVV)=VKON*CONDFT(KVV)
      CALL TLSKIN(KVV,IELEM,NH,NE,ZLLY,SQK,EMUT,NOP,NPN,CONDFT)
```

** – { LENGTH SCALE OF TURBULENCE FOR THE ROOM INLET DUCT. } –

FETHSOLVAC (CONT.)

```
  300 CONTINUE
      EMU=0.0
      V=0.0
      CONDF=0.0
      DO 400 LVV=1,9
      EMU=EMU+(EMUE(LVV)/9.000)      ue
      CONDF=CONDF+(CONDFE(LVV)/9.000) ke } Per Element
  400 CONTINUE
      IUPWIN=0
      V=EMU/RHO
      GO TO 630
   62 CONTINUE
      EMU=VKIN*RHO
      IUPWIN=INTS
      V=VKIN
      CONDF=VKON
  630 CONTINUE
      VKINM(IELEM)=V
      VMUDYN(IELEM)=EMU
      VCOND(IELEM)=CONDF
      GO TO 650
   64 CONTINUE
      V=VKINM(IELEM)
      EMU=VMUDYN(IELEM)
      CONDF=VCOND(IELEM)
  650 CONTINUE
   65 CONTINUE
      WRITE(8,9999)NELL,EMU,V,  CONDF
 9999 FORMAT(1H ,'ELEMENT NO.',I5,'EMU,V,CONDF,  ARE:',I5,3F20.10)
      RETURN
      END
      SUBROUTINE TLSKIN(KVV,IELEM,NH,NE,ZLLX,SOK,EMUT,NDP,NBN,CONDFT)
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      DIMENSION NDP(NE,NBN),EMUT(NBN),CONDFT(NBN)
      COMMON/TLSKIN1/ TLS(461),EKE(461),TRMU(461),ITERMAN
      COMMON/TLSKIN2/ TRCOND(461)
      KN=IABS(NDP(IELEM,KVV))
      TLS(KN)=ZLLX
      EKE(KN)=SOK
      TRMU(KN)=EMUT(KVV)
      TRCOND(KN)=CONDFT(KVV)
      RETURN
      END
C
C
C
C
C
C
      SUBROUTINE EVPROP(IELEM)
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      DIMENSION DVISC(9),EFKON(9),STEMP(9)
      COMMON/CONTR/
```

FETHSOLVAC (CONT.)

```
     1 X, Y, V, CONDF, BETA, CPF, RHO, HCOFX, HCOFY,
     2 GPF, GPG, GPH, EMU, XG(3), CG(3), DS, DX, DY,
     3 NP, NH, NE, NB, NDF, NCN, NEN, IT1, ND1, MTRD
     4, NTIME, MARK, NTR, LTIM, MTRIT, NCARDS, NSID, NAXI
     5, NRT, MWGA, NNP, NELL, NTRA, NGAUSS, NPR, NCR, NLP, NCP
     6, NCORD, IG, NG, NEV, NET, NEWTON, ITURB, ICOND
      COMMON/GEP/
     1 TEMP(461), CORD(461, 2), RSPEC(461, 6)
     2, R1(1553), R2(1553), VARI(1553), VARA(1553), BC(1553)
     3, VALV(560), AVARI(1553), NOP(122, 8), NDN(122), LPR(122)
     4, NOPP(461), MDF(461), NCOD(1553), NODV(560)
      COMMON/GUARD/
     1 SK(40000), ESTIFM(28, 28), GISH(500), INTEG(2700)
      COMMON/UPWIN/
     1 AA1, AA2, A1, A2, BB1, BB2, B1, B2, DIS(3, 461)
     2, WP(8), WDEL(2, 8), WB(2, 8), DWB(2, 72), DWP(72), TT(8)
     3, UU(8), VV(8), UAVE(2), VAVE(2), IUPWIN, IWTS, VKIN, VKON
C
C*****************************************************************
C***  EVALUATE THE VISCOSITY AND CONDUCTIVITY ON THE BASIS
C***  OF VARIABLE PROPERTY CONSTANTS DEPENDENT ON
C***  THE TEMPERATURE (K).
C*****************************************************************
C
      IF(NTR. GT. 1) RETURN
      DO 115 NN=1, NEN
      STEMP(NN)=0. 0
      L=IABS(NOP(IELEM, NN))
      IDF=MDF(L)
      J=NOPP(L)-1
      IF(IDF. LT. NDF) GO TO 105
      IF(NDF. EQ. 2) GO TO 115
      STEMP(NN)=VARI(J+IDF)
      GO TO 115
  105 IF(IDF. EQ. 1) GO TO 110
      GO TO 115
  110 STEMP(NN)=VARI(J+1)
  115 CONTINUE
      TAV=0. 0
      DO 100 IVV=1, 8
      TEMPK=0. 0
      DVISC(IVV)=0. 0
      EFKON(IVV)=0. 0
      TEMPK=STEMP(IVV)+273. 0
      VNUM1=((TEMPK)**1. 5)*1. 4580-06
      VDEN=110. 4+TEMPK
      DVISC(IVV)=VNUM1/VDEN
      SNUMK=2. 64820-03*SQRT(TEMPK)
      SDENK1=-12. 0/TEMPK
      SDENK2=10. 0**SDENK1
```

FETHSOLVAC (CONT.)

```
      SDENK3=245.4*SDENK2
      SDENK4=1.0+(SDENK3)/TEMPK
      EFKON(IVV)=(SNUMK/SDENK4)
      TAV=TAV+(TEMPK/8.)
  100 CONTINUE
      EMU=0.0
      V=0.0
      CONDF=0.0
      DO 200 JVV=1,8
      EMU=EMU+(DVISC(JVV))/8.0
      CONDF=CONDF+(EFKON(JVV))/8.0
  200 CONTINUE
      V=EMU/RHO
      T0=18.0
      BETA=1.0/TAV
      CPF=((0.2383)-(0.7910-05*TAV)+(0.48140-07*TAV*TAV))*1000.0
      RHO=RHO*(1.0-(BETA*(TAV-T0)))
      RETURN
      END
C
C
C
C
C
C
C
C*************************
      SUBROUTINE ABFORMS
C*************************
C
C*****************************************************************
C     TEMPERATURE DEPENDENT FORM
C     COUPLED FORM OF NAVIER-STOKES EQUATION AND
C     ENERGY EQUATION IN ONE MATRIX.
C     CARTESIAN COORDINATE NAXI=0
C     CYLINDRICAL-COORDINATE AXISYMMETRIC NAXI=1
C     USING ITERATION METHOD ONLY NEWTON=0
C     USING NEWTON-RAPHSON METHOD NEWTON=1
C     IUPWIN=1,TO USE UPWINDING TECHNIQUE.
C     IUPWIN=0,TO USE GALERKIN METHOD,WITHOUT UPWINDING.
C*****************************************************************
C
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      COMMON/CONTR/
     1 X,Y,W,CONDF,BETA,CPF,RHO,HCOFX,HCOFY,
     2 GPF,GPG,GPH,EMU,XG(3),CG(3),DS,DX,DY,
     3 NP,NH,NE,NB,NDF,NCN,NBN,IT1,ND1,MTRD
     4,NTIME,MAPK,NTR,LTIM,MTRIT,NCARDS,NSID,NAXI
     5,NRT,MWGA,NNP,NELL,NTPA,NGAUSS,NPR,NCR,NLP,NCP
     6,NCORD,IG,NG,NBV,NBT,NEWTON,ITURB,ICOND
```

FETHSOLVAC (CONT.)

```
      COMMON/GEP/
     1 TEMP(461),CORD(461,2),RSPEC(461,6)
     2,R1(1553),R2(1553),VARI(1553),VARA(1553),BC(1553)
     3,VALV(560),AVARI(1553),NOP(122,9),NDN(122),LPR(122)
     4,NOPP(461),MDF(461),NCOD(1553),NODV(560)
      COMMON/GUARD/
     1 SK(40000),ESTIFM(29,28),GISH(600),INTEG(2700)
      COMMON/UPWIN/
     1 AA1,AA2,A1,A2,BB1,BB2,B1,B2,DIS(3,461)
     2,WP(9),WDEL(2,9),WB(2,9),DWB(2,72),DWP(72),TT(9)
     3,UU(9),VV(9),UAVE(2),VAVE(2),IUPWIN,IWTS,VKIN,VKON
      DIMENSION AI1(9),AI2(9),P(9),B(2,9),AI3(9)
      DIMENSION AA(29,28),PP(4),BB(2,4),CB(2,36),CP(36)
      DIMENSION DB(2,72),DP(72),DDA(9)
      EQUIVALENCE
     1 (ESTIFM(1,1),AA(1,1))
C
      ANWT=0.0
      IF(NTR.GT.2)ANWT=FLOAT(NEWTON)
      JDN=NDN(NELL)
      IM=4
      IF(JDN.NE.NEN)IM=3
      DO 2 J=1,JDN
      AI1(J)=0.
      AI3(J)=0.
    2 AI2(J)=0.
      DO 4 I=1,NCN
      DO 4 J=1,NCN
    4 AA(I,J)=0.
C
C*****************************************************
C    READ IN ELEMENT DATA FROM PERIPHERAL STORAGE
C*****************************************************
C
      READ(10)
     1 N,NG,LL,((DB(L,I),L=1,2),DP(I),I=1,NG),(DDA(L),L=1,LL),NGG
     2,((CB(L,I),L=1,2),CP(I),I=1,NGG)
      IF(IUPWIN.EQ.0)GO TO 7
      READ(9)
     1 N,NG,LL,((DWB(L,I),L=1,2),DWP(I),I=1,NG)
    7 CONTINUE
      DO 20 NG=1,LL
      DA=DDA(NG)
      DO 9 I=1,JDN
      NJ=(NG-1)*JDN+I
      P(I)=DP(NJ)
      WP(I)=P(I)
      IF(IUPWIN.GT.0)WP(I)=DWP(NJ)
      DO 6 L=1,2
      B(L,I)=DB(L,NJ)
```

FETHSOLVAC (CONT.)

```
      WB(L,I)=B(L,I)
      IF(IUPWIN.GT.0)WB(L,I)=DWB(L,NJ)
    6 CONTINUE
    8 CONTINUE
      DO 10 I=1,IM
      NJ=(NG-1)*IM+I
      PP(I)=CP(NJ)
      DO 9 L=1,2
    9 BB(L,I)=CB(L,NJ)
   10 CONTINUE
      G1=0.
      G2=0.
      G4=0.
      G5=0.
      G6=0.
      G7=0.
      G8=0.
      G9=0.
      G10=0.
      DO 12 L=1,JON
      K=IABS(NOF(N,L))
      M1=NOPP(K)
      M2=M1-MOF(K)-2
      H4=P(L)
      G1=G1-VARI(M1)*H4
      G2=G2-COPP(K,2)*H4
      G4=G4+VARI(M2)*H4
      IF(PNWT.EQ.0)GO TO 12
      M4=M1-1
      G5=G5-VARI(M1)*P(1,L)
      G6=G6-VARI(M1)*P(2,L)
      G7=G7-VARI(M2)*P(1,L)
      G8=G8-VARI(M2)*P(2,L)
      G9=G9-VARI(M4)*P(1,L)
      G10=G10-VARI(M4)*P(2,L)
   12 CONTINUE
      IF(NTR.EQ.1) G1=0.0
      IF(NTR.EQ.1) G4=0.0
      G3=0
      IF(NAXI.EQ.1)G3=1./RE
      IF(NAXI.EQ.1)G4=G4+G3
C
C*********************
C     RIGHT HAND SIDE
C*********************
C
      IF(PNWT.EQ.0)GO TO 3
      DO 14 I=1,JON
      H1=P(I)
      WH1=WP(I)
```

$$\underbrace{\left[\begin{array}{ccc|c} a_{11} & a_{12} & a_{13} & a_{14} \\ a_{21} & a_{22} & a_{23} & a_{24} \\ a_{31} & a_{32} & a_{33} & a_{34} \\ \hline a_{41} & a_{42} & a_{43} & a_{44} \end{array}\right]}_{=\begin{bmatrix} J_1,J_2 & J_1,JJ & J_1,J_{22} & J_1,J_{22+1} \\ J_{1+1},J_2 & J_{1+1},JJ & J_{1+1},J_{22} & J_{1+1},J_{22+1} \\ J_{11},J_2 & J_{11},JJ & J_{11},J_{22} & J_{11},J_{22+1} \\ J_{11+1},J_2 & J_{11+1},JJ & J_{11+1},J_{22} & J_{11+1},J_{22+1} \end{bmatrix}} \begin{Bmatrix} u \\ p \\ v \\ T \end{Bmatrix} = \begin{Bmatrix} q_1 \\ 0 \\ q_2 \\ q_3 \end{Bmatrix}$$

FETHSOLVAC (CONT.)

```
      AI1(I)=AI1(I)+H1*DA*(G1*G5+G4*G6)*ANWT
      AI2(I)=AI2(I)+H1*DA*(G1*G7+G4*G8)*ANWT
      AI3(I)=AI3(I)+WH1*DA*(G1*G9+G4*G10)*ANWT
   14 CONTINUE
  5   CONTINUE
C
C*************************
C     FORM FLUID MATRIX
C*************************
C
      DO 19 I1=1,IM
      DO 18 I2=1,2
      J1=(I1-1)*7+4*I2-3
      J11=(I1-1)*7+3*I2
      K1=2*(I1-1)+I2
      H1=P(K1)
      WH1=WP(K1)
      H2=B(1,K1)
      WH2=WB(1,K1)
      H3=B(2,K1)
      WH3=WB(2,K1)
      DO 18 L1=1,IM
      JJ=(L1-1)*7+2
C
C*************************************
C   PRESSURE TERM FOR MOMENTUM EQUATION
C*************************************
C
      AA(J1,JJ)=AA(J1,JJ)+H1*DA*BB(1,L1)/RHO
      AA(J11,JJ)=AA(J11,JJ)+H1*DA*BB(2,L1)/RHO
      DO 18 L2=1,2
      J2=(L1-1)*7+4*L2-3
      J22=(L1-1)*7+3*L2
      K2=2*(L1-1)+L2
      H4=P(K2)
      H5=B(1,K2)
      H6=B(2,K2)
C
C*****************************************
C  SHEAR & ADVECTION TERM & ENERGY EQUATION
C*****************************************
C
      H7=DA*(H2*H5+H3*H6)
      H8=H1*DA*(G1*H5+G4*H6)
      H10=H1*DA*H4*G3
      AA(J1,J2)=AA(J1,J2)+H7*V+H8+H1*DA*H4*G5*ANWT
      AA(J1,J22+1)=AA(J1,J22+1)+H1*DA*X*BETA*H4      a14
      AA(J11,J22)=AA(J11,J22)+H7*V+H8+H10*G3*V+H1*DA*H4*G8*ANWT
      AA(J11,J22-1)=AA(J11,J22-1)+H1*DA*Y*BETA*H4    a34                a44
      AA(J11+1,J22+1)=AA(J11+1,J22+1)+(WH2*H5+WH3*H6)*DA*CONDF/(RHO*CPF)
```

FETHSOLVAC (CONT.)

```
      1+WH1*DA*(G1*H5+G4*H6)
       IF(ANWT.EQ.0)GO TO 15
       AA(J1,J22)=AA(J1,J22)+H1*DA*H4*G6*ANWT
       AA(J11,J2)=AA(J11,J2)+H1*DA*H4*G7*ANWT
       AA(J11+1,J2)=AA(J11+1,J2)+WH1*DA*H4*G9*ANWT a41
       AA(J11+1,J22)=AA(J11+1,J22)+WH1*DA*H4*G10*ANWT a43
   15  CONTINUE
C
C*********************
C    CONTINUITY EQUATION
C*********************
C
       IF(I2.EQ.2)GO TO 16
       AA(J1+1,J2)=AA(J1-1,J2)+PP(I1)*DA*H5
       AA(J1+1,J22)=AA(J1-1,J22)+PP(I1)*DA*H6+PP(I1)*DA*H4*G3
   16  CONTINUE
   18  CONTINUE
   20  CONTINUE
       DO 22 I=1,JDN
       K=IABS(NOP(N,I))
       M1=NOPP(K)
       M3=M1+MOF(K)-2
       M4=M3+1
       R1(M1)=R1(M1)+RI1(I)
       R1(M3)=R1(M3)+RI2(I)
       R1(M4)=R1(M4)+RI3(I)
   22  CONTINUE
       RETURN
       END
C
C
C
C
C
C
C
C
C
C*********************
       SUBROUTINE TEMPM
C*********************
C
C*****************************************************************
C      MATRIX EQUATION FOR TEMPERATURE EQ. FOR KNOWN VELOCITY.
C      AXISYMMETRIC AND CARTESIAN SYSTEMS
C      IUPWIN=0,WITH UPWINDING.
C      IUPWIN=1,WITHOUT UPWINDING.
C      SPECIFIED TEMPERATURE GRADIENTS ON BOUNDARY IS NOT INCLUDED
C      EXCEPT ZEROS TEMPERATURE  GRADIENTS.
C*****************************************************************
C
       IMPLICIT DOUBLE PRECISION (A-H,O-Z)
```

FETHSOLVAC (CONT.)

```
      COMMON/CONTR/
     1 X, Y, V, CONDF, BETA, CPF, RHO, HCOFX, HCOFY,
     2 GPF, GPG, GPH, EMU, XG(3), CG(3), DS, DX, DY,
     3 NP, NH, NE, NB, NDF, NCN, NBN, IT1, ND1, MTRD
     4, NTIME, MARK, NTR, LTIM, MTRIT, NCARDS, NSID, NAXI
     5, NRT, MWGA, NNP, NELL, NTRA, NGAUSS, NPR, NCR, NLP, NCP
     6, NCORD, IG, NG, NEV, NET, NEWTON, ITURB, ICOND
      COMMON/GEP/
     1 TEMP(461), CORD(461, 2), RSPEC(461, 6)
     2, P1(1553), P2(1553), VARI(1553), VARA(1553), BC(1553)
     3, VALV(560), AVARI(1553), NDP(122, 8), NDN(122), LPR(122)
     4, NOPP(461), MDF(461), NCOD(1553), NODV(560)
      COMMON/GUARD/
     1 SK(40000), ESTIFM(28, 29), GISH(600), INTEG(2700)
      COMMON/UPWIN/
     1 AP1, AP2, A1, A2, BB1, BB2, B1, B2, DIS(2, 461)
     2, WP(8), WDEL(2, 8), WB(2, 8), DWB(2, 72), DWP(72), TT(8)
     3, UU(8), VV(8), UAVE(2), VAVE(2), IUPWIN, IWTS, VKIN, VKON
      DIMENSION P(8), B(2, 8)
      DIMENSION AA(28, 29), PP(4), BB(2, 4), CB(2, 36), CP(36)
      DIMENSION DB(2, 72), DP(72), DDA(3)
      EQUIVALENCE
     1 (ESTIFM(1, 1), AA(1, 1))
      JDN=NDN(NELL)
      IM=4
      IF(JDN. NE. NBN)IM=3
      DO 4 I=1, NBN
      DO 4 J=1, NBN
    4 AA(I, J)=0. 0
C
C*****************************************************
C    READ IN ELEMENT DATA FROM PERIPHERAL STORAGE
C*****************************************************
C
      READ(10)
     1 N, NG, LL, ((DB(L, I), L=1, 2), DP(I), I=1, NG), (DDA(L), L=1, LL), NGG
     2, ((CB(L, I), L=1, 2), CP(I), I=1, NGG)
      IF( IUPWIN. EQ. 1) READ(8)
     1 N, NG, LL, ((DWB(L, I), L=1, 2), DWP(I), I=1, NG)
      DO 20 NG=1, LL
      DA=DDA(NG)
      DO 8 I=1, JDN
      NJ=(NG-1)*JDN+I
      P(I)=DP(NJ)
      WP(I)=P(I)
      IF(IUPWIN. EQ. 1)WP(I)=DWP(NJ)
      DO 6 L=1, 2
      B(L, I)=DB(L, NJ)
      WB(L, I)=B(L, I)
      IF(IUPWIN. EQ. 1)WB(L, I)=DWB(L, NJ)
```

FETHEOLVAC (CONT.)

```
    6  CONTINUE
 8     CONTINUE
       G1=0.
       G2=0.
       G4=0.
       G5=0.
       G6=0.
       G7=0.
       G8=0.
       DO 12 L=1,JDN
       K=IABS(NOF(N,L))
       M1=NOFP(K)
       M3=M1+MDF(K)-1
       H4=P(L)
       G1=G1+VARI(M1)*H4
       G2=G2+CORD(K,2)*H4
       G4=G4+VARI(M3)*H4
       G5=G5+VARI(M1)*B(1,L)
       G6=G6+VARI(M1)*B(2,L)
       G7=G7+VARI(M3)*B(1,L)
       G8=G8+VARI(M3)*B(2,L)
 12    CONTINUE
       IF(NAXI.EQ.1)DA=DA+G2
C
C*****************************************
C    ASSEMBLE ENERGY EQUATION AT ELEMENT LEVEL
C*****************************************
C
       DO 16 I=1,JDN
       H4=WP(I)
       DO 16 L=1,JDN
       AP(I,L)=AP(I,L)+(WB(1,I)*B(1,L)+WB(2,I)*B(2,L))*CONDF/(RHO*CPF)*DA
      1+DA*H4*(G1*B(1,L)+G4*B(2,L))
 16    CONTINUE
 20    CONTINUE
 40    CONTINUE
       RETURN
       END
C
C
C
C
C
C
C
C*******************
       SUBROUTINE SFR
C*******************
C
C*****************************************************************
```

FETHSOLVAC (CONT.)

```
C       SHAPE FUNCTION ROUTINE
C       G AND H DENOTE XSI AND ETA VALUES AT THE POINT CONSIDERED
C*****************************************************************
C
        IMPLICIT DOUBLE PRECISION (A-H,O-Z)
        COMMON/CONTP/
       1 X,Y,V,CONDF,BETA,CPF,RHO,HCOFX,HCOFY,
       2 GPF,GPG,GPH,EMU,XG(3),CG(3),DS,DX,DY,
       3 NP,NH,NE,NB,NDF,NCN,NBN,IT1,ND1,MTRD
       4,NTIME,MARK,NTR,LTIM,MTRIT,NCARDS,NSID,NAXI
       5,NRT,MWGA,NNP,NELL,NTRA,NGAUSS,NPR,NCR,NLP,NCP
       6,NCORD,IG,NG,NBV,NET,NEWTON,ITURB,ICOND
        COMMON/GEP/
       1 TEMP(461),CORD(461,2),RSPEC(461,6)
       2,P1(1553),P2(1553),VARI(1553),VAPR(1553),BC(1553)
       3,VALW(560),AVARI(1553),NOP(122,8),NON(122),LPR(122)
       4,NOPP(461),MDF(461),NCOD(1553),NODV(560)
        COMMON/GUARD/
       1 SK(40000),ESTIFM(28,28),GISH(600),INTEG(2700)
        COMMON/UPWIN/
       1 AA1,AA2,A1,A2,BB1,BB2,B1,B2,DIS(3,461)
       2,WP(8),WDEL(2,8),WB(2,8),DWB(2,72),DWP(72),TT(8)
       3,UU(8),VV(8),UAVE(2),VAVE(2),IUPWIN,IWTS,VKIN,VKON
        DIMENSION
       1 P(8),DEL(2,8),B(2,8),CJ(2,2),CJI(2,2)
       2,PP(4),BB(2,4),CB(2,36),CP(36)
       3,DB(2,72),DP(72),DDA(9)
        EQUIVALENCE
       1 (SK(1),P(1)),(SK(10),DEL(1,1))
       2,(SK(30),B(1,1)),(SK(50),CJ(1,1))
       3,(SK(55),CJI(1,1)),(SK(60),PP(1))
       4,(SK(70),DDA(1)),(SK(80),CB(1,1))
       5,(SK(160),CP(1)),(SK(200),DB(1,1))
       6,(SK(350),DP(1)),(SK(430),ELX)
       7,(SK(431),ELY)
C
        G=GPG
        H=GPH
        NIC=NBN/4
        GO TO (2,4,6),NIC
      2 CONTINUE
C
C*****************************************
C       FOUR NODED ARBITRARY QUADRILATERAL
C       ANTICLOCKWISE NUMBERING
C*****************************************
C
        GH=G*H
        P(1)      = (1.-G-H+GH)/4.
        P(2)      = (1.+G-H-GH)/4.
```

FETHSOLVAC (CONT.)

```
      P(3)      = (1. +G+H+GH)/4.
      P(4)      = (1. -G+H-GH)/4.
      DEL(1,1) = (-1. +H)/4.
      DEL(1,2) = ( 1. -H)/4.
      DEL(1,3) = ( 1. +H)/4.
      DEL(1,4) = (-1. -H)/4.
      DEL(2,1) = (-1. +G)/4.
      DEL(2,2) = (-1. -G)/4.
      DEL(2,3) = ( 1. +G)/4.
      DEL(2,4) = ( 1. -G)/4.
      GO TO 8
    4 CONTINUE
C
C*****************************
C     PARABOLIC ELEMENT
C     ANTI CLOCKWISE NUMBERING
C*****************************
C
C
      GH = G*H
      GG = G*G
      HH = H*H
      GGH = GG*H
      GHH = G*HH
      G2 = G*2.
      H2 = H*2.
      GH2 = GH*2.
       P( 1) = (-1. +GH+GG+HH-GGH-GHH)/4.
       P( 2) = ( 1. -H-GG+GGH)/2.
       P( 3) = (-1. -GH+GG+HH-GGH+GHH)/4.
       P( 4) = ( 1. +G-HH-GHH)/2.
       P( 5) = (-1. +GH+GG+HH+GGH+GHH)/4.
       P( 6) = ( 1. +H-GG-GGH)/2.
       P( 7) = (-1. -GH+GG+HH+GGH-GHH)/4.
       P( 8) = ( 1. -G-HH+GHH)/2.
      DEL(1,1)=( H+G2-GH2-HH)/4.
      DEL(1,2)= -G+GH
      DEL(1,3)=(-H+G2-GH2+HH)/4.
      DEL(1,4)=( 1. -HH)/2.
      DEL(1,5)=( H+G2+GH2+HH)/4.
      DEL(1,6)= -G-GH
      DEL(1,7)=(-H+G2+GH2-HH)/4.
      DEL(1,8)=(-1. +HH)/2.
      DEL(2,1)=( G+H2-GG-GH2)/4.
      DEL(2,2)=(-1. +GG)/2.
      DEL(2,3)=(-G+H2-GG+GH2)/4.
      DEL(2,4)= -H-GH
      DEL(2,5)=( G+H2+GG+GH2)/4.
      DEL(2,6)=( 1. -GG)/2.
      DEL(2,7)=(-G+H2+GG-GH2)/4.
```

FETHSOLWAC (CONT.)

```
      DEL(2,8)= -H+GH
C
C*****************************************
C     FOR IUPWIN NONZERO,USE UPWIND WEIGHTS
C*****************************************
C
      IF(IUPWIN.EQ.0)GO TO 8
      G1=(1.+G)/2.
      G2=(1.-G)/2.
      H1=(1.+H)/2.
      H2=(1.-H)/2.
      FJ=5.*G1*(2.*G1*G1-3.*G1+1.)/2.
      FH=5.*H1*(2.*H1*H1-3.*H1+1.)/2.
      DFG=5.*(6.*G1*G1-6.*G1+1.)/4.
      DFH=5.*(6.*H1*H1-6.*H1+1.)/4.
      WP(1)=P(1)-G2*B2*FH-H2*A1*FJ
      WP(2)=P(2)+H2*4.*AA1*FJ
      WP(3)=P(3)-G1*B1*FH-H2*A1*FJ
      WP(4)=P(4)+G1*4.*BB1*FH
      WP(5)=P(5)-G1*B1*FH-H1*A2*FJ
      WP(6)=P(6)+H1*4.*AA2*FJ
      WP(7)=P(7)-G2*B2*FH-H1*A2*FJ
      WP(8)=P(8)+G2*4.*BB2*FH
      WDEL(1,1)=DEL(1,1)+.5*B2*FH-H2*A1*DFG
      WDEL(1,2)=DEL(1,2)+H2*4.*AA1*DFG
      WDEL(1,3)=DEL(1,3)-.5*B1*FH-H2*A1*DFG
      WDEL(1,4)=DEL(1,4)+2.*BB1*FH
      WDEL(1,5)=DEL(1,5)-.5*B1*FH-H1*A2*DFG
      WDEL(1,6)=DEL(1,6)+H1*4.*AA2*DFG
      WDEL(1,7)=DEL(1,7)+.5*B2*FH-H1*A2*DFG
      WDEL(1,8)=DEL(1,8)-2.*BB2*FH
      WDEL(2,1)=DEL(2,1)-G2*B2*DFH+.5*A1*FJ
      WDEL(2,2)=DEL(2,2)-2.*AA1*FJ
      WDEL(2,3)=DEL(2,3)-G1*B1*DFH+.5*A1*FJ
      WDEL(2,4)=DEL(2,4)+G1*4.*BB1*DFH
      WDEL(2,5)=DEL(2,5)-G1*B1*DFH-.5*A2*FJ
      WDEL(2,6)=DEL(2,6)+2.*AA2*FJ
      WDEL(2,7)=DEL(2,7)-G2*B2*DFH-.5*A2*FJ
      WDEL(2,8)=DEL(2,8)+G2*4.*BB2*DFH
      GO TO 8
    6 CONTINUE
    8 CONTINUE
      RETURN
      END
C
C
C
C
C
C
```

FETHSOLVAC (CONT.)

```
C
C*************************
      SUBROUTINE WYSET(MM)
C*************************
C
C*************************************
C   OPTIMISE UPWIND WEIGHT PARAMETERS
C*************************************
C
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      COMMON/CONTR/
     1 X,Y,V,CONDF,BETR,CPF,RHO,HCOFX,HCOFY,
     2 GPF,GPG,GPH,EMU,XG(3),CG(3),DS,DX,DY,
     3 NP,NH,NE,NE,NDF,NCN,NEN,IT1,ND1,MTRD
     4,NTIME,MARK,NTR,LTIM,MTRIT,NCARDS,NSID,NAVI
     5,NRT,MWGA,NNP,NELL,NTRA,NGAUSS,NPR,NCR,NLP,NCP
     6,NCOPD,IG,NG,NBV,NET,NEWTON,ITURB,ICOND
      COMMON/GEP/
     1 TEMP(461),COPD(461,2),RSPEC(461,6)
     2,R1(1553),R2(1553),VARI(1553),VARA(1553),BC(1553)
     3,VALV(560),AVARI(1553),NOP(122,8),NON(122),LPR(122)
     4,NOPP(461),MDF(461),NCOD(1553),NOOV(560)
      COMMON/GUARD/
     1 SK(40000),ESTIFM(28,28),GISH(600),INTEG(2700)
      COMMON/UPWIN/
     1 AA1,AA2,A1,A2,BB1,BB2,B1,B2,DIS(3,461)
     2,WP(8),WDEL(2,8),WB(2,8),DWB(2,72),DWP(72),TT(8)
     3,UU(8),VV(8),UPVE(2),VAVE(2),IUPWIN,IWTS,VKIN,VKON
      DIMENSION
     1 P(8),DEL(2,8),B(2,8),CJ(2,2),CJI(2,2)
     2,PP(4),BB(2,4),CB(2,36),CP(36)
     3,DB(2,72),DP(72),DDA(9)
      EQUIVALENCE
     1 (SK(1),P(1)),(SK(10),DEL(1,1))
     2,(SK(30),B(1,1)),(SK(50),CJ(1,1))
     3,(SK(55),CJI(1,1)),(SK(60),PP(1))
     4,(SK(70),DDA(1)),(SK(80),CB(1,1))
     5,(SK(160),CP(1)),(SK(200),DB(1,1))
     6,(SK(350),DP(1)),(SK(430),ELX)
     7,(SK(431),ELY)
C
C*************************************
C    OBTAIN AVERAGE VELOCITY COMPONENTS
C*************************************
C
      IF(MARK.EQ.3)GO TO 1
      DO 11 I=1,NH
      IDF=MDF(I)
      J=NOPP(I)
      IF(IDF.EQ.2) JJ=J+1
```

FETHSOLVAC (CONT.)

```
3351:          IF(IDF.EQ.3) JJ=J+2
3352:          DIS(1,I)=VARI(J)
3353:          DIS(2,I)=VARI(JJ)
3354:     11 CONTINUE
3355:          GO TO 3
3356:    1     CONTINUE
3357:          DO 2 I=1,NH
3358:          IDF=MDF(I)
3359:          J=NOPP(I)
3360:          IF(IDF.EQ.3)JJ=J+1
3361:          IF(IDF.EQ.4)JJ=J+2
3362:          DIS(1,I)=VARI(J)
3363:          DIS(2,I)=VARI(JJ)
3364:    2     CONTINUE
3365:    3     CONTINUE
3366:          IF(IUPWIN.EQ.1) ALPHA=CONDF/(RHO*CPF)
3367:          IF(IUPWIN.EQ.2) ALPHA=V
3368:          DPX=ALPHA
3369:          DPY=ALPHA
3370:          DO 10 I=1,NBN
3371:          K=IABS(NOP(MM,I))
3372:          UU(I)=DIS(1,K)
3373:          VV(I)=DIS(2,K)
3374:     10 CONTINUE
3375:          UAVE(1)=(UU(1)+UU(3))*0.5
3376:          UAVE(2)=(UU(5)+UU(7))*0.5
3377:          VAVE(1)=(VV(3)+VV(5))*0.5
3378:          VAVE(2)=(VV(1)+VV(7))*0.5
3379: C
3380: C*************************
3381: C    SET UP OPTIMUM VALUES
3382: C*************************
3383: C
3384:          IX1=IABS(NOP(MM,3))
3385:          IX2=IABS(NOP(MM,1))
3386:          HX1=CORD(IX1,1)
3387:          HX2=CORD(IX2,1)
3388:          HX=ABS(HX1-HX2)
3389:          XX1=0.25*ABS(UAVE(1))*HX/DPX
3390:          IF(XX1.LE.0.001) GO TO 21
3391:          AA1=(1./TANH(XX1))-1./XX1
3392:          XX1=2.*XX1
3393:          XX=TANH(XX1)
3394:          A1=2.*XX-4./XX1+(2.+AA1*XX1)*(3.*XX-XX1)/(XX1*XX1)
3395:          GO TO 22
3396:     21 AA1=0.
3397:          A1=0.
3398:     22 CONTINUE
3399:          IX1=IABS(NOP(MM,5))
3400:          IX2=IABS(NOP(MM,7))
```

FETHSOLVAC (CONT.)

```
      HX1=CORD(IX1,1)
      HX2=CORD(IX2,1)
      HX=ABS(HX1-HX2)
      XX2=0.25*ABS(UAVE(2))*HX/DPX
      IF(XX2.LE.0.001) GO TO 23
      AA2=(1./TANH(XX2))-1./XX2
      XX2=2.*XX2
      XX=TANH(XX2)
      A2=2.*XX-4./XX2+(2.+AA2*XX2)*(3.*XX-XX2)/(XX2*XX2)
      GO TO 24
   23 AA2=0.
      A2=0.
   24 CONTINUE
      IY1=IABS(NOP(MM,3))
      IY2=IABS(NOP(MM,5))
      HY1=CORD(IY1,2)
      HY2=CORD(IY2,2)
      HY=ABS(HY1-HY2)
      YY1=0.25*ABS(VAVE(1))*HY/DPY
      IF(YY1.LE.0.001) GO TO 31
      BB1=(1./TANH(YY1))-1./YY1
      YY1=2.*YY1
      YY=TANH(YY1)
      B1=2.*YY-4./YY1+(2.+BB1*YY1)*(3.*YY-YY1)/(YY1*YY1)
      GO TO 32
   31 BB1=0.
      B1=0.
   32 CONTINUE
      IY1=IABS(NOP(MM,7))
      IY2=IABS(NOP(MM,1))
      HY1=CORD(IY1,2)
      HY2=CORD(IY2,2)
      HY=ABS(HY1-HY2)
      YY2=0.25*ABS(VAVE(2))*HY/DPY
      IF(YY2.LE.0.001) GO TO 33
      BB2=(1./TANH(YY2))-1./YY2
      YY2=2.*YY2
      YY=TANH(YY2)
      B2=2.*YY-4./YY2+(2.+BB2*YY2)*(3.*YY-YY2)/(YY2*YY2)
      GO TO 34
   33 BB2=0.
      B2=0.
   34 CONTINUE
C
C*****************************************
C    CHECK DIRECTION FOR UPWIND WEIGHTS
C*****************************************
C
      IF(UAVE(1).GT.0.) GO TO 41
      A1=-A1
```

FETHSOLVAC (CONT.)

```
      AA1=-AA1
   41 IF(UAVE(2).GT.0.) GO TO 42
      A2=-A2
      AA2=-AA2
   42 IF(VAVE(1).GT.0.) GO TO 43
      B1=-B1
      BB1=-BB1
   43 IF(VAVE(2).GT.0.) GO TO 50
      B2=-B2
      BB2=-BB2
   50 CONTINUE
      WRITE(NLP,101) MM,AA1,A1,AA2,A2,BB1,B1,BB2,B2
  101 FORMAT(I10,8F10.5)
      RETURN
      END
C
C
C
C
C
C
C
C*********************
      SUBROUTINE FRONT
C*********************
C
C*****************************************************************
C     FRONTAL ELIMINATION ROUTINE USING DIAGONAL PIVOTING
C*****************************************************************
C
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      COMMON/CONTR/
     1 X,Y,V,CONDF,BETA,CPF,RHO,HCOFX,HCOFY,
     2 GPF,GPG,GPH,EMU,XG(3),CG(3),DS,DX,DY,
     3 NP,NH,NE,NB,NDF,NCN,NEM,IT1,ND1,MTRD
     4,NTIME,MARK,NTP,LTIM,MTRIT,NCARDS,NSID,NAKI
     5,NPT,MWGA,NNP,NELL,NTPA,NGAUSS,NPR,NCR,NLP,NCF
     6,NCORD,IG,NG,NEV,NBT,NEWTON,ITURB,ICOND
      COMMON/GEP/
     1 TEMP(461),CORD(461,2),FSPEC(461,6)
     2,R1(1553),R2(1553),VARI(1553),VARR(1553),BC(1553)
     3,VALW(560),AVARI(1553),NOP(122,8),NDN(122),LPR(122)
     4,NOPP(461),MDF(461),NCOD(1553),NODW(560)
      COMMON/GUARD/
     1 SK(40000),ESTIFM(28,28),GISH(600),INTEG(2700)
      COMMON/UPWIN/
     1 AA1,AA2,A1,A2,BB1,BB2,B1,B2,DIS(3,461)
     2,WP(8),WDEL(2,8),WB(2,8),DWB(2,72),DWP(72),TT(8)
     3,UU(8),VV(8),UPVE(2),VAVE(2),IUPWIN,IWTS,WKIN,WKON
      COMMON/TLSKIN1/ TLS(461),EKE(461),TRMU(461),ITERNAN
```

FETHSOLVAC (CONT.)

```
      DIMENSION
     1 LDEST(28),KDEST(28),NK(28),AA(28,28)
     2,EQ(200,200),LHED(250),KHED(250),KPIV(250),LPIV(250)
     3,JMOD(250),QQ(250)
     4,NBOUNDA(28)
      EQUIVALENCE
     1 (SK(1),EQ(1,1)),(GISH(1),QQ(1))
     2,(ESTIFM(1,1),AA(1,1)),(INTEG(1),LDEST(1))
     3,(INTEG(30),KDEST(1)),(INTEG(60),NK(1))
     4,(INTEG(90),LHED(1)),(INTEG(180),KHED(1))
     5,(INTEG(270),KPIV(1)),(INTEG(360),LPIV(1))
     6,(INTEG(450),JMOD(1))
C
      NMAX=200
C
C***************
C     PREFRONT
C***************
C
      LFPON=0
      NCRIT=80
C
      NLARG=NMAX-10
      NELL=0
CC    WRITE(NLP,400)
      IF(NTPR.EQ.0)GO TO 14
C
C*****************************************
C     FIND LAST APPEARPEANCE OF EACH NODE
C*****************************************
C
      NLAST=0
      DO 12 I=1,NH
      DO 9 N=1,NE
      JDN=NDN(N)
      DO 4 L=1,JDN
      IF(NOP(N,L).NE.I)GO TO 4
      NLAST1=N
      IF(NLAST.NE.NLAST1)GO TO 3
      NERROR=1
      WRITE(NLP,416)NERROR,N
      STOP
    3 CONTINUE
      NLAST=N
      L1=L
    4 CONTINUE
CC    WRITE(NLP,404)I,NLAST
    9 CONTINUE
      NOP(NLAST,L1)=-NOP(NLAST,L1)
      NLAST=0
```

FETHSOLVAC (CONT.)

```
   12 CONTINUE
CC    WRITE(NLP,408)
CC    WRITE(NLP,412)(N,(NOP(N,L),L=1,NBN),N=1,NE)
C
C**************
C     ASSEMBLY
C**************
C
   14 CONTINUE
      LCOL=0
      DO 16 I=1,NMAX
      DO 16 J=1,NMAX
      EO(J,I)=0.
   16 CONTINUE
   18 NELL=NELL+1
      CALL ABFINO
      N=NELL
      JDN=NDN(NELL)
      DO 200 I=1,NCN
      NBOUNDA(I)=0
  200 CONTINUE
      KC=0
      IF(MWGA.NE.0) GO TO 250
      DO 210 I=1,JDN
      K=IABS(NOP(N,I))
      L=NOPP(K)
      IDF=MDF(K)
      DO 210 J=1,IDF
      KC=KC+1
      M=L+J-1
      NBOUNDA(KC)=M
      IF(NCOD(M).EQ.0) GO TO 210
      NBOUNDA(KC)=-M
      WAL=BC(M)
      KD=0
      DO 211 IA=1,JDN
      KK=IABS(NOP(N,IA))
      LL=NOPP(KK)
      IIDF=MDF(KK)
      DO 211 JJ=1,IIDF
      KD=KD+1
      MM=LL+JJ-1
      R1(MM)=R1(MM)-AA(KD,KC)*WAL
  211 CONTINUE
  210 CONTINUE
      GO TO 280
  250 CONTINUE
      DO 260 I=1,JDN
      K=IABS(NOP(N,I))
      KC=KC+1
```

FETHSOLVAC (CONT.)

```
      NBOUNDA(KC)=K
      IF(NCOD(K).EQ.0) GO TO 280
      NBOUNDA(KC)=-K
      VAL=BC(K)
      KD=0
      DO 270 IP=1,JDN
      KK=IABS(NOP(N,IP))
      KD=KD+1
      P1(KK)=P1(KK)-AA(KD,KC)*VAL
  270 CONTINUE
  280 CONTINUE
  290 CONTINUE
      KC=0
      IF(MWGA.EQ.0)GO TO 21
      DO 20 I=1,JDN
      NK(I)=NOP(N,I)
   20 CONTINUE
      KC=JDN
      GO TO 22
   21 CONTINUE
      DO 22 J=1,JDN
      NN=NOP(N,J)
      M=IABS(NN)
      K=NOPP(M)
      IDF=MDF(M)
      DO 22 L=1,IDF
      KC=KC+1
      II=K+L-1
      IF(NN.LT.0)II=-II
      NK(KC)=II
   22 CONTINUE
   22 CONTINUE
C
C*****************************
C     SET UP HEADING VECTORS
C*****************************
C
      DO 36 LK=1,KC
      IF(NBOUNDA(LK).LT.0) GO TO 36
      NODE=NK(LK)
      IF(LCOL.EQ.0)GO TO 28
      DO 24 L=1,LCOL
      LL=L
      IF(IABS(NODE).EQ.IABS(LHED(L)))GO TO 32
   24 CONTINUE
   28 LCOL=LCOL+1
      LDEST(LK)=LCOL
      LHED(LCOL)=NODE
      GO TO 36
   32 LDEST(LK)=LL
```

FETHSOLVAC (CONT.)

```
      LHED(LL)=NODE
   36 CONTINUE
      IF(MARK.GE.4.AND.NTR.EQ.1.AND.ITERNAN.EQ.0)
     -WRITE(NLP,490)N,LCOL
CC    WRITE(NLP,420)KROW,LCOL
CC    WRITE(NLP,424)
CC    WRITE(NLP,429) (KHED(K),LHED(K),K=1,NMAX)
CC    WRITE(NLP,432)
CC    WRITE(NLP,429) (KDEST(K),LDEST(K),K=1,KC)
      IF(LCOL.LE.NMAX)GO TO 54
      NERROR=2
      WRITE(NLP,417)NERROR
      STOP
   54 CONTINUE
      DO 56 L=1,KC
      IF(NBOUNDA(L).LT.0) GO TO 56
      LL=LDEST(L)
      DO 57 K=1,KC
      IF(NBOUNDA(K).LT.0) GO TO 57
      KK=LDEST(K)
      EQ(KK,LL)=EQ(KK,LL)+AA(K,L)
   57 CONTINUE
   56 CONTINUE
CC    WRITE(NLP,436)NELL
CC    WRITE(NLP,440)((EQ(I,J),J=1,NMAX),I=1,NMAX)
      IF(LCOL.LT.NCPIT.AND.NELL.LT.NE)GO TO 18
C
C*****************************************************
C     FIND OUT WHICH MATRIX ELEMENTS ARE FULLY SUMMED
C*****************************************************
C
   60 LC=0
      DO 64 L=1,LCOL
      KT=LHED(L)
      IF(KT.GE.0)GO TO 64
      LC=LC+1
      LPIV(LC)=L
   64 CONTINUE
CC    WRITE(NLP,448)LC,KR
CC    WRITE(NLP,428)(LPIV(K),KPIV(K),K=1,NMAX)
      IF(LC.GT.0) GO TO 72
      IF(NELL.LT.NE) GO TO 18
      NERROR=3
      WRITE(NLP,418)NERROR
      STOP
   72 CONTINUE
CC    WRITE(NLP,460)
CC    WRITE(NLP,464)(I,R1(I),I=1,NP)
C
C*******************************
```

FETHSOLVAC (CONT.)

```
C      SEARCH FOR ABSOLUTE PIVOT
C*****************************
C
       PIVOT=0.
       DO 76 L=1,LC
       LPIVC=LPIV(L)
       KPIVR=LPIVC
       PIVA=EQ(KPIVR,LPIVC)
       IF(ABS(PIVA).LT.PIVOT)GO TO 74
       PIVOT=PIVA
       LPIVCO=LPIVC
       KPIVRO=KPIVR
    74 CONTINUE
    76 CONTINUE
C
C*************************
C      NORMALISE PIVOTAL ROW
C*************************
C
       LCO=IABS(LHED(LPIVCO))
       KRO=LCO
    78 CONTINUE
       IF(ABS(PIVOT).LT.1E-10)GO TO 152
       DO 80 L=1,LCOL
       QQ(L)=EQ(KPIVRO,L)/PIVOT
    80 CONTINUE
       RHS=R1(KRO)/PIVOT
       R1(KRO)=RHS
CC     WRITE(NLP,468)
CC     WRITE(NLP,440)(QQ(L),L=1,LCOL)
C
C*****************************************************
C      ELIMINATE THEN DELETE PIVOTAL ROW AND COLUMN
C*****************************************************
C
       IF(KPIVRO.EQ.1)GO TO 104
       KPIVR=KPIVRO-1
       DO 100 K=1,KPIVR
       KRW=IABS(LHED(K))
       FAC=EQ(K,LPIVCO)
CC     WRITE(NLP,480)FAC
       IF(LPIVCO.EQ.1.OR.FAC.EQ.0.)GO TO 88
       LPIVC=LPIVCO-1
       DO 84 L=1,LPIVC
       EQ(K,L)=EQ(K,L)-FAC*QQ(L)
    84 CONTINUE
    88 IF(LPIVCO.EQ.LCOL)GO TO 96
       LPIVC=LPIVCO+1
       DO 92 L=LPIVC,LCOL
       EQ(K,L-1)=EQ(K,L)-FAC*QQ(L)
```

FETHSOLVAC (CONT.)

```
   92 CONTINUE
   96 R1(KRW)=R1(KRW)-FAC*RHS
  100 CONTINUE
  104 IF(KPIVRO.EQ.LCOL)GO TO 128
      KPIVR=KPIVRO+1
      DO 124 K=KPIVR,LCOL
      KRW=IABS(LHED(K))
      FAC=EQ(K,LPIVCO)
CC    WRITE(NLP,480)FAC
      IF(LPIVCO.EQ.1)GO TO 112
      LPIVC=LPIVCO-1
      DO 108 L=1,LPIVC
      EQ(K-1,L)=EQ(K,L)-FAC*QQ(L)
  108 CONTINUE
  112 IF(LPIVCO.EQ.LCOL)GO TO 120
      LPIVC=LPIVCO-1
      DO 116 L=LPIVC,LCOL
      EQ(K-1,L-1)=EQ(K,L)-FAC*QQ(L)
  116 CONTINUE
  120 R1(KRW)=R1(KRW)-FAC*RHS
  124 CONTINUE
  128 CONTINUE
C
C*************************************
C     WRITE PIVOTAL EQUATION ON DISC
C*************************************
C
      WRITE(ND1)
    1 KRO,LCOL,LPIVCO,(LHED(L),QQ(L),L=1,LCOL)
      DO 130 L=1,LCOL
      EQ(L,LCOL)=0.
      EQ(LCOL,L)=0.
  130 CONTINUE
CC    WRITE(NLP,436)NELL
CC    WRITE(NLP,440)((EQ(I,J),J=1,NMAX),I=1,NMAX)
CC    WRITE(NLP,460)
CC    WRITE(NLP,464)(I,R1(I),I=1,NP)
C
C*********************************
C     REARRANGE HEADING VECTORS
C*********************************
C
      LCOL=LCOL-1
      IF(LPIVCO.EQ.LCOL+1)GO TO 136
      DO 132 L=LPIVCO,LCOL
      LHED(L)=LHED(L+1)
  132 CONTINUE
  136 CONTINUE
CC    WRITE(NLP,420)KROW,LCOL
CC    WRITE(NLP,424)
```

FETHSOLVAC (CONT.)

```
CC      WRITE(NLP,428) (KHED(K),LHED(K),K=1,NMAX)
C
C*****************************************************************
C       DETERMINE WHETHER TO ASSEMBLE,ELIMINATE,OR BACKSUBSTITUTE
C*****************************************************************
C
        IF(LCOL.GT.1.OR.NELL.LT.NE) GO TO 60
        LCO=IABS(LHED(1))
        KPIVRO=1
        PIVOT=EQ(1,1)
        KRO=LCO
        LPIVCO=1
        QQ(1)=1.
        IF(ABS(PIVOT).LT.1E-08)GO TO 152
        P1(KRO)=P1(KRO)/PIVOT
        WRITE(ND1)
     1      KRO,LCOL,LPIVCO,LHED(1),QQ(1)
        CALL BACSUB
        GO TO 156
  152   CONTINUE
        WRITE(NLP,476)
        WRITE(NLP,408)
        LFPON=1
        NTRA=0
        DO 154 I=1,NP
        IF(NCOD(I).GT.0)NCOD(I)=1
  154   CONTINUE
        REWIND 10
        REWIND ND1
        REWIND 8
        CALL FRONTA
  156   CONTINUE
  400   FORMAT(5H NODE,6H NLAST)
  404   FORMAT(1X,2I5)
  408   FORMAT(//16H NODPL NUMBERING/)
  412   FORMAT(9I5)
  416   FORMAT(/8H NERROR=,I5//I5,
     1 62H TH. ELEMENT HAS MORE THAN ONE NODE WITH THE
     1/62H SAME NODAL NUMBER
     1/)
  417   FORMAT(/8H NERROR=,I5//
     1/   INSUFFICIENT SPACE TO ASSEMBLE NEXT ELEMENT
     1  INCREASE NMAX'./)
  418   FORMAT(/8H NERROR=,I5//
     1 62H THERE ARE NO MORE ROWS FULLY SUMMED,THIS MAY BE DUE TO---
     1/62H (1)INCORRECT CODING OF NOP OR NK ARRAYS
     1/62H (2)INCORRECT VALUE OF NMAX . INCREASE NMAX  TO PERMIT
     1/62H    WHOLE FRONT TO BE ASSEMBLED
     1/)
  420   FORMAT(/6H KROW=,I5,6H LCOL=,I5/)
```

FETHSOLVAC (CONT.)

```
  424 FORMAT(/5H KHED,5H LHED/)
  428 FORMAT(2I6)
  432 FORMAT(/6H KDEST,6H LDEST/)
  436 FORMAT(/22H EQ MATRIX ELEMENT NO=,I3/)
  440 FORMAT(20F5.2)
  448 FORMAT(/4H LC=,I3,/4H KR=,I3/6H  LPIV,6H  KPIV/)
  452 FORMAT(13H PIVOTAL ROW=,I4,16H PIVOTAL COLUMN=,I4,7H PIVOT=,E20.10
     1)
  456 FORMAT(/5H JMOD/)
  460 FORMAT(/18H RIGHT HAND VECTOR/)
  464 FORMAT(1X,4(I5,E20.10))
  468 FORMAT(/12H PIVOTAL ROW/)
  476 FORMAT(43H WARNING-MATRIX SINGULAR OR ILL CONDITIONED)
  480 FORMAT(5H FAC=,E20.10)
  484 FORMAT(13H NCRIT VALUE=,I4)
  488 FORMAT(///
     1 57H DIAGONAL PIVOTING ABANDONED,FULL PIVOTING PROGRAM CALLED//)
  490 FORMAT('  ELEMENT',I5,'  FRONTWIDTH=',I5)
      RETURN
      END
C
C
C
C
C
C
C
C*********************
      SUBROUTINE BACSUB
C*********************
C
C*****************************************
C     BACK SUBSTITUTION FOR DIAGONAL PIVOTING
C*****************************************
C
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      COMMON/CONTP/
     1 X,Y,V,CONDF,BETA,CPF,RHO,HCOFX,HCOFY,
     2 GPF,GPG,GFH,EMU,XG(3),CG(3),DS,DX,DY,
     3 NP,NH,NE,NB,NDF,NCN,NBN,IT1,ND1,MTRD
     4,NTIME,MAPI,NTR,LTIM,MTRIT,NCARDS,NSID,NAXI
     5,NRT,MWGA,NNF,NELL,NTRA,NGAUSS,NPR,NCR,NLP,NCP
     6,NCORD,IG,NG,NEV,NBT,NEWTON,ITURB,ICOND
      COMMON/GEP/
     1 TEMP(461),CORD(461,2),RSPEC(461,6)
     2,R1(1552),R2(1552),VARI(1553),VARR(1553),BC(1553)
     3,VALV(560),AVARI(1553),NOP(122,8),NDN(122),LPR(122)
     4,NOPP(461),MDF(461),NCOD(1553),NODV(560)
      COMMON/GUARD/
     1 SK(40000),ESTIFM(28,28),GISH(600),INTEG(2700)
```

FETHSOLVAC (CONT.)

```
      COMMON/UPWIN/
     1 AA1,AA2,A1,A2,BB1,BB2,B1,B2,DIS(3,461)
     2,WP(8),WDEL(2,8),WB(2,8),DWB(2,72),DWP(72),TT(8)
     3,UU(8),VV(8),UAVE(2),VAVE(2),IUPWIN,IWTS,VKIN,VKON
      DIMENSION
     1 LDEST(28),KDEST(28),NK(28),AA(28,28)
     2,EQ(200,200),LHED(250),KHED(250),KPIV(250),LPIV(250)
     3,JMOD(250),QQ(250)
      EQUIVALENCE
     1 (SK(1),EQ(1,1)),(GISH(1),QQ(1))
     2,(ESTIFM(1,1),AA(1,1)),(INTEG(1),LDEST(1))
     3,(INTEG(30),KDEST(1)),(INTEG(60),NK(1))
     4,(INTEG(90),LHED(1)),(INTEG(180),KHED(1))
     5,(INTEG(270),KPIV(1)),(INTEG(360),LPIV(1))
     6,(INTEG(450),JMOD(1))
C
      NMAX=200
C
C*************************
C     BACK SUBSTITUTION
C*************************
C
      DO 4 I=1,NP
    4 SK(I)=BC(I)
      IF(MWGA.EQ.0) NPP=NP-NBV
      IF(MWGA.NE.0) NPP=NP-NBT
      DO 32 IV=1,NPP
      BACKSPACE ND1
      READ(ND1)
     1 KRO,LCOL,LPIVCO,(LHED(L),QQ(L),L=1,LCOL)
      BACKSPACE ND1
CC    WRITE(NLP,404)
CC    WRITE(NLP,408) KRO,LCOL,LPIVCO
CC    WRITE(NLP,408) (LHED(L),L=1,LCOL)
CC    WRITE(NLP,412) (QQ(L),L=1,LCOL)
      IF(NCOD(KRO).GT.0)GO TO 24
      GASH=0.
      QQ(LPIVCO)=0.
      DO 16 L=1,LCOL
      GASH=GASH-QQ(L)*SK(IABS(LHED(L)))
   16 CONTINUE
      SK(KRO)=R1(KRO)+GASH
      GO TO 32
   24 CONTINUE
      NCOD(KRO)=1
   32 CONTINUE
  404 FORMAT(14H DISC CONTENTS)
  408 FORMAT(10I5)
  412 FORMAT(5E20.10)
      RETURN
```

FETHSOLVAC (CONT.)

```
      END
C
C
C
C
C
C
C
C*********************
      SUBROUTINE FRONTA
C*********************
C
C
C*****************************************************
C     FRONTAL ELIMINATION ROUTINE USING FULL PIVOTING
C*****************************************************
C
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      COMMON/CONTF/
     1 X,Y,V,CONDF,BETA,CPF,RHO,HCOFX,HCOFY,
     2 GPF,GPG,GFH,EMU,XG(3),CG(3),DS,DX,DY,
     3 NP,NH,NE,NB,NDF,NCN,NBN,IT1,ND1,MTRD
     4,NTIME,MARK,NTR,LTIM,MTRIT,NCARDS,NSID,NAXI
     5,NRT,MWGA,NNP,NELL,NTRA,NGAUSS,NPR,NCR,NLP,NCP
     6,NCOPO,IG,NG,NBV,NET,NEWTON,ITURB,ICOND
      COMMON/GEP/
     1 TEMP(461),COORD(461,2),RSPEC(461,6)
     2,R1(1553),R2(1553),VARI(1553),VARA(1553),BC(1553)
     3,VALV(560),AVARI(1553),NOP(122,8),NDN(122),LPR(122)
     4,NOPP(461),MOF(461),NCOD(1553),NODV(560)
      COMMON/GUPPD/
     1 SK(40000),ESTIFM(29,29),GISH(600),INTEG(2700)
      COMMON/UPWIN/
     1 AP1,AP2,P1,P2,BB1,BB2,B1,B2,DIS(3,461)
     2,WP(8),WDEL(2,8),WB(2,8),DWB(2,72),DWP(72),TT(8)
     3,UU(8),VV(8),UAVE(2),VAVE(2),IUPWIN,IWTS,VKIN,VKON
      DIMENSION
     1 LDEST(28),KDEST(28),NK(28),AA(29,29)
     2,EQ(200,200),LHED(250),KHED(250),KPIV(250),LPIV(250)
     3,JMOD(250),QQ(250)
     4,NBOUNDA(29)
      EQUIVALENCE
     1 (SK(1),EQ(1,1)),(GISH(1),QQ(1))
     2,(ESTIFM(1,1),AA(1,1)),(INTEG(1),LDEST(1))
     3,(INTEG(30),KDEST(1)),(INTEG(60),NK(1))
     4,(INTEG(90),LHED(1)),(INTEG(180),KHED(1))
     5,(INTEG(270),KPIV(1)),(INTEG(360),LPIV(1))
     6,(INTEG(450),JMOD(1))
C
      NMAX=200
```

FETHSOLVAC (CONT.)

```
C
C***************
C       PREFRONT
C***************
C
        NCRIT=80
        NELL=0
CC      WRITE(NLP,400)
        IF(NTRA.EQ.0)GO TO 14
C
C*****************************************
C       FIND LAST APPEARENCE OF EACH NODE
C*****************************************
C
        NLAST=0
        DO 12 I=1,NH
        DO 8 N=1,NE
        JDN=NDN(N)
        DO 4 L=1,JDN
        IF(NOP(N,L).NE.I)GO TO 4
        NLAST1=N
        IF(NLAST.NE.NLAST1)GO TO 3
        NERROR=1
        WRITE(NLP,416)NERROR,N
        STOP
      3 CONTINUE
        NLAST=N
        L1=L
      4 CONTINUE
CC      WRITE(NLP,404)I,NLAST
      8 CONTINUE
        NOP(NLAST,L1)=-NOP(NLAST,L1)
        NLAST=0
     12 CONTINUE
CC      WRITE(NLP,408)
CC      WRITE(NLP,412)(N,(NOP(N,L),L=1,NBN),N=1,NE)
C
C***************
C       ASSEMBLY
C***************
C
     14 CONTINUE
        LCOL=0
        KROW=0
        DO 16 I=1,NMAX
        DO 16 J=1,NMAX
        EQ(J,I)=0.
     16 CONTINUE
     18 NELL=NELL+1
        CALL ABFIND
```

FETHSOLVAC (CONT.)

```
      N=NELL
      JDN=NDN(NELL)
      KC=0
      IF(MWGA.EQ.0)GO TO 21
      DO 20 I=1,JDN
      NK(I)=NOP(N,I)
   20 CONTINUE
      KC=JDN
      GO TO 22
   21 CONTINUE
      DO 22 J=1,JDN
      NN=NOP(N,J)
      M=IABS(NN)
      K=NOPP(M)
      IDF=MDF(M)
      DO 22 L=1,IDF
      KC=KC+1
      II=K+L-1
      IF(NN.LT.0)II=-II
      NK(KC)=II
   22 CONTINUE
   23 CONTINUE
C
C*****************************
C     SET UP HEADING VECTORS
C*****************************
C
CC    IF(NTP.EQ.1) WRITE(NLP,420) KROW,LCOL
CC    IF(NTP.EQ.1) WRITE(NLP,424)
CC    IF(NTP.EQ.1) WRITE(NLP,429) (KHED(K),LHED(K),K=1,LCOL)
CC    IF(NTP.EQ.1) WRITE(NLP,432)
CC    IF(NTP.EQ.1) WRITE(NLP,428) (KDEST(K),LDEST(K),K=1,KC)
      DO 52 LK=1,KC
      NODE=NK(LK)
      IF(LCOL.EQ.0)GO TO 28
      DO 24 L=1,LCOL
      LL=L
      IF(IABS(NODE).EQ.IABS(LHED(L)))GO TO 32
   24 CONTINUE
   28 LCOL=LCOL+1
      LDEST(LK)=LCOL
      LHED(LCOL)=NODE
      GO TO 36
   32 LDEST(LK)=LL
      LHED(LL)=NODE
   36 IF(KROW.EQ.0)GO TO 44
      DO 42 K=1,KROW
      KK=K
      IF(IABS(NODE).EQ.IABS(KHED(K)))GO TO 48
   42 CONTINUE
```

FETHSOLVAC (CONT.)

```
   44 CONTINUE
      KROW=KROW+1
      KDEST(LK)=KROW
      KHED(KROW)=NODE
      GO TO 52
   48 CONTINUE
      KDEST(LK)=KK
      KHED(KK)=NODE
   52 CONTINUE
CC    IF(NTP.EQ.1) WRITE(NLP,420)KROW,LCOL
CC    IF(NTP.EQ.1) WRITE(NLP,424)
CC    IF(NTP.EQ.1) WRITE(NLP,428) (KHED(K),LHED(K),K=1,NMAX)
CC    IF(NTP.EQ.1) WRITE(NLP,432)
CC    IF(NTP.EQ.1) WRITE(NLP,428) (KDEST(K),LDEST(K),K=1,KC)
      IF(KROW.LE.NMAX.AND.LCOL.LE.NMAX)GO TO 54
      NERROR=2
      WRITE(NLP,417)NERROR
      STOP
   54 CONTINUE
      DO 56 L=1,KC
      LL=LDEST(L)
      DO 56 K=1,KC
      KK=KDEST(K)
      EQ(KK,LL)=EQ(KK,LL)+AA(K,L)
   56 CONTINUE
CC    WRITE(NLP,436)NELL
CC    WRITE(NLP,440)((EQ(I,J),J=1,NMAX),I=1,NMAX)
      IF(KROW.LT.NCRIT.AND.NELL.LT.NE)GO TO 18
C
C*****************************************************
C     FIND OUT WHICH MATRIX ELEMENTS ARE FULLY SUMMED
C*****************************************************
C
   60 LC=0
      DO 64 L=1,LCOL
      IF(LHED(L).GE.0)GO TO 64
      LC=LC+1
      LPIV(LC)=L
   64 CONTINUE
      IR=0
      KR=0
      DO 68 K=1,KROW
      KT=KHED(K)
      IF(KT.GE.0)GO TO 68
      KR=KR+1
      KPIV(KR)=K
      KRO=IABS(KT)
      IF(NCOD(KRO).NE.1)GO TO 68
      IR=IR+1
      JMOD(IR)=K
```

FETHSOLVAC (CONT.)

```
      NCOD(KRO)=2
      R1(KRO)=BC(KRO)
   68 CONTINUE
C
C*****************************************************
C     MODIFY EQUATIONS WITH APPLIED BOUNDARY CONDITIONS
C*****************************************************
C
CC    WRITE(NLP,448)LC,KR
CC    WRITE(NLP,428)(LPIV(K),KPIV(K),K=1,NMAX)
      IF(IR.EQ.0)GO TO 71
CC    WRITE(NLP,456)
      DO 70 IRR=1,IR
      K=JMOD(IRR)
CC    WRITE(NLP,428)K
      KH=IABS(KHED(K))
      DO 69 L=1,LCOL
      EQ(K,L)=0.
      LH=IABS(LHED(L))
      IF(LH.EQ.KH)EQ(K,L)=1.
   69 CONTINUE
   70 CONTINUE
   71 CONTINUE
      IF(KR.GT.0.AND.LC.GT.0)GO TO 72
      NERROR=3
      WRITE(NLP,416)NERROR
      STOP
   72 CONTINUE
CC    WRITE(NLP,460)
CC    WRITE(NLP,464)(I,R1(I),I=1,NP)
C
C*******************************
C     SEARCH FOR ABSOLUTE PIVOT
C*******************************
C
      PIVOT=0.
      DO 76 L=1,LC
      LPIVC=LPIV(L)
      KPIVR=LPIVC
      PIVA=EQ(KPIVR,LPIVC)
      IF(ABS(PIVA).LT.ABS(PIVOT))GO TO 76
      PIVOT=PIVA
      LPIVCO=LPIVC
      KPIVRO=KPIVR
   76 CONTINUE
C
C*************************
C     NORMALISE PIVOTAL ROW
C*************************
C
```

FETHSOLVRC (CONT.)

```
      KRO=IABS(KHED(KPIVRO))
      LCO=IABS(LHED(LPIVCO))
      IF(NTP.EQ.1)WRITE(NLP,452)KRO,LCO,PIVOT,NELL
      IF(ABS(PIVOT).LT.1E-08)WRITE(NLP,476)
      DO 80 L=1,LCOL
      QO(L)=EQ(KPIVRO,L)/PIVOT
   80 CONTINUE
      RHS=R1(KRO)/PIVOT
      R1(KRO)=RHS
CC    WRITE(NLP,468)
CC    WRITE(NLP,440)(QO(L),L=1,LCOL)
C
C*****************************************************
C     ELIMINATE THEN DELETE PIVOTAL ROW AND COLUMN
C*****************************************************
C
      IF(KPIVRO.EQ.1)GO TO 104
      KPIVR=KPIVRO-1
      DO 100 K=1,KPIVR
      KRW=IABS(KHED(K))
      FAC=EQ(K,LPIVCO)
CC    WRITE(NLP,480)FAC
      IF(LPIVCO.EQ.1.OR.FAC.EQ.0.)GO TO 88
      LPIVC=LPIVCO-1
      DO 84 L=1,LPIVC
      EQ(K,L)=EQ(K,L)-FAC*QO(L)
   84 CONTINUE
   88 IF(LPIVCO.EQ.LCOL)GO TO 96
      LPIVC=LPIVCO-1
      DO 92 L=LPIVC,LCOL
      EQ(K,L-1)=EQ(K,L)-FAC*QO(L)
   92 CONTINUE
   96 R1(KRW)=R1(KRW)-FAC*RHS
  100 CONTINUE
  104 IF(KPIVRO.EQ.KROW)GO TO 126
      KPIVR=KPIVRO+1
      DO 124 K=KPIVR,KROW
      KRW=IABS(KHED(K))
      FAC=EQ(K,LPIVCO)
CC    WRITE(NLP,480)FAC
      IF(LPIVCO.EQ.1)GO TO 112
      LPIVC=LPIVCO-1
      DO 108 L=1,LPIVC
      EQ(K-1,L)=EQ(K,L)-FAC*QO(L)
  108 CONTINUE
  112 IF(LPIVCO.EQ.LCOL)GO TO 120
      LPIVC=LPIVCO+1
      DO 116 L=LPIVC,LCOL
      EQ(K-1,L-1)=EQ(K,L)-FAC*QO(L)
  116 CONTINUE
```

```
  120 R1(KRW)=R1(KRW)-FRC*FHS
  124 CONTINUE
  125 CONTINUE
C
C*************************************
C     WRITE PIVOTAL EQUATION ON DISC
C*************************************
C
      WRITE(ND1)
     1 KRO,LCOL,LPIVCO,(LHED(L),QQ(L),L=1,LCOL)
     2,KROW,PIVOT,KPIVRO,(KHED(K),K=1,KROW)
      DO 129 K=1,KROW
      EQ(K,LCOL)=0.
  129 CONTINUE
      DO 130 L=1,LCOL
      EQ(KROW,L)=0.
  130 CONTINUE
CC    WRITE(NLP,436)NFLL
CC    WRITE(NLP,440)((EQ(I,J),J=1,NMAX),I=1,NMAX)
CC    WRITE(NLP,450)
CC    WRITE(NLP,464)(I,R1(I),I=1,NP)
C
C*****************************
C     REARRANGE HEADING VECTORS
C*****************************
C
      LCOL=LCOL-1
      IF(LPIVCO.EQ.LCOL-1)GO TO 136
      DO 132 L=LPIVCO,LCOL
      LHED(L)=LHED(L+1)
  132 CONTINUE
  136 KROW=KROW-1
      IF(KPIVRO.EQ.KROW+1)GO TO 144
      DO 140 K=KPIVRO,KROW
      KHED(K)=KHED(K+1)
  140 CONTINUE
  144 CONTINUE
CC    WRITE(NLP,420)KROW,LCOL
CC    WRITE(NLP,424)
CC    WRITE(NLP,429) (KHED(K),LHED(K),K=1,NMAX)
C
C*****************************************************************
C     DETERMINE WHETHER TO ASSEMBLE,ELIMINATE,OR BACKSUBSTITUTE
C*****************************************************************
C
      IF(KROW.GT.NCRIT)GO TO 60
      IF(NELL.LT.NE)GO TO 18
      IF(KROW.GT.1)GO TO 60
      LCO=IABS(LHED(1))
      KPIVRO=1
```

FETHEOLVAC (CONT.)

```
      PIVOT=E0(1,1)
      KRO=IABS(KHED(1))
      LPIVCO=1
      QQ(1)=1.
      IF(NTR.EQ.1)WRITE(NLP,452)LCO,KRO,PIVOT,NELL
      IF(ABS(PIVOT).LT.1E-06)WRITE(NLP,476)
      P1(KRO)=P1(KRO)/PIVOT
      WRITE(ND1)
     1      KRO,LCOL,LPIVCO,LHED(1),QQ(1)
     2,KROW,PIVOT,KPIVRO,KHED(1)
      CALL BACSUBR
  400 FORMAT(5H NODE 6H NLAST)
  404 FORMAT(1X,2I5)
  408 FORMAT(//16H NODAL NUMBERING/)
  412 FORMAT(3I5)
  416 FORMAT(/8H NERROR=,I5//I5,
     1 62H TH. ELEMENT HAS MORE THAN ONE NODE WITH THE
     1/62H SAME NODAL NUMBER
     1/)
  417 FORMAT(/9H NERROR=,I5//
     1 62H THE DIFFERENCE NMAX-NCRIT IS NOT SUFFICIENTLY LARGE
     1/62H TO PERMIT THE ASSEMBLY OF THE NEXT ELEMENT---
     1/62H EITHER INCREASE NMAX OR LOWER NCRIT
     1/)
  419 FORMAT(/8H NERROR=,I5//
     1 62H THERE ARE NO MORE ROWS FULLY SUMMED,THIS MAY BE DUE TO---
     1/62H (1)INCORRECT CODING OF NOP OR NK ARRAYS
     1/62H (2)INCORRECT VALUE OF NCRIT. INCREASE NCRIT TO PERMIT
     1/62H    WHOLE FRONT TO BE ASSEMBLED
     1/)
  420 FORMAT(/6H KROW=,I5,6H LCOL=,I5/)
  424 FORMAT(/5H KHED,5H LHED/)
  428 FORMAT(2I6)
  432 FORMAT(/6H KDEST,6H LDEST/)
  436 FORMAT(/22H EQ MATRIX ELEMENT NO=,I3/)
  440 FORMAT(20F5.2)
  448 FORMAT(/4H LC=,I3,/4H KR=,I3/6H  LPIV,6H  KPIV/)
  452 FORMAT(13H PIVOTAL ROW=,I4,16H PIVOTAL COLUMN=,I4,7H PIVOT=,E20.10
     1,/ NELL=/,I5)
  456 FORMAT(/5H JHOD/)
  460 FORMAT(/18H RIGHT HAND VECTOR/)
  464 FORMAT(I5,E20.10)
  468 FORMAT(/12H PIVOTAL ROW/)
  476 FORMAT(43H WARNING-MATRIX SINGULAR OR ILL CONDITIONED)
  480 FORMAT(5H FAC=,E20.10)
      RETURN
      END
C
C
C
```

FETHSOLVAC (CONT.)

```
C
C
C
C
C*************************
      SUBROUTINE BACSUBA
C*************************
C
C
C*****************************************
C     BACK-SUBSTITUTION FOR FULL PIVOTING
C*****************************************
C
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      COMMON/CONTR/
     1 X,Y,V,CONDF,BETA,CPF,RHO,HCOFX,HCOFY,
     2 GFF,GFG,GFH,EMU,XG(3),CG(3),DS,DX,DY,
     3 NP,NH,NE,NE,NDF,NCN,NBN,IT1,ND1,MTRD
     4,NTIME,MAPV,NTR,LTIM,MTRIT,NCARDS,NSID,NAXI
     5,NRT,MWGA,NNP,NELL,NTRA,NGPUSS,NPR,NCP,NLP,NCP
     6,NCOFD,IG,NG,NEV,NBT,NEWTON,ITURB,ICONO
      COMMON/GEP/
     1 TEMP(461),COORD(461,2),RSPEC(461,6)
     2,R1(1553),R2(1553),VAFI(1553),VPRA(1553),BC(1553)
     3,VALV(560),AVAFI(1553),NOP(122,8),NDN(122),LPR(122)
     4,NOPP(461),MDF(461),NCOD(1553),NODV(560)
      COMMON/GUARD/
     1 SK(40000),ESTIFM(29,29),GISH(600),INTEG(2700)
      COMMON/UPWIN/
     1 AA1,AA2,A1,A2,BB1,BB2,B1,B2,DIS(3,461)
     2,WP(8),WDEL(2,8),WB(2,8),DWB(2,72),DWP(72),TT(8)
     3,UU(8),VV(8),UAVE(2),VAVE(2),IUPWIN,IWTS,VKIN,VKON
      DIMENSION
     1 LDEST(29),KDEST(29),NK(29),AA(29,29)
     2,EQ(200,200),LHED(250),KHED(250),KPIV(250),LPIV(250)
     3,JMOD(250),QQ(250)
      EQUIVALENCE
     1 (SK(1),EQ(1,1)),(GISH(1),QQ(1))
     2,(ESTIFM(1,1),AA(1,1)),(INTEG(1),LDEST(1))
     3,(INTEG(30),KDEST(1)),(INTEG(60),NK(1))
     4,(INTEG(90),LHED(1)),(INTEG(180),KHED(1))
     5,(INTEG(270),KPIV(1)),(INTEG(360),LPIV(1))
     6,(INTEG(450),JMOD(1))
C
      NMAX=200
C
C*************************
C     BACK SUBSTITUTION
C*************************
```

FETHSOLVRC (CONT.)

```
C
      DO 4 I=1,NP
    4 SK(I)=BC(I)
      DO 32 IV=1,NP
      BACKSPACE ND1
      READ(ND1)
     1      KRO,LCOL,LPIVCO,(LHED(L),QQ(L),L=1,LCOL)
     2,KROW,PIVOT,KPIVRO,(KHED(K),K=1,KROW).
      BACKSPACE ND1
CC    WRITE(NLP,404)
CC    WRITE(NLP,405) KRO,LCOL,LPIVCO
CC    WRITE(NLP,409) (LHED(L),L=1,LCOL)
CC    WRITE(NLP,412) (QQ(L),L=1,LCOL)
      IF(NCOD(KRO) GT.0)GO TO 24
      GASH=0.
      QQ(LPIVCO)=0.
      DO 16 L=1,LCOL
      GASH=GASH-QQ(L)*SK(IABS(LHED(L)))
   16 CONTINUE
      SK(KRO)=R1(KRO)+GASH
      GO TO 32
   24 CONTINUE
      NCOD(KRO)=1
   32 CONTINUE
  404 FORMAT(144 DISC CONTENTS)
  408 FORMAT(10I5)
  412 FORMAT(5E20.10)
      RETURN
      END
C
C
C
C
C
C
C
C
      SUBROUTINE RESOL
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
C-----------------------------------------------------------------------
C     RESOLUTION FOR FULL PIVOTING
C-----------------------------------------------------------------------
      COMMON/CONTP/
     1 X,Y,V,CONDF,BETA,CPF,RHO,HCOFX,HCOFY,
     2 GPF,GPG,GFH,EMU,XG(3),CG(3),DS,DX,DY,
     3 NP,NH,NE,NB,NDF,NCN,NBN,IT1,ND1,MTRD
     4,NTIME,MARK,NTR,LTIM,MTRIT,NCARDS,NSID,NAXI
     5,NPT,MWGP,NNF,NELL,NTRA,NGAUSS,NPR,NCP,NLP,NCP
     6,NCOPD,IG,NG,NBV,NBT,NEWTON,ITURB,ICOND
      COMMON/GEP/
```

FETHEDLVAC (CONT.)

```
     1 TEMP(461),CORD(461,2),RSPEC(461,6)
     2,R1(1553),R2(1553),VARI(1553),VARP(1553),BC(1553)
     3,VALV(560),AVARI(1553),NOP(122,8),NON(122),LPR(122)
     4,NOPP(461),MDF(461),NCOD(1553),NODV(560)
      COMMON/GUARD/
     1 SK(40000),ESTIFM(28,28),GISH(600),INTEG(2700)
      COMMON/UPWIN/
     1 AA1,AA2,A1,A2,BB1,BB2,B1,B2,DIS(3,461)
     2,WP(8),WDEL(2,8),WB(2,8),DWB(2,72),DWP(72),TT(8)
     3,UU(8),VV(8),UAVE(2),VAVE(2),IUPWIN,IWTS,VKIN,VKON
      DIMENSION
     1 LDEST(28),KDEST(28),NK(28),AA(28,28)
     2,EQ(200,200),LHED(250),KHED(250),KPIV(250),LPIV(250)
     3,JMOD(250),QQ(250),PVKOL(250)
     4,NBOUNDA(28)
      EQUIVALENCE
     1 (SK(1),EQ(1,1)),(GISH(1),QQ(1))
     2,(ESTIFM(1,1),AA(1,1)),(INTEG(1),LDEST(1))
     3,(INTEG(30),KDEST(1)),(INTEG(60),NK(1))
     4,(INTEG(90),LHED(1)),(INTEG(180),KHED(1))
     5,(INTEG(270),KPIV(1)),(INTEG(360),LPIV(1))
     6,(INTEG(450),JMOD(1))
C*********************************************************************
C...  RESOLUTION
C*********************************************************************
      REWIND ND1
      DO 2 NX=1,NE
      CALL ABFIND
    2 CONTINUE
      NUM=28
      CALL TIMER(K1)
      WRITE(9,476)K1
C     WRITE(9,472)
      DO  4 I=1,NP
C     WRITE(9,464)NCOD(I),BC(I)
      IF(NCOD(I).LT.1) GO TO 4
      R1(I)=BC(I)
    4 CONTINUE
       DO 12 NLL=1,NP
      READ(ND1)
     1 KRO,LCOL,LPIVCO,(LHED(L),QQ(L),L=1,LCOL)
     2,KROW,PIVOT,KPIVRO,(PVKOL(K),KHED(K),K=1,KROW)
      PVKOL(KPIVRO)=0.
C     WRITE(9,408)KROW,KPIVRO
C     WRITE(9,412)(PVKOL(K),K=1,KROW)
C     WRITE(9,416)(KHED(K),K=1,KRO W)
      RHS=R1(KRO)/PIVOT
      R1(KRO)=RHS
      DO 8 K=1,KROW
      KRW=IABS(KHED(K))
```

FETHSOLVRC (CONT.)

```
      IF(NCOD(KRW).GT.0.AND.KHED(K).GT.0) GO TO   8
      R1(KRW)=R1(KRW)-PVKOL(K)*RHS
    8 CONTINUE
      WRITE(9,400)
      WRITE(9,404)(I,R1(I),I=1,NP)
   12 CONTINUE
      CALL BAKSUB
      CALL TIMER(K2)
      WRITE(9,477)K2
  400 FORMAT(/19H RIGHT HAND VECTOR/)
  404 FORMAT(I5,E20.10)
C  408 FORMAT(14H DISC CONTENTS/6H KROW=,I5,7H PIVOT=,E20.10
C    1,8H KPIVRO=,I5)
C 412 FORMAT(5E20.10)
C 416 FORMAT(10I5)
C 464 FORMAT(I5,E20.10)
C 472 FORMAT(20H BOUNDARY CONDITIONS)
  476 FORMAT(/,2X,'RIGHT HAND SIDE PROCESSING STARTS AT
     1CPU-TIME OF',I10,2X,'SECONDS')
  477 FORMAT(/,2X,'RIGHT HAND SIDE PROCESSING FINISHED
     1AT CPU-TIME OF',I5,2X,'SECONDS')
      RETURN
      END
C
C
C
C
C
C
C
      SUBROUTINE PSICALC
C
C*****************************************************************
C      CALCULATES STREAM FUNCTION FROM A VELOCITY FIELD
C
C*****************************************************************
C
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      COMMON/CONTR/
     1 X,Y,V,CONDF,BETA,CPF,RHO,HCOFX,HCOFY,
     2 GPF,GPG,GPH,EMU,XG(3),CG(3),DS,DX,DY,
     3 NP,NH,NE,NB,NDF,NCN,NBN,IT1,ND1,MTRD
     4,NTIME,MAFK,NTP,LTIM,MTRIT,NCARDS,NSID,NAXI
     5,NRT,MWGP,NNP,NELL,NTRA,NGAUSS,NPR,NCR,NLP,NCP
     6,NCOPD,IG,NG,NBV,NBT,NEWTON,ITURB,ICOND
      COMMON/GEP/
     1 TEMP(461),CORD(461,2),RSPEC(461,6)
     2,P1(1553),P2(1553),VARI(1553),VARA(1553),BC(1553)
     3,VALV(560),AVARI(1553),NOP(122,8),NON(122),LPR(122)
     4,NOPP(461),MDF(461),NCOD(1553),NODV(560)
```

FETHSOLVAC (CONT.)

```
      COMMON/GUARD/
     1 SK(40000),ESTIFM(28,28),GISH(600),INTEG(2700)
      COMMON/UPWIN/
     1 AA1,AA2,A1,A2,BB1,BB2,B1,B2,DIS(3,461)
     2,WP(8),WDEL(2,8),WB(2,8),DWB(2,72),DWP(72),TT(8)
     3,UU(8),VV(8),UAVE(2),VAVE(2),IUPWIN,IWTS,VKIN,VKON
      COMMON/PSIW/
     1PSI(1000),NODP(200),VALP(200),
     2NODW(200),VALW(200),ALEN(40),BLEN(40),KINZ(40),KOUZ(40),
     3ITER,NCR,JAY,KINL,KOUT,PSIF,NBP,
     4NEW,NLB,NUB,NPRA,JFRON,KFRON,LFRON
      NPRA=1
      ITER=0
      REWIND ND1
      REWIND 10
      DO 24 I=1,NH
      NCOD(I)=0
      BC(I)=0.
      P2(I)=0.
   24 P1(I)=0.
      READ(NCR,122) IAUTO
      WRITE(NLP,128) IAUTO
C
C*****************************************************************
C     IF   IAUTO=0   SPECIFY STREAM FUNCTION VALUES AT EVERY NODE ON
C                    THE BOUNDARIES.
C          IAUTO=1   SUBROUTINE AUTOBC CALLED TO COMPUTE STREAM
C                    FUNCTION VALUES AT THE BOUNDARIES.
C*****************************************************************
C
      IF(IAUTO.EQ.1) GO TO 28
      READ(NCR,122) NB
      WRITE(NLP,116) NB
      NBP=NB
      DO 25 I=1,NB
      READ(NCR,124) NOD,VAL
      WRITE(NLP,124)NOD,VAL
      NCOD(NOD)=1
      BC(NOD)=VAL
      NODP(I)=NOD
      VALP(I)=VAL
   25 CONTINUE
      GO TO 30
   15 CONTINUE
      IF(IAUTO.EQ.1) GO TO 28
C
C*****************************************************************
C     (IF IAUTO=0) SPECIFYING STREAM FUNCTION BOUNDARY VALUES,
C                  NB....TOTAL NUMBER OF BOUNDARY NODES.
C                  NOD...NODE NUMBER.
```

FETHEOLVAC (CONT.)

```
C                    VAL...STREAM FUNCTION VALUE.
C*****************************************************************
C
      DO 20 I=1,NBP
      NOD=NODP(I)
      NCOD(NOD)=1
      BC(NOD)=VALP(I)
   20 CONTINUE
      GO TO 30
   28 CONTINUE
C
C*****************************************************************
C       (IF IPUTO=1) CALL AUTOMATIC STREAM FUNCTION BOUNDARY
C                    EVALUATING ROUTINE.
C*****************************************************************
C
      ITER=ITER+1
      CALL AUTOBC
   30 CONTINUE
      REWIND ND1
      REWIND 10
      NCA=ITER
C
C*****************************************************************
C     SETTING UP PARAMETERS FOR SOLUTION ROUTINE
C     AND CALL FRONTAL SOLUTION ROUTINE.
C*****************************************************************
C
      NF=NP
      NV=NDF
      LO=NCN
      NP=NH
      NDF=1
      NCN=NBN
      MWGA=-1
      IF(NPRA EQ.0) GO TO 36
      CALL FRONT
      KFRON=LFRON
      GO TO 38
   36 CONTINUE
      LFRON=KFRON
C     CALL RESOL
   38 CONTINUE
C
C*****************************************************************
C     OUTPUT STREAM FUNCTION VALUES (PSI(N))
C*****************************************************************
C
      NTRA=0
      REWIND 10
```

FETHSOLVAC (CONT.)

```
      WRITE(NLP,126)
      DO 40 N=1,NH
      NCOD(N)=0
      BC(N)=0.
      PSI(N)=SK(N)
      WRITE(NLP,152)PSI(N)
C     IF(NCARDS.NE.0)WRITE(NCP,130)N,PSI(N)
   40 CONTINUE
C
C*****************************************************************
C     CALLING VORTICITY COMPUTING ROUTINE
C*****************************************************************
C
      CALL WCALC
      REWIND 10
      NP=NF
      NOF=NV
      NCN=LQ
      MWBA=0
      NPRA=0
      CALL TIMER(IT3)
      ITIME2=IT3-IT1
      WRITE(NLP,102)NCA,ITIME2
      IF(ITER.EQ.1) GO TO 101
      GO TO 15
  101 CONTINUE
C
  102 FORMAT(//51H STREAM FUNCTION/VORTICITY CALCULATIONS CASE NUMBER,I3
     1,/,1H ,22H EXECUTION FINISHED AT,I4,6H SECS.//)
  116 FORMAT(I5,36H STREAM FUNCTION BOUNDARY CONDITIONS)
  122 FORMAT(I5)
  124 FORMAT(I10,F20.10)
  126 FORMAT(//16H STREAM FUNCTION//)
  129 FORMAT(7H IPUTO=,I2)
  130 FORMAT(I10,E20.10)
  152 FORMAT(30X,E15.7)
      RETURN
      END
C
C
C
C
C
C
      SUBROUTINE WCALC
C
C*****************************************************************
C     CALCULATES A VORTICITY FIELD FROM A VELOCITY FIELD
C*****************************************************************
```

FETHSOLVAC (CONT.)

```
C
C
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      COMMON/CONTR/
     1 X,Y,V,CONDF,BETA,CPF,RHO,HCOFX,HCOFY,
     2 GPF,GPG,GPH,EMU,XG(3),CG(3),DS,DX,DY,
     3 NP,NH,NE,NB,NDF,NCN,NBN,IT1,ND1,MTRD
     4,NTIME,MARK,NTR,LTIM,MTRIT,NCARDS,NSID,NAXI
     5,NRT,MWGA,NMP,NELL,NTRA,NGAUSS,NPR,NCR,NLP,NCP
     6,NCORD,IG,NG,NBV,NBT,NEWTON,ITURB,ICOND
      COMMON/GEP/
     1 TEMP(461),CORD(461,2),RSPEC(461,6)
     2,R1(1553),R2(1553),VARI(1553),VARA(1553),BC(1553)
     3,VALV(560),AVARI(1553),NOP(122,8),NDN(122),LPR(122)
     4,NOPP(461),MDF(461),NCOD(1553),NODV(560)
      COMMON/GUARD/
     1 SK(40000),ESTIFM(28,28),GISH(600),INTEG(2700)
      COMMON/UPWIN/
     1 AA1,AA2,A1,A2,BB1,BB2,B1,B2,DIS(3,461)
     2,WP(8),WDEL(2,8),WB(2,8),DWB(2,72),DWP(72),TT(9)
     3,UU(8),VV(8),UAVE(2),VAVE(2),IUPWIN,IWTS,VKIN,VKON
      COMMON/PSIW/
     1PSI(1000),NODP(200),VALP(200),
     2NODW(200),VALW(200),ALEN(40),BLEN(40),KINZ(40),KOUZ(40),
     3ITER,NCR,JAY,KINL,KOUT,PSIF,NBP,
     4NBW,NLB,NUB,NPRA,JFRON,KFRON,LFRON
      REWIND ND1
      IF(ITER.GT.1) GO TO 2
C
C*****************************************************************
C     READING IN VORTICITY BOUNDARY CONDITIONS (FOR EVERY NODE
C     ON THE BOUNDARY):
C             NB... TOTAL NUMBER OF BOUNDARY NODES,
C             NOD... NODE NUMBER,
C             VAL... VORTICITY VALUE.
C*****************************************************************
C
      READ(NCR,122)NB
      WRITE(NLP,116)NB
      NBW=NB
      IF(NB.EQ.0) GO TO 4
      DO 1 I=1,NB
      READ(NCR,124)NOD,VAL
      WRITE(NLP,124)NOD,VAL
      NCOD(NOD)=1
      BC(NOD)=VAL
      NODW(I)=NOD
      VALW(I)=VAL
    1 CONTINUE
      GO TO 4
```

FETHSOLVAC (CONT.)

```
      2 IF(NBW.EQ.0)GO TO 4
        DO 3 I=1,NBW
        NOD=NODW(I)
        NCOD(NOD)=1
        BC(NOD)=VALW(I)
      3 CONTINUE
      4 CONTINUE
        DO 5 I=1,NP
      5 R1(I)=0.
        MWGA=1
        IF(NPRA.EQ.0)GO TO 6
C
C*****************************************************************
C       CALLING FRONTAL ROUTINE
C*****************************************************************
C
        CALL FRONT
        JFRON=LFRON
        GO TO 8
      6 CONTINUE
        LFRON=JFRON
C       CALL RESOL
C
C*****************************************************************
C       OUTPUTING VORTICITY VALUES (R2(I))
C*****************************************************************
C
      8 WRITE(NLP,100)
        DO 12 N=1,NP
        R2(N)=SK(N)
        WRITE(NLP,153)R2(N)
     12 CONTINUE
        IF(NCARDS.EQ.0) GO TO 16
        DO 14 I=1,NP
C       WRITE(NCP,130)I,R2(I)
   14   CONTINUE
   16 CONTINUE
C
  100 FORMAT(/10H VORTICITY/)
  116 FORMAT(I5,30H VORTICITY BOUNDARY CONDITIONS)
  122 FORMAT(I5)
  124 FORMAT(I10,F20.10)
  130 FORMAT(I10,E20.10)
  152 FORMAT(I5,3E18.10,I5)
  153 FORMAT(30X,E15.7)
  200 FORMAT(/RIGHT HAND VECTORS FOR VORTICITY CALCULATIONS/)
  202 FORMAT(1X,3E20.6)
C
        RETURN
        END
```

FETHSOLVAC (CONT.)

```
C
C
C
C
C
C
      SUBROUTINE AUTOBC
C
C*****************************************************************
C     DETERMINE BOUNDARY VALUES FOR THE STREAM FUNCTION FIELD
C     CARTESIAN COORDINATES
C*****************************************************************
C
C
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      COMMON/CONTR/
     1 K,Y,V,CONDF,BETA,CPF,RHO,HCOFX,HCOFY,
     2 GPF,GPG,GPH,EMU,XG(3),CG(3),DS,DX,DY,
     3 NP,NH,NE,NB,NDF,NCN,NBN,IT1,ND1,MTRD
     4,NTIME,MARK,NTR,LTIM,MTRIT,NCARDS,NSID,NAKI
     5,NRT,MWGA,NNP,NELL,NTRA,NGAUSS,NPR,NCR,NLP,NCF
     6,NCORD,IG,NG,NBV,NBT,NEWTON,ITURB,ICOND
      COMMON/GEP/
     1 TEMP(461),COORD(461,2),RSPEC(461,6)
     2,R1(1553),R2(1553),VARI(1553),VARA(1553),BC(1553)
     3,VALV(560),AVARI(1553),NOP(122,8),NDN(122),LPR(122)
     4,NOPP(461),MDF(461),NCOD(1553),NODV(560)
      COMMON/GUARD/
     1 SK(40000),ESTIFM(28,28),GISH(600),INTEG(2700)
      COMMON/UPWIN/
     1 AA1,AA2,A1,A2,BB1,BB2,B1,B2,DIS(3,461)
     2,WP(8),NDEL(2,8),WB(2,8),DWB(2,72),DWP(72),TT(8)
     3,UU(8),VV(8),UAVE(2),VAVE(2),IUPWIN,IWTS,VKIN,VKON
      COMMON/PSIH/
     1PSI(1000),NODP(200),VALP(200),
     2NODW(200),VALW(200),ALEN(40),BLEN(40),KINZ(40),KOUZ(40),
     3ITER,NCA,JAY,KINL,KOUT,PSIF,NBP,
     4NBW,NLB,NUB,NPRA,IFRON,KFRON,LFRON
      IF(ITER.GT.1) GO TO 5
C
C*****************************************************************
C     READ INLET AND OUTLET NODES IN ORDER OF INCREASING PSI
C     READ IN ELEMENT SIDE LENGTH
C*****************************************************************
C
      WRITE(NLP,104)
C
C*****************************************************************
C     KINL= NUMBER OF ELEMENTS ON INLET BOUNDARY.
```

FETHSOLVAC (CONT.)

```
C*****************************************************************
C
      READ(NCR,100)KINL
      WRITE(NLP,102)KINL
      DO 2 I=1,KINL
C
C*****************************************************************
C     KINZ(I)= ELEMENT NUMBER.
C     ALEN(I)= LENGTH OF ELEMENT SIDE.
C*****************************************************************
C
      READ(NCR,106)KINZ(I),ALEN(I)
    2 WRITE(NLP,106)KINZ(I),ALEN(I)
C
C*****************************************************************
C     KOUT= NUMBER OF ELEMENTS ON OUTLET BOUNDARY
C*****************************************************************
C
      READ(NCR,100)KOUT
      WRITE(NLP,108)KOUT
C
C*****************************************************************
C     KOUZ(I)=ELEMENT NUMBER.
C     BLEN(I)=LENGTH OF ELEMENT SIDE.
C*****************************************************************
C
      DO 4 I=1,KOUT
      READ(NCR,106)KOUZ(I),BLEN(I)
    4 WRITE(NLP,106)KOUZ(I),BLEN(I)
C
C*****************************************************************
C     READ IN PSI VALUE ON FIXED BOUNDARY I.E. VALUE OF STREAM
C     FUNCTION TO BE SPECIFIED ON DATUM BOUNDARY
C*****************************************************************
C
      READ(NCR,110)PSIF
      WRITE(NLP,112)PSIF
C
C*****************************************************************
C     INLET AND OUTLET VALUES
C*****************************************************************
C
    5 CONTINUE
      P1(KINZ(1))=PSIF
      KIN=KINL-2
      DO 6 I=1,KIN,2
      J1=NOPP(KINZ(I))
      J2=NOPP(KINZ(I+1))
      J3=NOPP(KINZ(I+2))
      P1(KINZ(I+1))=P1(KINZ(I))
```

```
      1 +ALEN(I+1)*((5.*VARI(J1)-VARI(J3))/24.+VARI(J2)/3.)
        R1(KINZ(I+2))=R1(KINZ(I))
      1 +ALEN(I+1)*((VARI(J1)+VARI(J3))/6.-2.*VARI(J2)/3.)
    6 CONTINUE
C
        R1(KOUZ(1))=PSIF
        KOU=KOUT-2
        DO 8 I=1,KOU,2
        J1=NOPP(KOUZ(I))
        J2=NOPP(KOUZ(I+1))
        J3=NOPP(KOUZ(I+2))
        R1(KOUZ(I+1))=R1(KOUZ(I))
      1 +ALEN(I+1)*((5.*VARI(J1)-VARI(J3))/24.-VARI(J2)/3.)
        R1(KOUZ(I+2))=R1(KOUZ(I))
      1 +ALEN(I+1)*((VARI(J1)+VARI(J3))/6.-2.*VARI(J2)/3.)
    8 CONTINUE
        QASH=(R1(KINZ(KINL))+R1(KOUZ(KOUT)))/2.
        WRITE(NLP,124)R1(KINZ(KINL)),R2(KOUZ(KOUT))
        IF(ITER.GT.1) GO TO 25
C
C-----------------------------------------------------------------------
C       READING BOUNDARY NODES ON FIXED DATUM BOUNDARY
C       AND SETTING UP BOUNDARY CONDITIONS.
C           NLB= TOTAL NUMBER OF BOUNDARY NODES ON FIXED BOUNDARY.
C           NOD= NODE NUMBER.
C-----------------------------------------------------------------------
C
        READ(NCR,100)NLB
        WRITE(NLP,115)NLB
        DO 15 I=1,NLB
        READ(NCR,100)NOD
        WRITE(NLP,100)NOD
        NCOD(NOD)=1
        EO(NOD)=PSIF
        NODP(I)=NOD
   15 CONTINUE
C
C-----------------------------------------------------------------------
C       READING IN BOUNDARY NODES NOT ON FIXED DATUM BOUNDARY
C       AND SETTING UP CODING FOR BOUNDARY CONDITIONS.
C           NUB= TOTAL NUMBER OF BOUNDARY NODES NOT ON FIXED BOUNDARY.
C           NOD= NODE NUMBER.
C-----------------------------------------------------------------------
C
        READ(NCR,100)NUB
        WRITE(NLP,120)NUB
        DO 20 I=1,NUB
        READ(NCR,100)NOD
        WRITE(NLP,100)NOD
        NCOD(NOD)=1
```

FETHSOLVAC (CONT.)

```
      BC(NOD)=GASH
      L=NLB+I
      NODP(L)=NOD
   20 CONTINUE
      GO TO 40
   25 CONTINUE
      DO 30 I=1,NLB
      NOD=NODP(I)
      NCOD(NOD)=1
      BC(NOD)=PSIF
   30 CONTINUE
      DO 35 I=1,NUB
      L=NLB+I
      NOD=NODP(L)
      NCOD(NOD)=1
      BC(NOD)=GASH
   35 CONTINUE
   40 CONTINUE
      DO 50 I=1,NH
   50 R1(I)=0.
  100 FORMAT(I5)
  102 FORMAT(6H KINL=,I3)
  104 FORMAT(/'STREAM FUNCTION INLET/OUTLET NODE NUMBERS',/)
  106 FORMAT(I10,F20.10)
  108 FORMAT(6H KOUT=,I3)
  110 FORMAT(F20.10)
  112 FORMAT(11H PSI VALUE=,F20.10)
  116 FORMAT(/,I5,'STREAM FUNCTION SPECIFIED BOUNDARY CONDITIONS',/)
  120 FORMAT(/,I5,'STREAM FUNCTION CALCULATED BOUNDARY CONDITIONS',/)
  124 FORMAT(/'STREAM FUNCTION CALCULATED BOUNDARY VALUES'/2E20.10/)
      RETURN
      END
C
C
C
C
C
C
C
      SUBROUTINE ABFORMS
C
C*****************************************************
C     ELEMENT ASSEMBLING ROUTINE TO BE CALLED FROM
C     *FRONTAL* SOLUTION ROUTINE.
C-----------------------------------------------------
C     STREAM FUNCTION AND VORTICITY
C     JAY=0 , FOR CARTESIAN COORDINATES
C     JAY=1 , FOR AXISYMMETRIC CASE
C*****************************************************
C
```

FETHSOLVAC (CONT.)

```
C
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      COMMON/CONTR/
     1 X,Y,V,CONDF,BETA,CPF,RHO,HCOFX,HCOFY,
     2 GPF,GPG,GPH,EMU,XG(3),CG(3),DS,DX,DY,
     3 NP,NH,NE,NB,NDF,NCN,NBN,IT1,ND1,MTRD
     4,NTIME,MARK,NTR,LTIM,MTRIT,NCARDS,NSID,NAXI
     5,NRT,MWGR,NNP,NELL,NTRA,NGAUSS,NPR,NCR,NLP,NCP
     6,NCORD,IG,NG,NBV,NET,NEWTON,ITURB,ICOND
      COMMON/GEP/
     1 TEMP(461),CORD(461,2),RSPEC(461,6)
     2,R1(1553),R2(1553),VARI(1553),VARP(1553),BC(1553)
     3,VALW(560),AVARI(1553),NOP(122,8),NON(122),LPR(122)
     4,NOPP(461),MDF(461),NCOD(1553),NODW(560)
      COMMON/GUARD/
     1 SK(40000),ESTIFM(28,28),GISH(600),INTEG(2700)
      COMMON/UPWIN/
     1 AA1,AA2,A1,A2,BB1,BB2,B1,B2,DIE(3,461)
     2,WP(8),WDEL(2,8),WB(2,8),DWB(2,72),DWP(72),TT(8)
     3,UU(8),VV(8),UAVE(2),VAVE(2),IUPWIN,IWTS,VKIN,VKON
      COMMON/PSIW/
     1PSI(1000),NODP(200),VALP(200),
     2NODW(200),VALW(200),ALEN(40),BLEN(40),KINZ(40),KOUZ(40),
     3ITER,NCA,JAY,KINL,KOUT,PSIF,NBP,
     4NBW,NLB,NUB,NPRA,JFRON,KFRON,LFRON
      DIMENSION
     1AI1(12),AI2(12),P(12),DEL(2,12),B(2,12),AB(12,12),
     2CJ(2,2),CJI(2,2),GM(2,2),FF(2),FG(3),ETABLE(10,3),
     3PA(28,28),NK(28),PP(4),BB(2,4),CB(2,36),CP(36),
     4DE(2,72),DP(72),DDA(9),PHI(4),W(4,20),NAC(20)
      EQUIVALENCE
     1(ESTIFM(1,1),AA(1,1))
      JAV=NAXI
      JA=2
      IF(MARK.NE.3) JA=1
      DO 2 J=1,NBN
      AI1(J)=0.
    2 AI2(J)=0.
      DO 4 I=1,NBN
      DO 4 J=1,NBN
      AB(I,J)=0.
    4 AA(I,J)=0.
      READ(10)
     1 N,NG,LL,((DB(L,I),L=1,2),DP(I),I=1,NG),(DDA(L),L=1,LL),NGG
     2,((CB(L,I),L=1,2),CP(I),I=1,NGG)
      DO 20 NG=1,LL
      DA=DDA(NG)
      DO 9 I=1,NBN
      NJ=(NG-1)*NBN+I
      P(I)=DP(NJ)
```

FETHSOLVAC (CONT.)

```
      DO 6 L=1,2
    6 B(L,I)=DE(L,NJ)
    8 CONTINUE
      G1=0.
      G2=0.
      DO 12 L=1,NBN
      K=IABS(NOP(N,L))
      M1=NOPP(K)
      M3=M1+MDF(K)-JA
      G1=G1+B(1,L)*VARI(M3)-B(2,L)*VARI(M1)
      G2=G2+CORD(K,2)*P(L)
   12 CONTINUE
      G3=JAY/G2
      G4=(G2-1)*JAY+1
C
C*****************************************************************
C     RIGHT HAND SIDE
C*****************************************************************
C
      DO 14 I=1,NBN
      RI1(I)=RI1(I)+P(I)*DA*G1
      RI2(I)=RI2(I)+P(I)*DA*G1*G4
   14 CONTINUE
C
C*****************************************************************
C     FORM FLUID MATRICES
C*****************************************************************
C
      IF(NCA.GT.1) GO TO 18
      DO 16 I=1,NBN
      DO 16 L=1,NBN
      AA(I,L)=AA(I,L)+(B(1,I)*B(1,L)+B(2,I)*B(2,L))*DA
     1 +P(I)*G3*B(2,L)*DA
      AB(I,L)=AB(I,L)+P(I)*P(L)*DA
   16 CONTINUE
   18 CONTINUE
   20 CONTINUE
      IF(MWGA.LT.0)GO TO 30
      DO 25 I=1,NBN
      NI=IABS(NOP(NELL,I))
      R1(NI)=R1(NI)+RI1(I)
      DO 25 J=1,NBN
      AP(I,J)=AB(I,J)
   25 CONTINUE
      GO TO 40
   30 DO 35 I=1,NBN
      NI=IABS(NOP(NELL,I))
      R1(NI)=R1(NI)+RI2(I)
   35 CONTINUE
   40 CONTINUE
```

FETHSOLVAC (CONT.)

```
5101:C      WRITE(NLP,100)((AA(I,L),I=1,NBN),L=1,NBN)
5102    100 FORMAT(8E10.3)
5103:       RETURN
5104:       END
```

- END -

# APPENDIX III

## PROGRAM INPUT/OUTPUT

```
LOUGHBOROUGH UNIVERSITY

****   ***   **** *****
*   * *   * *      *
****  ***** * *** ****
*     *   * *   * *
*     *   *  **** *****

*****  ***  ****  *   *  ***  ***** ***** ***** ****
*     *   * *   * ** ** *   *   *     *     *     *   *
****  *   * ****  * * * *****   *     *     ****  ****
*     *   * *  *  *   * *   *   *     *     *     *  *
*       ***  *   * *   * *   *   *     *     ***** *   *

VERSION 4
```

## INPUT/OUTPUT

PROGRAMMER : Mohammed J. K. Alshatam
DATE : 11 . 01 . 1985
TIME : 13:53

INPUT/OUTPUT

```
     INDATA5-40DEG
This is the data file for both coupled
and uncoupled solutions.


            LAMINAR AND TURBULENT RECIRCULATING, CONVECTIVE, BUOYANT FLOWS
            AND HEAT TRANSFER ANALYSIS OF SOLAR POWERED VENTILATION AND
            AIR-CONDITIONING SYSTEM USING THE FINITE ELEMENT METHOD (F.E.M.)
  3    0    0    0    1
     0.0262400000        0.0033160000     1005.7000000000
     0.0000198300        1.1774000000        0.0000000000      -9.810000000
461
  0
  1
  0
  10800
170
       1   0.0000000000   0.0000000000
       3   0.0000000000   0.0180000000
       5   0.0000000000   0.0310000000
       7   0.0000000000   0.0510000000
       9   0.0000000000   0.0910000000
      11   0.0000000000   0.1410000000
      13   0.0000000000   0.3210000000
      15   0.0000000000   0.5010000000
      17   0.0000000000   0.6810000000
      19   0.0000000000   0.8610000000
      21   0.0030000000   1.0410000000
      23   0.0030000000   1.1430000000
      25   0.0030000000   1.1630000000
      39   0.0450000000   0.0000000000
      41   0.0450000000   0.0180000000
      43   0.0450000000   0.0310000000
      45   0.0450000000   0.0510000000
      47   0.0450000000   0.0910000000
      49   0.0450000000   0.1410000000
      51   0.0450000000   0.3210000000
      53   0.0450000000   0.5010000000
      55   0.0450000000   0.6810000000
      57   0.0450000000   0.8610000000
      59   0.0450000000   1.0410000000
      61   0.0450000000   1.1430000000
      63   0.0450000000   1.1630000000
      77   0.0900000000   0.0000000000
      79   0.0900000000   0.0180000000
      81   0.0900000000   0.0310000000
      83   0.0900000000   0.0510000000
      85   0.0900000000   0.0910000000
      87   0.0900000000   0.1410000000
```

INPUT/OUTPUT (CONT.)

| | | |
|---|---|---|
| 89 | 0.0900000000 | 0.3210000000 |
| 91 | 0.0900000000 | 0.5010000000 |
| 93 | 0.0900000000 | 0.6810000000 |
| 95 | 0.0900000000 | 0.8610000000 |
| 97 | 0.0900000000 | 1.0410000000 |
| 99 | 0.0900000000 | 1.1430000000 |
| 101 | 0.0900000000 | 1.1630000000 |
| 105 | 0.1080000000 | 0.0180000000 |
| 107 | 0.1080000000 | 0.0580000000 |
| 109 | 0.1080000000 | 0.0680000000 |
| 111 | 0.1080000000 | 0.1410000000 |
| 113 | 0.1080000000 | 0.4110000000 |
| 115 | 0.1080000000 | 0.6810000000 |
| 117 | 0.1080000000 | 0.8610000000 |
| 119 | 0.1080000000 | 0.9510000000 |
| 121 | 0.1080000000 | 1.0230000000 |
| 123 | 0.1080000000 | 1.0410000000 |
| 125 | 0.1080000000 | 1.1430000000 |
| 127 | 0.1080000000 | 1.1630000000 |
| 140 | 0.1505000000 | 0.0180000000 |
| 142 | 0.1505000000 | 0.0580000000 |
| 144 | 0.1505000000 | 0.0680000000 |
| 146 | 0.1505000000 | 0.1410000000 |
| 148 | 0.1505000000 | 0.4110000000 |
| 150 | 0.1505000000 | 0.6810000000 |
| 152 | 0.1505000000 | 0.8610000000 |
| 154 | 0.1505000000 | 0.9510000000 |
| 156 | 0.1505000000 | 1.0230000000 |
| 158 | 0.1505000000 | 1.0410000000 |
| 160 | 0.1505000000 | 1.1430000000 |
| 162 | 0.1505000000 | 1.1630000000 |
| 175 | 0.1980000000 | 0.0180000000 |
| 177 | 0.1980000000 | 0.0580000000 |
| 179 | 0.1980000000 | 0.0680000000 |
| 181 | 0.1980000000 | 0.1410000000 |
| 183 | 0.1980000000 | 0.4110000000 |
| 185 | 0.1980000000 | 0.6810000000 |
| 187 | 0.1980000000 | 0.8610000000 |
| 189 | 0.1980000000 | 0.9510000000 |
| 191 | 0.1980000000 | 1.0230000000 |
| 193 | 0.1980000000 | 1.0410000000 |
| 195 | 0.1980000000 | 1.1430000000 |
| 197 | 0.1980000000 | 1.1630000000 |
| 207 | 0.3740000000 | 0.0180000000 |
| 209 | 0.3740000000 | 0.0580000000 |
| 211 | 0.3740000000 | 0.0680000000 |
| 213 | 0.3740000000 | 0.1410000000 |
| 215 | 0.3740000000 | 0.4110000000 |
| 217 | 0.3740000000 | 0.6810000000 |
| 219 | 0.3740000000 | 0.8610000000 |

INPUT/OUTPUT (CONT.)

| | | |
|---|---|---|
| 221 | 0.3740000000 | 0.9510000000 |
| 223 | 0.3740000000 | 1.0230000000 |
| 233 | 0.5740000000 | 0.0180000000 |
| 235 | 0.5740000000 | 0.0580000000 |
| 237 | 0.5740000000 | 0.0680000000 |
| 239 | 0.5740000000 | 0.1410000000 |
| 241 | 0.5740000000 | 0.4110000000 |
| 243 | 0.5740000000 | 0.6810000000 |
| 245 | 0.5740000000 | 0.8610000000 |
| 247 | 0.5740000000 | 0.9510000000 |
| 249 | 0.5740000000 | 1.0230000000 |
| 259 | 0.8292000000 | 0.0180000000 |
| 261 | 0.8292000000 | 0.0580000000 |
| 263 | 0.8292000000 | 0.0680000000 |
| 265 | 0.8292000000 | 0.1410000000 |
| 267 | 0.8292000000 | 0.4110000000 |
| 269 | 0.8292000000 | 0.6810000000 |
| 271 | 0.8292000000 | 0.8610000000 |
| 273 | 0.8292000000 | 0.9510000000 |
| 275 | 0.8292000000 | 1.0230000000 |
| 285 | 1.0056000000 | 0.0180000000 |
| 287 | 1.0056000000 | 0.0580000000 |
| 289 | 1.0056000000 | 0.0680000000 |
| 291 | 1.0056000000 | 0.1410000000 |
| 293 | 1.0056000000 | 0.4110000000 |
| 295 | 1.0056000000 | 0.6810000000 |
| 297 | 1.0056000000 | 0.8610000000 |
| 299 | 1.0056000000 | 0.9510000000 |
| 301 | 1.0056000000 | 1.0230000000 |
| 311 | 1.1230000000 | 0.0180000000 |
| 313 | 1.1230000000 | 0.0580000000 |
| 315 | 1.1230000000 | 0.0680000000 |
| 317 | 1.1230000000 | 0.1410000000 |
| 319 | 1.1230000000 | 0.4110000000 |
| 321 | 1.1230000000 | 0.6810000000 |
| 323 | 1.1230000000 | 0.8610000000 |
| 325 | 1.1230000000 | 0.9510000000 |
| 327 | 1.1230000000 | 1.0230000000 |
| 337 | 1.1480000000 | 0.0180000000 |
| 339 | 1.1480000000 | 0.0580000000 |
| 341 | 1.1480000000 | 0.0680000000 |
| 343 | 1.1480000000 | 0.1410000000 |
| 345 | 1.1480000000 | 0.4110000000 |
| 347 | 1.1480000000 | 0.6810000000 |
| 349 | 1.1480000000 | 0.8610000000 |
| 351 | 1.1480000000 | 0.9510000000 |
| 353 | 1.1480000000 | 1.0230000000 |
| 357 | 1.1660000000 | 0.0180000000 |
| 359 | 1.1660000000 | 0.0580000000 |
| 361 | 1.1660000000 | 0.0680000000 |

INPUT/OUTPUT (CONT.)

| | | |
|---|---|---|
| 364 | 1.2372500000 | 0.0180000000 |
| 366 | 1.2372500000 | 0.0580000000 |
| 369 | 1.3160000000 | 0.0180000000 |
| 371 | 1.3160000000 | 0.0580000000 |
| 373 | 1.3160000000 | 0.0680000000 |
| 377 | 1.3340000000 | 0.0000000000 |
| 379 | 1.3340000000 | 0.0180000000 |
| 381 | 1.3340000000 | 0.0580000000 |
| 383 | 1.3340000000 | 0.0680000000 |
| 385 | 1.3340000000 | 0.1410000000 |
| 387 | 1.3340000000 | 0.3210000000 |
| 389 | 1.3340000000 | 0.5010000000 |
| 391 | 1.3340000000 | 0.6810000000 |
| 393 | 1.3340000000 | 0.8610000000 |
| 395 | 1.3340000000 | 1.0230000000 |
| 397 | 1.3340000000 | 1.0710000000 |
| 409 | 1.3765000000 | 0.0000000000 |
| 411 | 1.3765000000 | 0.0180000000 |
| 413 | 1.3765000000 | 0.0580000000 |
| 415 | 1.3765000000 | 0.0680000000 |
| 417 | 1.3765000000 | 0.1410000000 |
| 419 | 1.3765000000 | 0.3210000000 |
| 421 | 1.3765000000 | 0.5010000000 |
| 423 | 1.3765000000 | 0.6810000000 |
| 425 | 1.3765000000 | 0.8610000000 |
| 427 | 1.3765000000 | 1.0230000000 |
| 429 | 1.3765000000 | 1.0710000000 |
| 441 | 1.4190000000 | 0.0000000000 |
| 443 | 1.4190000000 | 0.0180000000 |
| 445 | 1.4190000000 | 0.0580000000 |
| 447 | 1.4190000000 | 0.0680000000 |
| 449 | 1.4190000000 | 0.1410000000 |
| 451 | 1.4190000000 | 0.3210000000 |
| 453 | 1.4190000000 | 0.5010000000 |
| 455 | 1.4190000000 | 0.6810000000 |
| 457 | 1.4190000000 | 0.8610000000 |
| 459 | 1.4190000000 | 1.0230000000 |
| 461 | 1.4190000000 | 1.0710000000 |

122

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 26 | 39 | 40 | 41 | 27 | 3 | 2 |
| 2 | 3 | 27 | 41 | 42 | 43 | 28 | 5 | 4 |
| 3 | 5 | 28 | 43 | 44 | 45 | 29 | 7 | 6 |
| 4 | 7 | 29 | 45 | 46 | 47 | 30 | 9 | 8 |
| 5 | 9 | 30 | 47 | 48 | 49 | 31 | 11 | 10 |
| 6 | 11 | 31 | 49 | 50 | 51 | 32 | 13 | 12 |
| 7 | 13 | 32 | 51 | 52 | 53 | 33 | 15 | 14 |
| 8 | 15 | 33 | 53 | 54 | 55 | 34 | 17 | 16 |
| 9 | 17 | 34 | 55 | 56 | 57 | 35 | 19 | 18 |
| 10 | 19 | 35 | 57 | 58 | 59 | 36 | 21 | 20 |
| 11 | 21 | 36 | 59 | 60 | 61 | 37 | 23 | 22 |

INPUT/OUTPUT (CONT.)

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 12 | 23 | 37 | 61 | 62 | 63 | 38 | 25 | 24 |
| 13 | 39 | 64 | 77 | 78 | 79 | 65 | 41 | 40 |
| 14 | 41 | 65 | 79 | 80 | 81 | 66 | 43 | 42 |
| 15 | 43 | 66 | 81 | 82 | 83 | 67 | 45 | 44 |
| 16 | 45 | 67 | 83 | 84 | 85 | 68 | 47 | 46 |
| 17 | 47 | 68 | 85 | 86 | 87 | 69 | 49 | 48 |
| 18 | 49 | 69 | 87 | 88 | 89 | 70 | 51 | 50 |
| 19 | 51 | 70 | 89 | 90 | 91 | 71 | 53 | 52 |
| 20 | 53 | 71 | 91 | 92 | 93 | 72 | 55 | 54 |
| 21 | 55 | 72 | 93 | 94 | 95 | 73 | 57 | 56 |
| 22 | 57 | 73 | 95 | 96 | 97 | 74 | 59 | 58 |
| 23 | 59 | 74 | 97 | 98 | 99 | 75 | 61 | 60 |
| 24 | 61 | 75 | 99 | 100 | 101 | 76 | 63 | 62 |
| 25 | 97 | 102 | 123 | 124 | 125 | 103 | 99 | 98 |
| 26 | 99 | 103 | 125 | 126 | 127 | 104 | 101 | 100 |
| 27 | 105 | 128 | 140 | 141 | 142 | 129 | 107 | 106 |
| 28 | 107 | 129 | 142 | 143 | 144 | 130 | 109 | 108 |
| 29 | 109 | 130 | 144 | 145 | 146 | 131 | 111 | 110 |
| 30 | 111 | 131 | 146 | 147 | 148 | 132 | 113 | 112 |
| 31 | 113 | 132 | 148 | 149 | 150 | 133 | 115 | 114 |
| 32 | 115 | 133 | 150 | 151 | 152 | 134 | 117 | 116 |
| 33 | 117 | 134 | 152 | 153 | 154 | 135 | 119 | 118 |
| 34 | 119 | 135 | 154 | 155 | 156 | 136 | 121 | 120 |
| 35 | 121 | 136 | 156 | 157 | 158 | 137 | 123 | 122 |
| 36 | 123 | 137 | 158 | 159 | 160 | 138 | 125 | 124 |
| 37 | 125 | 138 | 160 | 161 | 162 | 139 | 127 | 126 |
| 38 | 140 | 163 | 175 | 176 | 177 | 164 | 142 | 141 |
| 39 | 142 | 164 | 177 | 178 | 179 | 165 | 144 | 143 |
| 40 | 144 | 165 | 179 | 180 | 181 | 166 | 146 | 145 |
| 41 | 146 | 166 | 181 | 182 | 183 | 167 | 148 | 147 |
| 42 | 148 | 167 | 183 | 184 | 185 | 168 | 150 | 149 |
| 43 | 150 | 168 | 185 | 186 | 187 | 169 | 152 | 151 |
| 44 | 152 | 169 | 187 | 188 | 189 | 170 | 154 | 153 |
| 45 | 154 | 170 | 189 | 190 | 191 | 171 | 156 | 155 |
| 46 | 156 | 171 | 191 | 192 | 193 | 172 | 158 | 157 |
| 47 | 158 | 172 | 193 | 194 | 195 | 173 | 160 | 159 |
| 48 | 160 | 173 | 195 | 196 | 197 | 174 | 162 | 161 |
| 49 | 175 | 198 | 207 | 208 | 209 | 199 | 177 | 176 |
| 50 | 177 | 199 | 209 | 210 | 211 | 200 | 179 | 178 |
| 51 | 179 | 200 | 211 | 212 | 213 | 201 | 181 | 180 |
| 52 | 181 | 201 | 213 | 214 | 215 | 202 | 183 | 182 |
| 53 | 183 | 202 | 215 | 216 | 217 | 203 | 185 | 184 |
| 54 | 185 | 203 | 217 | 218 | 219 | 204 | 187 | 186 |
| 55 | 187 | 204 | 219 | 220 | 221 | 205 | 189 | 188 |
| 56 | 189 | 205 | 221 | 222 | 223 | 206 | 191 | 190 |
| 57 | 207 | 224 | 233 | 234 | 235 | 225 | 209 | 208 |
| 58 | 209 | 225 | 235 | 236 | 237 | 226 | 211 | 210 |
| 59 | 211 | 226 | 237 | 238 | 239 | 227 | 213 | 212 |
| 60 | 213 | 227 | 239 | 240 | 241 | 228 | 215 | 214 |
| 61 | 215 | 228 | 241 | 242 | 243 | 229 | 217 | 216 |

INPUT/OUTPUT (CONT.)

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 62 | 217 | 229 | 243 | 244 | 245 | 230 | 219 | 218 |
| 63 | 219 | 230 | 245 | 246 | 247 | 231 | 221 | 220 |
| 64 | 221 | 231 | 247 | 248 | 249 | 232 | 223 | 222 |
| 65 | 233 | 250 | 259 | 260 | 261 | 251 | 235 | 234 |
| 66 | 235 | 251 | 261 | 262 | 263 | 252 | 237 | 236 |
| 67 | 237 | 252 | 263 | 264 | 265 | 253 | 239 | 238 |
| 68 | 239 | 253 | 265 | 266 | 267 | 254 | 241 | 240 |
| 69 | 241 | 254 | 267 | 268 | 269 | 255 | 243 | 242 |
| 70 | 243 | 255 | 269 | 270 | 271 | 256 | 245 | 244 |
| 71 | 245 | 256 | 271 | 272 | 273 | 257 | 247 | 246 |
| 72 | 247 | 257 | 273 | 274 | 275 | 258 | 249 | 248 |
| 73 | 259 | 276 | 285 | 286 | 287 | 277 | 261 | 260 |
| 74 | 261 | 277 | 287 | 288 | 289 | 278 | 263 | 262 |
| 75 | 263 | 278 | 289 | 290 | 291 | 279 | 265 | 264 |
| 76 | 265 | 279 | 291 | 292 | 293 | 280 | 267 | 266 |
| 77 | 267 | 280 | 293 | 294 | 295 | 281 | 269 | 268 |
| 78 | 269 | 281 | 295 | 296 | 297 | 282 | 271 | 270 |
| 79 | 271 | 282 | 297 | 298 | 299 | 283 | 273 | 272 |
| 80 | 273 | 283 | 299 | 300 | 301 | 284 | 275 | 274 |
| 81 | 285 | 302 | 311 | 312 | 313 | 303 | 287 | 286 |
| 82 | 287 | 303 | 313 | 314 | 315 | 304 | 289 | 288 |
| 83 | 289 | 304 | 315 | 316 | 317 | 305 | 291 | 290 |
| 84 | 291 | 305 | 317 | 318 | 319 | 306 | 293 | 292 |
| 85 | 293 | 306 | 319 | 320 | 321 | 307 | 295 | 294 |
| 86 | 295 | 307 | 321 | 322 | 323 | 308 | 297 | 296 |
| 87 | 297 | 308 | 323 | 324 | 325 | 309 | 299 | 298 |
| 88 | 299 | 309 | 325 | 326 | 327 | 310 | 301 | 300 |
| 89 | 311 | 328 | 337 | 338 | 339 | 329 | 313 | 312 |
| 90 | 313 | 329 | 339 | 340 | 341 | 330 | 315 | 314 |
| 91 | 315 | 330 | 341 | 342 | 343 | 331 | 317 | 316 |
| 92 | 317 | 331 | 343 | 344 | 345 | 332 | 319 | 318 |
| 93 | 319 | 332 | 345 | 346 | 347 | 333 | 321 | 320 |
| 94 | 321 | 333 | 347 | 348 | 349 | 334 | 323 | 322 |
| 95 | 323 | 334 | 349 | 350 | 351 | 335 | 325 | 324 |
| 96 | 325 | 335 | 351 | 352 | 353 | 336 | 327 | 326 |
| 97 | 337 | 354 | 357 | 358 | 359 | 355 | 339 | 338 |
| 98 | 339 | 355 | 359 | 360 | 361 | 356 | 341 | 340 |
| 99 | 357 | 362 | 364 | 365 | 366 | 363 | 359 | 358 |
| 100 | 364 | 367 | 369 | 370 | 371 | 368 | 366 | 365 |
| 101 | 369 | 374 | 379 | 380 | 381 | 375 | 371 | 370 |
| 102 | 371 | 375 | 381 | 382 | 383 | 376 | 373 | 372 |
| 103 | 377 | 398 | 409 | 410 | 411 | 399 | 379 | 378 |
| 104 | 379 | 399 | 411 | 412 | 413 | 400 | 381 | 380 |
| 105 | 381 | 400 | 413 | 414 | 415 | 401 | 383 | 382 |
| 106 | 383 | 401 | 415 | 416 | 417 | 402 | 385 | 384 |
| 107 | 385 | 402 | 417 | 418 | 419 | 403 | 387 | 386 |
| 108 | 387 | 403 | 419 | 420 | 421 | 404 | 389 | 388 |
| 109 | 389 | 404 | 421 | 422 | 423 | 405 | 391 | 390 |
| 110 | 391 | 405 | 423 | 424 | 425 | 406 | 393 | 392 |
| 111 | 393 | 406 | 425 | 426 | 427 | 407 | 395 | 394 |

INPUT/OUTPUT (CONT.)

```
  112     395  407  427  428  429  408  397  396
  113     409  430  441  442  443  431  411  410
  114     411  431  443  444  445  432  413  412
  115     413  432  445  446  447  433  415  414
  116     415  433  447  448  449  434  417  416
  117     417  434  449  450  451  435  419  418
  118     419  435  451  452  453  436  421  420
  119     421  436  453  454  455  437  423  422
  120     423  437  455  456  457  438  425  424
  121     425  438  457  458  459  439  427  426
  122     427  439  459  460  461  440  429  428
   1553
    0
  515
    1     1          0.0000000000
    1     3          0.0000000000
    2     3          0.0000000000
    3     3          0.0000000000
    4     3          0.0000000000
    5     3          0.0000000000
    6     3          0.0000000000
    7     1          0.0000000000
    7     3          0.0000000000
    8     1          0.0000000000
    8     3          0.0000000000
    9     1          0.0000000000
    9     3          0.0000000000
   10     1          0.0000000000
   10     3          0.0000000000
   11     1          0.0000000000
   11     3          0.0000000000
   12     1          0.0000000000
   12     3          0.0000000000
   13     1          0.0000000000
   13     3          0.0000000000
   14     1          0.0000000000
   14     3          0.0000000000
   15     1          0.0000000000
   15     3          0.0000000000
   16     1          0.0000000000
   16     3          0.0000000000
   17     1          0.0000000000
   17     3          0.0000000000
   18     1          0.0000000000
   18     3          0.0000000000
   19     1          0.0000000000
   19     3          0.0000000000
   20     1          0.0000000000
   20     3          0.0000000000
   21     1          0.0000000000
```

this is the total number of (U, V, P, T) boundary conditions for the coupled soln.

For uncoupled solution take away the temperature boundary conditions, which in this case are 152. Therefore, this number 515 changes to 515-152 = 363.

INPUT/OUTPUT (CONT.)

| | | |
|---|---|---|
| 21 | 3 | 0.0000000000 |
| 22 | 1 | 0.0000000000 |
| 22 | 3 | 0.0000000000 |
| 23 | 1 | 0.0000000000 |
| 23 | 3 | 0.0000000000 |
| 24 | 1 | 0.0000000000 |
| 24 | 3 | 0.0000000000 |
| 25 | 1 | 0.0000000000 |
| 25 | 3 | 0.0000000000 |
| 26 | 1 | 0.0000000000 |
| 26 | 3 | 0.0000000000 |
| 39 | 1 | 0.0000000000 |
| 39 | 3 | 0.0000000000 |
| 64 | 1 | 0.0000000000 |
| 64 | 3 | 0.0000000000 |
| 77 | 1 | 0.0000000000 |
| 77 | 3 | 0.0000000000 |
| 78 | 1 | 0.0000000000 |
| 78 | 3 | 0.0000000000 |
| 79 | 1 | 0.0000000000 |
| 79 | 3 | 0.0000000000 |
| 80 | 1 | 0.0000000000 |
| 80 | 3 | 0.0000000000 |
| 81 | 1 | 0.0000000000 |
| 81 | 3 | 0.0000000000 |
| 82 | 1 | 0.0000000000 |
| 82 | 3 | 0.0000000000 |
| 83 | 1 | 0.0000000000 |
| 83 | 3 | 0.0000000000 |
| 84 | 1 | 0.0000000000 |
| 84 | 3 | 0.0000000000 |
| 85 | 1 | 0.0000000000 |
| 85 | 3 | 0.0000000000 |
| 86 | 1 | 0.0000000000 |
| 86 | 3 | 0.0000000000 |
| 87 | 1 | 0.0000000000 |
| 87 | 3 | 0.0000000000 |
| 88 | 1 | 0.0000000000 |
| 88 | 3 | 0.0000000000 |
| 89 | 1 | 0.0000000000 |
| 89 | 3 | 0.0000000000 |
| 90 | 1 | 0.0000000000 |
| 90 | 3 | 0.0000000000 |
| 91 | 1 | 0.0000000000 |
| 91 | 3 | 0.0000000000 |
| 92 | 1 | 0.0000000000 |
| 92 | 3 | 0.0000000000 |
| 93 | 1 | 0.0000000000 |
| 93 | 3 | 0.0000000000 |
| 94 | 1 | 0.0000000000 |

INPUT/OUTPUT (CONT.)

| | | |
|---|---|---|
| 94 | 3 | 0.0000000000 |
| 95 | 1 | 0.0000000000 |
| 95 | 3 | 0.0000000000 |
| 96 | 1 | 0.0000000000 |
| 96 | 3 | 0.0000000000 |
| 97 | 1 | 0.0000000000 |
| 97 | 3 | 0.0000000000 |
| 102 | 1 | 0.0000000000 |
| 102 | 3 | 0.0000000000 |
| 105 | 1 | 0.0000000000 |
| 105 | 3 | 0.0000000000 |
| 106 | 1 | 0.0000000000 |
| 106 | 3 | 0.0000000000 |
| 107 | 1 | 0.0000000000 |
| 107 | 3 | 0.0000000000 |
| 108 | 1 | 0.0000000000 |
| 108 | 3 | 0.0000000000 |
| 109 | 1 | 0.0000000000 |
| 109 | 3 | 0.0000000000 |
| 110 | 1 | 0.0000000000 |
| 110 | 3 | 0.0000000000 |
| 111 | 1 | 0.0000000000 |
| 111 | 3 | 0.0000000000 |
| 112 | 1 | 0.0000000000 |
| 112 | 3 | 0.0000000000 |
| 113 | 1 | 0.0000000000 |
| 113 | 3 | 0.0000000000 |
| 114 | 1 | 0.0000000000 |
| 114 | 3 | 0.0000000000 |
| 115 | 1 | 0.0000000000 |
| 115 | 3 | 0.0000000000 |
| 116 | 1 | 0.0000000000 |
| 116 | 3 | 0.0000000000 |
| 117 | 1 | 0.0000000000 |
| 117 | 3 | 0.0000000000 |
| 118 | 1 | 0.0000000000 |
| 118 | 3 | 0.0000000000 |
| 119 | 1 | 0.0000000000 |
| 119 | 3 | 0.0000000000 |
| 120 | 1 | 0.0000000000 |
| 120 | 3 | 0.0000000000 |
| 121 | 1 | 0.0000000000 |
| 121 | 3 | 0.0000000000 |
| 122 | 1 | 0.0000000000 |
| 122 | 3 | 0.0000000000 |
| 123 | 1 | 0.0000000000 |
| 123 | 3 | 0.0000000000 |
| 128 | 1 | 0.0000000000 |
| 128 | 3 | 0.0000000000 |
| 140 | 1 | 0.0000000000 |

INPUT/OUTPUT (CONT.)

| | | |
|---|---|---|
| 140 | 3 | 0.0000000000 |
| 163 | 1 | 0.0000000000 |
| 163 | 3 | 0.0000000000 |
| 175 | 1 | 0.0000000000 |
| 175 | 3 | 0.0000000000 |
| 1 | 2 | 0.0000000000 |
| 3 | 2 | 0.0000000000 |
| 5 | 2 | 0.0000000000 |
| 7 | 2 | 0.0000000000 |
| 25 | 2 | 0.0000000000 |
| 63 | 2 | 0.0000000000 |
| 101 | 2 | 0.0000000000 |
| 127 | 2 | 0.0000000000 |
| 162 | 2 | 0.0000000000 |
| 197 | 2 | 0.0000000000 |
| 397 | 2 | 0.0000000000 |
| 429 | 2 | 0.0000000000 |
| 461 | 2 | 0.0000000000 |
| 191 | 1 | 0.0000000000 |
| 191 | 3 | 0.0000000000 |
| 192 | 1 | 0.0000000000 |
| 192 | 3 | 0.0000000000 |
| 193 | 1 | 0.0000000000 |
| 193 | 3 | 0.0000000000 |
| 194 | 1 | 0.0000000000 |
| 194 | 3 | 0.0000000000 |
| 195 | 1 | 0.0000000000 |
| 195 | 3 | 0.0000000000 |
| 196 | 1 | 0.0000000000 |
| 196 | 3 | 0.0000000000 |
| 197 | 1 | 0.0000000000 |
| 197 | 3 | 0.0000000000 |
| 198 | 1 | 0.0000000000 |
| 198 | 3 | 0.0000000000 |
| 206 | 1 | 0.0000000000 |
| 206 | 3 | 0.0000000000 |
| 207 | 1 | 0.0000000000 |
| 207 | 3 | 0.0000000000 |
| 223 | 1 | 0.0000000000 |
| 223 | 3 | 0.0000000000 |
| 224 | 1 | 0.0000000000 |
| 224 | 3 | 0.0000000000 |
| 232 | 1 | 0.0000000000 |
| 232 | 3 | 0.0000000000 |
| 233 | 1 | 0.0000000000 |
| 233 | 3 | 0.0000000000 |
| 249 | 1 | 0.0000000000 |
| 249 | 3 | 0.0000000000 |
| 250 | 1 | 0.0000000000 |
| 250 | 3 | 0.0000000000 |

INPUT/OUTPUT (CONT.)

| | | |
|---|---|---|
| 258 | 1 | 0.0000000000 |
| 258 | 3 | 0.0000000000 |
| 259 | 1 | 0.0000000000 |
| 259 | 3 | 0.0000000000 |
| 275 | 1 | 0.0000000000 |
| 275 | 3 | 0.0000000000 |
| 276 | 1 | 0.0000000000 |
| 276 | 3 | 0.0000000000 |
| 284 | 1 | 0.0000000000 |
| 284 | 3 | 0.0000000000 |
| 285 | 1 | 0.0000000000 |
| 285 | 3 | 0.0000000000 |
| 301 | 1 | 0.0000000000 |
| 301 | 3 | 0.0000000000 |
| 302 | 1 | 0.0000000000 |
| 302 | 3 | 0.0000000000 |
| 310 | 1 | 0.0000000000 |
| 310 | 3 | 0.0000000000 |
| 311 | 1 | 0.0000000000 |
| 311 | 3 | 0.0000000000 |
| 327 | 1 | 0.0000000000 |
| 327 | 3 | 0.0000000000 |
| 328 | 1 | 0.0000000000 |
| 328 | 3 | 0.0000000000 |
| 336 | 1 | 0.0000000000 |
| 336 | 3 | 0.0000000000 |
| 337 | 1 | 0.0000000000 |
| 337 | 3 | 0.0000000000 |
| 341 | 1 | 0.0000000000 |
| 341 | 3 | 0.0000000000 |
| 342 | 1 | 0.0000000000 |
| 342 | 3 | 0.0000000000 |
| 343 | 1 | 0.0000000000 |
| 343 | 3 | 0.0000000000 |
| 344 | 1 | 0.0000000000 |
| 344 | 3 | 0.0000000000 |
| 345 | 1 | 0.0000000000 |
| 345 | 3 | 0.0000000000 |
| 346 | 1 | 0.0000000000 |
| 346 | 3 | 0.0000000000 |
| 347 | 1 | 0.0000000000 |
| 347 | 3 | 0.0000000000 |
| 348 | 1 | 0.0000000000 |
| 348 | 3 | 0.0000000000 |
| 349 | 1 | 0.0000000000 |
| 349 | 3 | 0.0000000000 |
| 350 | 1 | 0.0000000000 |
| 350 | 3 | 0.0000000000 |
| 351 | 1 | 0.0000000000 |
| 351 | 3 | 0.0000000000 |

INPUT/OUTPUT (CONT.)

| | | |
|---|---|---|
| 352 | 1 | 0.0000000000 |
| 352 | 3 | 0.0000000000 |
| 353 | 1 | 0.0000000000 |
| 353 | 3 | 0.0000000000 |
| 354 | 1 | 0.0000000000 |
| 354 | 3 | 0.0000000000 |
| 356 | 1 | 0.0000000000 |
| 356 | 3 | 0.0000000000 |
| 357 | 1 | 0.0000000000 |
| 357 | 3 | 0.0000000000 |
| 359 | 1 | 0.0000000000 |
| 359 | 3 | 0.0000000000 |
| 360 | 1 | 0.0000000000 |
| 360 | 3 | 0.0000000000 |
| 361 | 1 | 0.0000000000 |
| 361 | 3 | 0.0000000000 |
| 362 | 1 | 0.0000000000 |
| 362 | 3 | 0.0000000000 |
| 363 | 1 | 0.0000000000 |
| 363 | 3 | 0.0000000000 |
| 364 | 1 | 0.0000000000 |
| 364 | 3 | 0.0000000000 |
| 365 | 1 | 0.0000000000 |
| 365 | 3 | 0.0000000000 |
| 367 | 1 | 0.0000000000 |
| 367 | 3 | 0.0000000000 |
| 368 | 1 | 0.0000000000 |
| 368 | 3 | 0.0000000000 |
| 369 | 1 | 0.0000000000 |
| 369 | 3 | 0.0000000000 |
| 371 | 1 | 0.0000000000 |
| 371 | 3 | 0.0000000000 |
| 372 | 1 | 0.0000000000 |
| 372 | 3 | 0.0000000000 |
| 373 | 1 | 0.0000000000 |
| 373 | 3 | 0.0000000000 |
| 374 | 1 | 0.0000000000 |
| 374 | 3 | 0.0000000000 |
| 376 | 1 | 0.0000000000 |
| 376 | 3 | 0.0000000000 |
| 377 | 1 | 0.0000000000 |
| 377 | 3 | 0.0000000000 |
| 378 | 1 | 0.0000000000 |
| 378 | 3 | 0.0000000000 |
| 379 | 1 | 0.0000000000 |
| 379 | 3 | 0.0000000000 |
| 383 | 1 | 0.0000000000 |
| 383 | 3 | 0.0000000000 |
| 384 | 1 | 0.0000000000 |
| 384 | 3 | 0.0000000000 |

INPUT/OUTPUT (CONT.)

| | | |
|---|---|---|
| 385 | 1 | 0.0000000000 |
| 385 | 3 | 0.0000000000 |
| 386 | 1 | 0.0000000000 |
| 386 | 3 | 0.0000000000 |
| 387 | 1 | 0.0000000000 |
| 387 | 3 | 0.0000000000 |
| 388 | 1 | 0.0000000000 |
| 388 | 3 | 0.0000000000 |
| 389 | 1 | 0.0000000000 |
| 389 | 3 | 0.0000000000 |
| 390 | 1 | 0.0000000000 |
| 390 | 3 | 0.0000000000 |
| 391 | 1 | 0.0000000000 |
| 391 | 3 | 0.0000000000 |
| 392 | 1 | 0.0000000000 |
| 392 | 3 | 0.0000000000 |
| 393 | 1 | 0.0000000000 |
| 393 | 3 | 0.0000000000 |
| 394 | 1 | 0.0000000000 |
| 394 | 3 | 0.0000000000 |
| 395 | 1 | 0.0000000000 |
| 395 | 3 | 0.0000000000 |
| 396 | 1 | 0.0000000000 |
| 396 | 3 | 0.0000000000 |
| 397 | 1 | 0.0000000000 |
| 397 | 3 | 0.0000000000 |
| 398 | 1 | 0.0000000000 |
| 398 | 3 | 0.0000000000 |
| 399 | 1 | 0.0000000000 |
| 399 | 1 | 0.0000000000 |
| 399 | 3 | 0.0000000000 |
| 399 | 1 | 0.0000000000 |
| 400 | 1 | 0.0000000000 |
| 400 | 3 | 0.0000000000 |
| 401 | 1 | 0.0000000000 |
| 401 | 1 | 0.0000000000 |
| 401 | 3 | 0.0000000000 |
| 402 | 1 | 0.0000000000 |
| 402 | 3 | 0.0000000000 |
| 403 | 1 | 0.0000000000 |
| 403 | 3 | 0.0000000000 |
| 404 | 1 | 0.0000000000 |
| 404 | 3 | 0.0000000000 |
| 405 | 1 | 0.0000000000 |
| 405 | 3 | 0.0000000000 |
| 406 | 1 | 0.0000000000 |
| 406 | 3 | 0.0000000000 |
| 407 | 1 | 0.0000000000 |
| 407 | 3 | 0.0000000000 |
| 408 | 1 | 0.0000000000 |
| 408 | 3 | 0.0000000000 |
| 409 | 1 | 0.0000000000 |
| 409 | 1 | 0.0000000000 |
| 409 | 3 | 0.0000000000 |
| 409 | 1 | 0.0000000000 |
| 410 | 1 | 0.0000000000 |
| 410 | 3 | 0.0000000000 |
| 411 | 1 | 0.0000000000 |
| 411 | 1 | 0.0000000000 |
| 411 | 3 | 0.0000000000 |
| 412 | 1 | 0.0000000000 |
| 412 | 3 | 0.0000000000 |
| 413 | 1 | 0.0000000000 |
| 413 | 3 | 0.0000000000 |
| 414 | 1 | 0.0000000000 |
| 414 | 3 | 0.0000000000 |
| 415 | 1 | 0.0000000000 |
| 415 | 3 | 0.0000000000 |
| 416 | 1 | 0.0000000000 |
| 416 | 3 | 0.0000000000 |
| 417 | 1 | 0.0000000000 |
| 417 | 3 | 0.0000000000 |
| 418 | 1 | 0.0000000000 |

INPUT/OUTPUT (CONT.)

| | | |
|---|---|---|
| 448 | 3 | 0.0000000000 |
| 449 | 1 | 0.0000000000 |
| 449 | 3 | 0.0000000000 |
| 450 | 1 | 0.0000000000 |
| 450 | 3 | 0.0000000000 |
| 451 | 1 | 0.0000000000 |
| 451 | 3 | 0.0000000000 |
| 452 | 1 | 0.0000000000 |
| 452 | 3 | 0.0000000000 |
| 453 | 1 | 0.0000000000 |
| 453 | 3 | 0.0000000000 |
| 454 | 1 | 0.0000000000 |
| 454 | 3 | 0.0000000000 |
| 455 | 1 | 0.0000000000 |
| 455 | 3 | 0.0000000000 |
| 456 | 1 | 0.0000000000 |
| 456 | 3 | 0.0000000000 |
| 457 | 1 | 0.0000000000 |
| 457 | 3 | 0.0000000000 |
| 458 | 1 | 0.0000000000 |
| 458 | 3 | 0.0000000000 |
| 459 | 1 | 0.0000000000 |
| 459 | 3 | 0.0000000000 |
| 460 | 1 | 0.0000000000 |
| 460 | 3 | 0.0000000000 |
| 461 | 1 | 0.0000000000 |
| 461 | 3 | 0.0000000000 |
| 1 | 4 | 23.0000000000 |
| 7 | 4 | 26.0000000000 |
| 8 | 4 | 26.0000000000 |
| 9 | 4 | 26.0000000000 |
| 10 | 4 | 26.0000000000 |
| 11 | 4 | 26.0000000000 |
| 12 | 4 | 26.0000000000 |
| 13 | 4 | 26.0000000000 |
| 14 | 4 | 26.0000000000 |
| 15 | 4 | 26.0000000000 |
| 16 | 4 | 26.0000000000 |
| 17 | 4 | 26.0000000000 |
| 18 | 4 | 26.0000000000 |
| 19 | 4 | 26.0000000000 |
| 20 | 4 | 26.0000000000 |
| 21 | 4 | 26.0000000000 |
| 22 | 4 | 24.0000000000 |
| 23 | 4 | 24.0000000000 |
| 24 | 4 | 24.0000000000 |
| 25 | 4 | 24.0000000000 |
| 26 | 4 | 18.0000000000 |
| 39 | 4 | 18.0000000000 |
| 64 | 4 | 18.0000000000 |

for uncoupled sol$^{n}$.,
Insert here the Number of Temperature specified boundary conditions, i.e. in this case 152 with a Format (I5).

INPUT/OUTPUT (CONT.)

| | | |
|---|---|---|
| 77 | 4 | 37.0000000000 |
| 78 | 4 | 37.0000000000 |
| 79 | 4 | 37.0000000000 |
| 80 | 4 | 37.0000000000 |
| 81 | 4 | 37.0000000000 |
| 82 | 4 | 37.0000000000 |
| 83 | 4 | 37.0000000000 |
| 84 | 4 | 37.0000000000 |
| 85 | 4 | 40.0000000000 |
| 86 | 4 | 40.0000000000 |
| 87 | 4 | 40.0000000000 |
| 88 | 4 | 40.0000000000 |
| 89 | 4 | 40.0000000000 |
| 90 | 4 | 40.0000000000 |
| 91 | 4 | 40.0000000000 |
| 92 | 4 | 40.0000000000 |
| 93 | 4 | 40.0000000000 |
| 94 | 4 | 40.0000000000 |
| 95 | 4 | 40.0000000000 |
| 96 | 4 | 40.0000000000 |
| 97 | 4 | 40.0000000000 |
| 102 | 4 | 32.0000000000 |
| 128 | 4 | 18.0000000000 |
| 140 | 4 | 18.0000000000 |
| 163 | 4 | 18.0000000000 |
| 175 | 4 | 18.0000000000 |
| 191 | 4 | 18.0000000000 |
| 192 | 4 | 18.0000000000 |
| 193 | 4 | 18.0000000000 |
| 194 | 4 | 18.0000000000 |
| 195 | 4 | 18.0000000000 |
| 196 | 4 | 18.0000000000 |
| 197 | 4 | 18.0000000000 |
| 198 | 4 | 18.0000000000 |
| 206 | 4 | 18.0000000000 |
| 207 | 4 | 18.0000000000 |
| 223 | 4 | 18.0000000000 |
| 224 | 4 | 18.0000000000 |
| 232 | 4 | 18.0000000000 |
| 233 | 4 | 18.0000000000 |
| 249 | 4 | 18.0000000000 |
| 250 | 4 | 18.0000000000 |
| 258 | 4 | 18.0000000000 |
| 259 | 4 | 18.0000000000 |
| 275 | 4 | 18.0000000000 |
| 276 | 4 | 18.0000000000 |
| 284 | 4 | 18.0000000000 |
| 285 | 4 | 18.0000000000 |
| 301 | 4 | 18.0000000000 |
| 302 | 4 | 18.0000000000 |

INPUT/OUTPUT (CONT.)

| | | |
|---|---|---|
| 310 | 4 | 18. 0000000000 |
| 311 | 4 | 18. 0000000000 |
| 327 | 4 | 18. 0000000000 |
| 328 | 4 | 18. 0000000000 |
| 336 | 4 | 18. 0000000000 |
| 337 | 4 | 18. 0000000000 |
| 341 | 4 | 18. 0000000000 |
| 342 | 4 | 18. 0000000000 |
| 343 | 4 | 18. 0000000000 |
| 344 | 4 | 18. 0000000000 |
| 345 | 4 | 18. 0000000000 |
| 346 | 4 | 18. 0000000000 |
| 347 | 4 | 18. 0000000000 |
| 348 | 4 | 18. 0000000000 |
| 349 | 4 | 18. 0000000000 |
| 350 | 4 | 18. 0000000000 |
| 351 | 4 | 18. 0000000000 |
| 352 | 4 | 18. 0000000000 |
| 353 | 4 | 18. 0000000000 |
| 354 | 4 | 18. 0000000000 |
| 356 | 4 | 18. 0000000000 |
| 357 | 4 | 18. 0000000000 |
| 359 | 4 | 18. 0000000000 |
| 360 | 4 | 18. 0000000000 |
| 361 | 4 | 18. 0000000000 |
| 362 | 4 | 18. 0000000000 |
| 363 | 4 | 18. 0000000000 |
| 364 | 4 | 18. 0000000000 |
| 366 | 4 | 18. 0000000000 |
| 367 | 4 | 18. 0000000000 |
| 368 | 4 | 18. 0000000000 |
| 369 | 4 | 18. 0000000000 |
| 371 | 4 | 18. 0000000000 |
| 372 | 4 | 18. 0000000000 |
| 373 | 4 | 18. 0000000000 |
| 374 | 4 | 18. 0000000000 |
| 376 | 4 | 18. 0000000000 |
| 377 | 4 | 18. 0000000000 |
| 378 | 4 | 18. 0000000000 |
| 379 | 4 | 18. 0000000000 |
| 383 | 4 | 18. 0000000000 |
| 384 | 4 | 18. 0000000000 |
| 385 | 4 | 18. 0000000000 |
| 386 | 4 | 18. 0000000000 |
| 387 | 4 | 18. 0000000000 |
| 388 | 4 | 18. 0000000000 |
| 389 | 4 | 18. 0000000000 |
| 390 | 4 | 18. 0000000000 |
| 391 | 4 | 18. 0000000000 |
| 392 | 4 | 18. 0000000000 |

INPUT/OUTPUT (CONT.)

```
393     4          18.0000000000
394     4          18.0000000000
395     4          18.0000000000
396     4          18.0000000000
397     4          18.0000000000
398     4          18.0000000000
409     4          18.0000000000
430     4          18.0000000000
441     4          18.0000000000
442     4          18.0000000000
443     4          18.0000000000
444     4          18.0000000000
445     4          18.0000000000
446     4          18.0000000000
447     4          18.0000000000
449     4          18.0000000000
449     4          18.0000000000
450     4          18.0000000000
451     4          18.0000000000
452     4          18.0000000000
453     4          18.0000000000
454     4          18.0000000000
455     4          18.0000000000
456     4          18.0000000000
457     4          18.0000000000
458     4          18.0000000000
459     4          18.0000000000
460     4          18.0000000000
461     4          18.0000000000
  0
  1
  1
  3
      112          0.0390000000
      122          0.0390000000
        3          0.0500000000
  5
       12          0.0050000000
       24          0.0720000000
       26          0.0180000000
       37          0.0225000000
       48          0.0275000000
       0.0000000000
175
  1
  2
  3
  4
  5
  7
```

175 conditions for $\underline{\underline{\psi}}$

INPUT/OUTPUT (CONT.)

```
443
444
445
446
447
448
449
450
451
452
453
454
455
456
457
458
459
460
461
 13
  6
 38
 63
 76
101
104
127
139
162
174
408
429
440
175
```

up to here

| | |
|---|---|
| 1 | 0.0000000000 |
| 2 | 0.0000000000 |
| 3 | 0.0000000000 |
| 4 | 0.0000000000 |
| 5 | 0.0000000000 |
| 7 | 0.0000000000 |
| 8 | 0.0000000000 |
| 9 | 0.0000000000 |
| 10 | 0.0000000000 |
| 11 | 0.0000000000 |
| 12 | 0.0000000000 |
| 13 | 0.0000000000 |
| 14 | 0.0000000000 |
| 15 | 0.0000000000 |
| 16 | 0.0000000000 |
| 17 | 0.0000000000 |

175 conditions for $\underline{\omega}$

INPUT/OUTPUT (CONT.)

```
453        0.0000000000
454        0.0000000000
455        0.0000000000
456        0.0000000000
457        0.0000000000
458        0.0000000000
459        0.0000000000
460        0.0000000000
461        0.0000000000
```

up to here

OUTPUT40DEG
This is the output file for the coupled solution.

```
FINITE ELEMENT PROGRAM IN INCOMPRESSIBLE VISCOUS
LAMINAR AND/OR  TURBULENT FLOW INCLUDING HEAT TRANSFER.
IT SOLVES N-S , CONTINUITY , AND THE GENERAL ENERGY
EQUATIONS FOR STEADY STATES.  IT ALSO CALCULATES VARIOUS
FLUID FLOW AND HEAT TRANSFER PARAMETERS.

%%%
```

INPUT/OUTPUT (CONT.)

DENSITY=RHO=(kg/m**3)
SPECIFIC HEAT CAPACITY FOR CONSTANT PRESSURE=CPF=
CP=[w/sec/kgK (J/kgK)]
DYNAMIC VISCOSITY=MU=[kg/m sec(N sec/m**2)]
KINEMATIC VISCOSITY=NU=(m**2/sec)
THERMAL CONDUCTIVITY=CONDF=K=(w/mK)
COEFFICIENT OF CUBICAL EXPANSION=BETA=(m**3/K)

ELEMENT DATA
NH=461
MTRO= 0
NCAPOS= 1
MTRIT= 0
LTIM=10800SECS.
NNP=170
NCN= 28

IRREGULAR COORDINATES-READ IN DATA

IRREGULAR MESH-READ IN NODAL DATA

NE=122

ELEMENT NODE NUMBERING

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 26 | 39 | 40 | 41 | 27 | 3 | 2 |
| 2 | 3 | 27 | 41 | 42 | 43 | 28 | 5 | 4 |
| 3 | 5 | 28 | 43 | 44 | 45 | 29 | 7 | 6 |
| 4 | 7 | 29 | 45 | 46 | 47 | 30 | 9 | 8 |
| 5 | 9 | 30 | 47 | 48 | 49 | 31 | 11 | 10 |
| 6 | 11 | 31 | 49 | 50 | 51 | 32 | 13 | 12 |
| 7 | 13 | 32 | 51 | 52 | 53 | 33 | 15 | 14 |
| 8 | 15 | 33 | 53 | 54 | 55 | 34 | 17 | 16 |
| 9 | 17 | 34 | 55 | 56 | 57 | 35 | 19 | 18 |
| 10 | 19 | 35 | 57 | 58 | 59 | 36 | 21 | 20 |
| 11 | 21 | 36 | 59 | 60 | 61 | 37 | 23 | 22 |
| 12 | 23 | 37 | 61 | 62 | 63 | 38 | 25 | 24 |
| 13 | 39 | 64 | 77 | 78 | 79 | 65 | 41 | 40 |
| 14 | 41 | 65 | 79 | 80 | 81 | 66 | 43 | 42 |
| 15 | 43 | 66 | 81 | 82 | 83 | 67 | 45 | 44 |
| 16 | 45 | 67 | 83 | 84 | 85 | 68 | 47 | 46 |
| 17 | 47 | 68 | 85 | 86 | 87 | 69 | 49 | 48 |
| 18 | 49 | 69 | 87 | 88 | 89 | 70 | 51 | 50 |

122 element connectivity

INPUT/OUTPUT (CONT.)

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 119 | 421 | 436 | 453 | 454 | 455 | 437 | 423 | 422 |
| 120 | 423 | 437 | 455 | 456 | 457 | 438 | 425 | 424 |
| 121 | 425 | 438 | 457 | 458 | 459 | 439 | 427 | 426 |
| 122 | 427 | 439 | 459 | 460 | 461 | 440 | 429 | 428 |

up to here

NP=1553

ICOND= 1553

INITIAL STATE

| NODE | U-VELOCITY | PRESSURES | V-VELOCITY | TEMPERATURE |
|---|---|---|---|---|
| 1 | 0.0000000000E+00 | 0.0000000000E+00 | 0.0000000000E+00 | 0.2200000000E+02 |
| 2 | 0.8380561628E-03 | | 0.0000000000E+00 | 0.2275073555E+02 |
| 3 | 0.1227721742E-02 | 0.0000000000E+00 | 0.0000000000E+00 | 0.2314081113E+02 |
| 4 | 0.1286932554E-02 | | 0.0000000000E+00 | 0.2358369827E+02 |
| 5 | 0.1281112824E-02 | 0.0000000000E+00 | 0.0000000000E+00 | 0.2405674627E+02 |
| 6 | 0.8401570776E-03 | | 0.0000000000E+00 | 0.2516029792E+02 |
| 7 | 0.0000000000E+00 | 0.0000000000E+00 | 0.0000000000E+00 | 0.2600000000E+02 |
| 8 | 0.0000000000E+00 | | 0.0000000000E+00 | 0.2600000000E+02 |
| 9 | 0.0000000000E+00 | -0.1299551978E-01 | 0.0000000000E+00 | 0.2600000000E+02 |
| 10 | 0.0000000000E+00 | | 0.0000000000E+00 | 0.2600000000E+02 |
| 11 | 0.0000000000E+00 | -0.7132372830E-02 | 0.0000000000E+00 | 0.2600000000E+02 |
| 12 | 0.0000000000E+00 | | 0.0000000000E+00 | 0.2600000000E+02 |
| 13 | 0.0000000000E+00 | -0.7444176796E-02 | 0.0000000000E+00 | 0.2600000000E+02 |
| 14 | 0.0000000000E+00 | | 0.0000000000E+00 | 0.2600000000E+02 |
| 15 | 0.0000000000E+00 | -0.6195314162E-02 | 0.0000000000E+00 | 0.2600000000E+02 |
| 16 | 0.0000000000E+00 | | 0.0000000000E+00 | 0.2600000000E+02 |
| 17 | 0.0000000000E+00 | -0.5709512882E-02 | 0.0000000000E+00 | 0.2600000000E+02 |
| 18 | 0.0000000000E+00 | | 0.0000000000E+00 | 0.2600000000E+02 |
| 19 | 0.0000000000E+00 | -0.4282656652E-02 | 0.0000000000E+00 | 0.2600000000E+02 |
| 20 | 0.0000000000E+00 | | 0.0000000000E+00 | 0.2600000000E+02 |
| 21 | 0.0000000000E+00 | -0.6061988543E-02 | 0.0000000000E+00 | 0.2600000000E+02 |
| 22 | 0.0000000000E+00 | | 0.0000000000E+00 | 0.2400000000E+02 |
| 23 | 0.0000000000E+00 | -0.3611024208E-02 | 0.0000000000E+00 | 0.2400000000E+02 |
| 24 | 0.0000000000E+00 | | 0.0000000000E+00 | 0.2400000000E+02 |
| 25 | 0.0000000000E+00 | 0.0000000000E+00 | 0.0000000000E+00 | 0.2400000000E+02 |
| 26 | 0.0000000000E+00 | | 0.0000000000E+00 | 0.1800000000E+02 |
| 27 | 0.1190456773E-02 | | 0.2693779268E-03 | 0.2316867101E+02 |
| 28 | 0.1238402447E-02 | | 0.4098241347E-03 | 0.2431531372E+02 |
| 29 | 0.7812244638E-03 | | 0.8714010995E-03 | 0.2700122239E+02 |
| 30 | -0.1067099224E-03 | | 0.8881661897E-03 | 0.2972055216E+02 |
| 31 | 0.1426551115E-04 | | 0.7921683790E-03 | 0.2938899790E+02 |
| 32 | -0.1714485483E-04 | | 0.9381019239E-03 | 0.2953954855E+02 |
| 33 | 0.4944592221E-05 | | 0.8249255178E-03 | 0.2953780796E+02 |
| 34 | -0.1710231204E-05 | | 0.8199085578E-03 | 0.2953725012E+02 |
| 35 | 0.6237493491E-05 | | 0.8574434982E-03 | 0.2946135842E+02 |
| 36 | 0.4142700307E-04 | | 0.6821705563E-03 | 0.2832927695E+02 |

461 nodes

INPUT/OUTPUT (CONT.)

up to here

| | | | | |
|---|---|---|---|---|
| 437 | -0.3317227602E-08 | | -0.6570711816E-04 | 0.1800229676E+02 |
| 438 | 0.1295424512E-08 | | -0.6574114798E-04 | 0.1800221179E+02 |
| 439 | 0.5743540448E-09 | | -0.6572789146E-04 | 0.1800216603E+02 |
| 440 | 0.0000000000E+00 | | -0.6572493207E-04 | 0.1800215563E+02 |
| 441 | 0.0000000000E+00 | -0.7527963181E-01 | 0.0000000000E+00 | 0.1800000000E+02 |
| 442 | 0.0000000000E+00 | | 0.0000000000E+00 | 0.1800000000E+02 |
| 443 | 0.0000000000E-00 | -0.7401452238E-01 | 0.0000000000E+00 | 0.1800000000E+02 |
| 444 | 0.0000000000E-00 | | 0.0000000000E+00 | 0.1800000000E+02 |
| 445 | 0.0000000000E+00 | -0.7120302803E-01 | 0.0000000000E+00 | 0.1800000000E+02 |
| 446 | 0.0000000000E+00 | | 0.0000000000E+00 | 0.1800000000E+02 |
| 447 | 0.0000000000E-00 | -0.7050012167E-01 | 0.0000000000E+00 | 0.1800000000E+02 |
| 448 | 0.0000000000E+00 | | 0.0000000000E+00 | 0.1800000000E+02 |
| 449 | 0.0000000000E-00 | -0.6536999992E-01 | 0.0000000000E+00 | 0.1800000000E+02 |
| 450 | 0.0000000000E+00 | | 0.0000000000E+00 | 0.1800000000E+02 |
| 451 | 0.0000000000E+00 | -0.5271670212E-01 | 0.0000000000E+00 | 0.1800000000E+02 |
| 452 | 0.0000000000E-00 | | 0.0000000000E+00 | 0.1800000000E+02 |
| 453 | 0.0000000000E+00 | -0.4006458515E-01 | 0.0000000000E+00 | 0.1800000000E+02 |
| 454 | 0.0000000000E+00 | | 0.0000000000E+00 | 0.1800000000E+02 |
| 455 | 0.0000000000E+00 | -0.2741254190E-01 | 0.0000000000E+00 | 0.1800000000E+02 |
| 456 | 0.0000000000E+00 | | 0.0000000000E+00 | 0.1800000000E+02 |
| 457 | 0.0000000000E+00 | -0.1476056681E-01 | 0.0000000000E+00 | 0.1800000000E+02 |
| 458 | 0.0000000000E+00 | | 0.0000000000E+00 | 0.1800000000E+02 |
| 459 | 0.0000000000E+00 | -0.3373834458E-02 | 0.0000000000E+00 | 0.1800000000E+02 |
| 460 | 0.0000000000E+00 | | 0.0000000000E+00 | 0.1800000000E+02 |
| 461 | 0.0000000000E+00 | 0.0000000000E+00 | 0.0000000000E+00 | 0.1800000000E+02 |

| NODE | NOFP | Y OR Z-COORDINATE | Y OR R-COORDINATE | NDF |
|---|---|---|---|---|
| 1 | 1 | 0.0000000000 | 0.0000000000 | 4 |
| 2 | 5 | 0.0000000000 | 0.0090000000 | 3 |
| 3 | 8 | 0.0000000000 | 0.0180000000 | 4 |
| 4 | 12 | 0.0000000000 | 0.0245000000 | 3 |
| 5 | 15 | 0.0000000000 | 0.0310000000 | 4 |
| 6 | 19 | 0.0000000000 | 0.0410000000 | 3 |
| 7 | 22 | 0.0000000000 | 0.0510000000 | 4 |
| 8 | 26 | 0.0000000000 | 0.0710000000 | 3 |
| 9 | 29 | 0.0000000000 | 0.0910000000 | 4 |
| 10 | 33 | 0.0000000000 | 0.1160000000 | 3 |
| 11 | 36 | 0.0000000000 | 0.1410000000 | 4 |
| 12 | 40 | 0.0000000000 | 0.2310000000 | 3 |
| 13 | 43 | 0.0000000000 | 0.3210000000 | 4 |
| 14 | 47 | 0.0000000000 | 0.4110000000 | 3 |
| 15 | 50 | 0.0000000000 | 0.5010000000 | 4 |
| 16 | 54 | 0.0000000000 | 0.5910000000 | 3 |
| 17 | 57 | 0.0000000000 | 0.6810000000 | 4 |
| 18 | 61 | 0.0000000000 | 0.7710000000 | 3 |
| 19 | 64 | 0.0000000000 | 0.8610000000 | 4 |
| 20 | 68 | 0.0015000000 | 0.9510000000 | 3 |
| 21 | 71 | 0.0030000000 | 1.0410000000 | 4 |
| 22 | 75 | 0.0030000000 | 1.0920000000 | 3 |

461 node, global d.o.f., and coordinate

INPUT/OUTPUT (CONT.)

| | | | | |
|---|---|---|---|---|
| 423 | 1422 | 1.3765000000 | 0.6810000000 | 4 |
| 424 | 1425 | 1.3765000000 | 0.7710000000 | 3 |
| 425 | 1429 | 1.3765000000 | 0.8610000000 | 4 |
| 426 | 1432 | 1.3765000000 | 0.9420000000 | 3 |
| 427 | 1436 | 1.3765000000 | 1.0230000000 | 4 |
| 428 | 1440 | 1.3765000000 | 1.0470000000 | 3 |
| 429 | 1442 | 1.3765000000 | 1.0710000000 | 4 |
| 430 | 1447 | 1.3977500000 | 0.0000000000 | 3 |
| 431 | 1450 | 1.3977500000 | 0.0180000000 | 3 |
| 432 | 1453 | 1.3977500000 | 0.0580000000 | 3 |
| 433 | 1456 | 1.3977500000 | 0.0680000000 | 3 |
| 434 | 1459 | 1.3977500000 | 0.1410000000 | 3 |
| 435 | 1462 | 1.3977500000 | 0.3210000000 | 3 |
| 436 | 1465 | 1.3977500000 | 0.5010000000 | 3 |
| 437 | 1468 | 1.3977500000 | 0.6810000000 | 3 |
| 438 | 1471 | 1.3977500000 | 0.9610000000 | 3 |
| 439 | 1474 | 1.3977500000 | 1.0270000000 | 3 |
| 440 | 1477 | 1.3977500000 | 1.0710000000 | 3 |
| 441 | 1480 | 1.4190000000 | 0.0000000000 | 4 |
| 442 | 1484 | 1.4190000000 | 0.0090000000 | 3 |
| 443 | 1487 | 1.4190000000 | 0.0180000000 | 4 |
| 444 | 1491 | 1.4190000000 | 0.0780000000 | 3 |
| 445 | 1494 | 1.4190000000 | 0.0580000000 | 4 |
| 446 | 1498 | 1.4190000000 | 0.0670000000 | 3 |
| 447 | 1501 | 1.4190000000 | 0.0680000000 | 4 |
| 448 | 1505 | 1.4190000000 | 0.1045000000 | 3 |
| 449 | 1508 | 1.4190000000 | 0.1410000000 | 4 |
| 450 | 1512 | 1.4190000000 | 0.2315000000 | 3 |
| 451 | 1515 | 1.4190000000 | 0.3210000000 | 4 |
| 452 | 1519 | 1.4190000000 | 0.4110000000 | 3 |
| 453 | 1522 | 1.4190000000 | 0.5010000000 | 4 |
| 454 | 1526 | 1.4190000000 | 0.5910000000 | 3 |
| 455 | 1529 | 1.4190000000 | 0.6810000000 | 4 |
| 456 | 1533 | 1.4190000000 | 0.7710000000 | 3 |
| 457 | 1536 | 1.4190000000 | 0.8610000000 | 4 |
| 458 | 1540 | 1.4190000000 | 0.9420000000 | 3 |
| 459 | 1543 | 1.4190000000 | 1.0230000000 | 4 |
| 460 | 1547 | 1.4190000000 | 1.0470000000 | 3 |
| 461 | 1550 | 1.4190000000 | 1.0710000000 | 4 |

up to here

NRT= 0

DATA GENERATION COMPLETE AT 19 SECS.

JACOBIAN AND DERIVATIVE CALCULATIONS COMPLETE AT 34 SECS.

515 BOUNDARY CONDITIONS

INPUT/OUTPUT (CONT.)

| NODE | D. O. F. 1 | D. O. F. 2 | D. O. F. 3 | D. O. F. 4 |
|---|---|---|---|---|
| 1 | 0. 0000000E+00 | | | |
| 1 | | | 0. 0000000E+00 | |
| 2 | | | 0. 0000000E+00 | |
| 2 | | | 0. 0000000E+00 | |
| 4 | | | 0. 0000000E+00 | |
| 5 | | | 0. 0000000E+00 | |
| 6 | | | 0. 0000000E+00 | |
| 7 | 0. 0000000E+00 | | | |
| 7 | | | 0. 0000000E+00 | |
| 9 | 0. 0000000E+00 | | | |
| 9 | | | 0. 0000000E+00 | |
| 9 | 0. 0000000E+00 | | | |
| 9 | | | 0 0000000E+00 | |
| 10 | 0. 0000000E+00 | | | |
| 10 | | | 0. 0000000E+00 | |
| 11 | 0. 0000000E+00 | | | |
| 11 | | | 0. 0000000E+00 | |
| 12 | 0. 0000000E+00 | | | |
| 12 | | | 0. 0000000E+00 | |
| 13 | 0. 0000000E+00 | | | |
| 13 | | | 0 0000000E+00 | |
| 14 | 0. 0000000E+00 | | | |
| 14 | | | 0. 0000000E+00 | |
| 15 | 0. 0000000E+00 | | | |
| 15 | | | 0. 0000000E+00 | |
| 16 | 0. 0000000E+00 | | | |
| 16 | | | 0. 0000000E+00 | |
| 17 | 0. 0000000E+00 | | | |
| 17 | | | 0. 0000000E+00 | |
| 18 | 0. 0000000E+00 | | | |
| 18 | | | 0. 0000000E+00 | |
| 19 | 0 0000000E+00 | | | |
| 19 | | | 0. 0000000E+00 | |
| 20 | 0. 0000000E+00 | | | |
| 20 | | | 0. 0000000E+00 | |
| 21 | 0. 0000000E+00 | | | |
| 21 | | | 0. 0000000E+00 | |
| 22 | 0. 0000000E+00 | | | |
| 22 | | | 0. 0000000E+00 | |
| 23 | 0. 0000000E+00 | | | |

515 cases for coupled soln.

INPUT/OUTPUT (CONT.)

| | |
|---|---|
| 446 | 0.1800000E+02 |
| 447 | 0.1800000E+02 |
| 448 | 0.1800000E+02 |
| 449 | 0.1800000E+02 |
| 450 | 0.1800000E+02 |
| 451 | 0.1800000E+02 |
| 452 | 0.1800000E+02 |
| 453 | 0.1800000E+02 |
| 454 | 0.1800000E+02 |
| 455 | 0.1800000E+02 |
| 456 | 0.1800000E+02 |
| 457 | 0.1800000E+02 |
| 458 | 0.1800000E+02 |
| 459 | 0.1800000E+02 |
| 460 | 0.1800000E+02 |
| 461 | 0.1800000E+02 |

up to here

SOLUTION ROUTINE ENTERED AT 36 SECS.

EXIT FROM SOLUTION ROUTINE AT 475 SECS.

LARGEST RELATIVE CHANGE IN ANY VARIABLE= 0.1152832599E-02

ITERATION NO. = 1

| NODE | U-VELOCITY | PRESSURES | V-VELOCITY | TEMPERATURE |
|---|---|---|---|---|
| 1 | 0.0000000000E+00 | 0.0000000000E+00 | 0.0000000000E+00 | 0.2300000000E+02 |
| 2 | 0.9379536631E-02 | | 0.0000000000E+00 | 0.2274645930E+02 |
| 3 | 0.1227422869E-02 | 0.0000000000E+00 | 0.0000000000E+00 | 0.2313433390E+02 |
| 4 | 0.1296F163398E-02 | | 0.0000000000E+00 | 0.2357744548E+02 |
| 5 | 0.1280795176E-02 | 0.0000000000E-00 | 0.0000000000E+00 | 0.2405095725E+02 |
| 6 | 0.9299404984E-02 | | 0.0000000000E+00 | 0.2515746222E+02 |
| 7 | 0.0000000000E+00 | 0.0000000000E+00 | 0.0000000000E+00 | 0.2600000000E+02 |
| 8 | 0.0000000000E+00 | | 0.0000000000E+00 | 0.2600000000E+02 |
| 9 | 0.0000000000E+00 | -0.1299101813E-01 | 0.0000000000E+00 | 0.2600000000E+02 |
| 10 | 0.0000000000E+00 | | 0.0000000000E+00 | 0.2600000000E+02 |
| 11 | 0.0000000000E+00 | -0.7130260618E-02 | 0.0000000000E+00 | 0.2600000000E+02 |
| 12 | 0.0000000000E+00 | | 0.0000000000E+00 | 0.2600000000E+02 |
| 13 | 0.0000000000E+00 | -0.7440605429E-02 | 0.0000000000E+00 | 0.2600000000E+02 |
| 14 | 0.0000000000E+00 | | 0.0000000000E+00 | 0.2600000000E+02 |

INPUT/OUTPUT (CONT.)

| | | | | |
|---|---|---|---|---|
| 15 | 0.0000000000E+00 | -0.6192562565E-02 | 0.0000000000E+00 | 0.2600000000E+02 |
| 16 | 0.0000000000E+00 | | 0.0000000000E+00 | 0.2600000000E+02 |
| 17 | 0.0000000000E+00 | -0.5797233889E-02 | 0.0000000000E+00 | 0.2600000000E+02 |
| 18 | 0.0000000000E+00 | | 0.0000000000E+00 | 0.2600000000E+02 |
| 19 | 0.0000000000E+00 | -0.4281256981E-02 | 0.0000000000E+00 | 0.2600000000E+02 |
| 20 | 0.0000000000E+00 | | 0.0000000000E+00 | 0.2600000000E+02 |
| 21 | 0.0000000000E+00 | -0.6057913757E-02 | 0.0000000000E+00 | 0.2600000000E+02 |
| 22 | 0.0000000000E+00 | | 0.0000000000E+00 | 0.2400000000E+02 |
| 23 | 0.0000000000E+00 | -0.3609983778E-02 | 0.0000000000E+00 | 0.2400000000E+02 |
| 24 | 0.0000000000E+00 | | 0.0000000000E+00 | 0.2400000000E+02 |
| 25 | 0.0000000000E+00 | 0.0000000000E+00 | 0.0000000000E+00 | 0.2400000000E+02 |
| 26 | 0.0000000000E+00 | | 0.0000000000E+00 | 0.1800000000E+02 |
| 27 | 0.1190152498E-02 | | 0.2693214644E-03 | 0.2316105223E+02 |
| 28 | 0.1238074668E-02 | | 0.4097194782E-03 | 0.2430862853E+02 |
| 29 | 0.7810764769E-03 | | 0.8711970196E-03 | 0.2699635257E+02 |
| 30 | -0.1066672556E-03 | | 0.9879301083E-03 | 0.2871387172E+02 |
| 31 | 0.1426442804E-04 | | 0.7919527068E-03 | 0.2938188227E+02 |
| 32 | -0.1713715656E-04 | | 0.9378618650E-03 | 0.2953129340E+02 |
| 33 | 0.4941125967E-05 | | 0.8247177069E-03 | 0.2952893812E+02 |
| 34 | -0.1708797923E-05 | | 0.8196499337E-03 | 0.2952482298E+02 |
| 35 | 0.6236495602E-05 | | 0.8572169672E-03 | 0.2945192859E+02 |
| 36 | 0.4141267544E-04 | | 0.6819760976E-03 | 0.2832181272E+02 |
| 37 | 0.4698413962E-04 | | 0.3698784744E-03 | 0.2524447408E+02 |
| 38 | 0.5153923015E-04 | | 0.2130641677E-03 | 0.2516266529E+02 |
| 39 | 0.0000000000E+00 | -0.1513050807E-01 | 0.0000000000E+00 | 0.1800000000E+02 |
| 40 | 0.5512948630E-03 | | 0.2194359656E-04 | 0.2125485551E+02 |
| 41 | 0.9185148779E-03 | -0.1102030793E-01 | 0.2730139576E-03 | 0.2362157456E+02 |
| 42 | 0.9750106266E-03 | | 0.3880467462E-03 | 0.2462200795E+02 |
| 43 | 0.9910959296E-03 | -0.9900347480E-02 | 0.5119246891E-03 | 0.2543362155E+02 |
| 44 | 0.3056992005E-03 | | 0.7688022422E-03 | 0.2736883254E+02 |
| 45 | 0.5639064494E-03 | -0.9266471119E-02 | 0.9439515174E-03 | 0.2917282381E+02 |
| 46 | 0.2268439202E-03 | | 0.1109354590E-02 | 0.3094571100E+02 |
| 47 | 0.2891214901E-05 | -0.7250124786E-02 | 0.1138211785E-02 | 0.3162771007E+02 |
| 48 | -0.9023059667E-04 | | 0.1123286865E-02 | 0.3250511515E+02 |
| 49 | -0.3357151080E-05 | -0.8036305211E-02 | 0.1138094790E-02 | 0.3282857513E+02 |
| 50 | 0.2968741353E-04 | | 0.1148269971E-02 | 0.3308453120E+02 |
| 51 | -0.2281613795E-04 | -0.7156083184E-02 | 0.1140910693E-02 | 0.3304949594E+02 |
| 52 | -0.1013170595E-04 | | 0.1134789426E-02 | 0.3305958502E+02 |
| 53 | 0.3100615184E-05 | -0.6311762405E-02 | 0.1140824710E-02 | 0.3305886545E+02 |
| 54 | 0.7448696535E-05 | | 0.1149748366E-02 | 0.3306264293E+02 |
| 55 | 0.7897022485E-05 | -0.5580438955E-02 | 0.1138668063E-02 | 0.3305900153E+02 |
| 56 | -0.1251926996E-04 | | 0.1117831247E-02 | 0.3307757010E+02 |
| 57 | -0.2107652219E-04 | -0.4614468410E-02 | 0.1169546352E-02 | 0.3289724309E+02 |
| 58 | 0.4220548581E-04 | | 0.1246182146E-02 | 0.3297746045E+02 |
| 59 | 0.1665204506E-03 | -0.5189941208E-02 | 0.9026052309E-03 | 0.3086772348E+02 |
| 60 | 0.1591531855E-03 | | 0.7682723850E-03 | 0.2859150190E+02 |
| 61 | 0.1532496222E-03 | -0.2915014604E-02 | 0.6470635265E-03 | 0.2603819104E+02 |
| 62 | 0.1300045132E-03 | | 0.5491666357E-03 | 0.2632408794E+02 |
| 63 | 0.1159851791E-03 | 0.0000000000E+00 | 0.5168518525E-03 | 0.2649055495E+02 |
| 64 | 0.0000000000E+00 | | 0.0000000000E+00 | 0.1800000000E+02 |

*INPUT/OUTPUT (CONT.)*

| | | | | |
|---|---|---|---|---|
| 65 | 0.1443771562E-03 | | 0.2137921313E-03 | 0.2897288076E+02 |
| 66 | 0.1680436293E-03 | | 0.3935729813E-03 | 0.3050824481E+02 |
| 67 | 0.7963119586E-04 | | 0.7459581386E-03 | 0.3345901258E+02 |
| 68 | 0.3953271679E-04 | | 0.8769022069E-03 | 0.3544520113E+02 |
| 69 | -0.7160522972E-05 | | 0.8944095387E-03 | 0.3639803635E+02 |
| 70 | -0.9410015663E-05 | | 0.8783540918E-03 | 0.3652581633E+02 |
| 71 | -0.1242520389E-05 | | 0.8907941877E-03 | 0.3653603528E+02 |
| 72 | 0.1169795098E-04 | | 0.8655178277E-03 | 0.3650026329E+02 |
| 73 | -0.3412295176E-04 | | 0.9435749883E-03 | 0.3654846178E+02 |
| 74 | 0.1564591998E-03 | | 0.6931477356E-03 | 0.3493451012E+02 |
| 75 | 0.1267527464E-03 | | 0.6042957327E-03 | 0.2730167779E+02 |
| 76 | 0.1272102234E-03 | | 0.5670537981E-03 | 0.2697210920E+02 |
| 77 | 0.0000000000E-00 | -0.1135839618E-01 | 0.0000000000E+00 | 0.3700000000E+02 |
| 78 | 0.0000000000E-00 | | 0.0000000000E+00 | 0.3700000000E+02 |
| 79 | 0.0000000000E-00 | -0.1022530717E-01 | 0.0000000000E+00 | 0.3700000000E+02 |
| 80 | 0.0000000000E-00 | | 0.0000000000E-00 | 0.3700000000E-02 |
| 81 | 0.0000000000E+00 | -0.8674873896E-02 | 0.0000000000E+00 | 0.3700000000E+02 |
| 82 | 0.0000000000E+00 | | 0.0000000000E-00 | 0.3700000000E+02 |
| 83 | 0.0000000000E+00 | -0.6390516882E-02 | 0.0000000000E+00 | 0.3700000000E+02 |
| 84 | 0.0000000000E+00 | | 0.0000000000E+00 | 0.3700000000E+02 |
| 85 | 0.0000000000E+00 | -0.7539515559E-02 | 0.0000000000E+00 | 0.4000000000E+02 |
| 86 | 0.0000000000E+00 | | 0.0000000000E+00 | 0.4000000000E+02 |
| 87 | 0.0000000000E+00 | -0.7929160105E-02 | 0.0000000000E+00 | 0.4000000000E+02 |
| 88 | 0.0000000000E+00 | | 0.0000000000E+00 | 0.4000000000E+02 |
| 89 | 0.0000000000E+00 | -0.7197067495E-02 | 0.0000000000E+00 | 0.4000000000E+02 |
| 90 | 0.0000000000E+00 | | 0.0000000000E+00 | 0.4000000000E+02 |
| 91 | 0.0000000000E+00 | -0.6237320618E-02 | 0.0000000000E+00 | 0.4000000000E+02 |
| 92 | 0.0000000000E+00 | | 0.0000000000E+00 | 0.4000000000E+02 |
| 93 | 0.0000000000E+00 | -0.5807551951E-02 | 0.0000000000E+00 | 0.4000000000E+02 |
| 94 | 0.0000000000E+00 | | 0.0000000000E+00 | 0.4000000000E+02 |
| 95 | 0.0000000000E+00 | -0.3918407604E-02 | 0.0000000000E+00 | 0.4000000000E+02 |
| 96 | 0.0000000000E+00 | | 0.0000000000E+00 | 0.4000000000E+02 |
| 97 | 0.0000000000E+00 | -0.7267286869E-02 | 0.0000000000E+00 | 0.4000000000E+02 |
| 98 | 0.1430231578E-03 | | 0.6539716041E-03 | 0.2854994797E+02 |
| 99 | 0.1140918641E-03 | -0.3108443589E-02 | 0.6090294924E-03 | 0.2734937838E+02 |
| 100 | 0.1125682793E-03 | | 0.5811641251E-03 | 0.2707901576E+02 |
| 101 | 0.1140430608E-03 | 0.0000000000E-00 | 0.5602915939E-03 | 0.2717055495E+02 |
| 102 | 0.0000000000E-00 | | 0.0000000000E+00 | 0.3200000000E+02 |
| 103 | 0.1292193423E-03 | | 0.5961079201E-03 | 0.2733000794E+02 |
| 104 | 0.1092637983E-03 | | 0.5713314418E-03 | 0.2668998865E+02 |
| 105 | 0.0000000000E-00 | -0.8204435984E-01 | 0.0000000000E+00 | 0.1801017987E+02 |
| 106 | 0.0000000000E-00 | | 0.0000000000E+00 | 0.1802578600E+02 |
| 107 | 0.0000000000E-00 | -0.7922609997E-01 | 0.0000000000E+00 | 0.1804448887E+02 |
| 108 | 0.0000000000E-00 | | 0.0000000000E+00 | 0.1804813050E+02 |
| 109 | 0.0000000000E-00 | -0.7952303343E-01 | 0.0000000000E+00 | 0.1805180049E+02 |
| 110 | 0.0000000000E-00 | | 0.0000000000E-00 | 0.1806217830E+02 |
| 111 | 0.0000000000E+00 | -0.7337426714E-01 | 0.0000000000E+00 | 0.1807534842E+02 |
| 112 | 0.0000000000E-00 | | 0.0000000000E+00 | 0.1808973133E+02 |
| 113 | 0.0000000000E-00 | -0.5432411833E-01 | 0.0000000000E+00 | 0.1812090550E+02 |
| 114 | 0.0000000000E-00 | | 0.0000000000E+00 | 0.1813826348E+02 |

*INPUT/OUTPUT (CONT.)*

| | | | | |
|---|---|---|---|---|
| 115 | 0.0000000000E+00 | -0.3527771896E-01 | 0.0000000000E+00 | 0.1818423760E+02 |
| 116 | 0.0000000000E+00 | | 0.0000000000E+00 | 0.1821645697E+02 |
| 117 | 0.0000000000E+00 | -0.2250009271E-01 | 0.0000000000E+00 | 0.1830897798E+02 |
| 118 | 0.0000000000E+00 | | 0.0000000000E+00 | 0.1835613837E+02 |
| 119 | 0.0000000000E+00 | -0.1613070083E-01 | 0.0000000000E+00 | 0.1847332977E+02 |
| 120 | 0.0000000000E+00 | | 0.0000000000E+00 | 0.1858429160E+02 |
| 121 | 0.0000000000E+00 | -0.1190049724E-01 | 0.0000000000E+00 | 0.1892220027E+02 |
| 122 | 0.0000000000E+00 | | 0.0000000000E+00 | 0.2307703975E+02 |
| 123 | 0.0000000000E+00 | -0.1597608067E-01 | 0.0000000000E+00 | 0.2751316544E+02 |
| 124 | 0.3046902051E-03 | | 0.4383660253E-03 | 0.2875522725E+02 |
| 125 | 0.1209323413E-03 | -0.5629931445E-03 | 0.5698031807E-03 | 0.2587920676E+02 |
| 126 | 0.1232434362E-03 | | 0.5715128216E-03 | 0.2637929017E+02 |
| 127 | 0.1254727478E-03 | 0.0000000000E+00 | 0.5626394771E-03 | 0.2665005377E+02 |
| 128 | 0.0000000000E+00 | | 0.0000000000E+00 | 0.1800000000E+02 |
| 129 | 0.7355442634E-05 | | 0.2194579922E-05 | 0.1804525730E+02 |
| 130 | -0.2147005176E-05 | | -0.1969129160E-05 | 0.1805136211E+02 |
| 131 | -0.4788144713E-06 | | 0.7040606668E-05 | 0.1807490203E+02 |
| 132 | 0.2309092087E-06 | | 0.1192710954E-04 | 0.1812088387E+02 |
| 133 | -0.3190115250E-06 | | 0.1169719149E-04 | 0.1818259134E+02 |
| 134 | 0.2901511889E-07 | | 0.1007089576E-04 | 0.1830372761E+02 |
| 135 | -0.9053499932E-05 | | 0.3004241611E-04 | 0.1845039623E+02 |
| 136 | 0.6915269054E-05 | | 0.5270697490E-04 | 0.1884169145E+02 |
| 137 | -0.1587325817E-03 | | 0.8466502939E-04 | 0.2509143711E+02 |
| 138 | 0.1705740963E-03 | | 0.4346237256E-03 | 0.2576123293E+02 |
| 139 | 0.1643254906E-03 | | 0.4859969164E-03 | 0.2570919511E+02 |
| 140 | 0.0000000000E+00 | -0.8204126610E-01 | 0.0000000000E+00 | 0.1800000000E+02 |
| 141 | -0.7645922402E-06 | | 0.2796031616E-06 | 0.1802154330E+02 |
| 142 | -0.3282496477E-06 | -0.7922768952E-01 | 0.5683236233E-05 | 0.1804295893E+02 |
| 143 | -0.9991940646E-06 | | 0.3581879402E-05 | 0.1804609968E+02 |
| 144 | -0.1956206915E-05 | -0.7952251817E-01 | 0.9350614095E-05 | 0.1804934972E+02 |
| 145 | -0.2474688795E-06 | | 0.5645987782E-05 | 0.1806017892E+02 |
| 146 | -0.3192663798E-05 | -0.7337446891E-01 | 0.1197627948E-04 | 0.1807412713E+02 |
| 147 | -0.1832981178E-05 | | 0.2096687743E-04 | 0.1808895156E+02 |
| 148 | 0.7977161450E-06 | -0.5432834985E-01 | 0.2223759973E-04 | 0.1812011832E+02 |
| 149 | 0.6259081311E-06 | | 0.2151577099E-04 | 0.1813702953E+02 |
| 150 | -0.2647922334E-06 | -0.3525765328E-01 | 0.2069178461E-04 | 0.1818097682E+02 |
| 151 | -0.1002437838E-06 | | 0.2013257557E-04 | 0.1821132949E+02 |
| 152 | -0.2470221117E-05 | -0.2260751127E-01 | 0.2160607970E-04 | 0.1829034846E+02 |
| 153 | -0.5115209292E-05 | | 0.2474633099E-04 | 0.1833251429E+02 |
| 154 | -0.1563394244E-04 | -0.1582966977E-01 | 0.5154103615E-04 | 0.1841411189E+02 |
| 155 | -0.1896315759E-04 | | 0.5759449612E-04 | 0.1845613316E+02 |
| 156 | -0.3210026871E-04 | -0.1568770102E-01 | 0.5990042526E-04 | 0.1863484517E+02 |
| 157 | -0.1299827629E-03 | | 0.1265540624E-03 | 0.2128372561E+02 |
| 158 | -0.1210252963E-03 | -0.1243707830E-01 | 0.9697453589E-04 | 0.2386202071E+02 |
| 159 | 0.7262042968E-04 | | 0.1387419665E-03 | 0.2568695909E+02 |
| 160 | 0.1916300158E-03 | -0.2058962347E-02 | 0.4002910272E-03 | 0.2517902866E+02 |
| 161 | 0.1676771521E-03 | | 0.3916178336E-03 | 0.2505949699E+02 |
| 162 | 0.1575558828E-03 | 0.0000000000E+00 | 0.3670528505E-03 | 0.2509056611E+02 |
| 163 | 0.0000000000E+00 | | 0.0000000000E+00 | 0.1800000000E+02 |
| 164 | -0.2765413916E-05 | | 0.4680244173E-05 | 0.1804133047E+02 |

*INPUT/OUTPUT (CONT.)*

| | | | | |
|---|---|---|---|---|
| 165 | -0.2997874296E-05 | | 0.2974369315E-05 | 0.1804733583E+02 |
| 166 | -0.5202565303E-05 | | 0.1438925277E-04 | 0.1807261707E+02 |
| 167 | 0.5895704688E-06 | | 0.2642677904E-04 | 0.1811995023E+02 |
| 168 | 0.3441602911E-06 | | 0.2406418555E-04 | 0.1817555069E+02 |
| 169 | -0.4280061731E-05 | | 0.2572915100E-04 | 0.1828097832E+02 |
| 170 | -0.1545960556E-04 | | 0.4585503937E-04 | 0.1835497591E+02 |
| 171 | -0.4492873258E-04 | | 0.4565690405E-04 | 0.1835192596E+02 |
| 172 | -0.2952369522E-04 | | -0.2053541618E-04 | 0.2043638816E+02 |
| 173 | 0.3244282916E-04 | | 0.3243649179E-04 | 0.2166933419E+02 |
| 174 | 0.5097235670E-04 | | 0.1114658237E-03 | 0.2161538209E+02 |
| 175 | 0.0000000000E+00 | -0.8204291984E-01 | 0.0000000000E+00 | 0.1800000000E+02 |
| 176 | -0.5888501987E-05 | | 0.9200042785E-06 | 0.1801904573E+02 |
| 177 | -0.1121604390E-04 | -0.7922756253E-01 | 0.4773902988E-05 | 0.1803823227E+02 |
| 178 | -0.1145041296E-04 | | 0.4601655453E-05 | 0.1804068443E+02 |
| 179 | -0.1150962872E-04 | -0.7952312476E-01 | 0.5153307546E-05 | 0.1804315258E+02 |
| 180 | -0.1117943075E-04 | | 0.1108304731E-04 | 0.1805659227E+02 |
| 181 | -0.9086871926E-05 | -0.7337725779E-01 | 0.1579586807E-04 | 0.1807113092E+02 |
| 182 | -0.4229586469E-05 | | 0.2592632174E-04 | 0.1808736795E+02 |
| 183 | 0.6299187048E-06 | -0.5432521265E-01 | 0.2950992026E-04 | 0.1811799616E+02 |
| 184 | 0.1654651728E-05 | | 0.2899129428E-04 | 0.1813471206E+02 |
| 185 | 0.5690570255E-06 | -0.3527040148E-01 | 0.2700747397E-04 | 0.1817247445E+02 |
| 186 | -0.9903191017E-06 | | 0.2494538502E-04 | 0.1820225559E+02 |
| 187 | -0.3954457748E-05 | -0.2253296872E-01 | 0.2678897585E-04 | 0.1825587767E+02 |
| 188 | -0.8650988764E-05 | | 0.3599539367E-04 | 0.1829683677E+02 |
| 189 | -0.2144653243E-04 | -0.1643833906E-01 | 0.4050279852E-04 | 0.1832836656E+02 |
| 190 | -0.2861033563E-04 | | 0.2776982946E-04 | 0.1827308375E+02 |
| 191 | 0.0000000000E+00 | -0.1040867811E-01 | 0.0000000000E+00 | 0.1800000000E+02 |
| 192 | 0.0000000000E+00 | | 0.0000000000E+00 | 0.1800000000E+02 |
| 193 | 0.0000000000E+00 | -0.1307361141E-01 | 0.0000000000E+00 | 0.1800000000E+02 |
| 194 | 0.0000000000E+00 | | 0.0000000000E+00 | 0.1800000000E+02 |
| 195 | 0.0000000000E+00 | -0.1470385311E-02 | 0.0000000000E+00 | 0.1800000000E+02 |
| 196 | 0.0000000000E+00 | | 0.0000000000E+00 | 0.1800000000E+02 |
| 197 | 0.0000000000E+00 | 0.0000000000E+00 | 0.0000000000E+00 | 0.1800000000E+02 |
| 198 | 0.0000000000E+00 | | 0.0000000000E+00 | 0.1800000000E+02 |
| 199 | -0.1875965370E-04 | | 0.2708604484E-05 | 0.1803370347E+02 |
| 200 | -0.2001895524E-04 | | 0.3462817907E-05 | 0.1803804975E+02 |
| 201 | -0.1669834692E-04 | | 0.1434721522E-04 | 0.1806321714E+02 |
| 202 | 0.2945643975E-06 | | 0.3340446989E-04 | 0.1810891133E+02 |
| 203 | 0.2919294371E-05 | | 0.2904021513E-04 | 0.1815266758E+02 |
| 204 | -0.4274974376E-05 | | 0.2445575036E-04 | 0.1817444800E+02 |
| 205 | -0.7367890664E-05 | | 0.4642230386E-05 | 0.1812419923E+02 |
| 206 | 0.0000000000E+00 | | 0.0000000000E+00 | 0.1800000000E+02 |
| 207 | 0.0000000000E+00 | -0.8203497738E-01 | 0.0000000000E+00 | 0.1800000000E+02 |
| 208 | -0.1572447582E-04 | | -0.2185229232E-06 | 0.1801270458E+02 |
| 209 | -0.2564396429E-04 | -0.7922237949E-01 | -0.2405340629E-06 | 0.1802548520E+02 |
| 210 | -0.2663305192E-04 | | -0.1589944337E-06 | 0.1802708354E+02 |
| 211 | -0.2760673220E-04 | -0.7851621050E-01 | 0.4180833300E-07 | 0.1802863303E+02 |
| 212 | -0.2945426320E-04 | | 0.2405186389E-05 | 0.1803870529E+02 |
| 213 | -0.2948975927E-04 | -0.7337493767E-01 | 0.6605423101E-05 | 0.1804959920E+02 |
| 214 | -0.1782987268E-04 | | 0.1917003393E-04 | 0.1807050420E+02 |

INPUT/OUTPUT (CONT.)

| | | | | |
|---|---|---|---|---|
| 215 | -0.1275435900E-05 | -0.5433173435E-01 | 0.2889611361E-04 | 0.1809808061E+02 |
| 216 | 0.3056957876E-05 | | 0.2923430349E-04 | 0.1811121146E+02 |
| 217 | 0.5498926702E-05 | -0.3526680482E-01 | 0.2599820290E-04 | 0.1812484681E+02 |
| 218 | 0.5756779161E-05 | | 0.2120497032E-04 | 0.1812816806E+02 |
| 219 | 0.3031515988E-05 | -0.2256502958E-01 | 0.1063767041E-04 | 0.1811165465E+02 |
| 220 | -0.1302657023E-05 | | 0.1948255651E-04 | 0.1810889871E+02 |
| 221 | -0.1314896825E-05 | -0.1610654068E-01 | 0.1102240914E-04 | 0.1809142419E+02 |
| 222 | 0.7021032076E-05 | | 0.1426751216E-05 | 0.1801821217E+02 |
| 223 | 0.0000000000E+00 | -0.1120456941E-01 | 0.0000000000E+00 | 0.1800000000E+02 |
| 224 | 0.0000000000E-00 | | 0.0000000000E+00 | 0.1800000000E+02 |
| 225 | -0.2771806425E-04 | | 0.5562255680E-06 | 0.1802049279E+02 |
| 226 | -0.2995160501E-04 | | 0.2967225979E-06 | 0.1802301749E+02 |
| 227 | -0.3528426688E-04 | | -0.2940155594E-06 | 0.1802777958E+02 |
| 228 | -0.5425329669E-05 | | 0.1755221362E-04 | 0.1807961281E+02 |
| 229 | 0.1046924926E-04 | | 0.1517792099E-04 | 0.1809073543E+02 |
| 230 | 0.1212981179E-04 | | 0.4491240370E-05 | 0.1807189359E+02 |
| 231 | 0.1213917209E-04 | | 0.4258127256E-05 | 0.1804727962E+02 |
| 232 | 0.0000000000E+00 | | 0.0000000000E+00 | 0.1800000000E+02 |
| 233 | 0.0000000000E-00 | -0.9200940374E-01 | 0.0000000000E+00 | 0.1800000000E+02 |
| 234 | -0.1297579414E-04 | | -0.1275136410E-06 | 0.1800673396E+02 |
| 235 | -0.2490623434E-04 | -0.7919296161E-01 | -0.3311214425E-06 | 0.1801347112E+02 |
| 236 | -0.2410347226E-04 | | -0.4764554053E-06 | 0.1801432063E+02 |
| 237 | -0.2693250559E-04 | -0.7849769620E-01 | -0.9677733229E-06 | 0.1801516965E+02 |
| 238 | -0.3346924374E-04 | | -0.1652692975E-05 | 0.1802029662E+02 |
| 239 | -0.3429558243E-04 | -0.7335579578E-01 | -0.4271327770E-05 | 0.1802535765E+02 |
| 240 | -0.2740733948E-04 | | -0.3267020263E-05 | 0.1804103173E+02 |
| 241 | -0.1027126767E-04 | -0.5433132108E-01 | 0.3786244945E-05 | 0.1805756474E+02 |
| 242 | 0.3246155753E-05 | | 0.5259296450E-05 | 0.1806609549E+02 |
| 243 | 0.1354477124E-04 | -0.3528196598E-01 | 0.4281209461E-05 | 0.1806486331E+02 |
| 244 | 0.1521583990E-04 | | 0.2791361126E-05 | 0.1805846425E+02 |
| 245 | 0.1610310058E-04 | -0.2259130483E-01 | 0.1298018500E-05 | 0.1804656679E+02 |
| 246 | 0.1605740979E-04 | | -0.3473229996E-06 | 0.1803795032E+02 |
| 247 | 0.1254718874E-04 | -0.1625511474E-01 | -0.1746736726E-05 | 0.1802952625E+02 |
| 248 | 0.6382703685E-05 | | -0.5491802709E-06 | 0.1802111405E+02 |
| 249 | 0.0000000000E-00 | -0.1113900421E-01 | 0.0000000000E+00 | 0.1800000000E+02 |
| 250 | 0.0000000000E-00 | | 0.0000000000E+00 | 0.1800000000E+02 |
| 251 | -0.2269155814E-04 | | -0.1156639154E-05 | 0.1800935257E+02 |
| 252 | -0.2515872796E-04 | | -0.1091379915E-05 | 0.1801055874E+02 |
| 253 | -0.3094209267E-04 | | -0.1519945000E-05 | 0.1801771945E+02 |
| 254 | -0.1268670275E-04 | | -0.9142772579E-05 | 0.1803866091E+02 |
| 255 | 0.1270794759E-04 | | -0.5242090857E-05 | 0.1804071673E+02 |
| 256 | 0.1594772515E-04 | | -0.2310519033E-05 | 0.1802795735E+02 |
| 257 | 0.1244357921E-04 | | -0.1901702297E-05 | 0.1801811379E+02 |
| 258 | 0.0000000000E+00 | | 0.0000000000E+00 | 0.1800000000E+02 |
| 259 | 0.0000000000E-00 | -0.8195855769E-01 | 0.0000000000E+00 | 0.1800000000E+02 |
| 260 | -0.1225155223E-04 | | -0.1671218265E-06 | 0.1800243986E+02 |
| 261 | -0.1859575737E-04 | -0.7916227912E-01 | -0.1410709408E-05 | 0.1800488511E+02 |
| 262 | -0.1871739217E-04 | | -0.1568992531E-05 | 0.1800518022E+02 |
| 263 | -0.1937113876E-04 | -0.7843577289E-01 | -0.1115249735E-05 | 0.1800547731E+02 |
| 264 | -0.2072217999E-04 | | -0.2375324740E-05 | 0.1800741379E+02 |

INPUT/OUTPUT (CONT.)

| | | | | |
|---|---|---|---|---|
| 265 | -0.27544129555E-04 | -0.72336717725E-01 | -0.26792199995E-05 | 0.18009439968E+02 |
| 266 | -0.27495420375E-04 | | -0.78749138995E-05 | 0.19017004471E+02 |
| 267 | -0.95340303704E-05 | -0.54319685542E-01 | -0.13311632645E-04 | 0.18022810655E+02 |
| 268 | 0.92217046905E-06 | | -0.14929513225E-04 | 0.18025419775E+02 |
| 269 | 0.93264403965E-05 | -0.25299923316E-01 | -0.10322017795E-04 | 0.18025120275E+02 |
| 270 | 0.12208229705E-04 | | -0.75312938405E-05 | 0.18023097105E+02 |
| 271 | 0.12419879265E-04 | -0.22527476725E-01 | -0.40856371075E-05 | 0.19018365445E+02 |
| 272 | 0.11352107535E-04 | | -0.20021056955E-05 | 0.18015800951E+02 |
| 273 | 0.98706410045E-05 | -0.16299734945E-01 | -0.73925109415E-06 | 0.18012260135E+02 |
| 274 | 0.64327042115E-05 | | 0.23557672565E-06 | 0.18004139975E+02 |
| 275 | 0.00000000000E+00 | -0.11262959495E-01 | 0.00000000000E+00 | 0.18000000000E+02 |
| 276 | 0.00000000000E+00 | | 0.00000000000E+00 | 0.18000000000E+02 |
| 277 | -0.12611622245E-04 | | -0.10856215645E-05 | 0.18003240925E+02 |
| 278 | -0.15095558775E-04 | | -0.15944591415E-05 | 0.18003612135E+02 |
| 279 | -0.29764232825E-04 | | -0.73411019855E-05 | 0.18006120795E+02 |
| 280 | -0.91194121955E-05 | | -0.10437280215E-04 | 0.18016359525E+02 |
| 281 | 0.64889790095E-05 | | -0.12985412315E-04 | 0.18018159295E+02 |
| 282 | 0.94719715825E-05 | | -0.49234029425E-05 | 0.18013467995E+02 |
| 283 | 0.64046260855E-05 | | -0.12058188055E-05 | 0.18009859405E+02 |
| 284 | 0.00000000000E+00 | | 0.00000000000E+00 | 0.18000000000E+02 |
| 285 | 0.00000000000E+00 | -0.92926179215E-01 | 0.00000000000E+00 | 0.18000000000E+02 |
| 286 | -0.63425750945E-05 | | 0.37167254795E-05 | 0.18000537275E+02 |
| 287 | -0.22279326795E-04 | -0.79150120995E-01 | 0.16111995955E-04 | 0.18001089755E+02 |
| 288 | -0.20616801665E-04 | | 0.19951739475E-04 | 0.18001175035E+02 |
| 289 | -0.27740570925E-04 | -0.79522196125E-01 | 0.18050073025E-04 | 0.18001260195E+02 |
| 290 | -0.26703277025E-04 | | 0.13334595975E-04 | 0.18000381815E+02 |
| 291 | -0.21409674795E-04 | -0.72533611665E-01 | 0.10001497125E-04 | 0.18000995755E+02 |
| 292 | -0.59751269645E-05 | | 0.59436916625E-05 | 0.18007233545E+02 |
| 293 | -0.80613412265E-05 | -0.54330914955E-01 | -0.10094511105E-04 | 0.18010429135E+02 |
| 294 | -0.14770994405E-05 | | -0.15342041845E-04 | 0.18012455635E+02 |
| 295 | 0.41007364135E-05 | -0.35099721405E-01 | -0.12291086295E-04 | 0.18012572075E+02 |
| 296 | 0.50197510295E-05 | | -0.99922157075E-05 | 0.18011681115E+02 |
| 297 | 0.49722615845E-05 | -0.22635357965E-01 | -0.51630447755E-05 | 0.18010025235E+02 |
| 298 | 0.48924259945E-05 | | -0.23298507285E-05 | 0.18009507725E+02 |
| 299 | 0.42172490955E-05 | -0.16310520165E-01 | -0.22505391175E-05 | 0.18006335955E+02 |
| 300 | 0.16079607125E-05 | | -0.69752437535E-06 | 0.18004203275E+02 |
| 301 | 0.00000000000E+00 | -0.11245963505E-01 | 0.00000000000E+00 | 0.18000000000E+02 |
| 302 | 0.00000000000E+00 | | 0.00000000000E+00 | 0.18000000000E+02 |
| 303 | -0.25534007095E-04 | | 0.14063121955E-04 | 0.18000637135E+02 |
| 304 | -0.41412992135E-04 | | 0.20122209775E-04 | 0.18000727315E+02 |
| 305 | -0.20098171965E-04 | | 0.27798299135E-04 | 0.18001679635E+02 |
| 306 | -0.12479909785E-05 | | -0.11607103685E-04 | 0.18007144485E+02 |
| 307 | 0.10375558565E-05 | | -0.95133009935E-05 | 0.18009448465E+02 |
| 308 | 0.23704390605E-05 | | -0.50293697775E-05 | 0.18006918515E+02 |
| 309 | 0.15874160975E-05 | | -0.17407939305E-05 | 0.18005006225E+02 |
| 310 | 0.00000000000E+00 | | 0.00000000000E+00 | 0.18000000000E+02 |
| 311 | 0.00000000000E+00 | -0.91567601395E-01 | 0.00000000000E+00 | 0.18000000000E+02 |
| 312 | -0.83390214415E-04 | | 0.19246572725E-04 | 0.18000009024E+02 |
| 313 | -0.90477380075E-04 | -0.79590169795E-01 | 0.42027823325E-04 | 0.18000174025E+02 |
| 314 | -0.79541079135E-04 | | 0.42436911335E-04 | 0.18000190405E+02 |

*INPUT/OUTPUT (CONT.)*

| | | | | |
|---|---|---|---|---|
| 315 | -0.69582049 76E-04 | -0.77695399 47E-01 | 0.45683175 64E-04 | 0.18000200 49E+02 |
| 316 | -0.11604199 93E-04 | | 0.32187553 83E-04 | 0.18000441 92E+02 |
| 317 | -0.91115503 45E-05 | -0.73430106 42E-01 | 0.21435963 67E-04 | 0.18000665 86E+02 |
| 318 | -0.35638536 08E-05 | | -0.64193041 30E-05 | 0.18000265 816E+02 |
| 319 | 0.16599718 05E-05 | -0.54293634 13E-01 | -0.47339022 24E-05 | 0.18000385 490E+02 |
| 320 | 0.55474708 08E-06 | | -0.69443977 64E-05 | 0.18000461 135E+02 |
| 321 | -0.42313129 43E-06 | -0.35309167 94E-01 | -0.67595456 47E-05 | 0.18000455 874E+02 |
| 322 | 0.32460363 05E-06 | | -0.54556795 09E-05 | 0.18000416 599E+02 |
| 323 | 0.86128322 21E-06 | -0.22626550 00E-01 | -0.30263729 29E-05 | 0.18000392 960E+02 |
| 324 | 0.65401631 52E-06 | | -0.11067947 79E-05 | 0.18000380 935E+02 |
| 325 | 0.38641934 63E-06 | -0.16307339 72E-01 | -0.50315210 79E-06 | 0.18000344 100E+02 |
| 326 | 0.13699710 89E-06 | | 0.10925375 97E-06 | 0.18000156 212E+02 |
| 327 | 0.00000000 00E-00 | -0.11250599 05E-01 | 0.00000000 00E+00 | 0.18000000 000E+02 |
| 328 | 0.00000000 00E-00 | | 0.00000000 00E+00 | 0.18000000 000E+02 |
| 329 | -0.93703315 72E-04 | | 0.51731245 14E-04 | 0.18000112 285E+02 |
| 330 | -0.48754309 99E-04 | | 0.50457971 05E-04 | 0.18000116 477E+02 |
| 331 | 0.14124207 76E-05 | | 0.13549921 09E-05 | 0.18000325 995E+02 |
| 332 | -0.69317914 06E-07 | | -0.31716609 52E-07 | 0.18001927 66E+02 |
| 333 | -0.10526604 96E-06 | | -0.44315195 25E-05 | 0.18002277 277E+02 |
| 334 | 0.14609592 72E-06 | | -0.12280020 57E-05 | 0.18001966 593E+02 |
| 335 | -0.71700994 95E-07 | | -0.12579114 47E-06 | 0.18001716 555E+02 |
| 336 | 0.00000000 00E+00 | | 0.00000000 00E+00 | 0.18000000 000E+02 |
| 337 | 0.00000000 00E+00 | -0.75774321 89E-01 | 0.00000000 00E+00 | 0.18000000 000E+02 |
| 338 | -0.11761121 15E-07 | | 0.90122548 47E-05 | 0.18000025 574E+02 |
| 339 | -0.82945968 77E-04 | -0.70405161 28E-01 | 0.55502759 77E-04 | 0.18000068 015E+02 |
| 340 | -0.52987161 03E-04 | | 0.57099735 99E-04 | 0.18000049 322E+02 |
| 341 | 0.00000000 00E+00 | -0.90014650 97E-01 | 0.00000000 00E+00 | 0.18000000 000E+02 |
| 342 | 0.00000000 00E+00 | | 0.00000000 00E+00 | 0.18000000 000E+02 |
| 343 | 0.00000000 00E+00 | -0.73224945 97E-01 | 0.00000000 00E+00 | 0.18000000 000E+02 |
| 344 | 0.00000000 00E+00 | | 0.00000000 00E+00 | 0.18000000 000E+02 |
| 345 | 0.00000000 00E+00 | -0.54261952 96E-01 | 0.00000000 00E+00 | 0.18000000 000E+02 |
| 346 | 0.00000000 00E+00 | | 0.00000000 00E+00 | 0.18000000 000E+02 |
| 347 | 0.00000000 00E+00 | -0.35294254 91E-01 | 0.00000000 00E+00 | 0.18000000 000E+02 |
| 348 | 0.00000000 00E+00 | | 0.00000000 00E+00 | 0.18000000 000E+02 |
| 349 | 0.00000000 00E+00 | -0.22671455 10E-01 | 0.00000000 00E+00 | 0.18000000 000E+02 |
| 350 | 0.00000000 00E+00 | | 0.00000000 00E+00 | 0.18000000 000E+02 |
| 351 | 0.00000000 00E+00 | -0.16304933 25E-01 | 0.00000000 00E+00 | 0.18000000 000E+02 |
| 352 | 0.00000000 00E+00 | | 0.00000000 00E+00 | 0.18000000 000E+02 |
| 353 | 0.00000000 00E+00 | -0.11247037 41E-01 | 0.00000000 00E+00 | 0.18000000 000E+02 |
| 354 | 0.00000000 00E+00 | | 0.00000000 00E+00 | 0.18000000 000E+02 |
| 355 | -0.15241745 92E-07 | | 0.55429561 20E-04 | 0.18000073 327E+02 |
| 356 | 0.00000000 00E+00 | | 0.00000000 00E+00 | 0.18000000 000E+02 |
| 357 | 0.00000000 00E+00 | -0.74752154 99E-01 | 0.00000000 00E+00 | 0.18000000 000E+02 |
| 358 | -0.90934650 52E-04 | | 0.29437499 77E-04 | 0.18000014 427E+02 |
| 359 | 0.00000000 00E+00 | -0.72259853 40E-01 | 0.00000000 00E+00 | 0.18000000 000E+02 |
| 360 | 0.00000000 00E+00 | | 0.00000000 00E+00 | 0.18000000 000E+02 |
| 361 | 0.00000000 00E+00 | -0.63475991 00E-01 | 0.00000000 00E+00 | 0.18000000 000E+02 |
| 362 | 0.00000000 00E+00 | | 0.00000000 00E+00 | 0.18000000 000E+02 |
| 363 | 0.00000000 00E+00 | | 0.00000000 00E+00 | 0.18000000 000E+02 |
| 364 | 0.00000000 00E+00 | -0.74290760 93E-01 | 0.00000000 00E+00 | 0.18000000 000E+02 |

INPUT/OUTPUT (CONT.)

| | | | | |
|---|---|---|---|---|
| 365 | -0.2914592092E-03 | | -0.9196958177E-05 | 0.1700000773E+02 |
| 366 | 0.0000000000E+00 | -0.7140159951E-01 | 0.0000000000E+00 | 0.1900000000E+02 |
| 367 | 0.0000000000E+00 | | 0.0000000000E+00 | 0.1900000000E+02 |
| 368 | 0.0000000000E+00 | | 0.0000000000E+00 | 0.1900000000E+02 |
| 369 | 0.0000000000E+00 | -0.7409915176E-01 | 0.0000000000E+00 | 0.1800000000E+02 |
| 370 | -0.2002146962E-04 | | -0.2350222584E-04 | 0.1900000075E+02 |
| 371 | 0.0000000000E+00 | -0.7129576977E-01 | 0.0000000000E+00 | 0.1900000000E+02 |
| 372 | 0.0000000000E+00 | | 0.0000000000E+00 | 0.1800000000E+02 |
| 373 | 0.0000000000E+00 | -0.7044579774E-01 | 0.0000000000E+00 | 0.1800000000E+02 |
| 374 | 0.0000000000E+00 | | 0.0000000000E+00 | 0.1900000000E+02 |
| 375 | -0.1162442951E-03 | | -0.7512145095E-04 | 0.1900000015E+02 |
| 376 | 0.0000000000E+00 | | 0.0000000000E+00 | 0.1900000000E+02 |
| 377 | 0.0000000000E+00 | -0.7526920955E-01 | 0.0000000000E+00 | 0.1900000000E+02 |
| 378 | 0.0000000000E+00 | | 0.0000000000E+00 | 0.1900000000E+02 |
| 379 | 0.0000000000E+00 | -0.7400321414E-01 | 0.0000000000E+00 | 0.1900000000E+02 |
| 380 | -0.1702574395E-03 | | -0.1345041595E-04 | 0.1900000074E+02 |
| 381 | -0.1442521443E-03 | -0.7119229555E-01 | -0.4610914605E-04 | 0.1900000077E+02 |
| 382 | -0.7591902810E-04 | | -0.5914725433E-04 | 0.1900000015E+02 |
| 383 | 0.0000000000E+00 | -0.7048942196E-01 | 0.0000000000E+00 | 0.1900000000E+02 |
| 384 | 0.0000000000E+00 | | 0.0000000000E+00 | 0.1900000000E+02 |
| 385 | 0.0000000000E+00 | -0.6515995774E-01 | 0.0000000000E+00 | 0.1900000000E+02 |
| 386 | 0.0000000000E+00 | | 0.0000000000E+00 | 0.1900000000E+02 |
| 387 | 0.0000000000E+00 | -0.5270995270E-01 | 0.0000000000E+00 | 0.1900000000E+02 |
| 388 | 0.0000000000E+00 | | 0.0000000000E+00 | 0.1900000000E+02 |
| 389 | 0.0000000000E+00 | -0.4005979695E-01 | 0.0000000000E+00 | 0.1900000000E+02 |
| 390 | 0.0000000000E+00 | | 0.0000000000E+00 | 0.1900000000E+02 |
| 391 | 0.0000000000E+00 | -0.2740964422E-01 | 0.0000000000E+00 | 0.1900000000E+02 |
| 392 | 0.0000000000E+00 | | 0.0000000000E+00 | 0.1900000000E+02 |
| 393 | 0.0000000000E+00 | -0.1475555020E-01 | 0.0000000000E+00 | 0.1900000000E+02 |
| 394 | 0.0000000000E+00 | | 0.0000000000E+00 | 0.1900000000E+02 |
| 395 | 0.0000000000E+00 | -0.3373371611E-02 | 0.0000000000E+00 | 0.1900000000E+02 |
| 396 | 0.0000000000E+00 | | 0.0000000000E+00 | 0.1900000000E+02 |
| 397 | 0.0000000000E+00 | 0.0000000000E+00 | 0.0000000000E+00 | 0.1900000000E+02 |
| 398 | 0.0000000000E+00 | | 0.0000000000E+00 | 0.1900000000E+02 |
| 399 | -0.1297792529E-04 | | 0.1358976142E-05 | 0.1900000005E+02 |
| 400 | -0.5271010795E-04 | | -0.5044527580E-04 | 0.1900000010E+02 |
| 401 | -0.3519917672E-04 | | -0.6563850518E-04 | 0.1900000003E+02 |
| 402 | 0.3229202577E-07 | | -0.6592308202E-04 | 0.1900000000E+02 |
| 403 | -0.1291374175E-05 | | -0.6570408654E-04 | 0.1900000000E+02 |
| 404 | 0.3259089125E-06 | | -0.6574115015E-04 | 0.1800000000E+02 |
| 405 | -0.9573970740E-07 | | -0.6567139172E-04 | 0.1900000000E+02 |
| 406 | 0.3903994287E-07 | | -0.6571080635E-04 | 0.1800000000E+02 |
| 407 | -0.1192994469E-07 | | -0.6563295117E-04 | 0.1900000000E+02 |
| 408 | 0.0000000000E+00 | | -0.6570410275E-04 | 0.1900000000E+02 |
| 409 | 0.0000000000E+00 | -0.7525924223E-01 | 0.0000000000E+00 | 0.1900000000E+02 |
| 410 | -0.5220145429E-05 | | 0.1043987791E-05 | 0.1900000002E+02 |
| 411 | -0.1794522072E-04 | -0.7400313197E-01 | -0.5172413990E-05 | 0.1900000004E+02 |
| 412 | -0.2544392610E-04 | | -0.3775957977E-04 | 0.1900000005E+02 |
| 413 | -0.4510149495E-04 | -0.7119220674E-01 | -0.6390947159E-04 | 0.1800000006E+02 |
| 414 | -0.3723077797E-04 | | -0.6255750955E-04 | 0.1800000007E+02 |

INPUT/OUTPUT (CONT.)

| | | | | |
|---|---|---|---|---|
| 415 | -0.2271198784E-04 | -0.7049941457E-01 | -0.7728874175E-04 | 0.1000000000E+01 |
| 416 | -0.2426200605E-07 | | -0.8550017007E-04 | 0.1000000000E+01 |
| 417 | -0.9997224577E-04 | -0.6535907414E-01 | -0.7970250757E-04 | 0.1000000000E+01 |
| 418 | 0.9773774194E-06 | | -0.8704437721E-04 | 0.1000000000E+01 |
| 419 | -0.5529171024E-06 | -0.5270993032E-01 | -0.8761074507E-04 | 0.1000000000E+01 |
| 420 | -0.2265524577E-06 | | -0.8770435414E-04 | 0.1000000000E+01 |
| 421 | 0.1211773426E-06 | -0.4005879754E-01 | -0.8760871084E-04 | 0.1000000000E+01 |
| 422 | 0.7297335404E-07 | | -0.8755507591E-04 | 0.1000000000E+01 |
| 423 | -0.4561941629E-07 | -0.2740964410E-01 | -0.8759732797E-04 | 0.1000000000E+01 |
| 424 | -0.2155244044E-07 | | -0.8761437217E-04 | 0.1000000000E+01 |
| 425 | 0.1630002567E-07 | -0.1475850067E-01 | -0.8759270027E-04 | 0.1000000000E+01 |
| 426 | 0.5729790949E-09 | | -0.8759255947E-04 | 0.1000000000E+01 |
| 427 | -0.6372271542E-09 | -0.3372371579E-02 | -0.8760019657E-04 | 0.1000000000E+01 |
| 428 | -0.4232009602E-09 | | -0.8760027795E-04 | 0.1000000000E+01 |
| 429 | 0.0000000000E+00 | 0.0000000000E+00 | -0.8759737415E-04 | 0.1000000000E+01 |
| 430 | 0.0000000000E+00 | | 0.0000000000E+00 | 0.1000000000E+01 |
| 431 | -0.1033912420E-04 | | -0.5037457979E-05 | 0.1000000000E+01 |
| 432 | -0.1595027979E-04 | | -0.4200251404E-04 | 0.1000000000E+01 |
| 433 | -0.1171425774E-04 | | -0.5445171601E-04 | 0.1000000000E+01 |
| 434 | -0.1021204763E-07 | | -0.5775021237E-04 | 0.1000000000E+01 |
| 435 | -0.1224917209E-06 | | -0.5571710056E-04 | 0.1000000000E+01 |
| 436 | 0.4212911322E-09 | | -0.5750142217E-04 | 0.1000000000E+01 |
| 437 | -0.4943447494E-09 | | -0.5562204710E-04 | 0.1000000000E+01 |
| 438 | 0.2155202520E-09 | | -0.5572337783E-04 | 0.1000000000E+01 |
| 439 | -0.5507704010E-09 | | -0.5569570275E-04 | 0.1000000000E+01 |
| 440 | 0.0000000000E+00 | | -0.5570074127E-04 | 0.1000000000E+01 |
| 441 | 0.0000000000E+00 | -0.7526927102E-01 | 0.0000000000E+00 | 0.1000000000E+01 |
| 442 | 0.0000000000E+00 | | 0.0000000000E+00 | 0.1000000000E+01 |
| 443 | 0.0000000000E+00 | -0.7400327140E-01 | 0.0000000000E+00 | 0.1000000000E+01 |
| 444 | 0.0000000000E+00 | | 0.0000000000E+00 | 0.1000000000E+01 |
| 445 | 0.0000000000E+00 | -0.7119221519E-01 | 0.0000000000E+00 | 0.1000000000E+01 |
| 446 | 0.0000000000E+00 | | 0.0000000000E+00 | 0.1000000000E+01 |
| 447 | 0.0000000000E+00 | -0.7049941599E-01 | 0.0000000000E+00 | 0.1000000000E+01 |
| 448 | 0.0000000000E+00 | | 0.0000000000E+00 | 0.1000000000E+01 |
| 449 | 0.0000000000E+00 | -0.6535907239E-01 | 0.0000000000E+00 | 0.1000000000E+01 |
| 450 | 0.0000000000E+00 | | 0.0000000000E+00 | 0.1000000000E+01 |
| 451 | 0.0000000000E+00 | -0.5270993144E-01 | 0.0000000000E+00 | 0.1000000000E+01 |
| 452 | 0.0000000000E+00 | | 0.0000000000E+00 | 0.1000000000E+01 |
| 453 | 0.0000000000E+00 | -0.4005879724E-01 | 0.0000000000E+00 | 0.1000000000E+01 |
| 454 | 0.0000000000E+00 | | 0.0000000000E+00 | 0.1000000000E+01 |
| 455 | 0.0000000000E+00 | -0.2740964145E-01 | 0.0000000000E+00 | 0.1000000000E+01 |
| 456 | 0.0000000000E+00 | | 0.0000000000E+00 | 0.1000000000E+01 |
| 457 | 0.0000000000E+00 | -0.1475850065E-01 | 0.0000000000E+00 | 0.1000000000E+01 |
| 458 | 0.0000000000E+00 | | 0.0000000000E+00 | 0.1000000000E+01 |
| 459 | 0.0000000000E+00 | -0.3372371597E-02 | 0.0000000000E+00 | 0.1000000000E+01 |
| 460 | 0.0000000000E+00 | | 0.0000000000E+00 | 0.1000000000E+01 |
| 461 | 0.0000000000E+00 | 0.0000000000E+00 | 0.0000000000E+00 | 0.1000000000E+01 |

ITERATION NO. 1 FINISHED AT MILLTIME 475 SECS

NHEAT= 0

```
INPUT/OUTPUT  (CONT.)

LENGTH SCALE DISTRIBUTION
                                        0.0000000E+00
                                        0.3258715E-02   461
                                        0.5118410E-02   values
KINETIC ENERGY DISTRIBUTION
                                        0.0000000E+00
                                        0.1595119E-02   461
                                        0.2336791E+02   values
TURBULENT VISCOSITY DISTRIBUTION
                                        0.0000000E+00   461
                                        0.5120177E-01   values
                                        0.1400705E+00
TURBULENT CONDUCTIVITY DISTRIBUTION
                                        0.0000000E+00   461
                                        0.8572105E-01   values
                                        0.1962152E-02

 IPSW=  1
IAUTO= 1

STREAM FUNCTION INLET/OUTLET NODE NUMBERS

KINL=  3
      112          0.0290000000
      122          0.0390000000
        3          0.0500000000
KOUT=  5
       12          0.0050000000
       24          0.0700000000
       35          0.0100000000
       17          0.0225000000
       49          0.0275000000
PSI VALUE=          0.0000000000

STREAM FUNCTION CALCULATED BOUNDARY VALUES
   0.7979219981E-05    0.0000000000E+00

  175STREAM FUNCTION SPECIFIED BOUNDARY CONDITIONS

    1
    2   175
    3   conditions

   13STREAM FUNCTION CALCULATED BOUNDARY CONDITIONS

    6
   38
   63
   76
  101
```

INPUT/OUTPUT (CONT.)

```
104
127
139
152
174
408
429
440

STREAM FUNCTION

                                    0.00000000E+00
                                    0.00000000E+00
                                    0.00000000E+00

 175 VORTICITY BOUNDARY CONDITIONS
        1          0.0000000000
        2          0.0000000000
        3          0.0000000000
        4          0.0000000000
VORTICITY

                                    0.00000000E+00
                                    0.00000000E+00
                                    0.00000000E+00
STREAM FUNCTION/VORTICITY CALCULATIONS DONE NUMBER  1
 EXECUTION FINISHED AT 617 SECS.
```

461 values

175 conditions

461 values

≈ 10.6 minutes (cpu).

OUTPUT4DEG-UC

This is the output file for the uncoupled solution of the same problem.

```
FINITE ELEMENT PROGRAM IN INCOMPRESSIBLE VISCOUS
LAMINAR AND/OR  TURBULENT FLOW INCLUDING HEAT TRANSFER.
IT SOLVES N-S , CONTINUITY , AND THE GENERAL ENERGY
EQUATIONS FOR STEADY STATES. IT ALSO CALCULATES VARIOUS
FLUID FLOW AND HEAT TRANSFER PARAMETERS.

////////////////////////////////////////////////////
 Programmer:  Mohammed Jassim Alghatam
////////////////////////////////////////////////////
```

```
INPUT/OUTPUT  (CONT.)


0 EXECUTION STARTED AT     0 SECS.

                    LAMINAR AND TURBULENT RECIRCULATING, CONVECTIVE, BUOYANT FLOWS
                    AND HEAT TRANSFER ANALYSIS OF SOLAR POWERED VENTILATION AND
                    AIR-CONDITIONING SYSTEM USING THE FINITE ELEMENT METHOD (F.E.M.


CONTROL DATA AND PHYSICAL QUANTITIES .


  FORCED OR MIXED CONVECTION,CARTESIAN SYSTEM
NORMAL VELOCITY GRADIENT BOUNDARY CONDITIONS

            CONDF                    BETA                        CPF
        0.02F2400000             0.0031160000        1005.7000000000
  MARK= 4      NMXI= 0      NEWTON= 0      IUPWIM= 0        ITURB= 1
  VISCOSITY= 0.19820E-04  DENSITY= 0.11774E+01  X BODY FORCE= 0.00000E+00
   Y BODY FORCE=-0.10000E-01  KINEMATIC VISCOSITY= 0.16842E-04


DENSITY=RHO=(kg/m**3)
SPECIFIC HEAT CAPACITY FOR CONSTANT PRESSURE=CPF=
CP=(m/sec/kgK (J/kgK))
DYNAMIC VISCOSITY=MU=(kg/m sec(N sec/m**2))
KINEMATIC VISCOSITY=NU=(m**2/sec)
THERMAL CONDUCTIVITY=CONDF=K=(m/mK)
COEFFICIENT OF CUBICAL EXPANSION=BETA=(m**3/K)

ELEMENT DATA
NE=3E1
MTRD=  0
NTARDS= 1
MTSIT=  0
LTIM=10000SECS.
NNP=179
NCN= 20


IRREGULAR COORDINATES-READ IN DATA



IRREGULAR MESH-READ IN NODAL DATA


NE=132
```

INPUT/OUTPUT (CONT.)

ELEMENT NODE NUMBERING

122 element connectivity

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 26 | 39 | 40 | 41 | 27 | 3 | 2 |
| 2 | 3 | 27 | 41 | 42 | 43 | 28 | 5 | 4 |
| 3 | 5 | 28 | 43 | 44 | 45 | 29 | 7 | 6 |

NP=1092

ICOND= 1553

INITIAL STATE

461 nodes

| NODE | U-VELOCITY | PRESSURES | V-VELOCITY |
|---|---|---|---|
| 1 | 0.0000000000E+00 | 0.0000000000E+00 | 0.0000000000E+00 |
| 2 | 0.9387336149E-03 | | 0.0000000000E+00 |
| 3 | 0.1229637547E-02 | 0.0000000000E+00 | 0.0000000000E+00 |
| 4 | 0.1287944295E-02 | | 0.0000000000E+00 |
| 5 | 0.1262121421E-02 | 0.0000000000E+00 | 0.0000000000E+00 |
| 6 | 0.9408136965E-03 | | 0.0000000000E+00 |
| 7 | 0.0000000000E+00 | 0.0000000000E+00 | 0.0000000000E+00 |
| 8 | 0.0000000000E+00 | | 0.0000000000E+00 |

INITIAL CONDITION STATE FOR TEMPERATURE

461 condition

| | |
|---|---|
| 1 | 27.0000 |
| 2 | 22.7639 |
| 3 | 23.1611 |
| 4 | 23.6034 |
| 5 | 24.0751 |
| 6 | 25.1694 |
| 7 | 26.0000 |
| 8 | 26.0000 |

461 node, global d.o.f., and coordinate

| NODE | NODE | X OR Z-COORDINATE | Y OR R-COORDINATE | MDF |
|---|---|---|---|---|
| 1 | 1 | 0.0000000000 | 0.0000000000 | 3 |
| 2 | 4 | 0.0000000000 | 0.0090000000 | 2 |
| 3 | 6 | 0.0000000000 | 0.0180000000 | 2 |
| 4 | 9 | 0.0000000000 | 0.0245000000 | 2 |
| 5 | 11 | 0.0000000000 | 0.0310000000 | 2 |
| 6 | 14 | 0.0000000000 | 0.0410000000 | 2 |
| 7 | 16 | 0.0000000000 | 0.0510000000 | 2 |
| 8 | 19 | 0.0000000000 | 0.0710000000 | 2 |
| 9 | 21 | 0.0000000000 | 0.0910000000 | 2 |
| 10 | 24 | 0.0000000000 | 0.1160000000 | 2 |
| 11 | 26 | 0.0000000000 | 0.1410000000 | 2 |
| 12 | 29 | 0.0000000000 | 0.2310000000 | 2 |

INPUT/OUTPUT (CONT.)

```
  13    31          0.0000000000          0.3210000000     3
  14    34          0.0000000000          0.4110000000     2
  15    36          0.0000000000          0.5010000000     3
  16    39          0.0000000000          0.5910000000     2
NFT= 0
```

DATA GENERATION COMPLETE AT 19 SECS.

JACOBIAN AND DERIVATIVE CALCULATIONS COMPLETE AT 34 SECS.

363 BOUNDARY CONDITIONS

```
NODE    D.O.F. 1        D.O.F. 2        D.O.F. 3        D.O.F. 4
   1  0.00000000E+00
   1                                   0.00000000E+00
   2                                   0.00000000E+00
   3                                   0.00000000E+00
-----------------------------------------------------------------
   4                                   0.00000000E+00
   5                                   0.00000000E+00
   6                                   0.00000000E+00
   7  0.00000000E+00
   7                                   0.00000000E+00
-----------------------------------------------------------------
   9  0.00000000E+00
   9                                   0.00000000E+00
   9  0.00000000E+00
   9                                   0.00000000E+00
  10  0.00000000E+00
-----------------------------------------------------------------
```

up to the 363rd condition

Temperature specified Boundary conditions are not read here.

SOLUTION ROUTINE ENTERED AT 35 SECS

```
ELEMENT     1  FRONTWIDTH=   10
ELEMENT     2  FRONTWIDTH=   19
ELEMENT     3  FRONTWIDTH=   27
ELEMENT     4  FRONTWIDTH=   35
ELEMENT     5  FRONTWIDTH=   43
ELEMENT     6  FRONTWIDTH=   51
ELEMENT     7  FRONTWIDTH=   59
ELEMENT     8  FRONTWIDTH=   67
ELEMENT     9  FRONTWIDTH=   75
ELEMENT    10  FRONTWIDTH=   83
ELEMENT    11  FRONTWIDTH=   62
ELEMENT    12  FRONTWIDTH=   68
```

INPUT/OUTPUT (CONT.)

| | | | |
|---|---|---|---|
| ELEMENT | 13 | FRONTWIDTH= | 72 |
| ELEMENT | 14 | FRONTWIDTH= | 75 |
| ELEMENT | 15 | FRONTWIDTH= | 78 |
| ELEMENT | 16 | FRONTWIDTH= | 81 |
| ELEMENT | 17 | FRONTWIDTH= | 48 |
| ELEMENT | 18 | FRONTWIDTH= | 51 |
| ELEMENT | 19 | FRONTWIDTH= | 54 |
| ELEMENT | 20 | FRONTWIDTH= | 57 |
| ELEMENT | 21 | FRONTWIDTH= | 60 |
| ELEMENT | 22 | FRONTWIDTH= | 63 |
| ELEMENT | 23 | FRONTWIDTH= | 70 |
| ELEMENT | 24 | FRONTWIDTH= | 76 |
| ELEMENT | 25 | FRONTWIDTH= | 84 |
| ELEMENT | 26 | FRONTWIDTH= | 21 |
| ELEMENT | 27 | FRONTWIDTH= | 31 |
| ELEMENT | 28 | FRONTWIDTH= | 39 |
| ELEMENT | 29 | FRONTWIDTH= | 47 |
| ELEMENT | 30 | FRONTWIDTH= | 55 |
| ELEMENT | 31 | FRONTWIDTH= | 63 |
| ELEMENT | 32 | FRONTWIDTH= | 71 |
| ELEMENT | 33 | FRONTWIDTH= | 79 |
| ELEMENT | 34 | FRONTWIDTH= | 87 |
| ELEMENT | 35 | FRONTWIDTH= | 61 |
| ELEMENT | 36 | FRONTWIDTH= | 68 |
| ELEMENT | 37 | FRONTWIDTH= | 74 |
| ELEMENT | 38 | FRONTWIDTH= | 82 |
| ELEMENT | 39 | FRONTWIDTH= | 67 |
| ELEMENT | 40 | FRONTWIDTH= | 74 |
| ELEMENT | 41 | FRONTWIDTH= | 81 |
| ELEMENT | 42 | FRONTWIDTH= | 67 |
| ELEMENT | 43 | FRONTWIDTH= | 74 |
| ELEMENT | 44 | FRONTWIDTH= | 81 |
| ELEMENT | 45 | FRONTWIDTH= | 65 |
| ELEMENT | 46 | FRONTWIDTH= | 68 |
| ELEMENT | 47 | FRONTWIDTH= | 71 |
| ELEMENT | 48 | FRONTWIDTH= | 73 |
| ELEMENT | 49 | FRONTWIDTH= | 81 |
| ELEMENT | 50 | FRONTWIDTH= | 51 |
| ELEMENT | 51 | FRONTWIDTH= | 58 |
| ELEMENT | 52 | FRONTWIDTH= | 65 |
| ELEMENT | 53 | FRONTWIDTH= | 72 |
| ELEMENT | 54 | FRONTWIDTH= | 79 |
| ELEMENT | 55 | FRONTWIDTH= | 86 |
| ELEMENT | 56 | FRONTWIDTH= | 47 |
| ELEMENT | 57 | FRONTWIDTH= | 55 |
| ELEMENT | 58 | FRONTWIDTH= | 63 |
| ELEMENT | 59 | FRONTWIDTH= | 69 |
| ELEMENT | 60 | FRONTWIDTH= | 76 |
| ELEMENT | 61 | FRONTWIDTH= | 83 |
| ELEMENT | 62 | FRONTWIDTH= | 51 |

INPUT/OUTPUT (CONT.)

| | | | |
|---|---|---|---|
| ELEMENT | 63 | FRONTWIDTH= | 58 |
| ELEMENT | 64 | FRONTWIDTH= | 61 |
| ELEMENT | 65 | FRONTWIDTH= | 69 |
| ELEMENT | 66 | FRONTWIDTH= | 76 |
| ELEMENT | 67 | FRONTWIDTH= | 83 |
| ELEMENT | 68 | FRONTWIDTH= | 51 |
| ELEMENT | 69 | FRONTWIDTH= | 58 |
| ELEMENT | 70 | FRONTWIDTH= | 65 |
| ELEMENT | 71 | FRONTWIDTH= | 72 |
| ELEMENT | 72 | FRONTWIDTH= | 75 |
| ELEMENT | 73 | FRONTWIDTH= | 53 |
| ELEMENT | 74 | FRONTWIDTH= | 51 |
| ELEMENT | 75 | FRONTWIDTH= | 59 |
| ELEMENT | 76 | FRONTWIDTH= | 59 |
| ELEMENT | 77 | FRONTWIDTH= | 72 |
| ELEMENT | 78 | FRONTWIDTH= | 79 |
| ELEMENT | 79 | FRONTWIDTH= | 86 |
| ELEMENT | 80 | FRONTWIDTH= | 47 |
| ELEMENT | 81 | FRONTWIDTH= | 53 |
| ELEMENT | 82 | FRONTWIDTH= | 62 |
| ELEMENT | 83 | FRONTWIDTH= | 69 |
| ELEMENT | 84 | FRONTWIDTH= | 76 |
| ELEMENT | 85 | FRONTWIDTH= | 83 |
| ELEMENT | 86 | FRONTWIDTH= | 51 |
| ELEMENT | 87 | FRONTWIDTH= | 59 |
| ELEMENT | 88 | FRONTWIDTH= | 61 |
| ELEMENT | 89 | FRONTWIDTH= | 69 |
| ELEMENT | 90 | FRONTWIDTH= | 74 |
| ELEMENT | 91 | FRONTWIDTH= | 77 |
| ELEMENT | 92 | FRONTWIDTH= | 80 |
| ELEMENT | 93 | FRONTWIDTH= | 36 |
| ELEMENT | 94 | FRONTWIDTH= | 39 |
| ELEMENT | 95 | FRONTWIDTH= | 42 |
| ELEMENT | 96 | FRONTWIDTH= | 45 |
| ELEMENT | 97 | FRONTWIDTH= | 49 |
| ELEMENT | 98 | FRONTWIDTH= | 50 |
| ELEMENT | 99 | FRONTWIDTH= | 54 |
| ELEMENT | 100 | FRONTWIDTH= | 59 |
| ELEMENT | 101 | FRONTWIDTH= | 65 |
| ELEMENT | 102 | FRONTWIDTH= | 70 |
| ELEMENT | 103 | FRONTWIDTH= | 79 |
| ELEMENT | 104 | FRONTWIDTH= | 86 |
| ELEMENT | 105 | FRONTWIDTH= | 25 |
| ELEMENT | 106 | FRONTWIDTH= | 34 |
| ELEMENT | 107 | FRONTWIDTH= | 42 |
| ELEMENT | 108 | FRONTWIDTH= | 50 |
| ELEMENT | 109 | FRONTWIDTH= | 58 |
| ELEMENT | 110 | FRONTWIDTH= | 66 |
| ELEMENT | 111 | FRONTWIDTH= | 74 |
| ELEMENT | 112 | FRONTWIDTH= | 78 |

INPUT/OUTPUT (CONT.)

```
ELEMENT  113  FRONTWIDTH=   52
ELEMENT  114  FRONTWIDTH=   52
ELEMENT  115  FRONTWIDTH=   55
ELEMENT  116  FRONTWIDTH=   58
ELEMENT  117  FRONTWIDTH=   61
ELEMENT  118  FRONTWIDTH=   64
ELEMENT  119  FRONTWIDTH=   67
ELEMENT  120  FRONTWIDTH=   70
ELEMENT  121  FRONTWIDTH=   73
ELEMENT  122  FRONTWIDTH=   74

EXIT FROM SOLUTION ROUTINE AT  311 SECS.


LARGEST RELATIVE CHANGE IN ANY VARIABLE=  0.9627922107E-01

ITERATION NO. = 1
```

| NODE | U-VELOCITY | PRESSURES | V-VELOCITY |
|---|---|---|---|
| 1 | 0.0000000000E-00 | 0.0000000000E+00 | 0.0000000000E+00 |
| 2 | 0.9440719654E-02 | | 0.0000000000E+00 |
| 3 | 0.1132981900E-02 | 0.0000000000E+00 | 0.0000000000E-00 |
| 4 | 0.1292214519E-02 | | 0.0000000000E+00 |
| 5 | 0.1286023988E-02 | 0.0000000000E+00 | 0.0000000000E+00 |
| 6 | 0.8429455054E-02 | | 0.0000000000E+00 |
| 7 | 0.0000000000E-00 | 0.0000000000E+00 | 0.0000000000E+00 |
| 8 | 0.0000000000E-00 | | 0.0000000000E+00 |
| 9 | 0.0000000000E+00 | -0.1303799984E-01 | 0.0000000000E+00 |
| 10 | 0.0000000000E+00 | | 0.0000000000E+00 |
| 11 | 0.0000000000E-00 | -0.7153993823E-02 | 0.0000000000E-00 |
| 12 | 0.0000000000E-00 | | 0.0000000000E+00 |
| 13 | 0.0000000000E-00 | -0.7515399188E-02 | 0.0000000000E+00 |
| 14 | 0.0000000000E-00 | | 0.0000000000E+00 |
| 15 | 0.0000000000E-00 | -0.6334941419E-02 | 0.0000000000E+00 |
| 16 | 0.0000000000E+00 | | 0.0000000000E+00 |
| 17 | 0.0000000000E+00 | -0.5999710865E-02 | 0.0000000000E-00 |
| 18 | 0.0000000000E-00 | | 0.0000000000E+00 |
| 19 | 0.0000000000E+00 | -0.4544437224E-02 | 0.0000000000E-00 |
| 20 | 0.0000000000E-00 | | 0.0000000000E+00 |
| 21 | 0.0000000000E-00 | -0.6285049393E-02 | 0.0000000000E+00 |
| 22 | 0.0000000000E+00 | | 0.0000000000E+00 |
| 23 | 0.0000000000E-00 | -0.3582949478E-02 | 0.0000000000E+00 |
| 24 | 0.0000000000E+00 | | 0.0000000000E-00 |
| 25 | 0.0000000000E+00 | 0.0000000000E+00 | 0.0000000000E+00 |
| 26 | 0.0000000000E+00 | | 0.0000000000E+00 |
| 27 | 0.1195322103E-02 | | 0.2735897316E-03 |
| 28 | 0.1242944672E-02 | | 0.4103897690E-03 |

INPUT/OUTPUT (CONT.)

| | | | |
|---|---|---|---|
| 29 | 0.7842746310E-03 | | 0.8735946523E-03 |
| 30 | -0.1977245295E-03 | | 0.8914797277E-03 |
| 31 | 0.1425806794E-04 | | 0.7941561019E-03 |
| 32 | -0.1729942569E-04 | | 0.8403162851E-03 |
| 33 | 0.4990211197E-05 | | 0.8268671900E-03 |
| 34 | -0.1745752738E-05 | | 0.8220976412E-03 |
| 35 | 0.6387921223E-05 | | 0.8586634139E-03 |
| 36 | 0.4173175627E-04 | | 0.5885009892E-03 |
| 37 | 0.4594192990E-04 | | 0.3695910119E-03 |
| 38 | 0.5040407613E-04 | | 0.2192821734E-03 |
| 39 | 0.0000000000E-00 | -0.1512479499E-01 | 0.0000000000E-00 |
| 40 | 0.5569651662E-03 | | 0.2048428275E-04 |
| 41 | 0.9217604064E-03 | -0.1112190121E-01 | 0.2751655499E-03 |
| 42 | 0.9793919963E-03 | | 0.3904253357E-03 |
| 43 | 0.3942254599E-03 | -0.9964711419E-02 | 0.5304042244E-03 |
| 44 | 0.9094491103E-03 | | 0.7749355606E-03 |
| 45 | 0.5665341235E-03 | -0.9315019558E-02 | 0.9549752572E-03 |
| 46 | 0.2279237194E-03 | | 0.1114262499E-02 |
| 47 | 0.2444553454E-03 | -0.7257956792E-02 | 0.1144440175E-02 |
| 48 | -0.9109019730E-04 | | 0.1127694127E-02 |
| 49 | -0.3516253922E-03 | -0.8065401945E-02 | 0.1142694614E-02 |
| 50 | 0.2996997090E-04 | | 0.1153405932E-02 |
| 51 | -0.2302057905E-04 | -0.7229719109E-02 | 0.1143099252E-02 |
| 52 | -0.1016405109E-04 | | 0.1139614114E-02 |
| 53 | 0.2214992774E-05 | -0.6454279103E-02 | 0.1143344367E-02 |
| 54 | 0.7399793954E-03 | | 0.1154330647E-02 |
| 55 | 0.7703324245E-05 | -0.5773913078E-02 | 0.1146506655E-02 |
| 56 | -0.1339199954E-04 | | 0.1120237547E-02 |
| 57 | -0.2049260125E-04 | -0.4976051973E-02 | 0.1172119877E-02 |
| 58 | 0.4224041790E-04 | | 0.1047150041E-02 |
| 59 | 0.1462959723E-03 | -0.5347391966E-02 | 0.9199412297E-03 |
| 60 | 0.1592001903E-03 | | 0.7750912700E-03 |
| 61 | 0.1513281355E-03 | -0.2992374549E-02 | 0.6625039245E-03 |
| 62 | 0.1279857777E-03 | | 0.5412947197E-03 |
| 63 | 0.1138182153E-03 | 0.0000000000E+00 | 0.5245061337E-03 |
| 64 | 0.0000000000E-00 | | 0.0000000000E+00 |
| 65 | 0.1425508417E-03 | | 0.2160432992E-03 |
| 66 | 0.1686419429E-03 | | 0.3943273557E-03 |
| 67 | 0.9104503937E-04 | | 0.7509724557E-03 |
| 68 | 0.2944049432E-04 | | 0.8917926386E-03 |
| 69 | -0.7285100121E-05 | | 0.8572713584E-03 |
| 70 | -0.9509510677E-05 | | 0.9804522091E-03 |
| 71 | -0.1132935920E-05 | | 0.9928697825E-03 |
| 72 | 0.1144896203E-04 | | 0.9679511891E-03 |
| 73 | -0.3359232246E-04 | | 0.9440192147E-03 |
| 74 | 0.1559214297E-03 | | 0.7100075759E-03 |
| 75 | 0.1237842884E-03 | | 0.6102393645E-03 |
| 76 | 0.1239393557E-03 | | 0.5770756395E-03 |
| 77 | 0.0000000000E-00 | -0.1169358900E-01 | 0.0000000000E+00 |
| 78 | 0.0000000000E-00 | | 0.0000000000E+00 |

INPUT/OUTPUT (CONT.)

| | | | |
|---|---|---|---|
| 79 | 0.0000000000E+00 | -0.1016601530E-01 | 0.0000000000E+00 |
| 80 | 0.0000000000E-00 | | 0.0000000000E-00 |
| 81 | 0.0000000000E+00 | -0.9723017560E-02 | 0.0000000000E+00 |
| 82 | 0.0000000000E+00 | | 0.0000000000E+00 |
| 83 | 0.0000000000E-00 | -0.6443799896E-02 | 0.0000000000E-00 |
| 84 | 0.0000000000E-00 | | 0.0000000000E+00 |
| 85 | 0.0000000000E+00 | -0.7542559942E-02 | 0.0000000000E+00 |
| 86 | 0.0000000000E-00 | | 0.0000000000E+00 |
| 87 | 0.0000000000E-00 | -0.7958502357E-02 | 0.0000000000E+00 |
| 88 | 0.0000000000E-00 | | 0.0000000000E+00 |
| 89 | 0.0000000000E-00 | -0.7269522367E-02 | 0.0000000000E-00 |
| 90 | 0.0000000000E-00 | | 0.0000000000E-00 |
| 91 | 0.0000000000E-00 | -0.6191177561E-02 | 0.0000000000E-00 |
| 92 | 0.0000000000E-00 | | 0.0000000000E-00 |
| 93 | 0.0000000000E-00 | -0.5997501012E-02 | 0.0000000000E-00 |
| 94 | 0.0000000000E-00 | | 0.0000000000E-00 |
| 95 | 0.0000000000E+00 | -0.4186805473E-02 | 0.0000000000E-00 |
| 96 | 0.0000000000E+00 | | 0.0000000000E+00 |
| 97 | 0.0000000000E+00 | -0.7416658970E-02 | 0.0000000000E+00 |
| 98 | 0.3402551715E-03 | | 0.5500952597E-03 |
| 99 | 0.1092046279E-03 | -0.3109854449E-02 | 0.6229089394E-03 |
| 100 | 0.1067634620E-03 | | 0.5917518787E-03 |
| 101 | 0.1032640833E-03 | 0.0000000000E+00 | 0.5679752229E-03 |
| 102 | 0.0000000000E-00 | | 0.0000000000E-00 |
| 103 | 0.1223104443E-03 | | 0.5556000278E-03 |
| 104 | 0.1070109994E-03 | | 0.5901491697E-03 |
| 105 | 0.0000000000E+00 | -0.8210415724E-01 | 0.0000000000E+00 |
| 106 | 0.0000000000E+00 | | 0.0000000000E+00 |
| 107 | 0.0000000000E-00 | -0.7927495259E-01 | 0.0000000000E+00 |
| 108 | 0.0000000000E+00 | | 0.0000000000E-00 |
| 109 | 0.0000000000E-00 | -0.7857310612E-01 | 0.0000000000E+00 |
| 110 | 0.0000000000E-00 | | 0.0000000000E+00 |
| 111 | 0.0000000000E-00 | -0.7341778462E-01 | 0.0000000000E+00 |
| 112 | 0.0000000000E-00 | | 0.0000000000E-00 |
| 113 | 0.0000000000E+00 | -0.5434194907E-01 | 0.0000000000E+00 |
| 114 | 0.0000000000E+00 | | 0.0000000000E-00 |
| 115 | 0.0000000000E-00 | -0.3526596380E-01 | 0.0000000000E+00 |
| 116 | 0.0000000000E-00 | | 0.0000000000E+00 |
| 117 | 0.0000000000E-00 | -0.2246918340E-01 | 0.0000000000E-00 |
| 118 | 0.0000000000E+00 | | 0.0000000000E-00 |
| 119 | 0.0000000000E+00 | -0.1608826560E-01 | 0.0000000000E+00 |
| 120 | 0.0000000000E+00 | | 0.0000000000E-00 |
| 121 | 0.0000000000E+00 | -0.1184595584E-01 | 0.0000000000E+00 |
| 122 | 0.0000000000E+00 | | 0.0000000000E+00 |
| 123 | 0.0000000000E+00 | -0.1609365389E-01 | 0.0000000000E+00 |
| 124 | 0.3007549576E-03 | | 0.4451519290E-03 |
| 125 | 0.1140942445E-03 | -0.4831579948E-03 | 0.5797215451E-03 |
| 126 | 0.1167656049E-03 | | 0.5785873413E-03 |
| 127 | 0.1221393705E-03 | 0.0000000000E+00 | 0.5689947306E-03 |
| 128 | 0.0000000000E+00 | | 0.0000000000E+00 |

INPUT/OUTPUT (CONT.)

| | | | |
|---|---|---|---|
| 129 | 0.3867406475E-05 | | 0.5744148032E-05 |
| 130 | -0.9226675052E-06 | | -0.2350576717E-05 |
| 131 | -0.5548396843E-06 | | 0.7126550915E-05 |
| 132 | 0.2496332099E-06 | | 0.1245443495E-04 |
| 133 | -0.3117988597E-06 | | 0.1183492129E-04 |
| 134 | 0.4457668746E-07 | | 0.1031443031E-04 |
| 135 | -0.9212046861E-05 | | 0.3055100520E-04 |
| 136 | 0.7131124379E-05 | | 0.5447954717E-04 |
| 137 | -0.1614667112E-03 | | 0.6731297911E-04 |
| 138 | 0.1656722654E-03 | | 0.4226937125E-03 |
| 139 | 0.1595531990E-03 | | 0.4813169100E-03 |
| 140 | 0.0000000000E-00 | -0.8209477717E-01 | 0.0000000000E+00 |
| 141 | -0.5648392074E-05 | | -0.4224291013E-05 |
| 142 | 0.2522197550E-05 | -0.7927926232E-01 | -0.2302796233E-05 |
| 143 | 0.1539126499E-05 | | 0.7529910471E-05 |
| 144 | -0.1444954199E-06 | -0.7957253276E-01 | 0.4328048329E-05 |
| 145 | 0.1161266067E-07 | | 0.7620749231E-05 |
| 146 | -0.3299404167E-05 | -0.7341772964E-01 | 0.1363559016E-04 |
| 147 | -0.1850492096E-05 | | 0.2177973031E-04 |
| 148 | 0.7928260796E-06 | -0.5434613399E-01 | 0.2277331391E-04 |
| 149 | 0.7135174895E-06 | | 0.2159026056E-04 |
| 150 | -0.2265843301E-06 | -0.3524997169E-01 | 0.2097946579E-04 |
| 151 | -0.1677937974E-06 | | 0.2032439941E-04 |
| 152 | -0.2522187443E-05 | -0.2258010599E-01 | 0.2190371145E-04 |
| 153 | -0.5385922968E-05 | | 0.2481745750E-04 |
| 154 | -0.1605461044E-04 | -0.1576193699E-01 | 0.5221949572E-04 |
| 155 | -0.1965018757E-04 | | 0.5865407160E-04 |
| 156 | -0.3224415451E-04 | -0.1574925947E-01 | 0.6273037749E-04 |
| 157 | -0.1337559735E-03 | | 0.1476337195E-03 |
| 158 | -0.1246780861E-03 | -0.1261762157E-01 | 0.7794797534E-04 |
| 159 | 0.3019212415E-04 | | 0.1599521610E-03 |
| 160 | 0.1789685328E-03 | -0.1971629821E-02 | 0.2756409537E-03 |
| 161 | 0.1649057485E-03 | | 0.3802117973E-03 |
| 162 | 0.1549072998E-03 | 0.0000000000E-00 | 0.3556412903E-03 |
| 163 | 0.0000000000E+00 | | 0.0000000000E+00 |
| 164 | -0.1169160295E-05 | | 0.1140931975E-04 |
| 165 | -0.1889901114E-05 | | 0.2659149474E-05 |
| 166 | -0.5210042099E-05 | | 0.1520415014E-04 |
| 167 | 0.7234290772E-06 | | 0.2649426025E-04 |
| 168 | 0.3913420976E-06 | | 0.2385372642E-04 |
| 169 | -0.4414130138E-05 | | 0.2565819377E-04 |
| 170 | -0.1586352372E-04 | | 0.4595615941E-04 |
| 171 | -0.4669889479E-04 | | 0.4722057970E-04 |
| 172 | -0.2197132181E-04 | | -0.5561789812E-04 |
| 173 | 0.2674455413E-04 | | 0.1937761919E-04 |
| 174 | 0.5296662919E-04 | | 0.1101307400E-03 |
| 175 | 0.0000000000E-00 | -0.8209954138E-01 | 0.0000000000E+00 |
| 176 | -0.7070599528E-05 | | -0.1761465519E-05 |
| 177 | -0.1162253236E-04 | -0.7927943195E-01 | -0.2686460024E-05 |
| 178 | -0.1192640397E-04 | | 0.2694913056E-05 |

INPUT/OUTPUT (CONT.)

| | | | |
|---|---|---|---|
| 179 | -0.1195521475E-04 | -0.7857334939E-01 | 0.5939471319E-05 |
| 180 | -0.1142102750E-04 | | 0.1372663885E-04 |
| 181 | -0.9259479461E-05 | -0.7742068442E-01 | 0.1667399571E-04 |
| 182 | -0.4190508650E-05 | | 0.2789511967E-04 |
| 183 | 0.7926789748E-06 | -0.5434296420E-01 | 0.2916236008E-04 |
| 184 | 0.1756196250E-05 | | 0.2939856437E-04 |
| 185 | 0.6184164661E-06 | -0.3526277820E-01 | 0.2644946979E-04 |
| 186 | -0.9550389854E-06 | | 0.2527919563E-04 |
| 187 | -0.3992050057E-05 | -0.2249875618E-01 | 0.2617534509E-04 |
| 188 | -0.9065671314E-05 | | 0.2671174644E-04 |
| 189 | -0.2209246244E-04 | -0.1641922482E-01 | 0.2962206998E-04 |
| 190 | -0.2927532287E-04 | | 0.2737421249E-04 |
| 191 | 0.0000000000E-00 | -0.1026774844E-01 | 0.0000000000E-00 |
| 192 | 0.0000000000E-00 | | 0.0000000000E-00 |
| 193 | 0.0000000000E-00 | -0.1225743715E-01 | 0.0000000000E-00 |
| 194 | 0.0000000000E-00 | | 0.0000000000E-00 |
| 195 | 0.0000000000E-00 | -0.1425961623E-02 | 0.0000000000E-00 |
| 196 | 0.0000000000E+00 | | 0.0000000000E-00 |
| 197 | 0.0000000000E-00 | 0.0000000000E+00 | 0.0000000000E+00 |
| 198 | 0.0000000000E+00 | | 0.0000000000E-00 |
| 199 | -0.1967920956E-04 | | 0.1574124805E-05 |
| 200 | -0.2093953904E-04 | | 0.2211272571E-05 |
| 201 | -0.1713745546E-04 | | 0.1273792497E-04 |
| 202 | 0.5676729771E-06 | | 0.3410047431E-04 |
| 203 | 0.3114244222E-05 | | 0.2933746577E-04 |
| 204 | -0.4057091109E-05 | | 0.2429220259E-04 |
| 205 | -0.7243455014E-05 | | 0.3172251463E-05 |
| 206 | 0.0000000000E-00 | | 0.0000000000E-00 |
| 207 | 0.0000000000E-00 | -0.9209946793E-01 | 0.0000000000E+00 |
| 208 | -0.1617759011E-04 | | -0.7591792755E-06 |
| 209 | -0.2442986762E-04 | -0.7927316739E-01 | -0.9497515537E-06 |
| 210 | -0.2755093101E-04 | | -0.2915492409E-07 |
| 211 | -0.2965372909E-04 | -0.7956395911E-01 | 0.1059222249E-05 |
| 212 | -0.3054835619E-04 | | 0.4297513657E-05 |
| 213 | -0.2941427295E-04 | -0.7741829519E-01 | 0.1145794207E-04 |
| 214 | -0.1910157479E-04 | | 0.2141979720E-04 |
| 215 | -0.1055154519E-05 | -0.5475000492E-01 | 0.2760447375E-04 |
| 216 | 0.1240042004E-05 | | 0.2977276697E-04 |
| 217 | 0.5902795442E-05 | -0.2525791197E-01 | 0.2720514797E-04 |
| 218 | 0.5049421979E-05 | | 0.2173721767E-04 |
| 219 | 0.3473179929E-05 | -0.2253868729E-01 | 0.1144542543E-04 |
| 220 | -0.1070085522E-05 | | 0.1099439739E-04 |
| 221 | -0.1074150099E-05 | -0.1606176293E-01 | 0.1195016217E-04 |
| 222 | 0.7555951199E-05 | | 0.1730244012E-05 |
| 223 | 0.0000000000E-00 | -0.1119047502E-01 | 0.0000000000E-00 |
| 224 | 0.0000000000E-00 | | 0.0000000000E+00 |
| 225 | -0.2874759950E-04 | | 0.9251043437E-05 |
| 226 | -0.3094190747E-04 | | 0.1457913299E-05 |
| 227 | -0.2655098835E-04 | | -0.2378186156E-05 |
| 228 | -0.5257022277E-05 | | 0.1832243144E-04 |

INPUT/OUTPUT (CONT.)

| | | | |
|---|---|---|---|
| 229 | 0.10547092065E-04 | | 0.15296431229E-04 |
| 230 | 0.12720696485E-04 | | 0.44527299745E-05 |
| 231 | 0.12570929934E-04 | | 0.52369759145E-05 |
| 232 | 0.00000000005E-00 | | 0.00000000005E-00 |
| 233 | 0.00000000000E-00 | -0.82962261055E-01 | 0.00000000000E-00 |
| 234 | -0.13475621414E-04 | | -0.25670029985E-06 |
| 235 | -0.25905198723E-04 | -0.79243572155E-01 | -0.56933957289E-06 |
| 236 | -0.27044293965E-04 | | -0.56548815299E-06 |
| 237 | -0.27961271955E-04 | -0.79546299445E-01 | -0.70143924265E-06 |
| 238 | -0.24599147145E-04 | | -0.27001742595E-07 |
| 239 | -0.25461214037E-04 | -0.72299420795E-01 | -0.12900175905E-05 |
| 240 | -0.28223711005E-04 | | -0.21564104115E-05 |
| 241 | -0.10225247425E-04 | -0.54750102945E-01 | 0.19435943615E-05 |
| 242 | 0.27010172295E-05 | | 0.57541200095E-05 |
| 243 | 0.14224244025E-04 | -0.37273169345E-01 | 0.40492742975E-05 |
| 244 | 0.17292742975E-04 | | 0.22842191075E-05 |
| 245 | 0.16775521445E-04 | -0.22554997725E-01 | 0.17154125225E-05 |
| 246 | 0.12712724125E-04 | | -0.20125994425E-05 |
| 247 | 0.14057229035E-04 | -0.16231199525E-01 | -0.22942937545E-05 |
| 248 | 0.54172154295E-05 | | -0.93425879905E-06 |
| 249 | 0.00000000005E-00 | -0.11099771275E-01 | 0.00000000005E+00 |
| 250 | 0.00000000000E-00 | | 0.00000000000E-00 |
| 251 | -0.27470291955E-04 | | -0.11729947155E-05 |
| 252 | -0.26007003975E-04 | | -0.12425072075E-05 |
| 253 | -0.21912274315E-04 | | -0.47971475575E-05 |
| 254 | -0.13147012995E-04 | | -0.55755512245E-05 |
| 255 | 0.14577792205E-04 | | -0.54552929795E-05 |
| 256 | 0.16721175375E-04 | | -0.35721294205E-05 |
| 257 | 0.12945931175E-04 | | -0.21257711075E-05 |
| 258 | 0.00000000005E+00 | | 0.00000000005E-00 |
| 259 | 0.00000000000E-00 | -0.20282291195E-01 | 0.00000000005E+00 |
| 260 | -0.12592275745E-04 | | -0.22294507125E-05 |
| 261 | -0.15044247015E-04 | -0.79210293175E-01 | -0.15359280755E-05 |
| 262 | -0.19162796105E-04 | | -0.16472024925E-05 |
| 263 | -0.19862044595E-04 | -0.79492294115E-01 | -0.11294502095E-05 |
| 264 | -0.21712224325E-04 | | -0.13422519795E-05 |
| 265 | -0.22207489195E-04 | -0.72177140435E-01 | -0.16117412795E-05 |
| 266 | -0.20112999995E-04 | | -0.24490035125E-05 |
| 267 | -0.17404475555E-07 | -0.54335914145E-01 | -0.12999745475E-04 |
| 268 | 0.11571325275E-07 | | -0.14524747104E-04 |
| 269 | 0.99200975795E-05 | -0.25292552405E-01 | -0.10074152275E-04 |
| 270 | 0.12792262925E-04 | | -0.78213121405E-05 |
| 271 | 0.12225791265E-04 | -0.22401370215E-01 | -0.29403579975E-05 |
| 272 | 0.11775165514E-04 | | -0.19154675315E-05 |
| 273 | 0.10246987495E-04 | -0.16263919585E-01 | -0.26124957125E-07 |
| 274 | 0.55109449045E-05 | | 0.24482810125E-05 |
| 275 | 0.00000000005E+00 | -0.11227697915E-01 | 0.00000000005E+00 |
| 276 | 0.00000000005E-00 | | 0.00000000005E+00 |
| 277 | -0.12990150705E-04 | | -0.10531543295E-05 |
| 278 | -0.15192760125E-04 | | -0.15777482445E-05 |

INPUT/OUTPUT (CONT.)

| | | | |
|---|---|---|---|
| 279 | -0.29000419133E-04 | | -0.25576114399E-05 |
| 280 | -0.92722297734E-05 | | -0.10256795095E-04 |
| 281 | 0.57941264439E-05 | | -0.12024408801E-04 |
| 282 | 0.88409265534E-05 | | -0.49964005195E-05 |
| 283 | 0.65256299000E-05 | | -0.16449772035E-05 |
| 284 | 0.00000000000E-00 | | 0.00000000000E-00 |
| 285 | 0.00000000000E-00 | -0.82076550775E-01 | 0.00000000000E-00 |
| 286 | -0.64065314415E-05 | | 0.36752421225E-05 |
| 287 | -0.32410319709E-04 | -0.79197529914E-01 | 0.10017306695E-04 |
| 288 | -0.30752011322E-04 | | 0.13754105575E-04 |
| 289 | -0.27479211745E-04 | -0.79579094185E-01 | 0.93479044175E-05 |
| 290 | -0.26409515700E-04 | | 0.13297407755E-04 |
| 291 | -0.21610593092E-04 | -0.73294391235E-01 | 0.99745449045E-05 |
| 292 | -0.60711199215E-05 | | 0.17575001075E-05 |
| 293 | -0.91437762734E-05 | -0.54249954485E-01 | -0.16743757705E-04 |
| 294 | -0.15473294035E-05 | | -0.15054444485E-04 |
| 295 | 0.42541470695E-05 | -0.35292206334E-01 | -0.10963915985E-04 |
| 296 | 0.52264970400E-05 | | -0.92594407485E-05 |
| 297 | 0.31944542815E-05 | -0.22610112475E-01 | -0.53812945565E-05 |
| 298 | 0.51047941255E-05 | | -0.35072595535E-05 |
| 299 | 0.44019607815E-05 | -0.16077131955E-01 | -0.35452892095E-05 |
| 300 | 0.15291444015E-05 | | -0.97307444575E-05 |
| 301 | 0.00000000000E-00 | -0.11003137308E-01 | 0.00000000000E+00 |
| 302 | 0.00000000000E-00 | | 0.00000000000E+00 |
| 303 | -0.35772782405E-04 | | 0.15844675005E-04 |
| 304 | -0.41723546555E-04 | | 0.20104277445E-04 |
| 305 | -0.20200054225E-04 | | 0.27641954875E-04 |
| 306 | -0.17797472205E-05 | | -0.11913752755E-04 |
| 307 | 0.10237245775E-05 | | -0.99557754875E-05 |
| 308 | 0.34715549645E-05 | | -0.52872055575E-05 |
| 309 | 0.17172741975E-05 | | -0.14339059905E-05 |
| 310 | 0.00000000000E-00 | | 0.00000000000E+00 |
| 311 | 0.00000000000E-00 | -0.81615515645E-01 | 0.00000000000E+00 |
| 312 | -0.37442049449E-04 | | 0.19265952915E-04 |
| 313 | -0.30575070775E-04 | -0.79676135035E-01 | 0.42059708205E-04 |
| 314 | -0.79627944365E-04 | | 0.42458475995E-04 |
| 315 | -0.73520975945E-04 | -0.77730338855E-01 | 0.45714942605E-04 |
| 316 | -0.11629959095E-04 | | 0.32207995595E-04 |
| 317 | -0.31795467321E-05 | -0.73471942065E-01 | 0.21466705115E-04 |
| 318 | -0.35879438465E-05 | | -0.67059179795E-05 |
| 319 | 0.16491101595E-05 | -0.54311756665E-01 | -0.47887599765E-05 |
| 320 | -0.55972613405E-06 | | -0.74457216095E-05 |
| 321 | -0.41129290175E-06 | -0.35301415955E-01 | -0.67927557755E-05 |
| 322 | 0.12377368942E-06 | | -0.57558650795E-05 |
| 323 | 0.99293027205E-06 | -0.22601056215E-01 | -0.30456758955E-05 |
| 324 | 0.70000092665E-06 | | -0.11823162995E-05 |
| 325 | 0.44189945945E-06 | -0.16273270615E-01 | -0.43420117755E-06 |
| 326 | 0.14607732665E-06 | | 0.16520002505E-06 |
| 327 | 0.00000000000E-00 | -0.11212062695E-01 | 0.00000000000E+00 |
| 328 | 0.00000000000E-00 | | 0.00000000000E+00 |

INPUT/OUTPUT (CONT.)

| | | | |
|---|---|---|---|
| 329 | -0.93797754445E-04 | | 0.53793355527E-04 |
| 330 | -0.48933187265E-04 | | 0.50545355515E-04 |
| 331 | 0.14171100205E-05 | | 0.13546823615E-05 |
| 332 | -0.71651666715E-07 | | -0.55135995435E-07 |
| 333 | -0.10271492365E-06 | | -0.44590350235E-05 |
| 334 | 0.15009937245E-06 | | -0.12345275915E-05 |
| 335 | -0.74929760675E-07 | | -0.10752374975E-05 |
| 336 | 0.00000000005E+00 | | 0.00000000000E+00 |
| 337 | 0.00000000000E+00 | -0.75917055310E-01 | 0.00000000000E+00 |
| 338 | -0.11372120314E-03 | | 0.50193284375E-05 |
| 339 | -0.93928054075E-04 | -0.70442043675E-01 | 0.59574594355E-04 |
| 340 | -0.53039867425E-04 | | 0.57157112255E-04 |
| 341 | 0.00000000000E+00 | -0.80263255532E-01 | 0.00000000000E+00 |
| 342 | 0.00000000000E+00 | | 0.00000000000E+00 |
| 343 | 0.00000000000E+00 | -0.73265974915E-01 | 0.00000000000E+00 |
| 344 | 0.00000000000E+00 | | 0.00000000000E+00 |
| 345 | 0.00000000000E+00 | -0.54280085295E-01 | 0.00000000000E+00 |
| 346 | 0.00000000000E+00 | | 0.00000000000E+00 |
| 347 | 0.00000000000E+00 | -0.35276473335E-01 | 0.00000000000E+00 |
| 348 | 0.00000000000E+00 | | 0.00000000000E+00 |
| 349 | 0.00000000000E+00 | -0.22405623945E-01 | 0.00000000000E+00 |
| 350 | 0.00000000000E+00 | | 0.00000000000E+00 |
| 351 | 0.00000000000E+00 | -0.14272002225E-01 | 0.00000000000E+00 |
| 352 | 0.00000000000E+00 | | 0.00000000000E+00 |
| 353 | 0.00000000000E+00 | -0.11203102225E-01 | 0.00000000000E+00 |
| 354 | 0.00000000000E+00 | | 0.00000000000E+00 |
| 355 | -0.15235792164E-03 | | 0.55587479925E-04 |
| 356 | 0.00000000000E+00 | | 0.00000000000E+00 |
| 357 | 0.00000000000E+00 | -0.74797514795E-01 | 0.00000000000E+00 |
| 358 | -0.50513331464E-04 | | 0.29456322915E-04 |
| 359 | 0.00000000000E+00 | -0.72298966715E-01 | 0.00000000000E+00 |
| 360 | 0.00000000000E+00 | | 0.00000000000E+00 |
| 361 | 0.00000000000E+00 | -0.63505069765E-01 | 0.00000000000E+00 |
| 362 | 0.00000000000E+00 | | 0.00000000000E+00 |
| 363 | 0.00000000000E+00 | | 0.00000000000E+00 |
| 364 | 0.00000000000E+00 | -0.74331461525E-01 | 0.00000000000E+00 |
| 365 | -0.23175467135E-03 | | -0.31781677655E-06 |
| 366 | 0.00000000000E+00 | -0.71429967965E-01 | 0.00000000000E+00 |
| 367 | 0.00000000000E+00 | | 0.00000000000E+00 |
| 368 | 0.00000000000E+00 | | 0.00000000000E+00 |
| 369 | 0.00000000000E+00 | -0.74129338065E-01 | 0.00000000000E+00 |
| 370 | -0.50513331464E-04 | | -0.23516051125E-04 |
| 371 | 0.00000000000E+00 | -0.71324193545E-01 | 0.00000000000E+00 |
| 372 | 0.00000000000E+00 | | 0.00000000000E+00 |
| 373 | 0.00000000000E+00 | -0.70483604205E-01 | 0.00000000000E+00 |
| 374 | 0.00000000000E+00 | | 0.00000000000E+00 |
| 375 | -0.11634648215E-03 | | -0.35119983455E-04 |
| 376 | 0.00000000000E+00 | | 0.00000000000E+00 |
| 377 | 0.00000000000E+00 | -0.75309187595E-01 | 0.00000000000E+00 |
| 378 | 0.00000000000E+00 | | 0.00000000000E+00 |

INPUT/OUTPUT (CONT.)

| | | | |
|---|---|---|---|
| 379 | 0.0000000000E+00 | -0.7404333001E-01 | 0.0000000000E+00 |
| 380 | -0.1724510666E-02 | | -0.1332879590E-04 |
| 381 | -0.1443813628E-03 | -0.7123069646E-01 | -0.4608938789E-04 |
| 382 | -0.7555972197E-04 | | -0.5819465376E-04 |
| 383 | 0.0000000000E+00 | -0.7052737627E-01 | 0.0000000000E+00 |
| 384 | 0.0000000000E+00 | | 0.0000000000E+00 |
| 385 | 0.0000000000E+00 | -0.6539394942E-01 | 0.0000000000E+00 |
| 386 | 0.0000000000E+00 | | 0.0000000000E+00 |
| 387 | 0.0000000000E+00 | -0.5273645805E-01 | 0.0000000000E+00 |
| 388 | 0.0000000000E+00 | | 0.0000000000E+00 |
| 389 | 0.0000000000E+00 | -0.4007926875E-01 | 0.0000000000E+00 |
| 390 | 0.0000000000E+00 | | 0.0000000000E+00 |
| 391 | 0.0000000000E+00 | -0.2742237509E-01 | 0.0000000000E+00 |
| 392 | 0.0000000000E+00 | | 0.0000000000E+00 |
| 393 | 0.0000000000E+00 | -0.1476577103E-01 | 0.0000000000E+00 |
| 394 | 0.0000000000E+00 | | 0.0000000000E+00 |
| 395 | 0.0000000000E+00 | -0.3374989607E-02 | 0.0000000000E+00 |
| 396 | 0.0000000000E+00 | | 0.0000000000E+00 |
| 397 | 0.0000000000E+00 | 0.0000000000E+00 | 0.0000000000E+00 |
| 398 | 0.0000000000E+00 | | 0.0000000000E+00 |
| 399 | -0.1567512642E-04 | | 0.2797245681E-05 |
| 400 | -0.5555034710E-04 | | -0.4025531249E-04 |
| 401 | -0.4147003986E-04 | | -0.5125142679E-04 |
| 402 | 0.3641237607E-05 | | -0.5045167478E-04 |
| 403 | -0.1106237269E-05 | | -0.5651188271E-04 |
| 404 | 0.2371921479E-05 | | -0.5937777991E-04 |
| 405 | -0.2512739933E-07 | | -0.5663325334E-04 |
| 406 | 0.4624452373E-06 | | -0.5861404329E-04 |
| 407 | 0.7143394266E-06 | | -0.5941544561E-04 |
| 408 | 0.0000000000E-00 | | -0.5944254756E-04 |
| 409 | 0.0000000000E+00 | -0.7530913744E-01 | 0.0000000000E+00 |
| 410 | -0.9527904500E-05 | | 0.1543320504E-05 |
| 411 | -0.2193174345E-04 | -0.7404343023E-01 | -0.4599742422E-05 |
| 412 | -0.3059581110E-04 | | -0.2525369396E-04 |
| 413 | -0.4950490765E-04 | -0.7123058308E-01 | -0.6379741929E-04 |
| 414 | -0.4048735264E-04 | | -0.6349251705E-04 |
| 415 | -0.3228198136E-04 | -0.7052737157E-01 | -0.7572096708E-04 |
| 416 | -0.3167717509E-05 | | -0.9245423125E-04 |
| 417 | -0.7379500587E-06 | -0.6539395640E-01 | -0.9279973015E-04 |
| 418 | 0.1251420636E-05 | | -0.8939019015E-04 |
| 419 | -0.4221327426E-06 | -0.5273645664E-01 | -0.9995595635E-04 |
| 420 | -0.2239100257E-06 | | -0.8396660352E-04 |
| 421 | -0.2501870363E-07 | -0.4007926923E-01 | -0.9725893151E-04 |
| 422 | 0.1177962330E-06 | | -0.8333729929E-04 |
| 423 | 0.2157172594E-06 | -0.2742237470E-01 | -0.9112075500E-04 |
| 424 | 0.1994375185E-06 | | -0.8516279296E-04 |
| 425 | 0.2450722164E-06 | -0.1476575222E-01 | -0.9346654540E-04 |
| 426 | 0.9160609113E-06 | | -0.8040787901E-04 |
| 427 | 0.1022790045E-05 | -0.3374990467E-02 | -0.9090002094E-04 |
| 428 | 0.6417524980E-06 | | -0.8377249236E-04 |

INPUT/OUTPUT (CONT.)

```
429   0.0000000000E+00   0.0000000000E+00  -0.8499865523E-04
430   0.0000000000E+00                       0.0000000000E+00
431  -0.1658395188E-04                      -0.8183757899E-05
432  -0.1687966120E-04                      -0.5638937441E-04
433  -0.1288790527E-04                      -0.6479060886E-04
434  -0.8929684091E-06                      -0.8410000140E-04
435  -0.7204223891E-07                      -0.7429578024E-04
436  -0.1249493535E-06                      -0.8623519519E-04
437   0.3046707528E-06                      -0.7602159718E-04
438  -0.6238026767E-07                      -0.7944354868E-04
439   0.1039801766E-05                      -0.7464084779E-04
440   0.0000000000E+00                      -0.6467787821E-04
441   0.0000000000E+00  -0.7520918829E-01   0.0000000000E+00
442   0.0000000000E+00                       0.0000000000E+00
443   0.0000000000E+00  -0.7404137245E-01   0.0000000000E+00
444   0.0000000000E+00                       0.0000000000E+00
445   0.0000000000E+00  -0.7123959786E-01   0.0000000000E+00
446   0.0000000000E+00                       0.0000000000E+00
447   0.0000000000E+00  -0.7052739429E-01   0.0000000000E+00
448   0.0000000000E+00                       0.0000000000E+00
449   0.0000000000E+00  -0.6539395463E-01   0.0000000000E+00
450   0.0000000000E+00                       0.0000000000E+00
451   0.0000000000E+00  -0.5273645715E-01   0.0000000000E+00
452   0.0000000000E+00                       0.0000000000E+00
453   0.0000000000E+00  -0.4007926878E-01   0.0000000000E+00
454   0.0000000000E+00                       0.0000000000E+00
455   0.0000000000E+00  -0.2742237551E-01   0.0000000000E+00
456   0.0000000000E+00                       0.0000000000E+00
457   0.0000000000E+00  -0.1476575137E-01   0.0000000000E+00
458   0.0000000000E+00                       0.0000000000E+00
459   0.0000000000E+00  -0.3374993676E-02   0.0000000000E+00
460   0.0000000000E+00                       0.0000000000E+00
461   0.0000000000E+00   0.0000000000E+00   0.0000000000E+00
ITERATION NO.   1 FINISHED AT MILLTIME   312 SECS
 152 TEMPERATURE BOUNDARY CONDITIONS
   1              23.0000000000
   7              26.0000000000
   8              26.0000000000
   9              26.0000000000
  10              26.0000000000
  11              26.0000000000
  12              26.0000000000
  13              26.0000000000
  14              26.0000000000
  15              26.0000000000
  16              26.0000000000
  17              26.0000000000
  18              26.0000000000
  19              26.0000000000
  20              26.0000000000
```

up to the 152nd temp. B.C.

INPUT/OUTPUT (CONT.)

NODAL TEMPERATURE VALUES

| | |
|---|---|
| 1 | 0.2300000000E+02 |
| 2 | 0.2274629169E+02 |
| 3 | 0.2313393225E+02 |
| 4 | 0.2357698023E+02 |
| 5 | 0.2405046285E+02 |
| 6 | 0.2515714273E+02 |
| 7 | 0.2600000000E+02 |
| 8 | 0.2600000000E+02 |
| 9 | 0.2600000000E+02 |
| 10 | 0.2600000000E+02 |
| 11 | 0.2600000000E+02 |
| 12 | 0.2600000000E+02 |
| 13 | 0.2600000000E+02 |
| 14 | 0.2600000000E+02 |
| 15 | 0.2600000000E+02 |
| 16 | 0.2600000000E+02 |
| 17 | 0.2600000000E+02 |
| 18 | 0.2600000000E+02 |
| 19 | 0.2600000000E+02 |
| 20 | 0.2600000000E+02 |
| 21 | 0.2600000000E+02 |
| 22 | 0.2400000000E+02 |
| 23 | 0.2400000000E+02 |
| 24 | 0.2400000000E+02 |
| 25 | 0.2400000000E+02 |
| 26 | 0.1500000000E+02 |
| 27 | 0.2216205051E+02 |
| 28 | 0.2430795587E+02 |
| 29 | 0.2599549614E+02 |
| 30 | 0.2971561176E+02 |
| 31 | 0.2939190777E+02 |
| 32 | 0.2953127341E+02 |
| 33 | 0.2952990701E+02 |
| 34 | 0.2952479983E+02 |
| 35 | 0.2945191412E+02 |
| 36 | 0.2932195854E+02 |
| 37 | 0.2524467229E+02 |
| 38 | 0.2716285419E+02 |
| 39 | 0.1800000000E+02 |
| 40 | 0.2125447022E+02 |
| 41 | 0.2362080053E+02 |
| 42 | 0.2462113276E+02 |
| 43 | 0.2543265517E+02 |
| 44 | 0.2736778214E+02 |
| 45 | 0.2917192554E+02 |
| 46 | 0.3094509206E+02 |
| 47 | 0.3162731694E+02 |

INPUT/OUTPUT (CONT.)

| | |
|---|---|
| 48 | 0.3250491801E+02 |
| 49 | 0.3292845479E+02 |
| 50 | 0.3308446899E+02 |
| 51 | 0.3304944965E+02 |
| 52 | 0.3305951554E+02 |
| 53 | 0.3305980514E+02 |
| 54 | 0.3305259490E+02 |
| 55 | 0.3305895134E+02 |
| 56 | 0.3307754892E+02 |
| 57 | 0.3297240706E+02 |
| 58 | 0.3297739974E+02 |
| 59 | 0.3086796206E+02 |
| 60 | 0.2959186917E+02 |
| 61 | 0.2602858132E+02 |
| 62 | 0.2632447109E+02 |
| 63 | 0.2649093379E+02 |
| 64 | 0.1900000000E+02 |
| 65 | 0.2887219128E+02 |
| 66 | 0.3050745984E+02 |
| 67 | 0.3345842700E+02 |
| 68 | 0.3544490752E+02 |
| 69 | 0.3639798210E+02 |
| 70 | 0.3652579620E+02 |
| 71 | 0.3652600455E+02 |
| 72 | 0.3650023977E+02 |
| 73 | 0.3654847995E+02 |
| 74 | 0.3497468939E+02 |
| 75 | 0.2739212412E+02 |
| 76 | 0.3237255204E+02 |
| 77 | 0.3700000000E+02 |
| 78 | 0.3700000000E+02 |
| 79 | 0.3700000000E+02 |
| 80 | 0.3700000000E+02 |
| 81 | 0.3700000000E+02 |
| 82 | 0.3700000000E+02 |
| 83 | 0.3700000000E+02 |
| 84 | 0.3700000000E+02 |
| 85 | 0.4000000000E+02 |
| 86 | 0.4000000000E+02 |
| 87 | 0.4000000000E+02 |
| 88 | 0.4000000000E+02 |
| 89 | 0.4000000000E+02 |
| 90 | 0.4000000000E+02 |
| 91 | 0.4000000000E+02 |
| 92 | 0.4000000000E+02 |
| 93 | 0.4000000000E+02 |
| 94 | 0.4000000000E+02 |
| 95 | 0.4000000000E+02 |
| 96 | 0.4000000000E+02 |
| 97 | 0.4000000000E+02 |

INPUT/OUTPUT (CONT.)

| | |
|---|---|
| 98 | 0.2954955626E+02 |
| 99 | 0.2724996992E+02 |
| 100 | 0.2797050295E+02 |
| 101 | 0.2717104472E+02 |
| 102 | 0.3200000000E+02 |
| 103 | 0.2723053249E+02 |
| 104 | 0.2669047359E+02 |
| 105 | 0.1901017659E+02 |
| 106 | 0.1902578073E+02 |
| 107 | 0.1904448145E+02 |
| 108 | 0.1904812629E+02 |
| 109 | 0.1905179942E+02 |
| 110 | 0.1906217358E+02 |
| 111 | 0.1907504369E+02 |
| 112 | 0.1908972699E+02 |
| 113 | 0.1812090301E+02 |
| 114 | 0.1813826261E+02 |
| 115 | 0.1819423824E+02 |
| 116 | 0.1821645775E+02 |
| 117 | 0.1830899261E+02 |
| 118 | 0.1835614851E+02 |
| 119 | 0.1947334935E+02 |
| 120 | 0.1859432238E+02 |
| 121 | 0.1892225699E+02 |
| 122 | 0.2707712497E+02 |
| 123 | 0.2751330315E+02 |
| 124 | 0.2875577444E+02 |
| 125 | 0.2597969700E+02 |
| 126 | 0.2637977940E+02 |
| 127 | 0.2665054792E+02 |
| 128 | 0.1600000000E+02 |
| 129 | 0.1904524925E+02 |
| 130 | 0.1905135995E+02 |
| 131 | 0.1907489710E+02 |
| 132 | 0.1912088141E+02 |
| 133 | 0.1918259197E+02 |
| 134 | 0.1830373173E+02 |
| 135 | 0.1945041475E+02 |
| 136 | 0.1894173225E+02 |
| 137 | 0.2509169789E+02 |
| 138 | 0.2576169497E+02 |
| 139 | 0.2570961941E+02 |
| 140 | 0.1900000000E+02 |
| 141 | 0.1902154030E+02 |
| 142 | 0.1904295535E+02 |
| 143 | 0.1904609391E+02 |
| 144 | 0.1904903406E+02 |
| 145 | 0.1906017247E+02 |
| 146 | 0.1907412210E+02 |
| 147 | 0.1908894725E+02 |

INPUT/OUTPUT (CONT.)

| | |
|---|---|
| 148 | 0.1812011596E+02 |
| 149 | 0.1913702872E+02 |
| 150 | 0.1919097735E+02 |
| 151 | 0.1921133009E+02 |
| 152 | 0.1929035134E+02 |
| 153 | 0.1933252212E+02 |
| 154 | 0.1941412997E+02 |
| 155 | 0.1945615617E+02 |
| 156 | 0.1963488179E+02 |
| 157 | 0.2126285334E+02 |
| 158 | 0.2386235918E+02 |
| 159 | 0.2568740944E+02 |
| 160 | 0.2517947151E+02 |
| 161 | 0.2505989406E+02 |
| 162 | 0.2509092170E+02 |
| 163 | 0.1800000000E+02 |
| 164 | 0.1804132726E+02 |
| 165 | 0.1804732867E+02 |
| 166 | 0.1807261199E+02 |
| 167 | 0.1811994777E+02 |
| 168 | 0.1817555139E+02 |
| 169 | 0.1828097957E+02 |
| 170 | 0.1835498887E+02 |
| 171 | 0.1835194483E-02 |
| 172 | 0.2043653513E+02 |
| 173 | 0.2166957548E-02 |
| 174 | 0.2141562179E+02 |
| 175 | 0.1800000000E-02 |
| 176 | 0.1801984204E-02 |
| 177 | 0.1803822485E-02 |
| 178 | 0.1804967576E-02 |
| 179 | 0.1804314465E-02 |
| 180 | 0.1805657579E+02 |
| 181 | 0.1807112585E+02 |
| 182 | 0.1808736372E+02 |
| 183 | 0.1811799374E+02 |
| 184 | 0.1813471141E+02 |
| 185 | 0.1817247529E+02 |
| 186 | 0.1820225592E+02 |
| 187 | 0.1825587748E+02 |
| 188 | 0.1829604045E+02 |
| 189 | 0.1832837599E+02 |
| 190 | 0.1827709494E+02 |
| 191 | 0.1800000000E+02 |
| 192 | 0.1800000000E+02 |
| 193 | 0.1800000000E+02 |
| 194 | 0.1800000000E+02 |
| 195 | 0.1800000000E+02 |
| 196 | 0.1800000000E+02 |
| 197 | 0.1800000000E+02 |

INPUT/OUTPUT (CONT.)

| | |
|---|---|
| 198 | 0.1800000000E-02 |
| 199 | 0.1803369594E-02 |
| 200 | 0.1803804208E-02 |
| 201 | 0.1806321332E-02 |
| 202 | 0.1810990893E-02 |
| 203 | 0.1815267006E-02 |
| 204 | 0.1817445299E-02 |
| 205 | 0.1813420995E-02 |
| 206 | 0.1800000000E-02 |
| 207 | 0.1800000000E-02 |
| 208 | 0.1801279404E-02 |
| 209 | 0.1802548420E-02 |
| 210 | 0.1803709246E-02 |
| 211 | 0.1802969189E-02 |
| 212 | 0.1803870364E-02 |
| 213 | 0.1804559744E-02 |
| 214 | 0.1807050017E-02 |
| 215 | 0.1809807923E-02 |
| 216 | 0.1811121122E-02 |
| 217 | 0.1812485071E-02 |
| 218 | 0.1812817212E-02 |
| 219 | 0.1811156348E-02 |
| 220 | 0.1810990902E-02 |
| 221 | 0.1809143346E-02 |
| 222 | 0.1801821592E-02 |
| 223 | 0.1800000000E-02 |
| 224 | 0.1800000000E-02 |
| 225 | 0.1802049228E-02 |
| 226 | 0.1803301744E-02 |
| 227 | 0.1803776967E-02 |
| 228 | 0.1807961159E-02 |
| 229 | 0.1809078876E-02 |
| 230 | 0.1807189949E-02 |
| 231 | 0.1804728456E-02 |
| 232 | 0.1800000000E-02 |
| 233 | 0.1800000000E-02 |
| 234 | 0.1800677315E-02 |
| 235 | 0.1801346974E-02 |
| 236 | 0.1801431911E-02 |
| 237 | 0.1801516890E-02 |
| 238 | 0.1802028415E-02 |
| 239 | 0.1802553075E-02 |
| 240 | 0.1804103143E-02 |
| 241 | 0.1805756536E-02 |
| 242 | 0.1806609725E-02 |
| 243 | 0.1806486598E-02 |
| 244 | 0.1805846695E-02 |
| 245 | 0.1804656929E-02 |
| 246 | 0.1803795080E-02 |
| 247 | 0.1802952568E-02 |

INPUT/OUTPUT (CONT.)

| | |
|---|---|
| 248 | 0.1802111424E+02 |
| 249 | 0.1800000000E+02 |
| 250 | 0.1800000000E+02 |
| 251 | 0.1800935151E+02 |
| 252 | 0.1801055739E+02 |
| 253 | 0.1801771562E+02 |
| 254 | 0.1803866068E+02 |
| 255 | 0.1804071718E+02 |
| 256 | 0.1802795618E+02 |
| 257 | 0.1801811139E+02 |
| 258 | 0.1800000000E+02 |
| 259 | 0.1800000000E+02 |
| 260 | 0.1800243926E+02 |
| 261 | 0.1800489190E+02 |
| 262 | 0.1800517995E+02 |
| 263 | 0.1800547599E+02 |
| 264 | 0.1800741215E+02 |
| 265 | 0.1800943646E+02 |
| 266 | 0.1801700245E+02 |
| 267 | 0.1802290954E+02 |
| 268 | 0.1802541935E+02 |
| 269 | 0.1802511944E+02 |
| 270 | 0.1802309595E+02 |
| 271 | 0.1801836368E+02 |
| 272 | 0.1801579877E+02 |
| 273 | 0.1801225833E+02 |
| 274 | 0.1800413043E+02 |
| 275 | 0.1800000000E+02 |
| 276 | 0.1800000000E+02 |
| 277 | 0.1800322978E+02 |
| 278 | 0.1800361103E+02 |
| 279 | 0.1800611949E+02 |
| 280 | 0.1801635863E+02 |
| 281 | 0.1801915763E+02 |
| 282 | 0.1801746691E+02 |
| 283 | 0.1800885665E+02 |
| 284 | 0.1800000000E+02 |
| 285 | 0.1800000000E+02 |
| 286 | 0.1800053718E+02 |
| 287 | 0.1800108958E+02 |
| 288 | 0.1800117483E+02 |
| 289 | 0.1800125598E+02 |
| 290 | 0.1800209155E+02 |
| 291 | 0.1800290948E+02 |
| 292 | 0.1800723367E+02 |
| 293 | 0.1801062915E+02 |
| 294 | 0.1801245532E+02 |
| 295 | 0.1801257177E+02 |
| 296 | 0.1801168072E+02 |
| 297 | 0.1801002468E+02 |

INPUT/OUTPUT (CONT.)

| | |
|---|---|
| 298 | 0.1800850667E+02 |
| 299 | 0.1800733629E+02 |
| 300 | 0.1800420277E+02 |
| 301 | 0.1800000000E+02 |
| 302 | 0.1800000000E+02 |
| 303 | 0.1800063407E+02 |
| 304 | 0.1800072717E+02 |
| 305 | 0.1800167939E+02 |
| 306 | 0.1800714445E+02 |
| 307 | 0.1800844828E+02 |
| 308 | 0.1800691804E+02 |
| 309 | 0.1800500543E+02 |
| 310 | 0.1800000000E+02 |
| 311 | 0.1800000000E+02 |
| 312 | 0.1800002021E+02 |
| 313 | 0.1800017339E+02 |
| 314 | 0.1800013034E+02 |
| 315 | 0.1800020942E+02 |
| 316 | 0.1800044181E+02 |
| 317 | 0.1800066571E+02 |
| 318 | 0.1800265315E+02 |
| 319 | 0.1800385484E+02 |
| 320 | 0.1800461104E+02 |
| 321 | 0.1800435572E+02 |
| 322 | 0.1800416620E+02 |
| 323 | 0.1800392917E+02 |
| 324 | 0.1800390915E+02 |
| 325 | 0.1800347556E+02 |
| 326 | 0.1800176149E+02 |
| 327 | 0.1800000000E+02 |
| 328 | 0.1800000000E+02 |
| 329 | 0.1800011222E+02 |
| 330 | 0.1800011664E+02 |
| 331 | 0.1800032590E+02 |
| 332 | 0.1800192764E+02 |
| 333 | 0.1800227726E+02 |
| 334 | 0.1800196245E+02 |
| 335 | 0.1800171589E+02 |
| 336 | 0.1800000000E+02 |
| 337 | 0.1800000000E+02 |
| 338 | 0.1800005572E+02 |
| 339 | 0.1800009013E+02 |
| 340 | 0.1800004930E+02 |
| 341 | 0.1800000000E+02 |
| 342 | 0.1800000000E+02 |
| 343 | 0.1800000000E+02 |
| 344 | 0.1800000000E+02 |
| 345 | 0.1800000000E+02 |
| 346 | 0.1800000000E+02 |
| 347 | 0.1800000000E+02 |

INPUT/OUTPUT (CONT.)

| | |
|---|---|
| 348 | 0.18000000000E-02 |
| 349 | 0.18000000000E-02 |
| 350 | 0.18000000000E-02 |
| 351 | 0.18000000000E-02 |
| 352 | 0.18000000000E-02 |
| 353 | 0.18000000000E-02 |
| 354 | 0.18000000000E-02 |
| 355 | 0.18000003325E-02 |
| 356 | 0.18000000000E-02 |
| 357 | 0.18000000000E-02 |
| 358 | 0.18000001403E-02 |
| 359 | 0.18000000000E-02 |
| 360 | 0.18000000000E-02 |
| 361 | 0.18000000000E-02 |
| 362 | 0.18000000000E-02 |
| 363 | 0.18000000000E-02 |
| 364 | 0.18000000000E-02 |
| 365 | 0.17000000722E-02 |
| 366 | 0.18000000000E-02 |
| 367 | 0.18000000000E-02 |
| 368 | 0.18000000000E-02 |
| 369 | 0.18000000000E-02 |
| 370 | 0.18000000755E-02 |
| 371 | 0.18000000000E-02 |
| 372 | 0.18000000000E-02 |
| 373 | 0.18000000000E-02 |
| 374 | 0.18000000000E-02 |
| 375 | 0.18000000017E-02 |
| 376 | 0.18000000000E-02 |
| 377 | 0.18000000000E-02 |
| 378 | 0.18000000000E-02 |
| 379 | 0.18000000000E-02 |
| 380 | 0.18000000714E-02 |
| 381 | 0.18000000077E-02 |
| 382 | 0.18000000014E-02 |
| 383 | 0.18000000000E-02 |
| 384 | 0.18000000000E-02 |
| 385 | 0.18000000000E-02 |
| 386 | 0.18000000000E-02 |
| 387 | 0.18000000000E-02 |
| 388 | 0.18000000000E-02 |
| 389 | 0.18000000000E+02 |
| 390 | 0.18000000000E-02 |
| 391 | 0.18000000000E+02 |
| 392 | 0.18000000000E+02 |
| 393 | 0.18000000000E+02 |
| 394 | 0.18000000000E+02 |
| 395 | 0.18000000000E+02 |
| 396 | 0.18000000000E+02 |
| 397 | 0.18000000000E+02 |

INPUT/OUTPUT (CONT.)

| | |
|---|---|
| 399 | 0.1000000000E+02 |
| 400 | 0.1000000000E+02 |
| 401 | 0.1000000000E+02 |
| 402 | 0.1000000000E+02 |
| 403 | 0.1000000000E+02 |
| 404 | 0.1000000000E+02 |
| 405 | 0.1000000000E+02 |
| 406 | 0.1000000000E+02 |
| 407 | 0.1000000000E+02 |
| 408 | 0.1000000000E+02 |
| 409 | 0.1000000000E+02 |
| 410 | 0.1000000000E+02 |
| 411 | 0.1000000000E+02 |
| 412 | 0.1000000000E+02 |
| 413 | 0.1000000000E+02 |
| 414 | 0.1000000000E+02 |
| 415 | 0.1000000000E+02 |
| 416 | 0.1000000000E+02 |
| 417 | 0.1000000000E+02 |
| 418 | 0.1000000000E+02 |
| 419 | 0.1000000000E+02 |
| 420 | 0.1000000000E+02 |
| 421 | 0.1000000000E+02 |
| 422 | 0.1000000000E+02 |
| 423 | 0.1000000000E+02 |
| 424 | 0.1000000000E+02 |
| 425 | 0.1000000000E+02 |
| 426 | 0.1000000000E+02 |
| 427 | 0.1000000000E+02 |
| 428 | 0.1000000000E+02 |
| 429 | 0.1000000000E+02 |
| 430 | 0.1000000000E+02 |
| 431 | 0.1000000000E+02 |
| 432 | 0.1000000000E+02 |
| 433 | 0.1000000000E+02 |
| 434 | 0.1000000000E+02 |
| 435 | 0.1000000000E+02 |
| 436 | 0.1000000000E+02 |
| 437 | 0.1000000000E+02 |
| 438 | 0.1000000000E+02 |
| 439 | 0.1000000000E+02 |
| 440 | 0.1000000000E+02 |
| 441 | 0.1000000000E+02 |
| 442 | 0.1000000000E+02 |
| 443 | 0.1000000000E+02 |
| 444 | 0.1000000000E+02 |
| 445 | 0.1000000000E+02 |
| 446 | 0.1000000000E+02 |
| 447 | 0.1000000000E+02 |

INPUT/OUTPUT (CONT.)

```
448   0.19000000000E+02
449   0.19000000000E+02
450   0.19000000000E+02
451   0.19000000000E+02
452   0.19000000000E+02
453   0.19000000000E+02
454   0.19000000000E+02
455   0.19000000000E+02
456   0.19000000000E+02
457   0.19000000000E+02
458   0.19000000000E+02
459   0.19000000000E+02
460   0.19000000000E+02
461   0.19000000000E+02
TEMPERATURE CALCULATIONS FINISHED AT   3.95555E
```

NHEAT= 0

LENGTH SCALE DISTRIBUTION

```
0.00000000E+00
0.32567165E-02
0.51192720E-02
0.55941113E-02
0.53424000E-02
0.35743615E-02
0.00000000E+00
0.00000000E+00
0.00000000E+00
0.00000000E+00
```

461 values

KINETIC ENERGY DISTRIBUTION

```
0.00000000E+00
0.15931545E+00
0.22367925E+00
0.24439305E-02
0.24254157E-02
0.15941160E-02
0.00000000E+00
0.00000000E+00
0.00000000E+00
0.00000000E+00
```

461 values

TURBULENT VISCOSITY DISTRIBUTION

```
0.00000000E+00
0.61263075E-01
0.14087295E+00
0.16132595E-00
0.15317995E-00
0.66544555E-01
0.00000000E+00
0.00000000E+00
0.00000000E+00
0.00000000E+00
```

461 values

INPUT/OUTPUT (CONT.)

TURBULENT CONDUCTIVITY DISTRIBUTION

```
0.0000000E+00
0.8532494E+02
0.1963363E+03
0.2249229E+03
0.2138311E+03
0.9277179E+02
0.0000000E+00
0.0000000E+00
0.0000000E+00
0.0000000E+00
```

461 values

```
 IPSW=  1
IAUTO= 1
```

STREAM FUNCTION INLET/OUTLET NODE NUMBERS

```
KINL=  3
      112          0.0350000000
      122          0.0350000000
        3          0.0500000000
KOUT=  5
       12          0.0050000000
       24          0.0720000000
       36          0.0190000000
       37          0.0225000000
       48          0.0275000000
PSI VALUE=          0.0000000000
```

STREAM FUNCTION CALCULATED BOUNDARY VALUES

```
  0.2000100702E-05     0.0000000000E+00
```

175STREAM FUNCTION SPECIFIED BOUNDARY CONDITIONS

```
  1
  2
  3
```

175 condition

13STREAM FUNCTION CALCULATED BOUNDARY CONDITIONS

```
  6
 38
 61
 76
101
104
127
139
152
174
409
```

INPUT/OUTPUT (CONT.)

```
429
440

STREAM FUNCTION

                                        0.0000000E+00
                                        0.0000000E+00
                                        0.0000000E+00
                                        0.0000000E+00
                                        0.0000000E+00
                                        0.4197872E-05
                                        0.0000000E+00
                                        0.0000000E+00
                                        0.0000000E+00
175 VORTICITY BOUNDARY CONDITIONS
        1          0.0000000000
        2          0.0000000000
        3          0.0000000000
        4          0.0000000000
VORTICITY

                                        0.0000000E+00
                                        0.0000000E+00
                                        0.0000000E+00
                                        0.0000000E+00
                                        0.0000000E+00
                                        0.2224172E-01
                                        0.0000000E+00
                                        0.0000000E+00
                                        0.0000000E+00
```

461 values

175 condition

461 values

STREAM FUNCTION/VORTICITY CALCULATIONS CASE NUMBER 1
EXECUTION FINISHED AT 551 SECS. ≈ 9.2 minutes(cpu).

- END -

# APPENDIX IV

## CUBIC SPLINE PROGRAM TO EXTRACT VELOCITY FROM ANEMOMETER VOLTAGE OF HOT-WIRE CALIBRATION CURVES

*LOUGHBOROUGH UNIVERSITY*

```
****   ***   ****  *****
*   * *   * *      *
****  ***** * *** ****
*     *   * *   * *
*     *   *  ****  *****
```

```
*****  ***  ****  *   *  ***  *****  *****  *****  ****
*     *   * *   * ** **  *   *   *     *     *     *   *
****  *   * ***** *  *  * ***** *     *     ****  ****
*     *   * *   * *   *  * *   *     *     *     *   *
*      ***  *   * *   *  * *   *     *     *****  *   *
```

*VERSION 4*

*SPLINEFIT*


*PROGRAMMER : Mohammed J. K. Alshatam*


*DATE : 10 . 01 . 1995*

*TIME : 16:24*

SPLINEFIT

```
0001:        DATA OF SENSOR (1):
0002:   12
0003:        2.7503     0.0000
0004:        2.7521     0.0600
0005:        2.7717     0.0800
0006:        2.7975     0.1000
0007:        2.8190     0.1200
0008:        2.8600     0.1600
0009:        2.9155     0.2000
0010:        2.9361     0.2500
0011:        2.9827     0.3200
0012:        3.0283     0.4000
0013:        3.0770     0.5000
0014:        3.1360     0.6100
0015:
0016:        DATA OF SENSOR (2):
0017:   12
0018:        2.6767     0.0000
0019:        2.7121     0.0600
0020:        2.7264     0.0800
0021:        2.7452     0.1000
0022:        2.7639     0.1200
0023:        2.7968     0.1600
0024:        2.8544     0.2000
0025:        2.9361     0.2500
0026:        2.8984     0.3200
0027:        3.9224     0.4000
0028:        3.9577     0.5000
0029:        3.0001     0.6300
0030:
0031:
0032:C*****************************************************
0033:C-----THIS PROGRAM IS DEVELOPED FROM THE ONE BY
0034:C-----JOEL H. FERZIGER IN "NUMERICAL METHODS FOR
0035:C-----ENGINEERING APPLICATIONS", WILEY-INTERSCIENCE,
0036:C-----1981, SEE "SPLINES"pp(17,19).
0037:C*****************************************************
0038:C
0039:C-----THE PROGRAM ACCEPTS AS INPUT THE COORDINATES OF THE
0040:C-----DATA POINTS (ASSUMED TO BE IN ORDER) AND COMPUTES
0041:C-----THE SPLINE INTERPOLATION AT THE DESIRED POINTS.
0042:C-----IN THIS CASE THE CORDINATES OF THE DATA POINTS FED
0043:C-----IN ARE THE (VOLTAGE/VELOCITY) POINTS OF THE
0044:C-----CALIBRATION CURVES FOR THE DUAL SENSOR HOT-WIRES.
0045:C-----SUBROUTINE SPLINE AND SPEVAL ARE CALLED BY THIS PROGRAM.
0046:        IMPLICIT DOUBLE PRECISION (A-H,O-Z)
0047:        DIMENSION X(200),Y(200),FDP(200)
0048:        OPEN(UNIT=5,FILE='grafdata1',FORM='FORMATTED')
0049:        OPEN(UNIT=6,FILE='grafdata2',FORM='FORMATTED')
0050:        OPEN(UNIT=9,FILE='veloutput',FORM='FORMATTED')
```

SPLINEFIT (CONT.)

```
C-----THE NUMBER OF POINTS IS REQUESTED FIRST
      WRITE(0,3)
    3 FORMAT(1H ,'TYPE WHICH SENSOR READINGS TO BE',
     -' INPUTED, SENSOR1 OR SENSOR2 ?')
      READ(0,*)ISN
      ISNN=ISN
      ISN=ISN+4
      READ(ISN,*)N
C-----NOW THE INPUT DATA ARE REQUIRED
      DO 10 I=1,N
      READ(ISN,*)X(I),Y(I)
   10 CONTINUE
C-----HAVING ALL THE DATA WE CALL SUBROUTINE SPLINE
      CALL SPLINE(N,X,Y,FDP)
C-----READ THE VALUE(S) OF X FOR WHICH THE INTERPOLATION
C-----IS DESIRED. ANY NUMBER CAN BE USED.
   15 WRITE(0,150)
  150 FORMAT(1H ,'TYPE THE VALUE OF X FOR WHICH YOU WANT THE FUNCTION')
      READ(0,*)XX
      IF(XX)170,155,155
  155 CONTINUE
C-----WE ARE NOW READY TO EVALUATE THE SPLINE.
      CALL SPEVAL(N,X,Y,FDP,XX,F)
C-----WRITE THE RESULTS.
      WRITE(0,160)ISNN,XX,F
      WRITE(5,160)ISNN,XX,F
  160 FORMAT(1H ,'SENSOR NO.',I3,/,1H ,
     -'VOLTAGE=',F6.4,X,'V',2X,'INTPLTD. VEL. =',F6.4,X,'m/sec.')
C-----THE FOLLOWING ASKS WHETHER FURTHER VALUES ARE WANTED
      GO TO 15
  170 STOP
      END



      SUBROUTINE SPLINE(N,X,Y,FDP)
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
C-----THIS SUBROUTINE COMPUTES THE SECOND DERIVATIVES NEEDED
C-----IN CUBIC SPLINE INTERPOLATION. THE INPUT DATA ARE:
C-----N = NUMBER OF DATA POINTS.
C-----X = ARRAY CONTAINING THE VALUES OF THE INDEPENDENT VARIABLE
C-----     (ASSUMED TO BE IN ASSENDING ORDER).
C-----Y = ARRAY CONTAINING THE VALUES OF THE FUNCTION AT THE
C-----     DATA POINTS GIVEN IN THE X ARRAY.
C-----THE OUTPUT IS THE ARRAY FDP WHICH CONTAINS THE SECOND
C-----DERIVATIVES OF THE INTERPOLATING CUBIC SPLINE.
      DIMENSION X(200),Y(200),A(200),B(200),C(200),R(200),FDP(200)
```

SPLINEFIT (CONT.)

```
C-----COMPUTE THE COEFFICIENTS AND THE RIGHT HAND SIDE
C-----OF THE EQUATIONS. THIS SUBROUTINE USES THE CANTILEVER
C-----WHICH IS A COMBINATION OF PARABOLIC RUNOUT AND
C-----NATURAL SPLINE.
C----- THE PARAMETER ALAMDA (LAMBDA) IS SET TO 1,
C-----BUT THIS CAN BE USER MODIFIED.
C-----A,B,C ARE THE THREE DIAGONALS OF THE TRIDIAGONAL SYSTEM,
C-----R IS THE RIGHT HAND SIDE. THESE ARE NOW ASSEMBLED.
      ALAMDA=1.0D0
      NM2=N-2
      NM1=N-1
      C(1)=X(2)-X(1)
      DO 1 I=2,NM1
      C(I)=X(I+1)-X(I)
      A(I)=C(I-1)
      B(I)=2.0D0*(A(I)+C(I))
      R(I)=6.0D0*((Y(I+1)-Y(I))/C(I)-(Y(I)-Y(I-1))/C(I-1))
    1 CONTINUE
      B(2)=B(2)+ALAMDA*C(1)
      B(NM1)=B(NM1)+ALAMDA*C(NM1)
C-----AT THIS POINT WE COULD CALL A TRIDIAGONAL SOLVER
C-----SUBROUTINE BUT THE NOTATION IS CLUMSY SO WE WILL SOLVE
C-----DIRECTLY. THE NEXT SECTION SOLVES THE SYSTEM WE HAVE
C-----JUST SET UP.
      DO 2 I=3,NM1
      T=A(I)/B(I-1)
      B(I)=B(I)-T*C(I-1)
      R(I)=R(I)-T*R(I-1)
    2 CONTINUE
      FDP(NM1)=R(NM1)/B(NM1)
      DO 3 I=2,NM2
      NMI=N-I
      FDP(NMI)=(R(NMI)-C(NMI)*FDP(NMI+1))/B(NMI)
    3 CONTINUE
      FDP(1)=ALAMDA*FDP(2)
      FDP(N)=ALAMDA*FDP(NM1)
C-----WE NOW HAVE THE DESIRED DERIVATIVES SO WE RETURN TO
C-----THE MAIN PROGRAM.
      RETURN
      END


      SUBROUTINE SPEVAL(N,X,Y,FDP,XX,F)
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
C-----THIS SUBROUTINE EVALUATES THE CUBIC SPLINE GIVEN THE
C-----DERIVATIVE COMPUTED BY SUBROUTINE SPLINE. THE INPUT
```

SPLINEFIT (CONT.)

```
C-----PARAMETERS N,X,Y,FDP HAVE THE SAME MEANING AS IN
C-----SUBROUTINE SPLINE.
      DIMENSION X(200),Y(200),FDP(200)
C-----THE FIRST JOB IS TO FIND THE PROPER INTERVAL.
      NM1=N-1
      DO 1 I=1,NM1
      IF(XX.LE.X(I+1)) GO TO 10
    1 CONTINUE
C-----NOW EVALUATE THE CUBIC
   10 DXM=XX-X(I)
      DXP=X(I+1)-XX
      DEL=X(I+1)-X(I)
      F=FDP(I)*DXP*(DXP*DXP/DEL-DEL)/6.000
     1  +FDP(I+1)*DXM*(DXM*DXM/DEL-DEL)/6.000
     2  +Y(I)*DXP/DEL+Y(I+1)*DXM/DEL
      RETURN
      END


      TYPICAL OUTPUT FOR SENSOR (1):

 SENSOR NO.   1
 VOLTAGE=2.7503 v  INTPLTD. VEL. =0.0000 m/sec.
 SENSOR NO.   1
 VOLTAGE=2.7521 v  INTPLTD. VEL. =0.0600 m/sec.
 SENSOR NO.   1
 VOLTAGE=2.7717 v  INTPLTD. VEL. =0.0800 m/sec.
 SENSOR NO.   1
 VOLTAGE=2.7975 v  INTPLTD. VEL. =0.1000 m/sec.
 SENSOR NO.   1
 VOLTAGE=2.8150 v  INTPLTD. VEL. =0.1200 m/sec.
 SENSOR NO.   1
 VOLTAGE=2.8600 v  INTPLTD. VEL. =0.1600 m/sec.
 SENSOR NO.   1
 VOLTAGE=2.9155 v  INTPLTD. VEL. =0.2000 m/sec.
 SENSOR NO.   1
 VOLTAGE=2.9361 v  INTPLTD. VEL. =0.2500 m/sec.
 SENSOR NO.   1
 VOLTAGE=2.9627 v  INTPLTD. VEL. =0.3200 m/sec.
 SENSOR NO.   1
 VOLTAGE=3.0263 v  INTPLTD. VEL. =0.4000 m/sec.
 SENSOR NO.   1
 VOLTAGE=3.0770 v  INTPLTD. VEL. =0.5000 m/sec.
 SENSOR NO.   1
 VOLTAGE=3.1360 v  INTPLTD. VEL. =0.6300 m/sec.
```

- END -

# APPENDIX V

## CONVECTIVE HEAT-TRANSFER CORRELATIONS AND HEAT FLOW BY RADIATION IN SOLAR COLLECTORS

The mechanism of energy transfer by natural convection involves the motion of a fluid past a solid boundary which is the result of a density difference resulting from the energy exchange. Because of this it is quite natural that the heat-transfer coefficients and their correlating equations will vary with the geometry of a given system[1].

The natural convection system most amenable to analytical treatment is that of a fluid adjacent to a vertical wall.

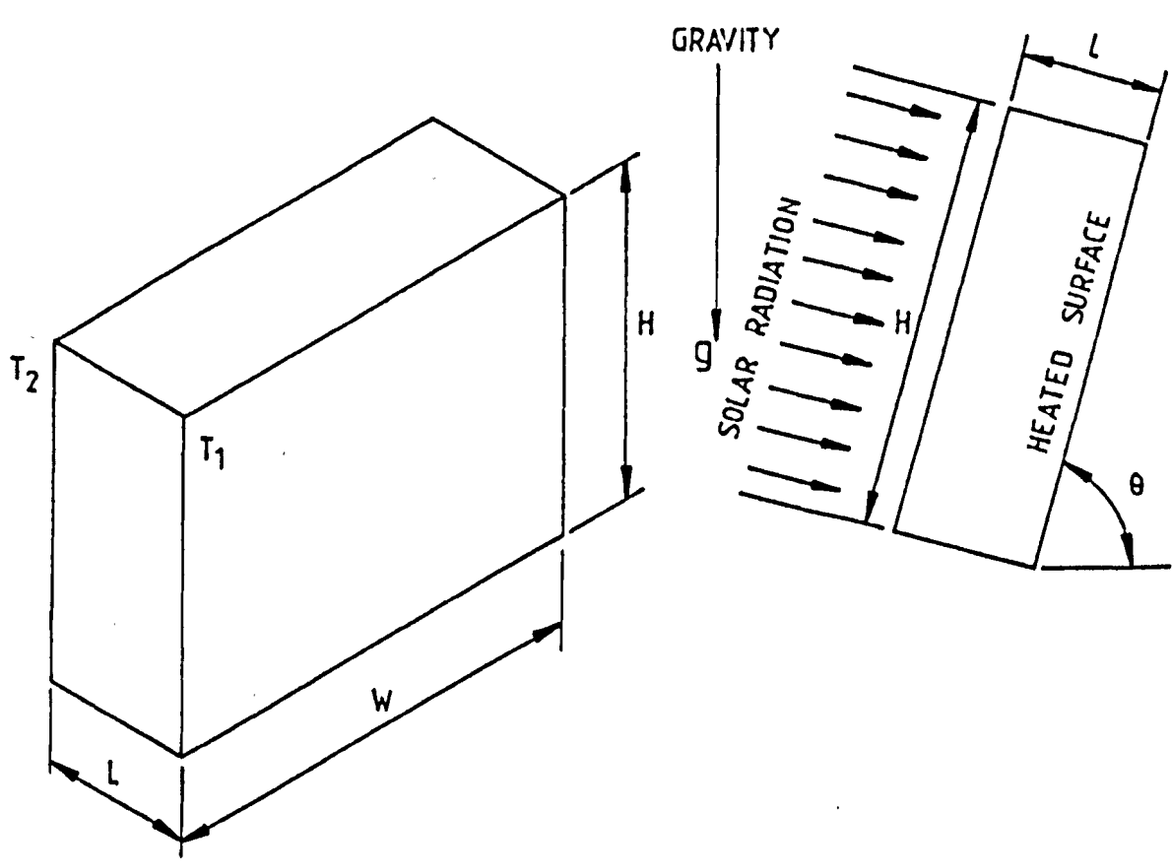



FIGURE AV.1: SOLAR COLLECTOR

Shown in the figure above is the configuration and nomenclature pertinent to rectangular enclosures. These cases have become much more important in recent years due to their application in solar collectors. Clearly, heat transfer will be affected by the angle of tilt, $\theta$; by the aspect ratio, H/L; and by the usual dimensionless parameters, $P_r$ and $R_a$.

The hotter of the two large surfaces is designated $T_1$, and the cooler surface is at temperature $T_2$. Fluid properties are evaluated at the fluid temperature $T_f = (T_1 + T_2)/2$. Convective heat flux is expressed as:

$$\frac{q}{A} = h\,(T_1 - T_2) \qquad \text{(AV.1)}$$

Case 1: Horizontal Collectors, $\theta = 0^o$

With the bottom surface heated a critical Rayleigh number has been determined by several investigators to exist. For cases where:

$$R_a = \frac{\beta g L \quad (T_1 - T_2)^3}{\alpha\,\nu} > 1700$$

conditions within an enclosure or a solar collector are thermally unstable and natural convection will occur. A correlation for this case has been proposed by Globe and Dropkin[2] in the form:

$$Nu = 0.069\,(R_a)^{1/3}\,(Pr)^{0.074} \qquad \text{(AV.2)}$$

for the range $3 \times 10^5 < R_a < 7 \times 10^9$.

When $\theta = 180^{o}$, that is, the upper surface is heated, or when $Ra < 1700$, heat transfer is by conduction: thus, $Nu = 1$.

Case 2: Vertical Collectors, $\theta = 90^{o}$

This is the case of our experimental system. For aspect ratio of less than 10, Catton[3] suggests the use of the following correlations.

$$Nu = 0.18 \left(\frac{Pr}{0.2 + Pr} R_a\right)^{0.29} \qquad \text{(AV.3)}$$

when $1 < H/L < 2$, $10^{-3} < Pr < 10^{5}$, $10^{3} < R_a\ Pr/(0.2 + Pr)$.
This condition of aspect ratio, Pr, and $R_a$ is the one applicable to our convective channel (solar collector), and

$$Nu = 0.22 \left(\frac{Pr}{0.22 + Pr} R_a\right)^{0.28} \left(\frac{H}{L}\right)^{-\frac{1}{4}} \qquad \text{(AV.4)}$$

when $2 < H/L < 10$, $Pr < 10^{5}$, $Ra < 10^{10}$.

For higher values of H/L, the correlations of MacGregor and Emery[4] are recommended, which are:

$$Nu = 0.42\ (R_a)^{\frac{1}{4}}\ (Pr)^{0.012}(H/L)^{-0.3} \qquad \text{(AV.5)}$$

For $10 < H/L < 40$, $1 < Pr < 2 \times 10^{4}$, $10^{4} < R_a < 10^{7}$, and

$$Nu = 0.46\ (R_a)^{1/3} \qquad \text{(AV.6)}$$

For $10 < H/L < 40$, $1 < Pr < 20$, $10^6 < R_a < 10^9$.

Case 3: Tilted Vertical Collectors, $0 < \theta < 90^o$:

Numerous relatively recent publications have dealt with this configuration . Correlations for this case, when the aspect ratio is large ($H/L > 12$), are the following;

$$Nu = 1.0 + 1.44 \left[1.0 - \frac{1708}{R_a \cos\theta}\right] \left[1.0 - \frac{1708 (\sin 1.80)^{1.6}}{R_a \cos\theta}\right]$$

$$+ \left[\left(\frac{R_a \cos\theta}{5830}\right)^{1/3} - 1.0\right] \qquad \text{(AV.7)}$$

when $H/L > 12$, $0 < \theta < 70^o$. In applying this relationship any bracketed term with a negative value should be set equal to zero[1]. Equation (AV.7) was suggested by Hollands et al[5] with collectors nearing the vertical. Ayyaswamy and Catton[6] suggested the relationship:

$$Nu_L = Nu_{Lv} (\sin \theta)^{\frac{1}{4}} \qquad \text{(AV.8)}$$

For all aspect ratios, and $70^o > \theta > 90^o$. The value $\theta = 70^o$ is termed the "critical" tilt angle for vertical collectors with $H/L > 12$. For smaller aspect ratios the critical angle of tilt is also smaller. A review article on the subject of inclined rectangular cavities is that of Buchberg, Catton and Edwards[7].

Heat Flow by Radiation:

The process of heat transfer through fluids between two solid walls of different temperature may, and probably will, involve all three modes of heat transfer, namely conduction, convection and radiation.

In the computer program only the first two modes were considered. When the fluid in a duct, channel, or cavity between the walls is itself non-absorbing, the radiation occurs independently of the presence of gaseous conduction and convection. Therefore to find the heat flux across the duct or channel (solar collector), the radiative component must be added to conductive/convective components.

The zero method described by Hottel and Sarofim[8] can be used to determine the amount of heat transfer by radiation in a duct or a solar collector. Consider the case where the solar collector of Figure AV.1 can be divided into four surfaces. Two walls at different temperatures ($T_1$), ($T_2$) and two adiabatic or known temperature walls at temperature ($T_a$) as shown in Figure AV.2. It is assumed that each surface is uniform in emissivity ($\varepsilon$) and temperature (T).

For a given solar collector geometry, temperature distribution and walls properties, the following matrix equation is valid:

$$\begin{bmatrix} F_{11} - \frac{A_1}{\rho_1} & F_{12} & F_{13} & F_{14} \\ F_{21} & F_{22} - \frac{A_2}{\rho_2} & F_{23} & F_{24} \\ F_{31} & F_{32} & F_{33} - \frac{A_3}{\rho_3} & F_{34} \\ F_{41} & F_{42} & F_{43} & F_{44} - \frac{A_4}{\rho_4} \end{bmatrix} \begin{Bmatrix} W_1 \\ W_2 \\ W_3 \\ W_4 \end{Bmatrix} = \begin{Bmatrix} \frac{A_1\ \varepsilon_1\ E_1}{\rho_1} \\ \frac{A_2\ \varepsilon_2\ E_2}{\rho_2} \\ \frac{A_3\ \varepsilon_3\ E_3}{\rho_3} \\ \frac{A_4\ \varepsilon_4\ E_4}{\rho_4} \end{Bmatrix}$$

TRANSFER MATRIX RESPONSE VECTOR EXCITATION VECTOR

where:

$F_{ij}$ = configuration factor of the areas relative to one another, where suffixes i and j represent the areas concerned

$A_i$ = surface area

$\rho_i$ = $1 = \delta_i$ = reflectance of the surface

$W_i$ = leaving flux density

$\varepsilon_i$ = emissivity of emittance of a surface

$E_i$ = total emissive power of a black body,

= $\sigma T_i^4$ where $\sigma$ = Stefan-Boltzman constant.

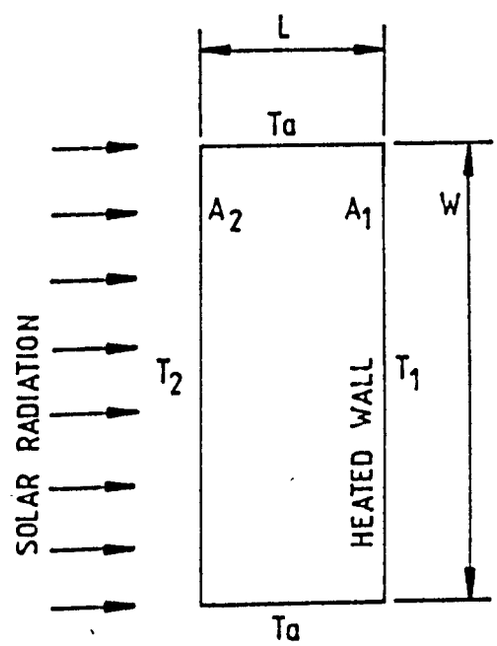



FIGURE AV.2

After solving the above matrix equation for $(N_i)$, the net radiant flux at surface $(A_i)$ may then be found by:

$$Q_i = \frac{\varepsilon_i}{\rho_i} (E_i - W_i) A_i \qquad \text{(AV.10)}$$

Configuration factors of the areas relative to one another are calculated according to the geometry[9].

The quantity of heat lost from inside the heated area $(A_1)$ to the outside area $(A_2)$ by radiation must be added to the heat flux across the solar collector. Radiation losses at different temperatures were similarly computed and tabulated by Sadhu[10]. For fixed geometry and material properties, the radiative heat transfer increases with increasing temperature difference.

The assumption of uniform surface temperature is not realistic, but the theory given gives a fairly good physical approximation. Probert[11] used an experimental technique, "vacuum analysis", to distinguish the convective/conductive components at the steady-state heat exchange through gases.

## References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# APPENDIX VI

## LIMITATIONS OF SCALE MODELS AND TURBULENT WALL JET VELOCITY PROFILES

### VI.A: Scale Models Limitations

It is a fundamental law in the ventilation/air-conditioning technique that a ventilation/air-conditioning installation can never be better than the air diffusion in the space concerned[1].

The aim of the ventilation/air-conditioning model system utilised in this work and portrayed in Chapter 4 is the assessment and analysis of:

i) the air flow rates required and dimensional parameters optimisation;

ii) the direction and velocity of air in the various regions of the system;

iii) the admissible temperature difference between the room inlet and exit to allow for an acceptable air temperature variation;

iv) the admissible inlet velocity to the room to allow for an acceptable ventilation/air-conditioning without causing draughts used in keeping with the acceptable temperature variations mentioned in (iii) above.

For a non-isothermal flow in a room, it is sufficient, besides geometrical similarity, to maintain equality of the Archimedes number in the model and the original in order to obtain the same flow features[2].

On a fluid element the Ar-number is:

$$Ar = \frac{\text{buoyancy force}}{\text{inertial force}} = \frac{\rho g\ \ell^3\ \beta\Delta\theta}{\rho\ \ell^2\ u^2} = \frac{g\ell\ \beta\Delta\theta}{u^2} \qquad \text{(VI.1)}$$

| | | |
|---|---|---|
| where: | $g$ = gravitational acceleration | $m/sec^2$ |
| | $\ell$ = characteristic length | m |
| | $u$ = characteristic velocity | m/sec |
| | $\beta$ = coefficient of cubical expansion (for air $\beta = \frac{1}{\theta_{(abs)}}$) | 1/K |
| | $\rho$ = characteristic density | $kg/m^3$ |
| | $\Delta\theta$ = characteristic temperature difference between two points | K |

It has not yet been proved experimentally that the above condition is also sufficient forquantitative similarity of both temperature and velocity distribution. This is why the differential equations of continuity, motion and of energy, which, together with the boundary conditions, govern the flow and temperature distribution, were solved in this thesis. Using the same equations and boundary conditions for both model and real situations will result in similar solutions. The equations are similar if the variables are made dimensionless.

Since these equations equally describe laminar and turbulent flow, similarity between model and original is valid whether the flow is turbulent or not. The introduction of the turbulent viscosity and

turbulent conductivity are not a requirement for similarity, but are the result of the particular geometry used and values of Re, Ar and Pr.

It is not possible to obtain Re(m) = Re(o) and Ar(m) = Ar(o) in the same time if both the model and original gases are air. (m) is the model and (o) is the original system. In fact it is very difficult to find a useful fluid as a medium that will simultaneously fulfil the requirements of Re, Ar and Pr with workable velocities and temperature differences in both (m) and (o).

For flow condition which is most general in ventilation/air-condioned rooms, namely non-isothermal turbulent flow, equality of (Ar) is much more important than equality of (Re)[1].

Müllejans[2] has shown that the general form of the flow in a series of model tests was similar at different (Re) and only dependent on buoyancy and (Ar). Wall jets such as the inlet duct to our ventilated/air-conditioned room are also an example of flows which can be similar at different (Re)[3,4]. Due to the variety of the inlet air duct conditions and variable geometry a fixed value for (Re) above which the flow will be (Re) independent cannot be given.

The numerical model shows that when changing the convective channel air inlet velocity, and hence (Re), the ratio of the velocity measured at different places in the solar room to the convective channel air inlet velocity remained constant. The experimental measurements seem to agree with this, but probably more elaborate measurements are required.

Temperature distribution similarity requires radiant heat to be equal. Heat transfer correlations and heat flow by radiation in solar collectors is described in Appendix V.

Local velocities cannot be predicted very accurately, although in the solar room deviations can be less than 17%. Small differences in inlet geometry lead to large differences in attachment point and recirculation size. Velocity measuring instruments used, namely hot-wire anemometers, must be used in the same way in the original system as in the model because of their directional dependence.

Non-isothermal scale model experiments are only possible for restricted scale ratios up to 1:8 for good insulated models. If radiation can be neglected, or if only the higher velocities such as inlet/outlet velocities, are of interest, then higher scale factors are attainable[1], see Figure VI-1 (overleaf).

Model experiments do not give a 100% reliable solution, this is why the solar ventilation/air-conditioning system was designed with variable dimensional parameters. This, for instance, makes the inlet duct flexible in delivering air quantity so that adjustments can be carried out easily. Similar design features were incorporated for temperatures.

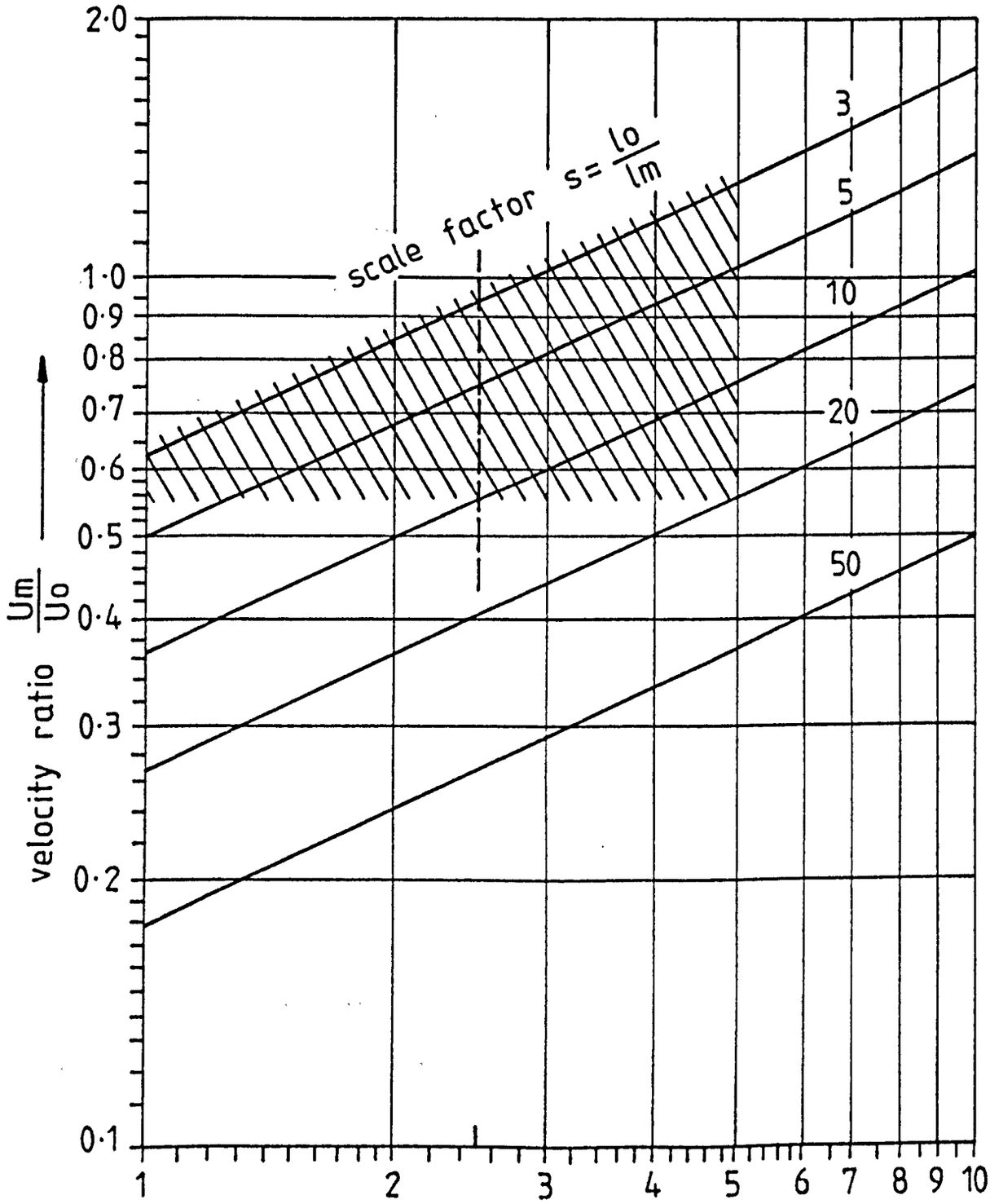


FIGURE VI-1: Relation between velocity ratio $u_m/u_o$ and temperature difference ratio $\Delta\theta_m/\Delta\theta_o$ for various scale factors S

## VI.B: Turbulent Wall Jet Longitudinal Velocity Profiles

The experimental investigation on plane wall jets was started by Förthmann[5], who reduced all mean velocity data to a single profile, by normalising them by the jet thickness and the maximum longitudinal velocity. The similarity of radial and plane wall jets was studied later[6,3]. Schwarz and Cosart[3] deduced the following expressions for the maximum velocity across the jet ($U_{max}$), and length scale $\delta_u$ [thickness of the jet at ($U_{max}/2$) in the outer layer]:

$$\frac{U_{max}}{U_o} = c_u \left(\frac{x - x_D + x_o}{h}\right)^{e_u} \qquad \text{(VI.2)}$$

and

$$\delta_u = c_{\delta u} \; (x - x_D + x_o)$$

where $x_D$ and $x_o$ are the coordinates of the inlet plane and the virtual origin of the jet - see Figure VI:2.

Current practice in the design of ventilation/air-conditioning systems is to assume that different inlet arrangements originate self-similar turbulent jets which may still be fitted by a suitable set of values $x_o$, $c_u$, $e_u$ and $c_{\delta u}$.

Works by Schwartzbach[8] and the ASHRAE Handbook of Fundamentals[7] support this assumption for several types of inlets and diffusers.

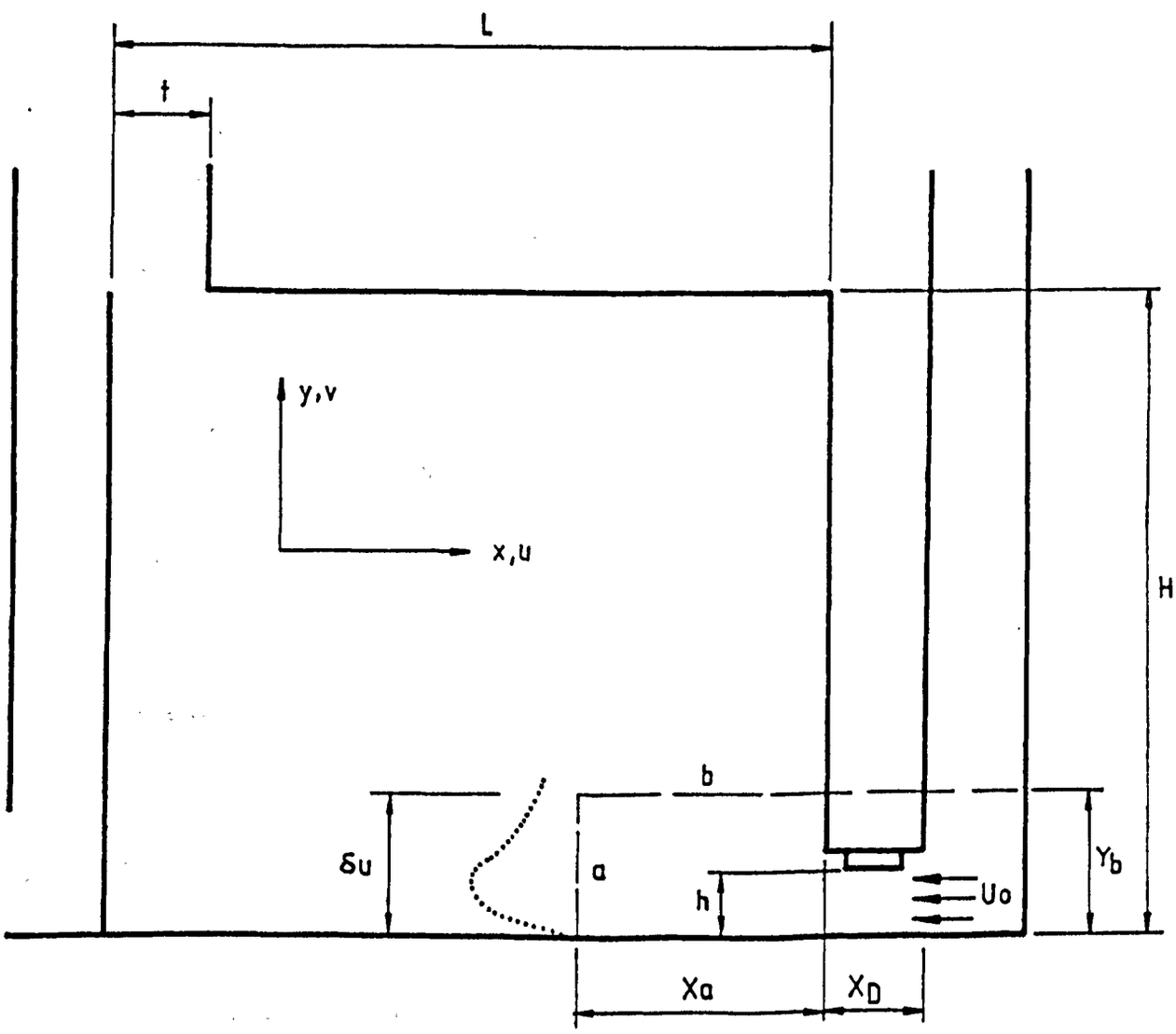


FIGURE VI-2: Parameters used in wall jet assumptions for the inlet duct to the solar ventilated/air-conditioned room

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# APPENDIX VII

# VALIDATION AND FURTHER CALCULATIONS

## VII.1 Validation of the Computational Model

The procedure used in this thesis and in the turbulent validation problems is that of implementing zonal turbulence modelling.

The central question to be considered here is whether a universal model for turbulent flows can be created or whether it is preferable to undertake zonal modelling, as in this work, in order to obtain results of engineering accuracy for the practical flows in hand. This question was addressed to a group of active researchers and government monitors at the NASA Langley Research Centre in May 1980, and resulted in a sharp and relatively even division of opinions.

The inspection of universality of turbulence models is a crucial one because it influences the central strategy of how one models turbulent flows. All man-made models of laws of nature are with some limits of range of domain and also with some residual uncertainties. This limit can be either broad or narrow to the relevant class of systems.

> *"The question is not whether a model is totally universal; none are adequate for all systems. The relevant question becomes (what is the domain over which this particular model gives adequately accurate predictions about nature?). This is precisely the question that confronts turbulence modelling"* (4)

There are advantages obviously for a universal model. It would allow turbulent flows to be modelled once and for all. It might be constructed more easily and quickly than a variety of models each fitted to special circumstances. It would assure true predictive rather than postdictive computations. A universal model would also appeal to the sense of mathematical fitness and elegance. However, the test is not elegance or seeming fitness, nor is it some desire to emulate Newton or Einstein. The only proper test is the practical one which is a fundamental requirement of design.

When the Navier-Stokes equations are time-averaged, information is lost which are inherent in the Reynolds stresses. For incompressible flow, these stresses are symmetric second-order tensor that is in general a multipoint function of four variables[4]. Such a tensor is a complex quantity mathematically. For compressible flows we must deal with a number of different variables each of which has this complexity even if simpler forms of the equations are used.

A geometric analogy would be to consider the nature of a model that might describe the topography of a complex terrain. Would a simple algebraic or differential equation with few adjustable constants describe such a task?

Turbulence is not a single or even a simple set of states; it is a very complex and variable set of states that often react in unanticipated ways to a great variety of circumstances.

The results in the 1980-1981 AFOSR-HTTM-Stanford Conference relevant to the question of universality of modelling[4] were:

i) No single turbulence model is accurate over the entire range of flow cases, however limited they might be.

ii) There is no correlation between sophisticated (i.e. level) of model and accuracy of results over the full range of usable models.
(In the conclusions of this thesis item 15 it was stated that numerical prediction accuracy is not proportional to the number of partial differential equations used in calculating turbulent viscosity and conductivity. It could well be true that the accuracy required for many design and engineering applications is obtainable from a simple well engineered model).

iii) Several times in discussions, individual computers reported success on some class followed by degradation of results when attempts were made to extend the range of domain using a single method.

*"The lesson to be drawn from all this is that there is a definite trade-off between accuracy of output and the range of domains attempted"*[4]. When we know enough about the physics, the structure of a given flow zone can be built into our model to obtain good accuracy.

To build separate models for various flow classes or applications is a hopeless task. There is an infinite number of scientific flow cases as well as an infinite number of geometries of practical and/or commercial importance. The task will be endless.

In most flows of interest there are only a limited number of identifiable structural flow zones where the flow field within each has roughly the same kind of flow structure. The computer has no particular difficulty in keeping track of where various zones lie throughout the computation, we know where we will need to patch or match[4].

The idea of zonal modelling tied to structural flow zones is not new. It is in fact central to the famous (1904) paper by Prandtl, to the analysis of isotropic flow and shocks. The concept of the boundary layer is a zonal model as well.
It will almost certainly accelerate progress if we iterate turbulence models with experiments on structure, not in general, but rather for particular structural flow zones one by one.

The evidence suggests that the profitable road for engineering calculations in the near and intermediate future is *"systematic exploitation of zonal models tied directly to structure features of the flows"*[4]. This approach has been extended and the details have been perfected in the work done in this thesis and in the subsequent validation test cases.

An argument is sometimes made that zonal modelling will be more work and will proceed more slowly than universal modelling. This is certainly untrue because no single, simple, adequate turbulence model exists. *"Nothing slower than a search for the non-existent"*[4].

The work in this thesis has shown that the zonal approach holds promise, and that design needs compel us towards development of the simpler forms of such zonal models in parallel with further development of higher order models.

Merging the various zones can be handled on the basis of known or observed/visualised phenomena so as to adjust the zones as per the physics. When using a universal model known physical zonal readjustments are simply ignored and not incorporated in the models. Universal modelling has been almost the only recognised game in town[4]. The leaders of the theoretical and computational research on turbulence and perhaps all the "mathematicians" have been "universalists". The only users and friends of "zonalism" have been some experimentalists, engineers, and some individuals in leading companies *"such as Boeing (USA), where the engineers were face-to-face with the need to make design decisions -sometimes with billions of dollars implications - and therefore had urgent need to guarantee accurate results. These engineers, under these conditions, chose to use models that were known to be explicitly tailored to specific classes of flow situations in order to guarantee accurate results"*[4]. It should not be surprising then that the zonal approach is correct, although universal modelling has been favoured and "oversold".

The governing differential equations contain all the physics and no more. Then any universal model that is simpler than the governing equations must represent less physics. This is the problem of universal modelling. If the model is adjusted to fit few flow classes, it will not fit in at least some other classes because the model does not represent all the physics. Suppose we now allow adjustment of the turbulence model from class to class i.e. zonal view, then the model can be fitted to the physics class by class with the gain of using more appropriate information on the physics for any given type of flow zone.

*"The central purpose of zonal modelling is precisely to enable us to incorporate more physics into the total set of models while still keeping computation size within the limits of available computers. If we could get enough physics into a universal model!, we would not need to go to zonal representation"*[4].

The zonal approach has been adopted and implemented successfully throughout this work where flow zones have been assigned different length scales of turbulence, while turbulence intensity was averaged and adjusted from measured values for each zone.

The author suggests in addition that efforts should be directed at this point towards deriving an empirical rule(s) for determining turbulence intensities in given flow situations, so as to use the current method with high degree of confidence in the absence of experimental results.

This section describes in detail the calculation of various test problems that have been mentioned in Chapter 6 through which the program was tested for correctness. The problems have either theoretical or experimental solutions available to compare them with.

In addition other relevant problems to the configuration which is the subject of this thesis as test and validation problems were imposed by Ref 1. Thus the test problems selected contain the ingredients of turbulent, buoyancy influenced flow with heat transfer across walls. References (5) and (7) and/or (8) were suggested. References (5) and (7) were chosen, and are called test cases (VII.1.9) and (VII.1.10).

### VII.1.1 Developing Flow Between Parallel Plates Using a Natural Velocity Gradient Boundary Prescription

As flow is expected to be symmetric about the film centre line, Figure VII-1 shows only half the flow domain. Boundary conditions on the fixed surface reflect a non-slip condition (U = V = 0) whereas a symmetric prescription is used at the mid-film position. Downstream conditions reflect a developed flow field with pressure specified at one point on an element corner node. Upstream prescription is the most difficult to apply, for the present solution a square axial velocity profile is used with a zero gradient on the cross-stream momentum equation is thought to be the most applicable.(2) The finite element mesh for this problem is shown in Figure VII-4A and dimensions are shown in Figure VII-4B. The mesh assumes a weighted form with fine elemental discretisation in the developing flow region. Computation has been

carried out at a Reynolds number of 100 where the distance between the plates is used for the characteristic length. Figure VII-5 shows the velocity vectors. Figure VII-6 shows the velocity contours. Figure VII-7 shows the pressure contours. The output was exactly as per the test case output[2] to within six decimal places.

### VII.1.2 Developing Pipe Flow Using Stress Boundary Conditions

Figure VII-2 illustrates the boundary prescription for the developing pipe flow problem. As in VII.1.1 the specification reflects non-slip conditions on the bounding surface, centreline symmetry and a developed downstream profile. Similar to VII.1.1 a square velocity profile is used at the upstream edge. However the stress formulations obviate the need for pressure specification as this is coupled into the stress prescription. The solution is for a nominal Reynolds number of 100. Figure VII-8 shows the velocity vectors. Figure VII-9 shows the velocity contours. Figure VII-10 shows the pressure contours. The output was exactly as per the test case output[2] to within the same accuracy of VII.1.1.

### VII.1.3 Forced Convection in Developing Pipe Flow

The boundary conditions for the fluid flow equations are identical to those discussed in VII.2. Temperature boundary conditions, see Figure VII-3, are applied to the energy equation in the form of a fixed surface and bulk inlet temperature, prescriptions on the pipe centreline and outflow reflect symmetry and fully developed conditions respectively. The mean Reynolds number for this solution was 100 and Prandtl number of

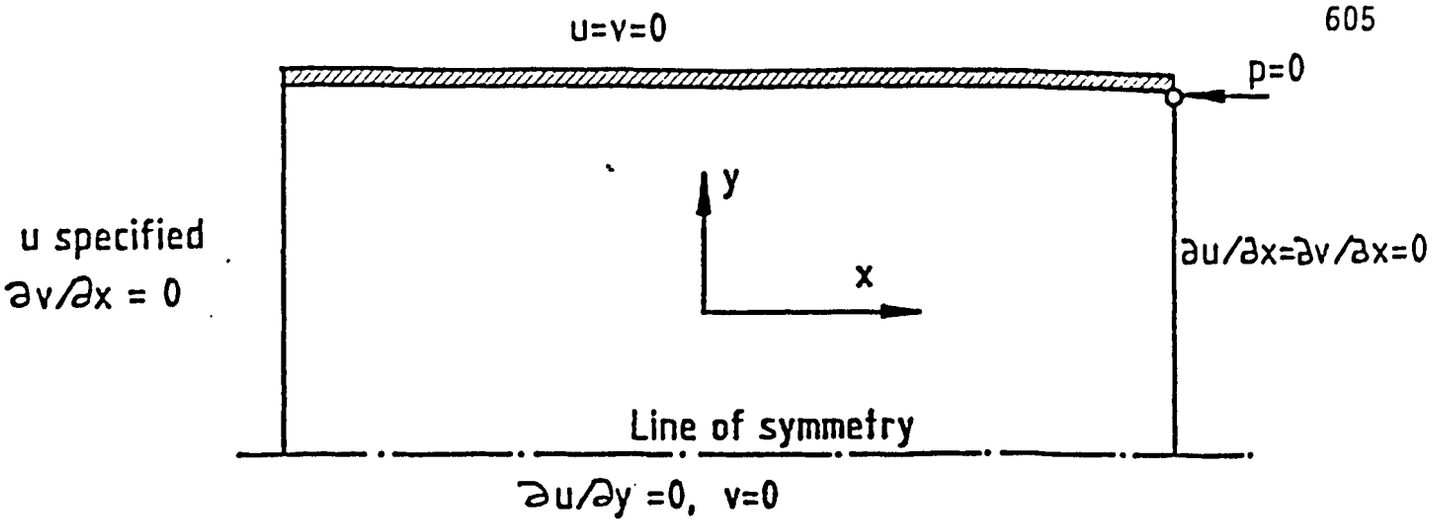



FIGURE (VII-1) BOUNDARY PRESCRIPTION FOR DEVELOPING FLOW BETWEEN PARALLEL PLATES-VELOCITY GRADIENT FORMULATION

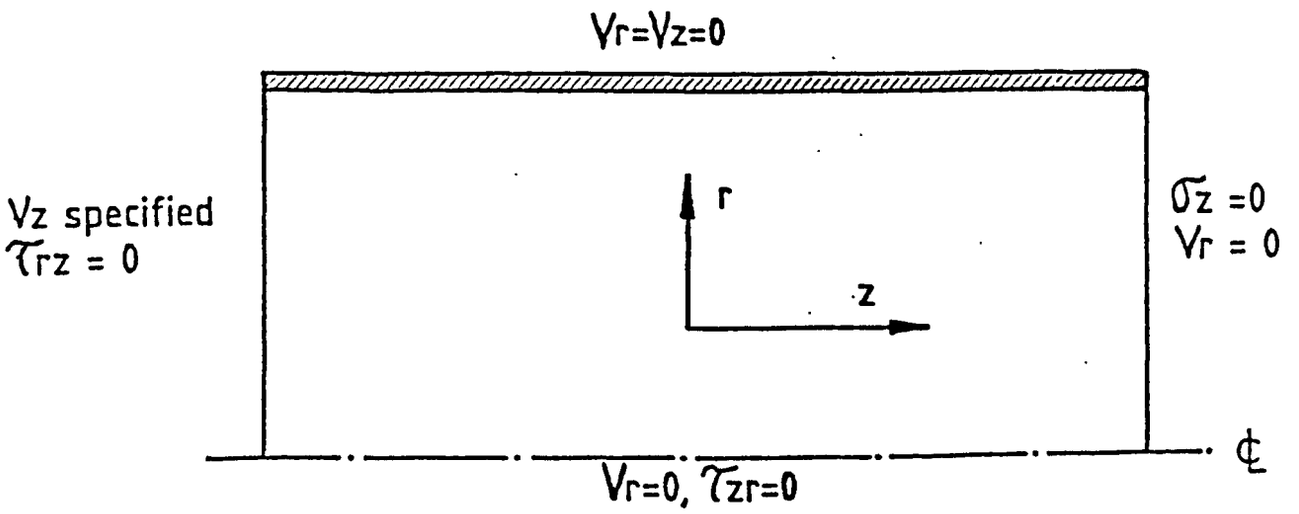



FIGURE (VII-2) BOUNDARY SPECIFICATION FOR DEVELOPING PIPE FLOW STRESS FORMULATION

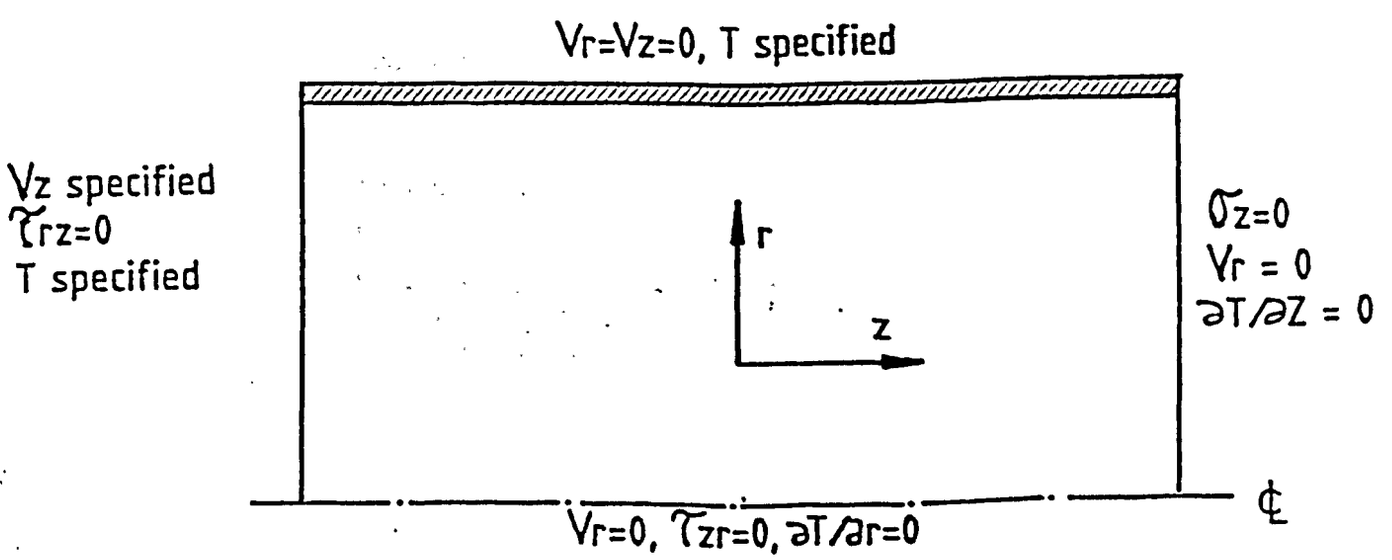



FIGURE (VII-3) BOUNDARY SPECIFICATION FORCED CONVECTION IN DEVELOPING PIPE FLOW

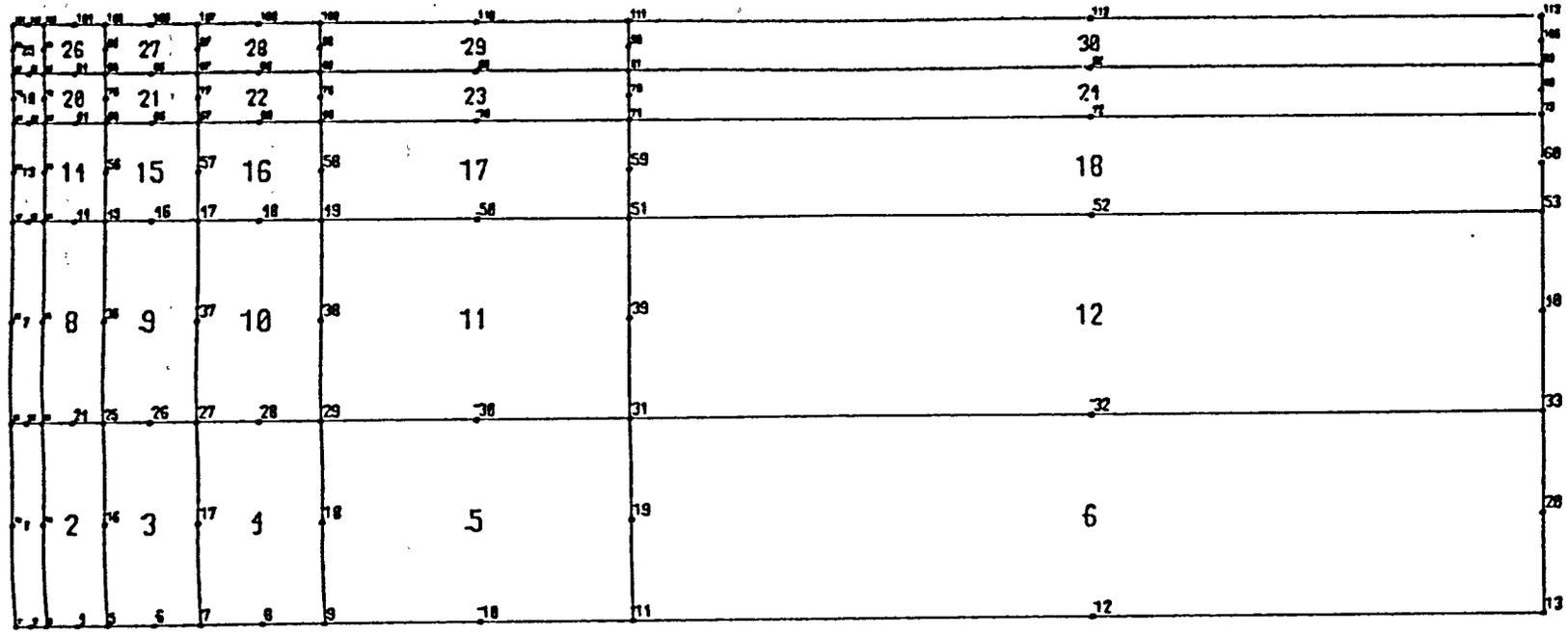



FIGURE VII-4A: Finite Element Mesh of Test Problems (VII.1.1), (VII.1.2), and (VII.1.3)

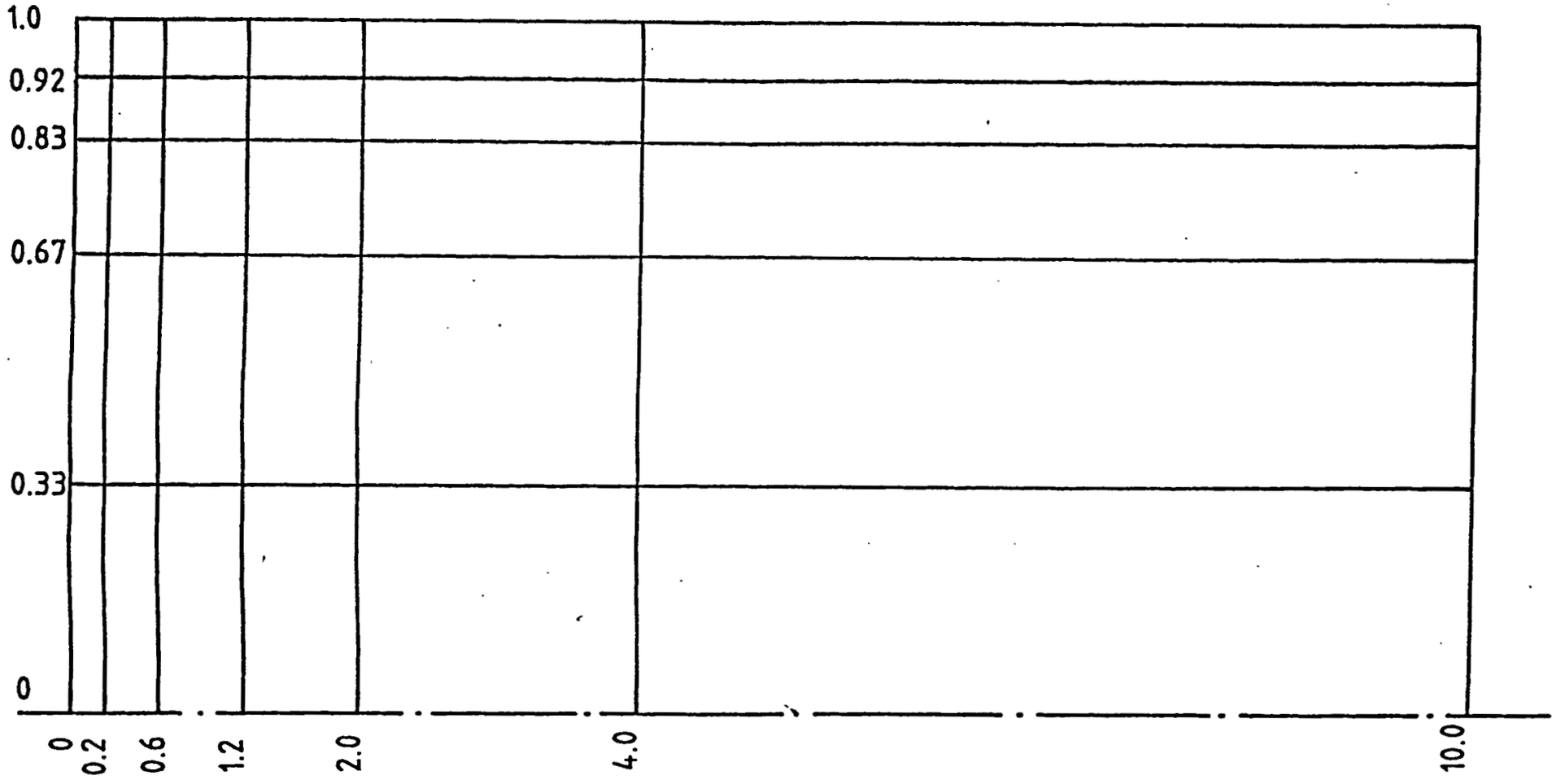



FIGURE (VII-4B) FINITE ELEMENT MESH DIMENSIONS FOR PROBLEMS OF FIGURES(VII-1)-to-(VII-3)

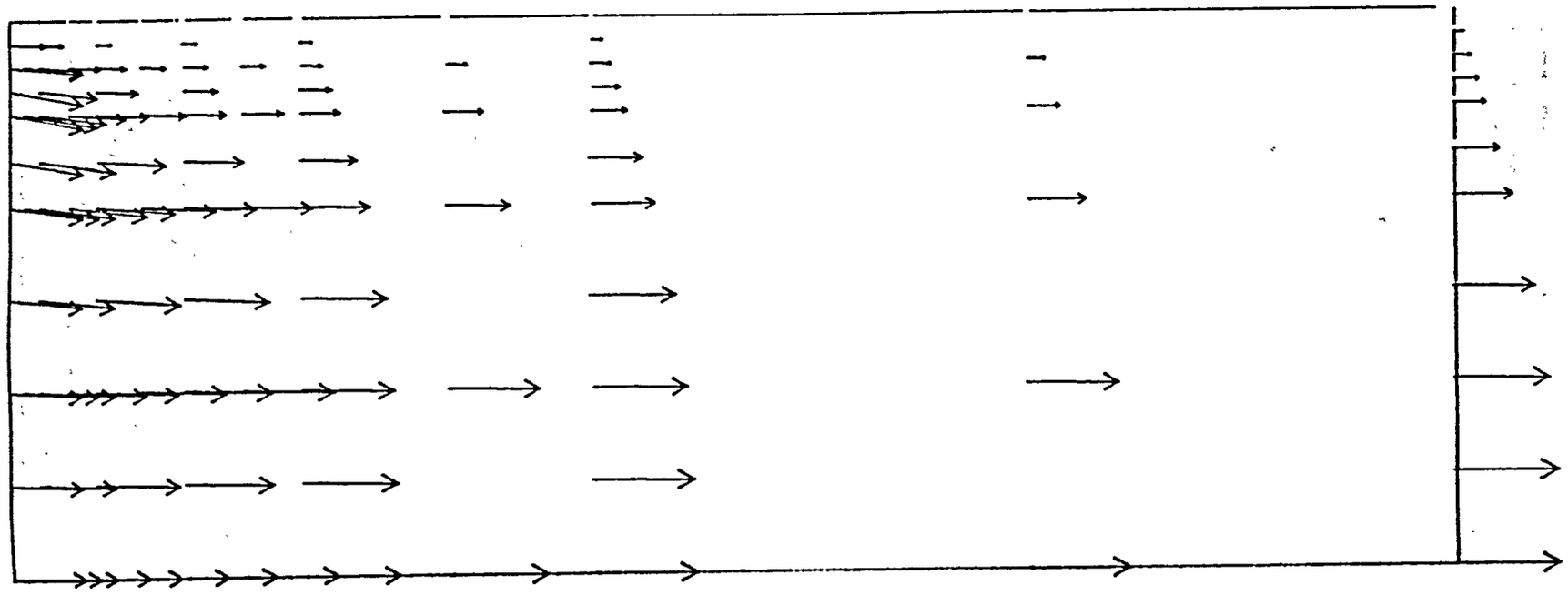


FIGURE VII-5: Test Case (VII.1.1) Velocity Vectors.
Developing Flow Between Parallel Plates

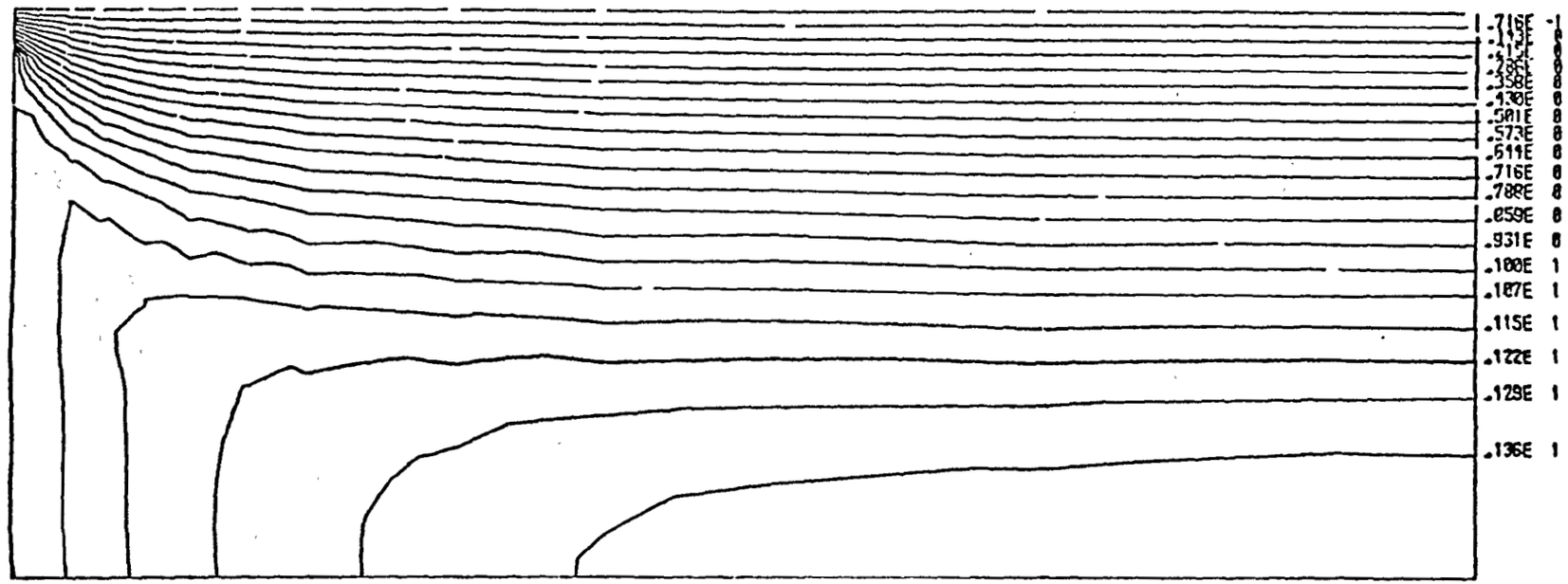



FIGURE VII-6: Test Case (VII.1.1) Velocity Contours (Isovels).
Developing Flow Between Parallel Plates

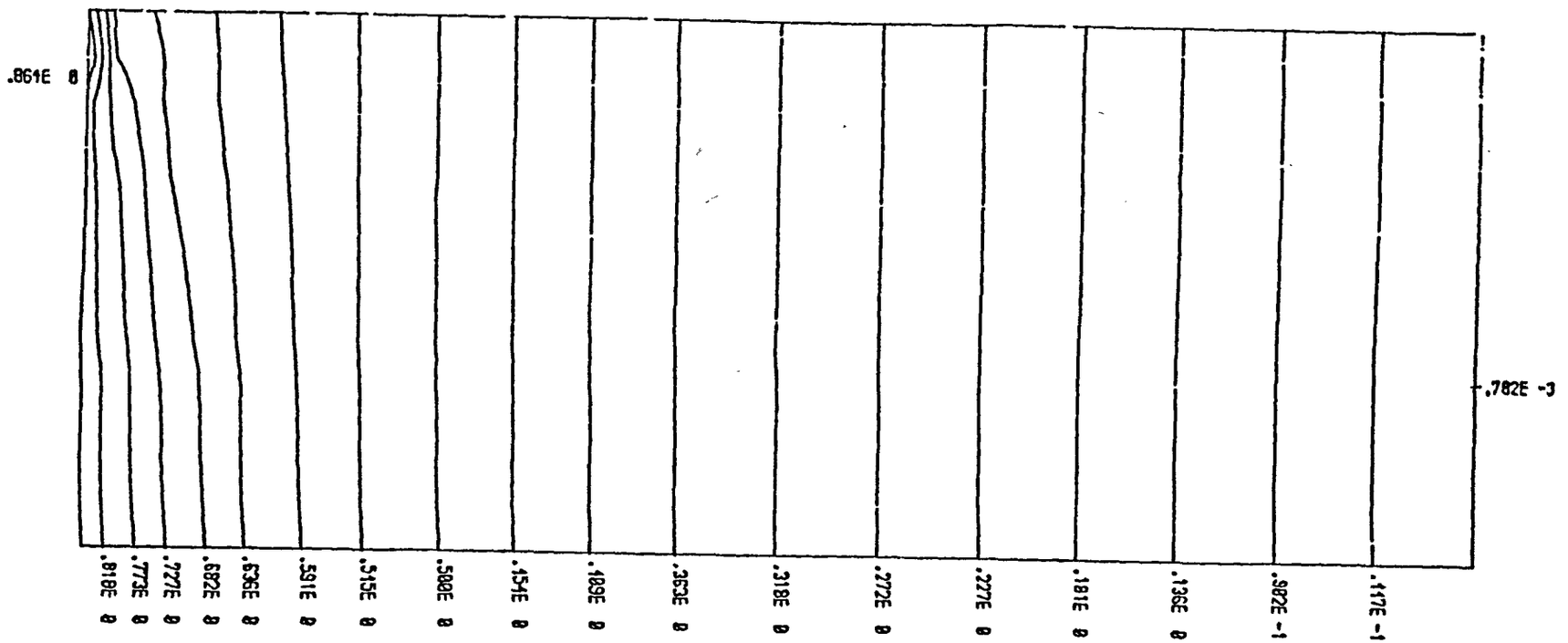



FIGURE VII-7: Test Case (VII.1) Pressure Contours (Isobars)
Developing Flow Between Parallel Plates

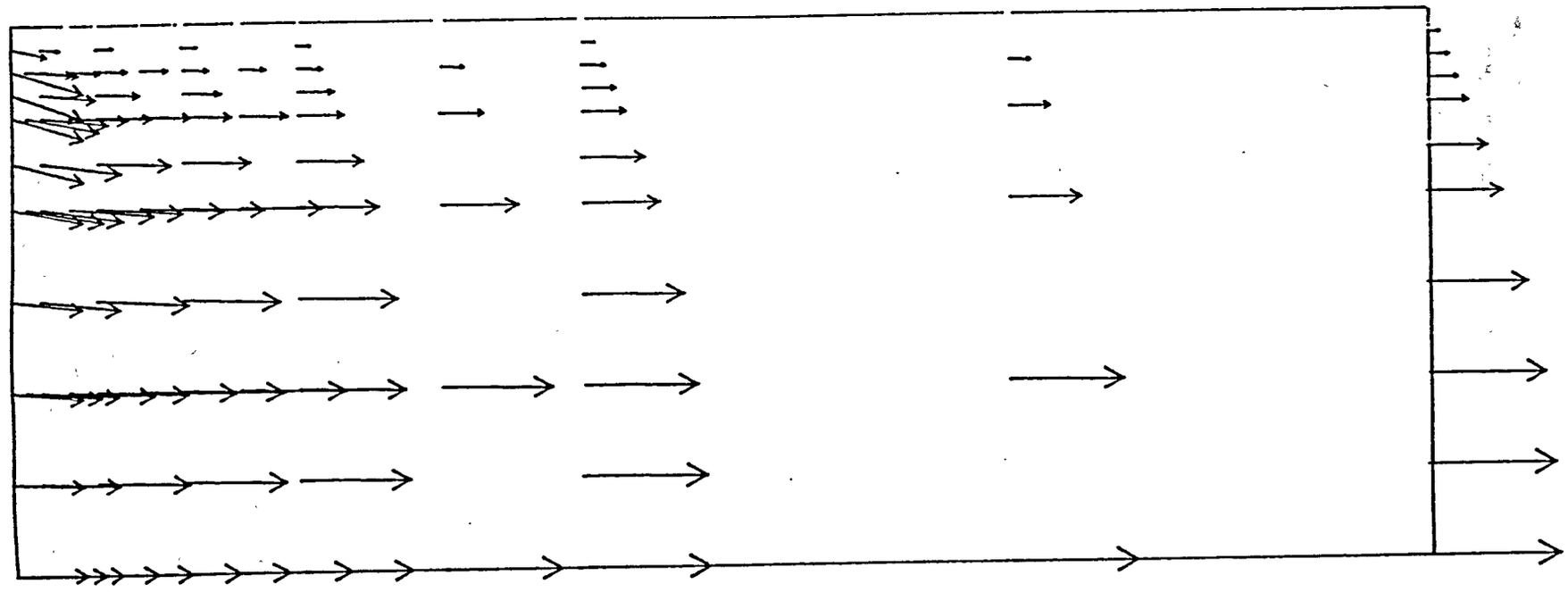


FIGURE VII-8: Test Case (VII.1.2) Velocity Vectors
Developing Pipe Flow

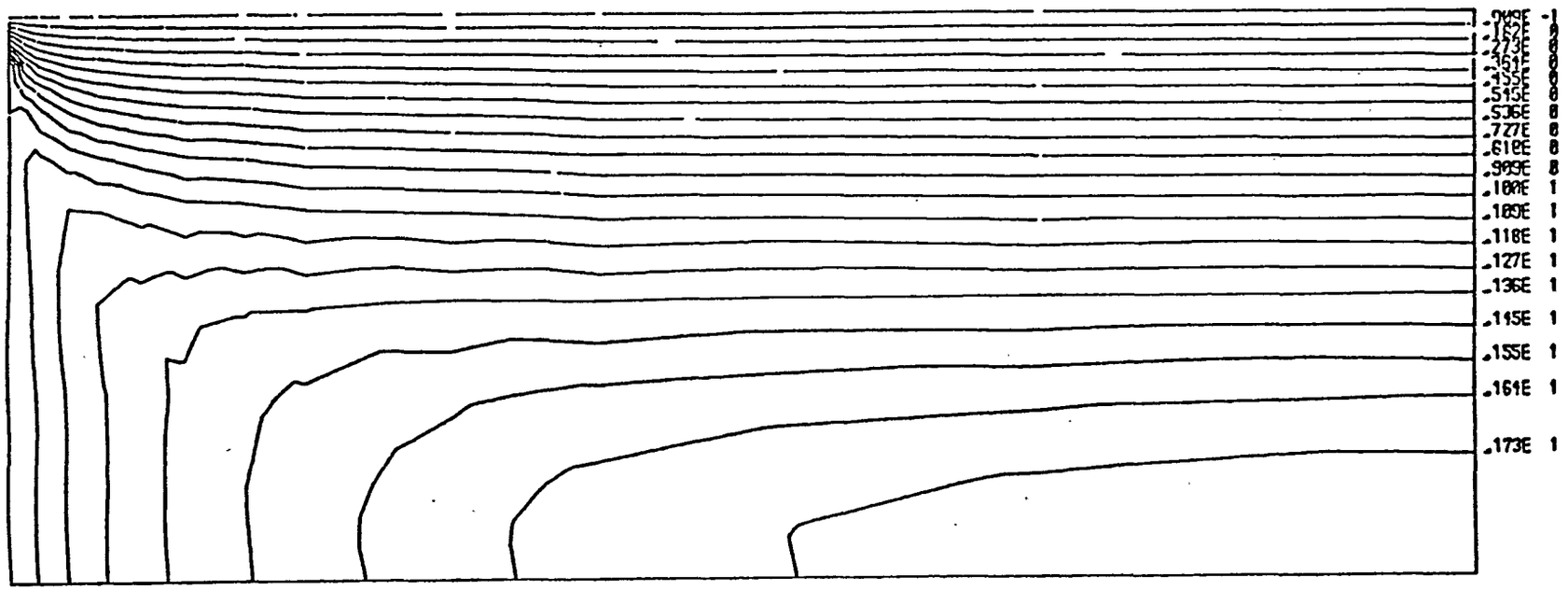



FIGURE VII-9: Test Case (VII.1.2) Velocity Contours (Isovels)
Developing Pipe Flow

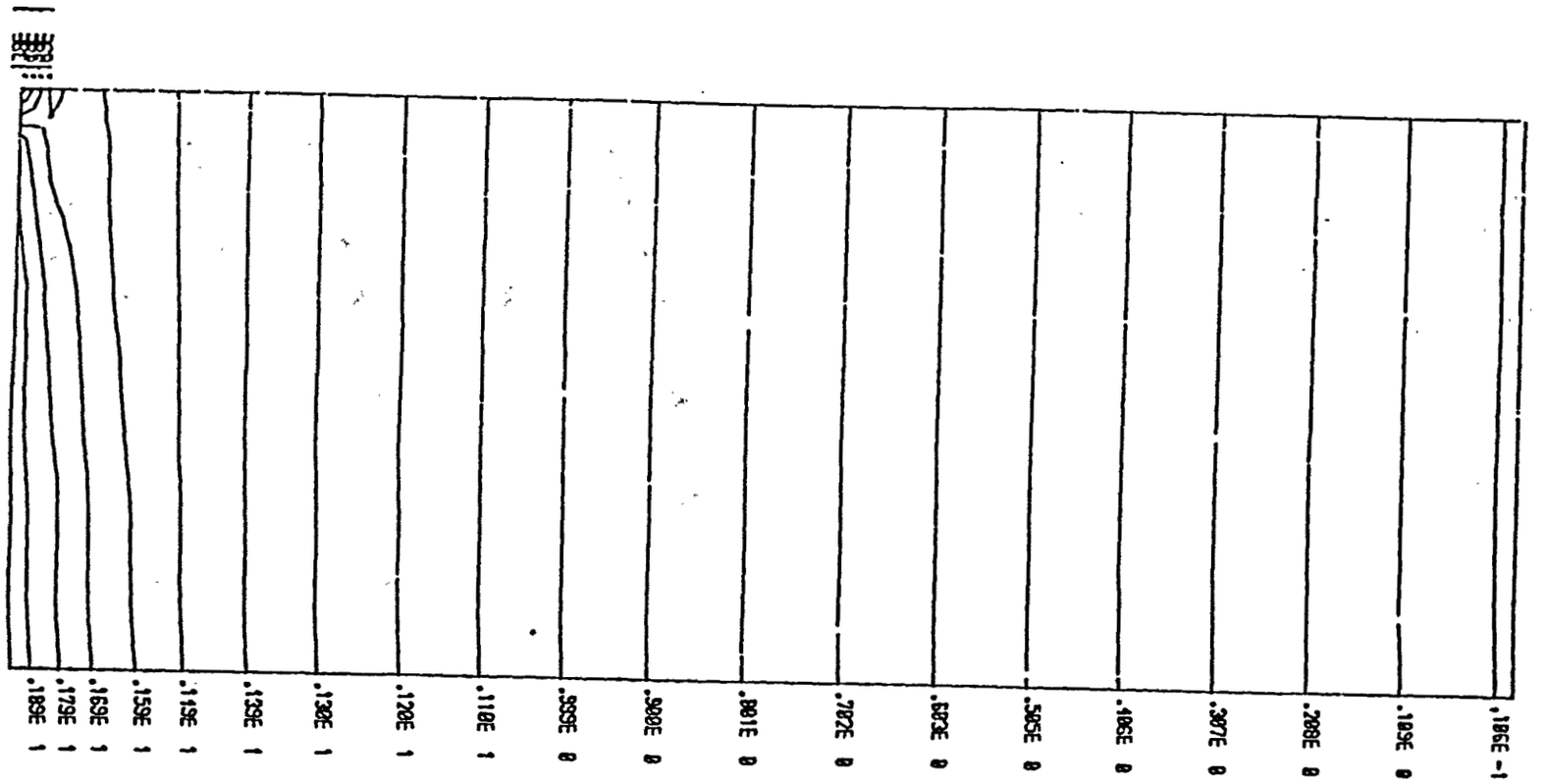



FIGURE VII-10: Test Case (VII.1.2) Pressure Contours (Isobars)
Developing Pipe Flow

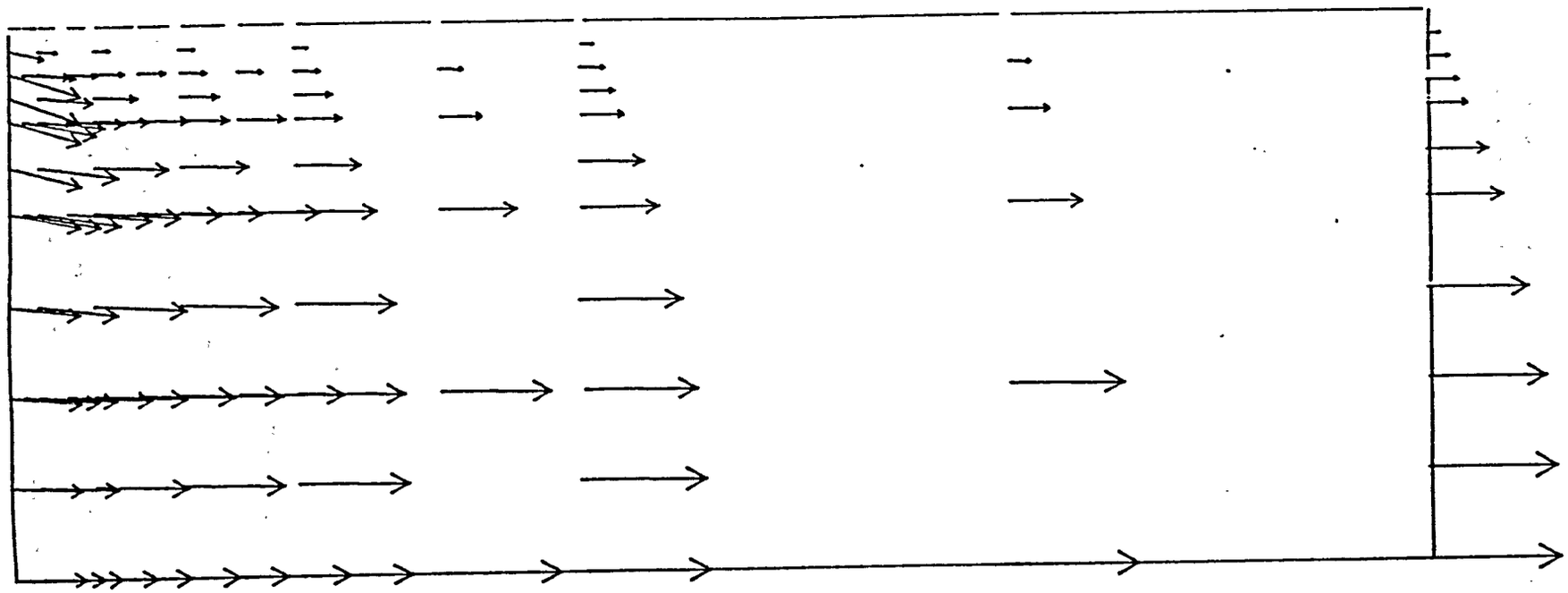


FIGURE VII-11: Test Case (VII.1.3) Velocity Vectors
Forced Convection in Developing Pipe Flow

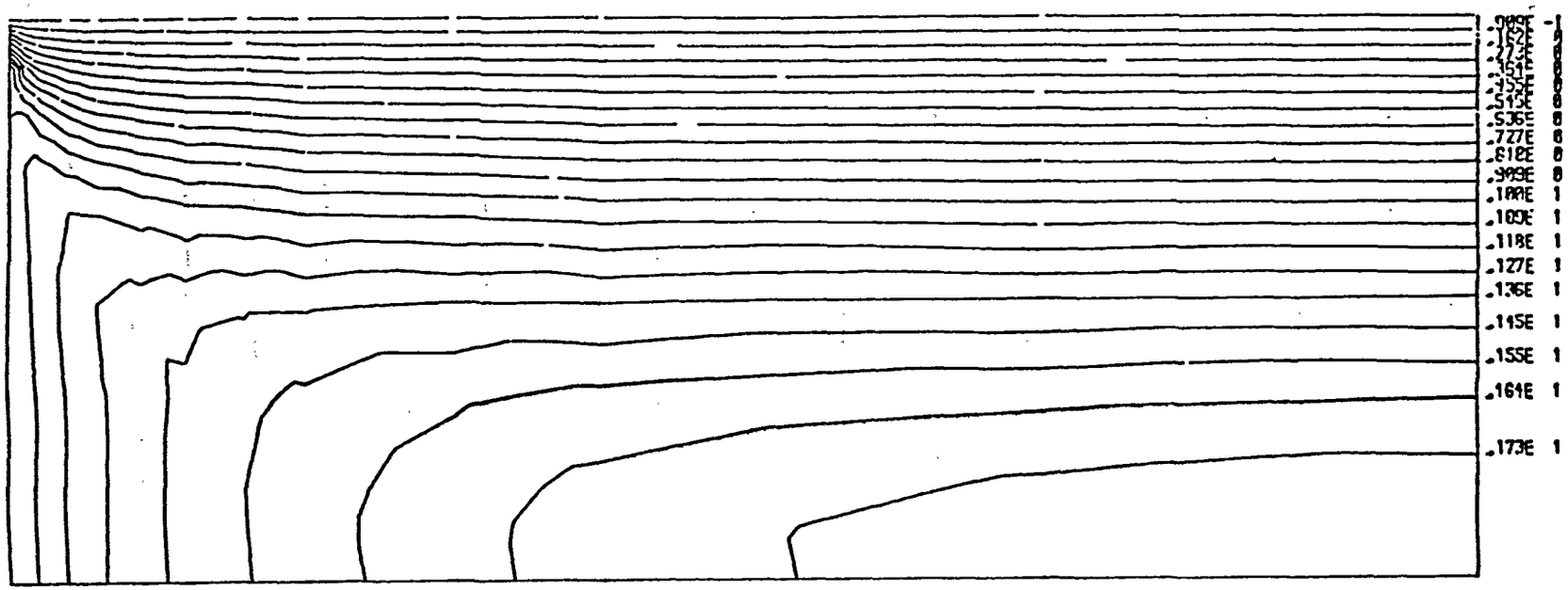



FIGURE VII-12: Test Case (VII.1.3) Velocity Contours (Isovels)
Forced Convection in Developing Pipe Flow

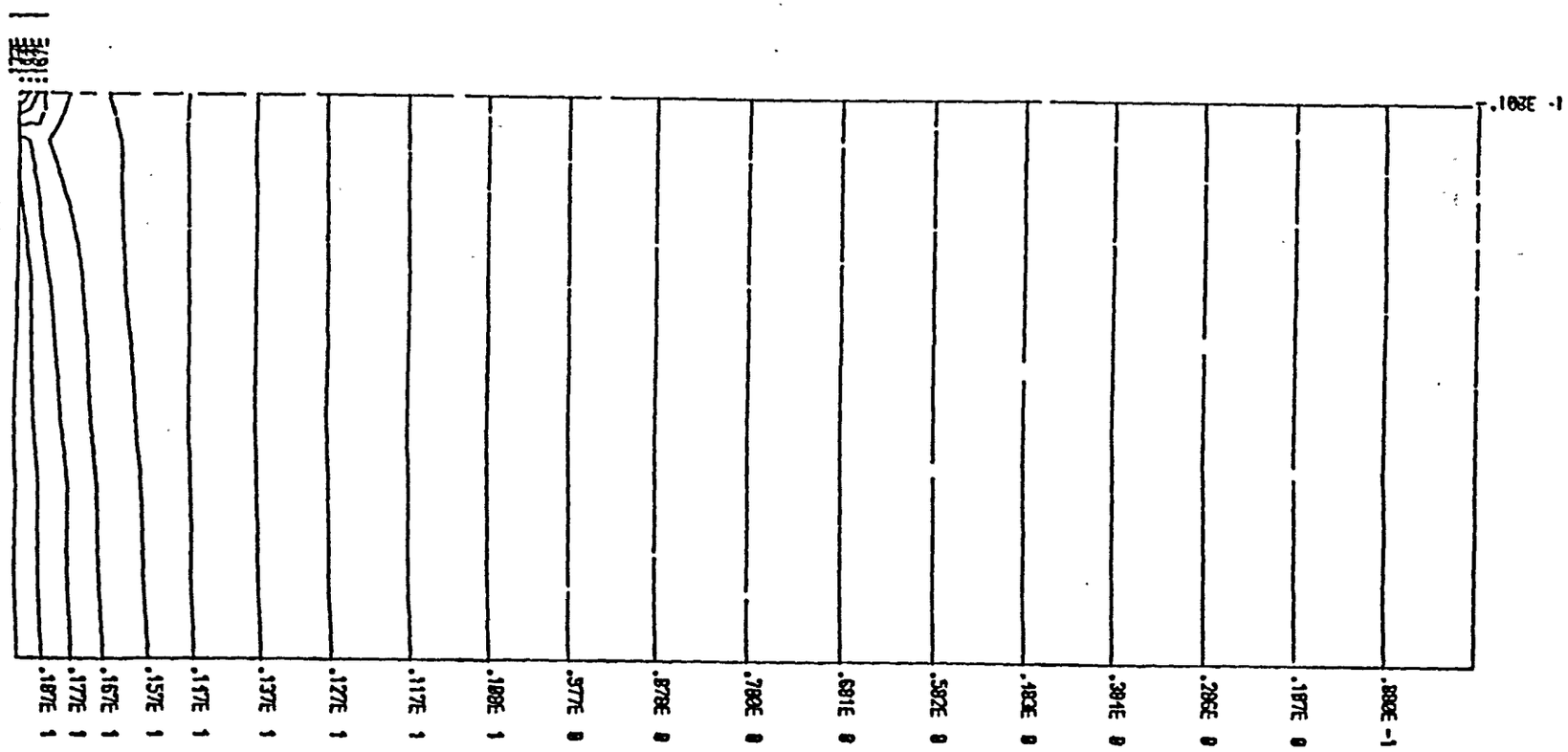



FIGURE VII-13A: Test Case (VII.1.3) Pressure Contours (Isobars)
Forced Convection in Developing Pipe Flow

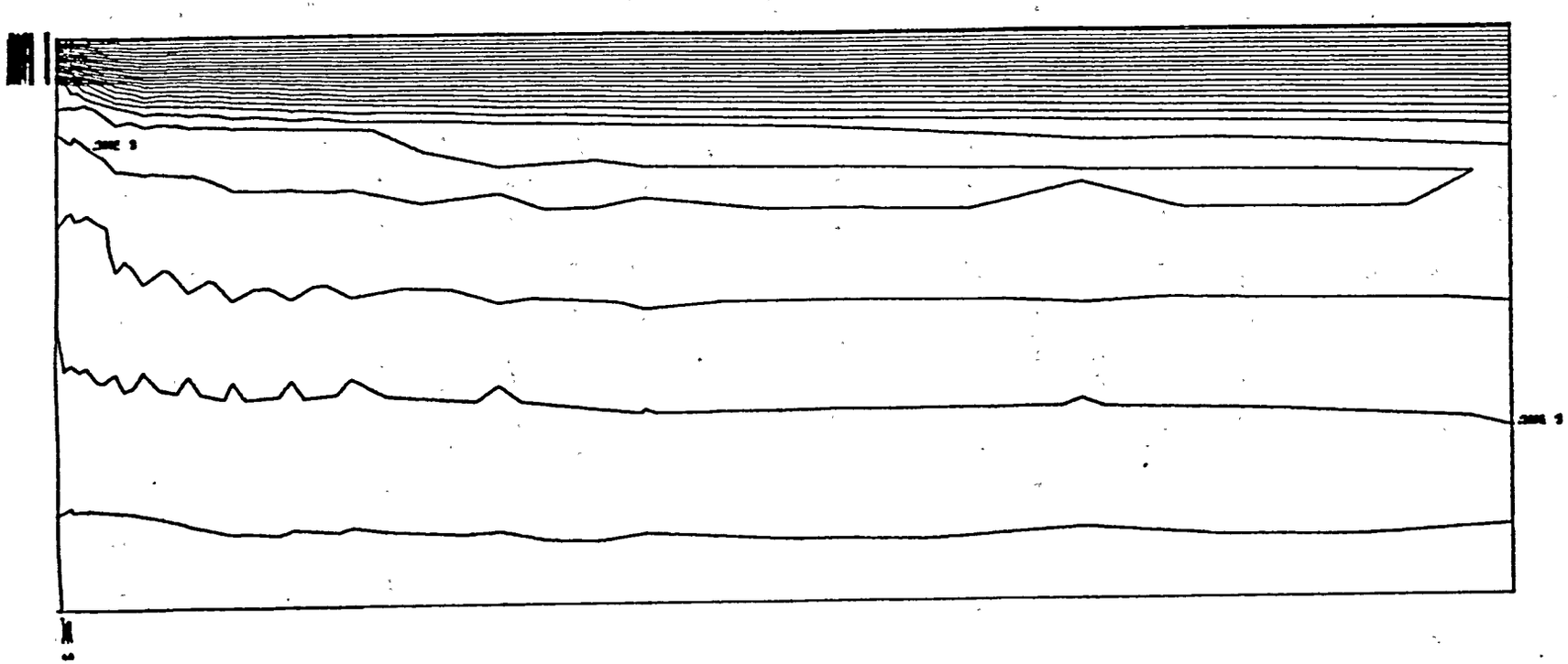


FIGURE VII-13B: Test Case (VII.1.3) temperature contours (Isotherms).
Forced convection in developing pipe flow

200. Figure VII-11 shows the velocity vectors. Figure VII-12 shows the velocity contours. Figure VII-13A shows the pressure contours; Figure VII-13B shows the temperature contours (isotherms). The output was exactly identical to the test case output[2] to within the same accuracy of VII.1.1 and VII.1.2.

### VII.1.4 Free Convection in a Rectangular Cavity

Boundary conditions and domain discretisation for this problem may be found in Figure VII-14. The mesh used is shown in Figure VII-15. The boundary conditions on the momentum equations reflect non-slip conditions on fixed surfaces with pressure specification at one point.

For this problem type the energy equation is cast in temperature difference form and thus boundary values express a difference with respect to a reference value on the left and right hand sides of the cavity, linear interpolation on the bottom side and zero gradient on the top side. Figure VII-16 shows the velocity vectors. Figure VII-17 shows the axial velocity contours. Figure VII-18 shows the overall velocity contours. Figure VII-19 shows the pressure contours. Figure VII-20 shows the temperature contours. Again the program output was identical to the test case[2].

### VII.1.5 Laminar Flow Past a Cylinder

Two dimensional laminar flow past a cylinder is one of the better documented problems of laminar flow. It provides a very useful practical model for verification of the program. This test case shows that it is

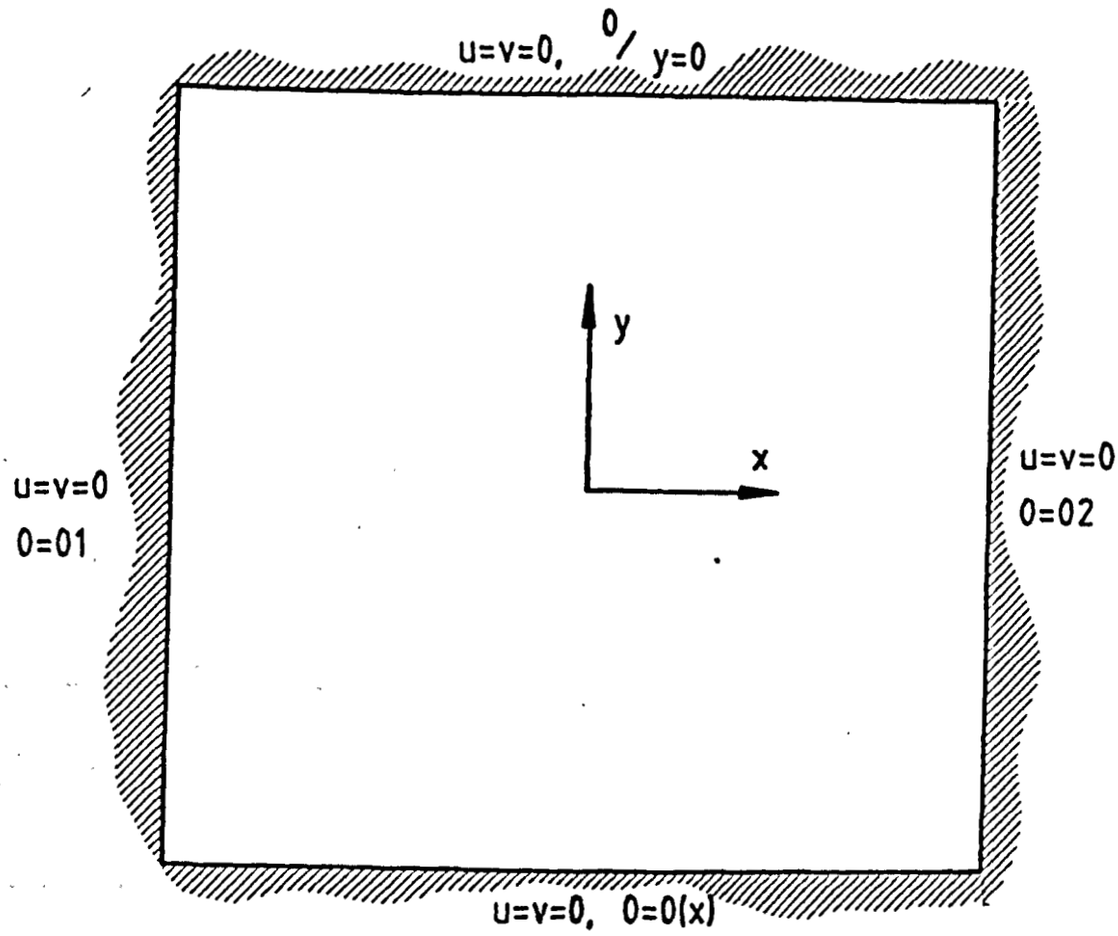



FIGURE (VII-14A) BOUNDARY PRESCRIPTION - FREE CONVECTION IN A RECTANGULAR CAVITY

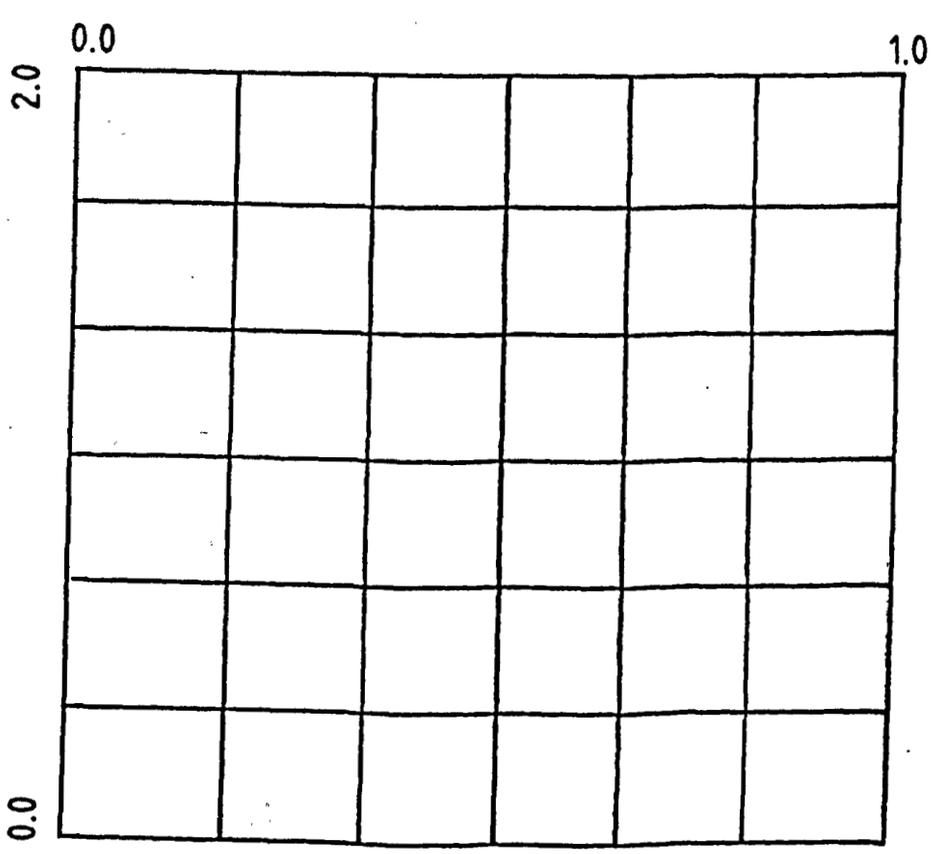



FIGURE (VII-14B) FINITE ELEMENT REPRESENTATION OF CAVITY

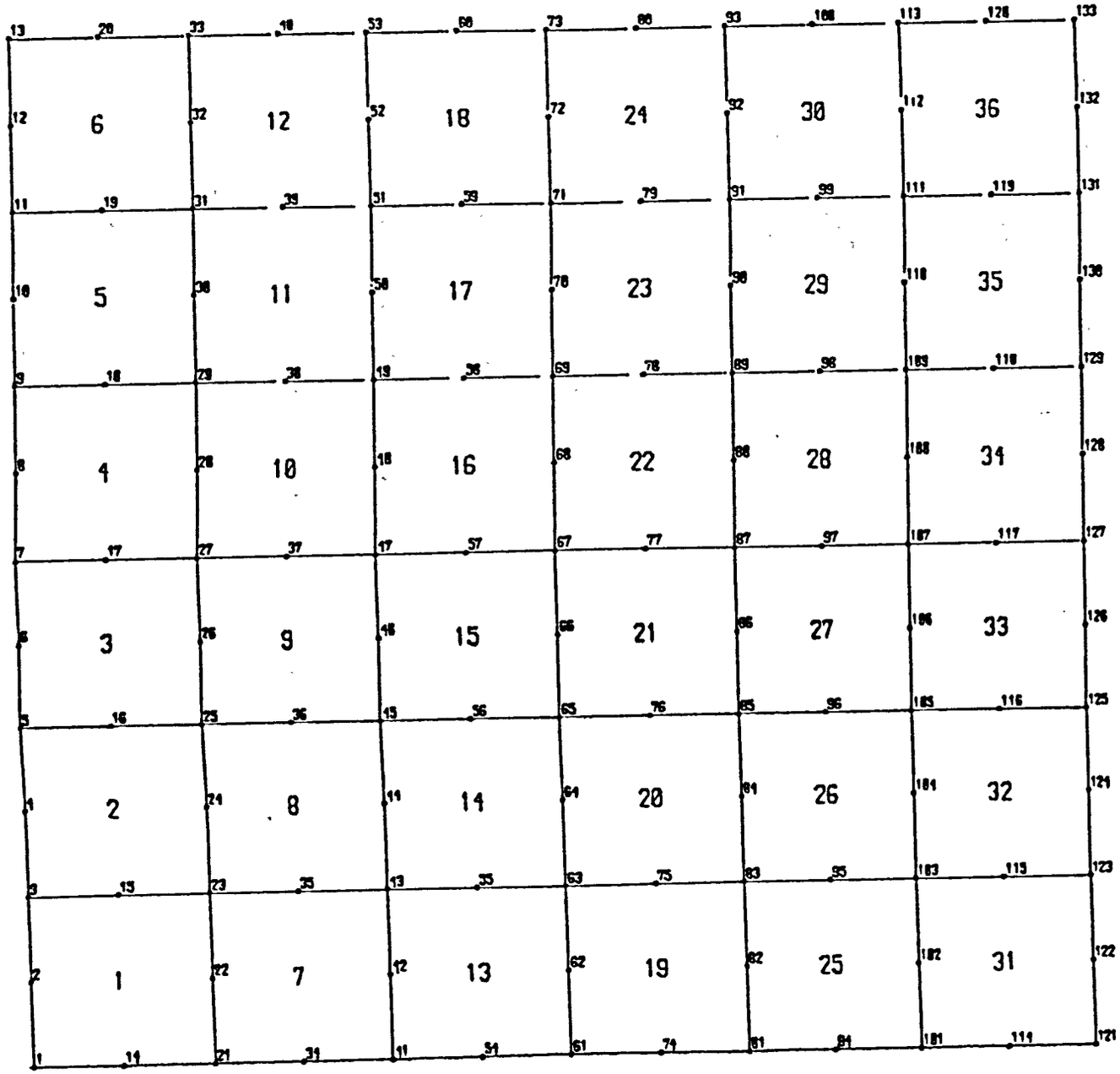



FIGURE VII-15:

The mesh used for test case (VII.1.4) of free convection in a rectangular cavity

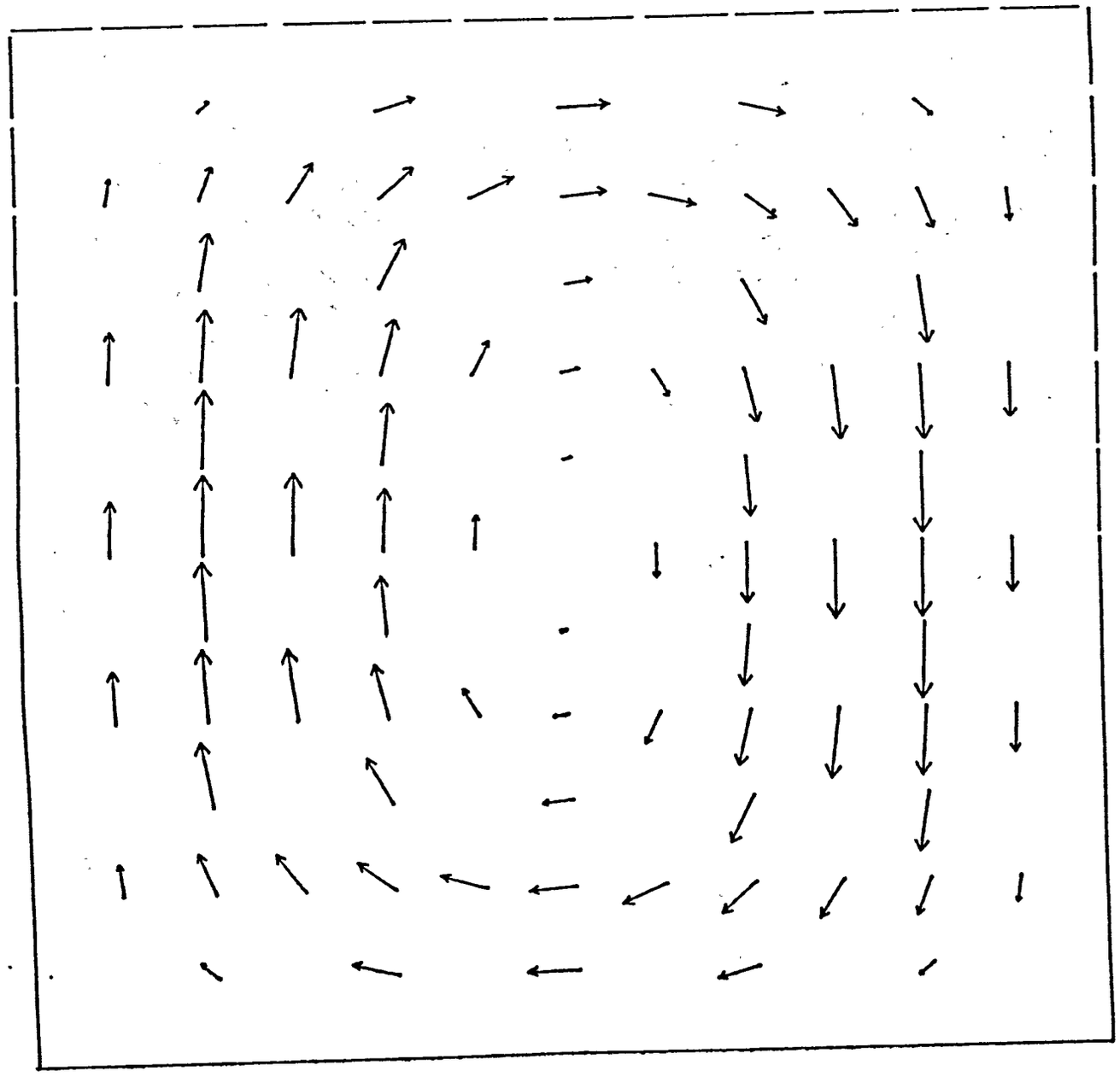


FIGURE VII-16: Test Case (VII.1.4) Velocity Vectors. Free Convection in a Rectangular Cavity

FIGURE VII-17:

Test Case (VII-1.4).
Axial velocity contours.
($\sqrt{U^2}$ Isovels)
Free convection in a
rectangular cavity

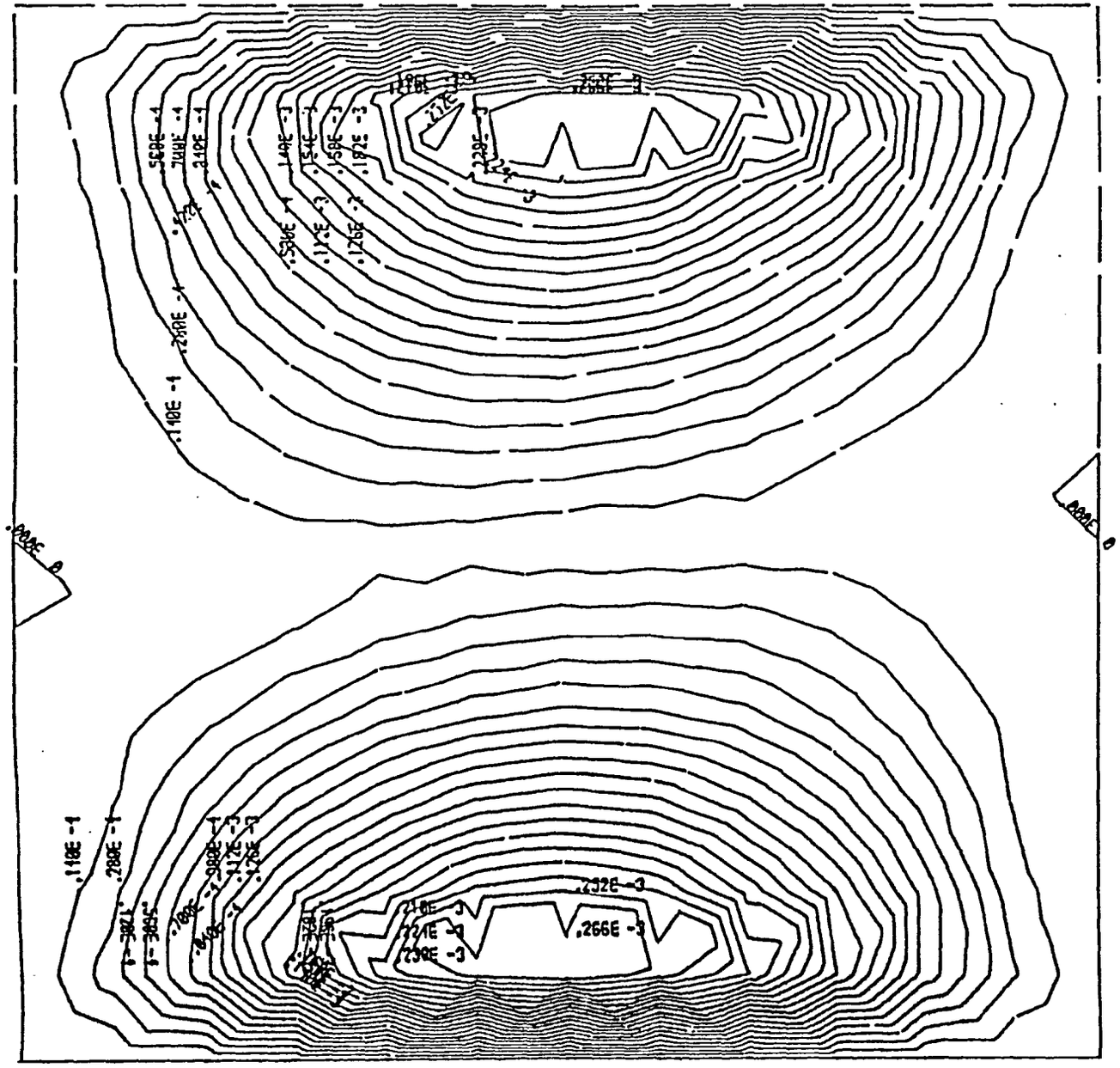
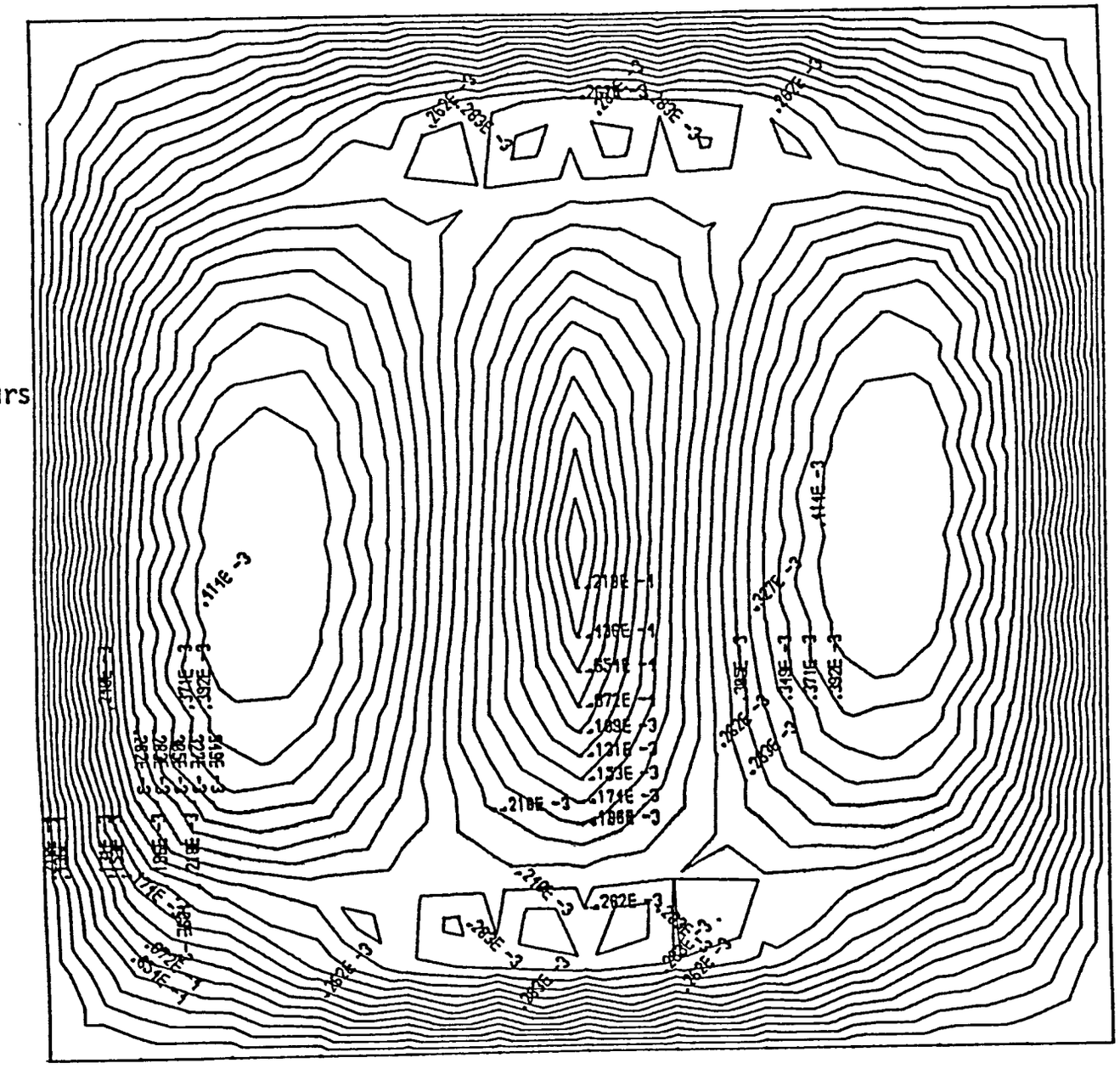


FIGURE VII-18:

Test Case (VII.1.4)
Overall Velocity Contours
($\sqrt{U^2 + V^2}$ - Isovels)

Free convection in a
rectangular cavity



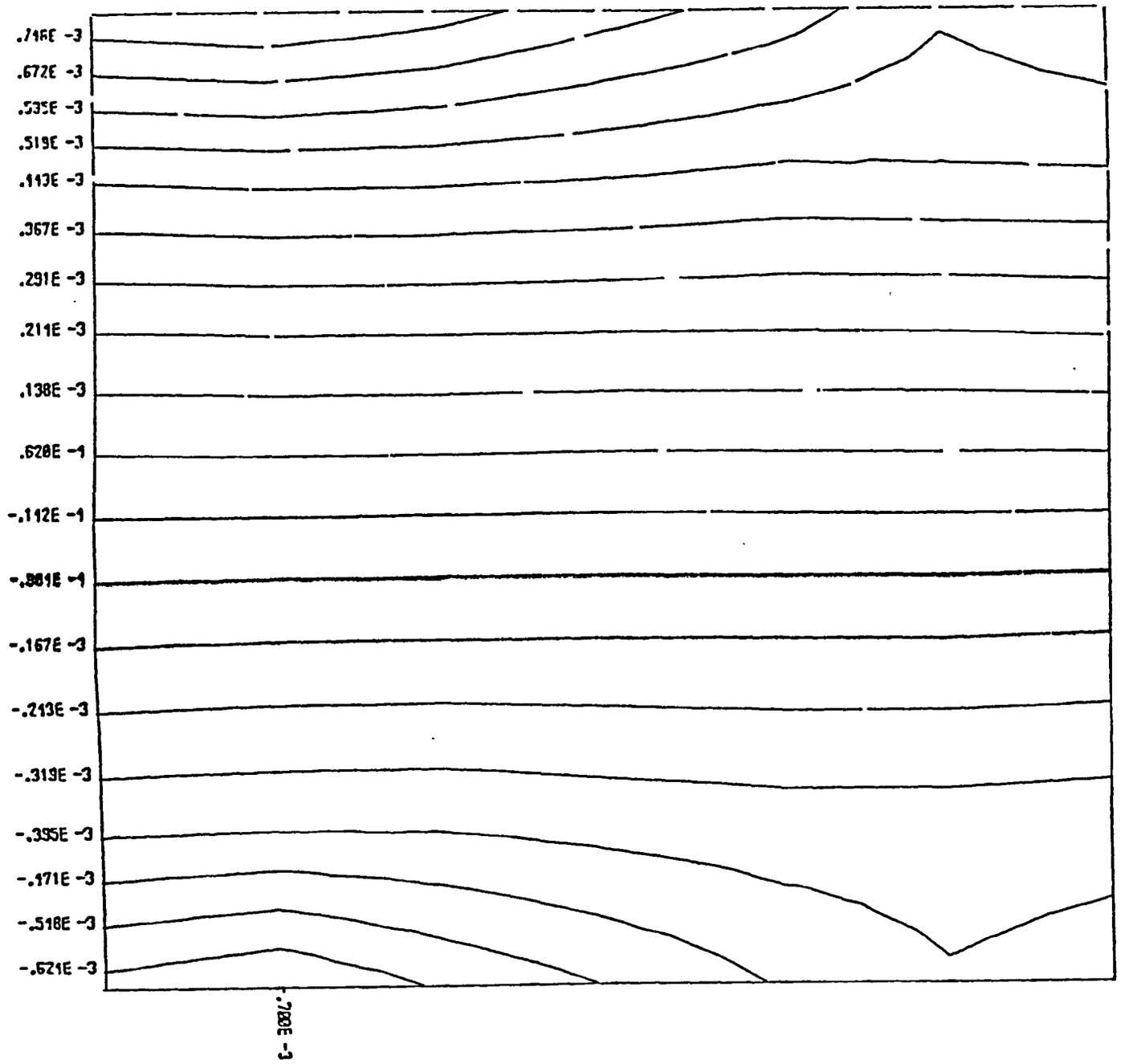



FIGURE VII-19:

Test Case (VII.1.4)
Pressure Contours (Isobars)
Free convection in a rectangular cavity

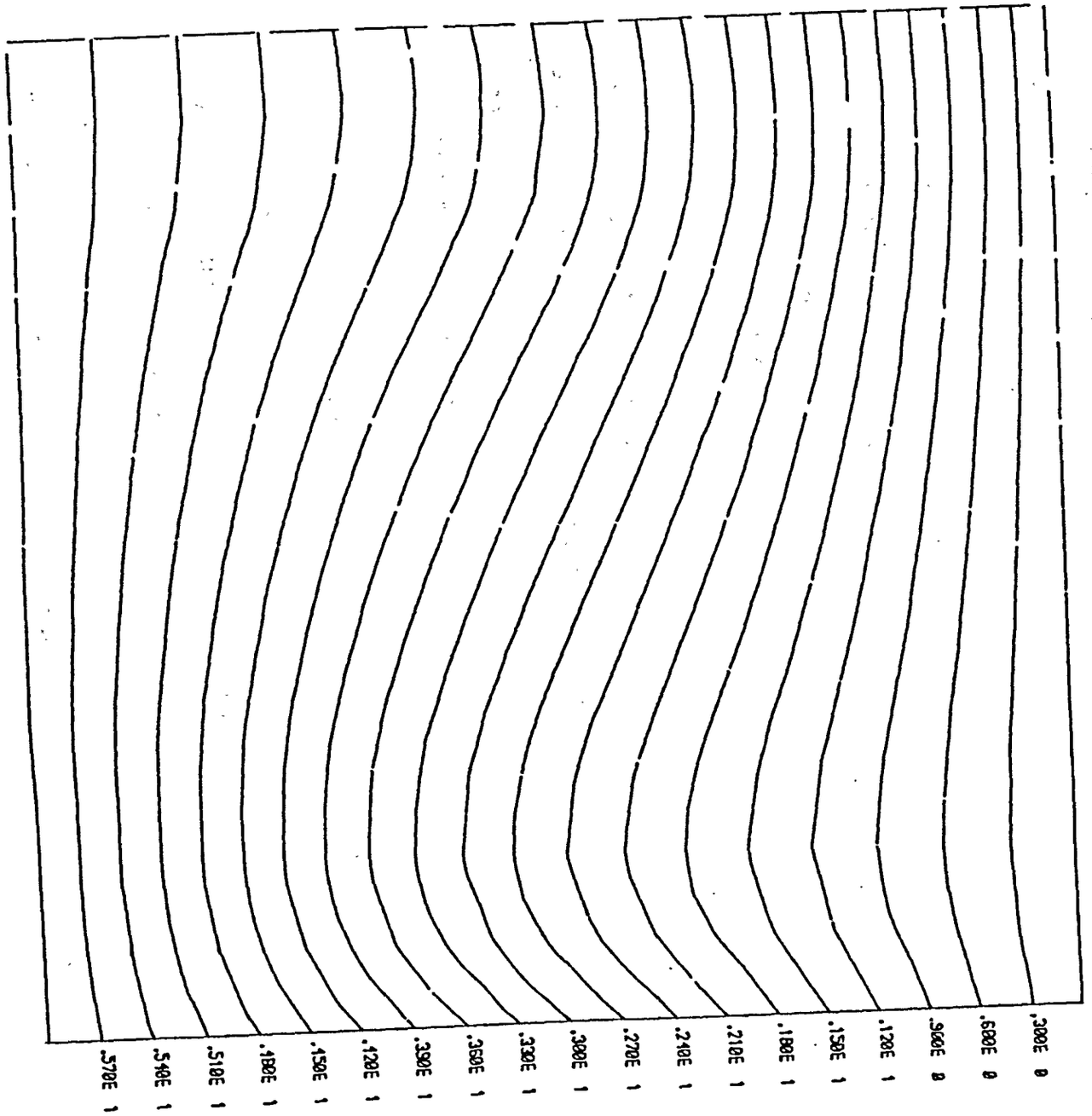



FIGURE VII-20:
Test Case VII.1.4)
Temperature contours
(Isotherms)
Free convection in a
rectangular cavity

theoretically and numerically possible to obtain solutions which predict symmetric stationary zones of separation behind the cylinder. Such solutions can be used to check the validity of a computer based numerical model[3]. The parameters associated with the current example are:

Reynolds number Re = 20 (based on the cylinder diameter)

Molecular viscosity $\mu = 0.1$

Fluid density $\rho = 1.0$

Fluid for field velocity $U_\infty = 1.0$

and subject to the boundary conditions shown on Figure VII-21. Body forces are assumed to be zero and, due to symmetry, only one half of the domain flow need be considered. The subdomain discretisation and correspondent element numbers are shown in the mesh in Figure VII-22.

Figure VII-23 shows the velocity vectors. Figure VII-24 shows a blown up view of the velocity vectors in the separation zone behind the cylinder. Figure VII-25 shows the velocity contours. Figure VII-26 shows a blown up view of the velocity contours in the separation zone behind the cylinder. Figure VII-27 shows the pressure contours. The program output was identical to the test case results of Ref. 3 exactly.

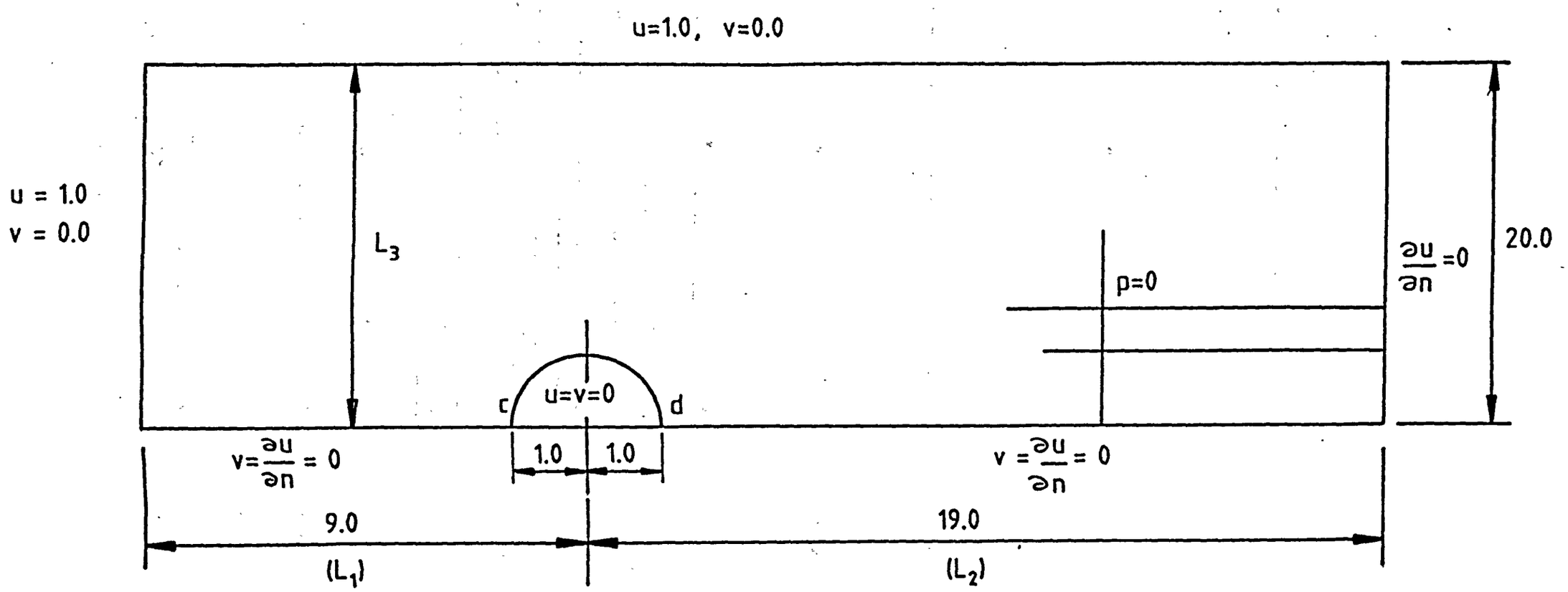



FIGURE VII-21: Boundary conditions and extent of domain. Flow past a cylinder

FIGURE VII-22:

The mesh used for test case (VII.1.5) of flow past a cylinder

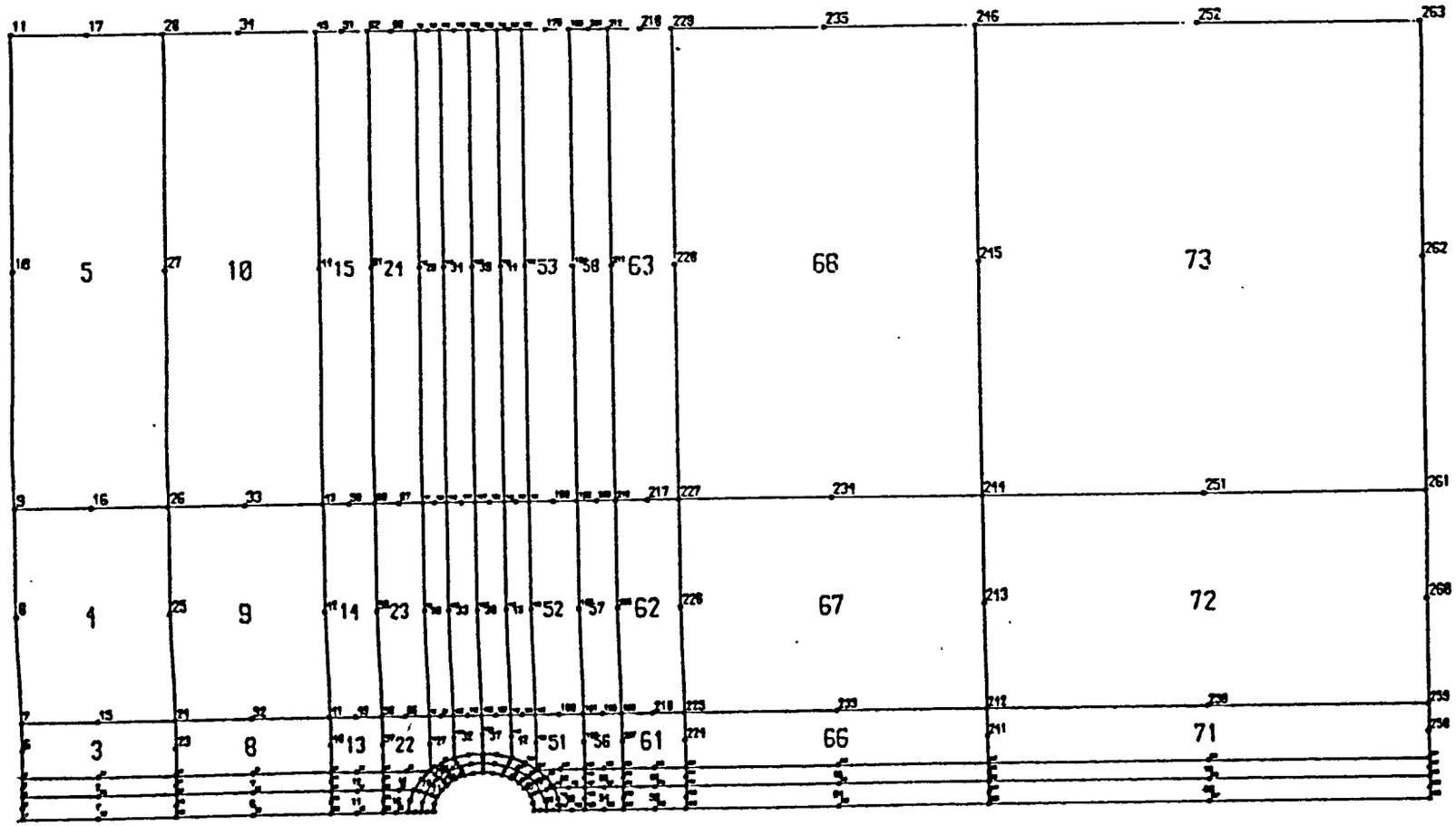


FIGURE VII-23:

Test Case (VII.1.5)
Velocity Vectors
Flow past a
cylinder

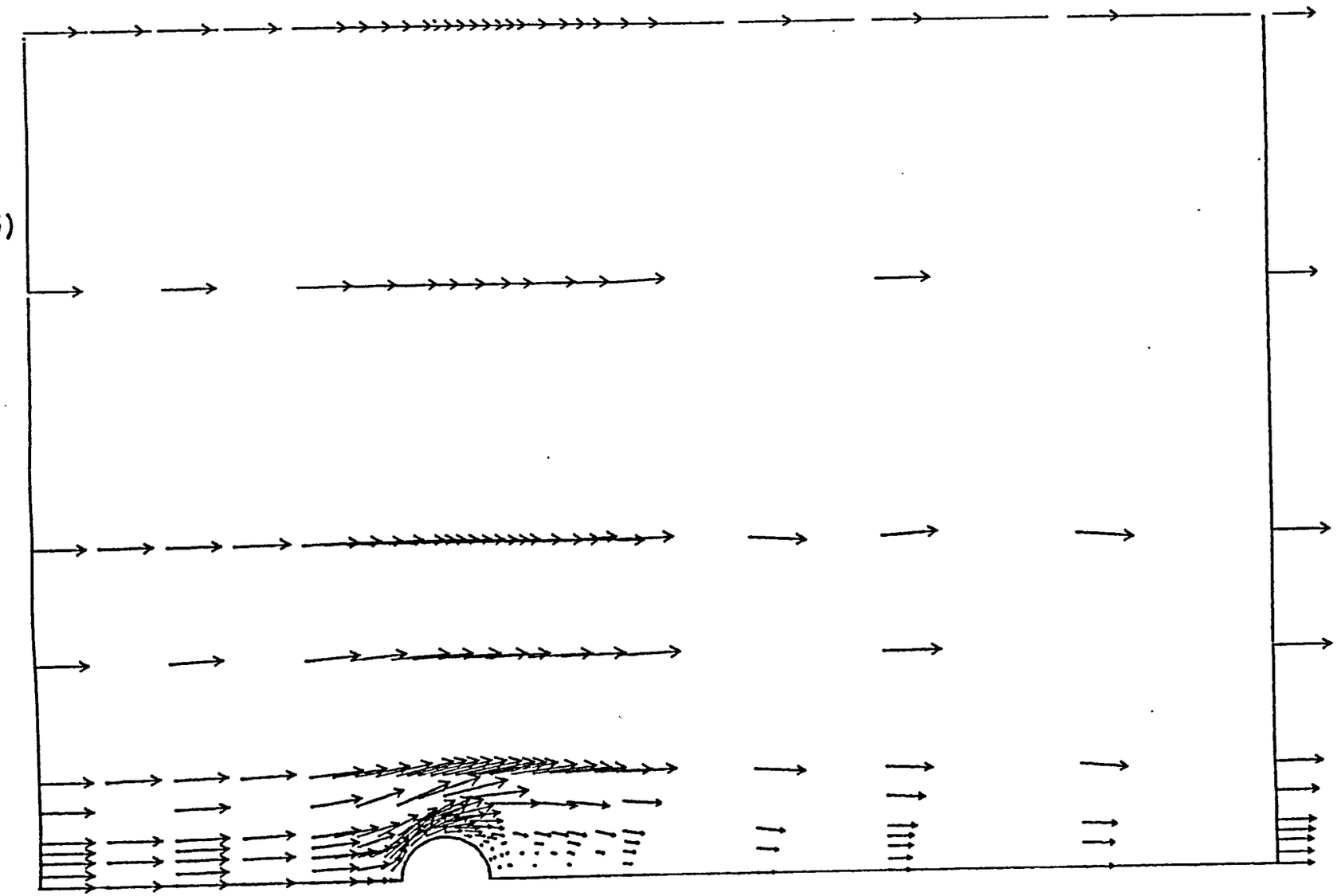
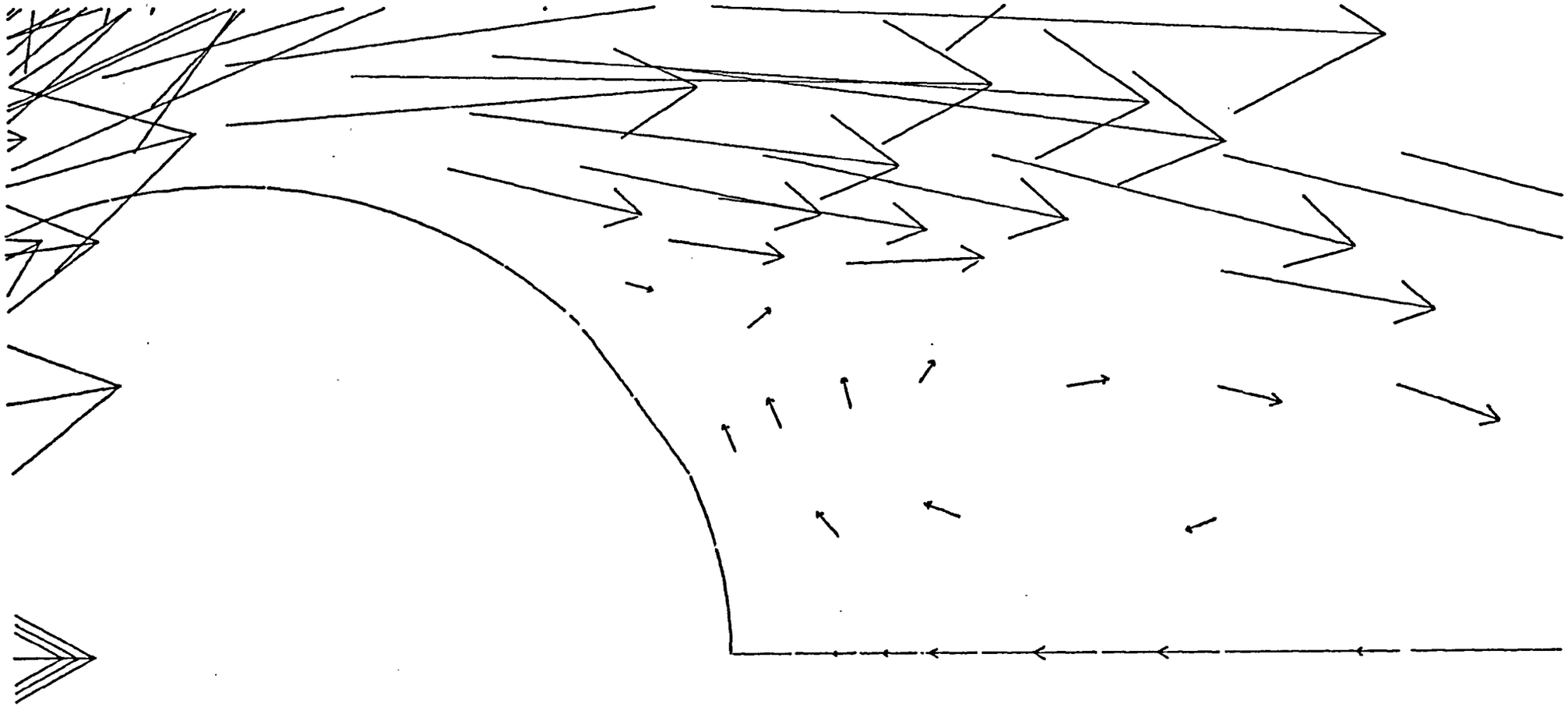
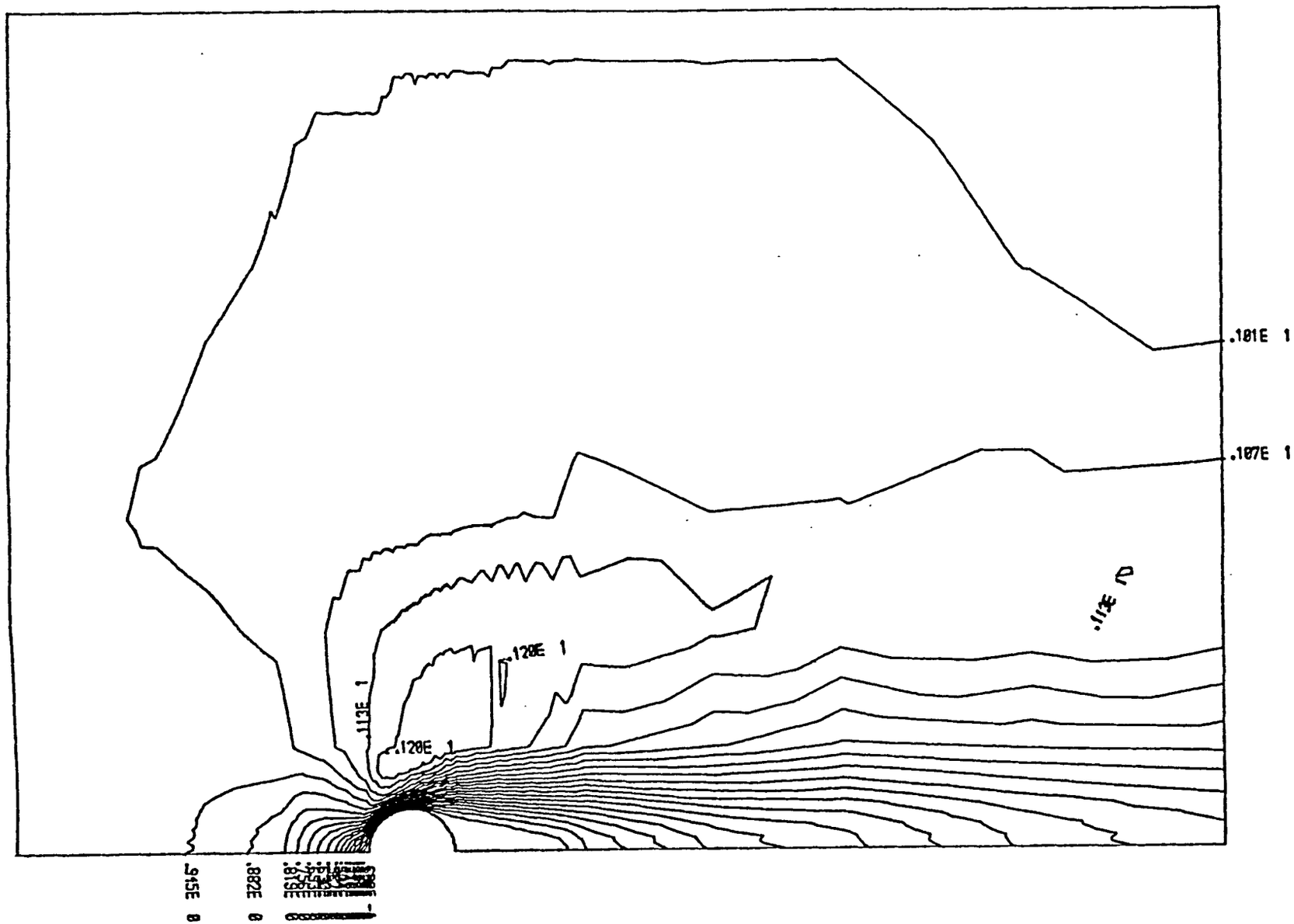


FIGURE VII-24: A blownup view of the velocity vectors in the separation zone behind the cylinder. Test case (VII.1.5) Flow past a cylinder



IGURE VII-25:
est case (VII.1.5)
elocity contours
Isovels)
low past a cylinder



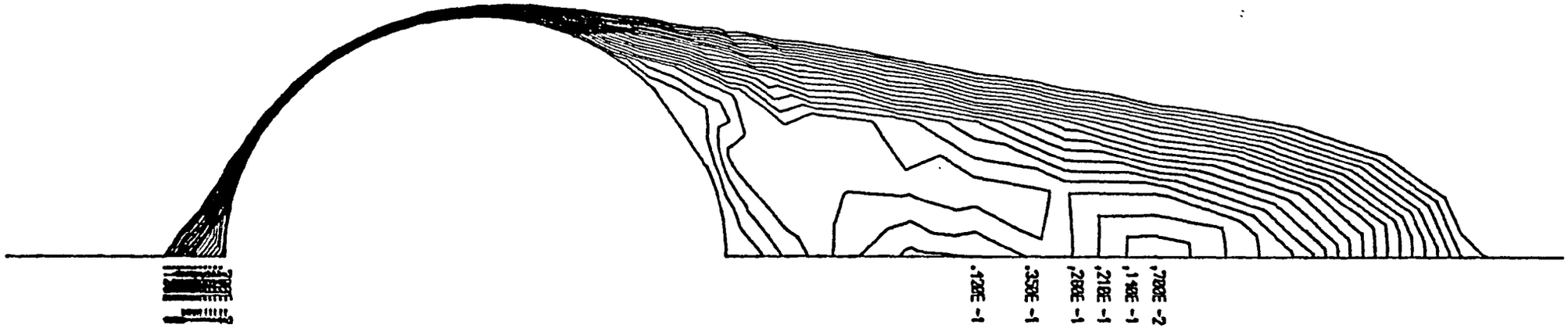



FIGURE VII-26: Test Case (VII-1.5). A blown-up view of the velocity contours in the separation zone behind the cylinder (Isovels). Flow past a cylinder

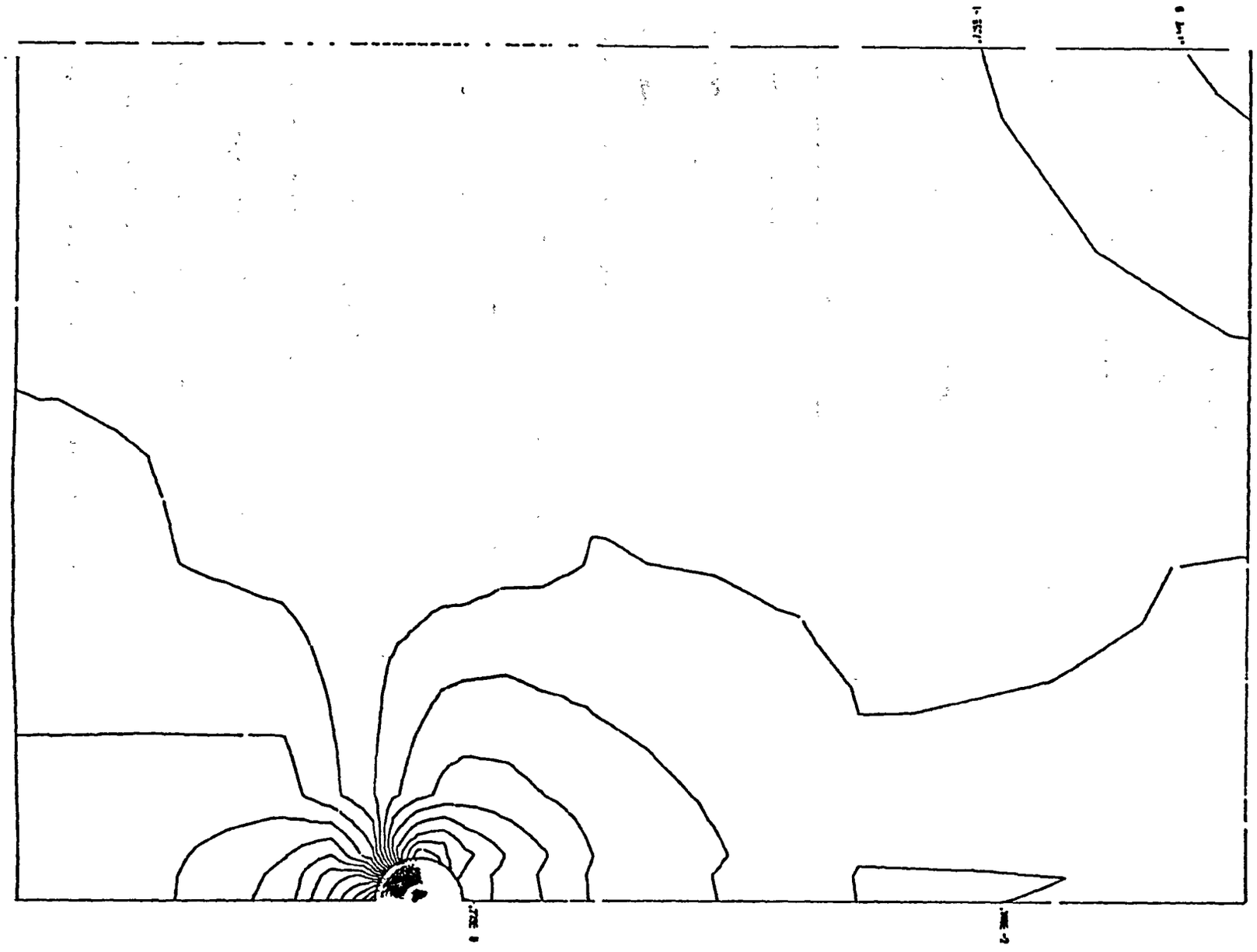


FIGURE VII-27: Test Case (VII.1.5). Pressure contours (Isobars). Flow past a cylinder

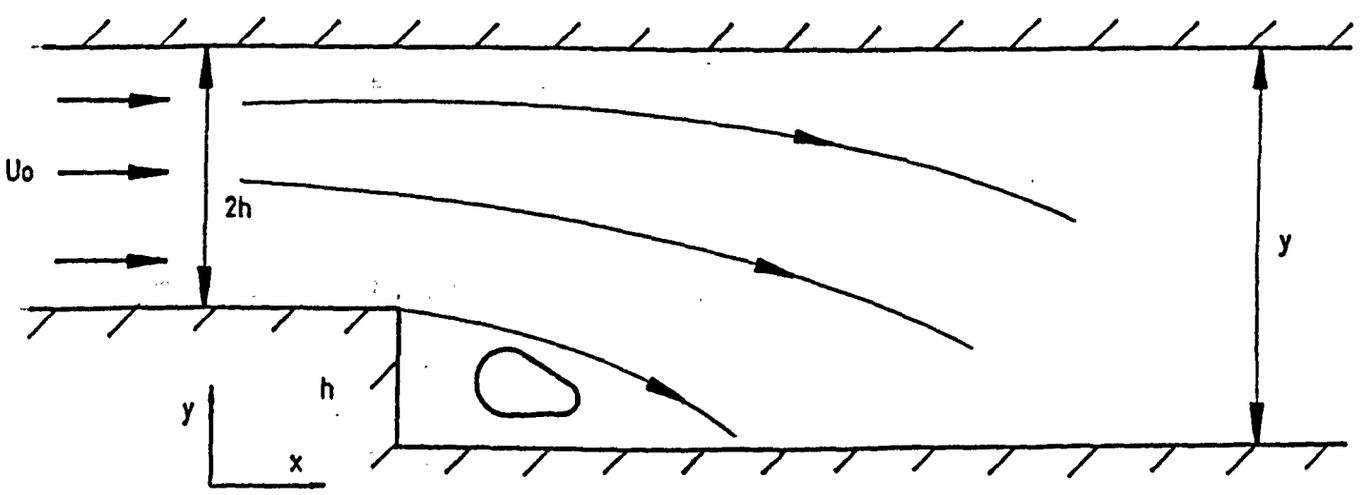
VII.1.6 Two Dimensional Laminar Flow Over a Backward Facing Step

Separation occupies an appreciable portion of the flow domain. In such a flow the advection terms in the momentum equations have become significant. Separation has been shown to occur at very low values of Reynolds number. The particular parameters for this problem are:

Reynolds number Re = 73 (based on the step height and average upstream velocity)

Molecular viscosity $\mu$ = 0.00457

Fluid density $\rho$ = 1.0




The extent of the physical domain taken for the numerical model is shown superimposed on the mesh used in Figure VII-28 and consists of 30 elements and 117 nodes. Figure VII-29 shows the velocity vectors. Figure VII-30 shows a blown up view of the velocity vectors at the separation (recirculation) zone. Figure VII-31 shows the velocity contours. Figure VII-32 shows the longitudinal velocity contours at the separation (recirculation) zone. Figure VII-33 shows a blown up view of the velocity contours at the separation (recirculation)

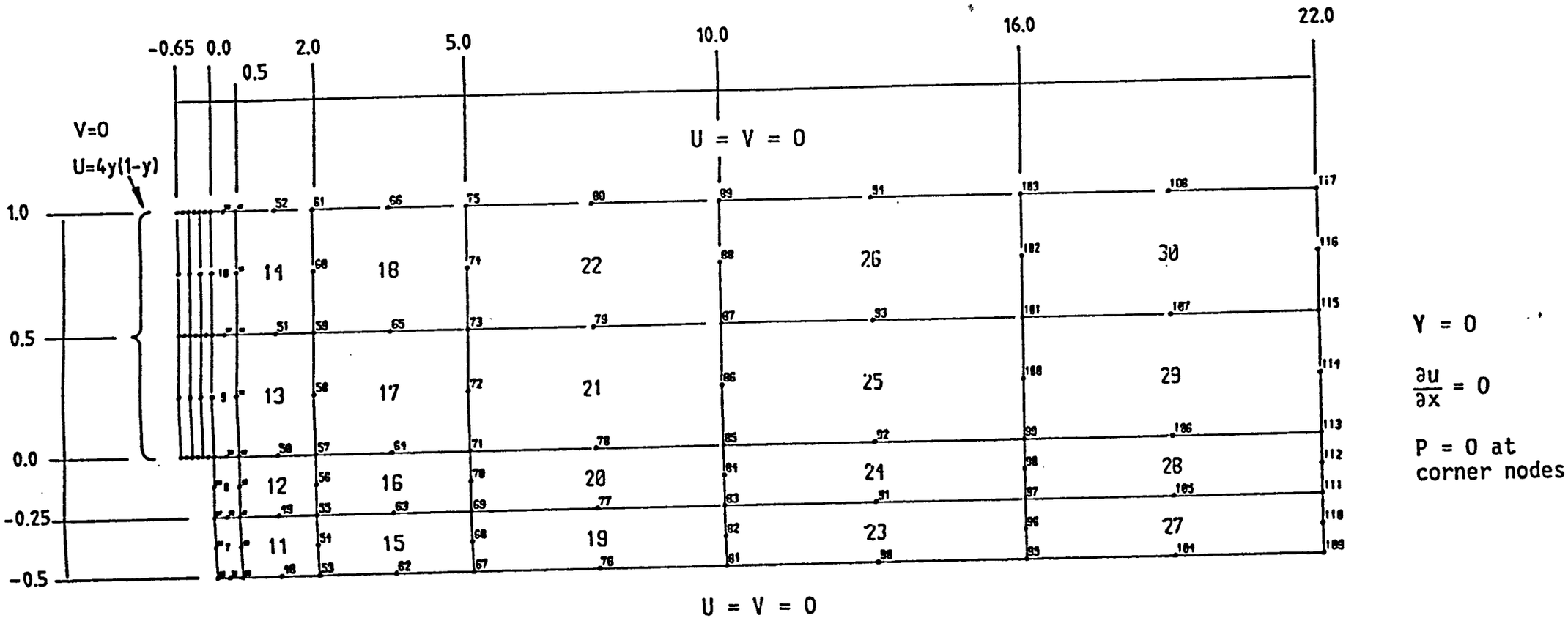



FIGURE VII-28: The mesh used for test case (VII.1.6) of flow over a backward facing step

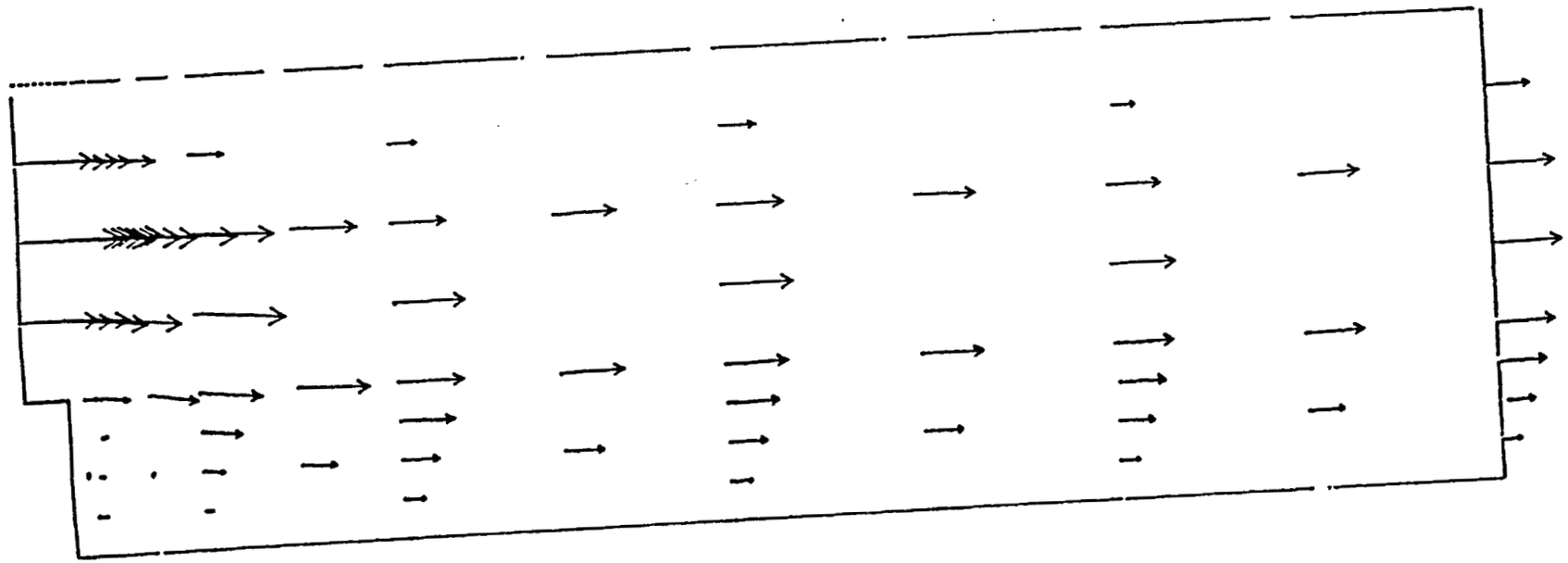


FIGURE VII-29: Test Case (VII.1.6) velocity vectors. Flow over a backward facing step

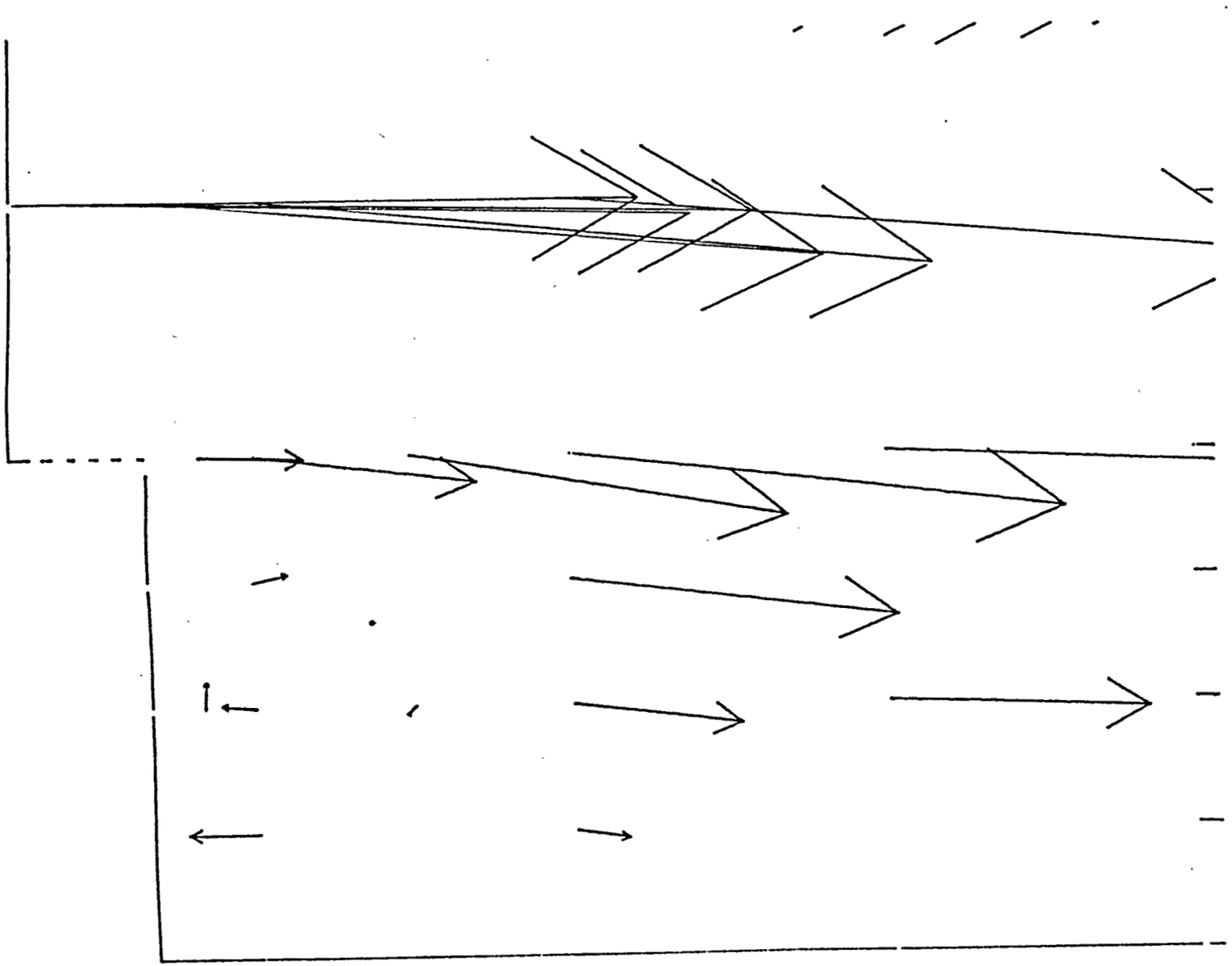


FIGURE VII-30:

Test case (VII.1.6)
A blown up view of the velocity vectors at the separation (recirculation) zone.
Flow over a backward facing step

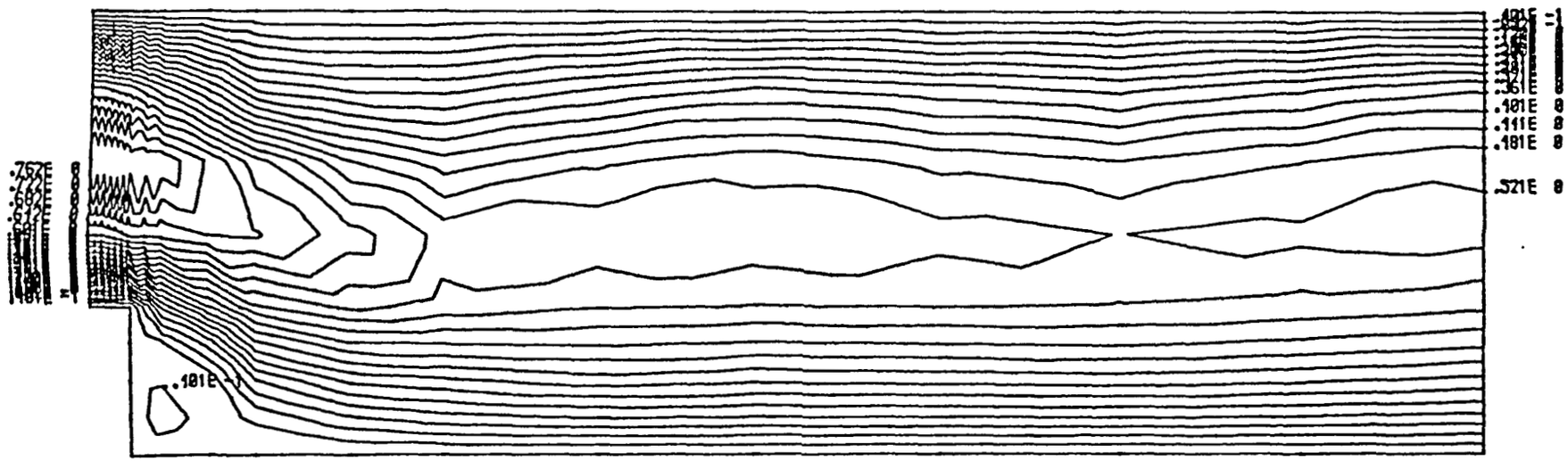



FIGURE VII-31: Test Case (VII.1.6), velocity contours (Isovels).
Flow past a backward facing step

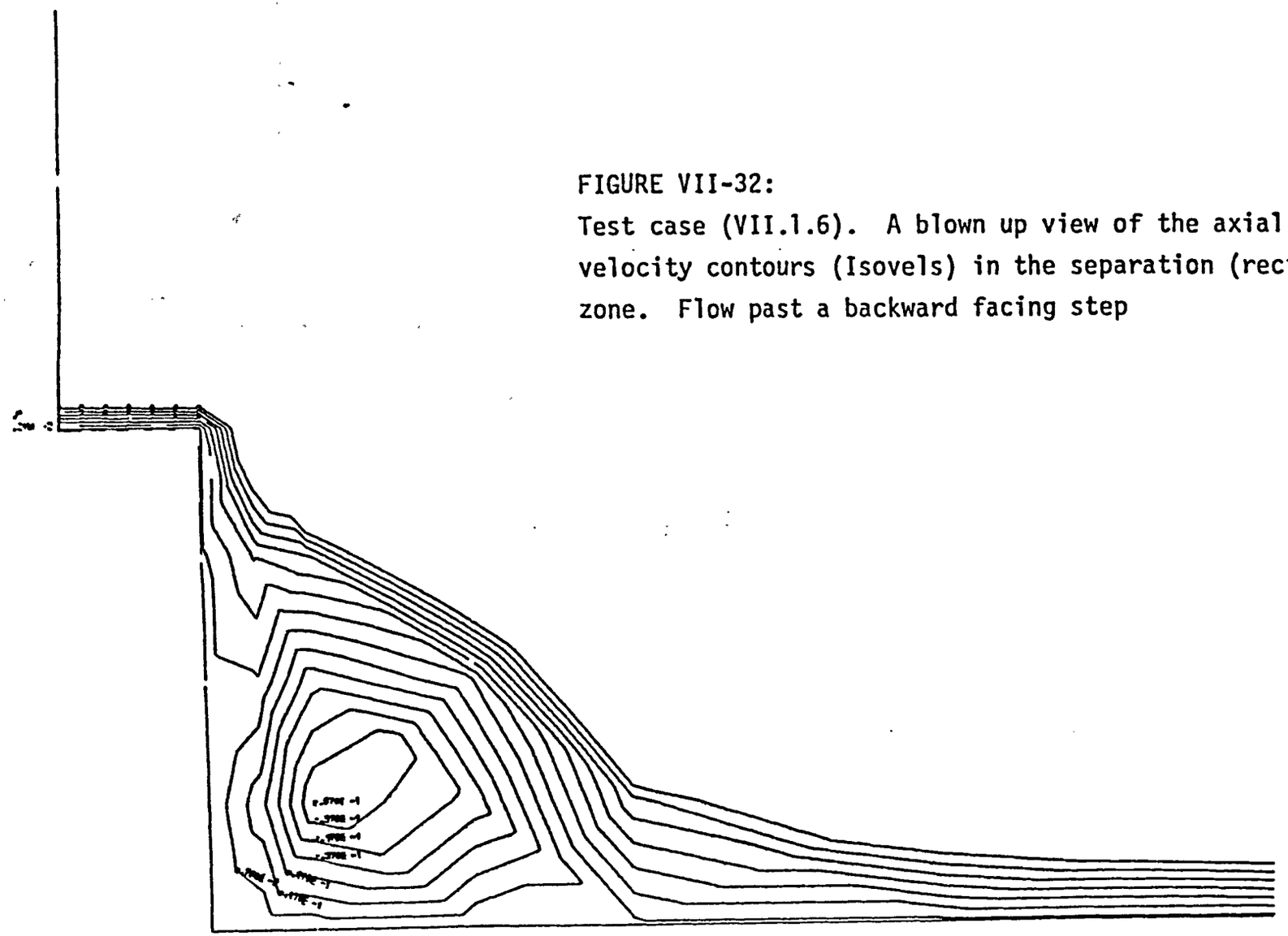
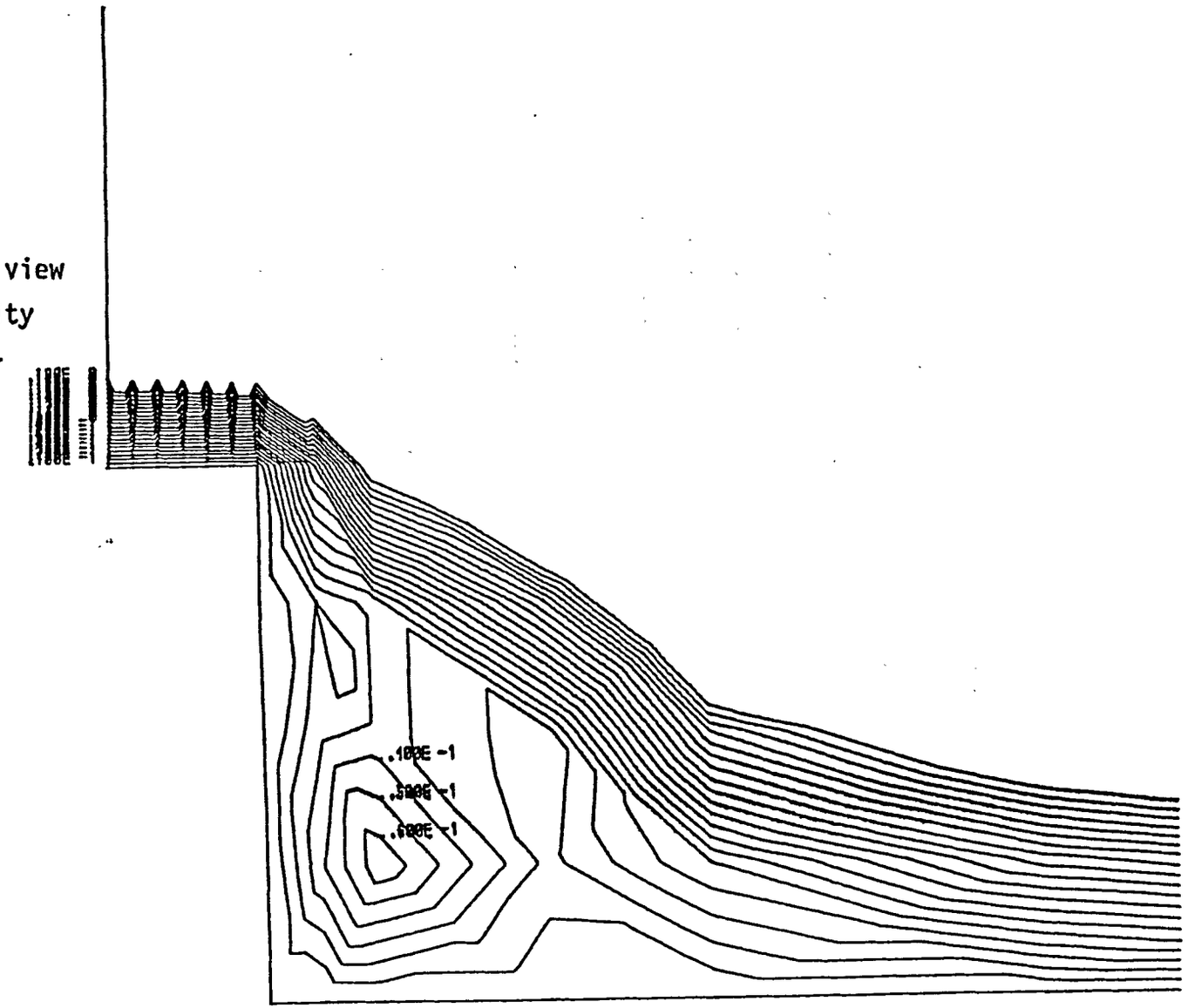


FIGURE VII-32:
Test case (VII.1.6). A blown up view of the axial ($\sqrt{\overline{U^2}}$) velocity contours (Isovels) in the separation (recirculation) zone. Flow past a backward facing step

FIGURE VII-33:

Test case (VII.1.6). A blown-up view of the overall ($\sqrt{U^2 + V^2}$) velocity contours (Isovels) in the separation (recirculation) zone. Flow past a backward facing step



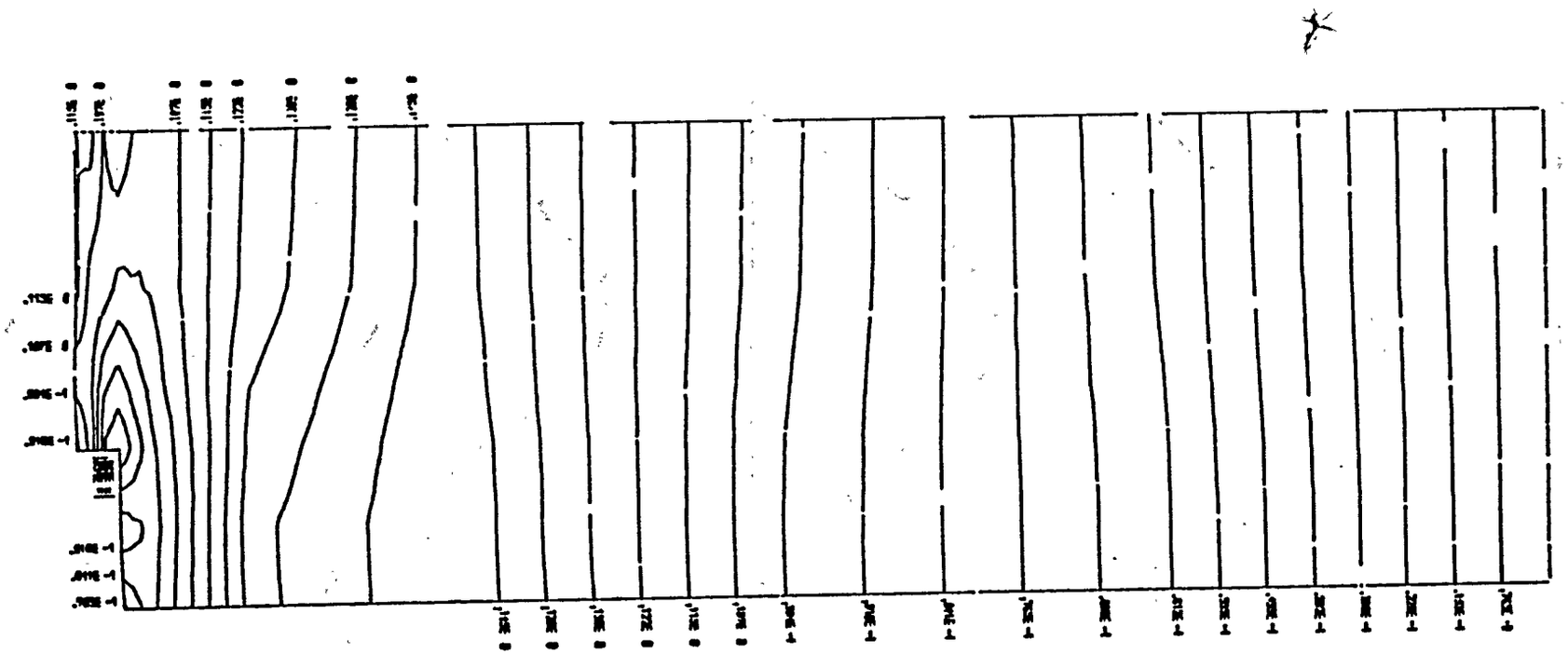


FIGURE VII-34: Test case (VII.1.6) pressure contours (Isobars).
Flow past a backward facing step

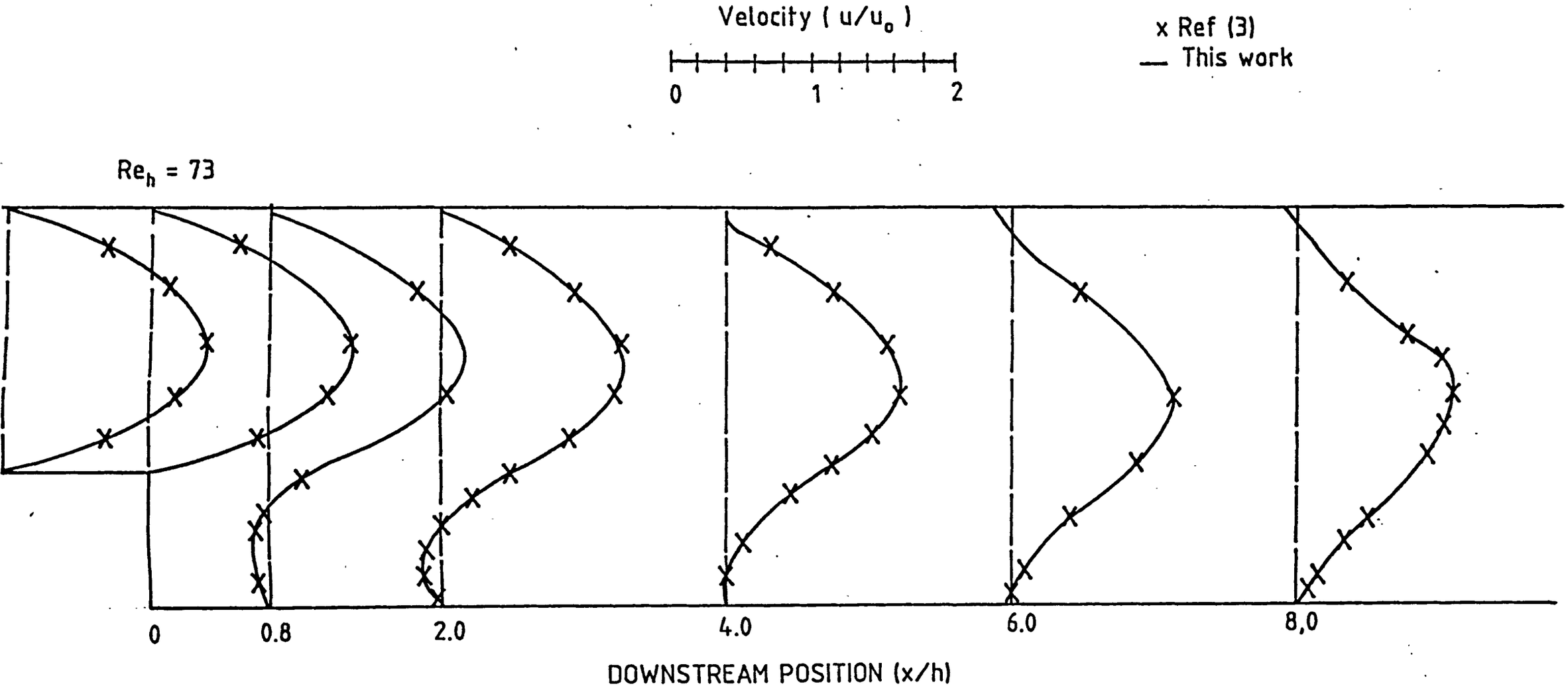



FIGURE (VII-35) NON-DIMENSIONALISED VELOCITY PLOT FOR A BACKWARD FACING STEP.

zone. Figure VII-34 shows the pressure contours. Longitudinal dimensionless velocity distributions are shown in Figure VII-35 and are seen to compare exactly with those published in Reference 3.

### VII.1.7 Fully Developed Turbulent Flow in a Pipe

Flow in a smooth walled pipe comprises a transition from a boundary layer flow near the entrance, Figure VII-36, to fully developed turbulent flow some distance downstream. The manner in which the flow develops is governed by the gradually thickening boundary layer adjacent to the pipe wall whose displacement thickness varies from zero at the pipe entrance to half the pipe diameter at some distance downstream. Under such conditions the free stream flow is completely masked and fully developed flow is subsequently established.

For fully developed flow the boundary layer width can be assumed equal to the radius of the pipe (R).

Adjusting the turbulent intensity to give the same values of effective viscosity as per the entrance nodes for the known nodes velocities from Reference 3 and utilising Nikuradse length scale of turbulence for flow in pipes i.e.

$$\ell \doteq R\,[0.14 - 0.08\,(1 - \frac{y}{R})^2 - 0.06\,(1 - \frac{y}{R})^4] \qquad \text{(VII.1)}$$

Fixing a density of unity, the only further requirement to define the pipe Reynolds number is the value of ($\tau_\omega$) and ($\mu$). This is achieved

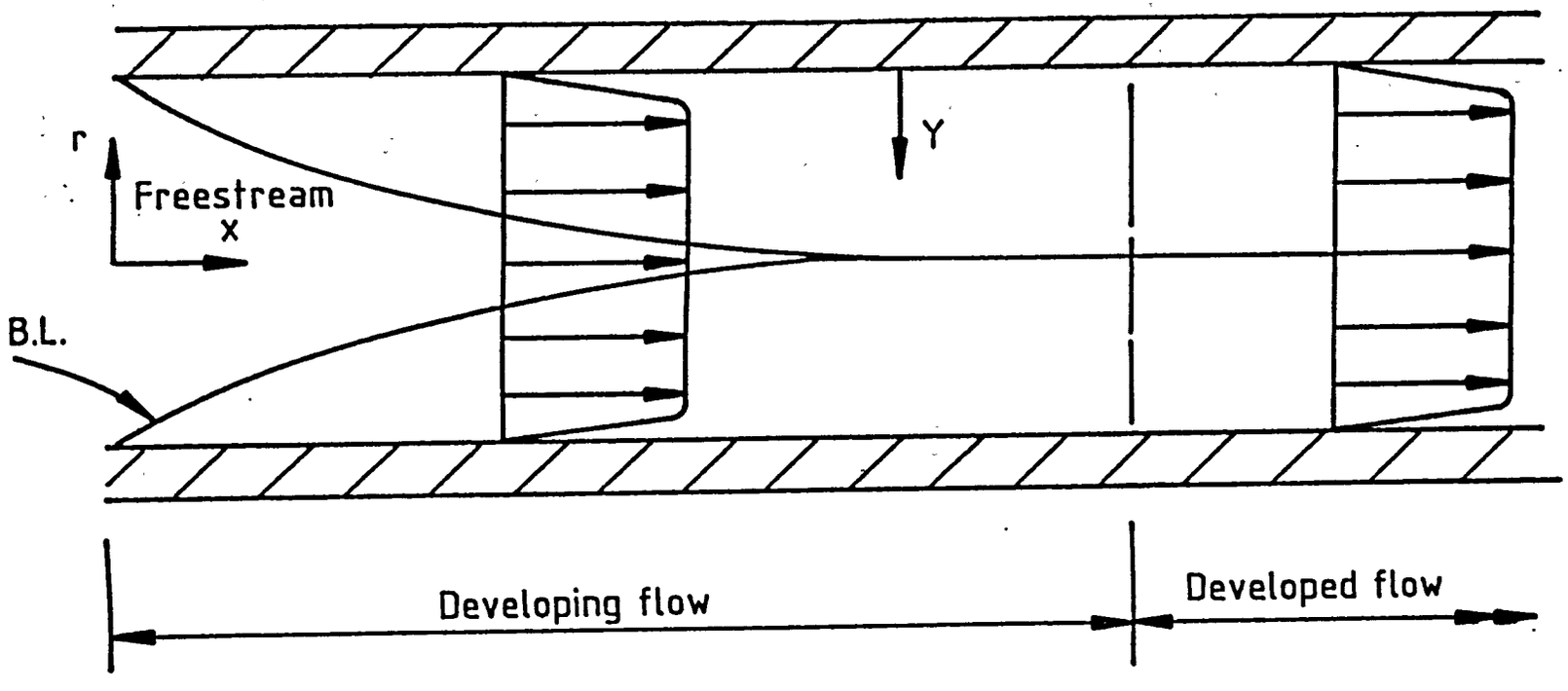



FIGURE (VII-36) SCHEMATIC REPRESENTATION OF DEVELOPING FLOW IN A PIPE

by manipulating the boundary conditions relating to the pressure since the wall shear stress is linearly dependent on the pressure gradient. For a specified section of pipe, length ($L_e$):

$$\frac{R}{2} \cdot \frac{P_u - P_d}{L_e} = \tau_o \qquad \text{(VII.2)}$$

in which ($P_u$) and ($P_d$) represent defined values of upstream and downstream pressure, respectively. The complete set of boundary conditions required to solve for fully developed flow Figure VII-37, are

$$V = \frac{\partial u}{\partial x} = 0, \quad x = 0, \quad x = L_e \qquad 0 \leqslant r \leqslant R$$

$$V = \frac{\partial u}{\partial r} = 0, \quad 0 \leqslant x \leqslant L_e \qquad r = 0$$

$$V = U = 0, \quad 0 \leqslant x \leqslant L_e \qquad r = R$$

$$P = Pu \text{ [to give } 4.5 \times 10^5 \text{ depending on } (L_e)], \; x = 0, \; 0 \leqslant r \leqslant R$$

$$P = P_d = 0.0, \quad x = L_e \qquad 0 \leqslant r \leqslant R$$

Initial values are not required since the non-linear convective terms are exactly zero for fully developed turbulent flow. The particular problem analysed is for Re = $4.5 \times 10^5$.

A suitable finite element mesh consisted of eight elements across the pipe radius, and eight elements across the pipe length, each decreasing in thickness in a geometric progression using a geometric constant of 0.35. The widths are shown in the mesh Figure VII-37 and a corner blown up is shown in Figure VII-38. Figure VII-39 shows the velocity vectors. Figure VII-40 shows the velocity contours. Figure VII-41 shows the pressure contours. Figure VII-42 shows the length scale of turbulence contours. Figure VII-43 shows the kinetic energy of turbulence contours. Figure VII-44 shows the turbulent viscosity contours. The output of the program was absolutely identical to that of Reference 3. An error of 1.2% is due to the fact that the model of turbulence in Reference 3 feeds in the effective viscosity for each node in the element matrix and in the numerical integration, while in this work although the $\nu_e$ is evaluated for each node but the average of elemental nodal $\nu_e$ is fed for each element in the element matrix and in the numerical integration. This is what we meant when we said in the discussion of this thesis that there was a slight difference in the absolute values. However Figure VII-45 shows an absolutely identical plot, for the normalised axial velocity at various normalised radius values at the pipe exit.

### VII.1.8 Developing Turbulent Flow in a Pipe

Reynolds number is limited here to Re = $1.0 \times 10^5$, because above such values a special wall element will be needed as per the work of References 1,2. The boundary conditions are similar to those used in the previous section VII.1.7, except that the pressure is now defined

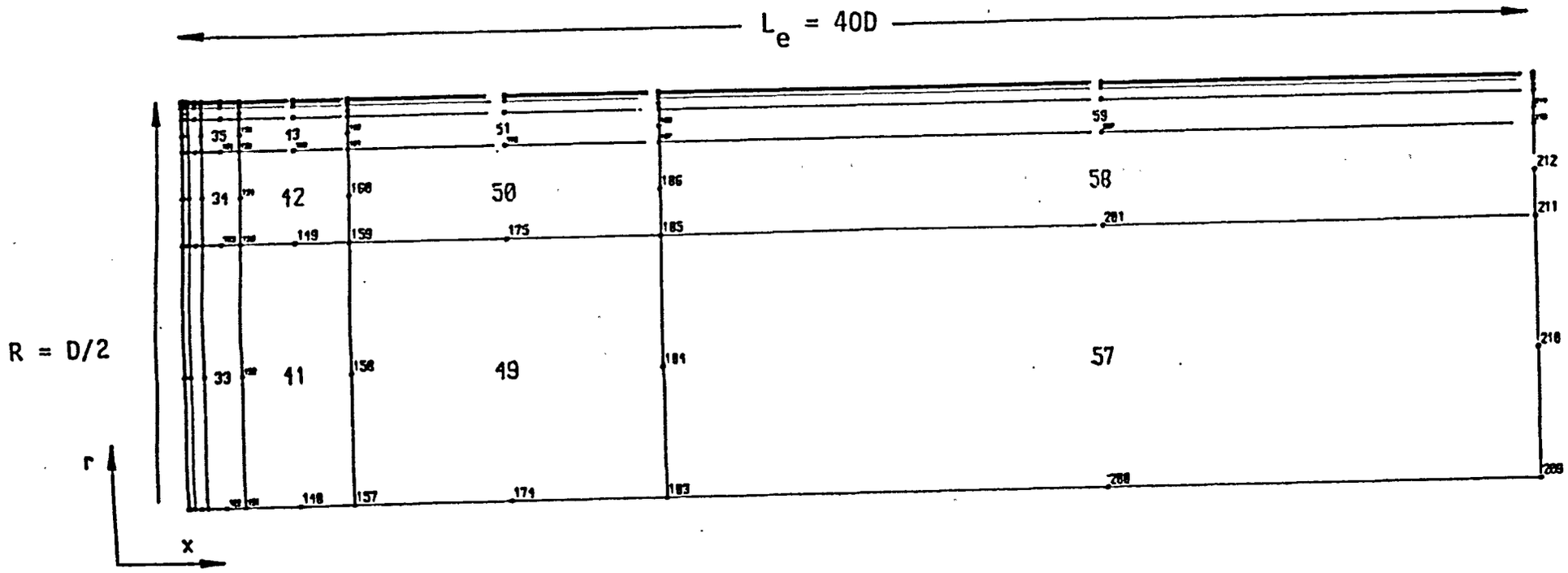
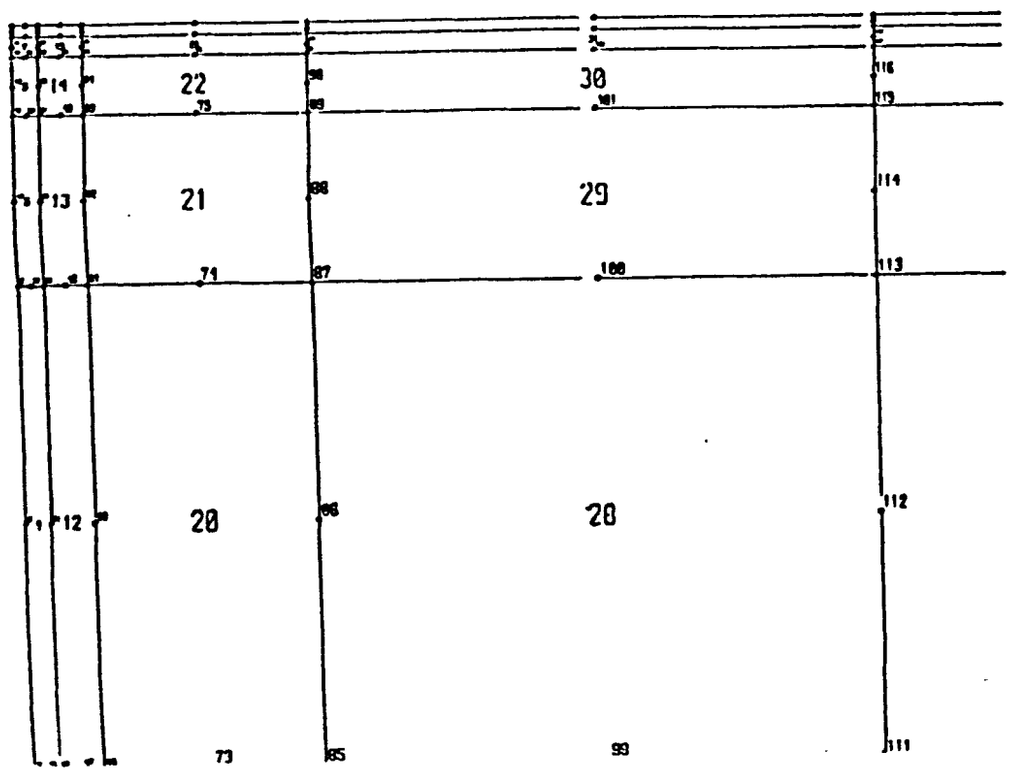



FIGURE VII-37: The mesh used for test case (VII.1.7) of fully developed turbulent flow in a pipe

FIGURE VII-38: A blown-up view of the mesh of test case (VII.1.7) of fully developed turbulent flow in a pipe



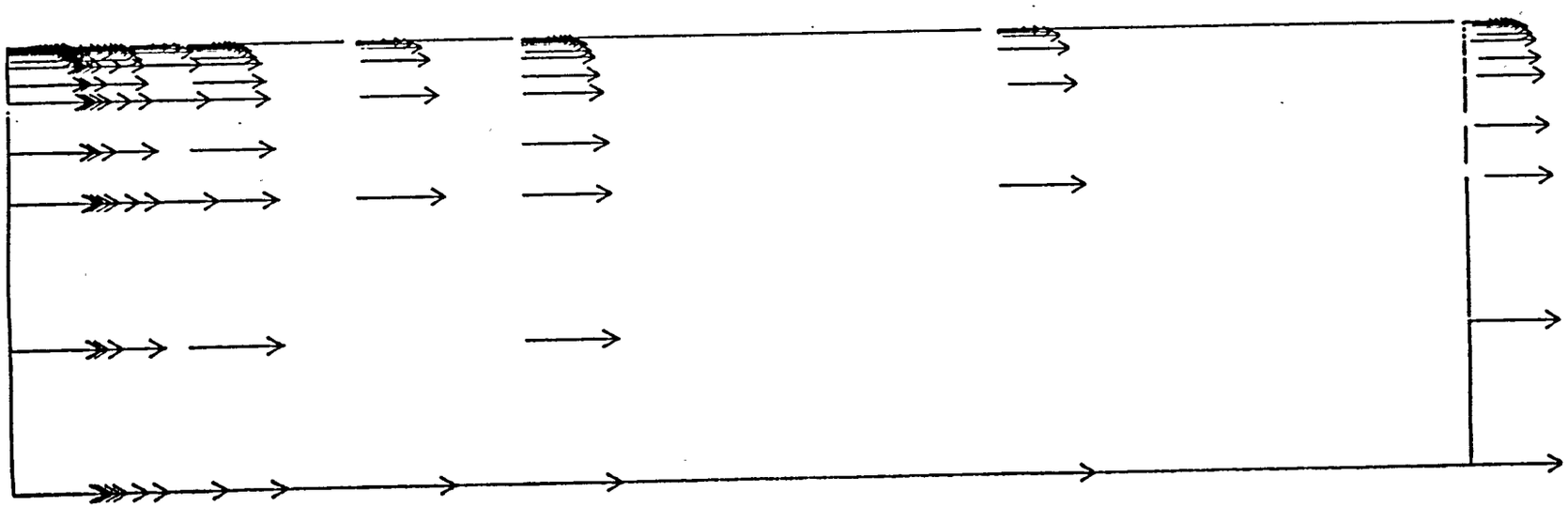


FIGURE VII-39: Test Case (VII.1.7) velocity vectors.
Fully developed turbulent pipe flow

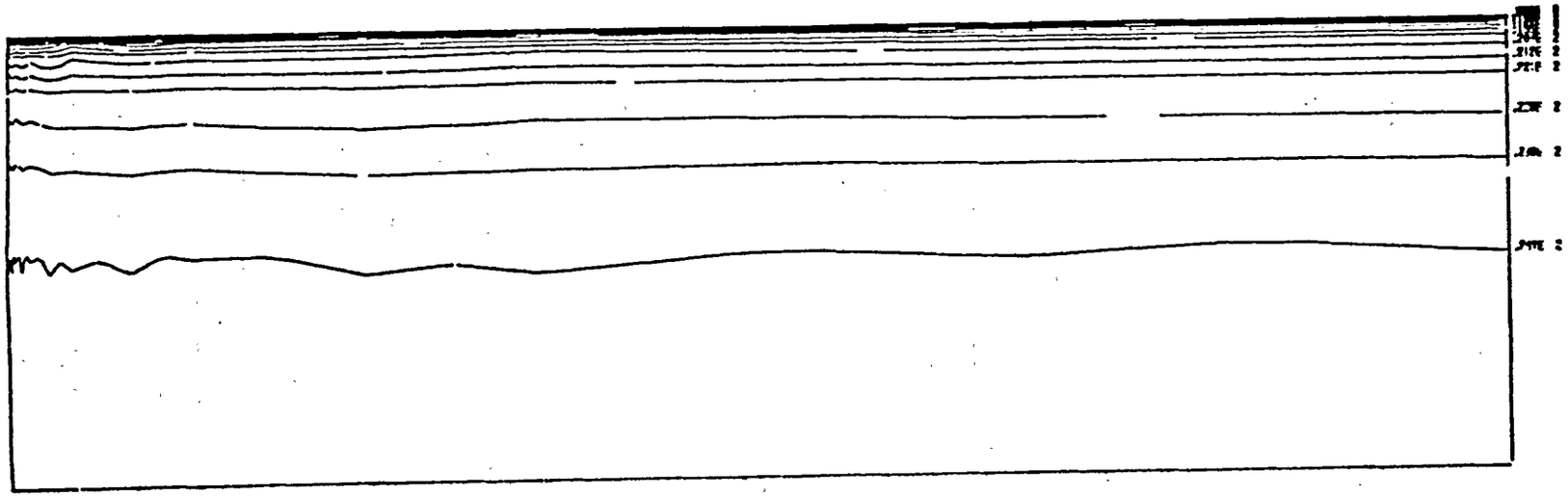


FIGURE VII-40: Test case (VII.1.7) velocity contours (Isovels).
Fully developed turbulent pipe flow.

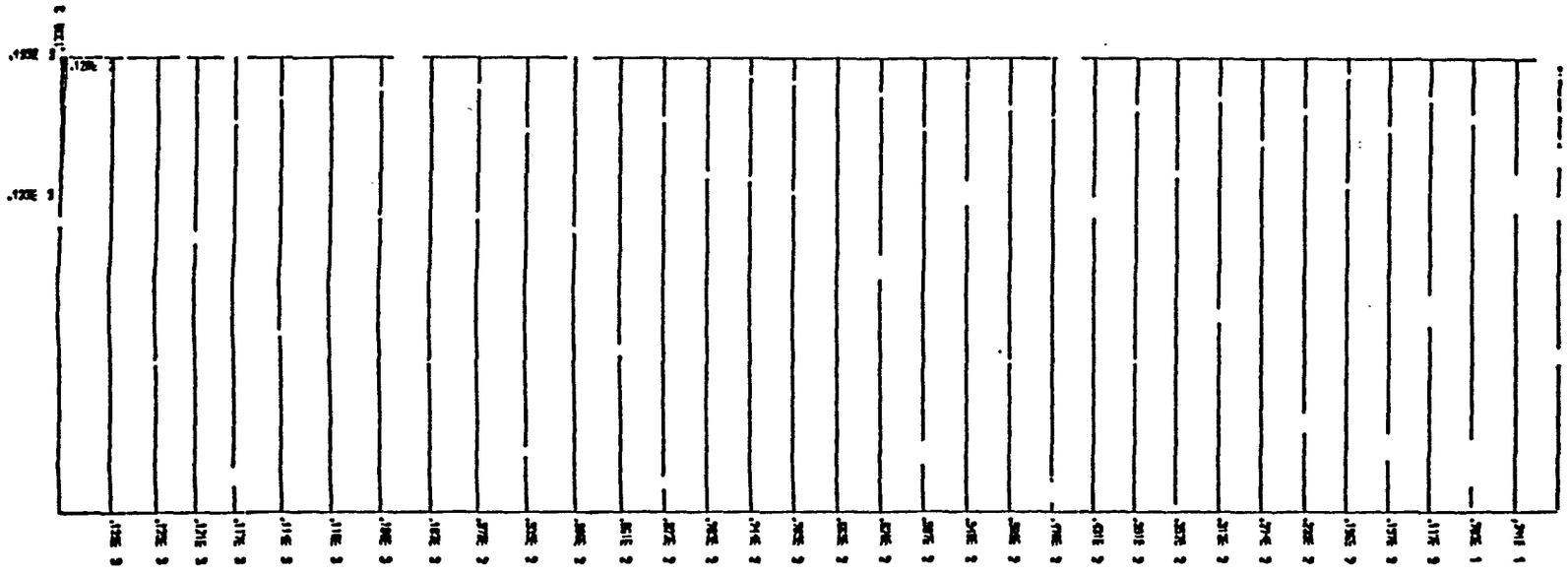


FIGURE VII-41: Test case (VII.1.7) pressure contours. (Isobars).
Fully developed turbulent pipe flow

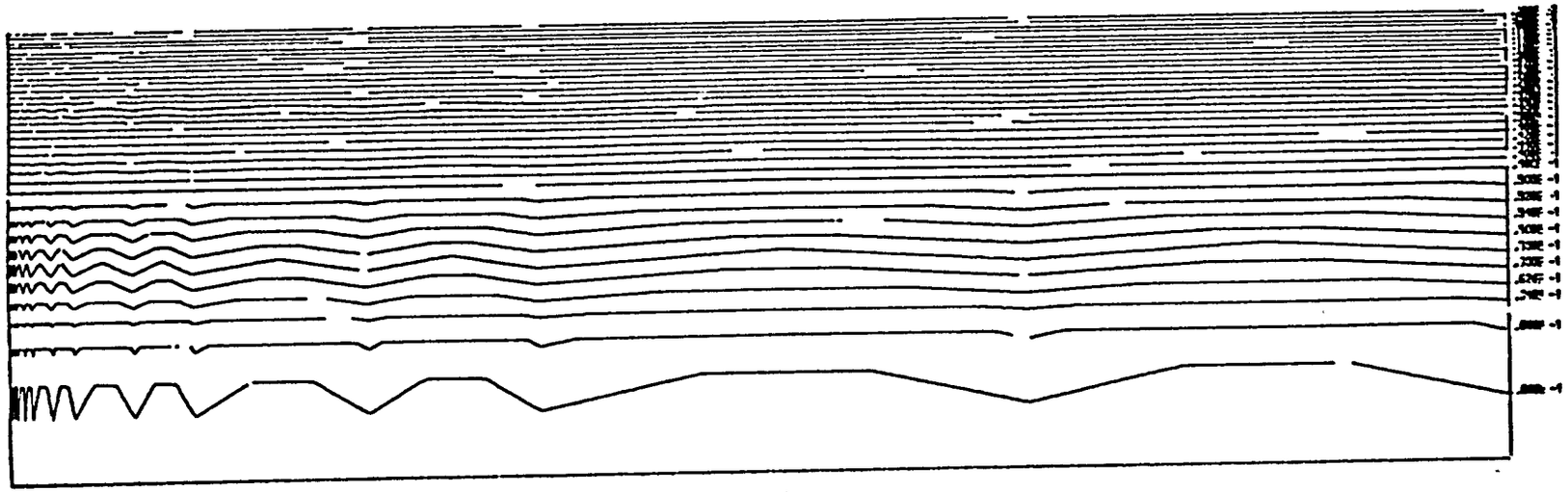


FIGURE VII-42: Test case (VII.1.7) length scale of turbulence contours.
Fully developed turbulent pipe flow.

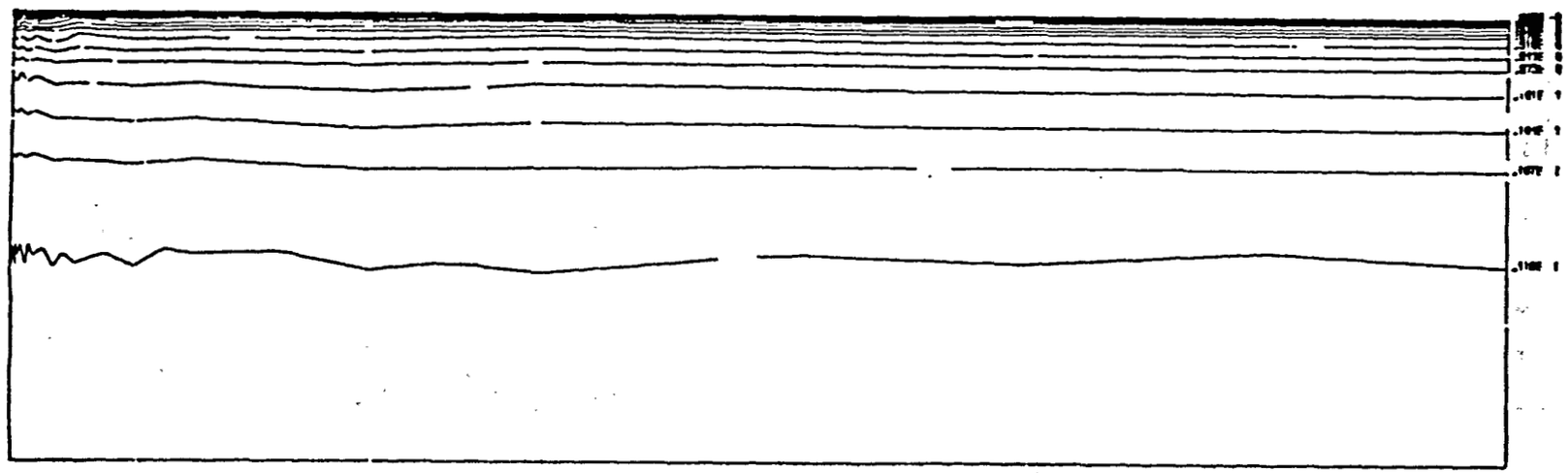


FIGURE VII-43: Test case (VII.1.7) kinetic energy of turbulence contours.
Fully developed turbulent pipe flow.

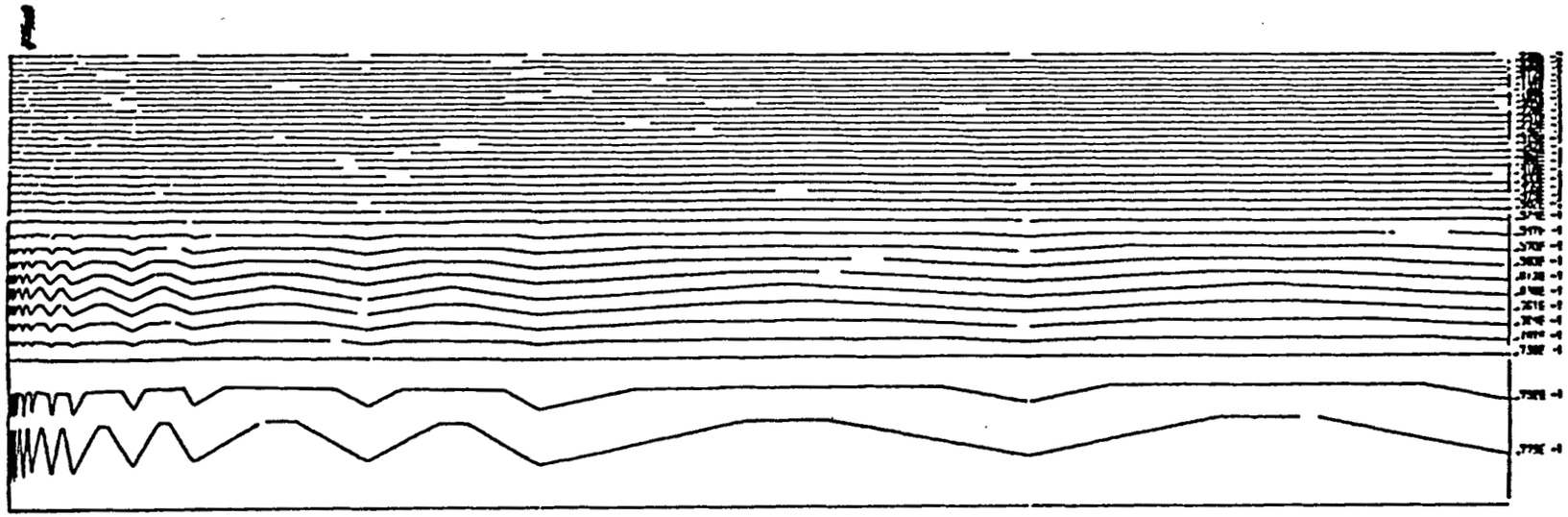


FIGURE VII-44: Test case (VII.1.7) turbulent viscosity contours.
Fully developed turbulent pipe flow

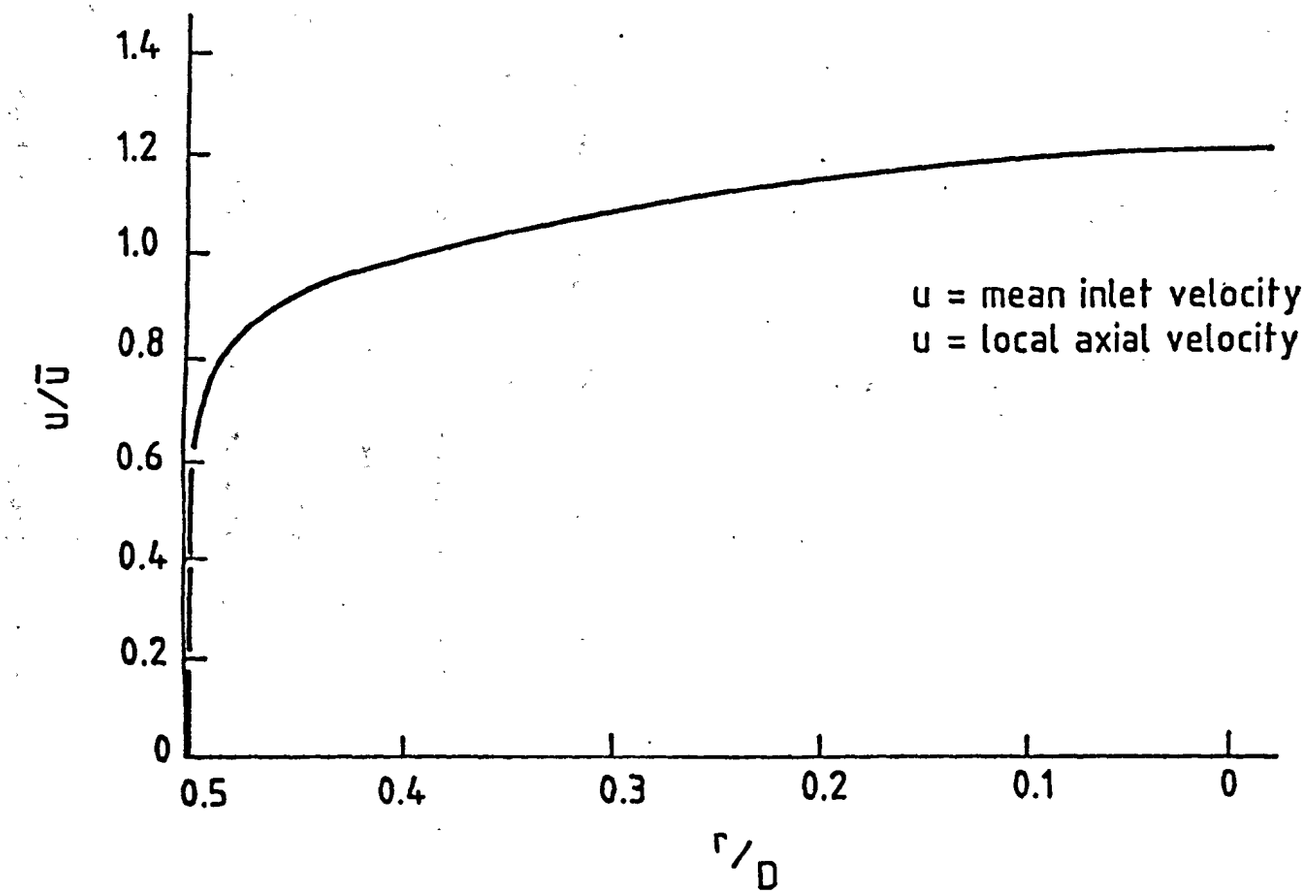



FIGURE (VII-45) DEVELOPED FLOW $R_e = 4.5 \times 10^5$
AXIAL PLOT OF VELOCITY AT X/D = 40

at the downstream section only where the flow has been assumed to be fully developed and the velocity is assumed to be uniform across the entry. The same mesh of VII.1.7 is used with the following boundary conditions:

| | | |
|---|---|---|
| $V = \frac{\partial u}{\partial x} = 0,$ | $x = 0,\ L_e = 40$ | $0 \leqslant r \leqslant R = 0.5$ |
| $V = \frac{\partial u}{\partial r} = 0,$ | $0 \leqslant x \leqslant L_e$ | $r = 0$ |
| $V = U = 0$ | $0 \leqslant x \leqslant L_e$ | $r = R$ |
| $U = \overline{U} = 1.0$ | $x = 0$ | $0 \leqslant r \leqslant R$ |
| $P = 0$ | $x = L_e$ | $0 \leqslant r \leqslant R$ |

Figure VII-46 shows the velocity vectors. Figure VII-47 shows the velocity contours. Figure VII-48 shows the pressure contours. Figure VII-49 shows the length scale of turbulence contours. Figure VII-50 shows the kinetic energy of turbulence contours. Figure VII-51 shows the turbulent viscosity contours. Figure VII-52 shows the axial velocity distribution at various longitudinal distances for various pipe radii. X/D = 0 is the entrance, X/D = 10 is the seventh column of elements in the vicinity of the exit, due to the regression used in dimensioning the elemental distances. Figure VII-52 shows a perfect agreement with Reference 3.

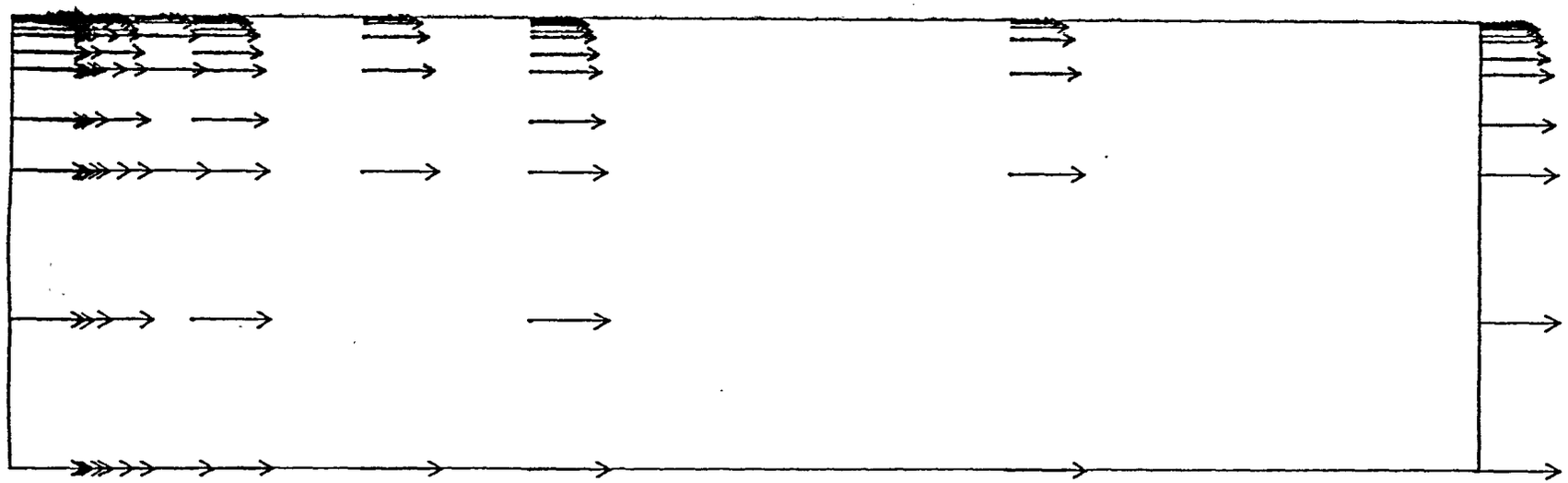


FIGURE VII-46: Test case (VII.1.8) velocity vectors.
Developing turbulent flow in a pipe

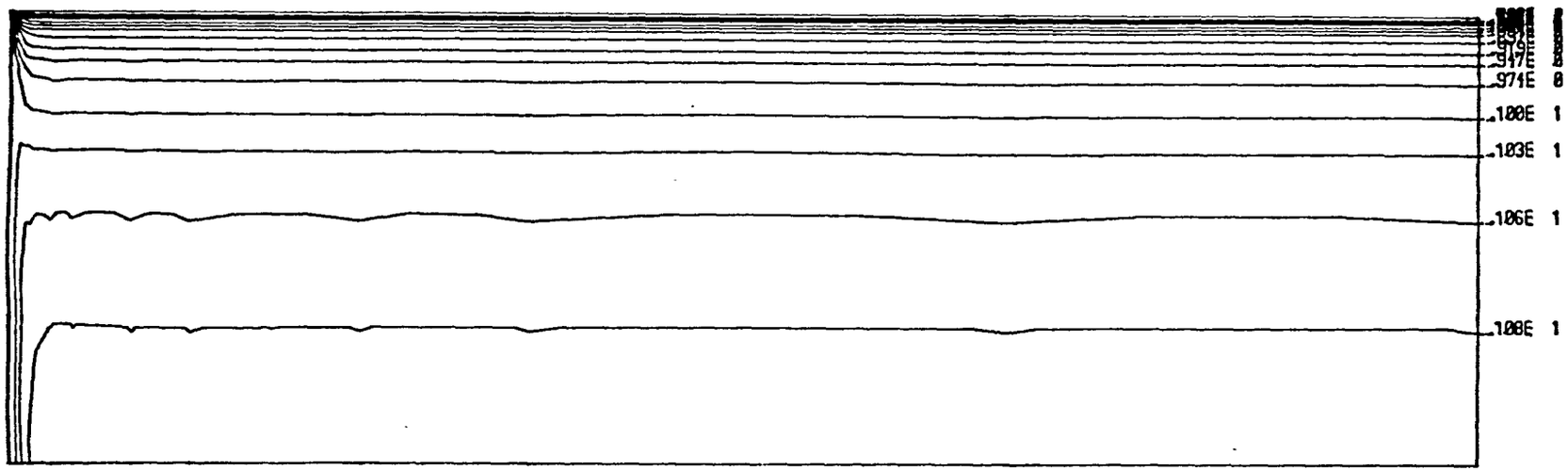



FIGURE VII-47: Test case (VII.1.8) axial velocity contours (Isovels).
Developing turbulent flow in a pipe

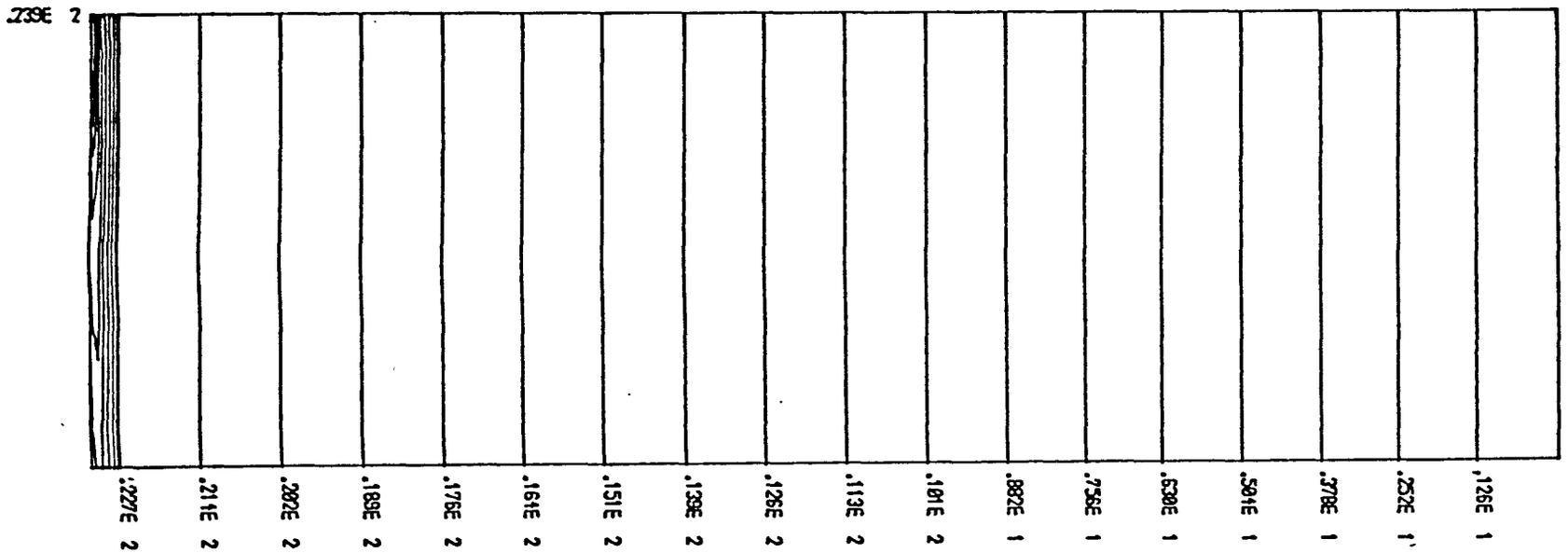



FIGURE VII-48: Test case (VII.1.8) pressure contours (Isobars).
Developing turbulent flow in a pipe

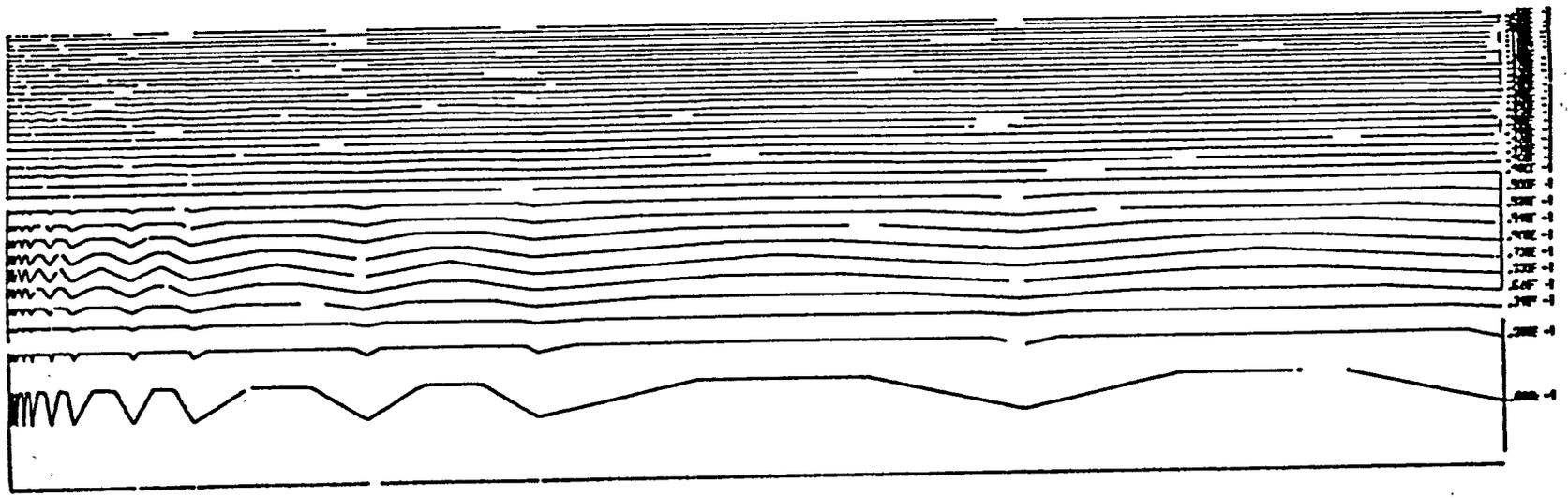


FIGURE VII-49: Test case (VII.1.8) length scale of turbulent contours.
Developing turbulent flow in a pipe

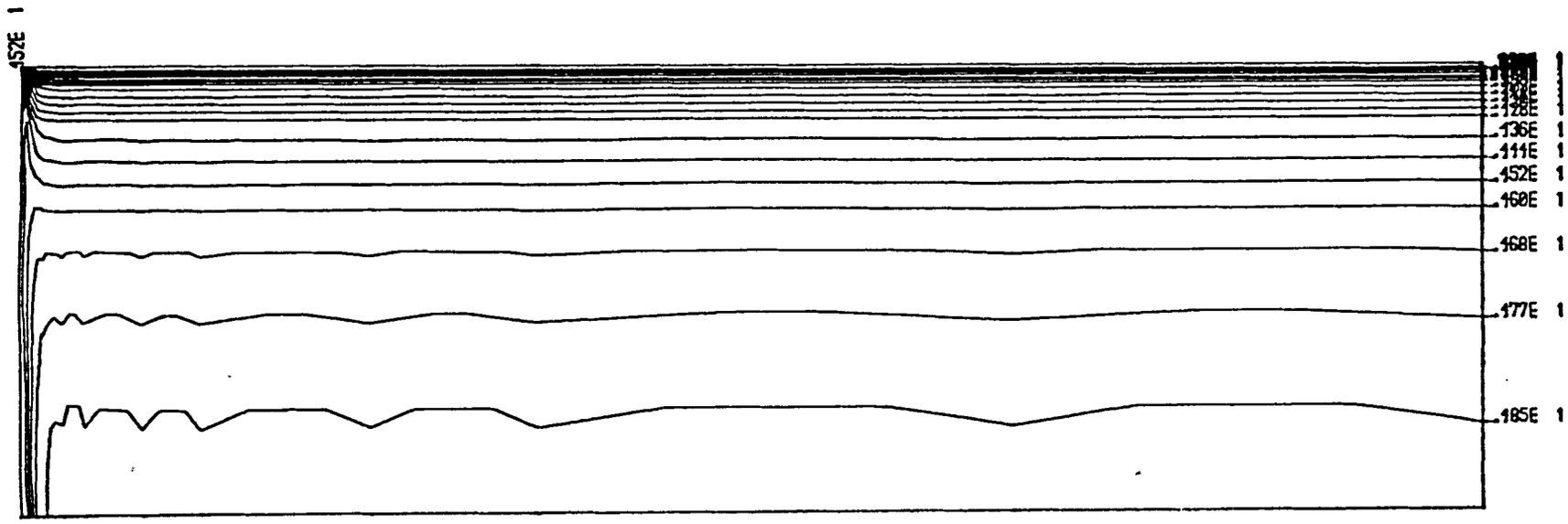



FIGURE VII-50: Test case (VII.1.8) kinetic energy of turbulence contours.
Developing turbulent flow in a pipe

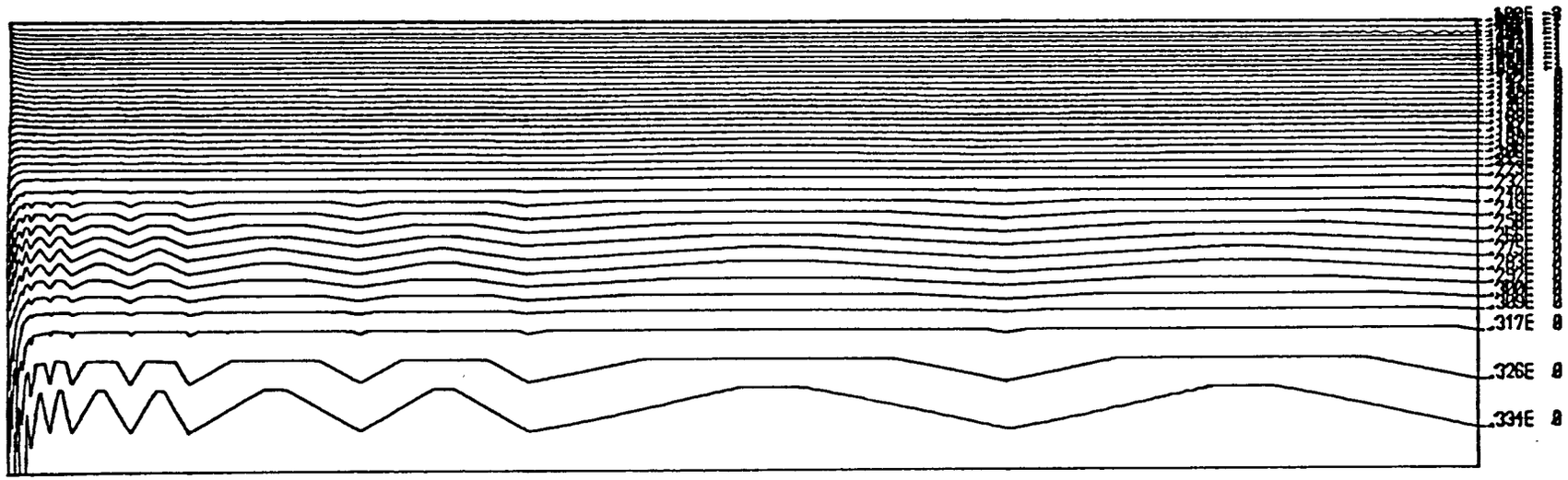



FIGURE VII-51: Test case (VII.1.8) turbulent viscosity contours.
Developing turbulent flow in a pipe

$\bar{u}$ = mean inlet velocity
u = local axial velocity

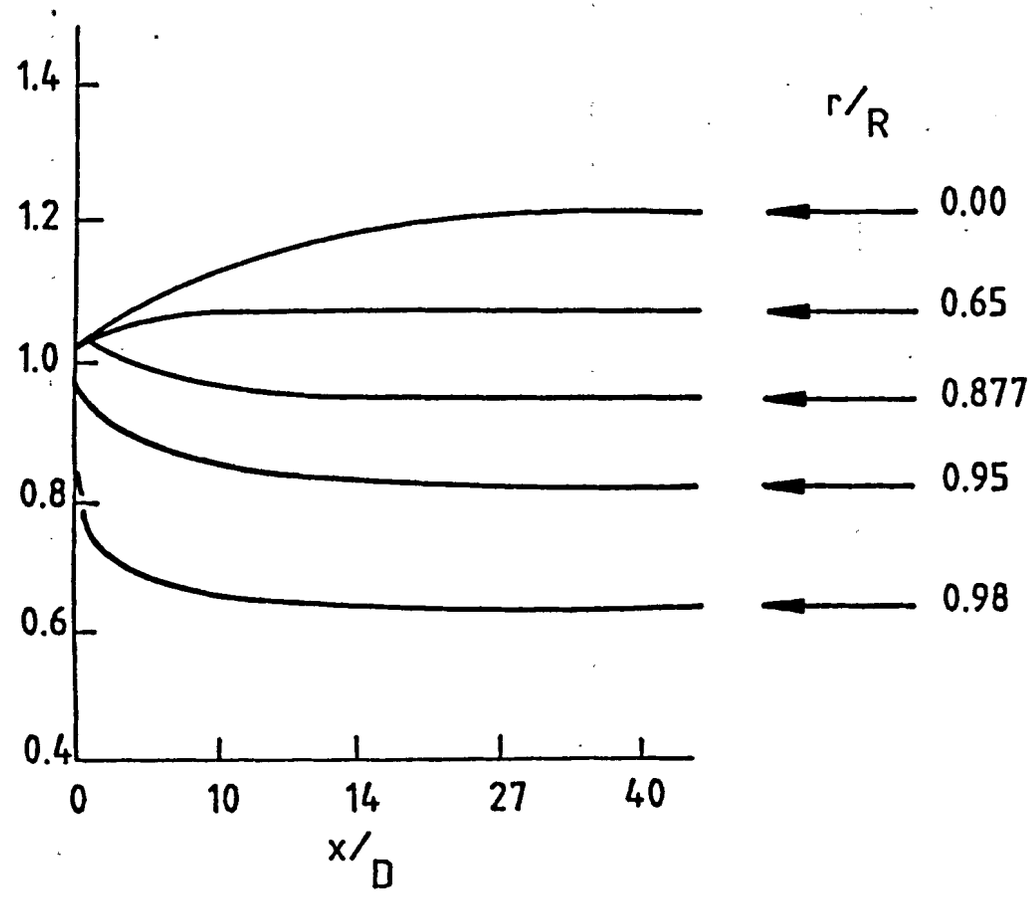



FIGURE (VII-52) DEVELOPING TURBULENT PIPE FLOW
VARIATION IN AXIAL VELOCITY $R_e = 1 \times 10^{10}$

## VII.1.9 The Velocity Characteristics of Ventilated Rooms: Turbulent Jet Induced Flow in Rectangular Enclosures

Reference 5 has measured and calculated values of the velocity characteristics of a modelled room with ventilation arrangements. The measurements were obtained by laser Doppler anemometry and the calculations by a (K-ε) finite difference model. The geometrical arrangements used are shown in Figure VII-53.

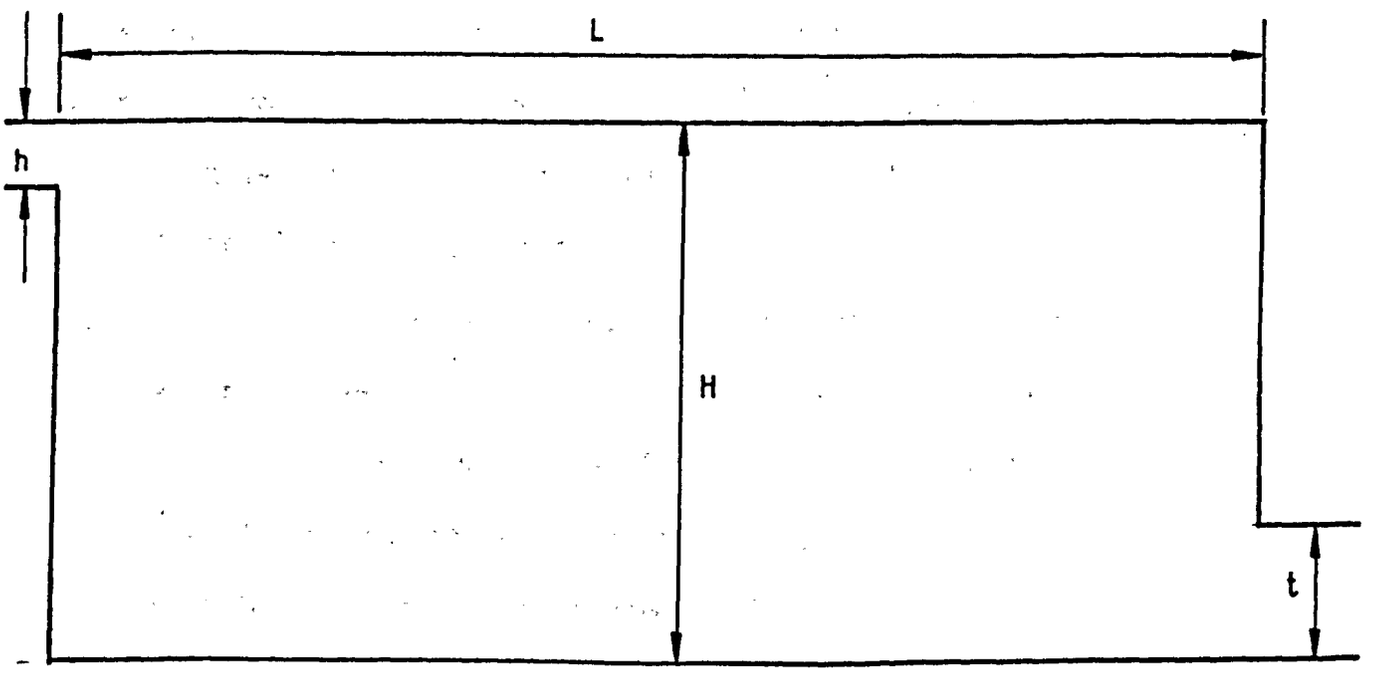


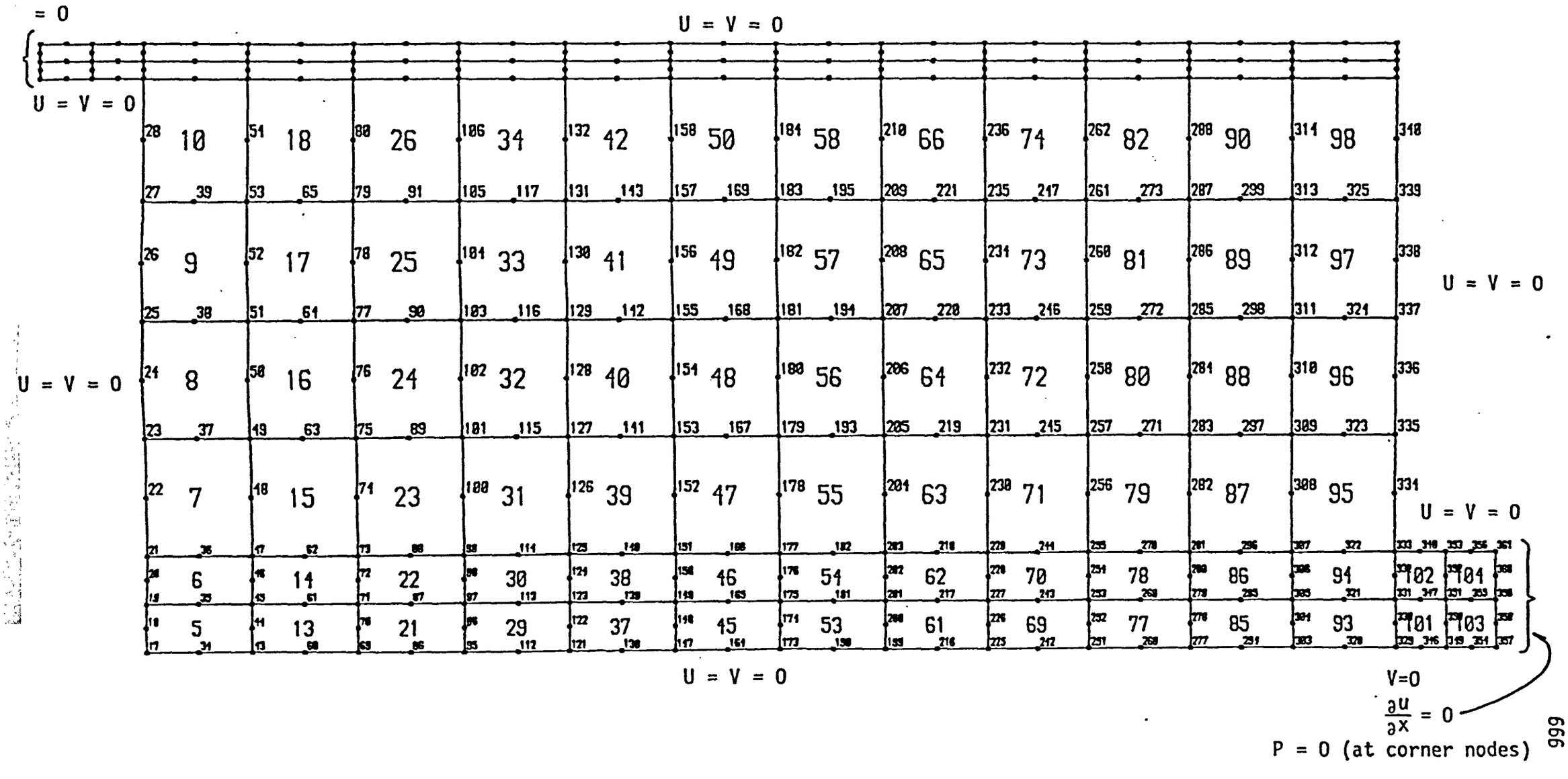

FIGURE VII-53: Geometrical Arrangements of Test Case (VII.1.9)

The model was constructed from perspex with a height (H = 89.3 mm). Other dimensions correspond to:

$$\frac{L}{H} = 3.0, \quad \frac{h}{H} = 0.056, \quad \frac{t}{H} = 0.16$$

Two values of the width of the inlet slot were used to assist the determination of the extent of influence of a three dimensional inlet flow on the velocity characteristics of the room. However, in this test case we are only considering the value of the inlet width that equals the width of the room, since our analysis is two-dimensional. The parameters used in the wall jet assumptions are those mentioned in Appendix VI of this thesis. The measured mean velocity profiles were done at Re = $\frac{\rho U_o h}{\mu}$ = 5000, where $U_o$ is the jet inlet velocity. The mesh used to represent this problem using the finite element zone technique together with the boundary conditions is shown in Figure VII.54. The flow domain has been subdivided into three flow zones. The first is the inlet with its extension throughout the length of the room. The second is the room itself, and the third is the exit duct. As was done in the thesis, Buleev's length scales were used in a straight channel flow for the inlet and exit, while the room was having the mean total horizontal and total vertical flows to simulate the flow separation. Figure VII.55 shows the inlet length scale for the wall jet flow together with a blown up zoom view of the inlet details. Figure VII.56 shows the length scale of turbulence distribution in the room itself for a totally horizontal flow. Figure VII.57 shows the length scale of turbulence distribution in the room for a totally vertical flow. Figure VII.58 shows the mean of the last two length scales of turbulence distributions of Figures VII.56 and VII.57. Figure VII.59

FIGURE VII-54: Test case (VII.1.9). The mesh and boundary conditions.
Turbulent het induced flow in rectangular enclosures



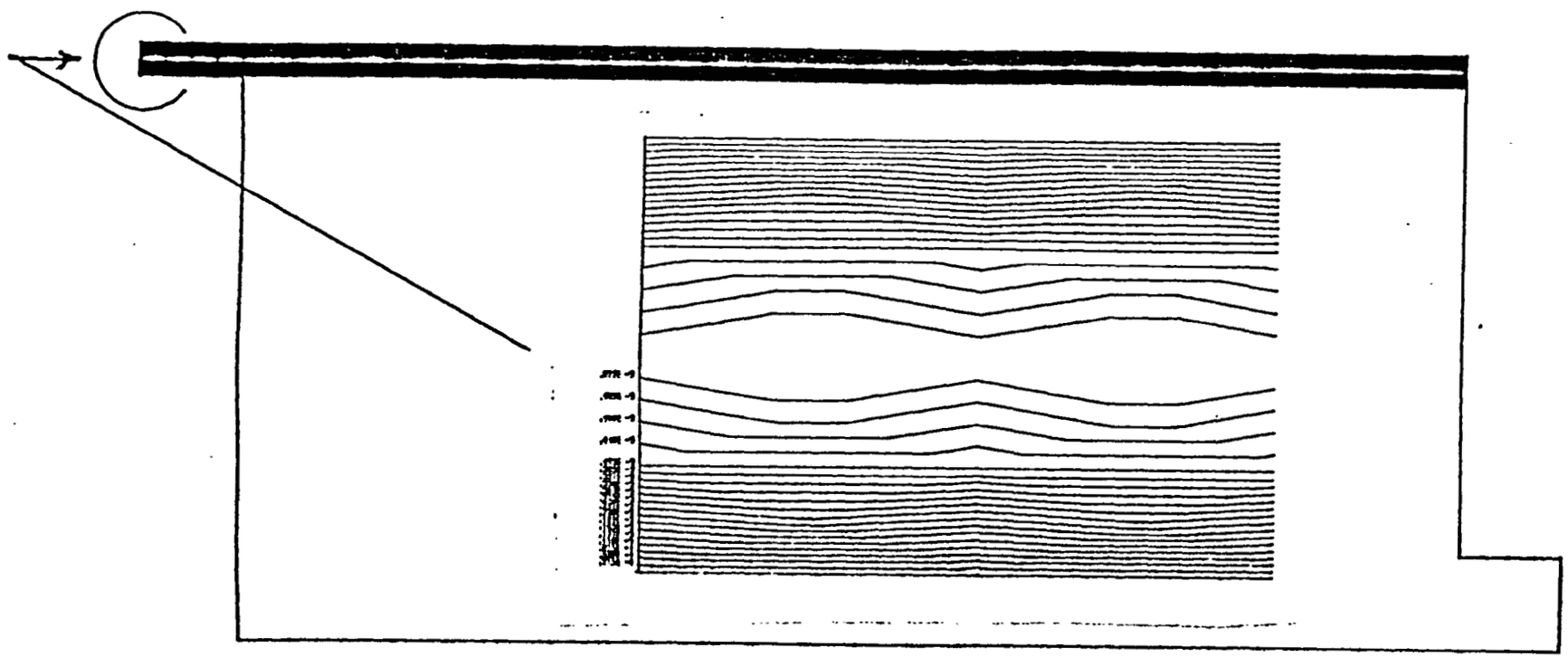


FIGURE VII.55: Test Case (VII.1.9) length scale of turbulence for the inlet wall jet, with a blown up zoom view of the inlet

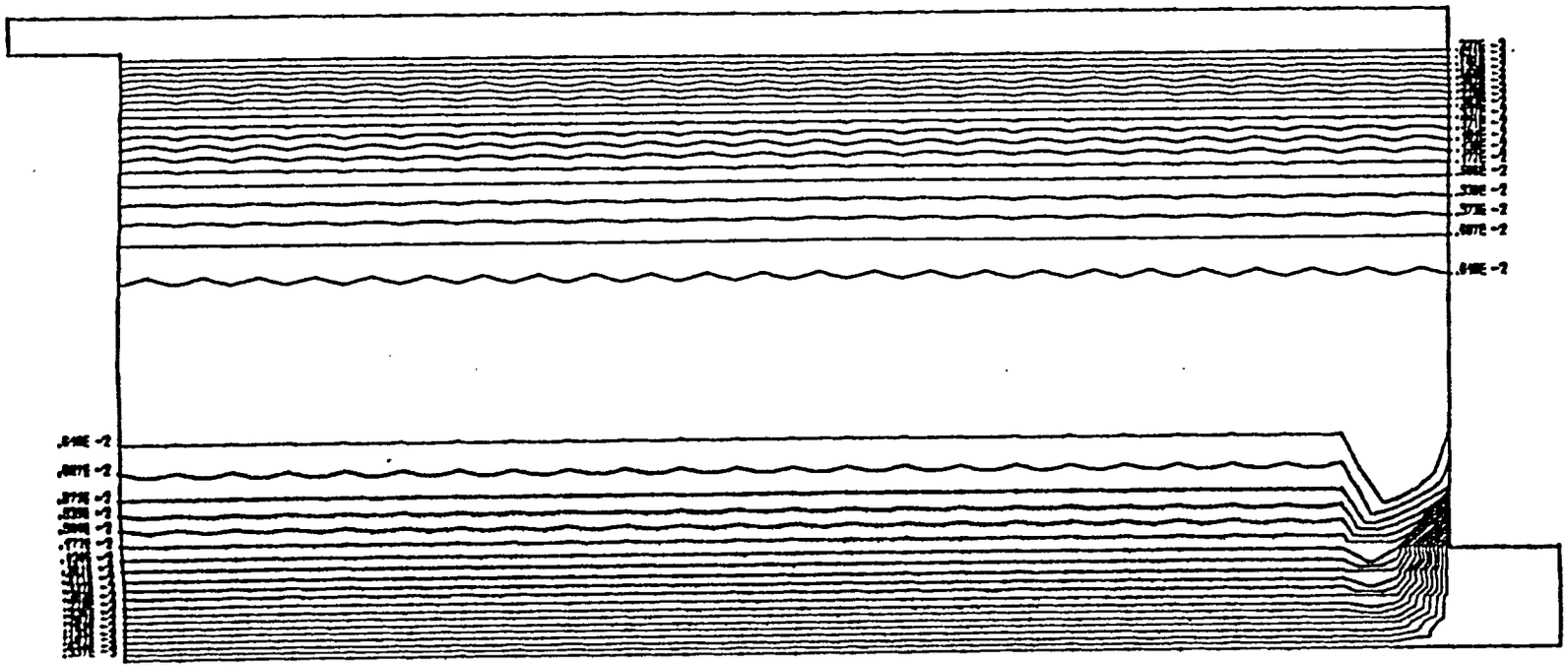


FIGURE VII.56: Test Case (VII.1.9) length scale of turbulence for a total horizontal flow in the room

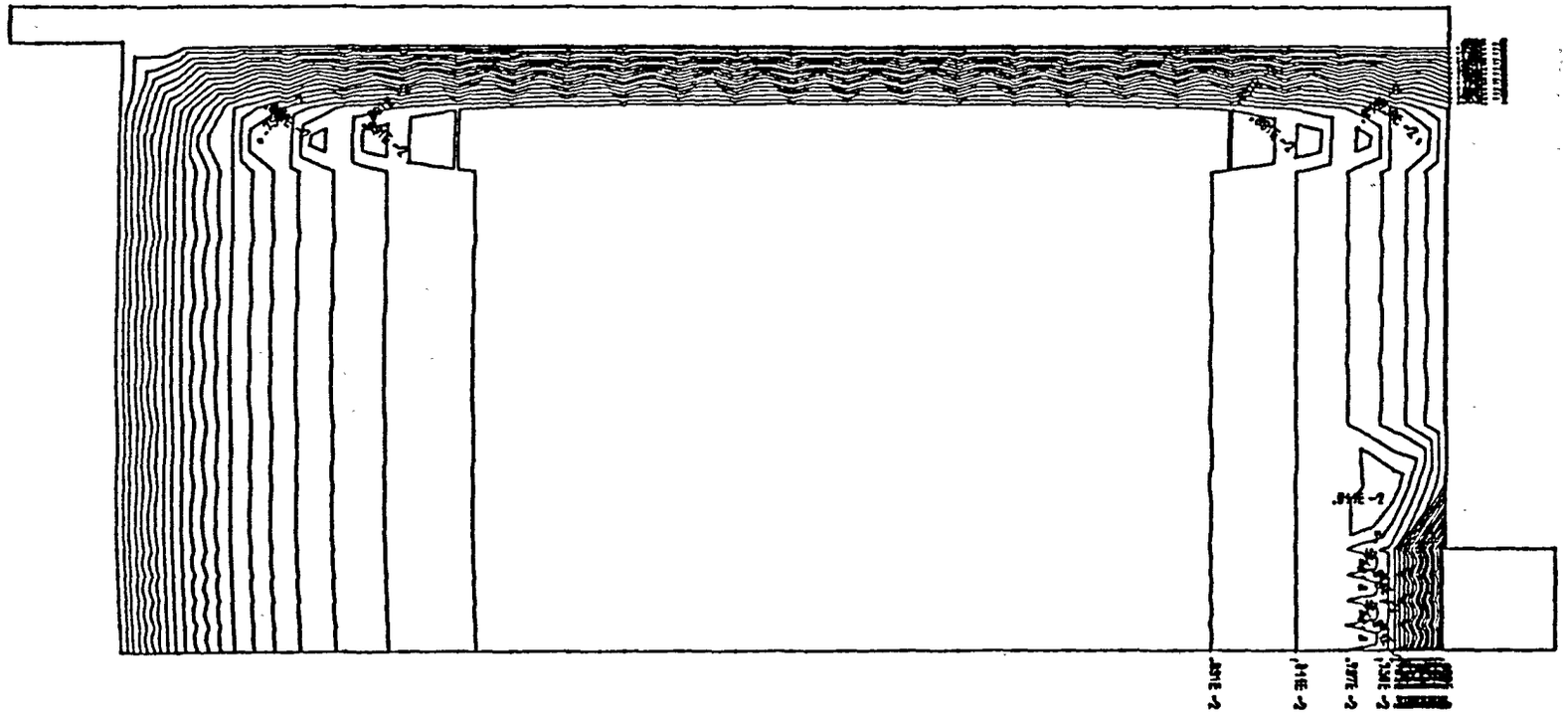


FIGURE VII.57: Test Case (VII.1.9) length scale of turbulence for a total vertical flow in the room, excluding the wall jet area

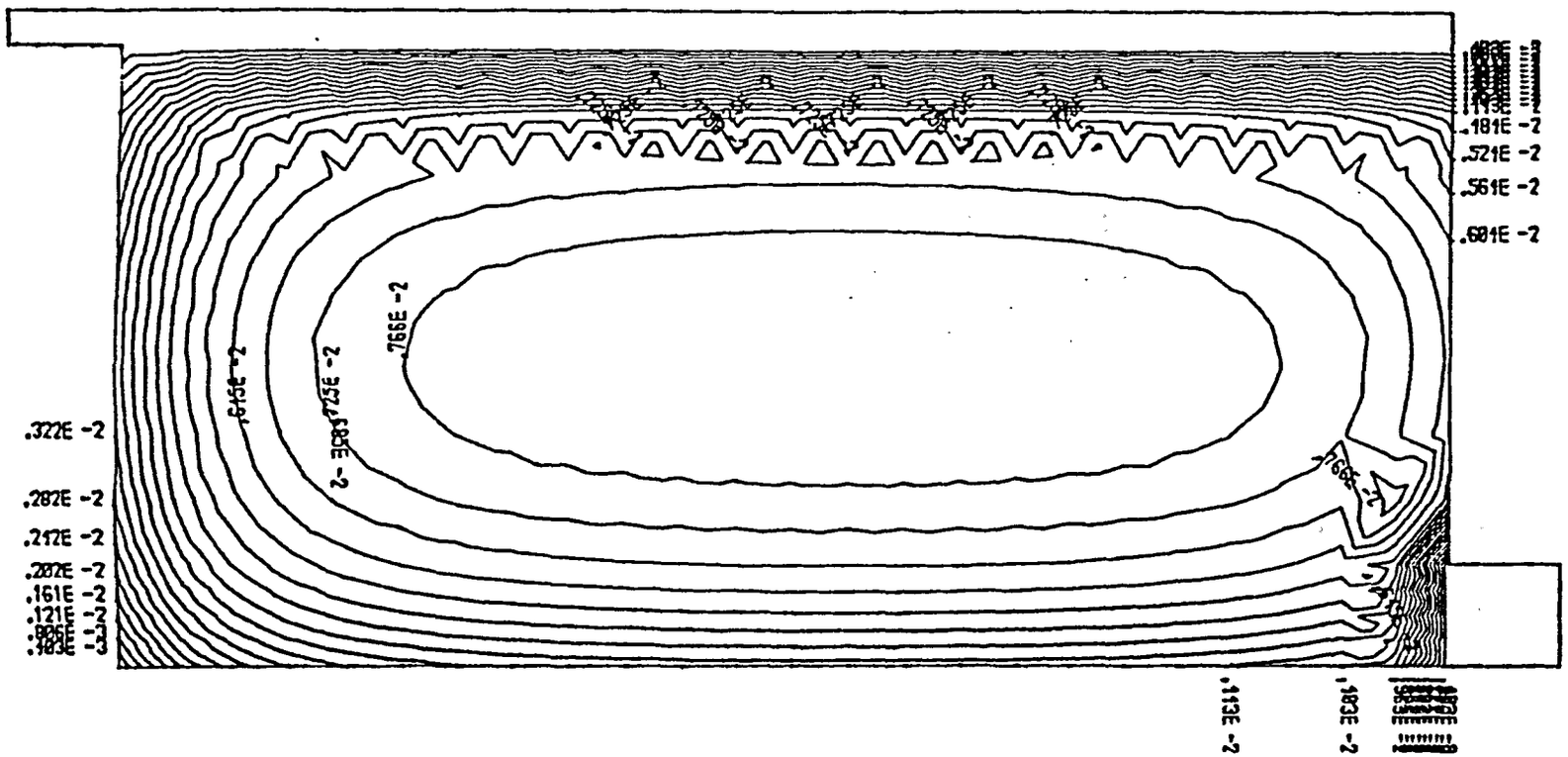



FIGURE VII.58: Test case (VII.1.9) length scale of turbulence of the room as a means of total horizontal and total vertical flows of Figures VII.56 and VII.57

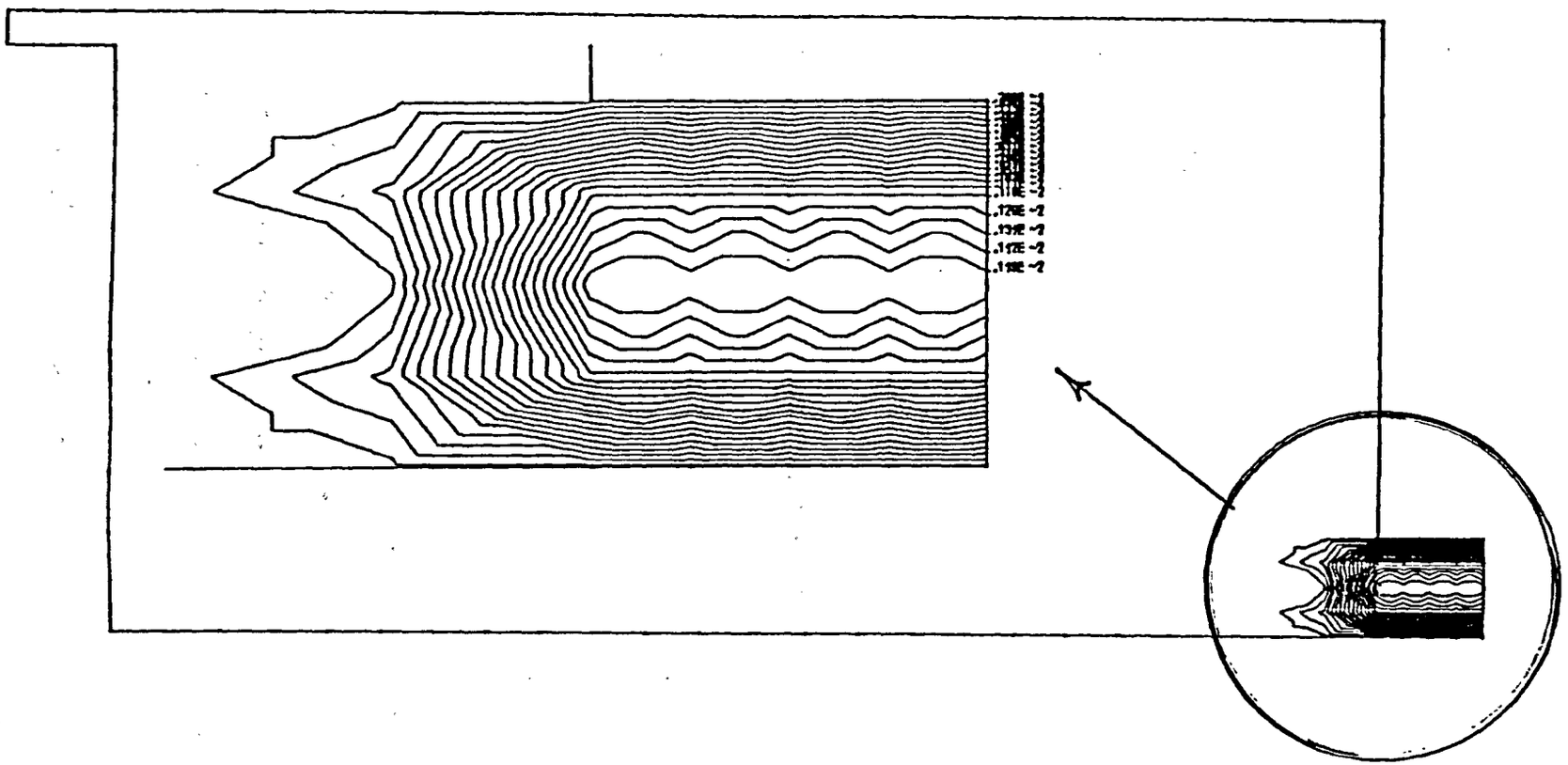


FIGURE VII.59: Test Case (VII.1.9) length scale of turbulence for the room exit, with a blown up zoom view

shows the length scale of turbulence of the exit duct with a blown up zoom view. Figure VII.60 shows the length scale of turbulence distribution for the whole flow domain after assembly of the sub-length scale zones. The turbulence intensity was set as a function of axial position, i.e.

For the jet length scale area: $I_1 = (0.25 - \frac{x}{1.5})\%$,

and for the room itself: $I_2 = (0.21 - \frac{x}{1.5})\%$,

While for the exit duct: $I_3 = (1.2)\%$ was fixed as constant.

Figure VII.61 shows the velocity vectors, the height of the room is increased in order to clarify the flow mechanism (not to scale). In reality and computation the room length is three times its height as mentioned before. Figures VII.62 and VII.63 show the small recirculation zones in the top right hand corner and bottom left hand corners respectively. Ref. 5 confirmed the existence of these two small recirculation zones but did not show them. Figure VII.64 shows the velocity contours. Figure VII.65 shows the pressure contours. Figure VII.66 shows a blown up zoom view of the pressure contours at the room inlet. Figure VII.67 shows the kinetic energy of turbulence contours. Figure VII.68 shows the turbulent viscosity contours. Finally, Figure VII.69 shows a comparison of normalised axial velocity between the experiment and prediction of Ref. 5 and this work. The excellent agreement needs no further explanation.

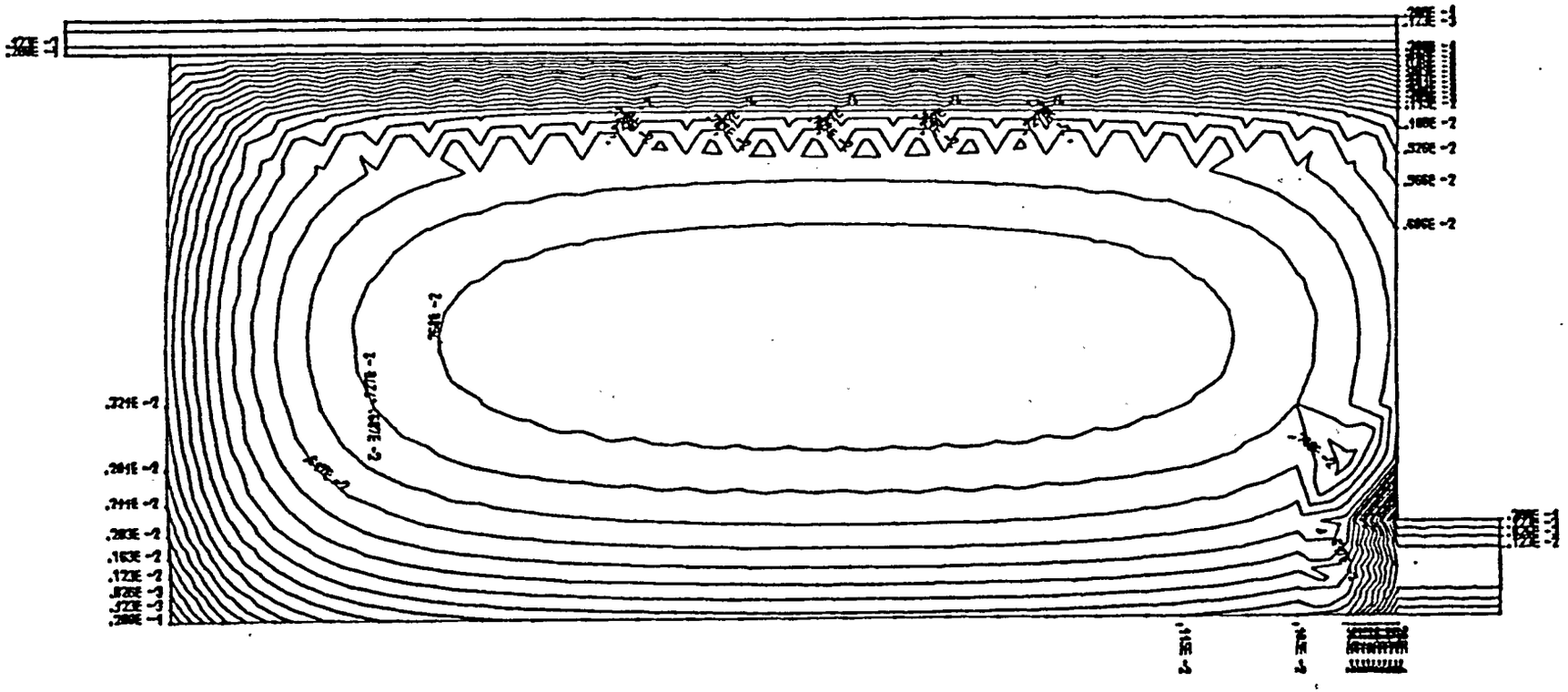


FIGURE VII.60: Test case (VII.1.9) length scale of turbulence of the whole flow domain after assembly of sub-length scale zones.

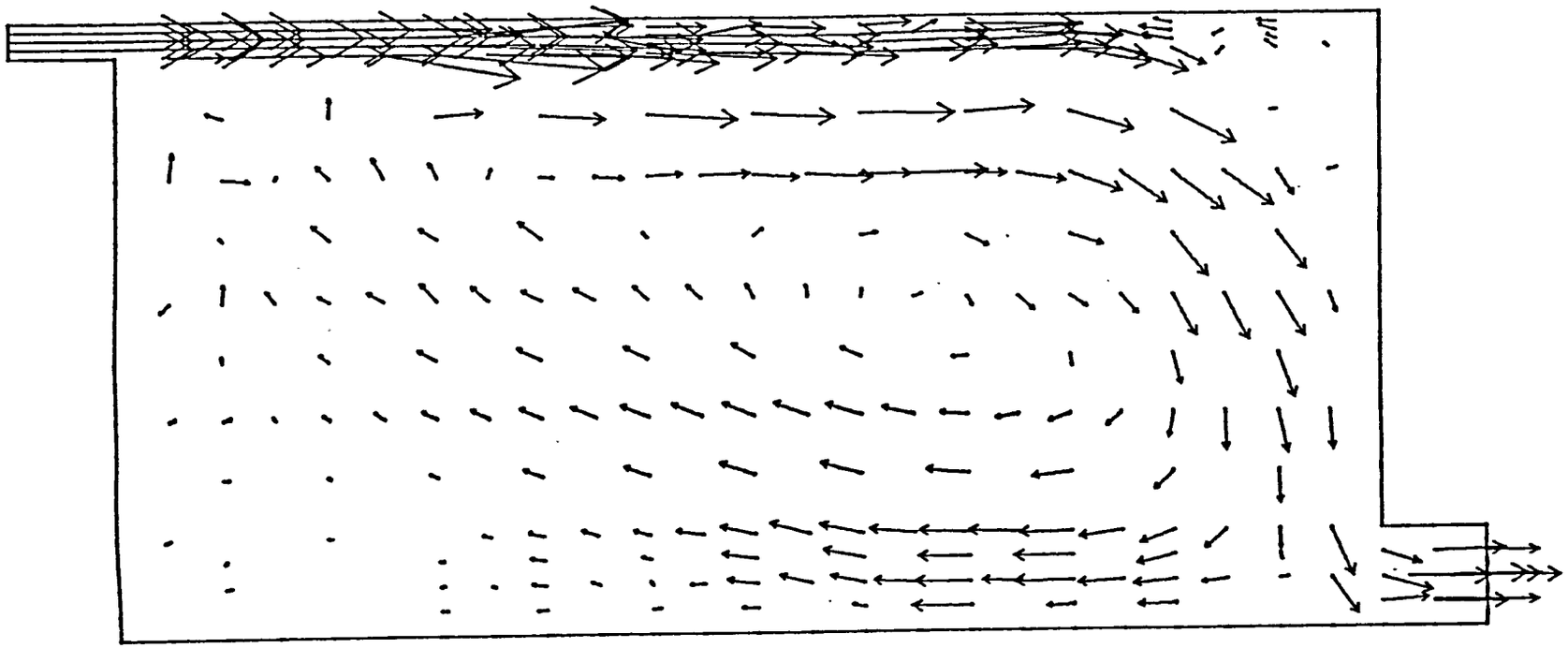


FIGURE VII.61: Test case (VII.1.9) velocity vectors. Velocity in ventilated rooms

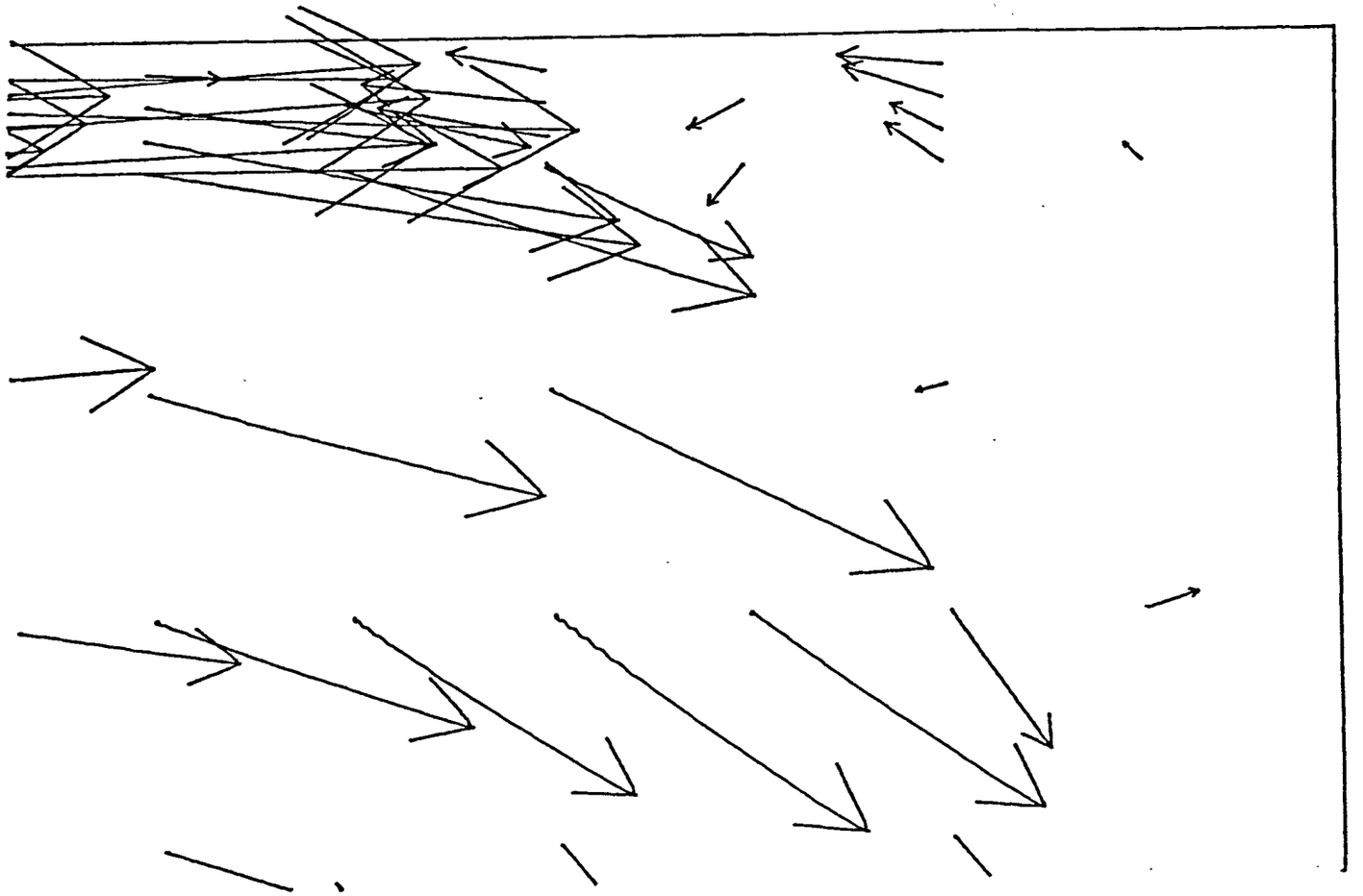


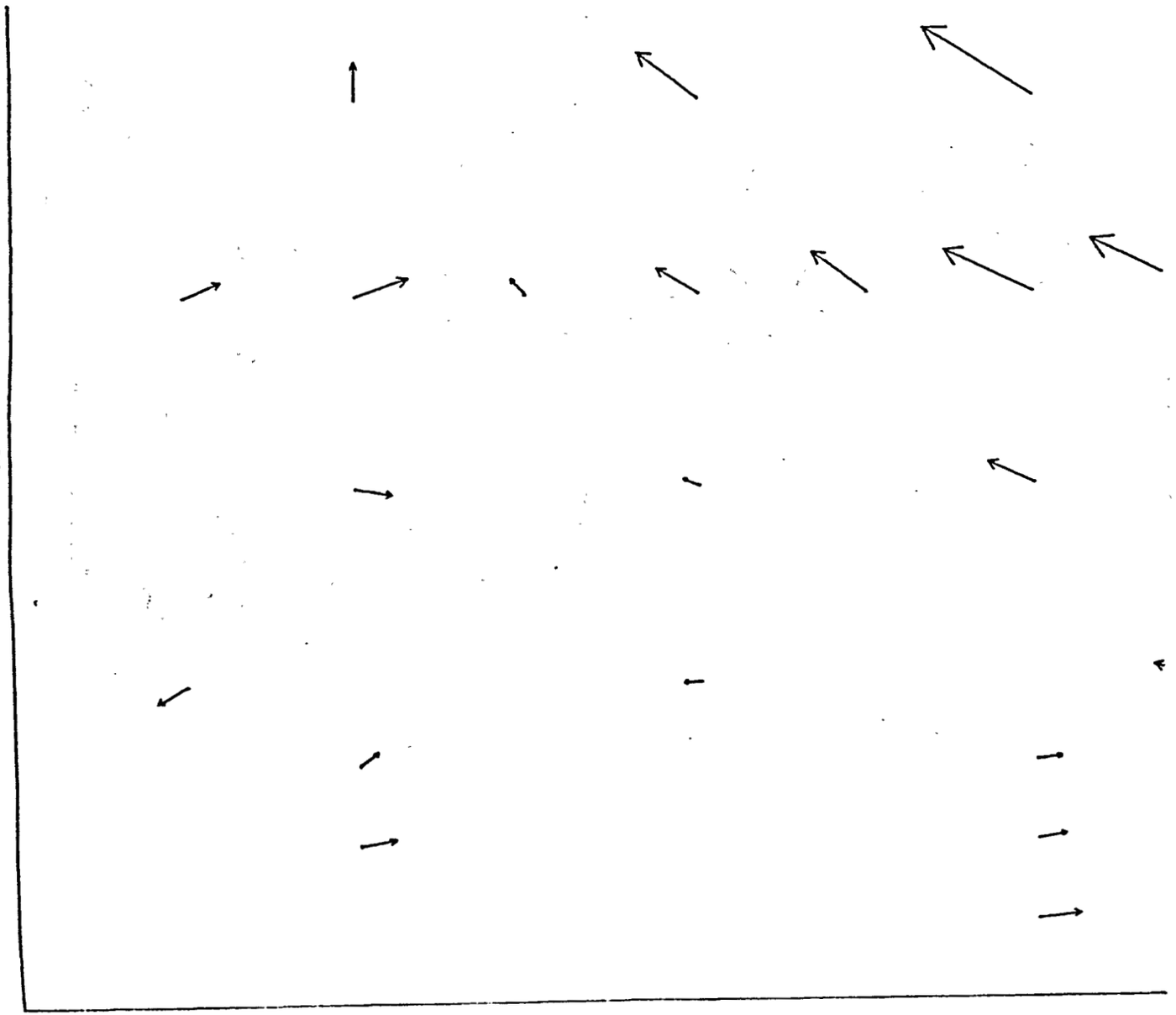
FIGURE VII.62:

Test case (VII.1.9) velocity vectors at top right hand side corner of the room showing the small recirculation zone

Velocity in ventilated rooms

FIGURE VII.63:

Test case (VII.1.9) velocity vectors at bottom left hand side corner of the room showing the small recirculation zone. Velocity in ventilated rooms



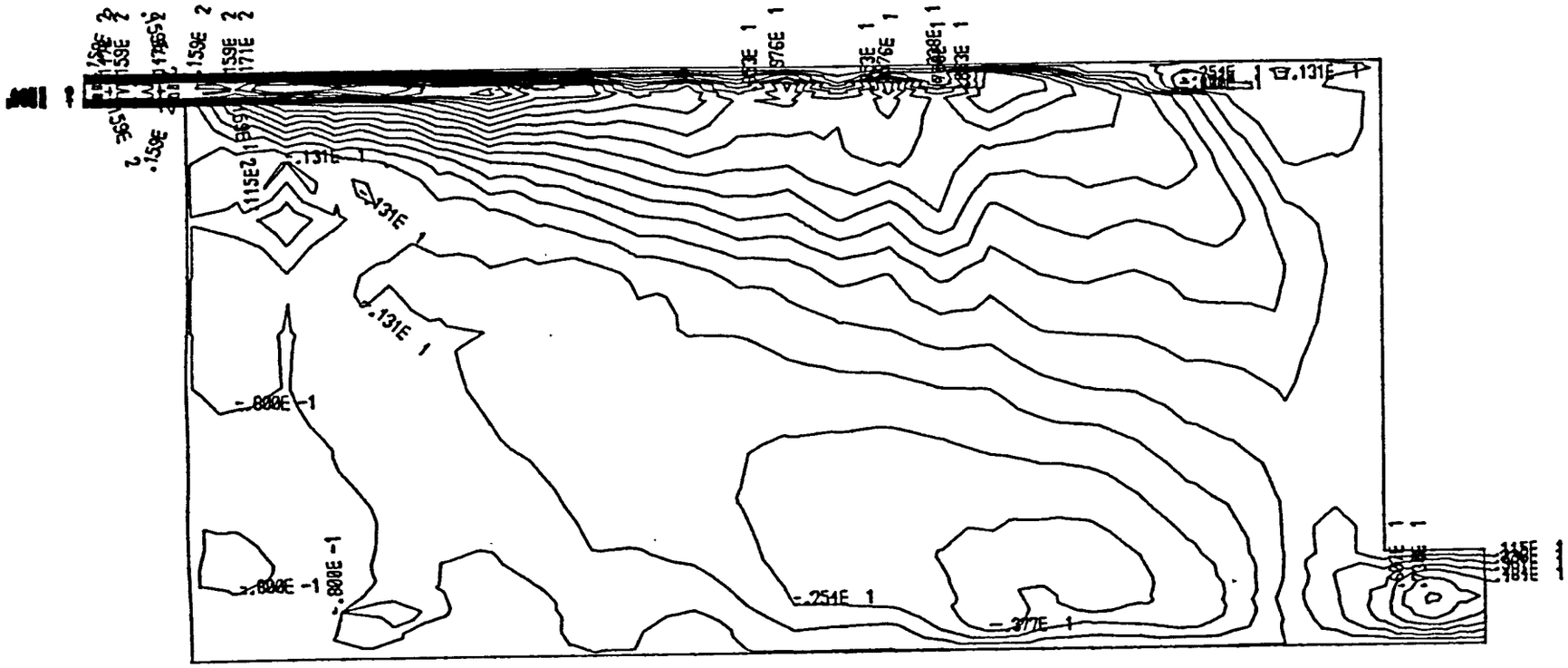



FIGURE VII.64: Test case (VII.1.9) axial velocity contours (Isovels). Velocity in ventilated rooms

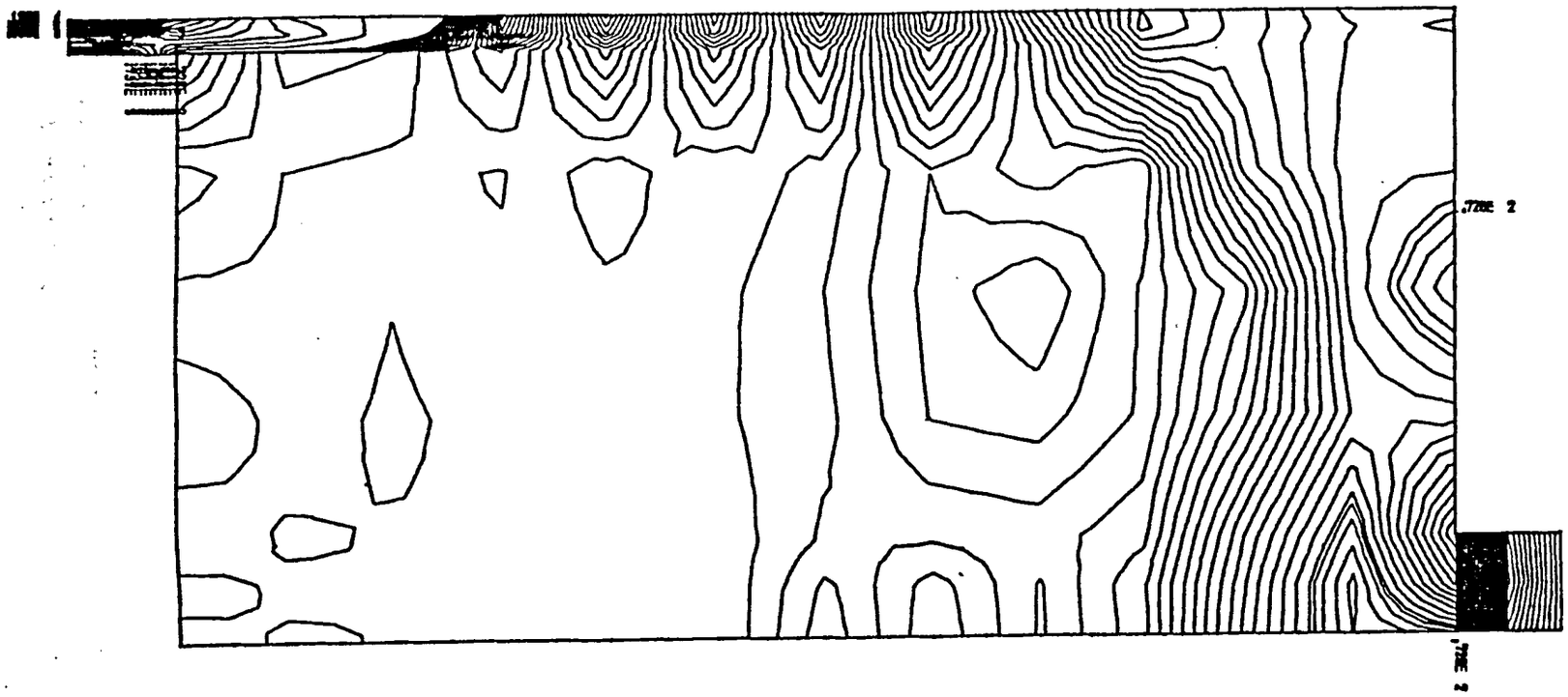



FIGURE VII.65: Test case (VII.1.9) pressure contours (Isobars). Velocity in ventilated rooms

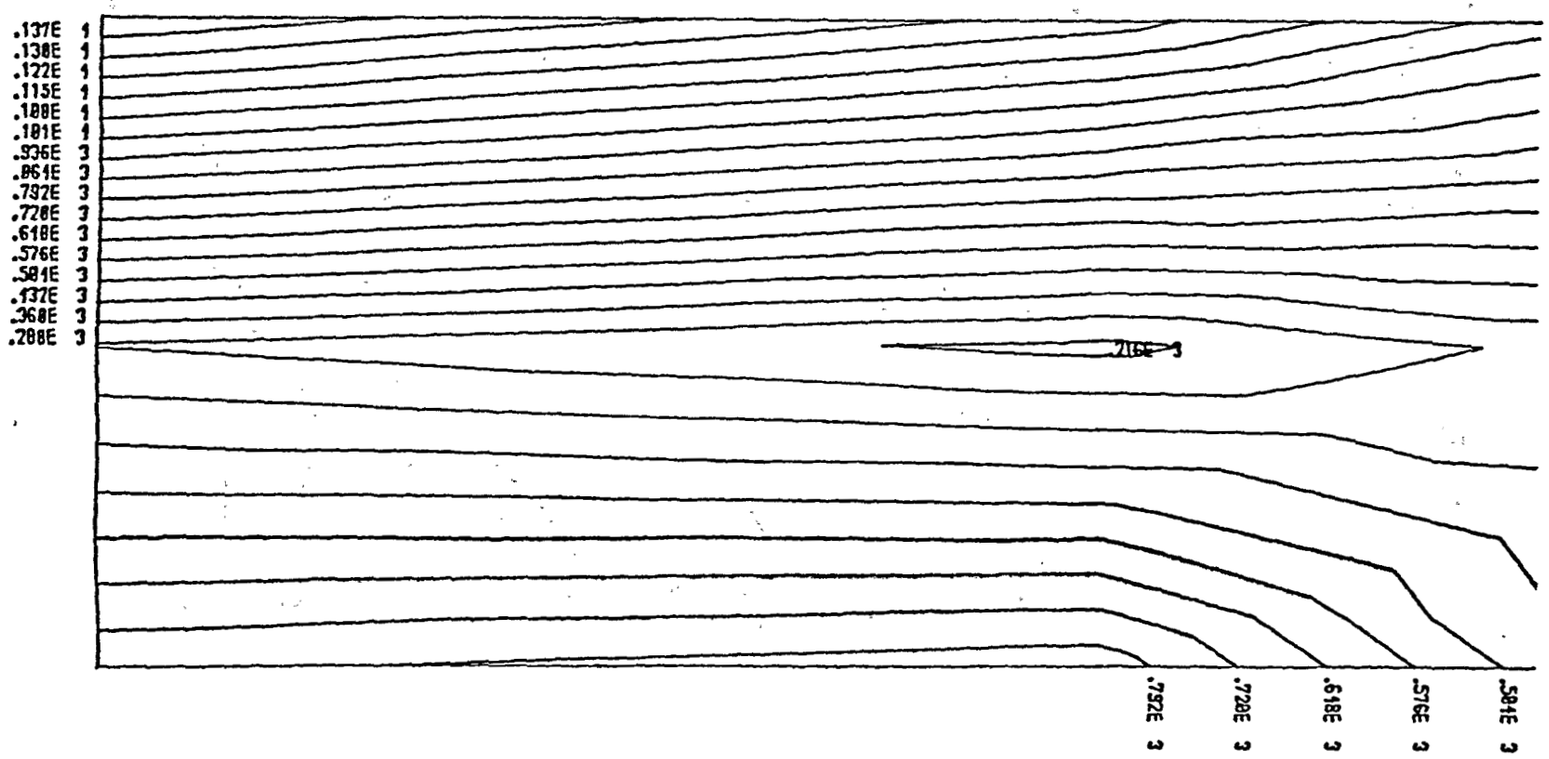



FIGURE VII.66: Test case (VII.1.9) blown up zoom view of the pressure contours (Isobars) at the inlet to the room

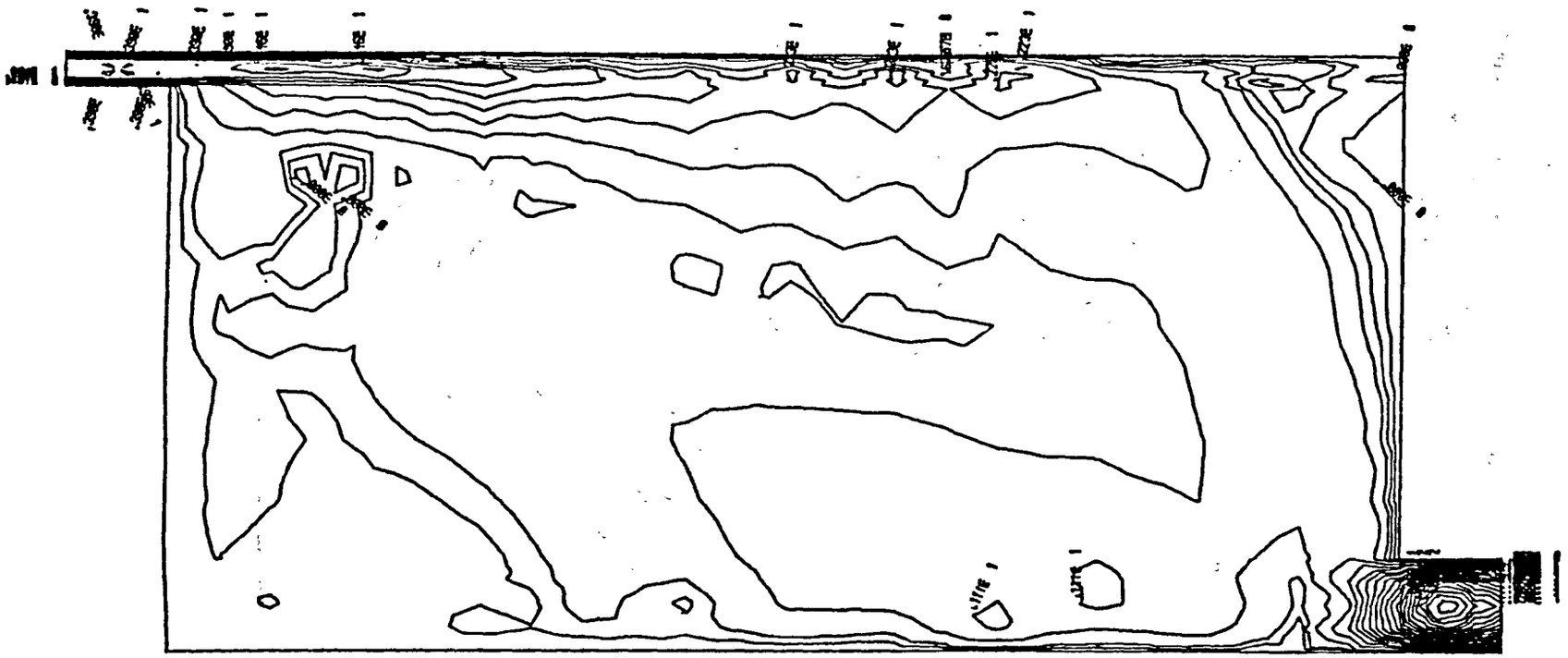


FIGURE VII.67: Test case (VII.1.9) kinetic energy of turbulence contours. Velocity in ventilated rooms

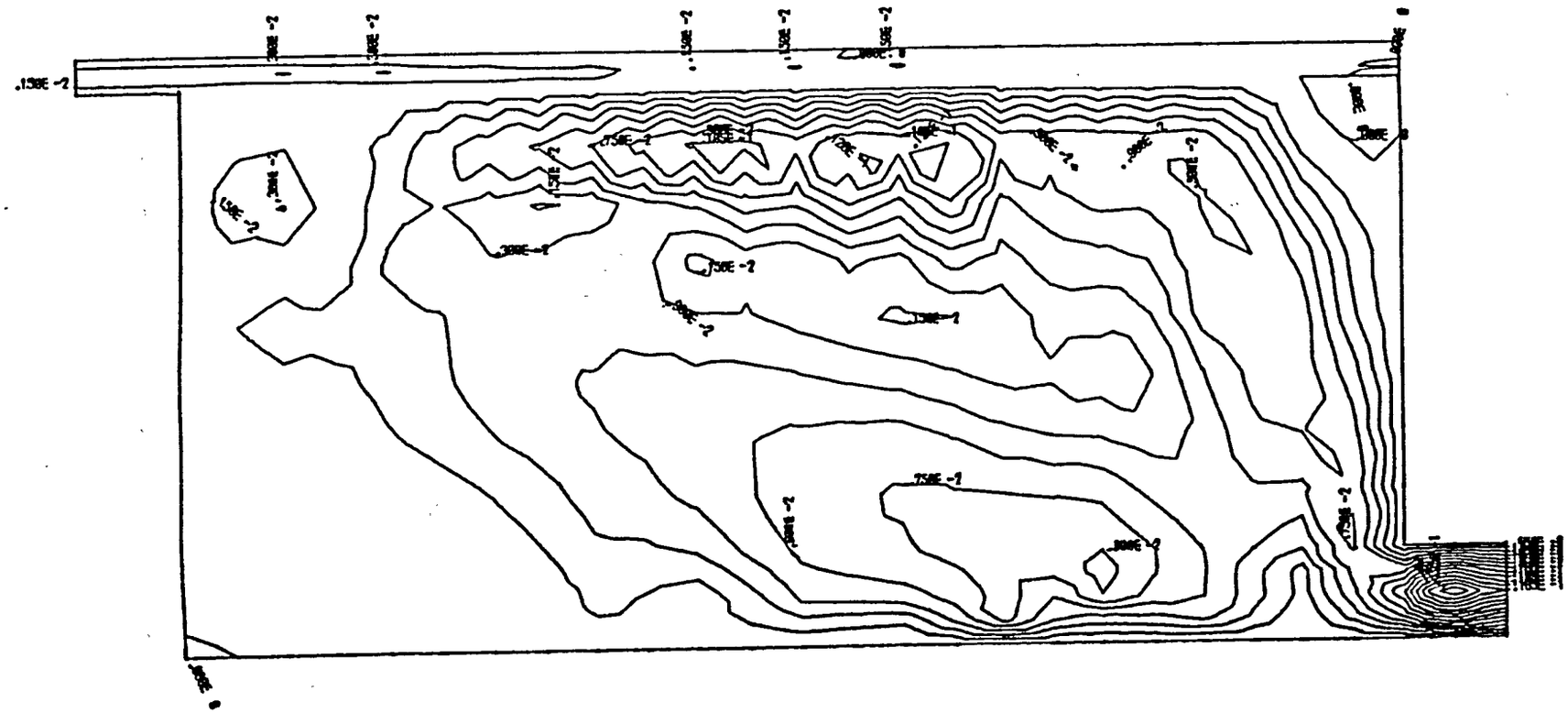


FIGURE VII.68: Test case (VII.1.9) turbulent viscosity contours. Velocity in ventilated rooms

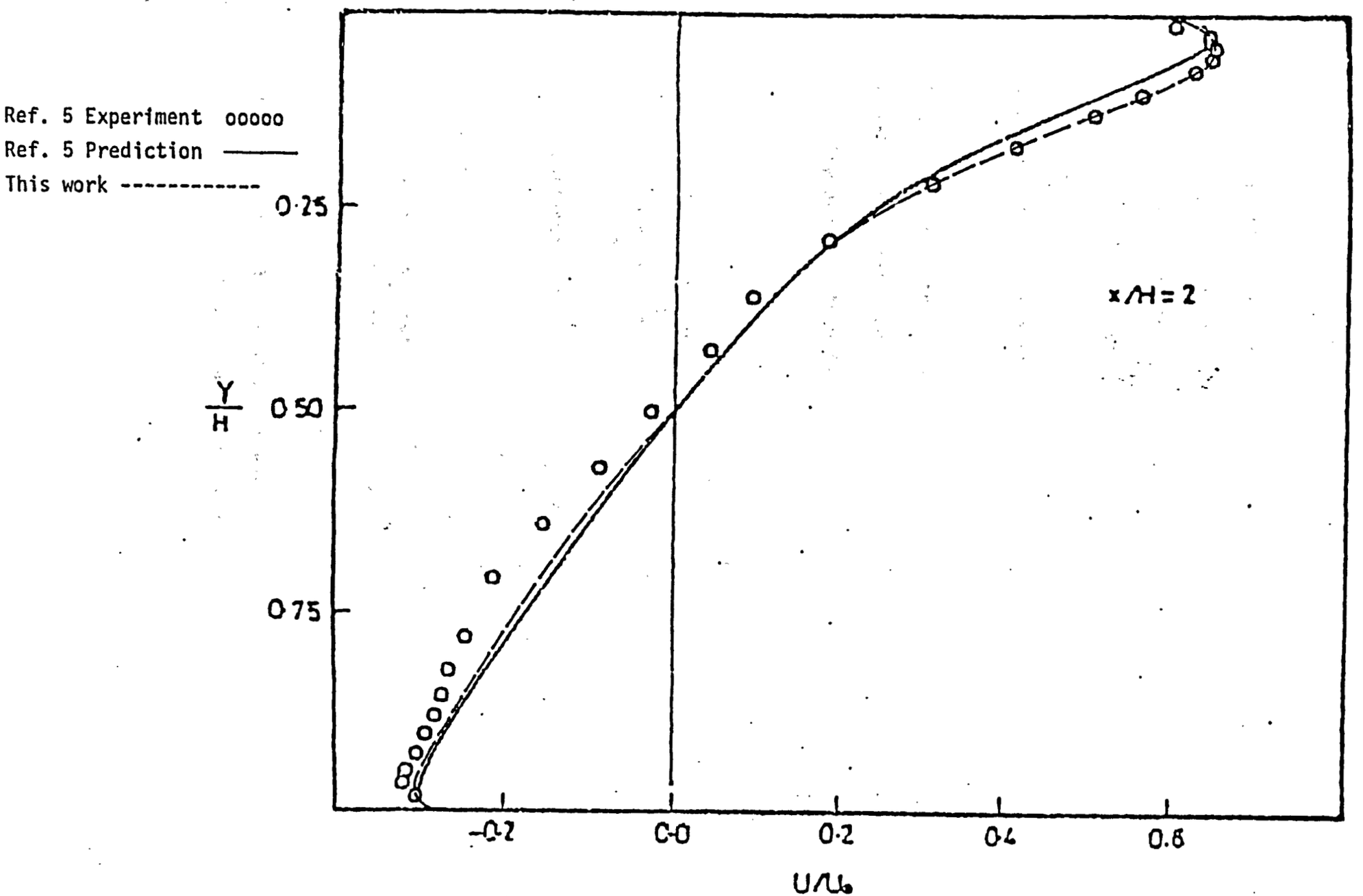



FIGURE VII.69: Test case (VII.1.9) comparison of normalised axial velocity with Ref. 5 experiment and prediction

## VII.1.10 Buoyancy Effects on Turbulent Transport in Combined Free and Forced Convection Between Vertical Parallel Plates

Ref. 7 investigated turbulent mixed flow of free and forced convection experimentally and theoretically. Experiments were carried out in the upward turbulent flow between vertical parallel plates at different wall temperatures. In this condition, the aiding and opposing flows arose simultaneously on the heated and cooled sides, respectively, and a fully developed condition was established.

Buoyancy effects on the mean velocity and temperature profiles were examined and confirmed. Figure VII.70 shows a schematic diagram of the flow and heat transfer.

$\delta$ = distance from the cooled wall to the maximum-velocity locations

$b$ = distance between parallel plates

$$Re = \frac{2ub}{\nu}$$

$$Gr = \frac{\rho^2 g\,(T_H - T_c)(2b)^3}{\mu^2}$$

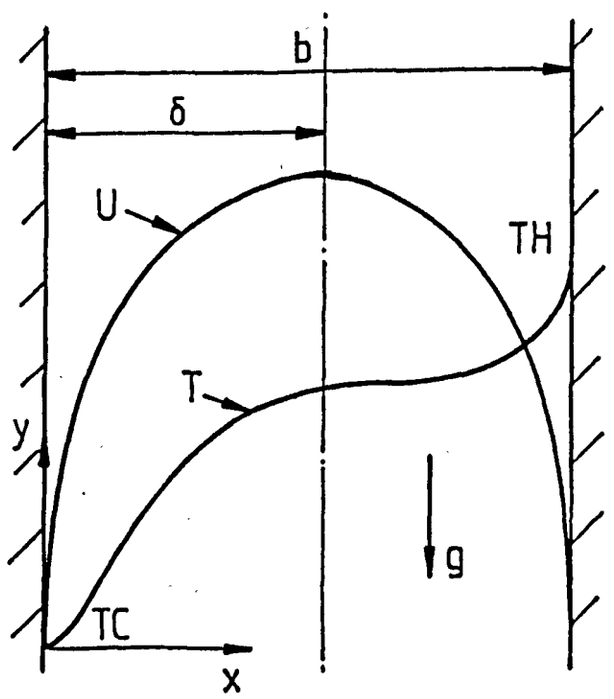



FIGURE VII.70: A schematic diagram of the flow and heat transfer at the measuring station (fully developed flow)

Ref. 7 noted that the concept of eddy diffusivity may become inadequate when the velocity or temperature gradient is zero, especially when the Reynolds stress is not equal to zero in spite of the zero velocity gradient. They expected these phenomena to appear in their flow configuration, since the distributions of mean velocity and turbulent properties are not symmetric at the plane of zero velocity gradient. These facts, however, did not cause a serious error in Ref. 7 predicted mean velocity and temperature profiles. Thus it is assumed as Ref. 7 did, that eddy diffusivity has a zero value once the velocity gradient vanishes. The distribution of the Prandtl number was not influenced very much by the buoyancy force[7] so that the relation for the turbulent Prandtl number in nearly-isothermal flows was assumed applicable to the mixed convection. The experimental arrangement is shown for the parallel plates in Figure VII.71, which shows the test section (duct). The inlet length was about 100 times the equivalent diameter.

There were two jackets behind the heat transfer surface. Through one jacket, cooled water was circulated to maintain the cooled wall at constant temperature. Steam or heated water flowed through the other jacket to maintain the wall at higher temperature. Side walls were made of phenolic-resin plates 1 mm thick in order to prevent heat conduction through the walls. Air was introduced upwards into the duct and discharged from the duct into the atmosphere. The difference in the bulk temperature between inlet and outlet sections was adjusted to be as small as possible in order to establish the fully-developed

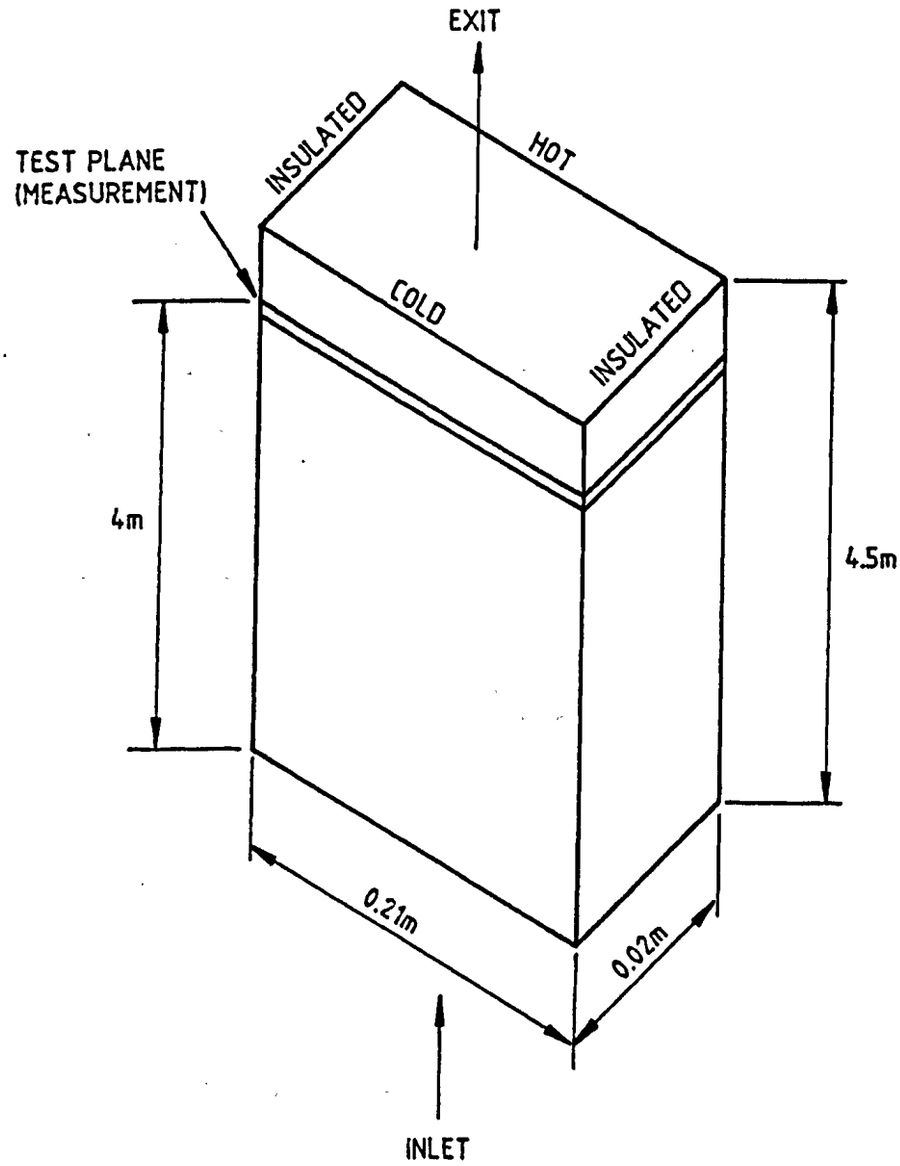



FIGURE Vii.71: Schematic diagram showing (isometric) view of the duct with the test section (plane of measurements)

temperature distribution in a shorter entrance length. The measurements of velocity and temperature, both mean and fluctuating quantities, were made with wire anemometer probes. The experiments were made at $Re = (4170 - 8270)$ and $(\frac{Gr}{Re^2}) = (1.12 \times 10^{-3}) - (1.82 \times 10^{-2})$. Two typical distributions of the mean velocity and temperature were shown:

i) For $(\frac{Gr}{Re^2}) = 2.2 \times 10^{-3}$, and $Re = 5870$

ii) For $(\frac{Gr}{Re^2}) = 1.49 \times 10^{-2}$, and $Re = 5140$

These two cases above were simulated using the current thesis model of turbulence utilizing the finite element technique. The mesh used together with the boundary conditions for both cases are shown in Figure VII.74.

For Case a:

$$Re = \frac{\rho u(2b)}{\mu} = 5870 = \frac{1.2494 \times U \times (0.02 \times 2)}{0.0000176416}, \quad \therefore \quad U_i = 2.0721$$

$$\frac{Gr}{Re^2} = 2.2 \times 10^{-3} = \frac{(1.2494)^2 \times 9.81 \times 0.003534 \times \Delta T \times (0.02 \times 2)^3/(0.0000176416)^2}{(5870)^2}$$

$\Delta T = 6.803$, and since $\Delta T = (T_H - T_C)$ where $T_C = 0.0$, $\therefore$ $T_H = 6.803$

where: $\rho_1 = 1.2494$

$\mu_1 = 0.0000176416$

$Cp_1 = 1006.06$

$K_1 = 0.024928$

$Pr_1 = 0.713$

$\beta_1 = 0.003536$

For Case b:

$$Re = \frac{u(2b)}{\mu} = 5140 = \frac{1.08528 \times U \times (0.02 \times 2)}{0.0000196722}, \quad \therefore \quad U_i = 2.3292$$

$$\frac{Gr}{Re^2} = 1.49 \times 10^{-2} = \frac{1.08528 \times 9.81 \times 0.003067 \times T \times (0.02 \times 2)^3/(0.0000196722)^2}{(5140)^2}$$

$\Delta T = T_H = 72.8862$

where: $\rho_2 = 1.08528$

$\mu_2 = 0.0000196722$

$Cp_2 = 1008$

$K_2 = 0.03$

$Pr_2 = 0.701$

$\beta_2 = 0.003067$

The measured turbulence intensities varied in the following manner:

For Case a:

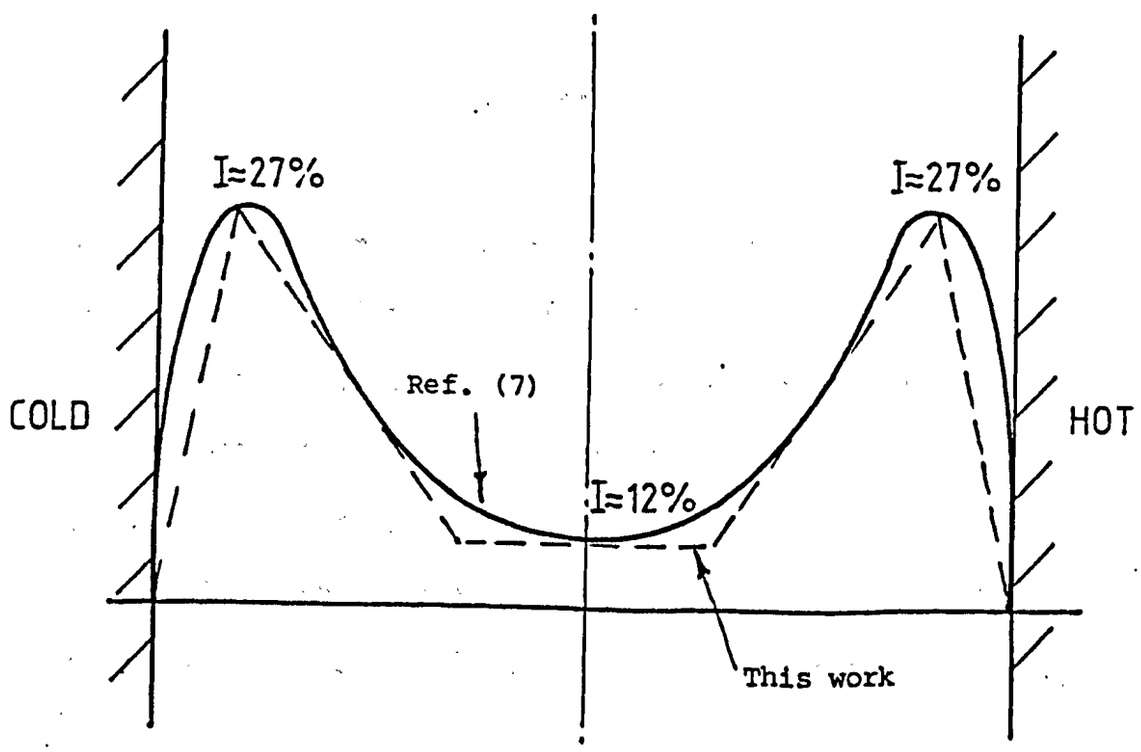



FIGURE VII.72

For Case b:

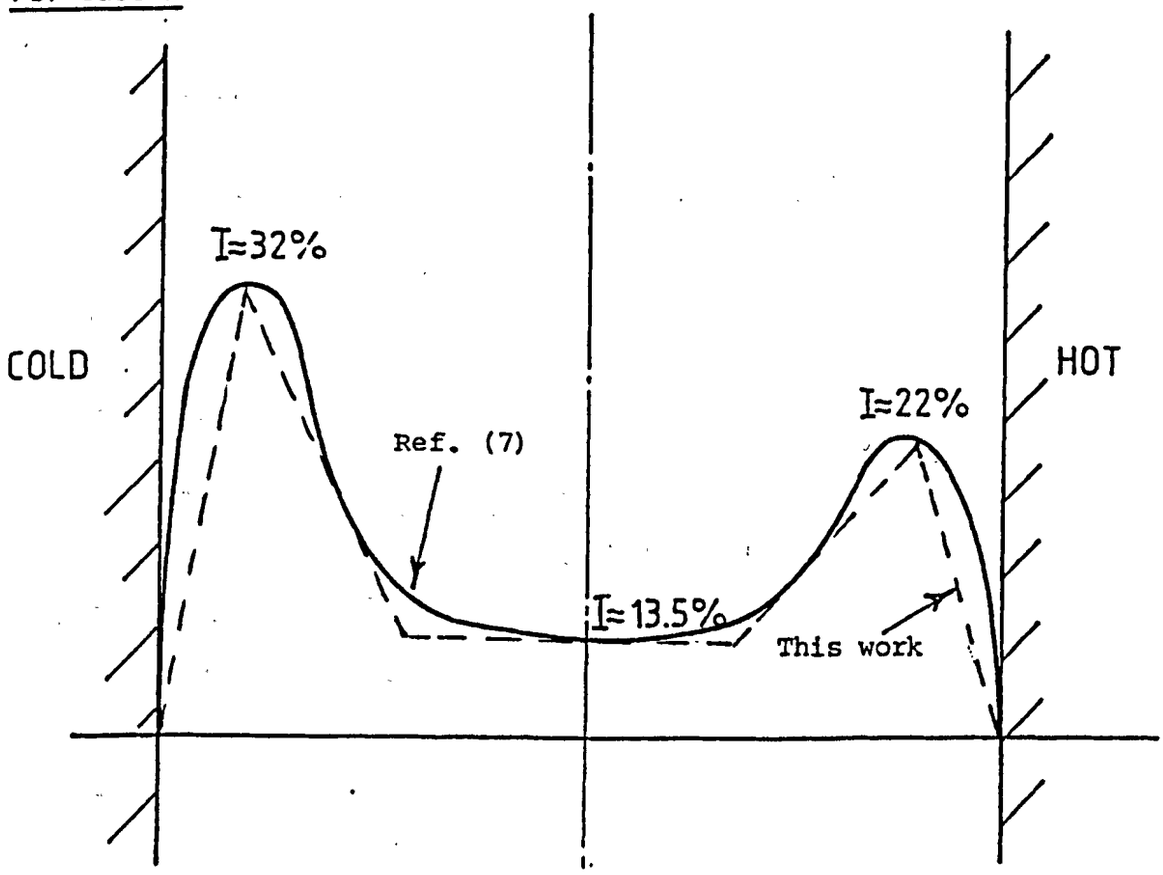



FIGURE VII.73

These variations in intensities can be accommodated in a formula as a function of axial position i.e. I = f(x), varying as per the intensity figures (VII.72, 73) above. Due to lack of time and to follow in the footsteps of the work done in this thesis, this has been cut down to an average approximation as was done for zonal intensities in this thesis. Hence the right half of the duct had a different average intensity than the left half. The following plots are shown for

Case (a):

Figure VII.75 shows the velocity vectors, case (a)

Figure VII.76 shows the velocity contours, case (a)

Figure VII.77 shows the pressure contours, case (a)

FIGURE VII.74:

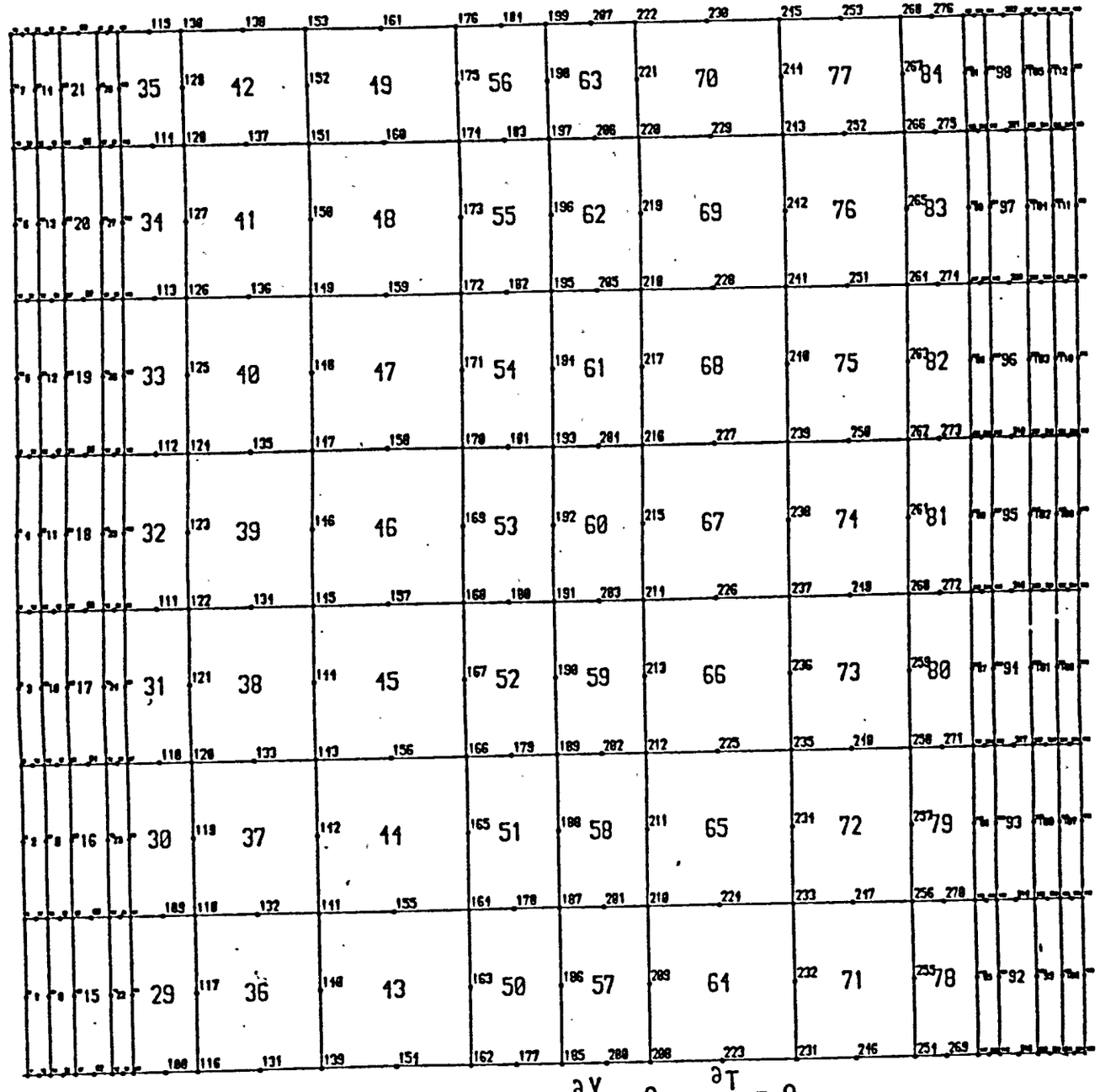
Test case (VII.1.10).

Turbulent mixed convection flow between vertical parallel plates. The mesh utilized and the boundary conditions

$U = 0,\ p = 0$ (at corner nodes), $\frac{\partial v}{\partial y} = 0,\ \frac{\partial T}{\partial y} = 0$

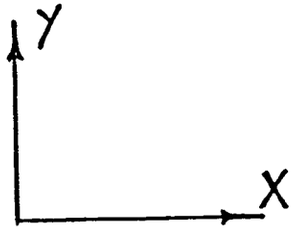
$U = V = 0$

$T = T_c$



$U = V = 0$

$T = T_H$




$V = V_i;\ U = 0,\ \frac{\partial v}{\partial y} = 0,\ \frac{\partial T}{\partial y} = 0$

FIGURE VII.75: Case (a). Test case (VII.1.10) velocity vectors
Turbulent mixed convection (b.v.p.p)

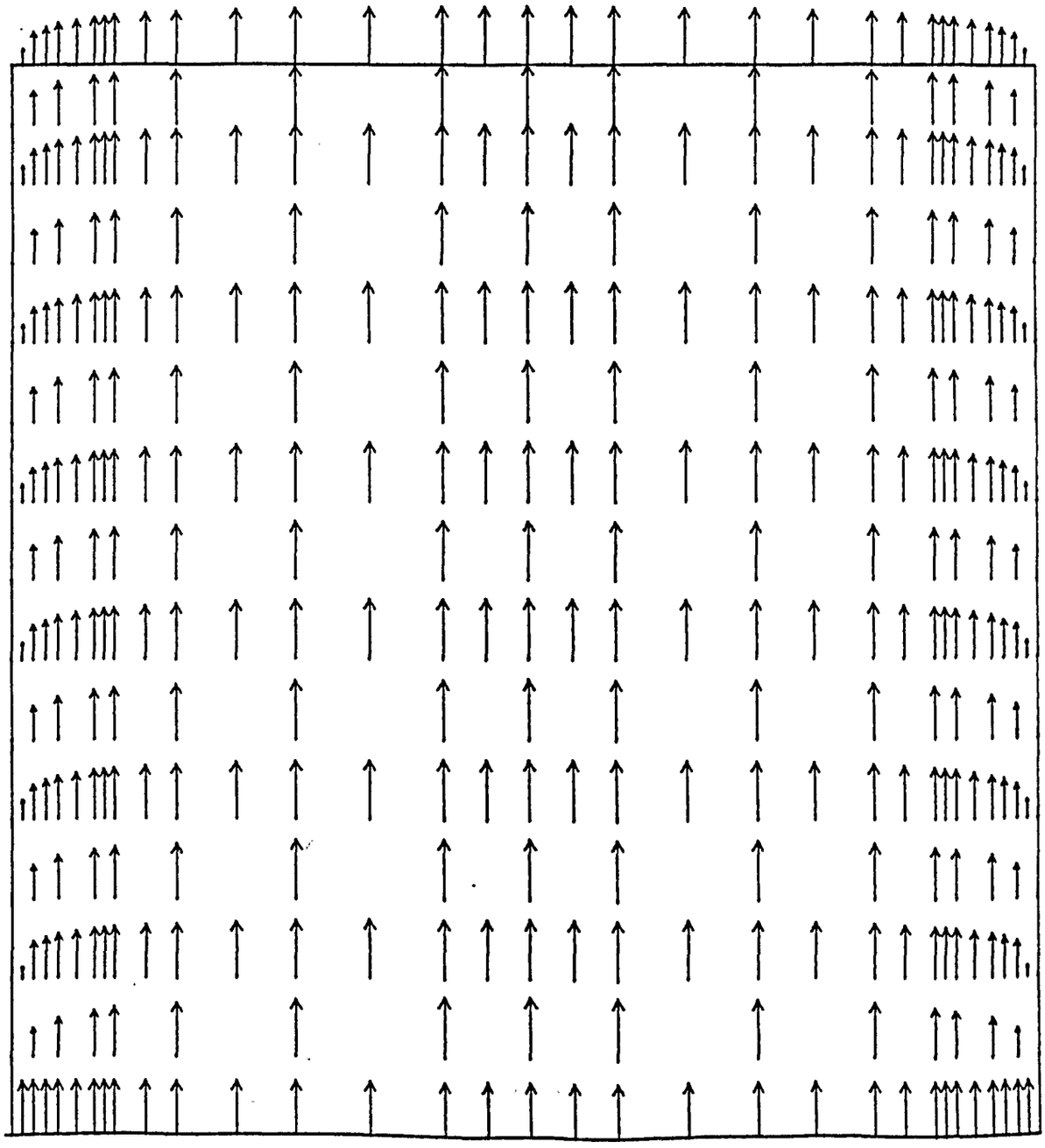


FIGURE VII.76: Case (a). Test case (VII.1.10) velocity contours (Isovels). Turbulent mixed convection (b.v.p.p)

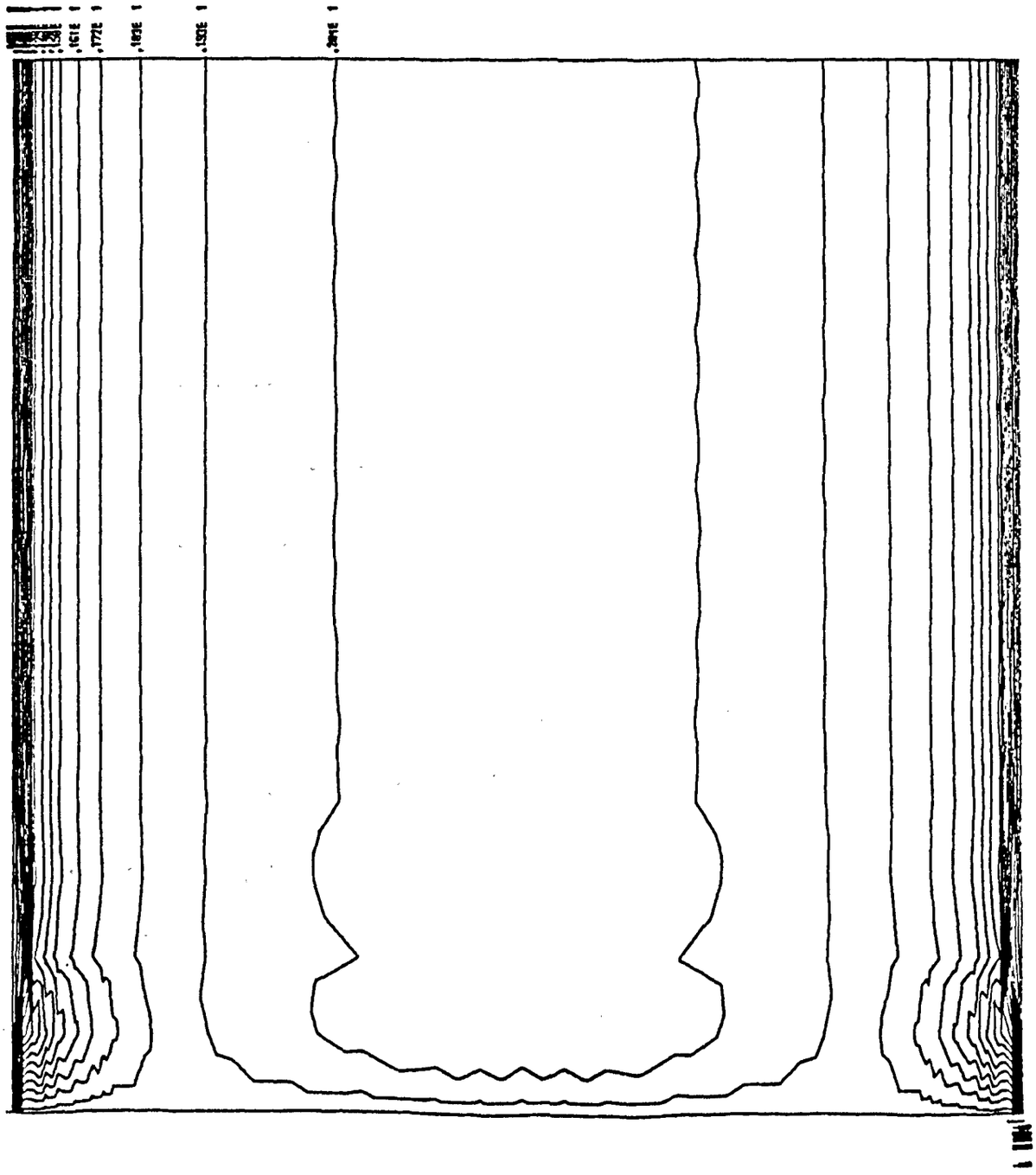


FIGURE VII.77: Case (a). Test case (VII.1.10) pressure contours (Isobars). Turbulent mixed convection (b.v.p.p)

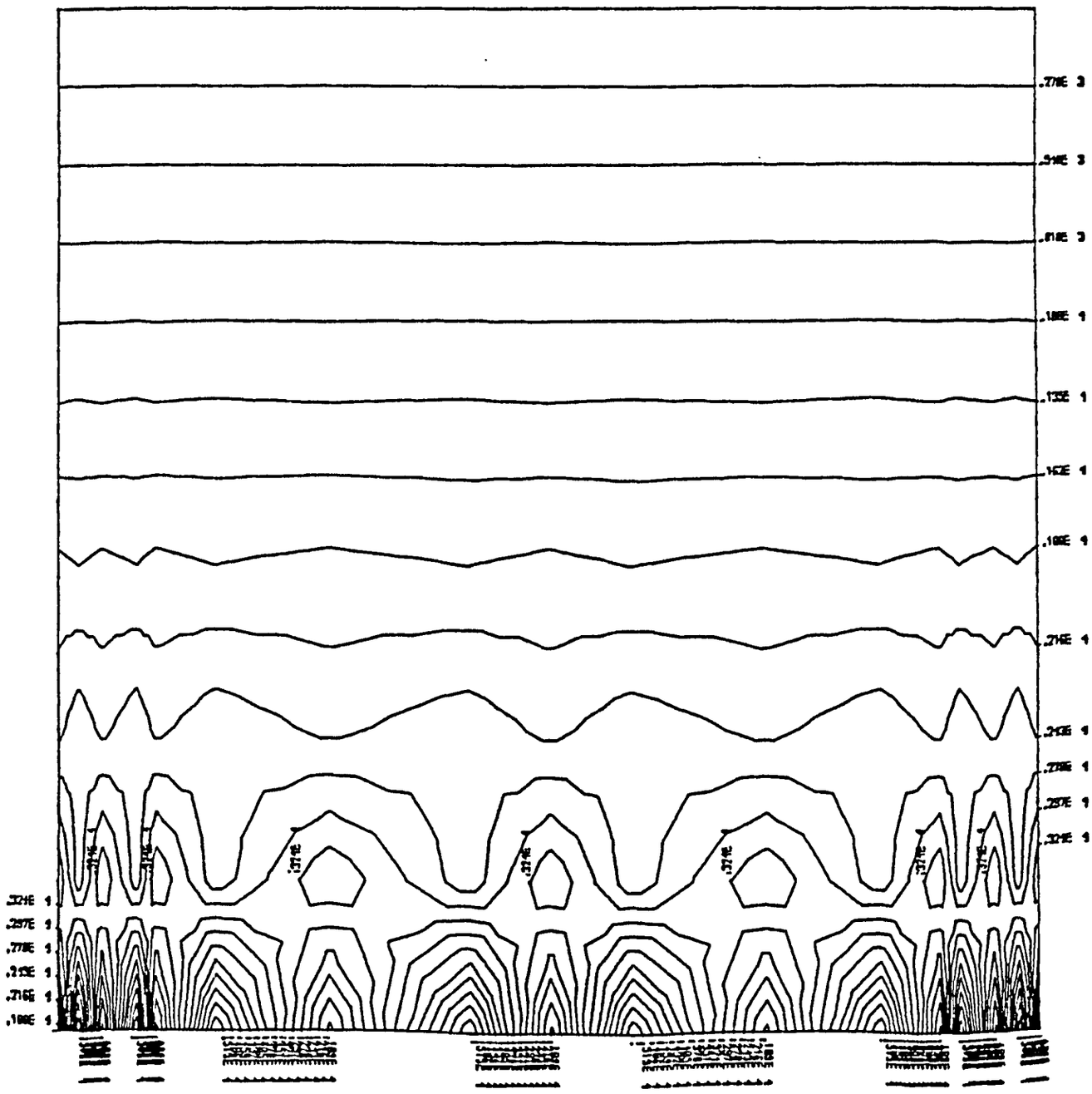


Figure VII.78 shows the temperature contours, case (a)

Figure VII.79 shows the length scale of turbulence distribution contours, Cases (a) and (b)

Figure VII.80 shows kinetic energy of turbulence contours

Figure VII.81 shows turbulent viscosity contours

Figure VII.82 shows turbulent conductivity contours

As for Case (b):

Figure VII.83 shows the velocity vectors, case (b)

Figure VII.84 shows the velocity contours, case (b)

Figure VII.85 shows the pressure contours, case (b)

Figure VII.86 shows the temperature contours, case (b)

Figure VII.87 shows the kinetic energy of turbulence contours, case (b)

Figure VII.88 shows the turbulent viscosity contours, case (b)

Figure VII.89 shows the turbulent conductivity contours, case (b)

Figure VII.90 shows the mean velocity and temperature profiles of Ref.7 and compares them with the results of this work. The splendid correlation requires no further explanation.

The predictions (Figure VII.90B) do not agree very well with Ref. 7 (Figure VII.90A) at $X/b \simeq 0.1$ and $X/b \simeq 0.9$ where there is a transition from the boundary layer type of flow to a mean flow. This is where the peaks take place in Figures VII.72 & VII.73, i.e. highest turbulent intensities positions. This is to be expected since only the average intensities were taken as mentioned before, in order to demonstrate the validity and applicability of the zonal approach.

If the turbulence intensities were taken as functions of positions i.e. $I = f(x)$ as was done successfully in test case (VII.1.9) and as per Figures VII.72 & VII.73 curves, very accurate agreement is foreseen.

FIGURE VII.78: Case (a). Test case (VII.1.10). Temperature contours (Isotherms). Turbulent mixed convection (b.v.p.p)

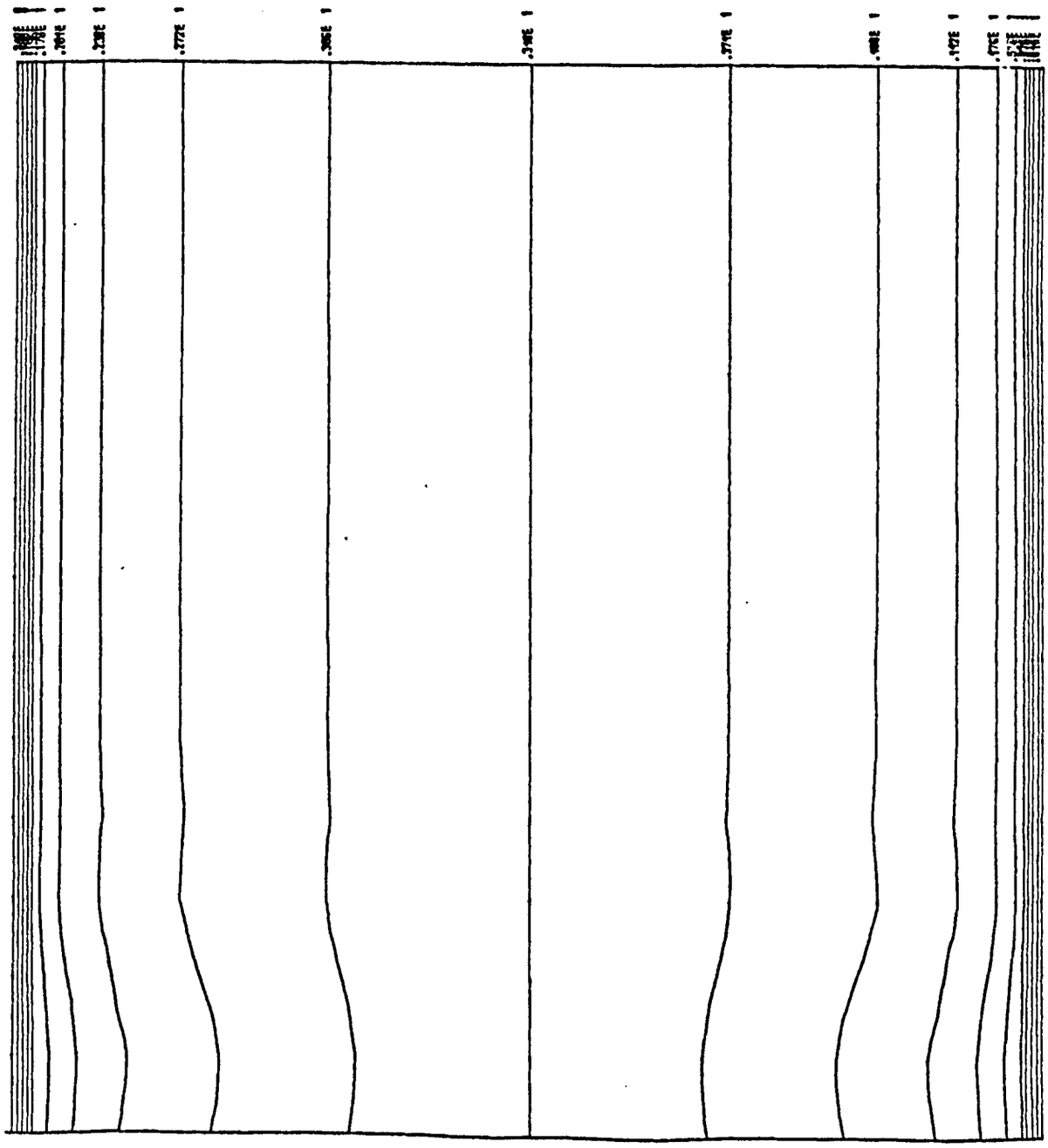


FIGURE VII.79: Cases (a) and (b). Test case (VII.1.10). Length scale of turbulent contours. Turbulent mixed convection (b.v.p.p)

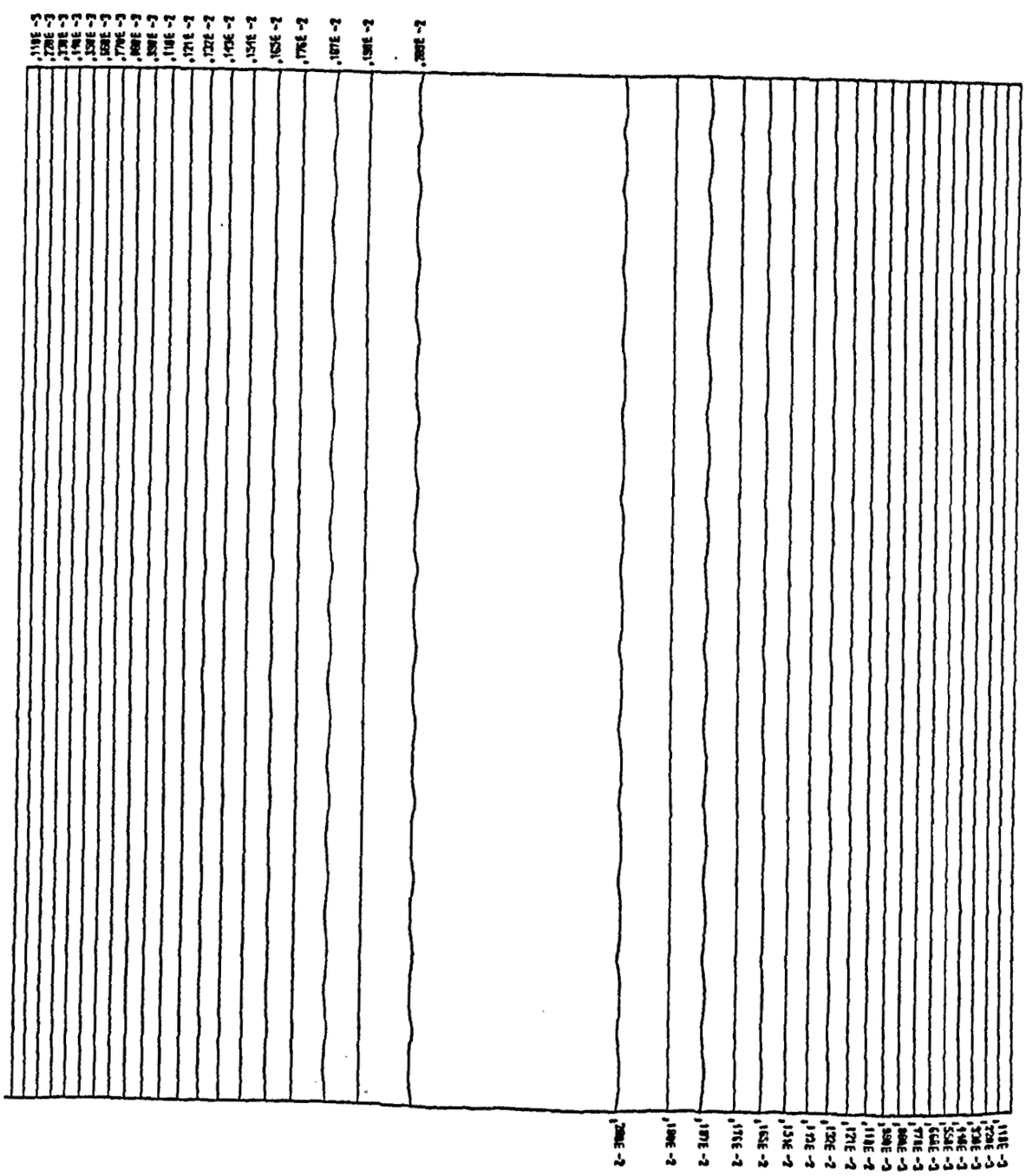


FIGURE VII.80: Case (a). Test case (VII.1.10). Kinetic energy of turbulence contours. Turbulent mixed convection (b.v.p.p)

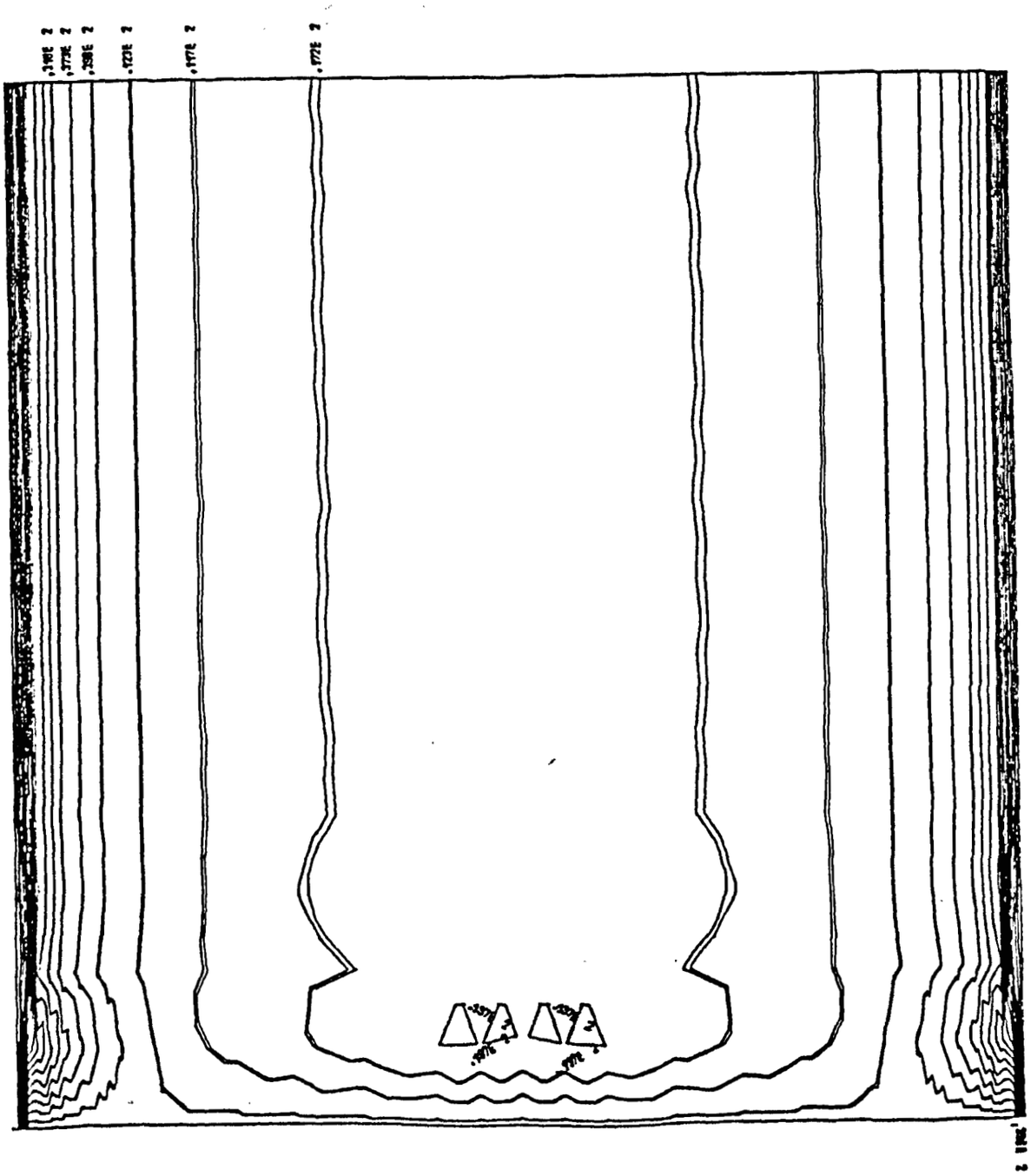


FIGURE VII.81: Case (a). Test case VII.1.10. Turbulent viscosity contours. Turbulent mixed convection (b.v.p.p)

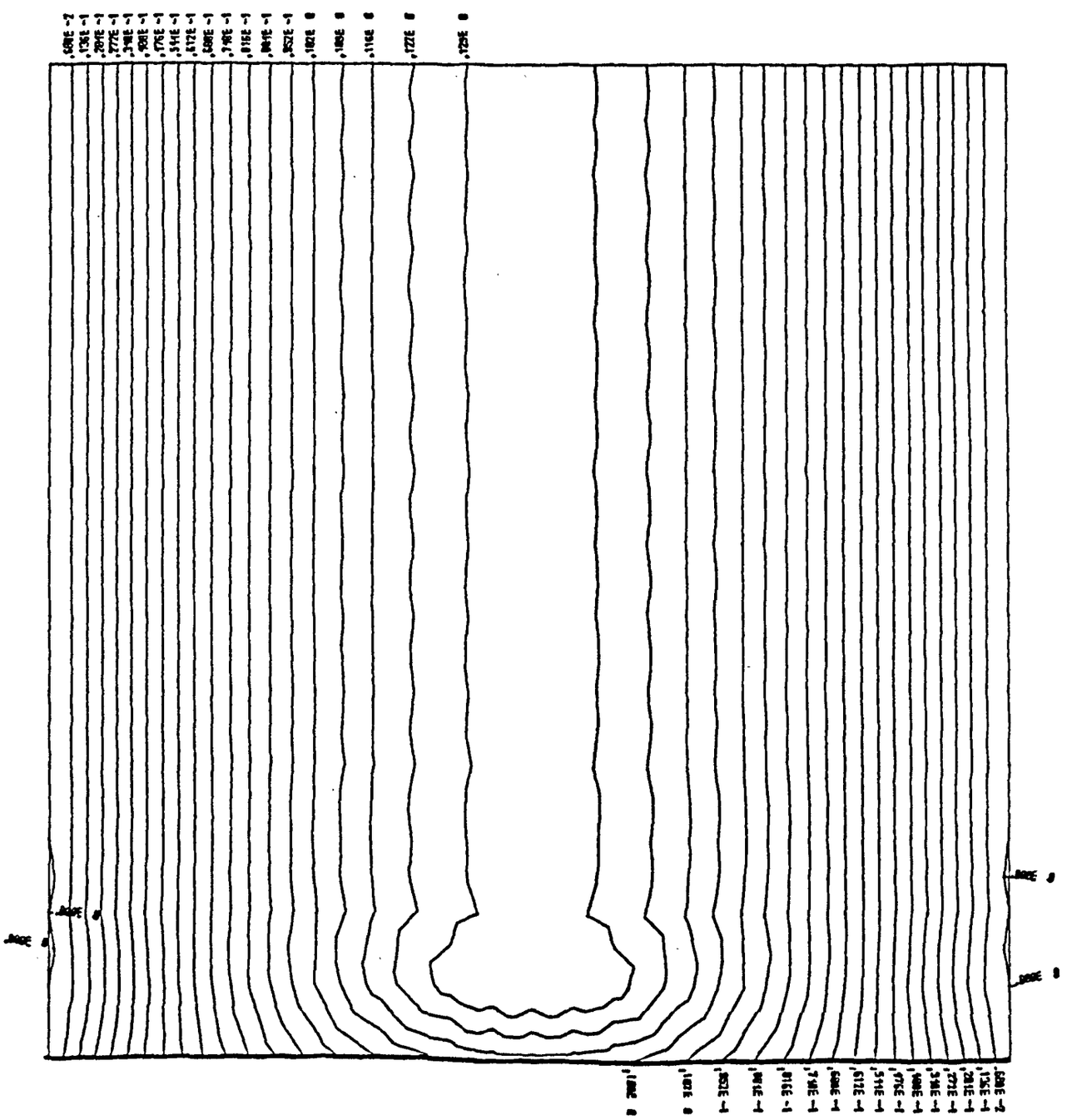


FIGURE VII.82: Case (a). Test case (VII.1.10). Turbulent conductivity contours. Turbulent mixed convection (b.v.p.p)

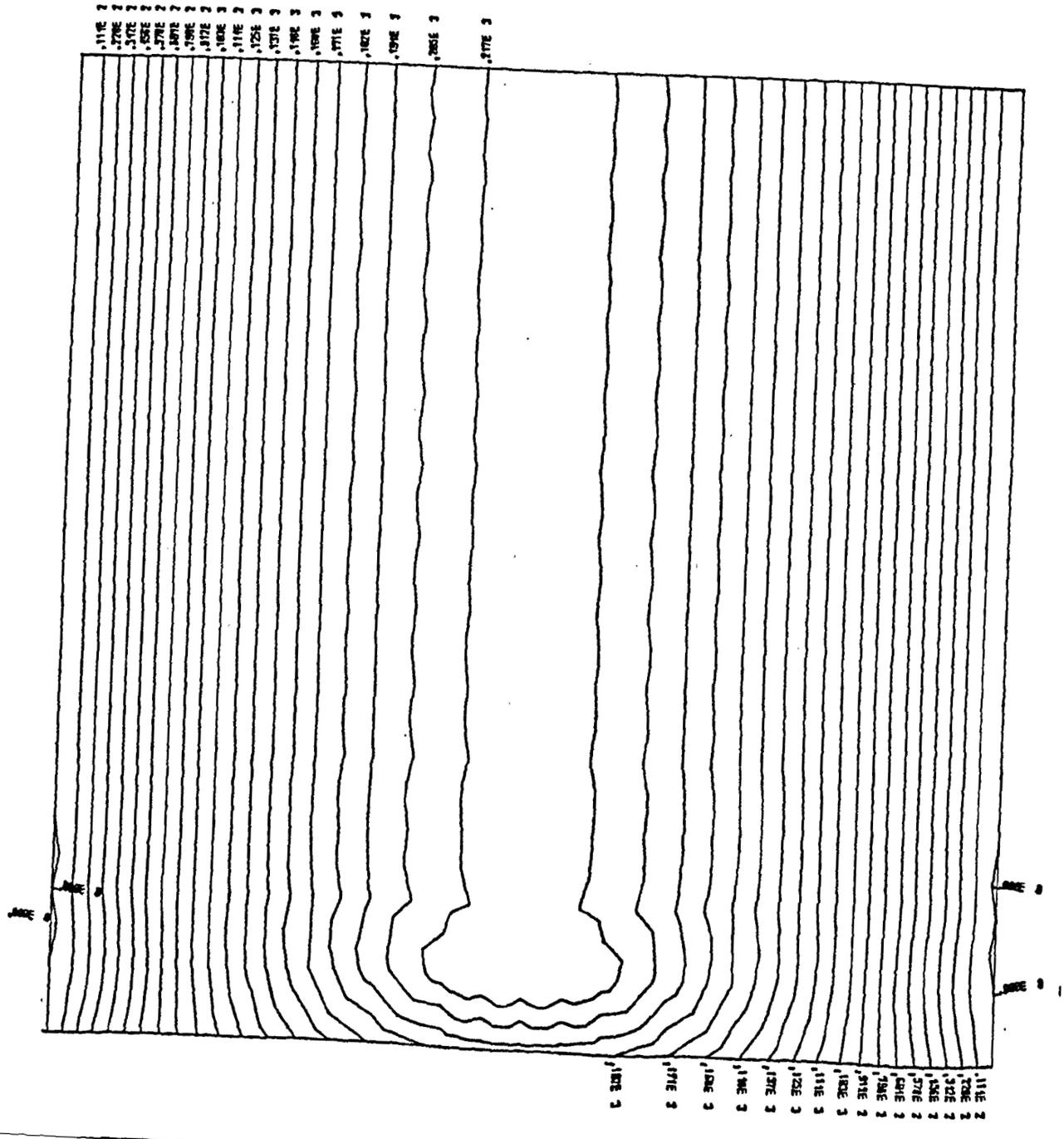


FIGURE VII.83: Case (b). Test case (VII.1.10) velocity vectors.
Turbulent mixed convection (b.v.p.p)

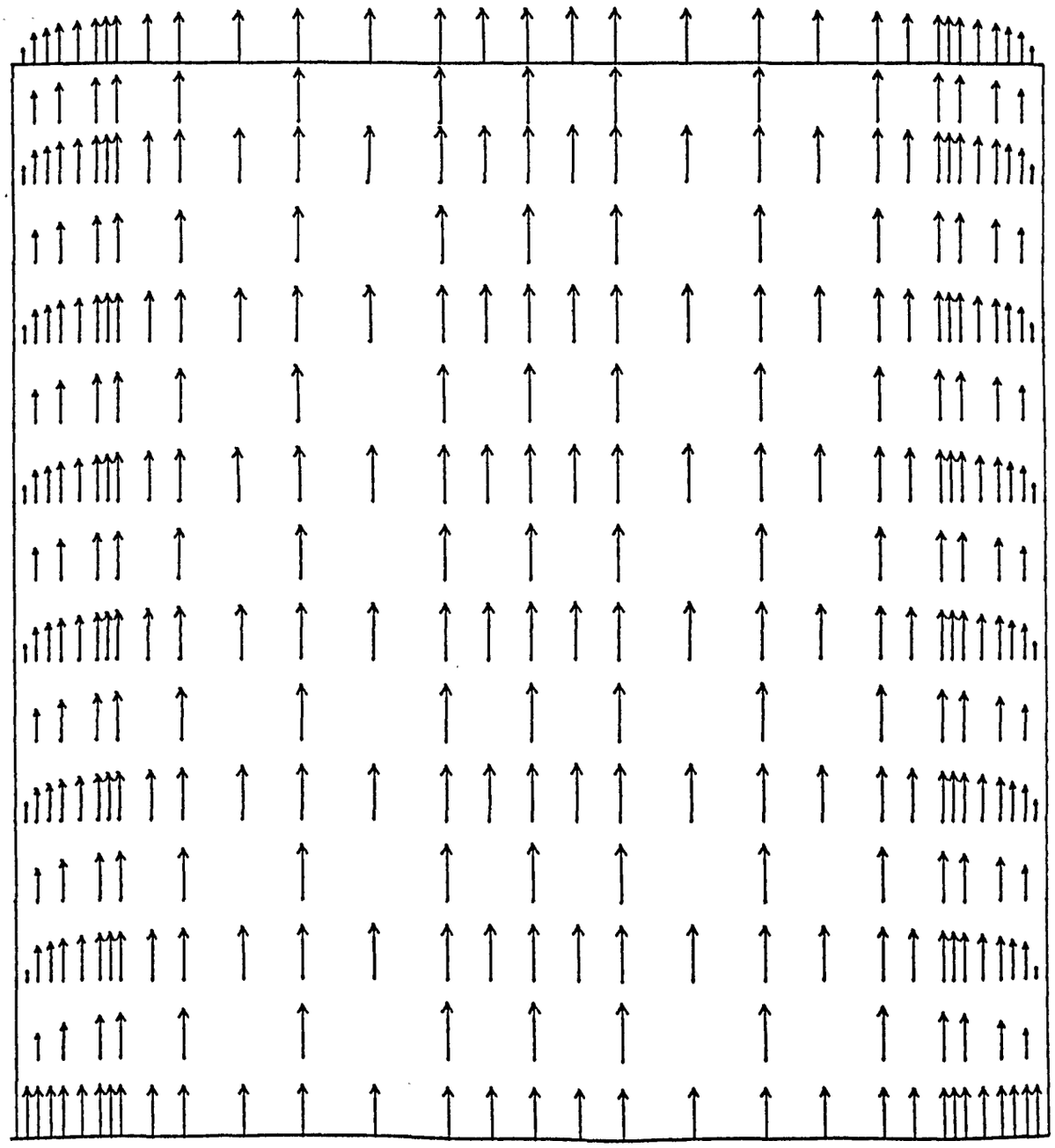


FIGURE VII.84: Case (b). Test case (VII.1.10). Velocity contours (Isovels). Turbulent mixed convection (b.v.p.p)

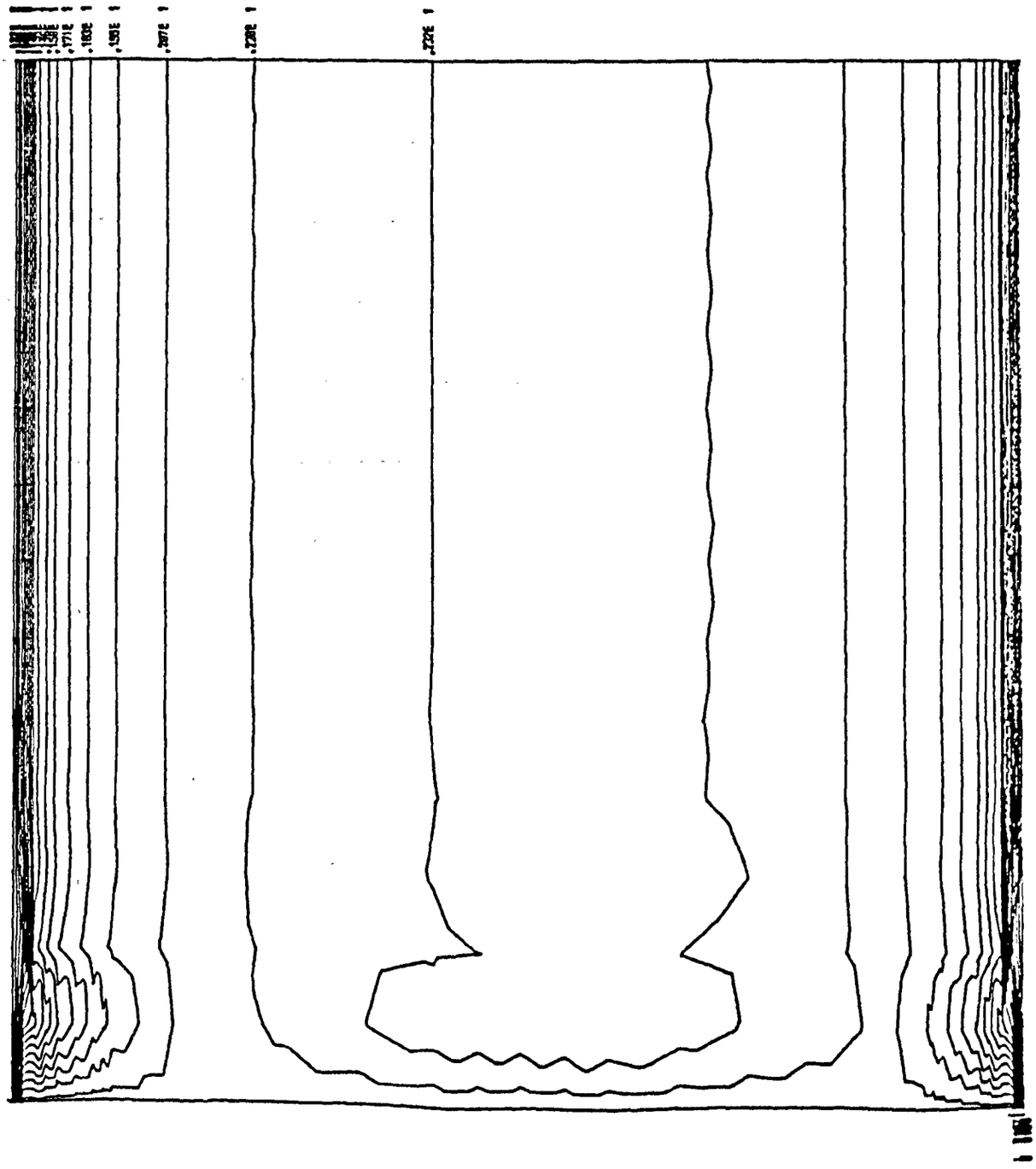


FIGURE VII.85: Case (b): Test case (VII.1.10). Pressure contours (Isobars). Turbulent mixed convection (b.v.p.p)

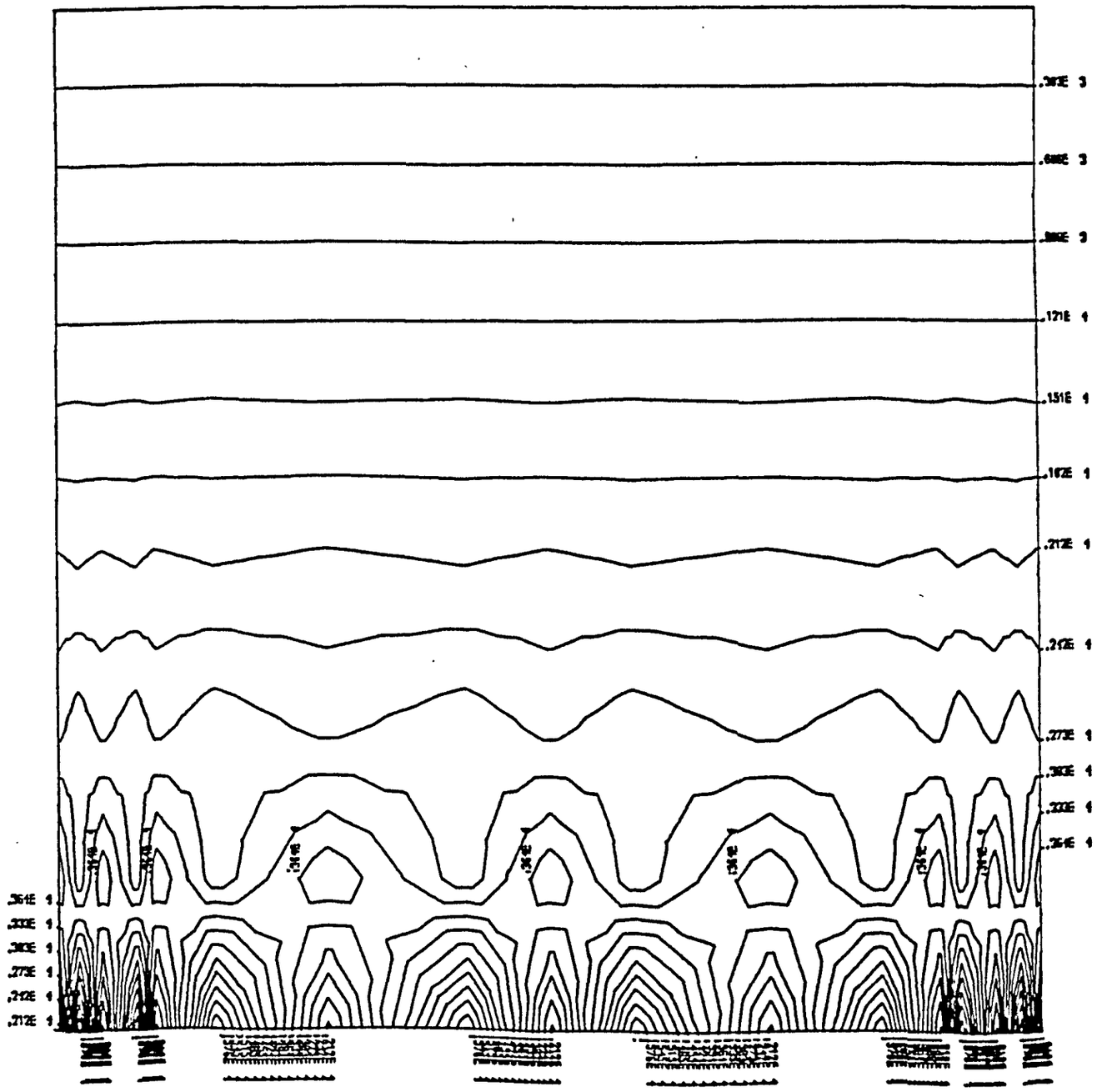


FIGURE VII.86: Case (b). Test case (VII.1.10). Temperature contours (Isotherms). Turbulent mixed convection (b.v.p.p)

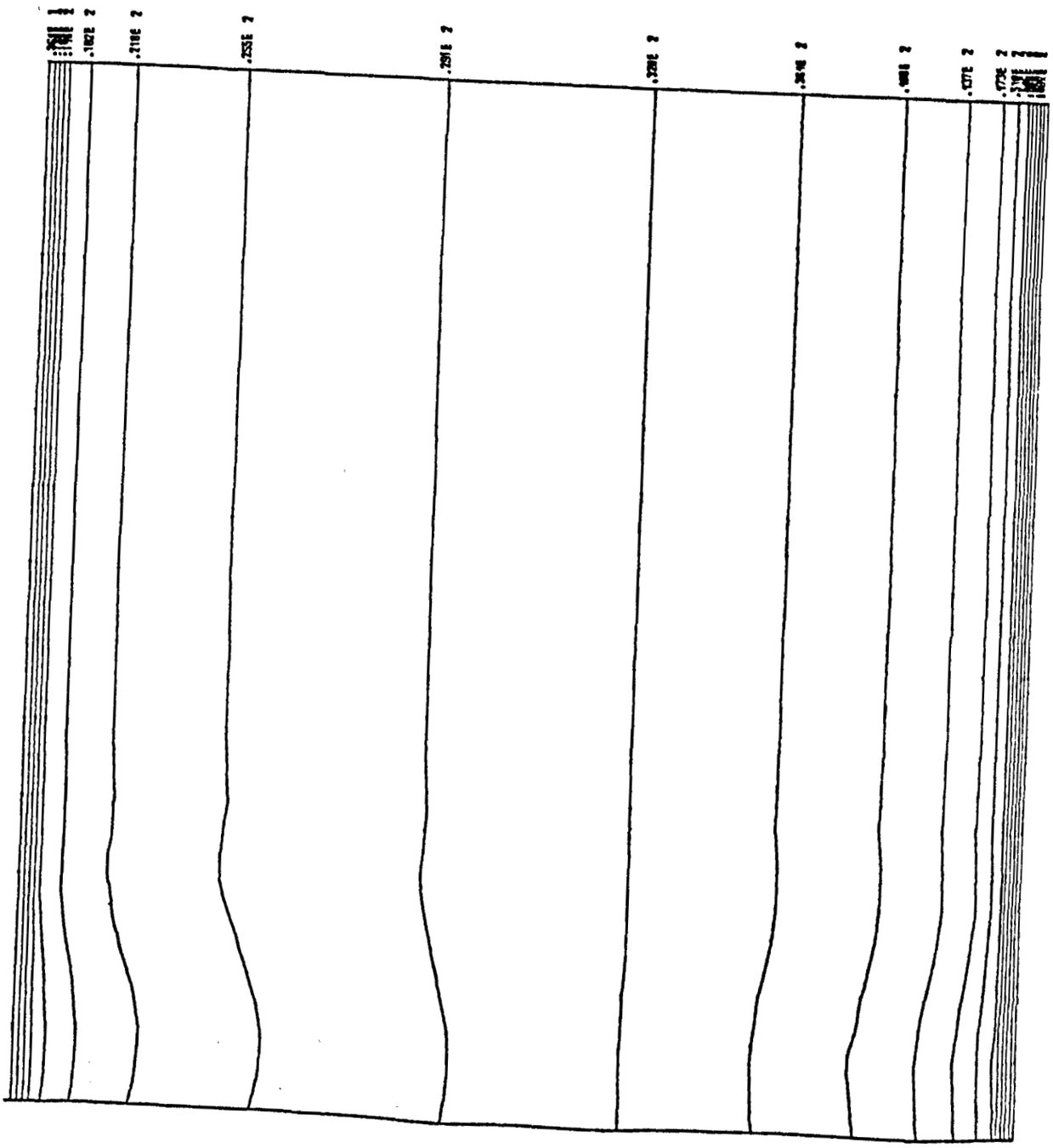


FIGURE VII.87: Case (b). Test case (VII.1.10). Kinetic energy of turbulence contours. Turbulent mixed convection (b.v.p.p)

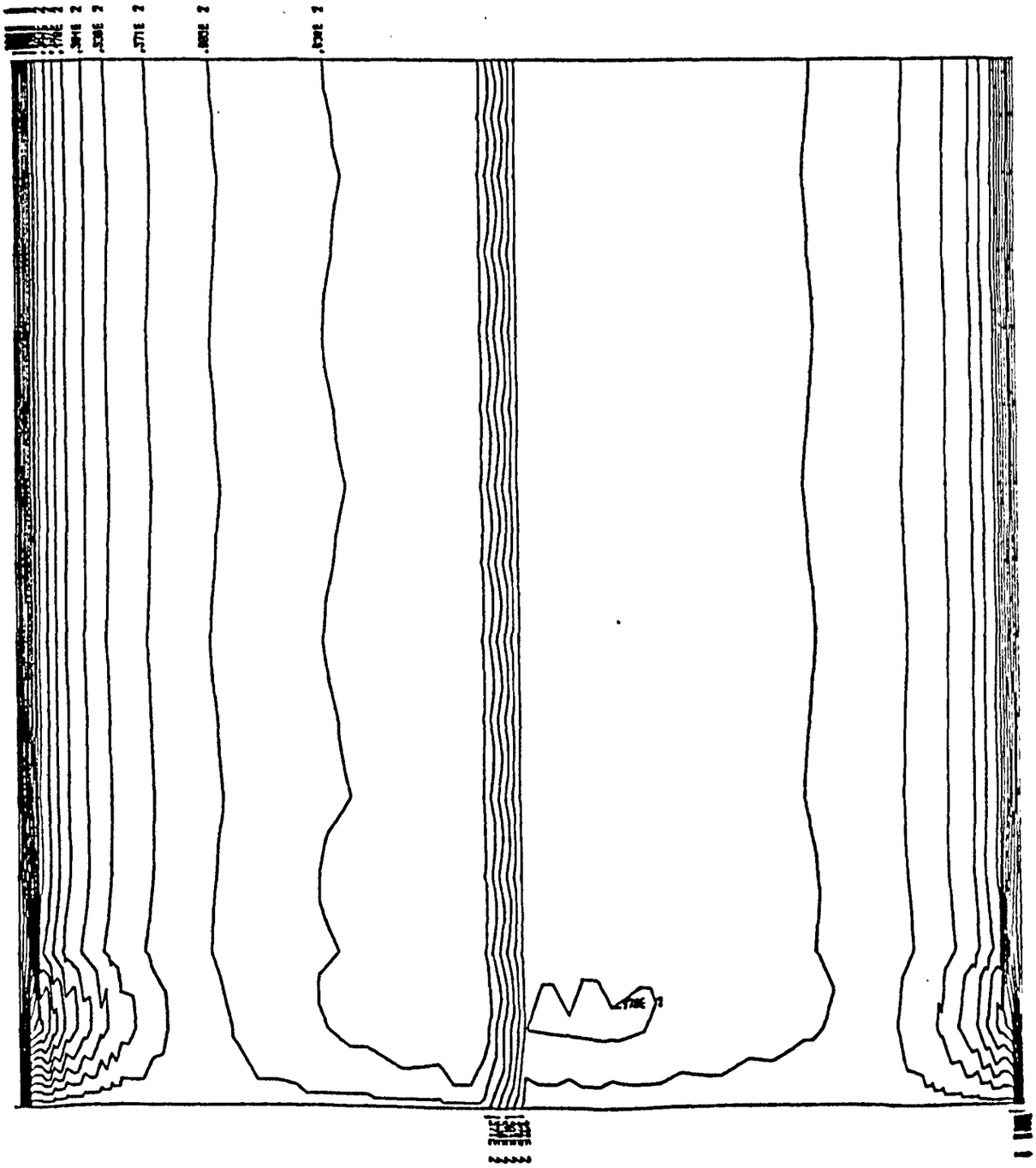


FIGURE VII.88: Case (b). Test case (VII.1.10). Turbulent viscosity contours. Turbulent mixed convection (b.v.p.p)

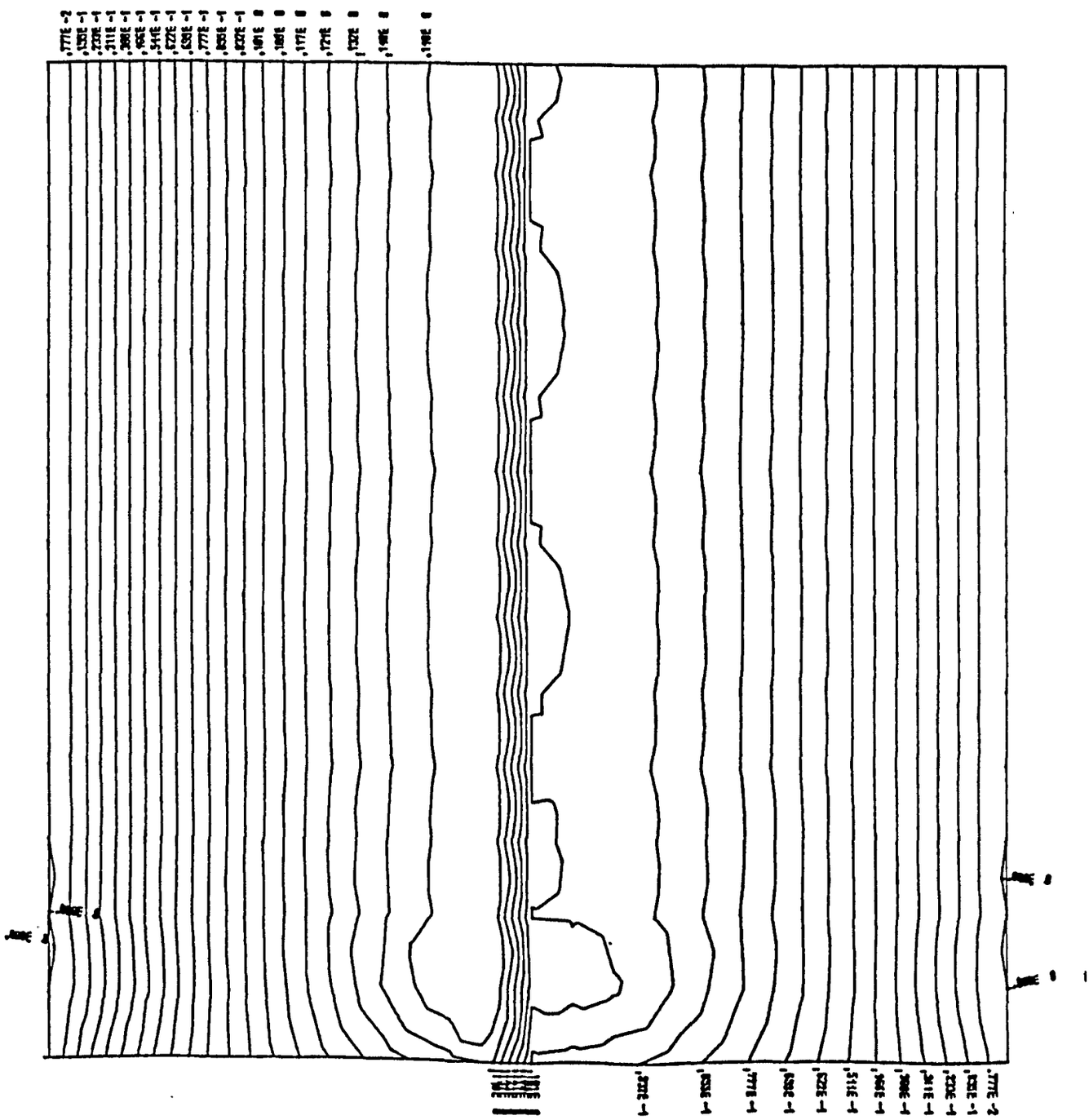


FIGURE VII.89: Case (b). Test case (VII.1.10). Turbulent conductivity. Turbulent mixed convection (b.v.p.p)

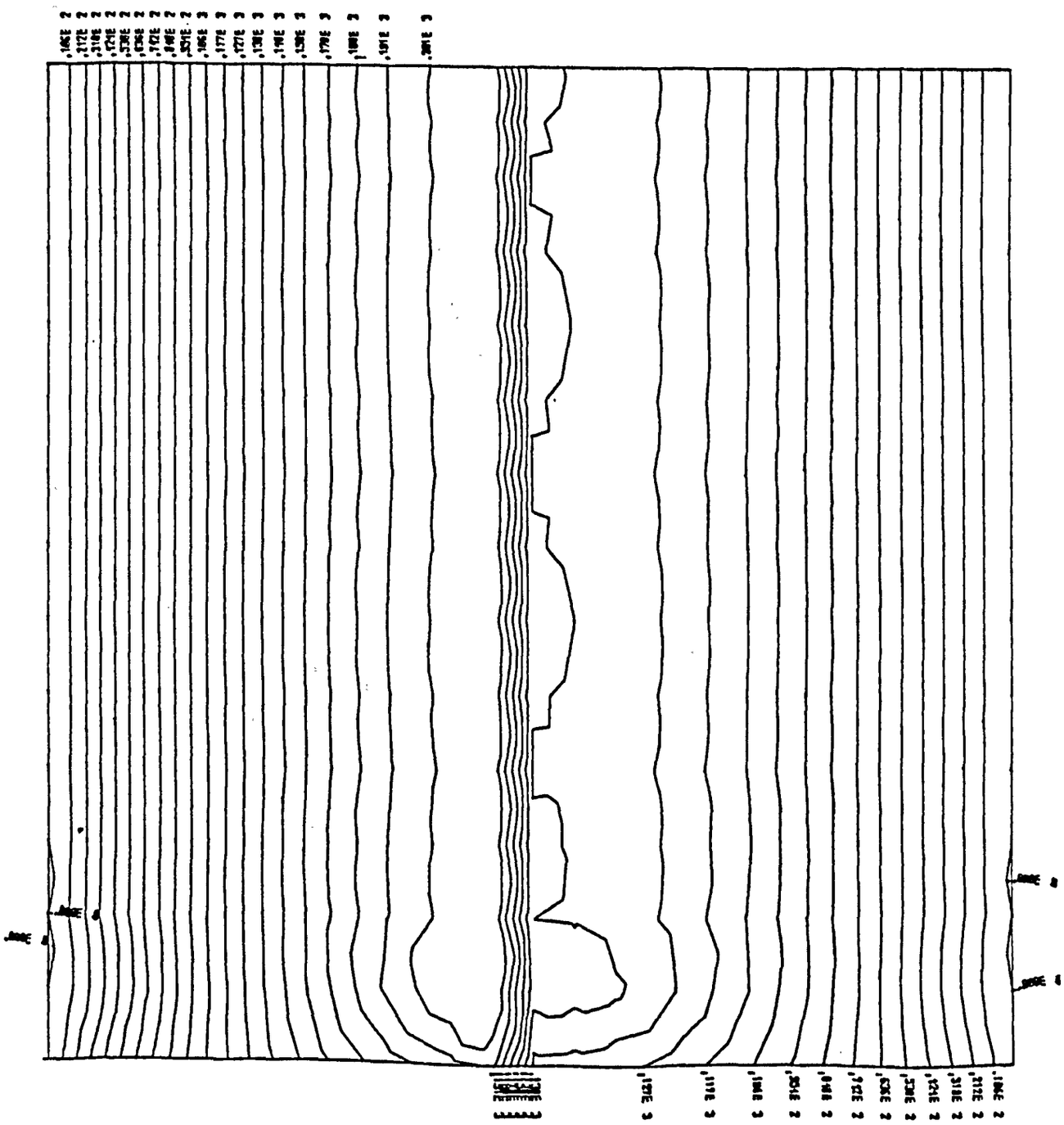


FIGURE VII.90 A:
Test case (VII.1.10) mean velocity and temperature profiles of Ref. 7 for comparison with this work.

Turbulent mixed convection (b.v.p.p)

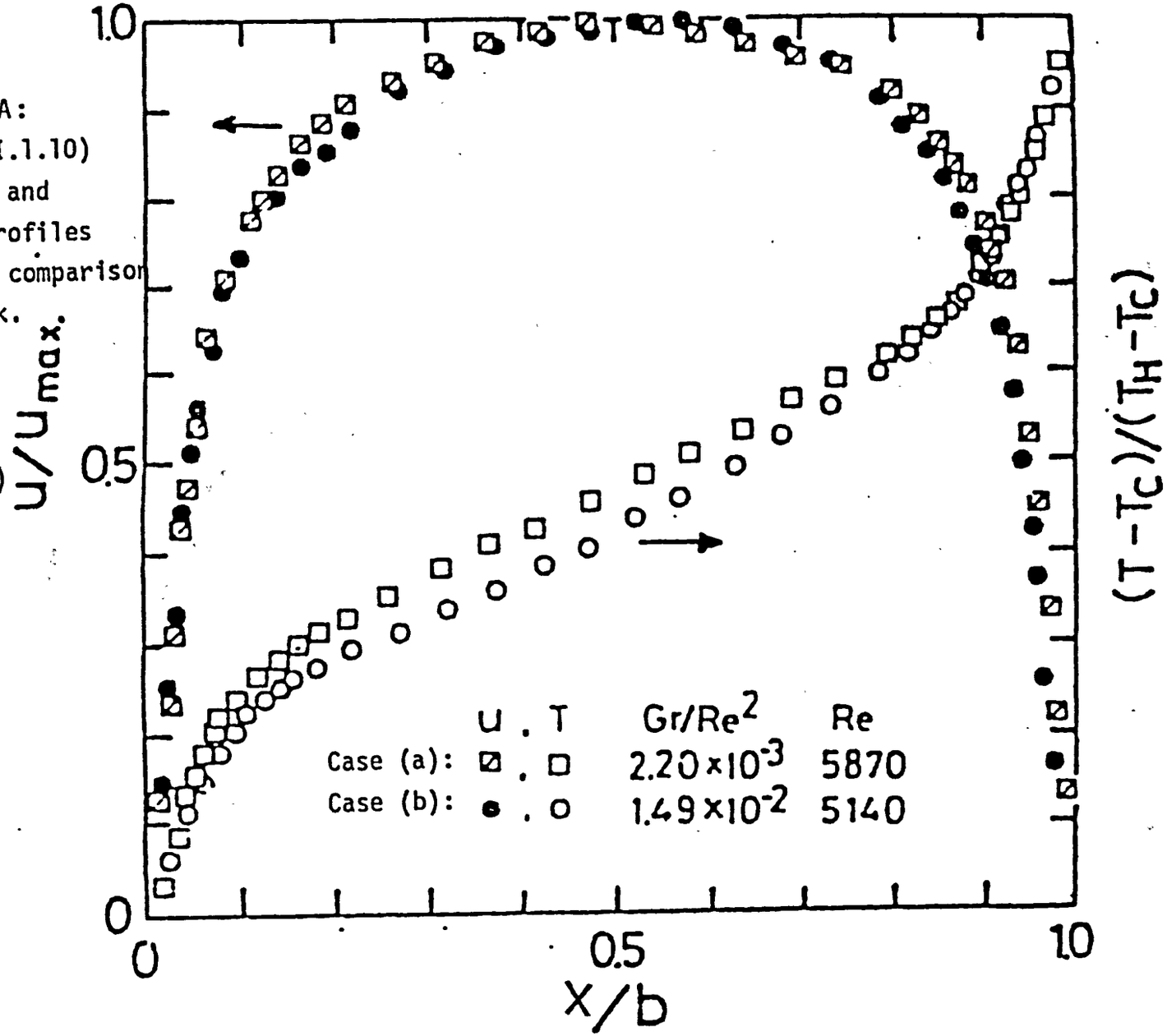
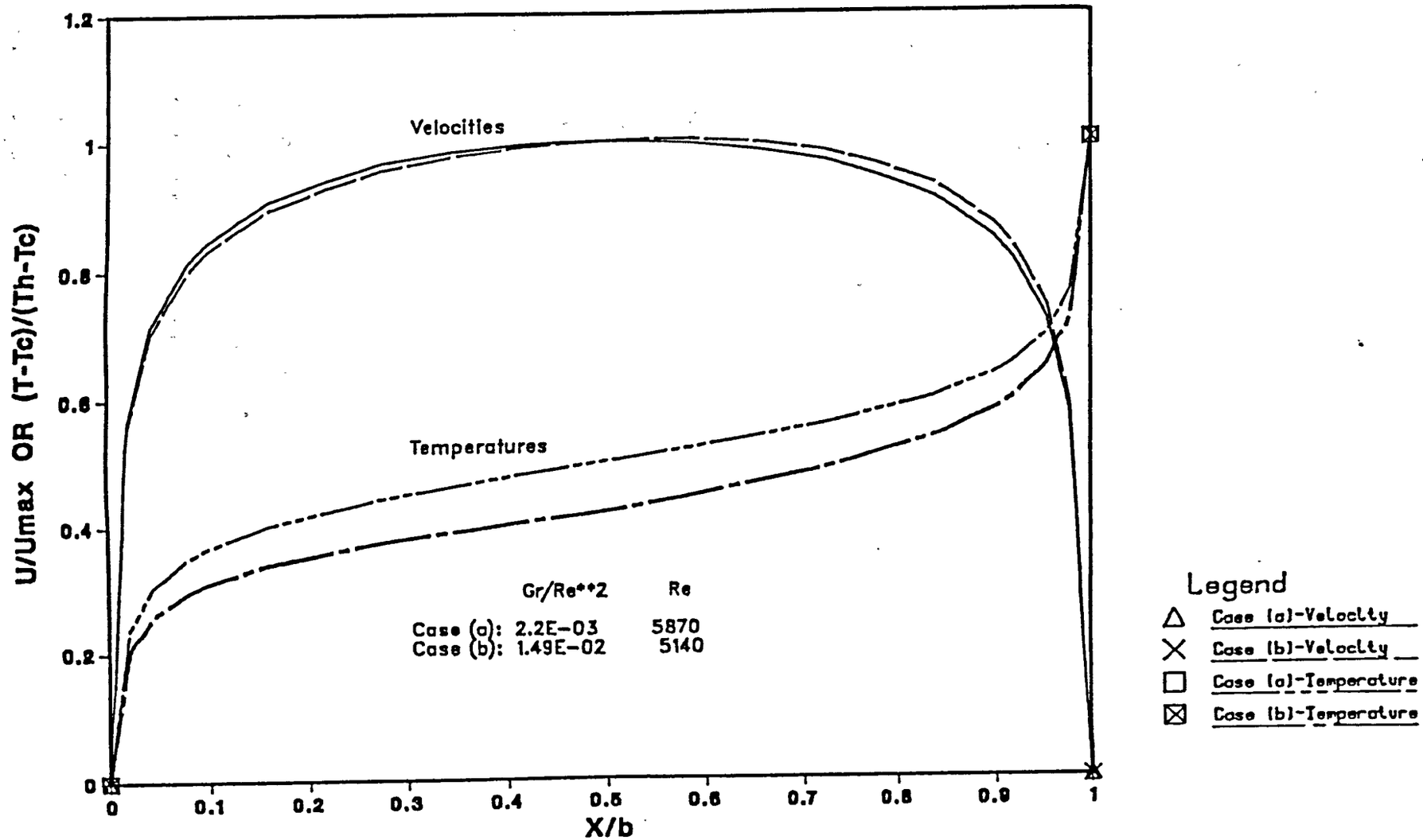


FIGURE VII.90B: Numerical Results Of This Work Giving Outstanding Agreement With The Analytical And Experimental Results Of Ref(7) For Mean Velocity And Temperature Profiles Of Mixed Turbulent Convection (B.V.P.P.)



## VII.2 Further Calculations

Further calculations are to be performed on the solar-ventilation and air-conditioning experimental rig, aiming to capture the dominant driving force of the flow in the room. This is to investigate the natural convection layer on the room-side of the solar heated wall which was partly ignored because no measured temperature boundary conditions were prescribed on it; this implied no flux due to the absence of the contour integrals. This further simulation run will attempt to model the flow with the temperature distribution on the room-side surface specified.

Two very important points ought to be mentioned here:

i) The experimental measurements of velocities and temperature that have been performed on the rig are the true values regardless of any simulation or calculation done in this thesis.

ii) These experimental measurements were only done at certain access positions and the solar collector back surface was not one of them and hence cannot compare with measured values. The flow zones in the model were made to simulate the information from access positions measurements and visualisation observations. Hence it is possible that certain zones were forced to aid in the flow mechanism role of the exit buoyancy flow as per visualisation observations. Hence agreement with access position values was maintained.

### VII.2.1 The Analysis of the Numerical Results

It was pointed out to the author[1] that in the second case of flow simulated in this thesis (taken as a typical case):

The maximum temperature of the convection channel black surface is 56°C, one third the distance from the top of the room and ≈46°C at top and bottom. Looking at the experimental results, Ref. 1, noted:

a) The temperature in the inlet channel is generally above ambient, temperature falls from the wall adjacent to the test section towards the outer wall and the fluid temperature increases as it moves down the channel. This led to suppose that the fluid was being heated from the left hand (i.e. test section adjacent) wall. This in turn must be receiving heat presumably from the test section (radiation)?

   It ought to be mentioned that these said temperatures were actually measured and fed in as boundary conditions to the program. The assumption of an indefinitely ideal ambient environment around the inlet channel can be found only in textbooks. One side of the channel that was facing the test section was also facing the laboratory lighting, while the other side was facing a spacious open surrounding. The average difference in temperature between the two faces is only ≈(0.25°C), and this argument is entirely explainable in these terms.

b) From the comparison graphs of experimental and numerical values of temperatures it was seen that the fluid enters the room at $\approx 22^{o}C$, but that the temperature in the bulk of the flow is much higher $\approx (24\text{-}25^{o}C)$. The temperature outside the wall jet is therefore $\approx 3^{o}C$ higher than the jet itself.

Thus the fluid in the room is receiving heat from some source other than the inlet flow. Estimating the Richardson Number (known as the Archimedes number - see Appendix VI of this thesis) associated with the wall jet:

$$Ar = \frac{Lg\,\beta\Delta\theta}{u^2} \qquad \text{(VII.2)}$$

From Figure 560, page 270, peak velocity of inlet wall jet $\approx 0.1$ m/sec and the height of the wall jet $\approx 0.04$m. From Figures 5.54 to 5.57 $\Delta\theta \approx 2^{o}C$. Using a value of $\beta = 3.316 \times 10^{-3}/^{o}C$

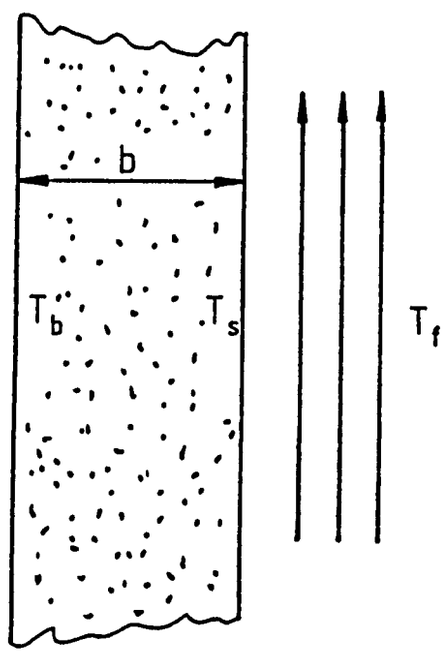
$$Ar \approx 0.26$$

If the (L) of the wall jet is taken as the width of the room = 1m,

$\therefore Ar \approx 6.5$

This indicates a mixed convection and not a solely dominant buoyancy driven natural convection. This is due to the entrainment role in the common chimney[9].

However, dominant buoyancy effects do exist but are not so overwhelming as suggested[1]. Consider the heat transfer from the solar collector wall into the room by conduction:




If the heat flux through the wall is (q):

$$q = \frac{K_\omega}{b}(T_b - T_s) = h(T_s - T_f)$$

Thus

$$T_s = \left(\frac{K_\omega}{hb} T_b + T_f\right)/\left(1 + \frac{K_\omega}{hb}\right) \qquad \text{(VII.3)}$$

where $K_\omega$ = conductivity of the wall

$h$ = heat transfer coefficient

values of quantities involved:

$K$ = 0.125 W/m$^o$C (Kaye and Laby - for homogeneous plywood)

$T_b$ = 56$^o$C (black surface temperature)

$T_f = 25^oC$

$b = 0.018m$

Let mean Nusselt number for heat transfer from the wall to the fluid layer on the room side be $\overline{Nu}$:

Then $$h = \frac{\overline{Nu}\ K_{(air)}}{L} \qquad \text{(VII.4)}$$

$L = 1m$, $K_{(air)} = 0.026\ W/m^oC$

$$\overline{Nu} = 0.0246\ (GrPr)^{0.4}\ [(Pr)^{1/6}/[1 + 0.494\ (Pr)^{2/3}]]^{0.4} \qquad \text{(VII.5)}$$

where: $Pr = 0.7$, and

$$Gr = \frac{g\ \beta\rho^2\ L^3(\Delta T)}{\mu^2} = \frac{9.81 \times (3.67 \times 10^{-3}) \times (1.1)^2 \times (1)^3 \times \Delta T}{(1.85 \times 10^{-5})^2}$$

$$= 12.7 \times 10^7\ (\Delta T) \qquad \text{(VII.6)}$$

where $\Delta T$ = temperature drop-wall to gas $= (T_s - 25^oC)$

Iterating around equations (VII.6) then (VII.5) then (VII.3) $\rightarrow$ ($\Delta T$) converges to the following results[1]:

$T_s = 46.98^oC$ (corresponding to $56^oC$ on the convection channel black surface)

$Gr = 2.79 \times 10^9$

$\overline{Nu} = 109.6$

Thus: $h = 2.85\ W/m^2\ {}^oC$

whereas $\frac{K_\omega}{b} = 6.94\ W/m^2\ {}^oC$

These are beautiful calculations, however, the temperature corresponding to the 56°C on the convection channel black surface was measured utilising three different engineering methods:

i) Thermocouples with calibrated microprocessor (±0.01°C),

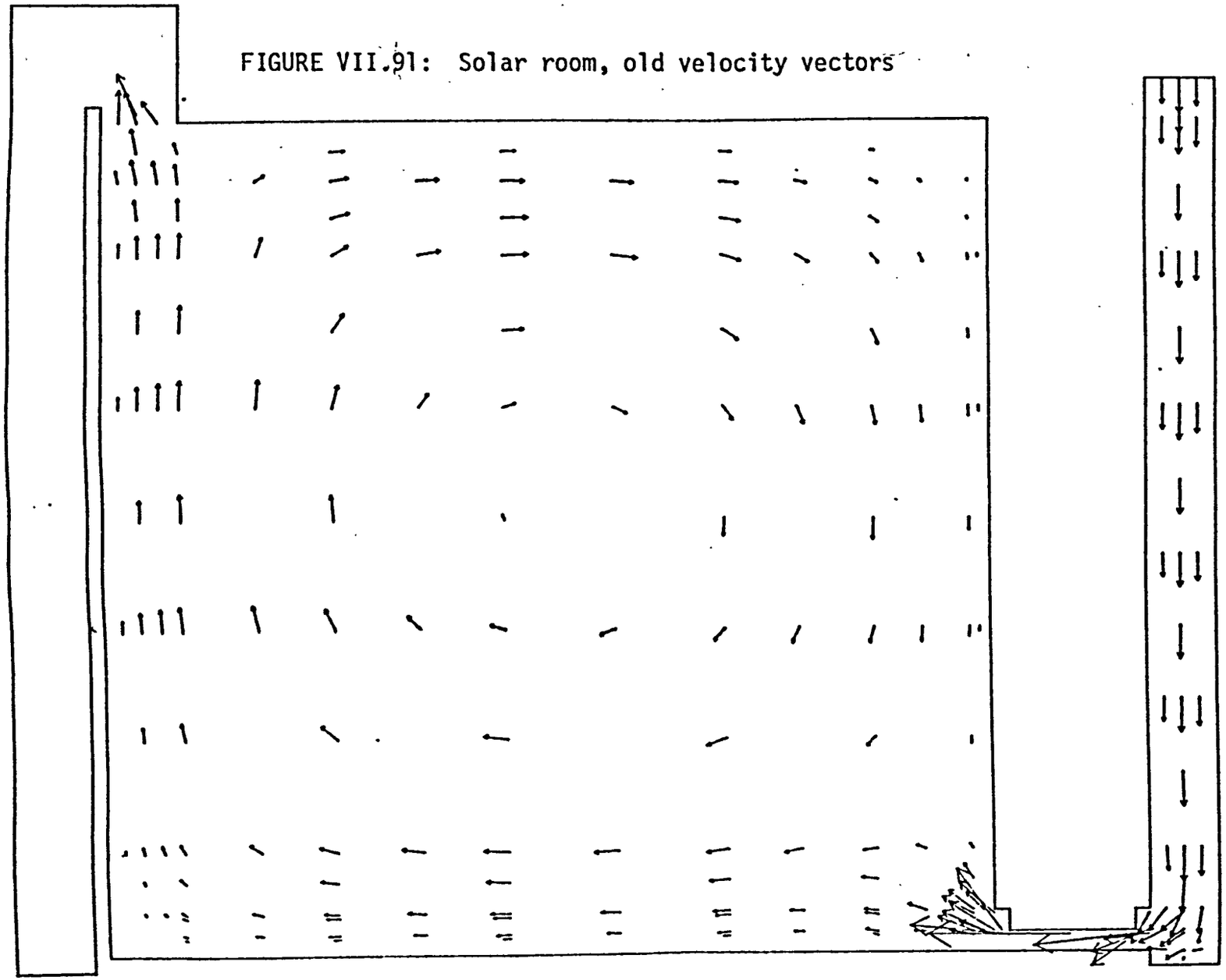
ii) Ordinary thermometer (±0.5°C),

iii) Liquid crystal strip (±0.25°C).

The temperature was found to be 38.8°C. Now this can be explained since plywood homogeneity was assumed in the calculations, and not taken as a composite material. All the nodal temperatures on the exit wall were then measured and fed in the program as boundary conditions.

Figure VII.91 shows the velocity vectors of the old simulation without the newly measured wall temperatures prescribed. Figure VII.92 shows the old temperature contours. Figure VII.93 shows the old temperature/velocity relationship indicating that the solar collector back wall flow is with no heat flux and is due solely to conduction i.e. velocity vectors perpendicular to the wall isotherms.

FIGURE VII.91: Solar room, old velocity vectors



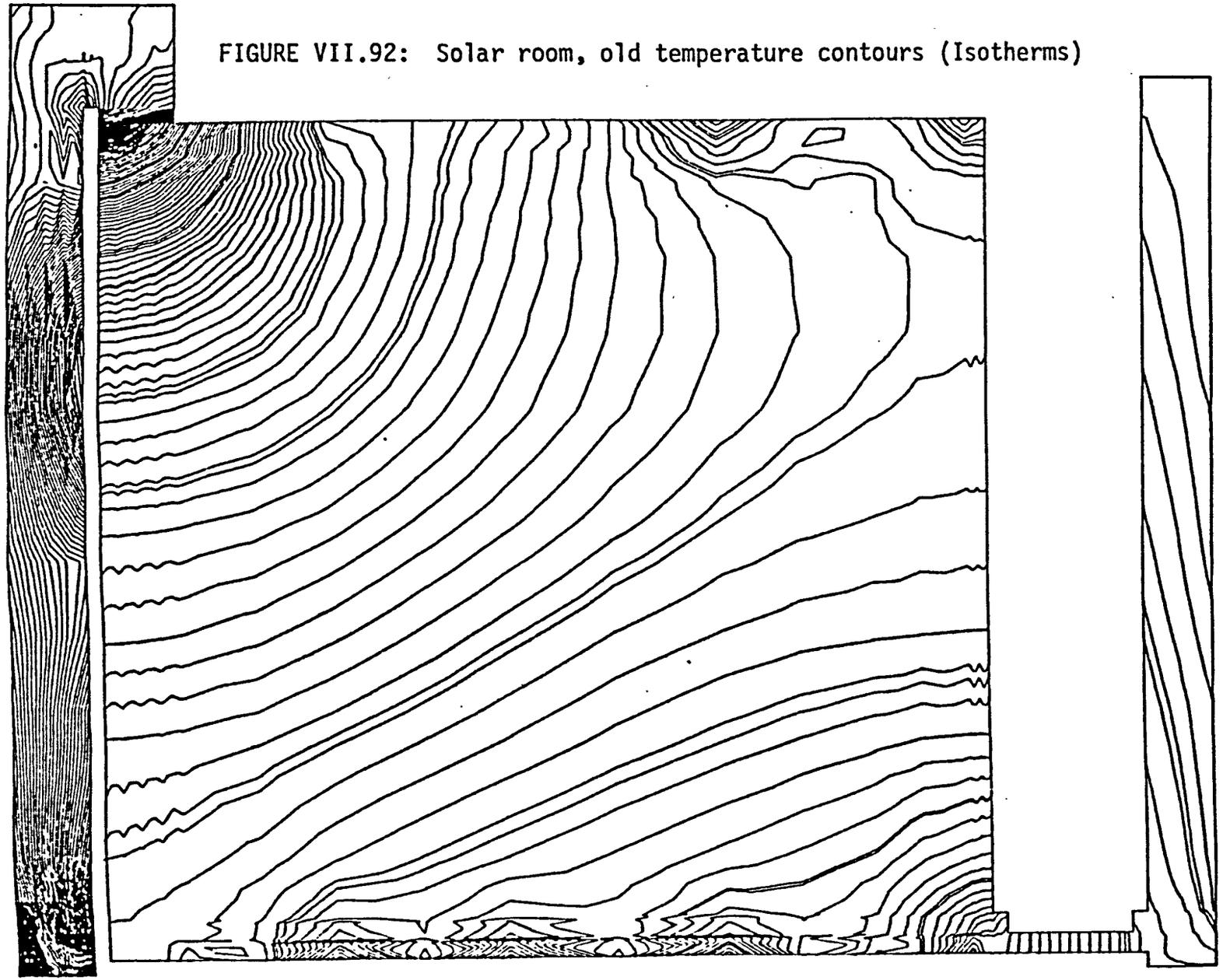


FIGURE VII.92: Solar room, old temperature contours (Isotherms)

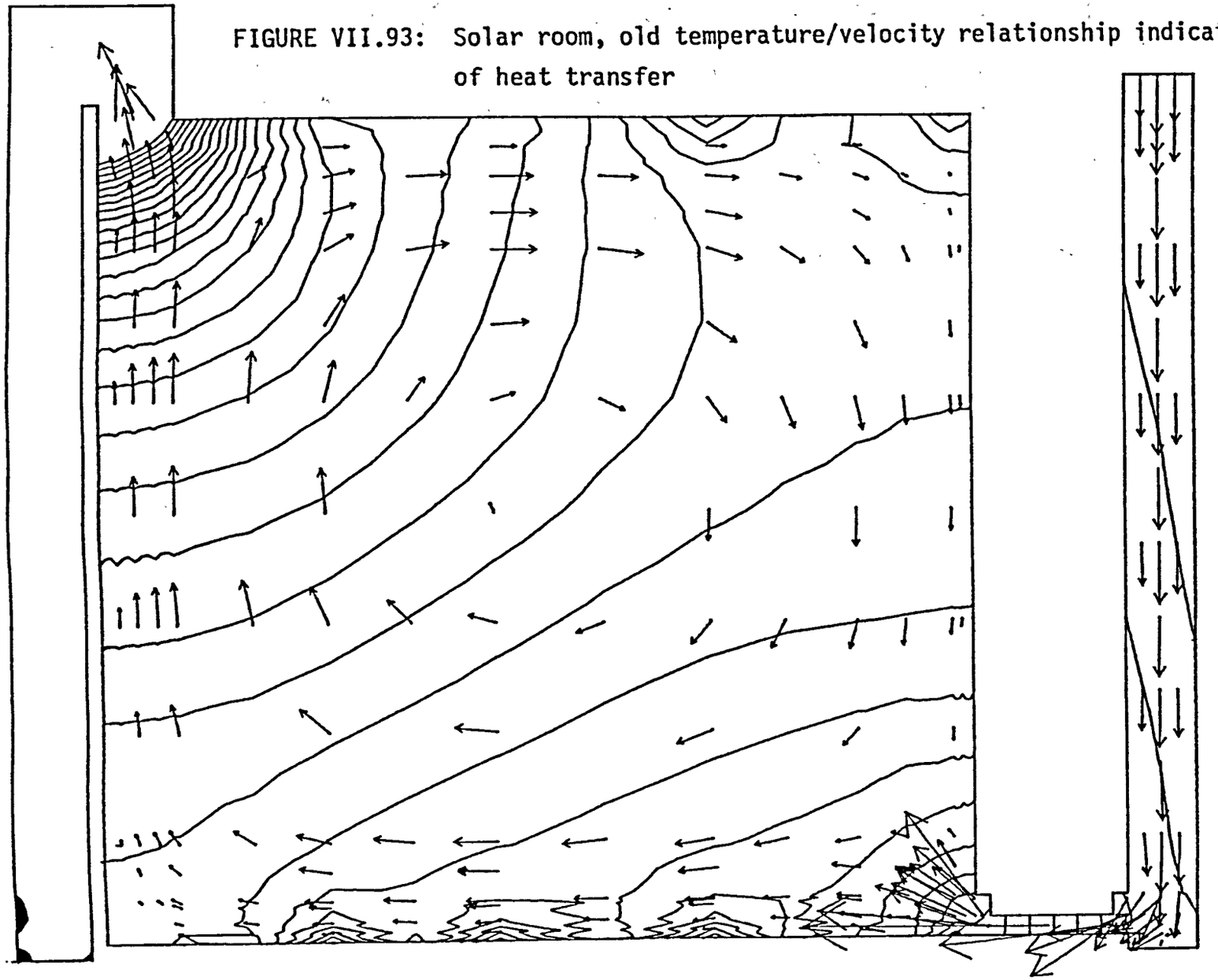


FIGURE VII.93: Solar room, old temperature/velocity relationship indicating the type of heat transfer

After prescribing the newly measured temperature values at the exit wall, Figures VII.94 and VII.95 show the velocity vectors and temperature contours respectively. It can be seen from the last figure that heat flux is varying up the exit wall now and convection is taking place. This resulted in an increase in the average flow velocities of about ≈12%. This was combatted by increasing the exit wall jet flow zone turbulence intensity by ≈(14.2%) and the room exit part of the common chimney elements intensities by ≈(5.2%). This resulted in bringing the flow back to its original magnitude with an average velocity error of ±2.1%.

Figure VII.96 shows the new temperature/velocity relation indicating the type of heat transfer at the exit wall is due to mixed convection with dominating buoyancy natural convection force. This confirms dominantly buoyancy driven boundary layer up the exit wall which is just in the turbulent regime. In the old velocity vectors/isotherm simulation agreement with experiment was achieved due to the prescription of zonal roles which forced the flow to act realistically. The transport of heat within the room was almost entirely by diffusion i.e. heat diffused back from the chimney into the room against the flow. This is further confirmed by examining Figure 5.79 (page 286) for turbulent conductivity and Figure 5.78 (page 285) for turbulent viscosity which implied turbulent Prandtl numbers ≈0.001.

The ability to manipulate zonal properties, not just turbulence intensities made it possible to counteract the high gravity forces in the floor inlet wall jet.

It is to be remembered that the old calculations and simulations are still correct and valid for all the access positions and as compared with experimental measurements.

FIGURE VII.94: Solar room, new velocity vectors

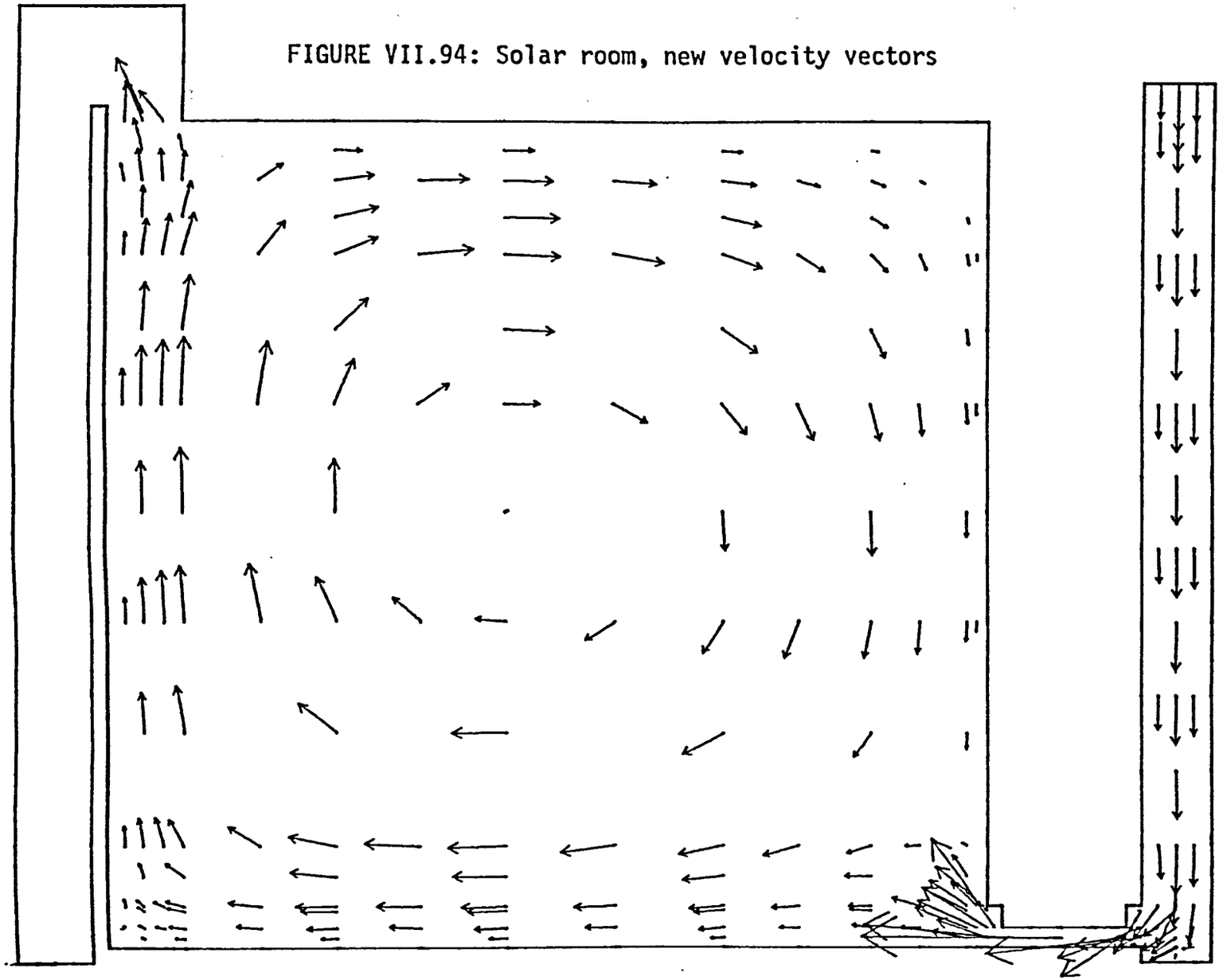
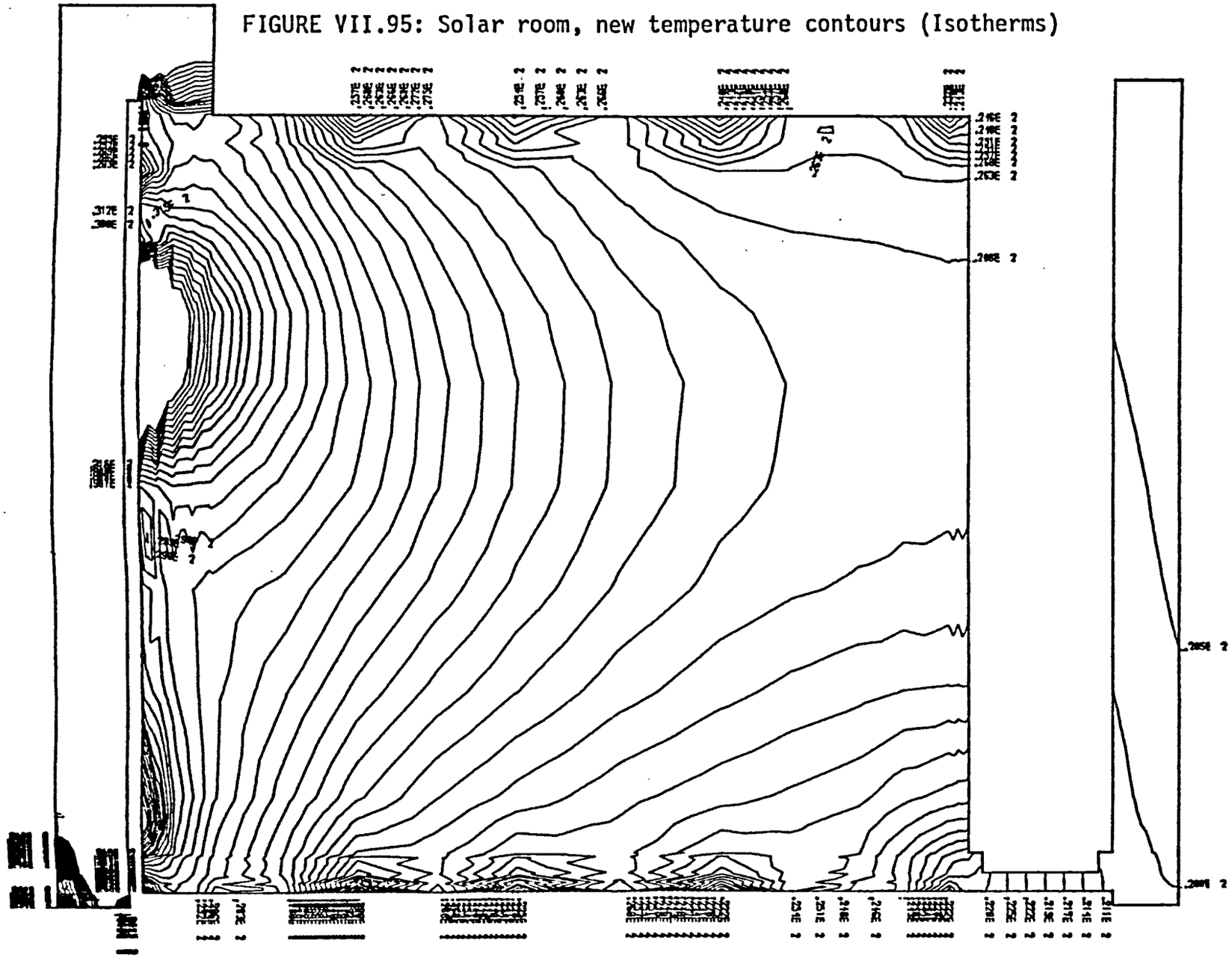


FIGURE VII.95: Solar room, new temperature contours (Isotherms)



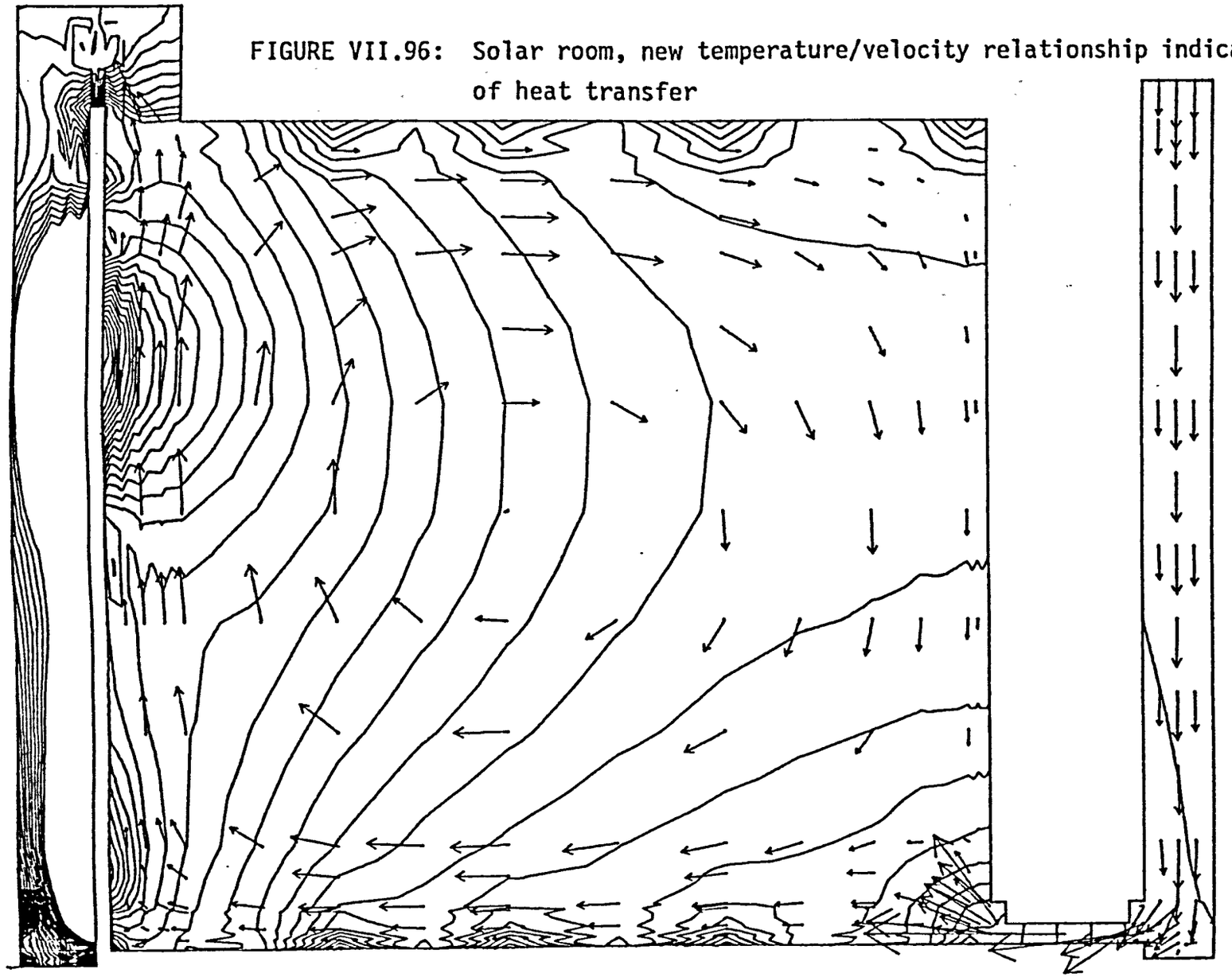


FIGURE VII.96: Solar room, new temperature/velocity relationship indicating the type of heat transfer

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