NASA Contractor Report 165997

THE CMC/3DPNS COMPUTER PROGRAM FOR
PREDICTION OF THREE-DIMENSIONAL,
SUBSONIC, TURBULENT AERODYNAMIC
JUNCTURE REGION FLOW

VOLUME II - USERS' MANUAL

P. D. Manhardt

COMPUTATIONAL MECHANICS CONSULTANTS, INC.
Knoxville, Tennessee 37920

Contract NAS1-15105
September 1982

NASA
National Aeronautics and
Space Administration

Langley Research Center
Hampton, Virginia 23665

CONTENTS

SUMMARY

The CMC fluid mechanics computer program system is being developed to transmit the theoretical evolution of finite element numerical solution methodology, applied to nonlinear field problems into a versatile computer code for comprehensive flowfield analysis. This report is Volume II of a three volume set and presents data deck procedures for the CMC three-dimensional Parabolic Navier-Stokes (PNS) algorithm. General data procedures are introduced, followed by detailed description of a juncture corner flow standard test case data deck. A complete listing of the data deck is given in Appendix A, followed by a detailed explanation of grid generation methodology in Appendix B. Subsequent appendices present descriptive tubulations of all commands and variables available to the user. These are in alphabetic order with cross-reference numbers which refer to storage addresses. Volume I of this report is referenced for details of the theoretical foundation, development of the finite element 3DPNS algorithm, and discussion of results for the juncture corner test case. The CMC computer program structure and description are detailed in Volume III.

INTRODUCTION

Input facilities for the CMC computer program are highly sophisticated and greatly simplify data deck preparation and modification. The program sequentially scans data deck card images and operates on command name data as encountered. Numerical data required for each command operation are input in free format directly following the command card. Command operations can cause vectors to be filled, initiate a series of solution operations or specify output formats and titles. Command card sequence is quite flexible and care has been taken to ensure that most operations which must be performed sequentially are specifiable under one command name.

The CMC data deck is divided into seven sections for description. Exclusive of machine related job control statements, the seven sections consist of a FORTRAN MAIN program and accompanying subroutines (specific to external corner flows), namelist data, geometric description, output format specification, boundary and initial condition data and solution directing commands, see Figure 1. Each of these data and its subset is preceded by a command card image which directs a program activity, and upon completion returns control to the next command data card. The program operates in a dynamic storage mode and the function of MAIN (data deck section one) is to allocate sufficient storage for the IZ array which is internally sized as a function of the number of finite elements requested for a specific problem. The namelist section of the deck (section two) is used to specify scalar, integer and floating point data utilizing the FORTRAN namelist option. The data are read in namelists NAME01 and NAME02, respectively, and stored in the arrays IARRAY and RARRAY.

The geometric description section (data deck section three) contains data required to generate a finite element grid suitable for the solution. One-dimensional and rectangular two-dimensional discretizations are formed by specification of grid refinement along the coordinate axes. More complex boundary shapes (nonrectangular) necessitate data specification along all domain boundaries and certain interior subdomain boundaries. Generated data consist of grid point coordinates for each generated node and a node connection table which defines the finite element domains.

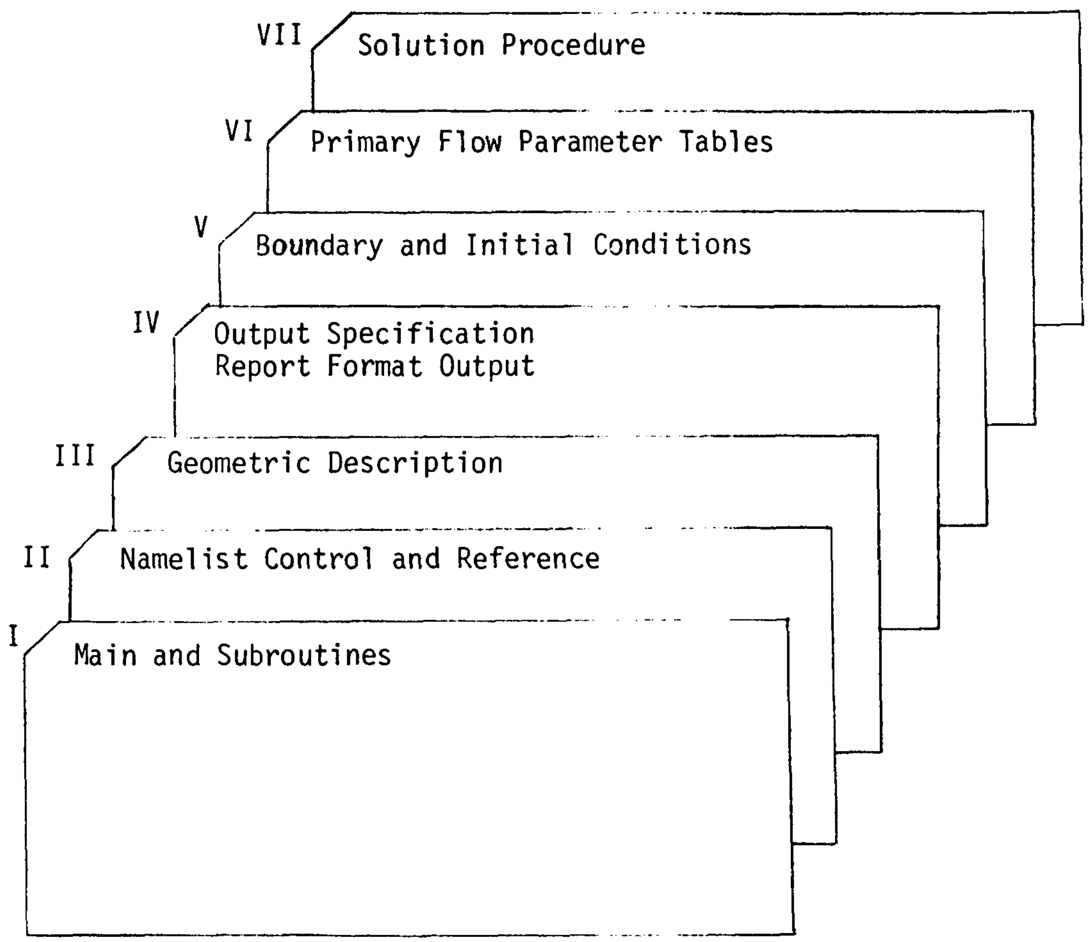


Figure 1.- CMC Data Deck Major Sections

CMC employs a highly adaptive output routine which allows for data specification of the scalar and array variables to be printed, scale factors to be applied to each variable and titling information to head each variable list. Each is specified under a command name in the output section (Section four, Fig. 1) of the data deck. The program operates in nondimensional units and data specified scale factors are utilized to provide flexibility of print units. A reference length parameter (REFL in NAME02) is also available to scale input and output coordinate data to a problem reference length. In addition, command names are available for specification of problem identifying titles to be printed at various strategic locations i.e., at the beginning of each set of printed output. The fifth section of the data deck contains the required boundary and initial condition data which is specified at the solution nodes. The finite element method easily handles mixed boundary conditions, hence, both fixed and Neumann type are allowed. Parameter tables, which are a function of the marching direction (i.e., axial pressure gradient) are specified in section six. Linear interpolation of these tables determines the value of the parameter at each computational station. The intended solution algorithm is input in Section seven of the data deck. Variation in solution procedure is obtained through command card input of the various program functional modules. Nonlinear, repetitive solutions are readily handled by the Linkcall list which is interrogated at each integration step.

The sections which follow give examples of some of the computer program features which greatly simplify data specification and manipulation of computed results. These are followed by a detailed description of the data requirements peculiar to data deck major sections. The data deck description follows for the specific juncture flow case, including sample print and plot data.

CMC DATA PROCEDURES

Program flow is controlled by sequentially scanning the data deck in 80 column increments. Subroutine BDINPT scans a card for a command name and initiates a program function for the given command. A list of the allowed acronyms is given in Appendix C. Eight columns are reserved for the command names beginning in card column 1. Beyond column 8, other data such as non-dimensionalizing scalars or control parameters associated with a specific name may be specified. If the function of a particular command name is to read and store a set of numerical or literal data, the cards containing the data must directly follow the command card. Control is returned to BDINPT by terminating a numerical data string with a "T" or a "blank card". Literal data are terminated with the word "DONE" beginning in card column 1.

Most of the numerical and literal data, other than command data specified in the CMC input deck, may be input in free format. Data delimiters may be blanks or commas, thus allowing for esthetic and meaningful arrangement of numerical data. Exceptions are namelist data which utilizes the standard FORTRAN namelist option and certain special card types which combine literal and numerical data. Several features which greatly simplify sequential and repetitive data specification are available in free format. For example:

Repetitive Numbers	12. 5*7.	T
Fills Array	12. 7. 7. 7. 7. 7.	
Repetitive Sequence (one per card only)	2(5. 2. 4.	
Fills Array	5. 2. 4. 5. 2. 4	
Repetitive Blanks (Δ)	10. 12. 3*P 22.	T
Fills Array	10. 12. Δ Δ Δ 22.	
Increment by a constant	5*I50 10	T
Fills Array	10 60 110 160 210	
Exponential Notation	6. 10.E-2 14.E-4	T
Fills Array	6. .1 .0014	

Solutions which proceed in marching integration fashion may be restarted at specific intervals by allocating file space and specifying the command SAVETAPE in the data deck prior to initiating integration. This command causes all pertinent arrays to be written on the specified file at each solution print interval. File space is minimized by specifying a small repeat number which rewinds the file following the specified number of writes. For example:

```
SAVETAPE           9     3        T     Save data in unit 9
```

will cause the data arrays to be written on unit 9 at each print interval. On the fourth write, the file will be rewound before writing, thus obliterating the first three sets of data. A restart of the solution is accomplished by issuing command RESTART. In this case the second integer indicates the data file at which to start reading. For example:

```
RESTART            9     1        T     Restart at first set of data
```

will cause the first set of array data on unit 9 to be read into the storage arrays. Caution must be observed not to specify a restart set of data which is beyond the last write indicated in the initial run.

DATA DECK STRUCTURE

Main Program : (CMC Deck Section I)

The function of MAIN (Fig. 2) is to dimensionalize and initialize the IZ, IARRAY and RARRAY arrays and call the control subprogram BDINPT. The IZ array resides in common block ARRAYS and contains all data array variables required for intersubroutine communication. The size of IZ must be overestimated initially since the arrays residing in it are dynamically set in the GO step as a function of specific problem size and solution type. On subsequent runs the size may be adjusted to fit the problem storage requirements. Actual storage required by the program is computed and stored (DECIMAL) at location 100 in the IARRAY array. The IARRAY and RARRAY arrays reside in common block VARBLE and are utilized to communicate scalar integer and floating point data, respectively, between subroutines and I/O. All 500 locations in each of these arrays are printed upon encountering command ICOND, thus permitting demand review of the many keys and parameters utilized throughout the program.

```
      PROGRAM CORNER(INPUT,OUTPUT,RSTRT,TAPE5=INPUT,
     *                TAPE6=OUTPUT,TAPE3=RSTRT)
C          - - - C -   - M -   - C - - -
      COMMON / VARBLE / IARRAY(00500), RARRAY(00500)
      EQUIVALENCE ( IARRAY(00092), IZSIZE )
      COMMON / ARRAYS / IZ(110000)
      COMMON LIST(200)
      NZSIZE  =  110000
C     CALL ERRSET ( 207, 500, -1, 1, 0, 217 )
C
C     CALL ZEROTK
 100  CONTINUE
      CALL RESET ( 00500, IARRAY, 0 )
      CALL RESET ( 00500, RARRAY, 0.0 )
      IZSIZE  =  NZSIZE
      CALL RESET  ( IZSIZE, IZ, 0 )
      CALL RESET ( 00200, LIST,  0  )
      CALL BDINPT
      GO TO 100
      END
```

Figure 2. - CMC Main Program.

Namelist Control and Reference (CMC Deck Section II)

All scalar data of consequence are stored in the arrays IARRAY and RARRAY (Appendix C). Many of these are FORTRAN namelist specifiable and are input under &NAME01 and &NAME02, respectively. Namelist read is initiated through command FENAME which initializes all storage locations to default values prior to reading namelist. The namelist tables also contain the name IARRAY and RARRAY, thus allowing data to be read into all 500 locations in each array regardless of namelist name specification. For example, NEQKNN = 5, can also be specified as IARRAY(58) = 5, under &NAME01 in Section II of the data deck.

An alternative method of reading data into the scalar arrays is to use the IARRAY and RARRAY command names. These can be inserted anywhere in the data deck, external to namelist, and are useful for resetting print codes and dynamically calculating scalars to be used in subsequent steps. For example:

```
RARRAY        23         1.5142         -3         T         RESET TIME
```

stores a new value of 1.5142 ÷ ALC into location RARRAY(23). The (-3) indicates division by ALC which is the variable stored in RARRAY(3). Likewise for integer data

```
IARRAY      281            5048,     282    0,     283    71,     284    72
```

stores 5048, 0, 71, and 72 in IARRAY locations 281 through 284, respectively. Note that these data cannot be continued on following cards. This does not restrict the method, however, since the next card could contain a similar command.

Dynamic dimensioning is accomplished by filling the IZ array using the size specification NODE(decimal) as read under namelist NAME01. The command for this function is FEDIMN and it must be completed following NAMELIST read in Section II of the data deck. The dimensioning parameter NODE is discretization size oriented and is set slightly larger than the number of grid points in the solution. The starting addresses of the dimensioned variables in the IZ array are stored in the first NIZS (in NAME01) locations in IZ and are printed in decimal form if KDUMP = 1, in NAME01.

Geometric Description (CMC Deck Section III)

Finite element discretization of the flow domain is automatically generated from a coarse grid description.

The parabolic-elliptic form of PNS requires a grid of space dimension one less than the solution geometry. The most complex grid description required, therefore, is two dimensional. A solution is obtained by "marching" the entire two-dimensional grid in a third space dimension with solution dependent step-size forming a partial adaptive grid. Boundary shape changes are controlled by geometric transformation parameters specified in data deck Section VI and are reflected in the solution through differential equation metrics.

Simple Geometries

A rectangular domain having grid lines lying parallel to the coordinate axes is the simplest geometry, and therefore, is simplest to input. Grid size variation in each direction is accomplished using a geometric progression of finite element size in each direction. In the x_2 direction for example:

$$Y_{i+1} = Y_o + S \sum_{j=2}^{m+1} P^{i-2} \tag{1}$$

where p is the specified geometric progression ratio and m is the number of finite elements to be generated in the x_2 direction and scaled by S. Since i in equation (1) is always positive, progression ratio greater than unity will form a grid which becomes coarser as x_2 increases and p equal to unity forms a uniformly spaced grid. The equation is applied piecewise over the elements allowing different progression ratios over each segment. For two-dimensional domains, equation (1) is applied similarily in the second direction.

The data description for rectangular discretizations proceeds by first subdividing the domain into smaller rectangles (subdomains) each of which may have a different progression ratio in each coordinate direction. The four subdomain case illustrated in Figure 3a admits a fine discretization along the solid surface and in the tip region. Data for this case appear as follows.

```
LINK2              14

VX1SCL
     -5.0,    5    0.    .8,    10    1.0    1.25    T

VX2SCL
     -4.0,    5    0.    .8,    10    1.0    1.25    T

NDECRD
      1   16,    1    16,    0    T

ELEM

DONE
```

The first card is the discretization command card which effects a call to subr. DSCRTZ. The VX2SCL and VX1SCL commands read the subdomain data for the respective x_3 and x_2 directions of Figure 3(a). Each data string contains first coordinate, number of elements this subdomain, last coordinate this subdomain, and, progression ratio. Since the subdomain must be contiguous, the first coordinate of subsequent subdomains coincides with the last coordinate of the one preceding it and, therefore, is not repeated. The NDECRD command admits a choice of grid refinement to be used for solution, and generates the grid points. The data indicate first node in the x_2 direction (Fig. 3(a), last node in the x_2 direction, first node in the x_3 direction, and last node in the x_3 direction. In the example, 15 elements are described in each direction (VX1SCL) and (VX2SCL) and, hence, (1 16) will yield all elements described. If, however. only the upper half of the discretization were desired for a particular solution, the NDECRD data would appear as (6 16, 1, 16, 0 T). The ELEM command causes the finite element node connection table to be formed. The number of elements and nodes generated (NELEM and NNODE) in IARRAY are determined and stored automatically in the discretization process. The number of generated nodes must be less than NODE specified in Namelist NAME01.

Complex Geometries

Secondary flow geometries having boundaries of general curvature and multiple discontinuities require a more sophisticated approach. The CMC multidimensional grid generator employs a local parametric coordinate transformation technique over independent quadrilateral and triangular segments of

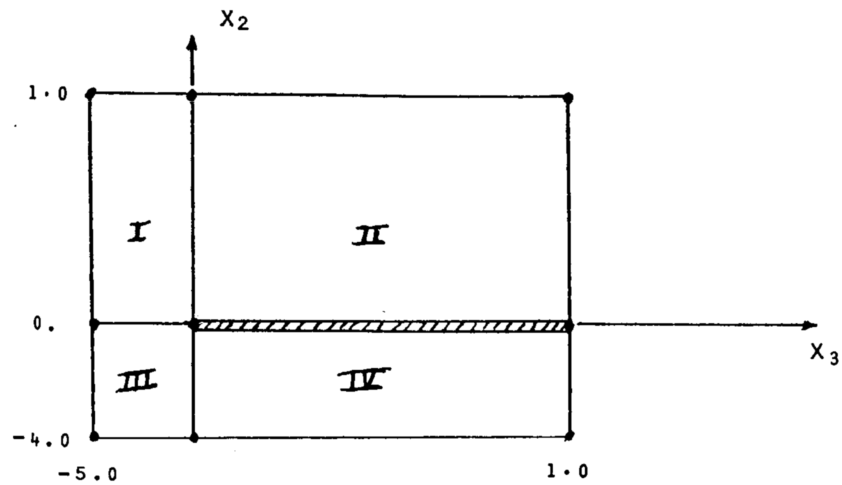


Figure 3a. Rectangular Domain Discretization (Flat Plate)

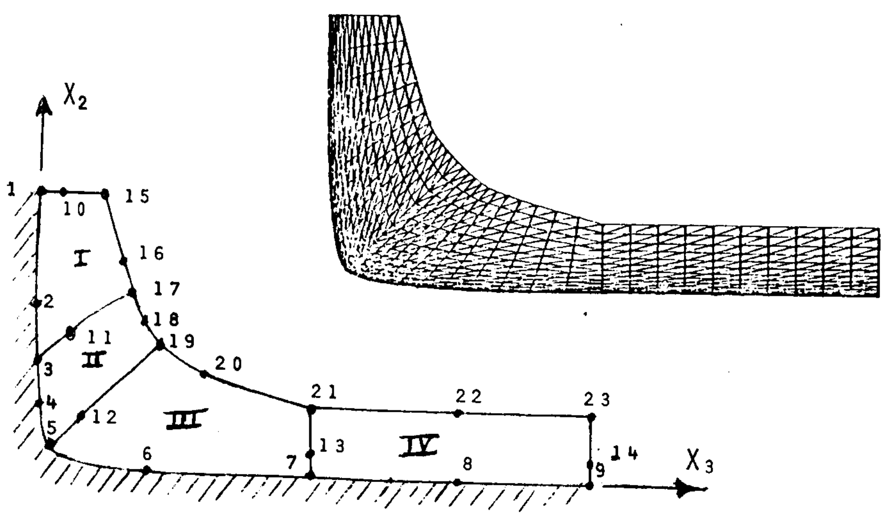


Figure 3(b). - Irregular Domain Discretization .

Figure 3. - Flow Domain Discretization.

the solution domain. A refined grid is generated over each local (single curved) subdomain and transformed into the global geometry. Figure 3(b) illustrates the method for a viscous corner flow problem where the potential core forms a curved boundary. Here four isoparametric quadrilateral subdomains having biquadratic variation are used to generate the two-dimensional triangular mesh (see Appendix B). This method requires the specification of only coordinates in any order and a subdomain connection table. The connection table order is: corner grid points, side grid points counter-clockwise starting anywhere. A local coordinate convention is used to order the generated data. The origin is the first grid point in the connection table, the abscissa runs along side 1, between the first and second grid points in the table and the ordinate runs along side 4 between the first and fourth grid points in the table. The generated discretization is ordered in adjacent rows running between sides 4 and 2 beginning at the local origin. For example, if subdomain 1 in Figure 3(b) is numbered

15 1 3 17 , 10 2 11 16

and 5 elements per side were requested, the generated nodes would be numbered 1 thru 6 along side one (15 1), 7 thru 12 along the adjacent row, etc. Note in Figure 3(b) that the number of generated elements along side (3b) must be the same for subdomains I and II in order to maintain nodal connectivity among the generated elements.

The nonuniform grid exhibited in Figure 3(b) is obtainable utilizing two distinctly different approaches. The first method involves movement of the subdomain side grid points (Fig.3(a)) toward the region of refinement. Since the number of generated nodes is equally distributed about the side node, a grid compression occurs for off-center side grid points resulting in a smoothly skewed grid over an entire subdomain. This method allows for great flexibility and control over spacial distributions of generated grid density with minimal input. The second method involves additional specification of geometric progression ratios along subdomain sides and setting scalar variable JPR = 1 in the IARRAY array. This separates the grid refinement specifications from geometry input, thus providing a means for changing grid refinement without having to locate a new geometry point. It also overcomes, at little expense, the further drawbacks of method 1, involving nonuniqueness and boundary shape inaccuracies of highly skewed discretizations.

To use this option it is necessary to specify the number of subdomains (NSELEM) and grid points (NSNODE) in Namelist NAME01. Node must also be set in NAME01 larger than the number of nodes being generated.

Report Format Output (CMC Deck Section IV)

The output section of the CMC data deck is devoted to organizing the print formats. Several print command names are available, each having a different function. Table 1 lists the print commands and gives a brief description of the function of each. Cards following the COMTITLE command are read and stored for print on command The command DESCRIPT 204 stores problem identifying titles for print at the beginning of each output header.

The variable specified print formats in CMC allow the user to arbitrarily select and title the scalar and array variables to be printed. Scalars are normally grouped together in a header print which precedes print of the variable arrays. The titles are input under command DESCRIPT 332 and are formatted to fit 5 titles per card with 16 characters maximum per title. The scalar variables associated with each title are input under command IONUMB. These data consist of integers indicating the locations in RARRAY to be printed. Multipliers to be applied to each printed number are likewise input as integer RARRAY locations following the command MPARA. The example below illustrates the input which prints velocity in the English, MKS, and CGS systems of units:

```
DESCRIPT   332
VELOCITY   FT/SEC     METERS/SEC      CENTIMETERS/SEC
DONE
IONUM -1
     200,    3*27          T
MPARA -1
     2*2,    164,    163   T
```

The DESCRIPT 332 command stores the four titles in the order read. The variable to be printed under each title, in this case RARRAY (200) = 0.0 and RARRAY (27) = U_∞ , are listed under the IONUM command and zeros are printed as blanks.

Table 1 Print Commands

Command	Function
COMTITLE	Reads title which is printed below the CMC symbol
DONE	Terminates literal data
DESCRIPT 204	Solution print heading
DONE	Same as above
DESCRIPT 332	Solution print parameter titles
MPARA -1	RARRAY locations of multiplier TO BE APPLIED TO PARAMETER PRINT
IONUMB -1	RARRAY locations of parameters to be printed
DESCRIPT 203	Titles to head dependent variable print
IOSAVE -1	List of dependent variables to be printed.
IOMULT -1	List of locations in RARRAY of multipliers to be applied to each dependent variable

The printed scalars are scaled by data in RARRAY locations specified under the MPARA command. In the example, therefore, U_{∞} is printed three times, scaled by RARRAY(2) for print under heading FT/SEC, scaled by RARRAY(164) for print under heading METERS/SEC, etc., where the multipliers are 1.0, feet to meters and feet to centimeters conversion factors. A typical header print obtained upon command LINK2 6 is illustrated in Figure 4, together with data description which created it. Note that the (x-x-) in Figure 4 print is specified as 999 under command IONUMB.

Titles heading the print of array variables are input under command DESCRIPT 203. Input format is 16 columns per title, 5 titles per card; 1 title is input for each variable to be printed. The arrays to be printed under each heading are assumed NNODE long and follow command IOSAVE. The program array variable/names are stored in the first NIZS locations of the IZ array and are described in the Section V data deck description following. Multipliers used to dimensionalize the print are specified for each variable following command IOMULT. Integer specification of RARRAY locations is used as described above for scalar data print.

Print format control is obtained for array printing through namelist data specification. The maximum number print digits are specified in IARRAY(20) = NPRNT in NAME01. Output field size is controlled by specifying the required digit accuracy in IARRAY(22). Output for a typical case having simple geometry is illustrated in Figure 5. The format assumes leading decimal point mantissa (not printed) and the exponent is printed once for each variable directly following the array name.

The print form reflects problem geometry and approximate coordinates are tabulated on the abscissa and ordinate of a Cartesian rectangular system for each variable printed. Coordinate values are in reference units and are real numbers with assumed leading decimal as described above.

```
DESCRIPT  332   T  IOPAR   PARAMETER TITLES FOR OUTPUT.     .
 REFERENCE       ENGLISH-FT       ENGLISH-IN       M-K-S            C-G-S
 LENGTH.........    .FT.........    .IN.........    .M..........    .CM.........
 VELOCITY.......    .FT/S.......    .N.A........    .M/S........    .CM/S.......
 DENSITY........    .LBM/FT3....    .N.A........    KG/M3.......    G/CC......
 TEMPERATURE....    .RANKINE....    .N.A........    .KELVIN.....    .N.A........
 ENTHALPY.......    .BTU/LBM....    .N.A........    .KJ/KG......    .N.A........
 FROZ.SPEC.HEAT.    .BTU/LBM-R..    .N.A........    .KJ/KG-K....    .N.A........
 VISCOSITY......    .LBM/FT-S...    .N.A........    .NT-S/M2....    .POISE......
 LOCAL PRESSURE.    .PSF........    .PSI........    'KNT/M2......    .TORR.......
 LOCAL SOLUTION.    .MACH NO....    .DPDX1......    .ENERGY.....    .INT. VAR...
 T2PFIX.........    .H21........    .G22.......    .G23........    .F1..........
 NWGEOM H'S.....    .H31........    .G32........    .G33........    .G1.........
 X1/LREF........    .DX1/LREF...    .EPSILON....    .DX1M/LREF..    .REFL RE NO.
DONE
MPARA       -1
  5*2,  2 2 162 164 163,  3*2 164 163,  3*2 170 174,
  3*2  165 2,  2 -175 3*2,  3*2 176 2,  3*2 177 178,
  2  2 169 168 167,  3*2 108 2,  5*2,  5*2,  5*2  T
IONUMB      -1
   999,  5*200,  999, 200 4*43,  200 27 200 27  27,
   200 10 200 10 10,  200 58 200 58 200,
   200 97 200 97 200,  200 30 200 30 200,
   200 38 200  38 38,  999,  39 4*36,  300 154 100 135 122,
  398 4*I1 186,  200 4*I1 139,  11  12  14  85  47  T
```

4(a). - Header Print Format Data.

```
 REFERENCE        ENGLISH-FT       ENGLISH-IN       M-K-S            C-G-S

X - X - X - X - X - X - X - X - X - X - X - X - X - X - X - X - X - X - X - X -
 LENGTH.........    .FT.........    .IN.........    .M..........    .CM.........
                     1000000E+01     1200000E+02     3048000E+00     3048000E+02
 VELOCITY.......    .FT/S.......    .N.A........    .M/S........    .CM/S.......
                     1000010E+03                     3048000E+02     3048000E+04
 DENSITY........    .LBM/FT3....    .N.A........    KG/M3.......    G/CC......
                     2330814E-02                     3733965E-01     3733965E-04
 TEMPERATURE....    .RANKINE....    .N.A........    .KELVIN.....    .N.A........
                     5300000E+03                     2944444E+03
 ENTHALPY.......    .BTU/LBM....    .N.A........    .KJ/KG......    .N.A........
                     1760684E+04                     4092533E+04
 FROZ.SPEC.HEAT.    .BTU/LBM-R..    .N.A........    .KJ/KG-K....    .N.A........
                     7721760E+01                     3230784E+02
 VISCOSITY......    .LBM/FT-S...    .N.A........    .NT-S/M2....    .POISE......
                     4074412E-06                     6062725E-06     6062725E-05
X - X - X - X - X - X - X - X - X - X - X - X - X - X - X - X - X - X - X - X -
 LOCAL PRESSURE.    .PSF........    .PSI........    KNT/M2......    .TORR.......
     9964654E+00     2116800E+04     1469906E+02     1013524E+06     7601429E+03
 LOCAL SOLUTION.    .MACH NO....    .DPDX1......    .ENERGY.....    .INT. VAR...
     0       E+00    8861539E-01     0       E+00    5847034E+00     0       E+00
 T2PFIX.........    .H21........    .G22.......    .G23........    .F1..........
     0       E+00    1000000E+01     0       E+00    0       E+00    0       E+00
 NWGEOM H'S.....    .H31........    .G32........    .G33........    .G1.........
                     1000000E+01     0       E+00    0       E+00    2129497E-14
 X1/LREF........    .DX1/LREF...    .EPSILON....    .DX1M/LREF..    .REFL RE NO.
     1100000E-01     1000000E-02     1000000E-01     0       E+00    5720616E+06
 - X - X - X - X - X - X - X - X - X - X - X - X - X - X - X - X - X - X - X - X -


                                                  X - X - X - X - X - X - X - X - X -
                                                    N-   N+  PASSES     PRINT    OF
                                                    0    0      1         0     100
```

4(b). - Header Print.

Figure 4. - Typical Solution Header Data and Print.

NODE AND COORDINATE MAP OF DISCRETIZATION

X2COR
SCALE
FACTOR
......
X2COR ...NODE NUMBERS...
......

X1COR
SCALE ... X1COR ...
FACTOR

- X - X - X - X - X - X - X - X - X - X - X - X - X - X - X - X - X - X - X - X - X - X - X - X - X - X - X - X - X -

E -1														
9990000	181	184	186	187	188	189			190					
8518973						179			180					
8349874				177	178									
8257089	171	174	176											
7239818									170					
7058205						169								
6923677				167	168									
6750211		165	166											
6655031	161	164												
6127510									160					
5872444						159								
5683506					158									
5543551				157										
5363089	153	155												
5160286	151								150					
4841347						149								
4605096					148									
4319221									140					
4300465		145	146											
4133315	143	144												
3944741	141					139								
3587861					138				130					
3309667			136											
3165084		134				129								
2951895	131								120					
2851916					128									
2398881			126			119			110					
2226535		124												
2142844	121				118									
1918000				117		109			100		090		080	
1526259		115			108									
1384951	113	114				099		089			079			069
1251201	111			107										
1047454			106											
0990099		105			098		088			078			068	
0697617	103	104		097		087		077				067		
0480963			096		086			076			066			056
0320479		095		085			075			065				055
0113544	093	094		083		073	074			063			053	054
0	091		081			071			061				051	
E-1	0000000	0201601	0595144	0701924	1047454	1279559	1455339	1698918	2066637	2156692	2448103	2619937	2971777	3113407

Figure 5. - Geometric Form Array Print

In addition to the flexible format print described above, other less flexible print may be obtained which provides input validation and verification of problem definition. Setting KDUMP = 1 in NAME01 will effect a line by line data deck reflection, including each command card and its associated data as read. Figure 6 illustrates typical data verification print. Common data errors such as not specifying "T" or blank card delimiters are easily detected since the reader will continue to read cards, including command names, until it encounters one of these. The print subsequently appears as continuous data reflection of all the cards under the original command name.

Scalar data stored in the arrays RARRAY and IARRAY are printed by inserting the command ICOND. Figure 7 illustrates the print format. This print provides verification of the namelist data specification, and program computed scalars which are stored in these arrays.

Upon call to QKINT, a series of prints is initiated. The first, illustrated in Figure 8, prints the variable numbers and types in the solution. If a restart unit is requested, the unit number is printed. The order of calls for solution process is listed and identified, followed by the variables and multipliers to appear following the header page at each DELP solution print interval. Following this print, a call to ICOND is initiated to print the RARRAY and IARRAY scalar lists. This is followed by a node map print which matches node numbers with their coordinates. A subsequent standard solution print, as described above, is output which lists the specified and default initial conditions.

Description of various debug print which is useful for verifying algorithm correctness and debugging the program is given in Volume III, the Programmer's guide.

Boundary and Initial Condition Specification (CMC Deck Section V)

CMC admits the simultaneous solution of multiple differential equations. Dependent and parameter array variables are stored sequentially, beginning at the address stored in IZ(48) and are input in arbitrary order following command IPINT. The number of differential equations, hence, number of dependent variables in a solution is specified by NEQKNN in NAME01, and the total number of variables specified in IPINT is input in NEQ. Each specified variable is actually a composite number which is decoded by the program for identification.

```
   DESCRIPT    203   T   TITLES FOR OUTPUT DEPENDENT VARIABLES.
U1/UREF          U2/UREF          U3/UREF          NU/NUREF         TKE/TKEREF
DISS/DISSREF     PP / PSTAG       P / PSTAG        PHI              U'U'
U'V'             U'W'             V'V'             V'W'             U1 PRIME
DENSITY          TEMPERATURE
DONE

   IOSAVE    -1
   1248 2248 3248 1247 5248,  6248 7248 8248 9248 3271,
   4271  5271  6271  7271  3301  284  285  T

      IOSAVE      17 ENTRIES.
49818-   1248 49819-  2248 49820-  3248 49821-  1247 49822-  5248 49823-  6248 49824-  7248 49825-  8248 49826-  9248 49827-  3271
49828-   4271 49829-  5271 49830-  6271 49831-  7271 49832-  3301 49833-   284 49834-   285

   IOMULT   -1
   3*2 21 13*2,  17*1  T

      IOMULT      34 ENTRIES.
49710-     2 49711-     2 49712-     2 49713-    21 49714-     2 49715-     2 49716-     2 49717-     2 49718-     2 49719-     2
49720-     2 49721-     2 49722-     2 49723-     2 49724-     2 49725-     2 49726-     2 49727-     1 49728-     1 49729-     1
49730-     1 49731-     1 49732-     1 49733-     1 49734-     1 49735-     1 49736      1 49737-     1 49738-     1 49739-     1
49740-     1 49741-     1 49742-     1 49743-     1

   LINK2     15

   LINK2(15) TIME =      7.07245E-02 SEC.     TOTAL TIME TO HERE =      2.70975E+01 SEC.

   LINK2      3
LINK2( 3) TIME =         4.49066E-02 SEC.     TOTAL TIME TO HERE =      2.71528E+01 SEC.

   LINK5      6
LINK5( 6) TIME =         2.84195E-01 SEC.     TOTAL TIME TO HERE +      2.74470E+01 SEC.
```

Figure 6. - Sample Data Reflection Print (KDUMP = 1 in NAME01)

STATUS OF IARRAY VALUES.

1	ND	=	1	2	MLTDIF	=	0	3	IROW	=	1	4	KEYMTD	=	1	5	NOMEGB	=	0
6	KODG	=	0	7	KOD5	=	2	8	KPRINT	=	0	9	NRSTRT	=	0	10	NV	=	0
11	NPTDOF	=	1	12	NCC	=	0	13	NCOORD	=	0	14	NFLEM	=	325	15	NN	=	0
16	NNODE	=	190	17	NNS	=	0	18	NPART	=	2	19	NOE	=	171	20	NPRNT	=	132
21	NROW	=	2	22	NC	=	8	23	NB	=	4	24	NPTEL	=	3	25	KIND	=	4
26	KOUNT	=	1	27	NSKIP	=	193	28	IPASS	=	0	29	IRUN	=	0	30	NP	=	8
31	NEQ	=	8	32	IWLSEP	=	19	33	NBUG	=	0	34	LPRINT	=	100	35	NPSICC	=	0
36	NPRSCC	=	0	37	NEWPRT	=	0	38	NOUTVC	=	10	39	NDRVDX	=	0	40	NOUTS	=	1
41	N2WAKE	=	0	42	INPUT	=	5	43	NEQADD	=	-2	44	NSTORE	=	0	45	NEXP	=	19
46	NF	=	4	47	LG	=	19	48	NDOF	=	0	49	NOEL	=	3	50	LCOL	=	30
51	NDBL	=	0	52	KROW	=	46	53	NH2	=	0	54	NHHALF	=	0	55	NODE	=	193
56	NDOUTZ	=	0	57	IASVEC	=	0	58	NEQKNN	=	5	59	NCPTAB	=	1	60	NMBOUT	=	13
61	KDUMP	=	0	62	NTITL	=	3	63	NIND	=	1047	64	NSM	=	10	65	NJ	=	0
66	NRHOSS	=	0	67	NS	=	26	68	NI	=	4633	69	NBSET	=	0	70	NDTSET	=	0
71	ISTATN	=	0	72	IVALUE	=	0	73	ISTAD	=	0	74	IRRAY	=	0	75		=	0
76		=	0	77		=	0	78		=	0	79	NQQ	=	9	80	NPRDCT	=	0
81	IVWVAL	=	0	82	IVSTA	=	0	83	IFSLT	=	0	84	NVARD	=	172	85	NVAR1	=	171
86	NPNT	=	1	87	NRTAPE	=	0	88	NLINE	=	60	89	NEMD	=	349	90	NYY	=	4
91	NZZ	=	4	92	IZSIZE	=	*0000	93	NTK	=	2	94	NIZS	=	250	95	NVELTB	=	0
96	IBASE	=	200	97	ITKE	=	1	98	IMAT	=	1	99	IBL	=	1	100	IREND	=	66216
101	NPRESS	=	0	102	KOUT	=	0	103	MTM	=	0	104	NFLIP	=	1	105	IPTSPL	=	0
106	KK	=	19	107	NE1E2	=	0	108	NCNADD	=	8	109	NTAPER	=	0	110	NPRESH	=	0
111	IMAX	=	9	112	NWALLS	=	4	113	KPLVAR	=	0	114	MSSD	=	0	115	IFORCE	=	69049
116	IGINIT	=	0	117	IBUG1	=	0	118	IBUG2	=	0	119	NGBUG	=	0	120	IFR	=	0
121	NSPEC	=	4	122	IWRIT	=	0	123	IGAS	=	0	124	NDERIV	=	2	125	NCALLS	=	2
126	ISPEED	=	0	127	IDIFRT	=	-2	128	ICNTND	=	190	129	IMATAB	=	2	130	NGETH	=	1
131	NBORD	=	52	132	IPWRIT	=	-12	133	ITOP	=	4	134	NPSIBD	=	2	135	NPSBDL	=	0
136	KSAV	=	0	137	LPSIA1	=	0	138	LPSIAM	=	0	139	INGAS	=	0	140	NTCNTS	=	0
141	KFSL	=	0	142	NOUTPR	=	68	143	ICALL5	=	0	144	ITRAN	=	0	145	IMIN	=	0
146	NSFDBE	=	1	147	NPAST	=	0	148	NONC	=	0	149	IT	=	0	150	NODNO	=	0
151	KWFLXS	=	0	152	INITKE	=	0	153	NPUNCH	=	0	154	NSDFCF	=	0	155	NS2DFC	=	1
156	ITWOCL	=	0	157	NPASS	=	0	158	INITCN	=	0	159	IL	=	1	160	IH	=	1
161	NPVSX	=	2660	162	IEPSET	=	0	163	NPSIST	=	0	164	NPSIND	=	0	165		=	0
166	N3DPNS	=	0	167	KNTPAS	=	200	168	NDPRES	=	0	169	KCDC	=	0	170	NBC	=	0
171	NBCND	=	194	172	LOWD	=	1	173	NCOMOC	=	0	174	NCOMTD	=	3	175	IFSL	=	0
176	NTKS	=	10	177	NU2POS	=	3	178	NU3POS	=	3	179	LOC	=	1	180	NSTRT	=	11
181	NVELP	=	0	182	LOGS	=	0	183	IRSLHS	=	0	184	NGTPRS	=	11	185	IP	=	0
186	ITDA	=	0	187	ITDB	=	0	188	NBUF	=	0	189	NSTD	=	8	190	NMOUT	=	2
191	NM	=	3	192	N2M	=	6	193	NM2	=	9	194	NDP	=	10	195	KFXBND	=	0
196	ITWALL	=	0	197	NTPRNT	=	2	198	NPGRDT	=	4	199	NPGRDV	=	4	200	INTPSI	=	0
201	NSTRFP	=	1	202	NSTRF	=	14	203	NTCRDM	=	1	204	INTOMG	=	0	205	ITIMER	=	0
206	NMDL	=	8	207	IBOT	=	3	208	NVRHS	=	8	209	NBIPRS	=	0	210	NCOMPG	=	35
211	IBIDRV	=	0	212	MLTRHS	=	1	213	IPHIPR	=	0	214	LMLT	=	0	215	ISUPRS	=	0
216	ITPSCL	=	0	217	NOPSCL	=	0	218	NCLPSI	=	7	219	KR	=	0	220	NBCNDT	=	0
221	NCYL	=	0	222		=	0	223	MLTLHS	=	3	224	ILHS	=	0	225	NVRH	=	7
226		=	0	227		=	0	228		=	0	229		=	0	230		=	0
231	IADSET	=	0	232	NPMOD	=	200	233	NODES	=	170	234	KNTARF	=	0	235	KNTSHP	=	0
236	NSAF	=	0	237	NARFPR	=	0	238	NSHAPF	=	0	239	NARF	=	0	240	NGRDSH	=	0
241	NWAKE	=	0	242	INAF	=	0	243	NODFT	=	0	244	NODTOT	=	0	245	NAF	=	0
246	NLC	=	0	247	NEG	=	1	248	KFIX	=	0	249	JSHP	=	0	250	IPHI	=	0
251	NSNODE	=	19	252	NSELEM	=	2	253	JCOORD	=	0	254	IPIN	=	0	255	IDIAGL	=	0
256	IPC	=	0	257	NFLUX	=	0	258	NFX	=	0	259	ISIDE	=	4	260	NVAR	=	3
261	IBC	=	0	262	NDCNT	=	0	263	LOCR	=	190	264	LNEL	=	190	265	KSIDE	=	32
266	JSIDE	=	0	267	KTE	=	0	268	NDIVHF	=	0	269	NFOT	=	1	270	ITERFF	=	0
271	IPRINT	=	0	272	KSKIP	=	0	273	NSTAG	=	0	274	NU	=	0	275	NL	=	0
276	NUS	=	0	277	NPTS	=	101	278	NNPT	=	0	279	NDIM	=	200	280	NSEL	=	2
281	IVYY	=	0	282	NV	=	0	283	NO1	=	0	284	NO2	=	0	285	NACA4D	=	0
286	NEQAV2	=	1	287	NEQAV3	=	1	288	NSORC	=	0	289	IPLOT	=	0	290	JQAD	=	0
291	JPR	=	1	292	JCYL	=	0	293	IAXSYM	=	0	294	IRAT	=	0	295	IPLOTV	=	0
296	IPCOEF	=	0	297	IPPSET	=	0	298	NPSETS	=	0	299	IPCFIT	=	0	300		=	0
301	NIMPLT	=	1	302	NMCNTR	=	0	303	NITER	=	0	304	NELPAS	=	0	305	NBAND	=	23
306	NMBJAC	=	4370	307	NCONV	=	0	308	N3MROW	=	386	309	N4MROW	=	579	310	NFMROW	=	386
311	JORDER	=	1	312	IUONLY	=	4	313	NR	=	1	314	KODE	=	0	315	NPT	=	0
316	NIT	=	1	317	NDBGPT	=	3	318	KKSKIP	=	0	319	KDPASS	=	0	320	ICHI	=	0
321	IPRNT	=	0	322	ISTART	=	0	323	NLAST	=	0	324	NCNTIT	=	0	325	NOUEDG	=	0
326		=	0	327	IDDXST	=	2	328	NVISC	=	136	329	NRJACB	=	1	330	LMDJAC	=	0
331	NCONSV	=	0	332	JACSAV	=	0	333	INOCRN	=	1	334	ITRMAX	=	0	335	MAXPAS	=	0
336	NPDBUG	=	40	337	NTRLST	=	0	338		=	0	339		=	0	340		=	9
341		=	0	342		=	0	343	NODQ23	=	0	344	IBLAS	=	0	345	IU1CON	=	0
346	NSPRED	=	0	347		=	1	348		=	1	349		=	0	350		=	0

Figure 7. - Scalar Arrays Print

```
            5 VARIABLES BEING INTEGRATED.
  1     5     6     2     3

             8 VARIABLES IN SOLUTION.
  1     5     6     2     3     7     8     9

ORDER OF CALLS AT END OF QKNUIN

    LINK2( 4) - CONTES

    PRINTOUT VARIABLES

 1248   2248   3248   1247   5248   6248   7248   3271   4271   5271
 6271   7271   8271

    PRINTOUT VARIABLE MULTIPLIERS.

    2      2      2     21      2      2      2     -2      2      2
   -2      2     -2

    PRINTOUT VARIABLE FACTORS. (N)
        N .EQ. 1; STRAIGHT PRINT.
        N .EQ. 2; MULT. LAST VEC. BY THIS ONE - STORE IN LAST.
        N .EQ. 3; ADD TO LAST VEC. - STORE IN LAST VEC. LOC.
        N .GE. 4; RAISE ENTRIES TO (N-2) POWER.
        N .LT. 0; TAKE NTH ROOT OF ENTRIES IF .GT. 0.0

    1      1      1      1      1      1      1      1      1      1
    1      1      1
```

Figure 8. - Solution Sequence and Variable Definition Print

The composite consists of two parts:

0 000

The first digit string contains the variable number and is specified only if the array appears as a variable under command IPINT.

The second digit string contains the indirect address of the variable. The indirect address is the position in the address array which points to the variable of concern plus, the integer constant IZBASE stored in the IARRAY array.

For example, specification of variable 1248 would cause integration of dependent variable No. 1 beginning at the address stored in IZ(200 + 48) where IZBASE is 200. Names and brief descriptions of the program variables are given on page 32 and in Appendix E.

Boundary conditions are separated into two types for clarity of description. The simplest to apply is fixed values of each dependent variable. The nodes where the variable is to be fixed are specified following the command KBNO I, where I is input beyond column 8 and is the number of the dependent variable to which the boundary condition will apply. The boundary nodes may be specified as literal data, therefore, if actual node numbers are to be input they must follow the literal data command ADD. For example, if nodes 1-5 are to be fixed for dependent variable 5 the input would appear as:

```
KBNO    5

ADD
    1, 2, 3, 4, 5    T

DONE
```

Note that a DONE command must be used to terminate literal data. For rectangular discretizations, the input is simplified by requiring only one name to specify an entire side. The names BOTTOM, RIGHT, TOP,and LEFT identify the side to be fixed. Interpretation of the names is associated with their appearance for a geometry in the first quadrant of a 2D rectangular Cartesian coordinate system. Input for the previous example would appear as follows if nodes 1 thru 5 represented the entire discretization along the abscissa.

KBNO

BOTTOM

DONE

Solution domain gradient boundary conditions are specified at grid points as a_1 and a_3 coefficients as they appear in Volume I (Eq. 35). Data are specified under the KBNO command as described above with special format to allow for specification of the coefficients. On the KBNO card, a 1 following the dependent variable number indicates that gradient boundary conditions are being applied. The literal node specification cards, such as BOTTOM contains the specified a_1 and a_3 coefficients. For example:

KBNO	1	1					
BOTTOM		0	1	5,	-.1	2,	0.	2
DONE							

applies an a_1 coefficient of -.1 times RARRAY(2) and an a_3 of 0. times RARRAY(2) to the nodes along the abscissa of a rectangular domain beginning at the left boundary (0 displacement) and spanning the first five nodes. For the case of viscous flow boundaries near a wall, an internally generated shear stress is applied by specifying a_3 = 1.234. By specifying a = 4.321 a second internally generated gradient boundary condition is applied which essentially satisfies the global continuity equation. Thus, for a two-dimensional flow problem, a $\frac{du_2}{dy}$ boundary condition is applied by simply letting $a_3 = \frac{du_1}{dx}$

Primary Flow Parameter Tables (COMOC Deck Section VI)

The Parabolic Navier-Stokes Equation system is marched in one direction and hence the grid in the marching direction is determined by the solution step size.

Since the step size is bariable and completely unpredictable, a linear interpolation scheme is used to evaluate parameters which are a function of the marching direction. As an example, external flows over curved boundaries generate an axial pressure gradient in the flow direction. The pressure variation may be solved for using an inviscid analysis and applied to a boundary layer solution through tabular input. Since linear interpolation is utilized, the table must contain sufficient data to effectively describe the pressure curve. The abscissa locations are specified in free format under command VX3ST and pressure levels are specified under command VPVSX.

	0.	.05	.1	.15	.3	.5	T
VPVSX							
	1.	-.6	-.5	-.3	-.1	-.05	T

The above data complete a table which is interrogated for pressure level upon command LINK1 4. Note that NPVSX must be set to at least the table size in Namelist NAME01. (Vol. I, P. 16).

Piecewise linear tabulated coordinate data describing variable geometry in the flow direction (Vol.I, P. 16) is input under commands VU3POS (x_1 direction coordinates) and VU3VAL (F_{21} (x_1) and F_{22} (x_1) coordinates). The tabular functions are input in the order F_{22} , F_{21} as illustrated below.

VU3POS -1

1.0 1.05 1.1 1.2 2.0 T

VU3VAL -1

$\underbrace{.5 \quad .6 \quad .7 \quad .8 \quad .9}_{F_{22}} \quad \underbrace{-.5 \quad -.6 \quad -.7 \quad -.8 \quad -.9}_{F_{21}}$ T

Table storage arrays for variable geometry coordinates are dimensioned by setting NU2POS and NU3POS in namelist NAME01 equal to the number of table values input (i.e., for the above case = 5). Note that variable geometry requires a nonzero ALC which may either be specified in namelist NAME02 or set internally by calling subroutine DIMEN (LINK3 4) prior to specifying variable geometry data.

Table look-up for the above is strictly interpolatory and, therefore, requires data to span the entire solution domain. Solution need not begin or end at the table endpoints, however.

Nonzero initial conditions must be specified for all variables in the IPINT array not internally computed as a function of flow parameters. This is done simply by using the commands VYY and VYYEND. As with other floating point data, the VYY Command card may also contain multipliers expressed as floating point numbers or integers pointing to locations in RARRAY. A negative sign (-) on an integer indicates multiplication by the reciprocal. Since no internal nondimensionalizing is performed on these arrays, the scale factors are usually used for this purpose. The VYYEND card must contain the variable number being initialized. For example:

```
VYY      -27
    210 * 300.    T
VYYEND     1
```

Variable number 1 in the IPINT array is initialized to a velocity of 300 ft/sec, nondimensionalized by U_∞ located in RARRAY (27).

In addition to variables in the IPINT array, other arrays may be initialized using the READ command. Starting address for storage in these arrays are stored in IZ array locations given in Appendix E. For example, initialization of nodal values of specific heat (see Appendix E), is accomplished by specifying variable 78 on the READ command card:

```
READ    5   300   78   0
    300 * 0.24    T
```

The READ command above is interpreted as: READ 300 values from unit 5 and store them at the address specified in IZ(78) plus 0. Similarly, data may be written from an array into a file for print, punch for later interrogation using the WRITE command.

Solution Procedure (CMC Deck Section VII)

COMOC employs a flexible solution scheme which, through command card specification, permits the user to call functional modules which perform sequences of operations pertinent to a particular set of equations. The heart of the system lies mainly in the 5 link subroutines listed in Volume III. The 3DPNS equations utilize many of these, such as: Thermodynamics (LINK2-9), Turbulence Models (LINK5-6), Nonhomogeneous Laplacian Equation (LINK2-7), and Gradient Boundary Conditions (LINK1-7), to name a few. The order of solution for the 3DPNS equations proceeds by first calling DIMEN (LINK3-4) to compute dimensionalizing parameters. This is followed by a call to GEOMFL (LINK1-3), to generate the finite element data. Nonlinear coefficients in the equations being integrated are evaluated at each integration step. The command LINKCALL is utilized to input the sequence of subroutine calls to be issued at each step, and the data are input in the form (link No., call list). For example, a data specification of:

```
LINKCALL     -1
     5   1,     2   9,     5   6,     T
```

would cause the program to sequentially call the subroutines (LINK5(1), LINK2(9), LINK5(6) prior to evaluating the derivatives at each integration step. By simply changing the linkcall list, therefore, one can vary the degree and type of nonlinearity in the solution. In the example, calling LINK5(1) allows the geometry to vary according to the F21, F22 functions input under commands VU3POS and VU3VAL as previously described.

TURBULENCE MODELING

The 3DPNS algorithm is structured to accommodate a variety of turbulence closure models. The program presently addresses an algebraic mixing length model, and a more general turbulence kinetic energy (TKE) model, solving two differential equations written on TKE and dissipation functions (Vol. I, p. 11). While the models appear straightforward in concept, a variety of coefficients are required to support their application, thus complicating their usability. Table 2 defines the pertinent coefficients and suggested values for general 3DPNS and boundary layer flows. The values are input as namelist data as indicated in the table and three principal options of use are available; mixing length theory, TKE, and a combination of both. Mixing length (MLT) is simplest to implement. Setting NE1E2 = 1 and ITKE = 0 will evaluate turbulent viscosity at each solution node until the solution has marched to the

Table 2

Turbulent Viscosity Models

	MLT to TKE	Two Equation TKE - DISS	MLT	
ITKE	0	1	0	&NAME01
NE1E2	1	2	1	
NEQKNN	ADD 2	ADD 2	0	
NEQADD	SUB. 2	SUB. 2	0	
CHEDSW	x_1(TKE)	>TF	>TF	&NAME02
C1KORE	1.0	1.0	NA	
CK	1.0	1.0	NA	
CD	.09	.09	NA	
YLTKE	.435	.435	NA	
ESCF	1.0	1.0	NA	
C2KORE	1.0	1.0	NA	
PRDIS	1.3	1.3	NA	
C1DORF	1.44	1.44	NA	
C2DORF	1.92	1.92	NA	
Init. Cond.	NA	TKE, DISS	NA	

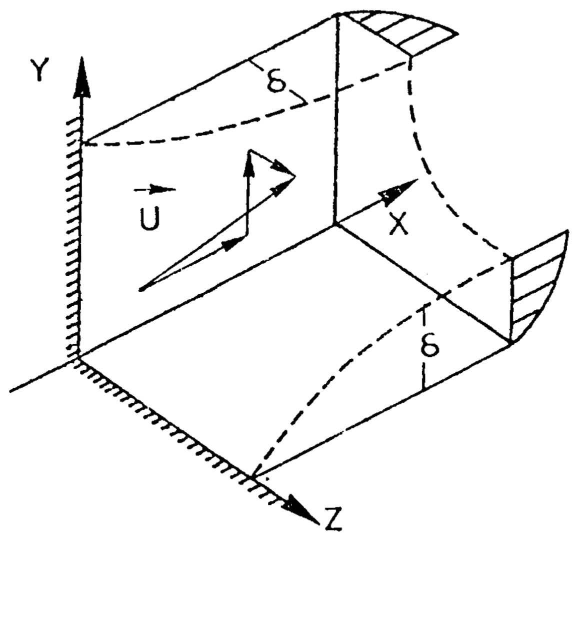
station denoted by E1E2SW in (NAME02). The two equation (TKE-DISS) model is implemented by setting the namelist values noted in the center column of Table 2.

In most instances, initial values of TKE and DISS are not available. They can, however, be estimated using MLT. The input data for this option would appear as in column one of Table 2. Initialization is accomplished on turbulent assumption, and switches are preset in namelist NAME02 to initialize the TKE and DISS profiles using MLT. At each step below C4EDSW, TKE and DISS are evaluated based upon the calculated mixing length. At station C4EDSW, ITKE is internally set to one and (-NEQADD) equations are switched from parameter status to differential equation variables. This is internally accomplished by increasing the NEQADD counter by two. Utilization of this option requires that variables in the IPINT array be arranged such that the TKE & DISS variable numbers are at the initial NEQINT (=NEQKNN & NEQADD) + 1 and + 2 locations. For 3DPNS, turbulent viscosities are evaluated in subroutine DFCFBL as coefficients for the viscous diffusion term in each of the momentum equations.

EXTERNAL JUNCTURE CORNER SAMPLE CASE DATA

The Juncture region test case consists of turbulent flow parallel to a corner formed by the intersection of two 10 percent thick parabolic arcs with coincident leading edge. Figure 9 illustrates the flow field geometry. For parabolic Navier-Stokes, the solution is initiated at the origin, in Figure 9, over a generated grid on the secondary flow plane (z,y). The turbulent momentum equations with continuity constraint are subsequently integrated in the positive X direction (Fig. 9) and under the influence of the three-dimensional inviscid pressure field. Boundary conditions on the flow field include zero velocities along the walls and free-stream conditions at the outer plane.

This section provides a detailed description of data requirements for the juncture region test case configuration, fully described in Volume I (section 5). The data deck description parallels the decomposition noted in the previous section and concentrates on description of specific pertinent variables. Each subsection of the deck is listed with line numbers and footnote-like descriptions of each line which follow immediately. A continuous listing of the complete test case data deck is given in Appendix A.



II.1. NAMELIST (Integer Scalar) Input

```
1     FENAME
2      &NAME01
3          NEQ = 9, NIZS = 250, NSNODE = 19, NSELEM = 2, ISIDE = 4,
4          NVAR = 3, IPHI = 1, NODE = 193, LCOL = 100, KROW = 100,
5          NDP = 10, NBAND = 23, LG = 32, NE1E2 = 1, NDERIV = 2,
6          NDIM = 200, NMOUT = 2, NMBOUT = 50, NC = 8, NOUTS = 1,
7          NOUTVC = 10, IBL = 1, NODES = 170, NPVSX = 2660, NMDL = 8,
8          NEQAV2 = 1, NEQAV3 = 1, NPTS = 101, JPR = 1,
9          INOCRN = 1, IDDXST = 2, NTABPT = 14, NLINE = 140,
10         NWALLS = 4, ICORN = 1, NPVSXT = 10,  NNROW = 9,
11         IWLSEP = 19,  NEQKNN = 5, NEQADD = -4,  NIMPLT = 1,
12         KNTPAS = 200,  NCNTIT = 0, NCNADD = 8,
13         LPSUP = 6, LPPNCH = 2,
14     &END
```

Line	Command	
1	FENAME	Command to initiate Namelist read
2	&NAME01	Integer Namelist Data Array Name
3	NEQ	Number of dependent variable and parameter arrays
	NSNODE	Number of subdomain grid points specified
	NSELEM	Number of subdomains specified
	ISIDE	Maximum number of subdomain sides
4	NVAR	Number of variables (including coordinates) input for distribution over the refined grid
	NODE	Slightly larger than the number of nodes in the solution
	LCOL	Larger than the number of nodes along abscissa (x_3) coordinate
	KROW	Larger than the number of nodes along the ordinate (x_2) coordinates
5	NDP	One greater than NEQ
	NBAND	Maximum bandwidth of Jacobian Matrix
	LG	Number of columns in solution field
	NE1E2	0 → No Mixing length theory (MLT) used 1 → MLT used for diffusion coef. 2 → Delay using MLT until E1E2SW is set to 1
6	NMOUT	(3,2) Print output in (Geometric form, Tabular form)
	NMBOUT	Number of variables to be printed
	NC	Number of characters in print fields
7	NODES	Greater than maximum subdomain generated node density
	NPVSX	Number of pressures in P Versus X_1 table
8	JPR	1 indicates that geometric progression ratios are input to form a nonuniform grid

Line	Command	
9	NLINE	Lines output per page control
11	NEQKNN	Number of ordinary differential equations solved = NEQKNN + NEOADD
	NEQADD	Number of ordinary differential equations initially not solved (Negative)
12	KNTPAS	Maximum number of integration steps between prints
	NCNADD	Number of integration steps prior to integrating secondary flow velocity equations
14	&END	NAMELIST End

II.2. NAMELIST (Real Scalar) Input

```
15      &NAME02
16           UINF = 100.0, TOFINF = 530.0, PINF = 2116.8, REFL = 1.0,
17           DSTART = 1.0,  E1E2SW = 10000.0, COMPX = 2.0, COMPY = 1.0,
18           TMULT = 1.21, TKEDGE = 1.0, PIBAR = 2.0, PALPH = 20.0,
19           XMUINF = 0.0, OSG = 1.0, ALC = 1.0, BLTH = 1.0, EFMULT = 1.0,
20           XNWGEO = 1., C4EDSW = .001, DELMLT = 1.E-4, PCFACT = 1.,
21           CHIEPS = 3.E-4, RHOIM = 1., PRDIS = 1.3, GUMULT = 1.,
22           ESCF = 1.0, RUEDSW = 1.0, XLAM = 0.11, VCMULT = 1., VLDMLT = 1.,
23           OSUSQ = 1.0E-5, OMEGXP = 1.5, XDELTA = 0.01, EPSMIN = 1.0E-5,
24           AOMGEX = 2.0, GAMFAC = 1.0E-20, GAMEXP = 9.0, BEXP = 4.0,
25           RHSCAL = 1.0, PPFACT = 1.0, U2STRS = 1.0, DELP = 101.0,
26           CHITST = 10.0, CHISTP = 5.0, TO = 0.011, SIMPLT = 0.011,
27           HSINIT = 1.0E-4, TD = 0.589,  HMAX = 1.0, TSADD = 0.05,
28      &END
```

Line	Command	
15	&NAME02	Real Namelist Data Array Name
16	UINF	Reference velocity
	TOFINF	Reference temperature
	PINF	Reference pressure level
	REFL	Reference length
17	DSTART	Initial step-size multiplier
	E1E2SW	Station at which to reset NE1E2
	COMPX	Geometric form print x_3 compression factor
	COMPY	Geometric form print x_2 compression factor
18	TMULT	Step size multiplier
19	XMUINF	Reference viscosity
	ALC	Characteristic Finite Element Size (minimum side length)
	EFMULT	Maximum TKE initial level (ABS Value)

Line	Command	
20	C4EDSW	Primary flow coordinate at which turbulence differential equations evaluation begins
	DELMLT	Turbulence equations source term scale factor
21	CHIEPS	ODE integration convergence factor
	RHOIM	Viscous wall damping factor
	PRDIS	Prandtl number for dissipation function
22	ESCF	Turbulence length scale factor
	RUEDSW	Boundary layer measure
	XLAM	Turbulence coefficient
	VEMULT	Secondary velocity convection term specifier
	VLDMLT	Secondary velocity laminar diffusion
23	OSUSQ	Minimum TKE level
	OMEGXP	Turbulence parameter
	XDELTA	Convergence criteria factor
	EPSMIN	Minimum diffusion level factor
24	AOMGEX	Exponent on wall damping factor
	GAMFAC	Diffusion factor
	GAMEXP	Diffusion factor
	BEXP	Diffusion factor
25	RHSCAL	Additional Reynolds stress turbulence model terms
	PPFACT	Implements the perturbation pressure in secondary flow velocity equations
	U2STRS	Implements Reynolds stress terms in secondary flow equations
	DELP	Print interval (% of total primary flow coord. Dim.)
26	CHITST	Maximum iteration count before step-size decrease
	CHISTP	Minimum iteration count before step size increase
	TO	Initial primary flow direction coordinate
27	HSINIT	Initial integration step size
	TD	Primary flow coordinate total length
	HMAX	Maximum step size (% of TD)
	TSADD	Implements additional perturbation pressure terms
28	&END	

II.3 DYNAMIC ARRAY DIMENSIONING AND DEPENDENT VARIABLE SPECIFICATION

```
29      FEDIMN
30      IPINT      -1
31        1 5 6 2 3 7 8 9 0 0,  0 0 0 7*0,  10*I1 1  T
```

Line	Command	
29	FEDIMN	Dimension arrays to fit problem size
30	IPINT	Cards following specify dependent variable and parameter arrays

Variable 1 primary flow velocity

2 Secondary flow velocity (vertical)

3 Secondary flow velocity (horizontal)

5 Turbulence kinetic energy

6 Dissipation function

7 Perturbation pressure (p_p)

8 Complementary pressure (p_c)

9 Continuity equation potential (ϕ_1)

Dependent variables and parameter arrays are stored in sequential arrays each of which is NODE long

In NAME01

NDP is the number of arrays for space allocation

NEQ is the number of equations to be integrated

NEQADD is the number of equations to begin integrating following initialization

```
32      LINK4     9
33      IARRAY    450  250
34      PSIBD     -1
35        1  -2  T
36      IARRAY       61   0
37      LINK2       14
38      NETA
39           9  9  T
40      NEPS
41          9  9  T
42      STYPE
43        2*4  T
44      SELCN
45              9  10  3  1  12  13  19  2,
46            1  3  14  15  19  16  17  18  T
47      DEPVAR    289  290  1248  T   TRANS. COORD., NORMAL COORD., U1 VEL.
48        0.0 0.869565  0.01918   5*0.0  0.0999 0.0999
49        0.0 1.20 .869565  .01918 0.0 1.15 1.20 1.15 1.20
50        0.0  0.0  .01918  5*0.0 0.0 .01918
51        3*0.0  .0999 .0999 4*0.0
52         0.0 0.0 .758   5*0.0   0.0 .783  3*0.0   .783 0.0  4*0.0  T
53      DONE
54      READ       5  63  -26
55          11 1 2,  2  12  11  T    TURN DIAGONAL IN LOWER RIGHT CORNER.
56      READ       5  63  -26   918
57          181  171  182,  171  172  182  T TURN DIAGONAL IN UPPER LEFT CORNER.
58      READ               5  63  -26  972
59         110  100  90  T  ADD TRIAGLE TO OUTSIDE CORNER.
60      IARRAY      14  325  T ADD 1 TO ELEMENT COUNT. -  NELEM = 325
```

Line	Command	
32	LINK4 9	Dynamically Dimensions Discretizer Arrays
33	IARRAY	Reset location 450 in the scalar integer array to the value 250
34	PSIBD	Set diagonals, each subdomain
37	LINK2 14	Initiates discretizer
38	NETA	Number of dimensions in the local coordinate system direction for each subdomain
40	NEPS	Coordinate system direction for each subdomain
		Number of divisions in the ε local coordinate system direction for each subdomain
42	STYPE	Number of corner verticies on each subdomain

Line	Command	
44	SELCN	Grid point numbering for subdomain local coordinate definition 1. Order is: Corner grid points counter-clockwise followed by side grid points counter-clockwise 2. Corner grid points 1 and 2 define the local abscissa direction Corner grid points 1 and 4 define the local ordinate direction 3. Nodes are generated in rows sweeping from the origin to the maximum ordinate
45	DEPVAR	Numbers on this card define the relative addresses for storage of coarse grid data following: 289 indicates abscissa coordinate values 290 indicates ordinate coordinate values 1248 indicates primary flow velocity data
53	DONE	Signifies end of discretizer data and causes the grid refinement to occur and primary flow velocity values to be distributed over the refined grid
55	READ	Reads integer data from unit 5 (card reader) into array beginning at relative address 63 (generated finite element numbers). The data are displaced in the array 918 words from the beginning
60	IARRAY	Reset the generated finite element count to 325

In NAME01

NSELEM is the number of subdomains specified

NSNODE is the number of specified grid points

ISIDE is the maximum number of sides

NODES dimensionalizes discretizer generated node-length arrays. Must be greater than the maximum number of nodes to be generated in a subdomain

NVAR is the number of arrays to be parametrically distributed

IV. TITLES AND HEADINGS

```
61        DESCRIPT  204
62           WING / FUSELAGE JUNCTURE FLOW.
63
64        DONE
65        COMTITLE
66           WING / FUSELAGE JUNCTURE FLOW.
67        DONE
68        DESCRIPT  332   T  IOPAR   PARAMETER TITLES FOR OUTPUT.
69         REFERENCE        ENGLISH-FT       ENGLISH-IN      M-K-S           C-G-S
70         LENGTH.........    .FT.........    .IN.........    .M..........    .CM.........
71         VELOCITY.......    .FT/S.......    .N.A........    .M/S........    .CM/S.......
72         DENSITY........    .LBM/FT3....    .N.A........    KG/M3.......    G/CC......
73         TEMPERATURE....    .RANKINE....    .N.A........    .KELVIN.....    .N.A........
74         ENTHALPY.......    .BTU/LBM....    .N.A........    .KJ/KG......    .N.A........
75         FROZ.SPEC.HEAT.    .BTU/LBM-R..    .N.A........    .KJ/KG-K....    .N.A........
76         VISCOSITY......    .LBM/FT-S...    .N.A........    .NT-S/M2....    .POISE......
77         LOCAL PRESSURE.    .PSF........    .PSI........    'KNT/M2......    .TORR.......
78         LOCAL SOLUTION.    .MACH NO....    .DPDX1......    .ENERGY.....    .INT. VAR...
79         T2PFIX.........    .H21........    .G22.......    .G23........    .F1..........
80         NWGEOM H'S.....    .H31........    .G32........    .G33........    .G1.........
81         X1/LREF........    .DX1/LREF...    .EPSILON....    .DX1M/LREF..    .REFL RE NO.
82        DONE
83        MPARA       -1
84          5*2,  2 2 162 164 163,  3*2 164 163,  3*2 170 174,
85          3*2  165 2,  2 -175 3*2,  3*2 176 2,  3*2 177 178,
86          2  2 169 168 167,  3*2 108 2,  5*2,  5*2,  5*2  T
87        IONUMB     -1
88           999,  5*200,  999, 200 4*43,  200 27 200 27  27,
89           200 10 200 10 10,  200 58 200 58 200,
90           200 97 200 97 200,  200 30 200 30 200,
91           200 38 200  38 38,  999,  39 4*36,  300 154 100 135 122,
92          398 4*I1 186,  200 4*I1 139,  11  12  14  85  47  T
93        DESCRIPT   203    T  TITLES FOR OUTPUT DEPENDENT VARIABLES.
94        U1/UREF          U2/UREF          U3/UREF          NU/NUREF          TKE/TKER
95        DISS/DISSREF     PP / PSTAG       U'               U'V'              U'W'
96        V'               V'W'             W'
97        DONE
98        IOSAVE     -1
99          1248 2248 3248 1247 5248,  6248 7248 3271 4271 5271,
100         6271 7271 8271  T
101       IOMULT     -1
102         3*2 21  3*2 -2 2 2 -2 2 -2,  13*1  T
```

Line	Command	
61	DESCRIPT 204	Std print titles
65	COMTITLE	Problem identifying titles
68	DESCRIPT 332	Std output header labels
83	MPARA	Scalar parameter print multipliers
87	IONUMB	Scalar parameter print locations
93	DESCRIPT 203	Dependent variable print labels
98	IOSAVE	Dependent variable print locations*
101	IOMULT	Dependent variable print multipliers (RARRAY LOC.)

*Note in line 99 that the dependent variables are identified by decoding each number specified (i.e. 1248 is stored in the first NODE locations beginning at the address in IZ(248); Variable 2, 2248, is directly behind Variable 1 since it is stored in the second NODE locations beginning at the address stored in IZ(248); etc.).

V.1 BOUNDARY CONDITIONS

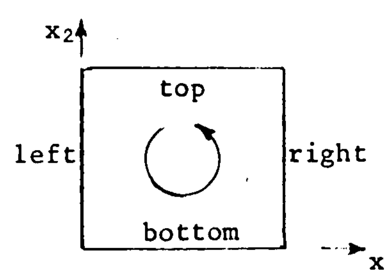
```
162     IBORD     -1
163          10*I1 1,  17*I110 20,  10*I-1 190,  18*I-10 171  T
164     KBNO       1
165     ADD                    DONE
166         19*I110  1  T  FIX WALL NODES.
167     KBNO       2
168     ADD                    DONE
169         19*I110  1  T  FIX WALL NODES.
170     KBNO       3
171     ADD                    DONE
172         19*I110  1  T  FIX WALL NODES.
173     KBNO       7
174     ADD                    DONE
175       19*I110  1  T  FIX WALL ONLY FOR PP
176     KBNO       8
177     ADD                    DONE
178       19*I110  10  T
179     KBNO       9
180     ADD                    DONE
181       9*I110 10,  9*I110 110  T  FIX OUTSIDE BOUNDARY - BUT NOT CORNER,
182                                      WHICH IS NOW INTERIOR.
```

Line	Command	
162	IBORD	List of adjacent domain boundary nodes
164	KBNO 1	Nodes where u_1 is held constant (wall nodes)
167	KBNO 2	Nodes where u_2 is held constant (wall nodes)
170	KBNO 3	Nodes where u_3 is held constant (wall nodes)
173	KBNO 7	Nodes where perturbation pressure held at intial state
176	KBNO 8	Nodes where complementary pressure held at initial state
179	KBNO 9	Nodes where equation potential (ϕ) is held at zero

Named-side cards are formatted [4(A8, I8, 4X)]

Boundary conditions are applied to secondary flow plane.

Positive direction is counter-clockwise (ie. [-RIGHT 2] fixes the right column and node numbers. Node numbers are stored beginning at the second row from the top and proceeding toward the bottom row).



V.2 INITIAL CONDITIONS

```
183     IARRAY     47   19
184     LINK3      4
185     IARRAY     250   0   T   IPHI IN GEOMFL
186     LINK1      3
187     LINK2       30   T   NODPCP
188     CNTPTS     -1
189       19*10   T
190     CNTNDS     -1
191       190*I1   1   T
192     IARRAY     47   19
193     LINK1      2
194     LINK1      11    T   NODPPR
195     LINK2      10    T     TBLINP
196     LINK1       11   T      NODPPR
197     IARRAY     374  190
198     RARRAY     390  1.0
199     LINK2      3
200     RARRAY        63   1.0
201     LINK2      15
202     LINK2      3
203     LINK5      6
204     LINK2      15
205     LINK2      3
206     LINK5      6
207     RARRAY     95   0.9E-3
208     LINK5      4
209     IARRAY     107   0   T   SET NE1E2 = 0
210     KBNO       5
211     ADD                     DONE
212       19*I10   1,  19*I10   10   T   FIX WALL AND FREESTREAM NODES.
213     KBNO       6
214     ADD                     DONE
215       19*I10   1,  19*I10   10   T   FIX WALL AND FREESTREAM NODES.
```

Line	Command	
184	LINK3 4	Compute the nondimensionalizing parameters
186	LINK1 3	Compute the finite element matrix coefficients
187	LINK2 30	Compute the complementary pressure from C_p table
188	CNTPTS	Reset the nodal subset string lengths
190	CNTNDS	Reset the nodal subset strings
193	LINK1 2	Generate finite element-node global connection table
194	LINK1 11	Evaluate initial distributed complementary pressure (P_c)
195	LINK2 10	Generate the primary flow velocities
196	LINK1 11	Re-evaluate initial distributed complementary pressure (P_c)
199	LINK2 3	Evaluate wall skin friction effects
201	LINK2 15	Evaluate effective boundary layer integral parameters
202	LINK2 3	Evaluate wall skin friction effects
203	LINK5 6	Evaluate initial turbulence diffusion coefficients

V.I PRIMARY FLOW PARAMETER TABLES

```
103     CNTPTS    -1
104       19  19  T
105     CNTNDS     -1
106       10*I-10 100,  9*I-1 9,  10*I10 100,  9*I-1  189  T
107     IARRAY     47  2
108     LINK2         23     T  CALL CPSTUP TO READ IN CP DATA.
109       0.0       0.02784   0.04731   0.07165   0.10210   0.14010   0.19000
110       0.26870   0.41840   0.76770   1.51600   3.01300   6.00800   9.00200
111       0.00999
112       0.46940   0.46940   0.42770   0.38980   0.36030   0.33690   0.31740
113       0.29980   0.28560   0.28160   0.28580   0.29330   0.33690   0.29710
114       0.01914
115       0.38290   0.38290   0.35650   0.32150   0.29170   0.26730   0.24680
116       0.22830   0.21360   0.20940   0.21440   0.21980   0.24730   0.22400
117       0.03126
118       0.29870   0.29870   0.28500   0.25710   0.22970   0.20600   0.18560
119       0.16700   0.15260   0.14910   0.15500   0.16010   0.17520   0.16460
120       0.04628
121       0.21490   0.21490   0.21020   0.19090   0.16830   0.14700   0.12800
122       0.11040   0.09699   0.09488   0.10170   0.10680   0.11750   0.11180
123       0.06409
124       0.13190   0.13190   0.13350   0.12220   0.10560   0.08826   0.07195
125       0.05642   0.04503   0.04494   0.05295   0.05821   0.06638   0.06353
126       0.08458
127        0.05079   0.05079   0.05659   0.05191   0.04182   0.02944   0.01691
128        0.00491  -0.00370  -0.00108   0.00823   0.01375   0.02055   0.01944
129        0.13310
130       -0.10500  -0.10500  -0.09411  -0.08947  -0.08799  -0.08917  -0.09175
131       -0.09444  -0.09397  -0.08425  -0.07182  -0.06549  -0.06010  -0.05904
132       0.1609
133     -0.1788   -0.1788   -0.1664   -0.1584   -0.1522   -0.148    -0.1451   0.
134       -1.0      -1.0      -1.0      -1.0      -1.0      -1.0      -1.0    0.
135     0.2224
136     -0.3151   -0.3151   -0.3012   -0.2879   -0.2739   -0.2601   -0.2466   .2
137       -1.0      -1.0      -1.0      -1.0      -1.0      -1.0      -1.0    0.
138     0.2908
139     -0.4296   -0.4296   -0.4155   -0.3982   -0.3783   -0.3571   -0.3345    0
140       -1.0      -1.0      -1.0      -1.0      -1.0      -1.0      -1.0    0.
141        0.40250
142       -0.54460  -0.54460  -0.53120  -0.51030  -0.48480  -0.45640  -0.42500
143       -0.38670  -0.34020  -0.29330  -0.26800  -0.25890  -0.25390  -0.25000
144        0.50
145       -0.57430  -0.57430  -0.56140  -0.53960  -0.51270  -0.48250  -0.44880
146       -0.40740  -0.35680  -0.30640  -0.28000  -0.27070  -0.26570  -0.26170
147     0.5975
148     -.5446    -.5446    -.5312    -.5103    -.4848    -.4567    -.425     .5
149     -1.0      -1.0      -1.0      -1.0      -1.0      -1.0      -1.0      .5
150     0.71
151     -.4296    -.4296    -.4155    -.3982    -.3783    -.357     -.3345    .7
152     -1.0      -1.0      -1.0      -1.0      -1.0      -1.0      -1.0      0.
153          T
154     VU2POS     -3
155       0.01  0.4  1.0  T
156     VU2VAL     136
157       1.0  1.0  1.0  T
158     VU3POS     -3
159       0.01  0.4  1.0  T
160     VU3VAL     136
161       1.0  1.0  1.0  T
```

Line	Command	
103	CNTPTS	Nodal subset string lengths
105	CNTNDS	Nodal subset strings
108	LINK2 23	Reads pressure coefficient table (C_p)
154	VU2POS	Primary flow coordinates
156	VU2VAL	X_2 coordinate variation at primary flow coordinates
158	VU3POS	Primary flow coordinates
160	VU3VAL	X_3 coordinate variation at primary flow coordinates

```
216      LINKCALL   -1
217         2   4    T    CONTES DUMMY CALL.
218      QKNINT
219      EXIT
220      CASE END
```

Line	Command	
216	LINKCALL	List called at the end of each integration step
218	QKNNT	Initialize implicit modified Newton Integration
219	EXIT	Terminate run and return to MAIN for next data case
220	CASE END	Last data case

APPENDIX A

Juncture Region Data Deck

```
FENAME
 &NAME01
      NEQ = 9, NIZS = 250, NSNODE = 19, NSELEM = 2, ISIDE = 4,
      NVAR = 3, IPHI = 1, NODE = 193, LCOL = 100, KROW = 100,
      NDP = 10, NBAND = 23, LG = 32, NE1E2 = 1, NDERIV = 2,
      NDIM = 200, NMOUT = 2, NMBOUT = 50, NC = 8, NOUTS = 1,
      NOUTVC = 10, IBL = 1, NODES = 170, NPVSX = 2660, NMDL = 8,
      NEQAV2 = 1, NEQAV3 = 1, NPTS = 101, JPR = 1,
      INOCRN = 1, IDDXST = 2, NTABPT = 14, NLINE = 140,
      NWALLS = 4, ICORN = 1, NPVSXT = 10,  NNROW = 9,
      IWLSEP = 19,  NEQKNN = 5, NEQADD = -4,  NIMPLT = 1,
      KNTPAS = 200,  NCNTIT = 0, NCNADD = 8,
      LPSUP = 6, LPPNCH = 2,
 &END
 &NAME02
      UINF = 100.0, TOFINF = 530.0, PINF = 2116.8, REFL = 1.0,
      DSTART = 1.0,  E1E2SW = 10000.0, COMPX = 2.0, COMPY = 1.0,
      TMULT = 1.21, TKEDGE = 1.0, PIBAR = 2.0, PALPH = 20.0,
      XMUINF = 0.0, OSG = 1.0, ALC = 1.0, BLTH = 1.0, EFMULT = 1.0,
      XNWGEO = 1., C4EDSW = .001, DELMLT = 1.E-4, PCFACT = 1.,
      CHIEPS = 3.E-4, RHOIM = 1., PRDIS = 1.3, GUMULT = 1.,
      ESCF = 1.0, RUEDSW = 1.0, XLAM = 0.11, VCMULT = 1., VLDMLT = 1.,
      OSUSQ = 1.0E-5, OMEGXP = 1.5, XDELTA = 0.01, EPSMIN = 1.0E-5,
      AOMGEX = 2.0, GAMFAC = 1.0E-20, GAMEXP = 9.0, BEXP = 4.0,
      RHSCAL = 1.0, PPFACT = 1.0, U2STRS = 1.0, DELP = 101.0,
      CHITST = 10.0, CHISTP = 5.0, TO = 0.011, SIMPLT = 0.011,
      HSINIT = 1.0E-4, TD = 0.589,  HMAX = 1.0, TSADD = 0.05,
 &END
FEDIMN
IPINT     -1
  1 5 6 2 3 7 8 9 0 0,  0 0 0 7*0,  10*I1 1  T
LINK4     9
IARRAY    450  250
PSIBD     -1
    1  -2  T
IARRAY        61   0
LINK2        14
NETA
     9  9  T
NEPS
   9  9  T
STYPE
  2*4  T
SELCN
      9  10  3  1  12  13  19  2,
     1  3  14  15  19  16  17  18  T
DEPVAR    289  290  1248  T   TRANS. COORD., NORMAL COORD., U1 VEL.
  0.0 0.869565  0.01918   5*0.0  0.0999 0.0999
  0.0 1.20 .869565  .01918 0.0 1.15 1.20 1.15 1.20
  0.0  0.0  .01918  5*0.0 0.0 .01918
  3*0.0  .0999 .0999 4*0.0
   0.0 0.0 .758   5*0.0   0.0 .783  3*0.0  .783 0.0  4*0.0  T
DONE
READ       5  63  -26
    11 1 2,  2  12  11  T    TURN DIAGONAL IN LOWER RIGHT CORNER.
READ       5  63  -26   918
    181  171  182,  171  172  182  T TURN DIAGONAL IN UPPER LEFT CORNER.
READ                 5  63  -26  972
   110  100  90  T  ADD TRIAGLE TO OUTSIDE CORNER.
IARRAY      14  325  T ADD 1 TO ELEMENT COUNT. -  NELEM = 325
```

```
DESCRIPT   204
   WING / FUSELAGE JUNCTURE FLOW.

DONE
COMTITLE
   WING / FUSELAGE JUNCTURE FLOW.
DONE
DESCRIPT  332    T  IOPAR   PARAMETER TITLES FOR OUTPUT.
 REFERENCE        ENGLISH-FT        ENGLISH-IN        M-K-S             C-G-S
 LENGTH.........    .FT.........    .IN.........    .M..........    .CM.........
 VELOCITY.......    .FT/S.......    .N.A........    .M/S........    .CM/S.......
 DENSITY........    .LBM/FT3....    .N.A........    KG/M3.......    G/CC......
 TEMPERATURE....    .RANKINE....    .N.A........    .KELVIN.....    .N.A........
 ENTHALPY.......    .BTU/LBM....    .N.A........    .KJ/KG......    .N.A........
 FROZ.SPEC.HEAT.    .BTU/LBM-R..    .N.A........    .KJ/KG-K....    .N.A........
 VISCOSITY......    .LBM/FT-S...    .N.A........    .NT-S/M2....    .POISE......
 LOCAL PRESSURE.    .PSF........    .PSI........    .KNT/M2.....    .TORR.......
 LOCAL SOLUTION.    .MACH NO....    .DPDX1......    .ENERGY.....    .INT. VAR...
 T2PFIX.........    .H21........    .G22.......    .G23........    .F1.........
 NWGEOM H'S.....    .H31........    .G32........    .G33........    .G1.........
 X1/LREF........    .DX1/LREF...    .EPSILON....    .DX1M/LREF..    .REFL RE NO.
DONE
MPARA      -1
  5*2,  2 2 162 164 163,  3*2 164 163,  3*2 170 174,
  3*2  165 2,  2 -175 3*2,  3*2 176 2,  3*2 177 178,
  2  2 169 168 167,  3*2 108 2,  5*2,  5*2,  5*2  T
IONUMB     -1
   999,  5*200,  999, 200 4*43,  200 27 200 27  27,
   200 10 200 10 10,  200 58 200 58 200,
   200 97 200 97 200,  200 30 200 30 200,
   200 38 200  38 38,  999,  39 4*36,  300 154 100 135 122,
  398 4*I1 186,  200 4*I1 139,  11  12  14  85  47  T
DESCRIPT   203    T  TITLES FOR OUTPUT DEPENDENT VARIABLES.
U1/UREF          U2/UREF          U3/UREF          NU/NUREF         TKE/TKER
DISS/DISSREF     PP / PSTAG       U'               U'V'             U'W'
V'               V'W'             W'
DONE
IOSAVE     -1
  1248 2248 3248 1247 5248,  6248 7248 3271 4271 5271,
  6271 7271 8271  T
IOMULT     -1
  3*2 21  3*2 -2 2 2 -2 2 -2,  13*1  T
CNTPTS     -1
  19  19  T
CNTNDS     -1
  10*I-10 100,  9*I-1 9,  10*I10 100,  9*I-1  189  T
IARRAY     47  2
LINK2          23     T  CALL CPSTUP TO READ IN CP DATA.
   0.0        0.02784    0.04731    0.07165    0.10210    0.14010    0.19000
   0.26870    0.41840    0.76770    1.51600    3.01300    6.00800    9.00200
   0.00999
   0.46940    0.46940    0.42770    0.38980    0.36030    0.33690    0.31740
   0.29980    0.28560    0.28160    0.28580    0.29330    0.33690    0.29710
   0.01914
   0.38290    0.38290    0.35650    0.32150    0.29170    0.26730    0.24680
   0.22830    0.21360    0.20940    0.21440    0.21980    0.24730    0.22400
   0.03126
   0.29870    0.29870    0.28500    0.25710    0.22970    0.20600    0.18560
   0.16700    0.15260    0.14910    0.15500    0.16010    0.17520    0.16460
   0.04628
   0.21490    0.21490    0.21020    0.19090    0.16830    0.14700    0.12800
   0.11040    0.09699    0.09488    0.10170    0.10680    0.11750    0.11180
   0.06409
   0.13190    0.13190    0.13350    0.12220    0.10560    0.08826    0.07195
   0.05642    0.04503    0.04494    0.05295    0.05821    0.06638    0.06353
   0.08458
```

```
       0.05079   0.05079   0.05659   0.05191   0.04182   0.02944   0.01691
       0.00491  -0.00370  -0.00108   0.00823   0.01375   0.02055   0.01944
       0.13310
      -0.10500  -0.10500  -0.09411  -0.08947  -0.08799  -0.08917  -0.09175
      -0.09444  -0.09397  -0.08425  -0.07182  -0.06549  -0.06010  -0.05904
      0.1609
    -0.1788    -0.1788    -0.1664    -0.1584    -0.1522    -0.148     -0.1451    0.
      -1.0       -1.0       -1.0       -1.0       -1.0       -1.0       -1.0    0.
    0.2224
    -0.3151    -0.3151    -0.3012    -0.2879    -0.2739    -0.2601    -0.2466    .2
      -1.0       -1.0       -1.0       -1.0       -1.0       -1.0       -1.0    0.
    0.2908
    -0.4296    -0.4296    -0.4155    -0.3982    -0.3783    -0.3571    -0.3345     0
      -1.0       -1.0       -1.0       -1.0       -1.0       -1.0       -1.0    0.
       0.40250
      -0.54460  -0.54460  -0.53120  -0.51030  -0.48480  -0.45640  -0.42500
      -0.38670  -0.34020  -0.29330  -0.26800  -0.25890  -0.25390  -0.25000
       0.50
      -0.57430  -0.57430  -0.56140  -0.53960  -0.51270  -0.48250  -0.44880
      -0.40740  -0.35680  -0.30640  -0.28000  -0.27070  -0.26570  -0.26170
    0.5975
    -.5446     -.5446     -.5312     -.5103     -.4848     -.4567     -.425      .5
    -1.0       -1.0       -1.0       -1.0       -1.0       -1.0       -1.0       .5
    0.71
    -.4296     -.4296     -.4155     -.3982     -.3783     -.357      -.3345     .7
    -1.0       -1.0       -1.0       -1.0       -1.0       -1.0       -1.0       0.
         T
    VU2POS    -3
      0.01  0.4  1.0  T
    VU2VAL    136
      1.0  1.0  1.0  T
    VU3POS    -3
      0.01  0.4  1.0  T
    VU3VAL    136
      1.0  1.0  1.0  T
    IBORD     -1
         10*I1 1,  17*I10 20,  10*I-1 190,  18*I-10 171  T
    KBNO      1
    ADD                 DONE
        19*I10  1  T  FIX WALL NODES.
    KBNO      2
    ADD                 DONE
        19*I10  1  T  FIX WALL NODES.
    KBNO      3
    ADD                 DONE
        19*I10  1  T  FIX WALL NODES.
    KBNO      7
    ADD                 DONE
      19*I10  1  T  FIX WALL ONLY FOR PP
    KBNO      8
    ADD                 DONE
      19*I10  10  T
    KBNO      9
    ADD                 DONE
      9*I10 10,  9*I10 110  T  FIX OUTSIDE BOUNDARY - BUT NOT CORNER,
                                 WHICH IS NOW INTERIOR.
    IARRAY    47  19
    LINK3     4
    IARRAY    250  0  T  IPHI IN GEOMFL
    LINK1     3
    LINK2      30  T  NODPCP
    CNTPTS    -1
      19*10  T
    CNTNDS    -1
      190*I1  1  T
    IARRAY    47  19
```

```
LINK1      2
LINK1      11   T  NODPPR
LINK2      10   T   TBLINP
LINK1       11  T    NODPPR
IARRAY     374  190
RARRAY     390  1.0
LINK2      3
RARRAY        63  1.0
LINK2      15
LINK2      3
LINK5      6
LINK2      15
LINK2      3
LINK5      6
RARRAY     95  0.9E-3
LINK5      4
IARRAY     107  0  T  SET NE1E2 = 0
KBNO       5
ADD                   DONE
  19*I10   1,  19*I10  10  T  FIX WALL AND FREESTREAM NODES.
KBNO       6
ADD                   DONE
  19*I10   1,  19*I10  10  T  FIX WALL AND FREESTREAM NODES.
LINKCALL   -1
   2  4    T   CONTES DUMMY CALL.
QKNINT
EXIT
CASE END
```

APPENDIX B

The CMC discretizer possesses the capability of refining coarsely discretized flow domains having boundaries of general shape. By subdividing the flow domain into a few shapes having quadratic variation along the boundaries, virtually any closed domain can be accurately modeled and discretized to conform to solution requirements. The method is graphically presented in Fig. B.1 for a single element two-dimensional airfoil in an infinite domain. In Fig. B.1a the flowfield has been divided into twelve subdomains consisting of eight quadrilateral and four triangular shapes. The grid points represent the data required to specify the subdomain boundaries. Note that all boundaries are of degree 2 or less. The side grid points serve to describe the curved surface shapes and their location relative to adjacent verticies determines the spacial distribution of the generated grid. Figure B.1b illustrates a 648 element grid generated from the subdomain description in Fig. B.1a. Note that the refined grid around the airfoil surface and toward the leading and trailing edges is due to the off center placement of the subdomain side grid points. Variations on refinement type and number of elements is readily accomplished from a single set of subdomain data by simply moving side grid points and respecifying the number of elements for each subdomain.

The grid refinement algorithm proceeds by looping over the subdomain and generating grid point and finite element correction data. For each of the quadrilateral and triangular subdomain shapes, a coordinate transformation exists which maps a local natural coordinate system onto the physical plane. The general form of the required transformation for all space is:

$$x_i = Q_j \, x_j \quad j = 1, n \tag{A.1}$$

where n is the total number of specified grid points on each subdomain boundary and summing over repeated indices is observed. The scalar x_i consists of the grid point physical values of the coordinates at the i^{th} generated node. The quantity Q_j is called the shape function and contains functions of ε and η which satisfy the transformation illustrated in Figure B.2 for ε and η of the $\{x_j\}$. Equation (B.1) is valid over one-, and two-, and three-dimensional Cartesion space and shape factors may be derived for a variety of geometric shapes and polynomial degrees. The Q_j for biquadratic functional shapes over a general quadrilateral for instance is

$$Q_j = \left\{ \begin{array}{l} \tfrac{1}{4}(1 - \varepsilon)(1 - \eta)(-\varepsilon - \eta - 1) \\ \tfrac{1}{4}(1 + \varepsilon)(1 - \varepsilon)(\varepsilon - \eta - 1) \\ \tfrac{1}{4}(1 + \varepsilon)(1 + \eta)(\varepsilon + \eta - 1) \\ \tfrac{1}{4}(1 - \varepsilon)(1 + \eta)(-\varepsilon + \eta - 1) \\ \tfrac{1}{2}(1 - \varepsilon^2)(1 - \eta) \\ \tfrac{1}{2}(1 + \varepsilon)(1 - \eta^2) \\ \tfrac{1}{2}(1 - \varepsilon^2)(1 + \eta) \\ \tfrac{1}{2}(1 - \varepsilon)(1 - \eta^2) \end{array} \right\}^T \tag{B. 2}$$

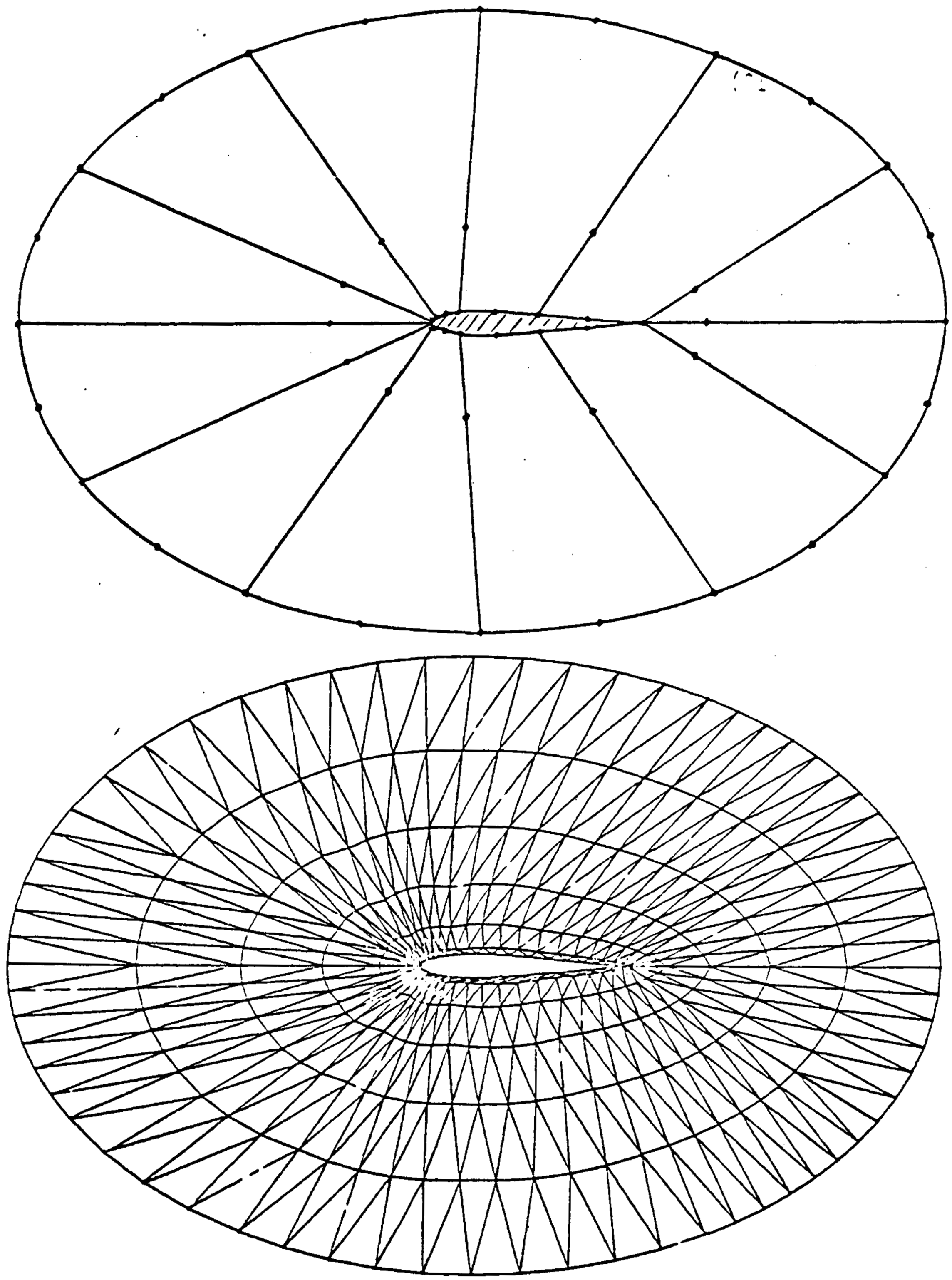
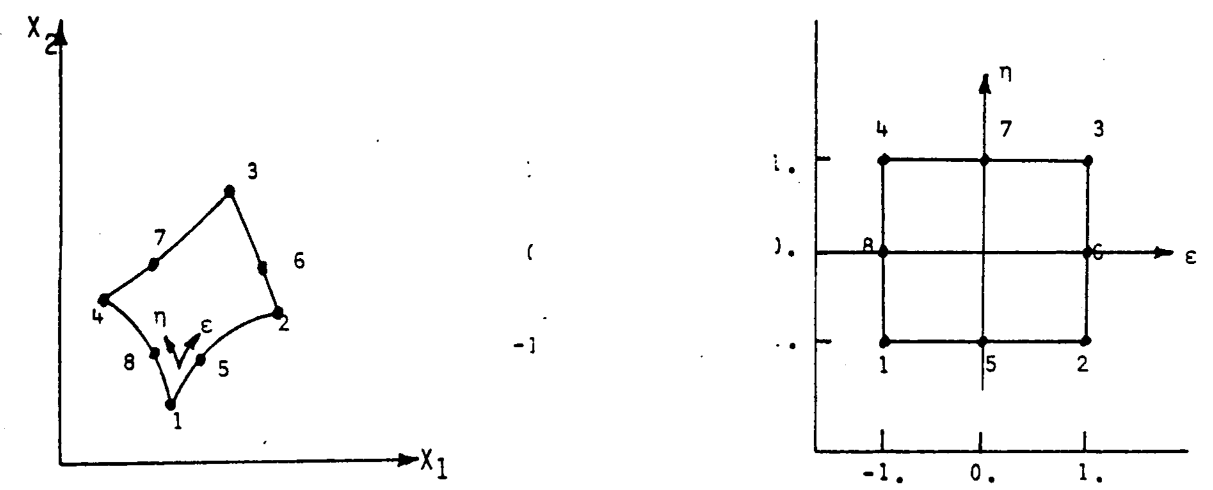


Fig. B.1.- Super Element and Finite Element Discretizations For Isolated Two-Dimensional Airfoil



B.2a Physical Plane

B.2b Transformed Plane

Fig. B .2 Mapping of a Quadrilateral Onto a Natural Coordinate Plane (ε η) where the ε, η axis bisects the quadrilateral and the equations are ordered according to the grid point numbering noted in Figure A.2. Substitution of equation B.2 into B.1 for a specific set of $\{x_i\}$ and evaluating the equation over the limits of ε and η (-1 to 1) yields a biquadratic approximation to x over the subdomain. Accuracy of the values of x_i are dependent upon the ability of the shape functions to approximate the physical geometry. A curvature which is exactly biquadratic, for instance, will be interpolated exactly using equation B.2. Note in Figure B.2b that the side located grid points lie at exactly midside, by definition. The side nodes in Figure B.2a, however, need not be at exactly mid-side since it is not required in the definition of {Q}. Movement of the specification of the side nodes in the physical plane, therefore, allows for a smoothly varying distribution of generated data over the subdomain as illustrated in Figure B.1. The coordinate transformation is of the serendipity family and can yield nonunique distributions if excessive skewing of the mid-side node is attempted; therefore, care must be taken when applying the method as in Figure B.1, where regions of highly refined grid are necessary along the airfoil surface.

Each of the subdomains of which the entire solution domain is composed may be treated independently if the data generated along subdomain boundaries is identical for each subdomain. This requires that intersubdomain boundaries share the same grid points and that $(\varepsilon;\eta)$ be independent along the subdomain interfaces. To illustrate that this is indeed the case, consider the two coincident subdomains of Fig. B.3.

Along the common boundary $(3,4,7)_1$ and $(4,1,8)_2$

$$\eta_1 = C = 1.0$$

$$\varepsilon_2 = c = -1.0$$

and evaluating equation (2) with these constraints yields:

$$Q = L\tfrac{1}{2}(\varepsilon + \varepsilon^2),\ \tfrac{1}{2}(-\varepsilon + \varepsilon^2),\ (1 - \varepsilon^2) \qquad (B.\ 3)$$

$$Q = L\tfrac{1}{2}(-\eta + \eta^2),\ \tfrac{1}{2}(\eta + \eta^2),\ (1 - \eta^2) \qquad (B.\ 4)$$

And since $\varepsilon_1 = -\eta_2$ along the boundary, equation (A.3) becomes

$$Q = L\tfrac{1}{2}(-\eta + \eta^2),\ \tfrac{1}{2}(\eta + \eta^2),\ (1 - \eta^2) \qquad (B.\ 5)$$

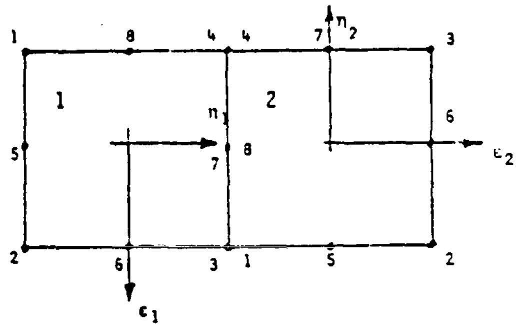


Fig. B .3 Two adjacent subdomains .

which is identical to equation (B.4). Other boundary combinations and the triangular shaped subdomain can be shown to yield similar results. Three-dimensional subdomains have surface interfaces and similar equations can be derived as above where the equivalent of equation (B.5) contains functional expressions for a planar surface. This demonstrated generality, therefore, completely eliminates any requirements for specifying the subdomains in a particular order and numbering may begin at any vertex.

It is impossible to encompass the entire spectrum of geometric shape and refinement requirements within a few subdomain types. The completeness of a data refinement scheme, therefore, requires that addition to its geometric flexibility be open ended. Utilizing the subdomain method, special subdomain functions may be developed and inserted directly into the system. An example of this is a telescoping quadrilateral having quadratic interpolation. The purpose of this special function is to provide a means for increasing or decreasing the number of generated triangular elements when progressing from one end of a subdomain to another. Fig. B.4 illustrates the effect for a quadrilateral expanding from three elements per side to six elements per side. This subdomain has proven very useful for flows having small areas of high velocity gradient where a very fine mesh is required relative to the overall flowfield mesh size, and windowing-in is not practical. Fig. B .5 illustrates such a case where vortex generation at a wing tip is to be computed. Very high velocity gradients occur in the immediate area of the tip and decay rapidly. Utilizing the telescoping subdomain, the grid size is reduced from six elements per side in the tip region to two elements per side where an infinite boundary condition was applied and 64 elements were eliminated from the computational domain.

The interpolation functions described above are used to distribute the grid point data over each subdomain. Combining the subdomains to form the complete **discretization**, however, poses the problem of having duplicate sets of data along the interconnecting boundaries. Removal of the duplication is accomplished through the construction of a subdomain connection table from the specified data and interrogating it from an algorithm which operates over the subdomain boundaries. Table B.1 illustrates the connection table for the first four subdomains of Fig. B.1. The storage requirements for the table are 2Σ(no. of subdomain sides).

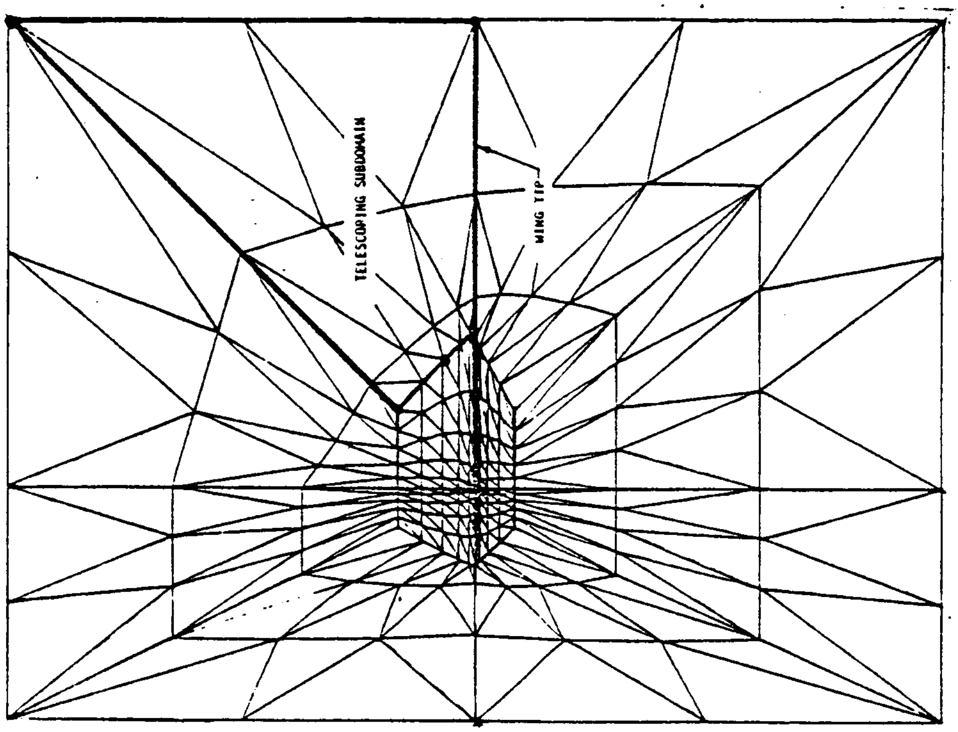


Fig. B .5- Wing tip discretization using telescoping subdomain

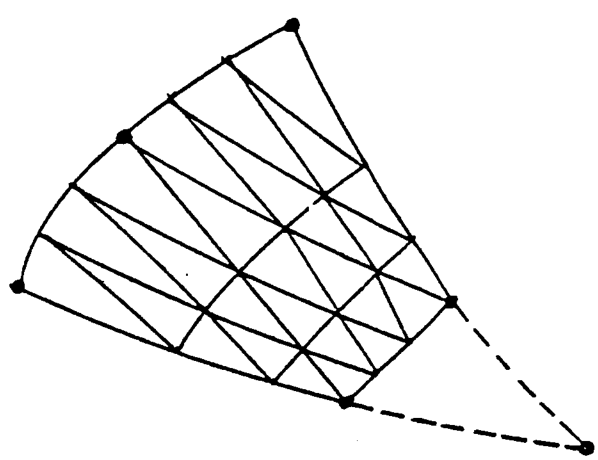


Fig. B.4 - Telescoping subdomain

TABLE B.1 Subdomain Connection Table for Joukowski Airfoil. (First 4 Subdomains)

Subdomain	Side	Subdomain	Side
1	1	10	3
1	2	0	0
1	3	2	1
1	4	0	0
2	1	1	3
2	2	0	0
2	3	3	1
2	4	0	0
3	1	2	3
3	2	0	0
3	3	4	1
3	4	0	0
4	1	3	3
4	2	0	0
4	3	5	1
4	4	0	0

Note that the first two columns need not be stored since they are sequential. For the solution domain of Fig.B .1, therefore, only eighty words of storage are required to administrate boundary duplication elimination. The algorithm proceeds subdomain by subdomain, first generating a sequence of local (dummy) node numbers, then interrogating the connection table to determine if any sides are connected to any other subdomain. Upon finding one which is of lower number it retrieves the local boundary node numbers for that subdomain and substitutes them for the coincident set into the proper locations. Simultaneously, the duplicate generated variable set at the boundary is eliminated. The finite element connection table is subsequently formed for all generated elements in the subdomain and sequential global node numbering is substituted in a simple loop at the end. The connection table is also useful for locating external boundaries since they appear as zeros in the table. Note in the above scheme that only the subdomain data were manipulated to sequence the generated data thus maintaining higher efficiency of the algorithm. Also, storage requirements are minimized by requiring operation on not more than two subdomains simultaneously, hence the data for a large problem could be generated interactively on a minicomputer or small time sharing system utilizing disk or tape intermediate storage. An especially useful feature of such a method when combined with a graphics package and a video (CRT) terminal is the ability to interactively modify and debug data decks. The above scheme is very efficient and generated data for 24 variables over 10 nodes/CPU sec on an IBM 360-65.

APPENDIX C

Command Name Input

```
A CONTROL CARD WITH THE FOLLOWING PARAMETERS IS READ IN -

    PARAMETER FORMAT     CARD COLS.      DESCRIPTION

    V1        A8          1 - 8     CONTROL VARIABLE.
    NMUL      FREE       AFTER 8    NMUL(1) = NX
                                    NMUL(2) = NPCD
                                    NMUL(3) = NREPET
                                    NMUL(4) = NRTAPE
                                    - - -
                                 TO NMUL(N)

IF KDUMP = 1 IN NAME01, THEN THE ENTIRE INPUT CARD IS PRINTED
IMMEDIATELY AFTER BEING READ FOLLOWED BY THE DATA THAT IS BEING
STORED ALONG WITH THE DATA'S ENTRY POSITION IN THE IZ ARRAY
```

ABSVAL N1 N2 N3	SET RZ(IZ(N2)) = ABS(RZ(IZ(N3))), I = 1, N1
(BLANK)	RETURN TO SCAN ANOTHER CARD.
COMDC	PRINT THE COMDC TITLE PAGE TWO TIMES.
COMTITLE	READ A TITLE CARD WHICH WILL APPEAR ON COMDC.
DESCRIPT NX	CALL DSCRPT AND PROCESS ACCORDING TO NX. NX BLANK - READ AND WRITE INFORMATION CARDS. 203 - READ TITLES FOR DEP. VAR. OUTPUT HEADINGS. 204 - READ DESCRIPTIVE TITLE FOR HEADING AT BEGINNING OF OUTPUT HEADER. 332 - READ TITLES FOR PARAMETERS PRINTED IN THE OUTPUT HEADER.
END	RETURN CONTROL TO MAIN PROGRAM, RESET ARRAYS AND RETURN TO BDINPT.
EXIT	CALL EXIT.
2DPF	SET IBL = 0 AND IPHI = 1.
3DBP	SET IBL = 1.
3DPNS	SET IBL = 1 AND N3DPNS = 1.
2DNS	SET IBL = 0.
FEDIMN	CALL DIMENSIONALIZATION ROUTINE FEDIMN.
FENAME	CALL FENAME TO SET DEFAULT SCALARS AND THEN CALL NMELST TO READ IN NAME01 AND NAME02 NAMELISTS.

COMMAND NAME	DESCRIPTION
IARRAY N1, N2, N3, N4, ETC.	SET IARRAY(N1) = N2, IARRAY(N3) = N4, ETC.
ICOND	CALL ICOND TO PRINT REAL AND INTEGER SCALARS.
INDEXSET N1 N2 N3 N4 N5 N6 N7	DO FOR I = 1, NX K = IZ(IZ(N2)+N3+I) - 1 RZ(IZ(N4)+N5+K) = RZ(IZ(N6)+N7+I)
INPUT N1	SET INPUT UNIT TO N1.
INTEGER	ALLOWS NEW VALUES TO READ INTO A SEQUENCE OF LOCATIONS IN THE BORDER, IPLACE AND NLOC VECTORS.
KBND NX	ENTER FIXED NODES FOR DEP. VARIABLE NX. CALL GETBND
KBND NX 1	ENTER FIXED NODES AND/OR BOUNDARY CONDITIONS FOR DEP. VARIABLE NX. CALL GETBCD
LINK1 NX	CALL LINK1(NX)
LINK2 NX	CALL LINK2(NX)
LINK3 NX	CALL LINK3(NX,DUMMY1,DUMMY2)
LINK4 NX	CALL LINK4(NX,K)
LINK5 NX	CALL LINK5(NX)
MATSUM N1, N2, N3, N4, N5	CALL MATSUM (RZ(IZ(N2)), RZ(IZ(N3)), RARRAY(N4), RZ(IZ(N5)), N1)
NAMELIST	CALL NMELST TO READ IN NAME01 AND NAME02 NAMELISTS.
PDUMP N1 N2 N3	CALL PDUMP (IZ(IZ(N2)), IZ(IZ(N3)), N1)
PLUS N1 N2 N3 . . . ETC.	RARRAY(N1) = RARRAY(N2) + RARRAY(N3) + . . . +
RARRAY N1 N2 . . . C1 . . . CN . . . NN	RARRAY(N1) = RARRAY(N2) * . . . C1 * . . . RARRAY
READ N1 N2 N3 N4	READ (N1) RZ(IZ(N3)+N4) , I = 1, N2
RETRIEVE N1 N2	CALL NBNDRY (1, IZ(N2), IZ(IYY)) WITH NP = N1.
RESTOR N1 N2	CALL RESTOR (N1, IZ(N2), IZ(IYY))
SAVETAPE N1 N2	SAVE OUTPUT ON UNIT N1, REWIND AFTER MOD (KOUNT, N2) = 0.
SETVAL N1 N2 N3 N4 N5	CALL SETVAL (RZ(IZ(N2)), RZ(IZ(N3)), RARRAY(N4), RARRAY(N5), N1)
SQRT N1 N2 ...	RARRAY(N1) = SQRT(RARRAY(N2) RARRAY(N3) = SQRT(RARRAY(N4)) . . . ETC.
SQRT N1 N2 N3	RZ(IZ(N2) = SQRT(RZ(IZ(N3))), I = 1, N1
VECMUL N1 N2 N3 N4	DO FOR I = 0 TO NX-1 RZ(N2+I) = RZ(N3+I) * RZ(N4+I)
VYYEND NX	DENOTES END OF INPUT FOR DEP. VAR. NX.
WRITE N1 N2 N3 N4	WRITE (N1) RZ(IZ(N3)+N4) , I = 1, N2

THE FOLLOWING COMMANDS ARE UTILIZED TO LOCATE STORAGE ADDRESSES FOR INTEGER ARRAY DATA SPECIFICATION. THE CARDS ARE DIRECTLY FOLLOWED BY INTEGER DATA CARDS IN FREE FORMAT. THE READ SCAN IS TERMINATED BY A 'T' OR BLANK CARD.

IZ(IPLACE(K)) = LOCATION IN THE IZ ARRAY AT WHICH TO BEGIN STORING INTEGER ENTRIES.

IARRAY(NLOC(K)) = NUMBER OF ENTRIES STORED STARTING AT IZ(IPLACE(K)).

IF NX .NE. -1, ENTER LITERAL DATA. *
IF NX .EQ. -1, ENTER NUMERICAL DATA DIRECTLY.

K	COMMAND NAME	IPLACE(K)	NLOC(K)	DESCRIPTION.
3	THICK	68	93	ELEMENT THICKNESS VECTOR.
7	IPINT	5	31	SOLUTION SEQUENCE VECTOR.
12	LINKCALL	121	125	LINK NOS. TO BE CALLED AT END OF QKNUIN.
13	SPECIES	31	121	VARIABLE NOS. FOR SPECIES TO BE RUN.
14	IOMULT	123	67	OUTPUT VARIABLE MULTIPLIER FROM RARRAY.
15	IOSAVE	124	60	VARIABLE LIST TO BE DISPLAYED AT OUTPUT.
16	CNTPTS	127	47	CONTOUR NODES TO BE USED IN CONTES, DFCFBL, TRBTHK, WLFLXS, ETC.
17	CNTNDS	128	128	NO. OF NODES IN EACH CONTOUR LINE.
18	IBORD	38	131	COUNTER-CLOCKWISE LIST OF BOUNDARY.
21	IONUMB	131	142	LIST OF ENTRIES IN RARRAY TO BE DISPLAYED AT START OF EACH OUTPUT.
22	MPARA	135	67	LIST OF MULTIPLIERS IN RARRAY USED TO MULTIPLY IONUMB ENTRIES.
26	NX	74	67	DUMMY
27	NY	758	67	DUMMY
28	ELEMENTS	26	67	READ IN ELEMENT NODE CONNECTIONS.

* REFER TO SUBROUTINE 'GETBND'.

NOTE -
NLOC(K) OR NVOC(K) = 67 IMPLIES PRESET LENGTH IS NOT CHANGED.

THE FOLLOWING COMMANDS ARE UTILIZED TO LOCATE STORAGE ADDRESSES FOR REAL ARRAY DATA SPECIFICATION. THE NAME CARDS ARE DIRECTLY FOLLOWED BY REAL DATA CARDS IN FREE FORMAT. THE READ SCAN IS TERMINATED BY A 'T' OR BLANK CARD.

IZ(NPLACE(K)) = LOCATION IN THE IZ ARRAY AT WHICH TO BEGIN STORING REAL ENTRIES.

IARRAY(NVOC(K)) = NUMBER OF ENTRIES STORED STARTING AT IZ(NPLACE(K)).

THESE CONTROL CARDS CAN CONTAIN A GROUP OF MULTIPLIERS FOR THE ENTERED DATA.
E. G.
VYY 3 -100.0 -27
MULTIPLIES EACH INPUT VECTOR NUMBER BY
-100.0 * RARRAY(3) / KARRAY(27)

K	COMMAND NAME	NPLACE(K)	NVOC(K)	DESCRIPTION.
3	VU3PCS	65	178	X STATION FOR VARIABLE GRID CHANGE.
4	VU3VAL	66	67	SCALE FACTOR FOR VARIABLE GRID CHANGE.
5	VTHICK	70	67	VALUE OF ELEMENT THICKNESSES. DEFAULT = 1.0 / ALC
6	VRHO	84	67	DENSITY AT NODE POINTS. DEFAULT = RHOINF
7	VTTAB	19	59	TABLE LOOK-UP TEMPERATURES. DEFAULT = TOFINF
8	VCPTAB	18	67	TABLE LOOK-UP SPECIFIC HEATS. DEFAULT = CPOINF
9	VX1COR	89	16	X1-COORDINATES AT NODE POINTS.
10	VX2COR	90	16	X2-COORDINATES AT NODE POINTS.
11	VH	79	67	ENTHALPY DISTRIBUTION AT NODE POINTS. DEFAULT = 1.0
16	VPRESS	91	67	PRESSURE VALUES AT NODE POINTS. DEFAULT = PINF
17	VSCHMIDT	114	67	SCHMIDT NO. DIST. AT NODE POINTS. DEFAULT = SCT
18	VYY	92	67	DEPENDENT VAR. DIST. AT NODE POINTS.
19	VTEMP	85	67	TEMPERATURE DIST. AT NODE POINTS. DEFAULT = TOFINF
22	VTK	88	67	THICKNESS OF ELEMENTS IN THICK VECTOR. DEFAULT = 1.0 / ALC
23	VSUTHLD	133	67	STLDVR, STLDTR, STLDCR, STLDEX, STLCON ENTRIES FOR SUTHERLANDS LAW. DEF. .11635-4, 494.0, 204.0, 1.5, 0.0

APPENDIX C (Cont'd.)

K	COMMAND	NPLACE(K)	NVOC(K)	DESCRIPTION
24	VPRANDTL	134	67	PRANDTL NO. DIST. AT NODE POINTS. DEFAULT = PR
25	VX3ST	139	161	DOWNSTREAM STATIONS AT WHICH PRESSURE IS DEFINED.
26	VPVSX	140	67	DOWNSTREAM PRESSURES AT VX3ST.
27	VEPSILON	136	67	TURBULENT VISCOSITY AT NODE POINTS. DEFAULT = XMUINF
29	RARRAY	0	67	RARRAY(NX) = AMULT, WHERE AMULT = COMBINATION OF REMAINING ENTRIES.
31	VWALLSTA	67	82	DOWNSTREAM POS. AT WHICH TO INJECT TRANSVERSE VELOCITY.
32	VWALLVAL	68	81	VALUE OF INJECTED TRANSVERSE VELOCITY.

APPENDIX D

Scalar Variable Descriptions

VALUES IN PARENTHESIS ARE DEFAULT CONDITIONS.

ALPHANUMERIC IARRAY ENTRIES

```
IARRAY NAME       DESCRIPTION
 ENTRY

   96 IBASE  - (200) BASE NO. FOR IZ ENTRIES.
  261 IBC    - NUMBER OF BOUNDARY CONDITION TYPES.
   99 IBL    - 1 = BOUNDARY LAYER PROGRAM
  344 IBLAS  - EPS EXPONENT FOR U2, U3 CONVERGENCE CRITERION.
  207 IBOT   - 1ST ELEMENT AT WHICH TO PRINT DEBUG INFORMATION.
  327 IDDXST - (1)
  127 IDIFRT - NO. OF TIMES TO PRINT INTER. OUTPUT IN LINK1, GETPPR,
                 JNCPPR AND PRSGRD.
  162 IEPSET - 1 = FORCE COMPUTATION OF DISSIPATION FUNCTION.
  347 INCLFT - OUTPUT VECTOR INCREMENT FOR SETVAL AND MATSUM.
                1ST INPUT VECTOR INCREMENT FOR MATSUM.
  348 INCRGT - INPUT VECTOR INCREMENT FOR SETVAL.
                2ND INPUT VECTOR INCREMENT FOR MATSUM.
  158 INITCN - INITIALIZER IN CONTES.
  152 INITKE - 1 = TKE, DISSIPATION ARE ALREADY INITIALIZED.
  295 IPLOTV - DATA SET NUMBER ON WHICH TO STORE DATA FOR PLOTTING.
   42 INPUT  - (5) INPUT LOGICAL UNIT NUMBER.
   28 IPASS  - NO. OF CALLS TO DERVBL.
  105 IPTSPL - (0) = USE LUDWIEG - TILLMAN FORMULA FOR TAU WALL.
             - 1 = USE PATANKER AND SPALDING'S FORMULA FOR TAU WALL.
  132 IPWRIT - DEBUG CODE IN LINK3 AND STRF FOR INTERMEDIATE OUTPUT.
  294 IRAT   - SET = TO 1 WHEN N3DPNS IS FIRST TURNED ON.
  100 IREND  - END POSITION IN 'IZ' ARRAY.
  259 ISIDE  - NUMBER OF SIDES / SUPER ELEMENT.
  322 ISTART - STARTUP CODE IN IMPLCT.
  215 ISUPRS - 1 = SUPPRESS PRINTOUT OF:
                   A. STARTUP IN BDINPT.
                   B. NODE MAP.
                   C. OUTPUT STATIONS.

  186 ITDA   - UNIT NO. ON WHICH TO STORE INTEGRAL PARAMETER DATA
               FOR PLOTTING.
  187 ITDB   - UNIT NO. ON WHICH TO STORE 'PLOTS' DATA FOR PLOTTING.
  205 ITIMER - SET = NO. OF TIMES TO CALL TIMETK SUBROUTINE.
                NOTE: TIMETK NEEDS TO BE DEFINED FOR YOUR INSTALLATION.
   97 ITKE   - 0 = DO NOT INTEGRATE TKE - DISS. EQUATIONS.
               1 = USE TKE - DISS. TO COMPUTE TURBULENT VISCOSITY.
  133 ITOP   - 2ND ELEMENT AT WHICH TO PRINT DEBUG INFORMATION.
  196 ITWALL - 1 = USE DUDY FOR TAU WALL.
  312 IUONLY - (2) NO. OF STEPS UNTIL CONVERGENCE ON U1 ONLY.
  122 IWRIT  - DEBUG PRINT FLAG IN CONTES, DFCFBL, GETFSL AND TAUW.
   92 IZSIZE - MAXIMUM DIMENSION OF IZ VECTOR.
  291 JPR    - 1 = MIDSIDE NODES FOR ETA DIRECTION ARE
                    PROGRESSION RATIOS.
  169 KCDC   - 1 = RESET NLINE TO 50 AND DUMP KODE TO 2.
   61 KDUMP  - PRINT INPUT CARDS AND DATA GENERATED IN BDINPT.
  167 KNTPAS - (99) MAXIMUM NO. OF INTEGRATION STEPS BETWEEN PRINTS.
```

```
  6 KODG   - PRINT GEOMETRY OUTPUT IF .NE. 0.
  7 KOD5   - PRINT INTERMEDIATE DERVBL OUTPUT KOD5 TIMES.
 26 KOUNT  - RUNNING COUNT OF OUTPUT. ( LIMITED BY LPRINT.)
113 KPLVAR - (10) NO. OF VARIABLES TO BE PLOTTED OR PUNCHED.
 86 KPNT   - 1 = PRINT STATION ( SET DURING EXECUTION.)
  8 KPRINT - PRESENT VALUE OF PRINT COUNTER.
 52 KROW   - (100) NO. OF ROWS IN DISCRETIZATION.
151 KWFLXS - (LCOL) NO. OF SLICES AT WHICH TO COMPUTE TAU WALL.
 50 LCOL   - (20) NO. OF COLUMNS IN DISCRETIZATION.
 47 LG     - NO. OF COLS.  IN SOLUTION FIELD.
           -   IF .NE. 0 ON INPUT, THEN CNTPTS AND CNTNDS ARE
           -   TO BE READ IN.
330 LMDJAC - (1) COMPUTE JACOBIAN EACH ITERATION.
214 LMLT   - (LG) NO. OF CONTOURS FOR WHICH TO COMPUTE MIX. LENGTH
                   TURBULENT VISCOSITY.
179 LOC    - INTERVAL NO. FOUND IN LOOK SUBROUTINE.
172 LOWD   - (2) USE LAMINAR VISC. BELOW LOWD AND MLT FROM LOWD ON.
376 LPHI   - +/- 1 TO EVALUATE PHI OR PP RHS IN PPRES.
353 LPLOT  - FLAG TO INITIATE PRINT OF DATA AT PLOT STATION.
             (SEE DPSISQ AND REOUTP)
354 LPLTPR - FLAG TO ACTUATE PRINT OF DATA AT PLOT STATION (REOUTP)
352 LPPNCH - NO. OF PASSES BEFORE LPUNIT TAKES AFFECT FOR K, EPS.
 34 LPRINT - (100) LIMIT ON OUTPUT COUNT.
351 LPSUP  - NO. OF DATA STATIONS BEFORE LPLTPR TAKES AFFECT.
350 LPUNIT - UNIT NO. ON WHICH TO STORE PP, U1, U2, U3, K, EPS DATA.
212 MLTRHS - (1) NUMBER OF RIGHT HAND SIDES TO SOLVE FOR IN STRF.
377 MONE   - -1 IN PPRES TO ALTERNATE SIGN OF LPHI.
 23 NB     - (4) NO. OF CHAR. IN EACH WORD OF OUTPUT VAR. TITLE.
305 NBAND  - (2*LCOL+3) MAXIMUM BANDWIDTH OF JACOBIAN MATRIX.
170 NBC    - MAX. NO. OF BOUNDARY COND. FOR ANY ONE DEP. VAR.
131 NBORD  - NO. OF NODES AROUND BORDER OF DISCRETIZATION.
 22 NC     - (8) NO. OF CHARACTERS IN OUTPUT FORMAT.
125 NCALLS - (10) NO. OF ROUTINES TO CALL AT END OF INTEGRATION STEP.
108 NCNADD - BEGIN U2, U3 INTEGRATION AFTER NCNADD INTEGRATION STEPS.
173 NCOMOC - NO. OF CARDS READ IN FOR COMOC TITLE PAGE.
210 NCOMPG - (35) NO. OF ENTRIES TO PRINT FROM PRGDUM COMMON BLOCK.
174 NCOMTD - NO. OF CARDS READ IN FOR TITLE INFORMATION.
307 NCONV  - NON-CONVERGENCE FLAG SET IN IMPSLV.
 13 NCOORD - FLAG FOR GENERATING AXI-SYMMETRIC DATA IN GEOMFL.
 59 NCPTAB - (1) NO. OF ENTRIES IN SPECIFIC HEAT TABLE.
  1 ND     - INITIALIZATION PARAMETER IN DFCFNS.
317 NDBGPT - NO. OF ENTRIES TO PRINT IN VECTORS FOR DEBUGGING.
124 NDERIV - (2) = CALL DERVBL.
194 NDP    - (10) SPACE ALLOCATION IN IIPINT VECTOR.
 14 NELEM  - NUMBER OF ELEMENTS IN SOLUTION.
304 NELPAS - INTEGRATION STEP COUNTER.
 31 NEQ    - (5) MAXIMUM NO. OF VARIABLES TO BE SOLVED.
 43 NEQADD - NO. OF DIFF. EQNS. INITIALLY NOT SOLVED.
           - E.G. -2 = DELAY INT. TKE AND DISS.
                       UNTIL C4EDSW IS SATISFIED.
286 NEQAV2 - WHEN NCNADD IS SATISFIED, NEQADD = NEQAV2 + NEQAV3.
287 NEQAV3 - WHEN NCNADD IS SATISFIED, NEQADD = NEQAV2 + NEQAV3.
 58 NEQKNN - (1) NO. OF DEP. VAR. TO BE INTEG. IN QKNUIN.
 37 NEWPRT - (5) NO. OF SCALARS TO PRINT ACROSS A PAGE (MAX. = 8).
107 NE1E2  - 0 = DO NOT USE MIXING LENGTH THEORY FOR DIFF. COEF.
             1 = USE MLT FOR SOLUTION OF DIFF. COEF.
             2 = DELAY USING MLT UNTIL E1E2SW IS SATISFIED.
 46 NF     - (4) NO. OF 'NB' BYTE WORDS IN TITLE FOR EACH DEP. VAR.
 54 NHHALF - PASS AT WHICH MAXIMUM ITERATIONS TOOK PLACE.
 53 NDB    - CURRENT PASS (FOR PRINT POINT).
 68 NI     - STARTING LOC. IN DEP. VAR. MATRIX FOR THIS VARIABLE.
301 NIMPLT - (1) IMPLICIT INTEGRATION SCHEME BEING USED.
```

```
IARRAY NAME      DESCRIPTION
 ENTRY

  316 NIT     - KODE FOR DEBUG PRINT OF:
                1. JACOBIAN
                2. L/U DECOMPOSITION
  302 NITER   - ITERATION COUNTER.
   94 NIZS    - (200) NO. OF IZ ENTRY POINTS THAT CAN BE STORED.
  323 NLAST   - KODE FOR LAST STATION WHEN DX .LT. H.
   88 NLINE   - (60) LINE COUNT OUTPUT CONTROL.
  191 NM      - (3) TYPE OF ELEMENTS IN SOLUTION.
              - 2 = LINE (ONE-DIMENSIONAL).
              - 3 = TRIANGLE (TWO-DIMENSIONAL).
  306 NMBJAC  - (NBAND*NNODE) NO. OF ENTRIES IN JACOBIAN.
   60 NMBOUT  - (30) NO. OF VARIABLES TO BE PRINTED.
  206 NMDL    - (8) ALLOW EXTRA STORAGE IN IZ(71) AND IZ(72-76)
                LENGTH OF IZ(71) = MAXIMUM (NODE, NODE*NMDL)
                LENGTH OF IZ(72-76) = MAXIMUM ( NODE, (NODE/2)*NMDL)
  190 NMOUT   - (3) = PRINT OUTPUT IN GEOMETRY FORM.
                2 = PRINT OUTPUT IN NODE NO. SEQUENCE.
  193 NM2     - NM**2. USED FOR STORING FULL MATRICES.
   16 NNODE   - NUMBER OF NODES IN SOLUTION.
  340 NNROW   - NO. OF COLS. (ROWS) ON ONE SIDE OF JUNCTURE CORNER.
   55 NODE    - (100) VARIABLE DIMENSIONING PARAMETER IN FEDIMN.
  233 NODES   - (NODE) VECTOR LENGTH FOR REFINE GRID GENERATOR.
   19 NOE     - NO. OF EQUATIONS BEING SOLVED FOR DEP. VAR. 'NP'.
  325 NOUEDG  - FLAG TO STORE UEDGE FROM CP INFORMATION INTO U1 VECTOR.
  142 NOUTPR  - (100) NO. OF SCALARS TO PRINT IN OUTPUT.
   40 NOUTS   - (10) NO. OF OUTPUT VECTORS TO PROCESS AT ONE TIME.
   38 NOUTVC  - (5) NO. OF OUTPUT SCALARS ACROSS PAGE AT PRINT STATION.
   30 NP      - DEP. VARIABLE BEING SOLVED AT THIS TIME.
  157 NPASS   - NO. OF PASSES THRU DERVBL.
  336 NPDBUG  - NO. OF ITERATIONS FOR DEBUG IN DERVBL AT DEBUG POINT.
  198 NPGRDT  - (4) STARTUP COUNTER USED IN PRSGRD.
  199 NPGRDV  - (4) STARTUP COUNTER USED IN PRSGRD.
   20 NPRNT   - (132) NO. OF PRINT POSITIONS ON A LINE OF OUTPUT.
  153 NPUNCH  - SET = 7 IF ELEMENTS AND NODES ARE TO BE PUNCHED IN DIMEN.
  161 NPVSX   - (2) NO. OF PRESSURES IN P VS X TABLE.
  371 NPVSXT  - NO. OF ENTRIES IN EACH TABLE. (USED WITH NTABPT).
  313 NR      - NO. OF PRINTS FOR IMPLICIT INTEGRATION DEBUG.
  328 NRJACB  - (1) COMPUTE JACOBIAN EACH ITERATION.
   67 NS      - GENERAL DUMMY PARAMETER.
  154 NSD     - INITIALIZATION CODE IN DFCFBL.
  252 NSELEM  - NO. OF SUPER ELEMENTS IN GRID GENERATOR.
  146 NSFDBE  - RESET CONDITION FLAG IN 'FINDBE'.
   27 NSKIP   - (NODE) NO. OF BOUNDARY LOC. / DEP. VAR.
   64 NSM     - (10) STOP PROGRAM IF ANY OUTPUT EXP. IS .GT. NSM.
  251 NSNODE  - NO. OF SUPER NODES IN GRID GENERATOR.
  189 NSTD    - (8) NO. OF STANDARD MATRICES TO BE STORED.
  155 NS2     - INITIALIZATION CODE IN DFCFBL.
  394 NTABPT  - NO. OF TABLES TO BE READ IN CPSTUP.
  140 NTCNTS  - STARTUP PARAMETER IN CONTES.
  203 NTCRDM  - STARTUP PARAMETER IN XYCRDM.
   62 NTITL   - (10) NO. OF TITLE CARDS TO BE READ IN AND PRINTED AT THE
                        BEGINNING OF EACH OUTPUT SET.
  197 NTPRNT  - 99999 = DO NOT PRINT INTEGRAL PARAMETERS IN TRBTHK.
  177 NU2POS  - (20) MAX. NO. OF ENTRIES FOR VAR. GEOMETRY DEFINITION.
                        (CROSS PLANE)
  178 NU3POS  - (20) MAX. NO. OF ENTRIES FOR VAR. GEOMETRY DEFINITION.
                        (TRANSVERSE PLANE)
  260 NVAR    - NUMBER OF VARIABLES TO BE DISTRIBUTED OVER REFINED GRID.
   90 NYY     - (4)  SETS (NODE) / DEP. VAR. LOCATION IN IYY VECTOR.
   91 NZZ     - (4) SETS (NODE) / DEP. VAR. LOCATION IN IZZ VECTOR.
  192 N2M     - (NM*2)  USED FOR STORING SYMMETRIC MATRICES.
  166 N3DPNS  - SET = 1 WHEN JV .LE. (NEQKNN+NEQADD) IN IMPLCT.
```

APPENDIX D (Cont'd.)

```
RARRAY NAME      DESCRIPTION
 ENTRY

  156 AINF    - REFERENCE SPEED OF SOUND.
    5 AJ      - (778.28) JOULES CONSTANT.
    3 ALC     - (MIN. SIDE) CHARACTERISTIC ELEMENT SIZE.
  393 AM8     - TERM 8 MULTIPLIER IN PPRES FOR PP EQUATION.
  275 AOMGEX - (2.0) EXPONENT ON WALL DAMPING FACTOR 'OMEGA'
   86 AVD     - (25.3) DAMPING FACTOR IN DFCFBL.
  137 AVDP     AVDP = AVD * SQRT(RHO/RHOWAL) * ANULOC / ENUT
  279 BEXP    - (4.0) GAMMA = 0.01 * DELTAY * (Y/DELTA)**BEXP
  209 BLTH    - BOUNDARY LAYER THICKNESS, DELTA.
  176 CBTOKJ - (4.184) SPECIFIC HEAT BRITISH TO MKS.
  311 CC1     - COEF. FOR REYNOLD STRESSES COMPUTED FROM CPHI1 AND CPH2
                       IN DIMEN.
  312 CC2     - SAME AS CC1.
  313 CC3     - SAME AS CC1.
  314 CC4     - SAME AS CC1.
  365 CD      - (0.09) TKE - DISS. COEF.
  356 CE      - (1.0) DIFF. COEF. MULTIPLIER FOR TKE.
  303 CHIEPS - (1.0E-4) CONVERGENCE FACTOR FOR IMPLICIT INTEGRATION.
  302 CHISTP - (4.0) MAX. NO. OF ITERATIONS FOR INCREASING STEP SIZE.
  322 CHITST - (10.0) MAX. NO. OF ITER. BEFORE DECREASING STEP SIZE.
  304 CIMPTH - (0.5) RELAXATION FACTOR FOR IMPLICIT INTEGRATION.
  364 CK      - (1.0) TKE - DISS. COEF.
  211 CFOV2   - SKIN FRICTION
   83 COMPX   - COMPRESSION FACTOR FOR OUTPUT COL. VECTOR
                     INDICATES PERCENT OF X3 AXIS TO BE USED TO SHORTEN
                    SPACING INTERVALS.
   84 COMPY   - COMPRESSION FACTOR FOR OUTPUT ROW VECTOR.
                    SAME AS COMPX, BUT FOR X2 AXIS.
  124 CON     - (0.435) KARMANN'S CONSTANT USED IN MLT IN DFCFBL.
   70 CONRHO - IF .GT. 0.0, SET ALL RHO = CONRHO.
   62 CONV    - (1.0) OUTPUT SCALE FACTOR = 1.0 / REFL.
  207 CONVRG - REAL NO. EQUIVALENT OF NCONV (NO. OF ITERATIONS).
  309 CPHI1   - (2.8) EMPIRICAL CONSTANT FOR COMPUTING CC1 - CC4
  310 CPHI2   - (0.45) EMPIRICAL CONSTANT FOR COMPUTING CC1 - CC4
  158 CPA     - (.24*32.174) SPECIFIC HEAT OF AIR.
  159 CPH     - (3.445*32.174) SPECIFIC HEAT OF HYDROGEN.
  160 CPINF   - SPECIFIC HEAT COMPUTED IN CPINIT.
   30 CPOINF - (0.24*31.174) REFERENCE SPEDIFIC HEAT.
  153 CVCP    - (4186.0) SPEC. HEAT CONVERSION FACTOR.
  148 CVH     - (1.0) ENTHALPY CONVERSION FACTOR.
  151 CVP     - (4.725E-4) PRESSURE CONVERSION FACTOR.
  152 CVRHO   - (16.02) DENSITY CONVERSION FACTOR.
  150 CVT     - (1.0) TEMPERATURE CONVERSION FACTOR.
  149 CVU     - (0.3048) VELOCITY CONVERSION FACTOR.
  357 CW      - (1.0) SCALE FACTOR FOR DISSIPATION DIFF. COEF.
  182 C1DORF - (1.44) DISS. FCT. PRODUCTION TERM COEFFICIENT.
  183 C1KORE - (1.0) TKE PRODUCTION TERM COEFFICIENT.
  183 C2DORF - (1.92) DISS. FCT. DISSIPATION TERM COEFFICIENT.
  184 C2KORE - (1.0) TKE DISSIPATION TERM COEFFICIENT.
  315 C2C4    - (CC2*CC4) COEF. FOR DIFFUSION COEFFICIENTS.
  143 C4EDSW  - (30000.0) TKE - DISS. STARTUP POSITION IN DFCFBL.
  318 DCHECK - (DSTART*SSINIT)**3)
  336 DELCHK - (DELTST*DELMLT) GEN. AND DISS. TERMS FOR TKE, EPS
                 ARE SET TO 0.0 WHEN, DELUSQ .LT. DELCHK.
  338 DELMLT - (1.0E-5) SCALE FACTOR FOR DELCHK.
   13 DELP    -(2.0) PERCENT INTERVAL FOR PRINTOUT.
  205 DELSTR - DISPLACEMENT THICKNESS.
  337 DELTST - FIRST DERVBL PASS FOR LARGEST GRAD*U**2 ON ELEMENT.
  103 DEPLT   - (101.0) PERCENT OF TD TO BE USED FOR PLOTTING STATIONS.
  165 DRTODK - (5.0/9.0) DEGREES RANKINE TO DEGREES KELVIN
  319 DSTART - (10.0) SCALE FACTOR FOR DCHECK.
  390 DYNPRS - SET .GT. 0.0 FOR CONSTANT PRESSURE FIELD.
```

```
RARRAY NAME       DESCRIPTION
 ENTRY

 175 EBTOKJ - (2.3244) ENTHALPY BRITISH TO MKS.
 358 EFMULT - (-0.01) ABS(EFMULT) BECOMES LARGEST LEVEL
                       OF TKE INITIALIZED.
  90 EKNINF - (UINF**2) TKE NON-D FACTOR.
 204 ENER   - DIMENSIONAL ENERGY FOR U1 VELOCITY.
 135 ENERGY - NON-DIM. ENERGY FOR U1 VELOCITY.
 108 ENMULT - DIMENSIONALIZING FACTOR FOR ENERGY.
                (XMUINF*RE*UINF*UINF/(G*ALC**(NM-1))
  14 EPS    - CONVERGENCE FACTOR FOR INTEGRATION STEP.
  89 EPSINF - (UINF**3/ALC) NON-D FACTOR FOR DISSIPATION.
 274 EPSMIN - (1.0E-5) SCALE FACTOR ON XMUINF FOR MINIMUM
              LEVEL OF DIFFUSION.
  95 EPTEST - * EPMULT = ZERO TEST FOR DISSIPATION USED IN DERVBL.
  68 EP4MD  - (1.0) MULTIPLIER FOR XMDOT IN PRSGRD.
 368 ESCF   - (3.0) SCALE FACTOR IN TKE AND DISS. LENGTH.
 171 EULER  - (PSTAG/(RHOINF*UINF**2) EULER NUMBER.
 145 E1E2SW - (30000.0) STATION AT WHICH TO SET NE1E2 = 3 - NE1E2.
   1 FACT   - (ALC) NON-DIMEN. FACTOR.
  80 FACTH  - (1.0 / (CPOINF*TOFINF))
  59 FACTMU - (RHOINF*UINF*ALC)
  79 FACTP  - (1.0 / FACTMU)
 163 FTTOCM - (30.48) FEET TO CENTIMETERS.
 162 FTTOIN - (12.0) FEET TO INCHES.
 164 FTTOMT - (0.3048) FEET TO METERS.
 189 F1     - Y-COORDINATE OF F1 CURVE.
 329 F10    - LAST VALUE OF F1 CURVE.
 327 F2     - Y-COORDINATE OF F2 CURVE.
  31 G      - (1.0) GRAVITATION CONSTANT.
 277 GAMEXP - (9.0) GAMMA = 1.0/(1.0 + GAMFAC*(Y/DELTA)**GAMEXP)
 276 GAMFAC - (1.0E-20) SEE GAMEXP DEFINITION.
  60 GAMMAF - (1.4) FACTOR USED IN GAS LAWS.
 263 GSCALE - (0.1) SCALE FACTOR FOR U1 MULT. OF GRADIENT(PHI) IN PPRES.
 353 GUMULT - KODE TO ADD GRADIENT(PHI) TO RHS OF U2, U3 EQNS.
 142 G1     - Z-COORDINATE OF G1 CURVE.
 381 G10    - LAST VALUE OF G1.
 328 G2     - Z-COORDINATE OF G1 CURVE.
 187 G22    - VARIABLE GEOMETRY FACTOR.
 188 G23    - VARIABLE GEOMETRY SCALE FACTOR.
 140 G32    - VARIABLE FACTOR.
 141 G33    - VARIABLE FACTOR.
  15 H      - CURRENT TRIAL STEP SIZE.
  16 HMAX   - (2.0) MAX. PERCENT OF TD TO USE AS STEP SIZE.
  45 HS     - CURRENT STEP SIZE.
   7 HSINIT - (1.0E-5) START INTEGRATION STEP SIZE AT THIS VALUE.
  12 HT     - OUTPUT VAR. FOR TIME STEP = HS * FACT / REFL
 186 H21    - (1.0) GRID GROWTH SCALE FACTOR.
 386 H21L   - LAST VALUE OF H21. ( USED IN XYCRDM )
 139 H31    - (1.0) GRID GROWTH SCALE FACTOR.
 387 H31L   - LAST VALUE OF H31. ( USED IN XYCRDM )
 272 OMEGXP - (1.5) TKEEXP = 2.0 * ( 2.0 - OMEGXP )
   2 ONE    - (1.0) PROGRAM CONSTANT.
 396 OSG    - ADD STRESSES TO PP EQUATION IN PPRES.
 375 OSH1SQ - (1.0 / H21**2)
```

```
RARRAY NAME      DESCRIPTION
 ENTRY

  136 OSMAX  - HEIGHT OF SOLUTION DOMAIN AT INITIAL STATION.
  271 OSUSQ  - (1.0/TKEINF) MINIMUM TKE LEVEL ALLOWED.
  362 OS12   - 1.0/FACTORIAL(NM+1)
  361 OS6    - 1.0/FACTORIAL(NM)
  363 OS60   - (2.0/FACTORIAL(NM+2))
  339 PCFACT - ADD PC TERM TO U2, U3 EQUATIONS.
  174 PDFTOC - (0.01602) POUNDS/FT**3 TO GRAMS/CM**3
  170 PDFTOK - (16.02) POUNDS/FT**3 TO KG/M**3
   36 PEDDIM - DIMENSIONAL PRESSURE = PEDGE * PSTAG.
   39 PEDGE  - NON-DIM. PRESSURE AT PRESENT STATION.
  268 PHICOD - (1.0/H) GRADIENT PHI MULTIPLIER AT END OF PPRES.
   82 PIBAR  - UTAU COEF. FOR COMP. U1 IN JNCINP.
    9 PINF   - FREESTREAM PRESSURE. DEF. = 1ST VALUE IN P VS X TABLE
  180 PMSKGS - (1.0/2.2) POUNDS / KG.
  340 PPFACT - USE PP TERM IN U2, U3 EQUATIONS.
   99 PPRCON - (RHOINF*UINF**2/ALC)
  100 PPRIME - PRSSURE GRADIENT COMPUTED IN PRESSURE ROUTINE.
   67 PR     - (1.0) PRANDTL NUMBER.
  185 PRDIS  - (1.3) DISSIPATION PRANDTL NUMBER.
  166 PSFTOA - (4.725E-4) POUNDS/FT**2 TO PSIA
  169 PSFTOI - (6.924E-3) POUNDS/FT**2 TO POUNDS/IN**2
  168 PSFTON - (47.88) POUNDS/FT**2 TO NEWTONS/M**2
  167 PSFTOT - (0.3591) POUNDS/FT**2 TO TORR.
  351 PSTAG  - (PINF+0.5*RHOINF*UINF**2)
   20 PTIM   - PRINT TIME PARAMETER IN 'IMPLCT'.
  345 PUMULT - WHEN = 1, USE EDDY VISCOSITY FOR U2, U3 DIFF. TERM.
  179 RADCON - (57.2957759) CONVERSION FACTOR RADIANS TO DEGREES.
   21 RE     -  (RHOINF*UINF*ALC/XMUINF) REYNOLD'S NO.
   43 REFL   - (1.0) REFERENCE LENGTH.
   47 REFLRE - (RHOINF*UINF*REFL/XMUINF) REYNOLD'S NO. BASED ON REFL.
  285 RELAX  - (0.6) RELAXATION FACTOR FOR GRID GROWTH IN LOOKAV.
  289 RHOIM  - (1.0) USE WALL DAMPING FOR TKE, EPS EQNS. IN DERVBL.
   10 RHOINF - (PINF*XMA/(RUNIV*TSINF) FREESTREAM DENSITY.
  157 RHOUIN - RHOINF * UINF
  360 RHSCAL - ADDIT. TERMS FOR REYNOLD STRESSES IN RNLDST.
  199 RNULOC - 1.0 = USE LOCAL VISCOSITY FOR VAN DRIEST DAMPING FACTOR.
  290 ROMULT - (PINF*XMA/(RHOINF*RUNIV*TOFINF) CONV. FACTOR IN DRHOBL.
  119 ROUALC - RHOINF * UINF * ALC**2
  116 RR     - CPH / CPA
   32 RTCON1 - 2.0 * G * AJ
   56 RTCON5 - UINF**2 / (RTCON1*CPOINF*TOFINF)
  117 RTOHM1 - RR * ( TOH/TOA - 1.0 )
```

```
RARRAY NAME       DESCRIPTION
 ENTRY

  280 RUEDSW - (10.0) IF ( Y/DELTA .GT. RUEDSW )
                      EPSDIM = GAMREF*UEDGE*DSTAR*GAMMA
  138 RUESQ  - RHOEDG * UEDG * UEDG
   28 RUNIV  -(1545.33*32.174) UNIVERSAL GAS CONSTANT.
  129 SCT    - (1.0) CONSTANT SCHMIDT NUMBER.
  210 SHPFAC - SHAPE FACTOR.
  301 SIMPLT - (TO) STATION AT WHICH TO START IMPLICIT INT.
  190 SLOPE  - SLOPE OF VARIABLES COMPUTED IN LOOK.
   50 SSINIT - (HSINIT / FACT)
   75 STLCON - WHEN .GT. 0.0, HAVE CONSTANT VISCOSITY.
   73 STLDCR - (204.0) REF. CON. TEMP. IN SUTHERLAND.
   74 STLDEX - (1.5) EXPONENT USED IN SUTHERLAND.
   72 STLDTR - (492.0) REF. TEMP. USED IN SUTHERLAND.
   71 STLDVR - (1.163E-5) VISCOSITY USED IN SUTHERLAND.
  321 STPMLT - (1.1) STEP SIZE MULTIPLIER WHEN
                    ALL VARIABLES CONVERGE ON 1ST ITERATION.
  374 TAREA  - TOTAL COMPUTATIONAL AREA.
  372 TBAR   - MASS WEIGHTED AVERAGE TEMPERATURE.
   35 TD     - (1.0) TOTAL SOLUTION TIME ( DISTANCE ) FROM TO.
   22 TF     - (TF=TO+TD) FINAL STATION.
  206 THETA  - MOMENTUM THICKNESS.
    4 THK    - (1.0) DEF. NON-DIM. THICKNESS OF ELEMENTS.
   23 TIME   - CURRENT STATION.
   48 TIMESV - SAVED TIME LOCATION FOR IMPLICIT INTEGRATION.
   42 TKEDGE - LIMIT ON FREESTREAM EDDY VISCOSITY COMP. IN DFCFBL.
   90 TKEINF - (UINF**2)
  300 TMNTS  - TIME (MINUTES) OF CPU USED.
  305 TMULT  - (1.04) STEP SIZE MULTIPLIER.
   24 TO     - STARTING TIME (DISTANCE).
  146 TOA    - (533.0) AIR REFERENCE TEMP. FOR COMPUTATIONS IN DIMEN.
   58 TOFINF - (533.0) REFERENCE TEMPERATURE.
  147 TOH    - (520.0) H2 REF. TEMPERATURE FOR COMPUTATIONS IN DIMEN.
   40 TRATIO - 1.0 + (GAMMAF-1.0) * XMACHS**2 / 2.0
  284 TSADD  - INITIAL LEVEL FOR SCALE FACTOR 'TSCALE'
  347 TSCALE - SCALE FACTOR FOR T2FIX, T3FIX AND T2PFIX IN PPRES.
  155 TSINF  - STATIC TEMPERATURE COMPUTED IN CPINIT.
  111 TWELVE - (12.0) LENGTH SCALE USED IN BRDSHW.
   26 TWOPI  - (2.0*PI)
  394 T2FIX  - ADD U2 CONVECTION TO RHS OF PP EQUATION.
  398 T2PFIX - ADD U2' AND U3' TO RHS OF PP EQUATION.
  397 T3FIX  - ADD U3 CONVECTION TO RHS OF PP EQUATION.
  371 UBAR   - MASS WEIGHTED AVERAGE VELOCITY.
```

APPENDIX D (Cont'd.)

RARRAY ENTRY	NAME	DESCRIPTION
385	UCMULT	- (1.0) CONVECTION TERM MULTIPLIER FOR U1, TKE, EPS.
203	UED	- EDGE VELOCITY.
63	UEDGE	- UINF / UINFX USED IN BRDSHW.
27	UINF	- FREESTREAM VELOCITY.
354	UINFX	- (UINF)
202	UWALL	- VELOCITY JUST OF WALL.
458	U1MIN	- MINIMUM LEVEL OF U1 ALLOWED WHEN 'SETUP' IS CALLED.
282	U2STRS	- ADD REYNOLD STRESSES TO U2, U3 EQUATIONS.
120	VARB	- PACKED WORD OF VAR. BEING INTEGRATED. E.G. 12356.0 = U1, U2, U3, K, E
348	VCMULT	- CONVECTION TERM ADDED TO U2, U3 EQUATIONS.
104	VELCST	- UINF**2 / (2.0*G*AJ*CPA*TOA)
177	VLBTON	- (1.488) VISCOSITY BRITISH TO MKS.
178	VLBTOP	- (14.88) VISCOSITY BRITISH TO CGS.
346	VLDMLT	- LAMINAR DIFFUSION ADDED TO U2, U3 EQUATIONS.
102	VSTART	- (101.0) PERCENT OF TD AT WHICH TO START U2, U3 COMPUTATIONS IN CONTES.
383	WSMAX	- WIDTH OF SOLUTION DOMAIN AT INITIAL STATION.
273	XDELTA	- (0.01) FOR EPSDIM .GT. EPSMAX * XDELTA, EPSDIM = EPSMAX * XDELTA.
125	XLAM	- (0.09) CONSTANT USED IN DFCFBL.
109	XMA	- (28.97) MOLECULAR WEIGHT OF AIR.
61	XMACHO	- MACH NUMBER.
154	XMACHS	- LOCAL MACH NUMBER.
373	XMDOTC	- AVERAGE MAS FLOW.
66	XMF	- (29.4) MOLECULAR WEIGHT OF FLUID.
172	XMFACT	- (UINF*SQRT (XMA/(TOFINF*GAMMAF*G*RUNIV)))
110	XMH	- (2.016) MOLECULAR WEIGHT OF HYDROGEN.
38	XMUINF	- FREESTREAM VISCOSITY.
98	XPRIME	- NON-DIM. PRESUURE GRADIENT AT PRESENT STATION.
52	XSCALE	- (1.0) X1COR SCALE FACTOR.
11	XT	- DIMENSIONAL STATION.
201	XTC	- PRESENT STATION FOR INTEGRAL PARAMETER PRINT.
330	YMULT	- (1.0) SCALE FACTOR FOR GRID MULTIPLIER.
324	YNRMAD	- (F10) DISPLACEMENT OF COORD. IN Y DIRECTION.
198	YPLUS	- Y+ VALUE AT WHICH TO SWITCH FROM MLT TO TKE.
53	YSCALE	- (1.0) X2COR SCALE FACTOR.
382	ZMULT	- (1.0) SCALE FACTOR FOR GRID MULTIPLIER.
325	ZNRMAD	- (G10) DISPLACEMENT OF COORD. IN Z DIRECTION.

[redacted]

[redacted]

1. Report No.
NASA CR-165997

2. Government Accession No.

3. Recipient's Catalog No.

4. Title and Subtitle THE CMC/3DPNS COMPUTER PROGRAM FOR PREDICTION OF THREE-DIMENSIONAL, SUBSONIC, TURBULENT AERODYNAMIC JUNCTURE REGION FLOW, VOLUME II - USERS' MANUAL

5. Report Date
September 1982

6. Performing Organization Code
CMC : 82TR - 2.2

7. Author(s)
P. D. MANHARDT

8. Performing Organization Report No.

9. Performing Organization Name and Address
COMPUTATIONAL MECHANICS CONSULTANTS, INC. (COMCO)
3601-A Chapman Highway
Knoxville, Tennessee 37920

10. Work Unit No.

11. Contract or Grant No.
NAS1-15105/MOD. 5

12. Sponsoring Agency Name and Address
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, DC 20546

13. Type of Report and Period Covered
CONTRACTOR REPORT

14. Sponsoring Agency Code

15. Supplementary Notes
LANGLEY TECHNICAL MONITOR: DOUGLAS L. DWOYER

16. Abstract
The CMC fluid mechanics program system is being developed to transmit the theoretical evolution of finite element numerical solution methodology, applied to non-linear field problems into a versatile computer code for comprehensive flow field analysis. This Report is Volume II of a three volume set and presents data deck procedures for the CMC 3-dimensional Parabolic Navier-Stokes (PNS) algorithm. General data procedures are introduced, followed by detailed description of a juncture corner flow standard test case data deck. A complete listing of the data deck is given in Appendix A, followed by a detailed explanation of grid generation methodology in Appendix B. Subsequent appendices present descriptive tabulations of all commands and variables available to the user. These are in alphabetical order with cross-reference numbers which refer to storage addresses. Volume I of this Report is referenced for details of the theoretical foundation, development of the finite element 3DPNS algorithm and discussion of results for the juncture corner test case. The CMC computer program structure and description are detailed in Volume III.

17. Key Words (Suggested by Author(s))
NAVIER-STOKES
TURBULENT FLOW
FINITE ELEMENT
FORTRAN IV

18. Distribution Statement
[redacted]

19. Security Classif. (of this report)
UNCLASSIFIED

20. Security Classif. (of this page)
UNCLASSIFIED

21. No. of Pages
67

22. Price

[redacted]