TM 54/20-108
LMSC/HREC A783573

CR-81143

LOCKHEED MISSILES & SPACE COMPANY

HUNTSVILLE RESEARCH & ENGINEERING CENTER

HUNTSVILLE RESEARCH PARK

4800 BRADFORD DRIVE, HUNTSVILLE, ALABAMA

N67-15253

USERS MANUAL

DESCRIPTION OF A DIGITAL COMPUTER PROGRAM FOR NOZZLE AND PLUME ANALYSIS BY THE METHOD OF CHARACTERISTICS

11 December 1966

Contract JPL-951567

by

H. W. Butler

This work was performed for the Jet Propulsion Laboratory, California Institute of Technology, sponsored by the National Aeronautics and Space Administration under Contract NAS7-100.

APPROVED BY: B. G. Staton

B. G. Staton, Supervisor
Aero-Physics Section

D. C. Shea

D. C. Shea, Manager
Aero-Mechanics Department

J. S. Farrior

J. S. Farrior
Resident Manager

FOREWORD

This computer program represents the results of work performed by Lockheed Missiles & Space Company, Huntsville Research & Engineering Center under the sponsorship of several government agencies. Documentation was sponsored by the Jet Propulsion Laboratory, California Institute of Technology. This report satisfies the requirements of

ITEM 1 - Nozzle Flow Field Analysis, and

ITEM 2 - Rocket Exhaust Plume Flow Field Analysis

outlined in the statement of work of Contract JPL-951567.

ACKNOWLEDGEMENTS

Appreciation is hereby expressed to R. J. Prozan, who developed the computer program reported in this document, for his patience and skill in directing this work. Appreciation is also extended to A. W. Ratliff for his assistance in describing the operation of the program and to J. T. Stephens for his aid in organizing this document.

CONTENTS

Section		Page
	FOREWORD	ii
1	INTRODUCTION	1-1
2	PROGRAM CAPABILITIES AND APPLICATIONS	2-1
	2.1 Capabilities	2-1
	2.2 Applications	
3	DISCUSSION	3-1
	3.1 Symbols and Notations	3-3
	3.2 Index of Routines	3-4
	3.3 Description and Flowcharts of Individual Subroutines	3-6
	3.4 Input/Output Guide	3-135

Section 1

INTRODUCTION

Section 1
INTRODUCTION

A precise knowledge of local flow properties in nozzles and exhaust plumes is necessary for performance, radiation, attenuation, heat transfer and impingement analyses. All of these analyses are dependent on an accurate knowledge of the environment.

Lockheed Missiles & Space Company, Huntsville Research & Engineering Center has developed, under the sponsorship of several governmental agencies, a two-dimensional or axisymmetric method-of-characteristics program. The program is applicable for problems involving supersonic flow of an inviscid, adiabatic reacting gas in thermal equilibrium.

Areas of particular interest in the current JPL study are the critical design problems which result from the effects of rocket exhaust impingement on objects in the plume. Impingement has a dominant effect on the thermodynamic environment of objects in the plume and in addition, may cause severe structural loads or trajectory perturbations. As a preliminary step in the plume analysis, an accurate knowledge of the nozzle flow field is required. Both nozzle and plume calculations are performed with the same program. This program is a versatile, user-oriented, analytical tool which is capable of producing all of the gas dynamic nozzle or plume data required for an impingement analysis. The user may choose a solution for a

1. nozzle only,
2. plume only,
3. combination nozzle and plume,

depending on the options and starting data selected. This program has been in use for several years and experience has led to a continual refinement of the calculational procedure.

This document was prepared to facilitate operation and understanding of the program. Descriptions of the individual routines are presented, which are intended to augment the program listing rather than to duplicate it. Answers to any questions pertaining to the operation of the program should be found in this document or in the program listing. Questions involving initial assumptions made in applying the general theory can be answered by referring to Reference 1. Comparisons with experimental data for real and ideal gas plumes are reported in Reference 2.

REFERENCES

1. Prozan, R. J., "Development of a Method of Characteristics Solution for Supersonic Flow of an Ideal Frozen, or Equilibrium Reacting Gas Mixture," Technical Report, Lockheed Missiles & Space Company, Huntsville Research & Engineering Center, LMSC/HREC A782535, April 1966.

2. Ratliff, A. W., "Comparisons of Experimental Supersonic Flow Fields with Results Obtained by Using a Method of Characteristics Solution," Technical Report, Lockheed Missiles & Space Company, Huntsville Research & Engineering Center, LMSC/HREC A782592, April 1966.

Section 2

PROGRAM CAPABILITIES AND APPLICATIONS

Section 2
PROGRAM CAPABILITIES AND APPLICATIONS

2.1 CAPABILITIES

The nozzle and plume computer program described in this document can be used to solve a wide variety of problems in real gas, supersonic, compressible flow. Capabilities were previously discussed in Reference 1*; however, as improvements continue to be made to the basic program, new capabilities evolve. Some of the more important, basic capabilities of the existing program are outlined below:

- The gas may be ideal, or if real, frozen or equilibrium assumptions can be made.
- Two-dimensional or axisymmetric problem geometry can be used.
- Both upper and lower boundaries can be solid or free. (A solid boundary can be approximated by either a conic or polynomial equation.)
- One compression corner on the upper wall can be calculated. (Any number may be considered if the problem is re-started each time.)
- Any number of expansion corners can be considered on either the upper or lower wall.
- Various methods for obtaining an initial start line are utilized.
    1. The program will calculate a one-dimensional start line anywhere in the nozzle.
    2. The program will calculate a start line at points within the nozzle necessary to conserve mass.
    3. Characteristic data can be input at points across the flow field within the nozzle or in the plume.
    4. Any right running characteristic line can be used for a start line.
    5. Any left running characteristic line can be used (may be in combination with a normal start line).

*Reference 1: Prozan, R. J., "Development of a Method of Characteristics Solution for Supersonic Flow of an Ideal Frozen, or Equilibrium Reacting Gas Mixture," Technical Report, LMSC/HREC A782535, April 1966.

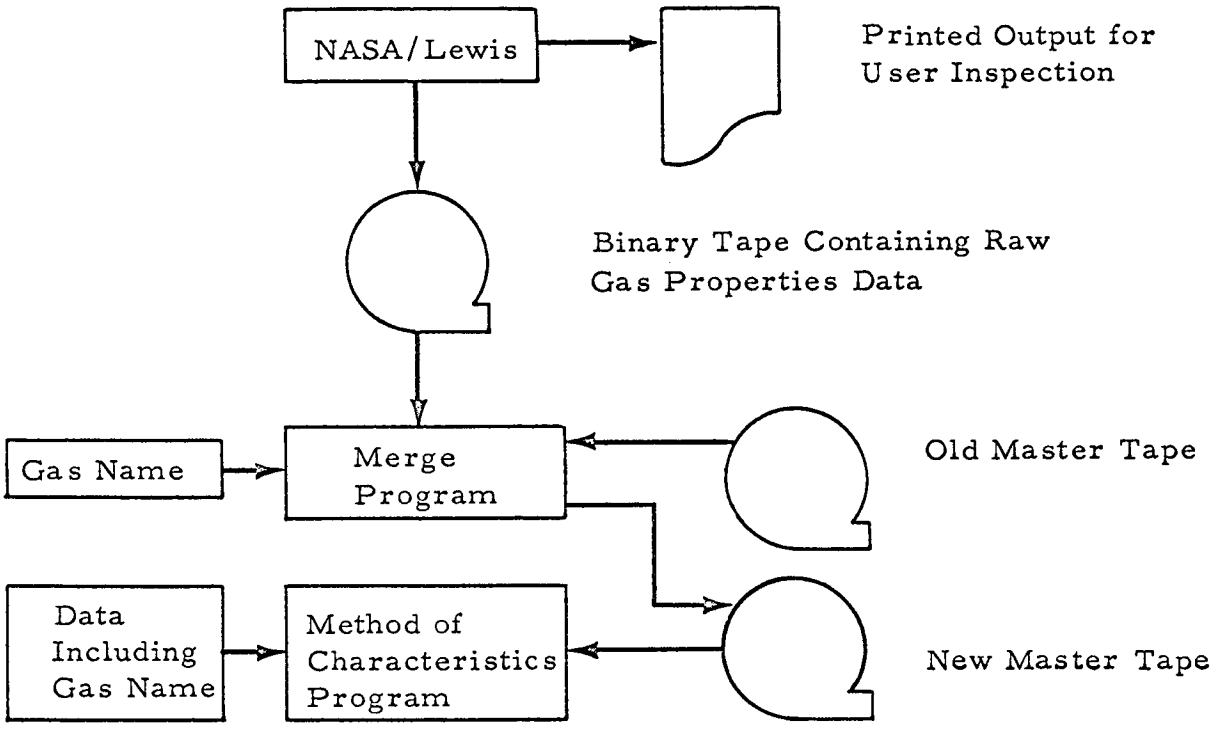
6. Any left running line may be input with a right running shock crossing it.

- SC-4020 plot capability of various parameters is available.
- Hypersonic or quiescent approach flow options may be used.
- Exit to ambient pressure ratios from over expanded to highly under expanded are possible.
- Viscous boundary layer approximations at the nozzle lip are available.
- Displacement of the axis of symmetry from the center of flow (i.e., the annular ring type of flow field) is possible.

Reacting gas solutions have been facilitated by modifying the NASA/Lewis Thermochemical program to provide binary tape output of its equilibrium or frozen real gas calculations. The method-of-characteristics program has the capability for selecting the proper case from a large set of real gas properties cases stored on a master tape. LMSC/HREC's master tape presently consists of approximately 70 cases and is continually being expanded. The method of generating this master tape is outlined in the diagram on the following page. Cases stored are uniquely identified by some characteristic of the particular gas under consideration. For example, a LOX/LH_2 system may be identified by the following:

Gas Type	Mixture Ratio	Chamber Pressure
ϕ2/H2	ϕ/F = 4.5	PC = 546.0

New cases of general interest may be added to the master tape; however, ad hoc cases should be prepared on a separate tape. Tape preparation sequence and communication with the method-of-characteristics program is diagramed on the following page.



Two-dimensional or axisymmetric solutions are selected by simply loading a control word in the program input data. This integer (0 or 1) is then multiplied by the term containing (1/r) in the governing differential equation. By appropriate description of the flow boundaries, it is possible to change from a solid to free boundary on either the upper or lower walls. Conversely, it is not possible to change from a free to a solid boundary on either wall.

Compression corners are allowed only on the upper wall. Because the program is restricted to a single shock within the flow field, the number of compression corners is limited to one. Also, right-running shocks only can be handled, thus, no provision exists for compression corners on the lower wall. Remembering that a mirror image solution is possible, the problem can be inverted for this type of solution. Note that the program will

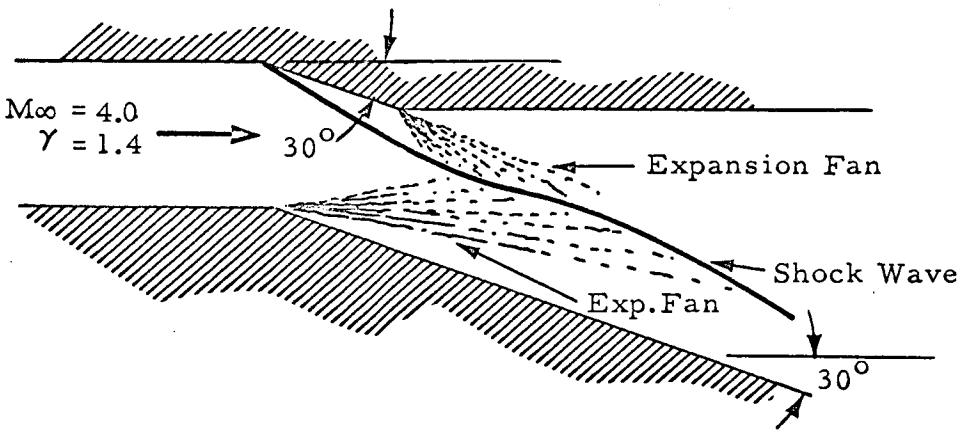
fortuitously handle two shocks if the first shock terminates by intersecting a lower free boundary before the second shock begins.

Choosing the proper start line option permits the problem to be restarted when termination is achieved by a shock intercepting the boundary. When the shock reflection is "regular," the procedures are standard. However, when a restart is required downstream of a "Mach reflection," a boundary equation simulating a cylindrical "pipe" must be used to approximate the subsonic region.

2.2 APPLICATIONS

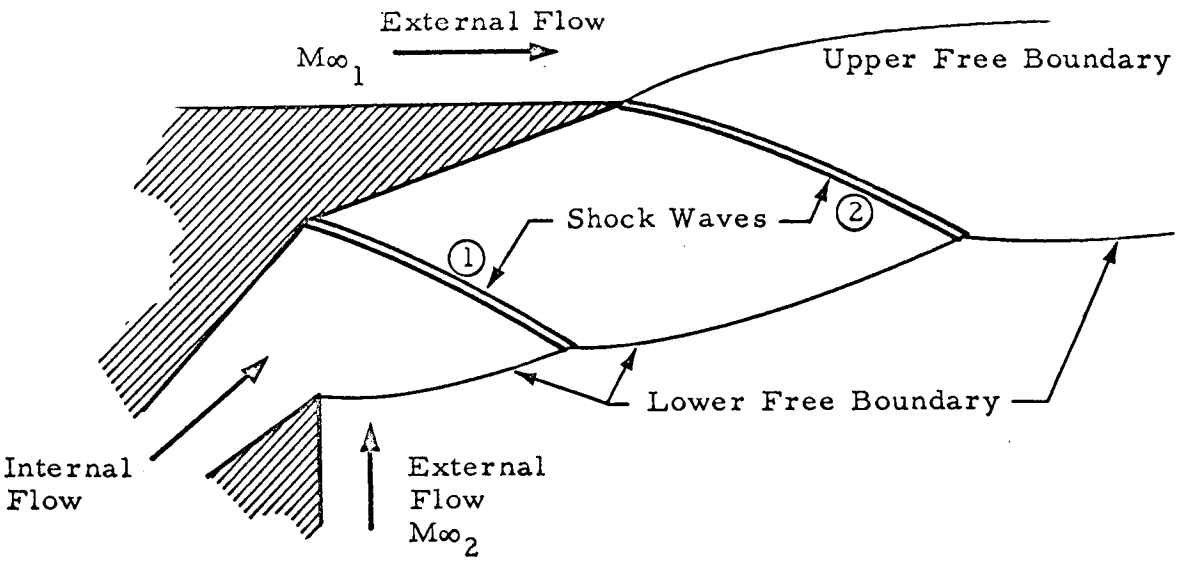
The most common applications of this program are in the areas of standard rocket nozzles and axisymmetric plumes. Many other complex flow fields can be treated, however, if the user is familiar with the flexibility of the program and its options. Other possible problems are discussed in the remaining paragraphs of this section since an understanding of the application of the program to these standard cases is assumed.

Consider the boundary conditions given below. This problem was run two dimensionally (although it could just as well have been axisymmetric) for the purpose of program demonstration.



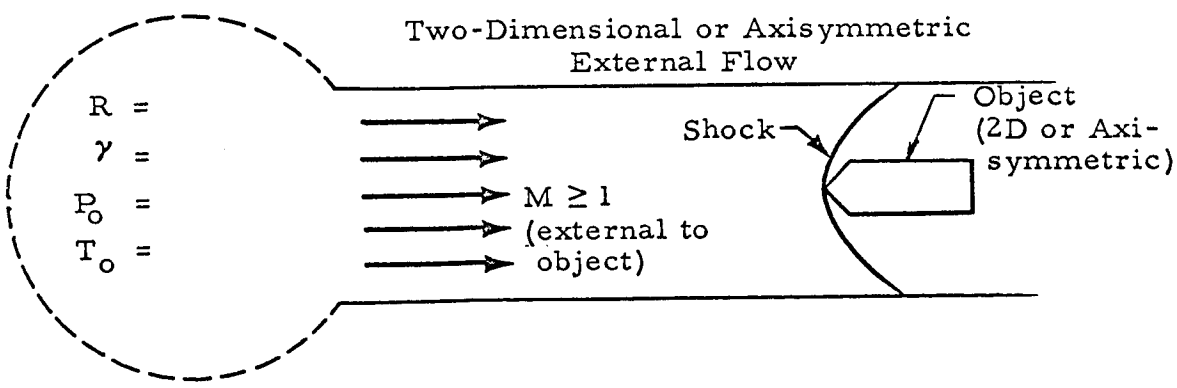
The problem above, while being restricted to one compression corner, could have had more expansion corners illustrating a more complex case.

Another problem depicting the program's versatility is the following:

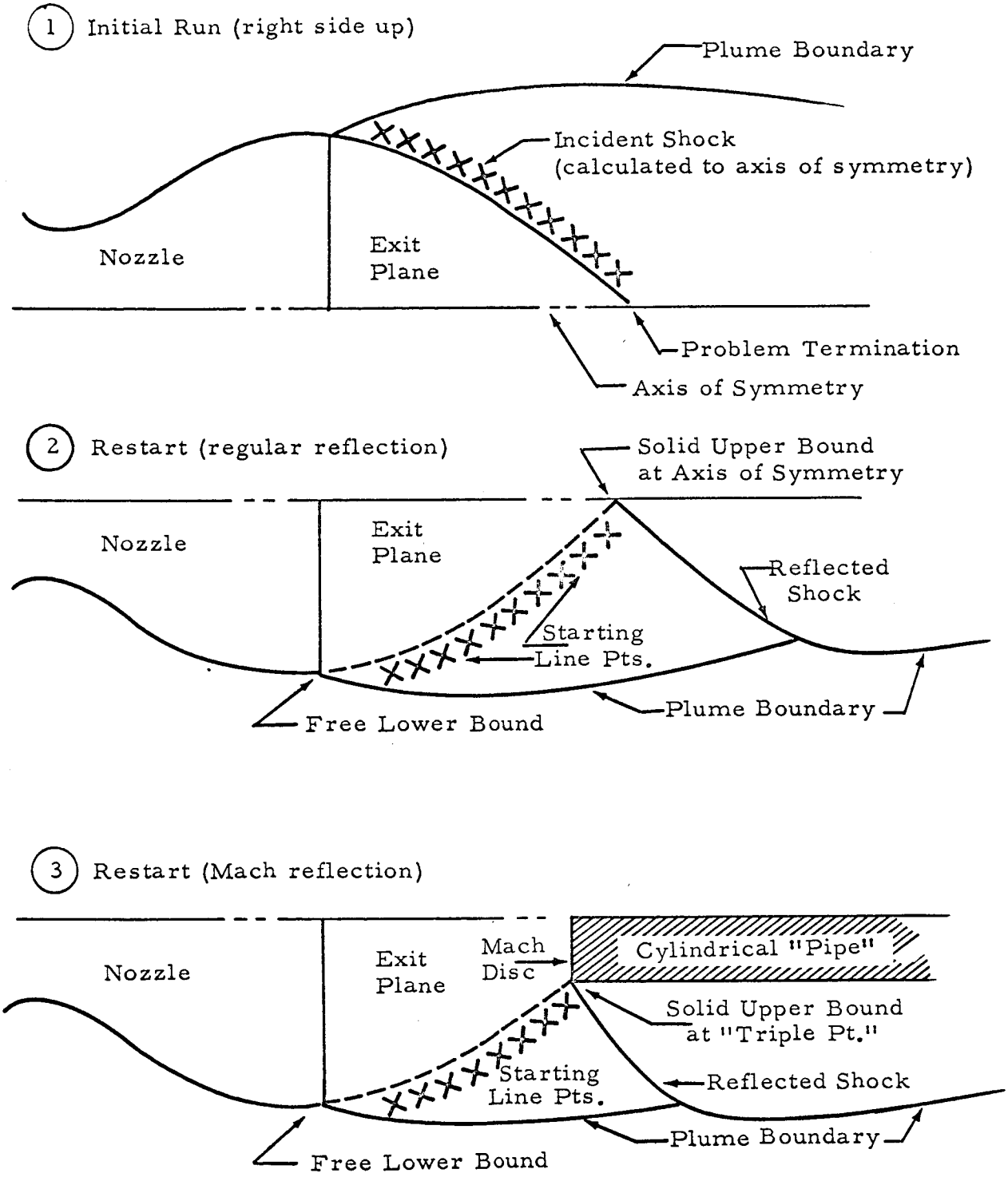


The restriction that the flow remain supersonic (inherent in the method-of-characteristics solution) must be observed through the flow field.

External flow can be simulated by specifying the necessary stagnation conditions and inserting a two-dimensional or axisymmetric object in the flow field.



The method of reflecting a shock "regularly" or through a "Mach reflection" is outlined in the diagram on the following page.


1 Initial Run (right side up)
Plume Boundary
Incident Shock
(calculated to axis of symmetry)
Nozzle
Exit
Plane
Problem Termination
Axis of Symmetry
2 Restart (regular reflection)
Solid Upper Bound
at Axis of Symmetry
Nozzle
Exit
Plane
Reflected
Shock
Starting
Line Pts.
Free Lower Bound
Plume Boundary
3 Restart (Mach reflection)
Nozzle
Exit
Plane
Mach
Disc
Cylindrical "Pipe"
Solid Upper Bound
at "Triple Pt."
Starting
Line Pts.
Reflected Shock
Plume Boundary
Free Lower Bound

Section 3

DISCUSSION

Section 3
DISCUSSION

The program consists of fifty-two active subroutines or functions which perform all the required calculations in the nozzle and plume. This building-block approach simplifies trouble-shooting and operation. Each of the fifty-two routines is explained separately and presented with its supporting flow chart. In addition, a general flow chart of the basic logic is presented in Figure 3.1. An index of all subroutines and functions precedes the individual writeups for a ready reference to their location and a quick sketch of their purpose.

Routines which use equations and logic described adequately in Reference 1 are reviewed generally in "Method of Solution" sections. Those routines which have not been dealt with in Reference 1 are presented in more detail.

Input procedure and output interpretation is covered in the Input/Output Section. The input instructions are simple and self explanatory. Some of the input instructions imply the use of inactive or "dummy" routines (i.e., the SC 4020 plot routines); these are retained for future use. The output interpretation instructions are in the form of flagged comments which refer to a corresponding section on a typical page of output.

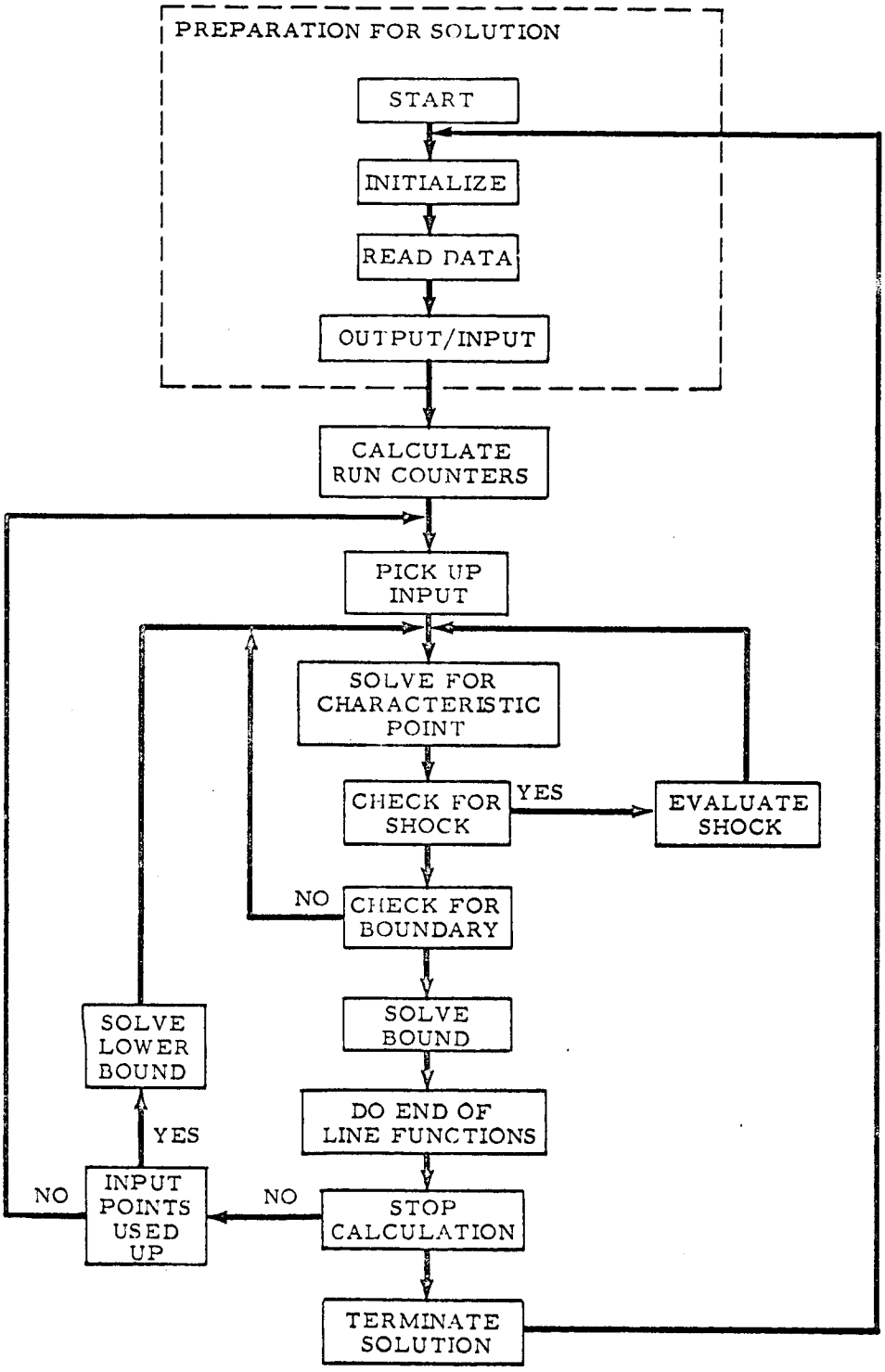


Figure 3.1 - General Flow Chart

3.1 SYMBOLS AND NOTATIONS

SYMBOL	DESCRIPTION
M	Mach number
R	"gas constant"
R, r	radial coordinate
X, x	axial coordinate
y	normal coordinate
P, p	pressure
T, t	temperature
S, s	entropy
V, v	velocity
H, h	enthalpy
$\dot{M}$	mass flow
A/A^*	area ratio
γ	isentropic exponent
δ	turning angle through shock
ϵ	shock angle
θ	flow angle
μ	Mach angle
β	characteristic angle
ρ	density
λ	equation modifier
ψ	operation function
Φ	point description information

Subscripts

∞	freestream conditions
o	stagnation conditions
B	boundary conditions

3.2 INDEX OF ROUTINES

SUBROUTINE/FUNCTION	IDENTIFICATION	PAGE
AOASTR	Mach number from area ratio	3-6
BOUND	solves boundary equations	3-8
DELTAF	turning angle through shock	3-10
DRIVER	provides control	3-11
EMOFP	Mach number from pressure	3-13
EMOFV	Mach number from velocity	3-14
ENTHAL	enthalpy from velocity	3-15
ENTROP	entropy rise through shock	3-16
ERRORS	prints error messages	3-17
ESHOCK	equilibrium shock calculations	3-20
FNEWTN	Newtonian impact pressure	3-23
GASRD	reads gas properties	3-24
GASTAP	gas properties from tape	3-27
HYPER	solves boundary pressure	3-30
IDTAPE	writes gas properties	3-33
INITP	initialization	3-35
INRSCT	finds straight line intersection	3-36
ITERM	tests for cutoff	3-37
ITSUB	iteration subroutine	3-39
KIKOFF	control return	3-42
LIMITS	tests boundary limits	3-43
LIPIN	calculates start line	3-45
MASCON	conserves mass	3-47
MASSCK	checks mass flow	3-49
MOCSOL	solves characteristic mesh	3-52
MONO	checks monotonic solution	3-59
OUT	writes data	3-61
OUTBIN	writes data on tape	3-64
OVEREX	shock angle (overexpanded)	3-65
PAGE	page ejects and comments	3-67

SUBROUTINE/FUNCTION	IDENTIFICATION	PAGE
PHASE1	provides logic	3-68
PLUMIN	reads input data	3-84
PLMOUT	writes input data	3-89
POFEM	pressure from Mach number	3-93
PRANDT	computes Prandtl-Meyer angle	3-94
RGMOFP	Mach number from pressure and entropy	3-96
RGVOFM	velocity from Mach number and entropy	3-98
RHOFEM	density from Mach number and entropy	3-100
ROTERM	computes rotational term	3-101
SHOCK	shock neighborhood solution	3-102
TABLE	utilizes gas tables	3-112
THETPM	calculates properties through expansion	3-116
THRUST	computes thrust	3-119
TOFEM	temperature from Mach number	3-122
TOFV	temperature from velocity	3-123
TURN	solves shock knowing turning angle	3-124
UOFEM	Mach angle from Mach number	3-126
UOFV	Mach angle from velocity	3-127
VISCUS	boundary layer at exit	3-128
VOFEM	velocity from Mach number	3-131
WEAK	solves weak shock	3-132
WOFA	weight flow per unit area	3-134

3.3 DESCRIPTION AND FLOW CHARTS OF INDIVIDUAL SUBROUTINES

3.3 DESCRIPTION AND FLOW CHARTS OF INDIVIDUAL SUBROUTINES

FUNCTION NAME: AOASTR

DESCRIPTION

This function finds the Mach number corresponding to a given area ratio by one-dimensional theory. Real gas effects are considered in this calculation.

CALLING SEQUENCE

EM = AOASTR (S, AOA)

where (EM) is the Mach number which exists, one dimensionally, at an area ratio of (AOA) and an entropy (S).

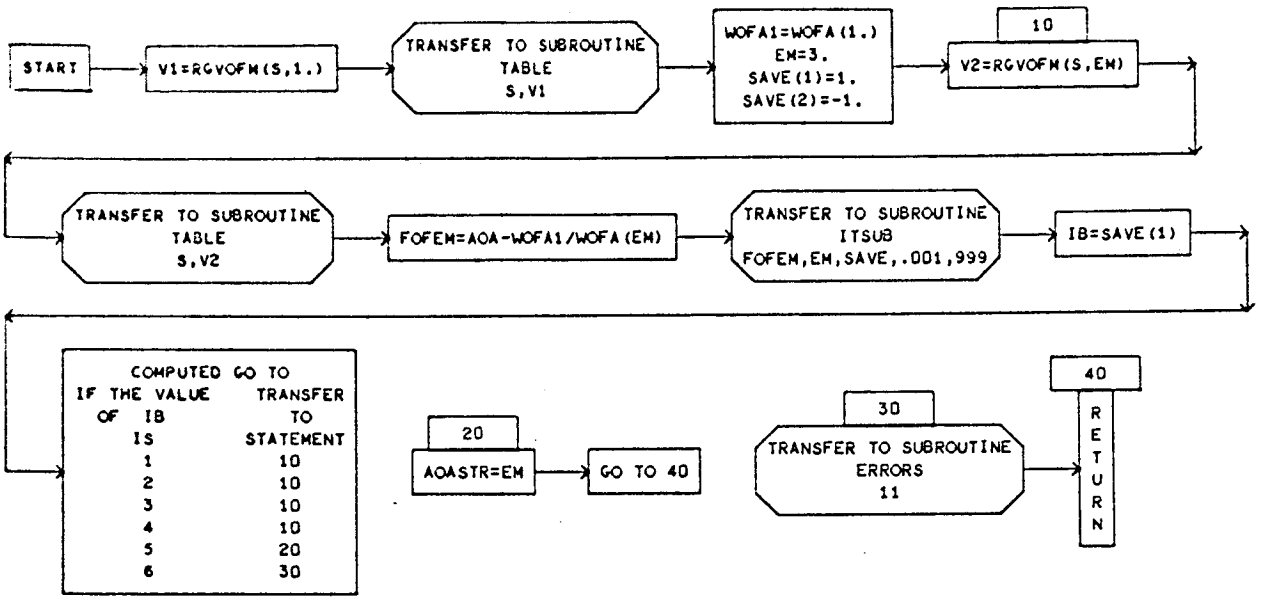
UTILITY ROUTINES AND COMMON REFERENCES

COMMON-None
ITSUB
RGVOFM
TABLE
WOFA

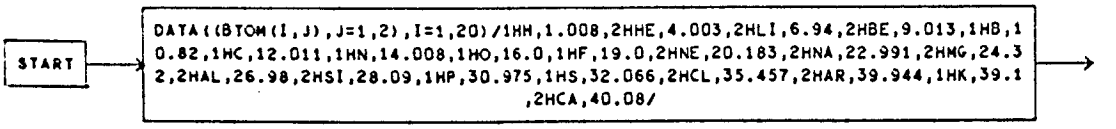
METHOD OF SOLUTION

The weight flow per unit area at Mach one is evaluated. An initial guess for the desired Mach number is made and ITSUB is initialized. An iterative solution of the equation FOFEM = AOA - WOFA1/WOFA (EM), driving FOFEM to zero, is performed with the aid of ITSUB.

FUNCTIONAOASTR(S,AOA)



BLOCK DATA



SUBROUTINE NAME: BOUND

DESCRIPTION

This subroutine finds the radial coordinate and flow angle (radians) for a given axial coordinate on an upper or lower solid boundary.

CALLING SEQUENCE

CALL BOUND (R, X, THETA, ITYPE)

where (R) is the radial coordinate, (X) is the known axial coordinate, THETA is the wall angle and ITYPE indicates whether upper or lower boundary equations are to be used.

UTILITY ROUTINES AND COMMON REFERENCES

COMMON/WALLFO/
UTILITY - None

METHOD OF SOLUTION

The block common region WALLFO contains the information necessary to evaluate R, THETA. Two types of equations are used;

$$r = a\left[\sqrt{b + cx + dx^2} + e\right] \qquad \text{CONIC TYPE 1}$$

and

$$r = ax^4 + bx^3 + cx^2 + dx + e \qquad \text{POLYNOMIAL TYPE 2}$$

The input fixed point variable ITYPE has a one or a two in the units position which selects the upper (2) or lower (1) coefficients and control information. IEQNOW contains the number of the equation to be used.

SUBROUTINEBOUND(R,X,THETA,ITYPE)

```
START
K=ITYPE-(ITYPE/10)*10
I=IEQNOW(K)
J=IWALL(I,K)
```

→

COMPUTED GO TO IF THE VALUE OF J IS	TRANSFER TO STATEMENT
1	10
2	20
3	40

10

```
R=WALLCO(I,1,K)*(SQRT(ABS(WALLCO(I,2,K)+(WALLCO(I,3,K)+WALLCO(I,4,K)*X)*X))+WA
LLCO(I,5,K))
THETA=.5*WALLCO(I,1,K)*(WALLCO(I,3,K)+2.*WALLCO(I,4,K)*X)/(SQRT(ABS(WALLCO(I,2
,K)+(WALLCO(I,3,K)+WALLCO(I,4,K)*X)*X)))
```

→ GO TO 30

20

```
R=(((WALLCO(I,1,K)*X+WALLCO(I,2,K))*X+WALLCO(I,3,K))*X+WALLCO(I,4,K))*X+WALLCO
(I,5,K)
THETA=((4.*WALLCO(I,1,K)*X+3.*WALLCO(I,2,K))*X+2.*WALLCO(I,3,K))*X+WALLCO(I,4,
K)
```

→ 30 THETA=ATAN(THETA) → 40 RETURN

FUNCTION NAME: DELTAF

DESCRIPTION

This function computes the turning angle through an oblique shock wave knowing the shock angle and the upstream Mach number.

CALLING SEQUENCE

DELTA = DELTAF (EPS, EM)

where (DELTA) the turning angle is found from the shock angle (EPS) and the upstream Mach number (EM). NOTE: The appropriate values of the ratio of specific heats must be in common corresponding to the input Mach number and the upstream entropy value.

UTILITY ROUTINES AND COMMON REFERENCES

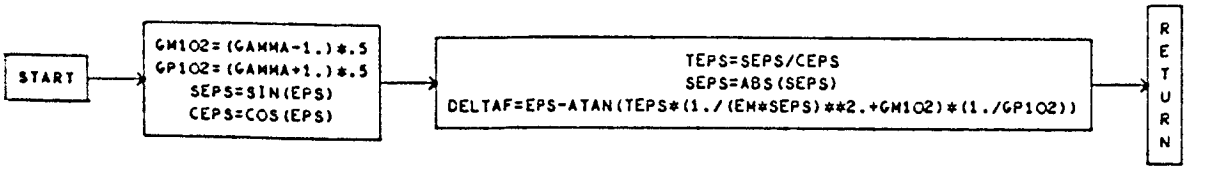
COMMON/GASCON/
UTILITY - None

METHOD OF SOLUTION

The oblique shock relations are solved for the turning angle using the relations;

$$\delta = \epsilon - \tan^{-1}\left\{\tan\epsilon\left(\frac{1}{M^2\sin^2\epsilon} + \frac{\gamma - 1}{2}\right)\left(\frac{2}{\gamma + 1}\right)\right\}$$

FUNCTION DELTAF (EPS,EM)



SUBROUTINE NAME: DRIVER

DESCRIPTION

Driver provides the highest order control for program execution. Initialization and logic subroutines are called from here. Most all the common storage needed in the remainder of the program is specified here.

CALLING SEQUENCE

CALL DRIVER (K)

where (K) is a control constant indicating whether or not errors exist in the execution of the program. (K = 1 for a detected error, K = 0 for no errors.)

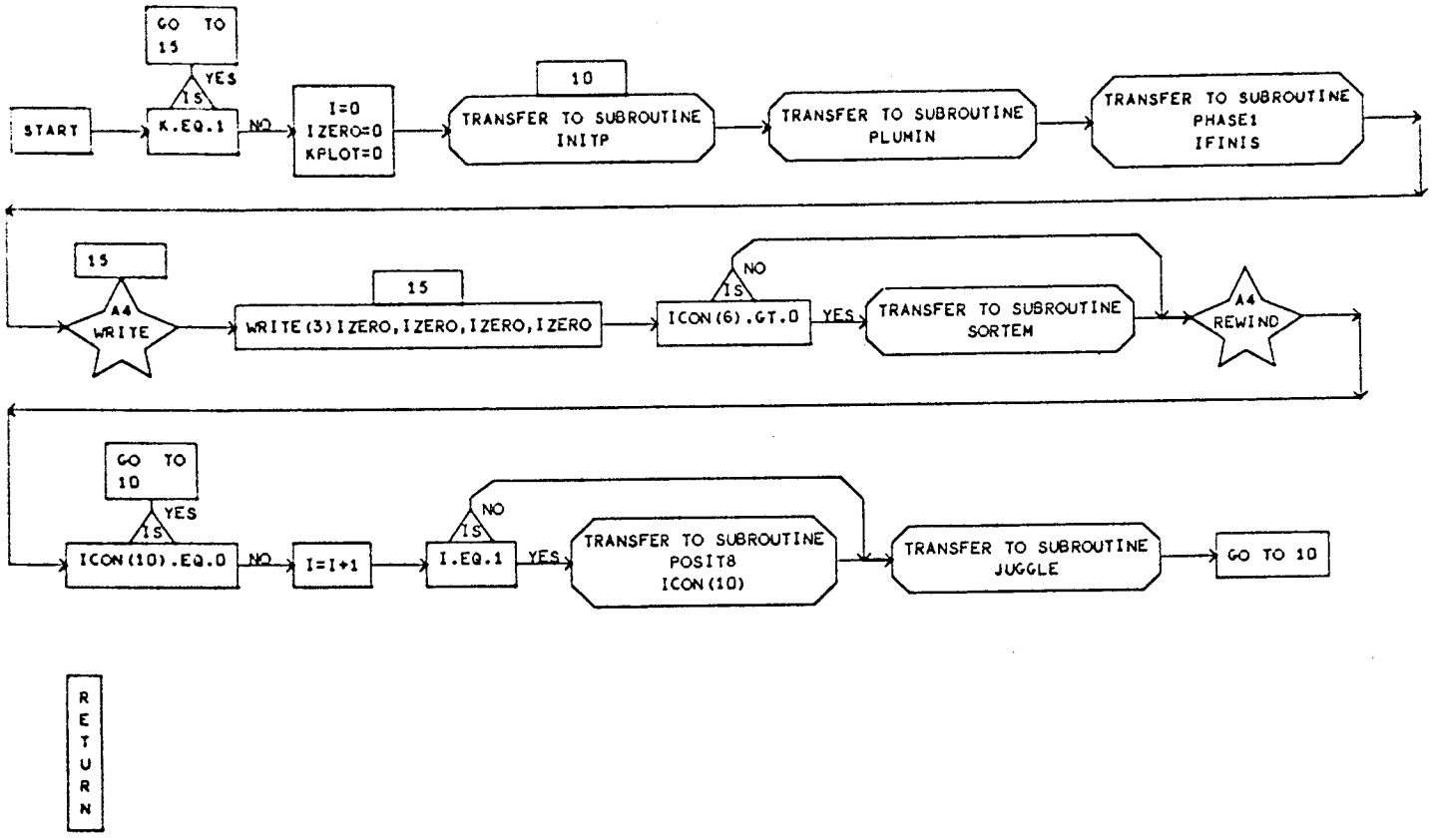
UTILITY ROUTINES AND COMMON REFERENCES

COMMON/CONTROL/	COMMON/JUGCOM/
COMMON/CRITER/	COMMON/PLOTEM/
COMMON/CURVES/	COMMON/STEPC/
COMMON/CUTFO/	COMMON/TAPEFO/
COMMON/DATAR/	INITP
COMMON/FORCE/	PLUMIN
COMMON/GASCON/	PHASE1
COMMON/HEAD/	SORTEM
COMMON/INPUT/	POSIT8
	JUGGLE

METHOD OF SOLUTION

Not applicable for this subroutine.

SUBROUTINE DRIVER(K)



FUNCTION NAME: EMOFP

DESCRIPTION

This routine computes the local Mach number as a function of local pressure (static) and the local entropy value.

CALLING SEQUENCE

EM = EMOFP (P, S)

where (EM) is the resultant Mach number found from the pressure (P) and entropy (S). NOTE: The appropriate values of the gas properties must be stored in common upon entry to this routine.

UTILITY ROUTINES AND COMMON REFERENCES

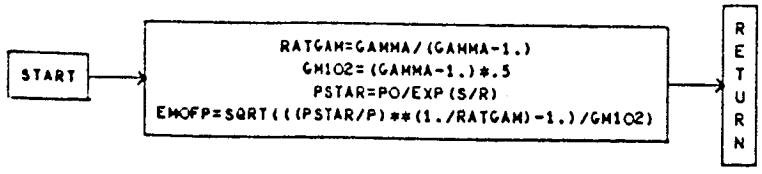
COMMON/GASCON/
UTILITY - None

METHOD OF SOLUTION

Perfect gas relationships (thermally perfect) are used to find the Mach number.

$$M = \sqrt{\left[\left(\frac{p_o e^{-S/R}}{p}\right)^{\frac{\gamma-1}{\gamma}} - 1\right]\frac{2}{\gamma - 1}}$$

FUNCTION EMOFP (P,S)



FUNCTION NAME: EMOFV

DESCRIPTION

This routine finds Mach number as a function of velocity.

CALLING SEQUENCE

EM = EMOFV (V)

where (EM) is the local Mach number which is found as a function of (V) the local velocity. NOTE: The appropriate values of the gas properties must be stored in common upon entry to this routine.

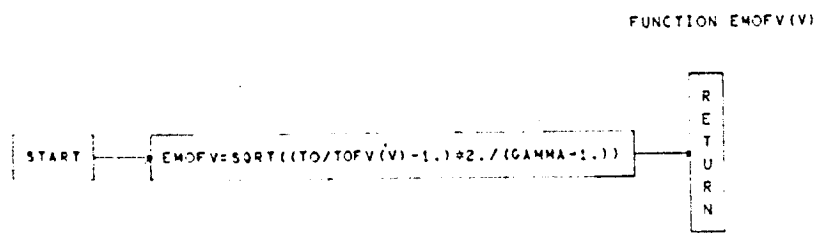
UTILITY ROUTINES AND COMMON REFERENCES

COMMON/GASCON/
TOFV

METHOD OF SOLUTION

Thermally perfect gas relationships are used to find the Mach number.

$$M = \sqrt{\left(\frac{T_o}{T} - 1\right)\left(\frac{2}{\gamma - 1}\right)}$$



FUNCTION NAME: ENTHAL

DESCRIPTION

This routine finds the local enthalpy as a function of velocity.

CALLING SEQUENCE

$$H = \text{ENTHAL}(V)$$

where (H) is the local enthalpy which is found as a function of the local velocity (V). NOTE: The appropriate values of the gas properties must be stored in common upon entry to this routine.

UTILITY ROUTINES AND COMMON REFERENCES

COMMON/GASCON/
TOFV

METHOD OF SOLUTION

Thermally perfect gas relationships are used to find the local enthalpy.

$$h = \frac{R\gamma}{\gamma - 1} T$$

```
                                    FUNCTION ENTHAL(V)                                    PAGE  1

START      ENTHAL=R*(GAMMA/(GAMMA-1.))*TOFV(V)  --->  RETURN
```

FUNCTION NAME: ENTROP

DESCRIPTION

This routine utilizes the oblique shock relations to find the entropy rise across a shock as a function of the shock angle and the upstream Mach number.

CALLING SEQUENCE

DS = ENTROP (EPS, EM)

where (DS) is the entropy rise across the shock and is a function of the shock angle (EPS) and the upstream Mach number (EM). NOTE: The appropriate values of the gas properties must be stored in common upon entry to this routine.

UTILITY ROUTINES AND COMMON REFERENCES

COMMON/GASCON/
UTILITY - None

METHOD OF SOLUTION

The oblique shock relations are employed to find the entropy rise across the shock.

$$ds = \frac{R}{\gamma - 1}\left\{\ell n\left[\frac{(2\gamma M^2 \sin^2\epsilon - (\gamma - 1))}{\gamma + 1}\right] + \gamma\, \ell n\left[\frac{\tan(\epsilon - \delta)}{\tan\epsilon}\right]\right\}$$

```
                    FUNCTION ENTROP(EPS,EMU)                                    PAGE  1

START    GM1O2=(GAMMA-1.)*.5          CV=R/(GAMMA-1.)                          RETURN
         GP1O2=(GAMMA+1.)*.5          EMEPSQ=(EMU*SEPS)**2.
         SEPS=SIN(EPS)                FACT1=((1./EMEPSQ+GM1O2)/GP1O2)**GAMMA
         SEPS=ABS(SEPS)               ENTROP=CV*(ALOG(((GAMMA*EMEPSQ-GM1O2)/GP1O2)*FACT1))
```

SUBROUTINE NAME: ERRORS

DESCRIPTION

This subroutine contains print messages for various errors which may occur. This is an open ended routine in that it can easily be extended to handle more print messages.

CALLING SEQUENCE

CALL ERRORS (I)

where (I) selects the message to be printed.

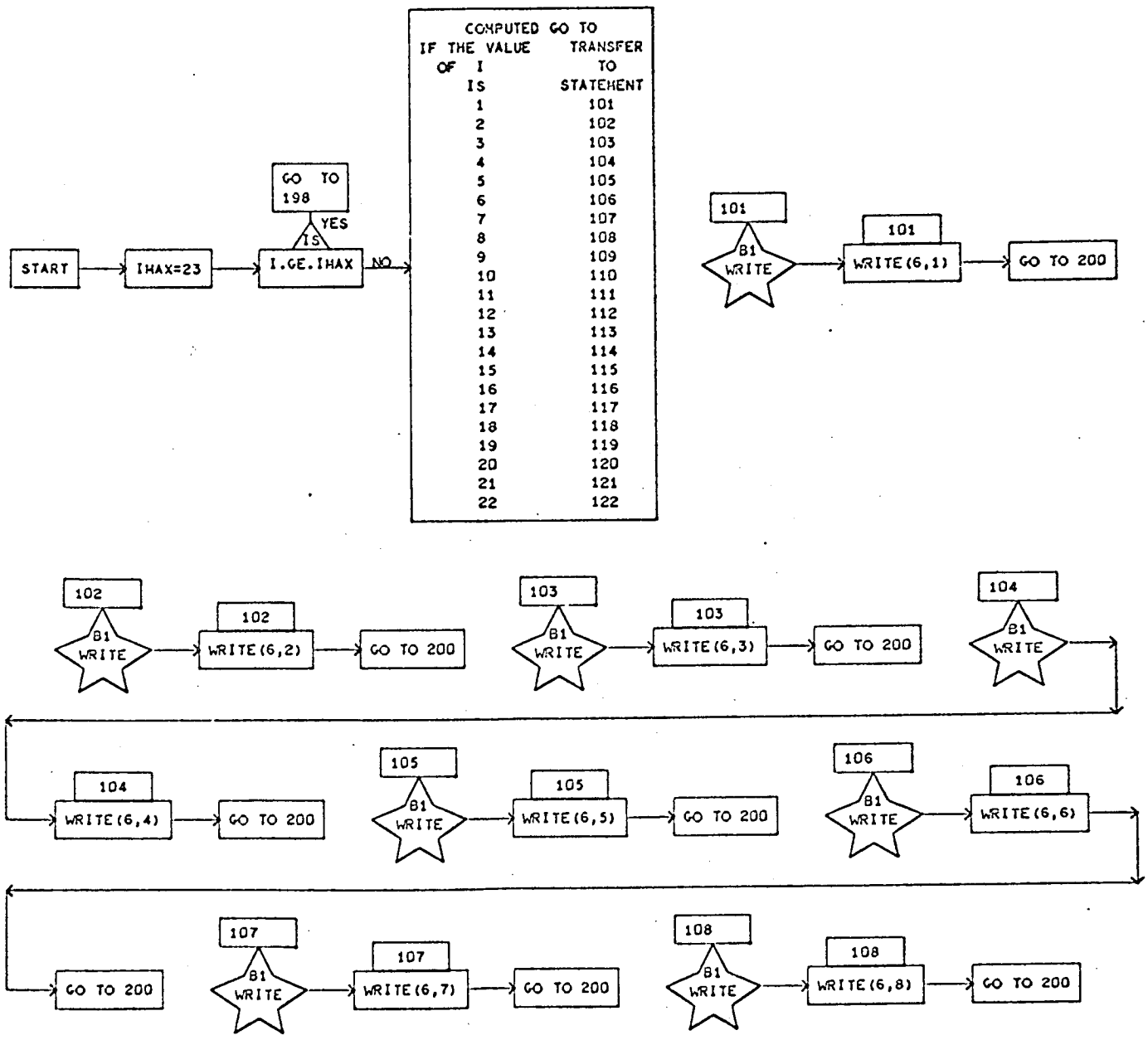
UTILITY ROUTINES AND COMMON REFERENCES

None

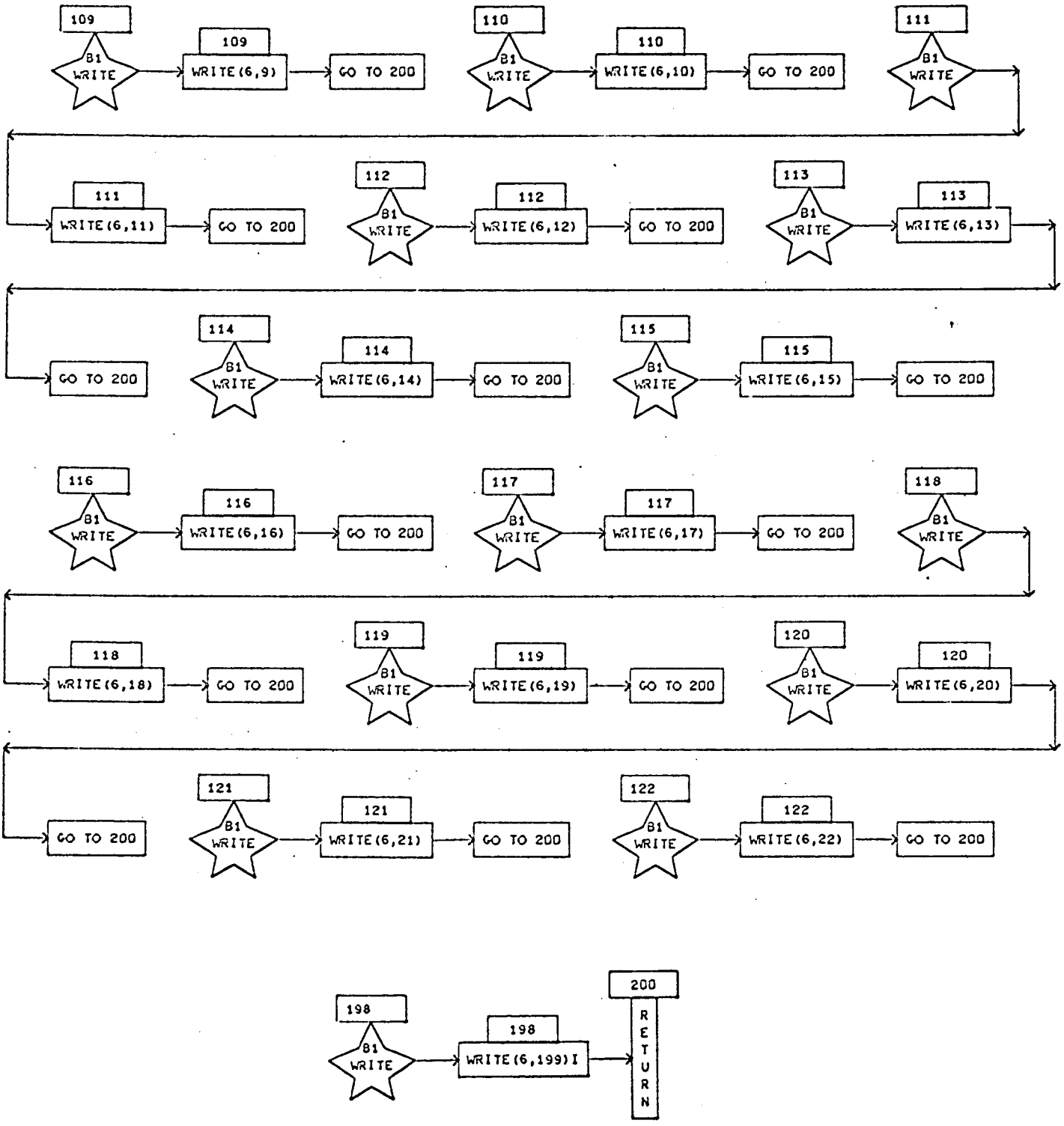
METHOD OF SOLUTION

Not applicable.

SUBROUTINE ERRORS(I)



SUBROUTINE ERRORS(I)



SUBROUTINE NAME: ESHOCK

DESCRIPTION:

This subroutine employes an iterative solution to perform the equilibrium shock calculations for a real or ideal gas. The real and ideal gas calculations are similar, the difference being that an ideal gas case converges on the first iteration.

CALLING SEQUENCE

CALL ESHOCK (S1, V1, EP, DELTA, S2, V2)

where the input properties are (S1, V1) the upstream entropy and velocity and (EP) the shock angle. The subroutine returns with (DELTA), the turning angle and (S2, V2), the downstream entropy and velocity.

UTILITY ROUTINES AND COMMON REFERENCES

COMMON/CONTRL/	
COMMON/GASCON/	
TABLE	RHOFEM
EMOFV	ENTROP
POFEM	DELTAF

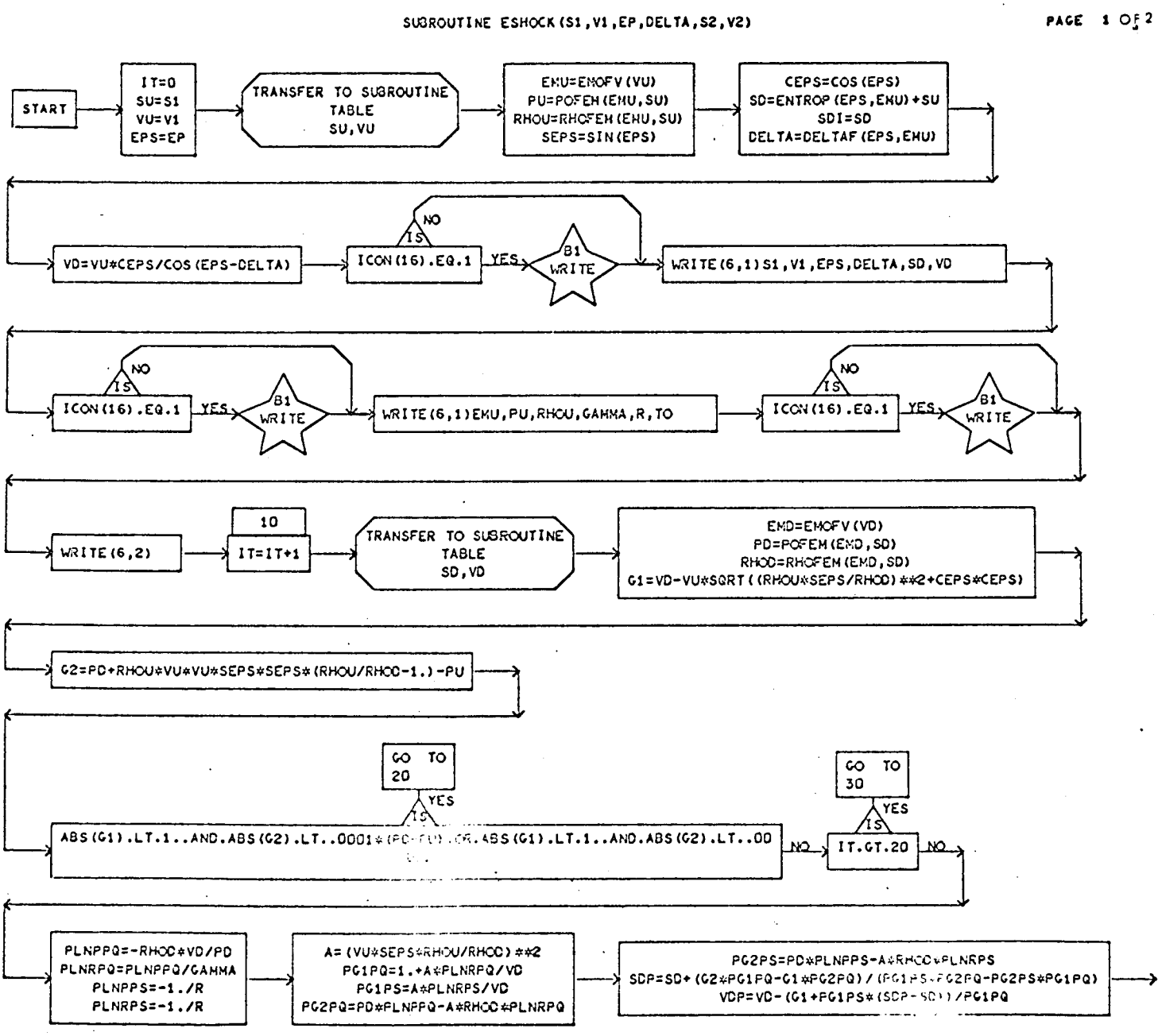
METHOD OF SOLUTION

The equation for conservation of mass through a shock wave and the two independent equations for momentum tangential and normal to the shock wave are rearranged. The rearrangement allows for expressing the equation as functions of four unknowns:

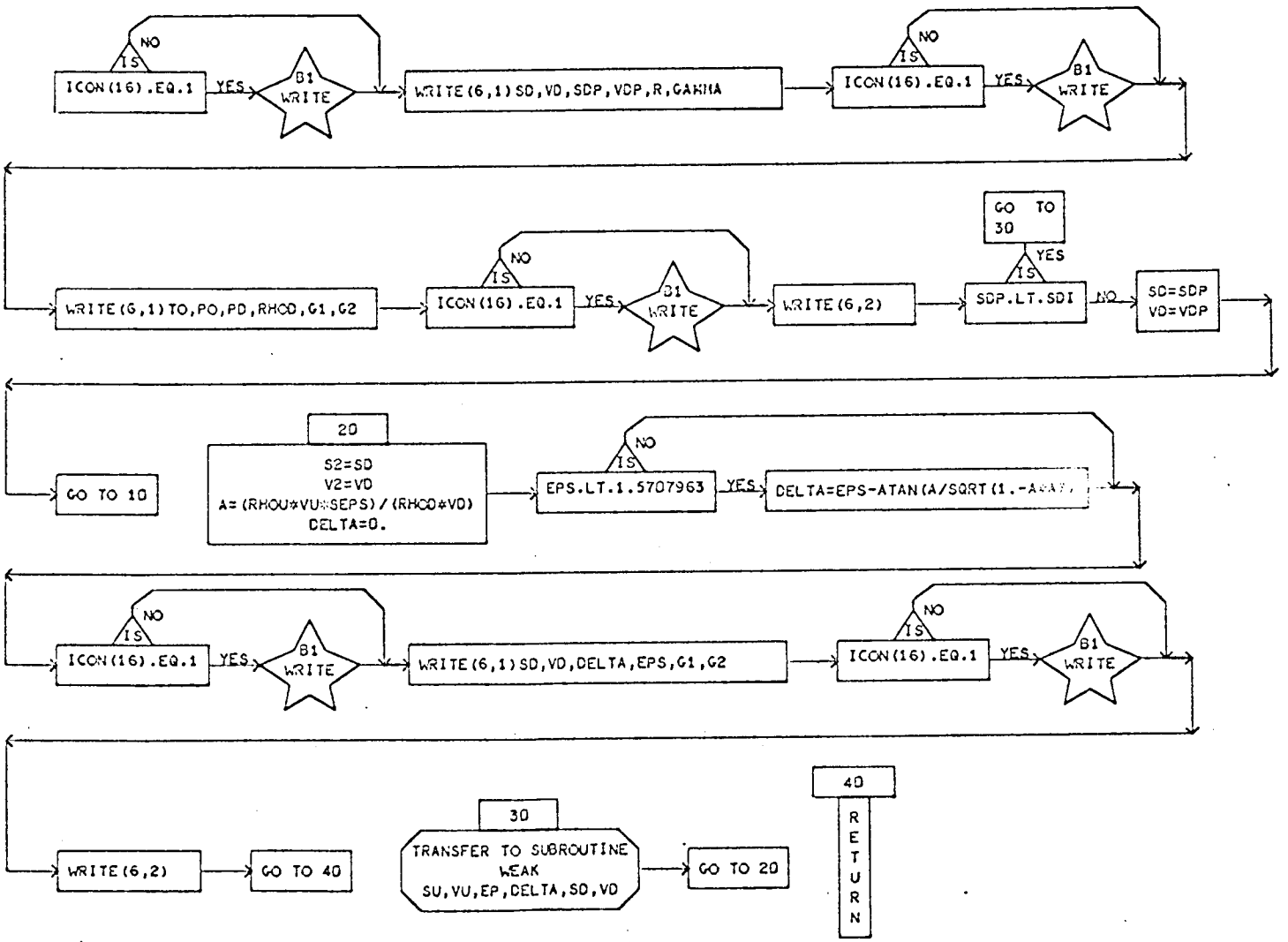
1. ϵ - the shock angle
2. δ - the turning angle
3. S2 - the entropy level downstream of the shock
4. q_2 - the velocity downstream of the shock

One of the unknowns, ϵ, is taken as an independent variable and an iterative solution employed to solve for the other three.

For a more detailed description of the method of solution and a derivation of the equations used, refer to Section 7 of Reference 1.



SUBROUTINE ESHOCK(S1,V1,EP,DELTA,S2,V2)



FUNCTION NAME: FNEWTN

DESCRIPTION

This function solves for the Newtonian impact pressure along the plume boundary. The calculation is accurate for hypersonic free stream velocities or quiescent conditions (i.e., $M_\infty = 0$).

CALLING SEQUENCE

$$P_{IM} = \text{FNEWTN (THETA3, X, ITYPE1)}$$

where (P_{IM}) is the hypersonic Newtonian impact pressure at the plume boundary, (THETA3) is the local flow angle at the boundary, (X) is the axial coordinate of the boundary point, and (ITYPE1) designates upper or lower boundary. (1 - lower, 2 - upper)

UTILITY ROUTINES AND COMMON REFERENCES

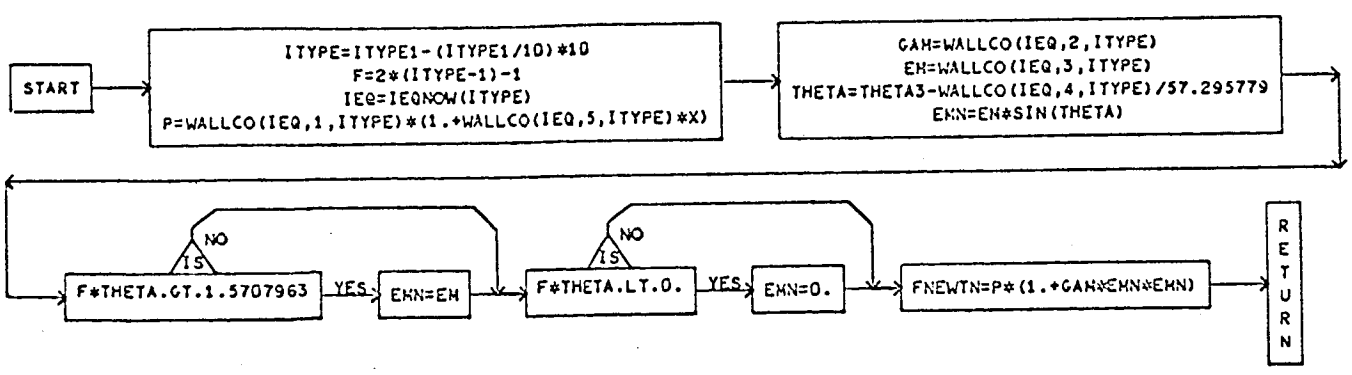
COMMON/DATAR/
UTILITY- None

METHOD OF SOLUTION

The block common region - WALLCO contains the necessary information to evaluate the free stream gas properties at the plume boundary point. The impact pressure is then calculated using the following equation

$$P = P_\infty (1 + ex)\left[1 + \gamma_\infty M_\infty^2 \sin^2(\theta_B - \theta_\infty)\right]$$

FUNCTION FNEWTN(THETA3,X,ITYPE1) PAGE 1



SUBROUTINE NAME: GASRD

DESCRIPTION:

This subroutine reads in the gas properties. These properties may be real or ideal and read in via cards or tape. The routine also converts input gas properties from MKS units to English (ENG) units if necessary.

CALLING SEQUENCE

```
CALL GASRD
```

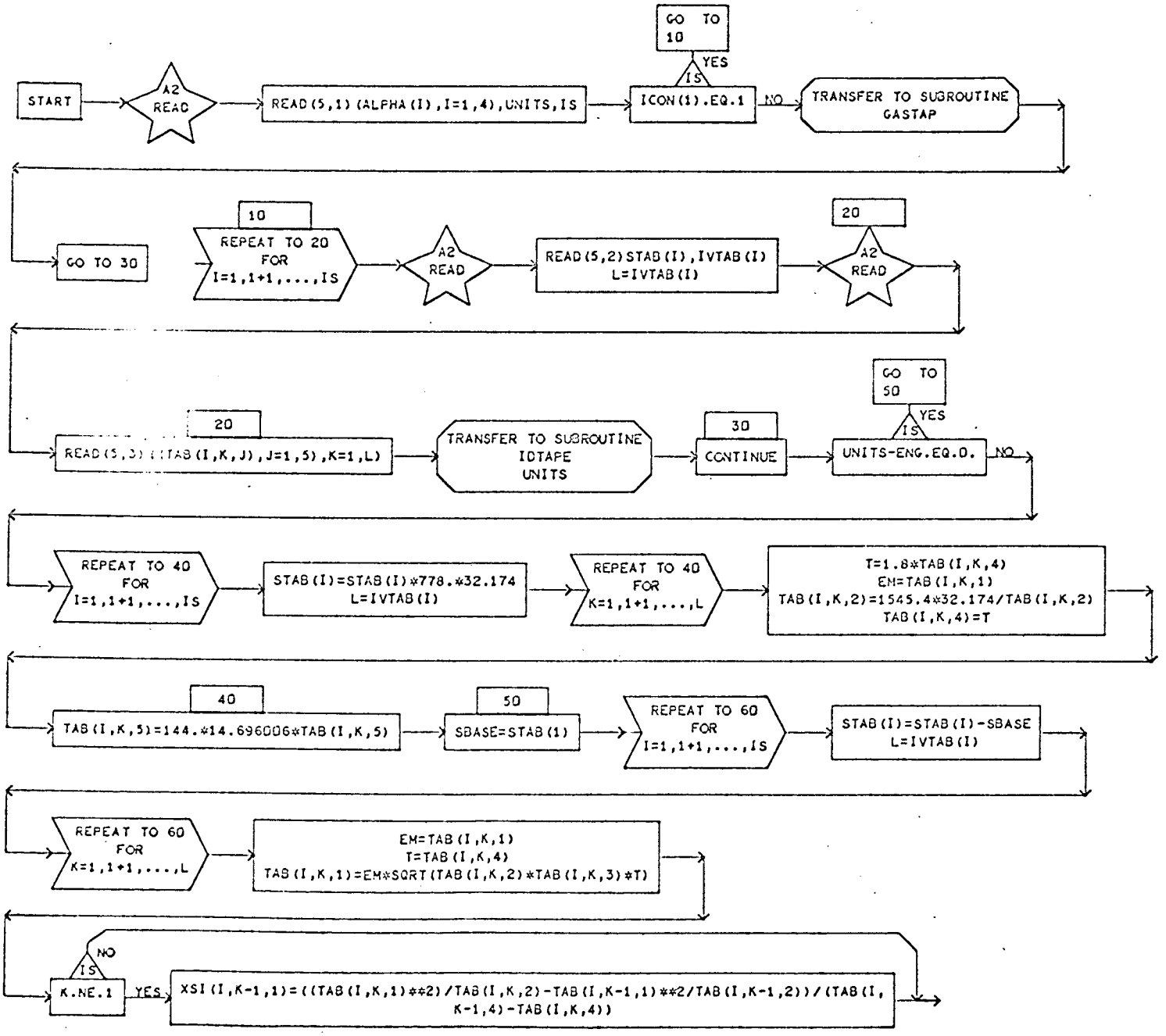
UTILITY ROUTINES AND COMMON REFERENCES

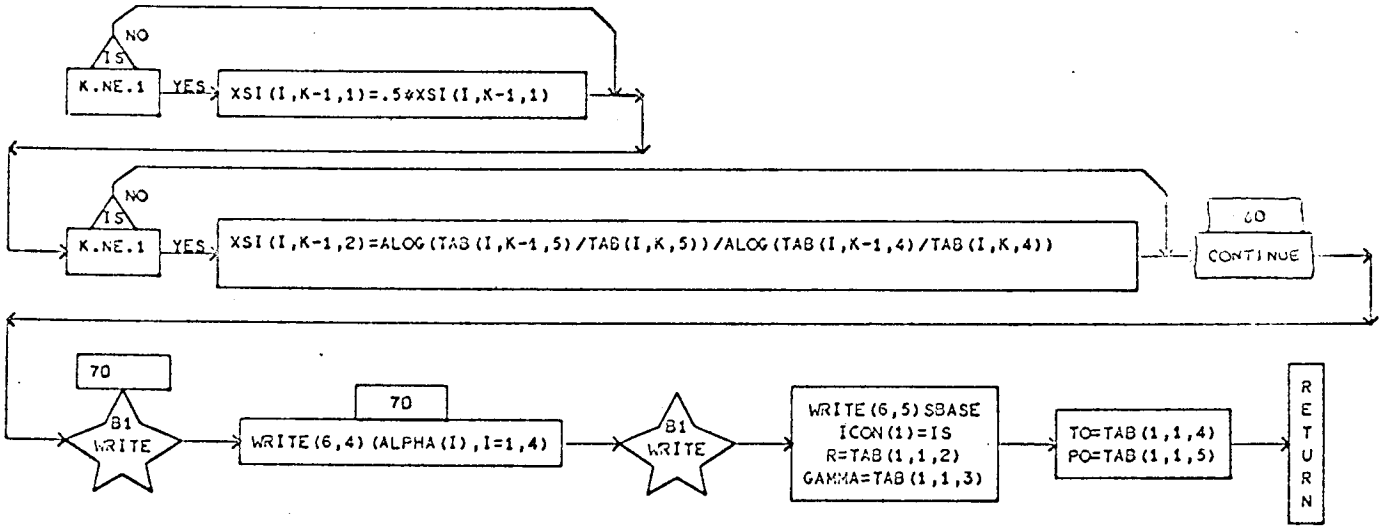
COMMON/XSICOM/
COMMON/CONTRL/
COMMON/DATAR/
COMMON/GASCON/
COMMON/TAPEFO/
GASTAP
IDTAPE

METHOD OF SOLUTION

The gas name (ALPHA(I)), type units, and number of entropy cuts are read in from an input card. If the gas properties are on cards, this subroutine reads the cards. If the gas properties are on tape, control of the reading of properties is given to GASTAP. In either case, the properties are converted from MKS to English (ENG) units by this subroutine if necessary.

SUBROUTINE GASRD




IS K.NE.1
NO
YES
XSI(I,K-1,1)=.5*XSI(I,K-1,1)
IS K.NE.1
NO
YES
XSI(I,K-1,2)=ALOG(TAB(I,K-1,5)/TAB(I,K,5))/ALOG(TAB(I,K-1,4)/TAB(I,K,4))
60
CONTINUE
70
B1 WRITE
70
WRITE(6,4) (ALPHA(I),I=1,4)
B1 WRITE
WRITE(6,5) SBASE
ICON(1)=IS
R=TAB(1,1,2)
GAMMA=TAB(1,1,3)
TO=TAB(1,1,4)
PO=TAB(1,1,5)
RETURN

SUBROUTINE NAME: GASTAP

DESCRIPTION

GASTAP recovers the real gas properties generated by the NASA LEWIS THERMOCHEMICAL DATA program and provides instructions for writing this data on the MOC flow field tape. Only the gas properties necessary for execution of the MOC program are recovered.

CALLING SEQUENCE

```
CALL GASTAP
```

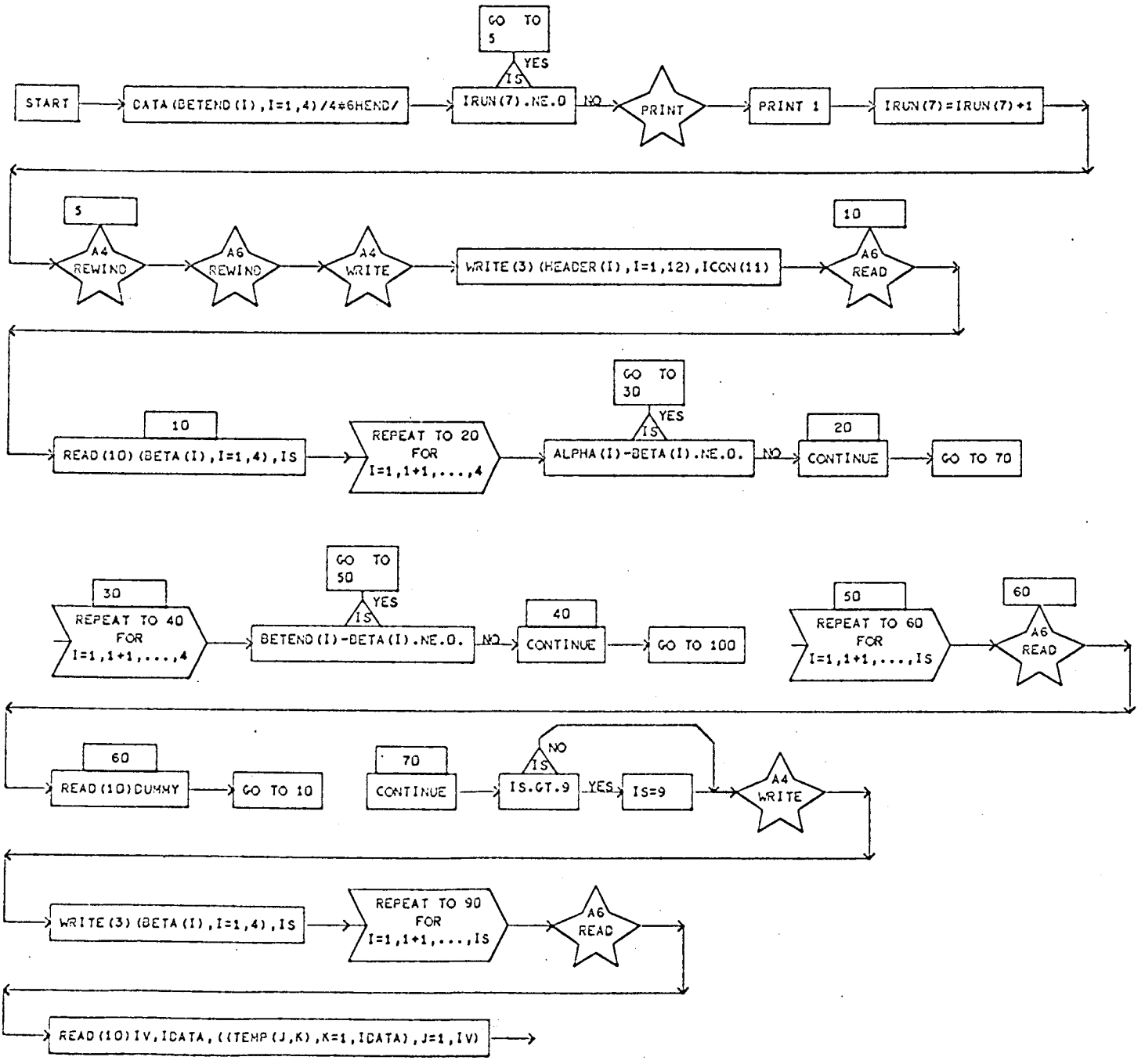
UTILITY ROUTINES AND COMMON REFERENCES

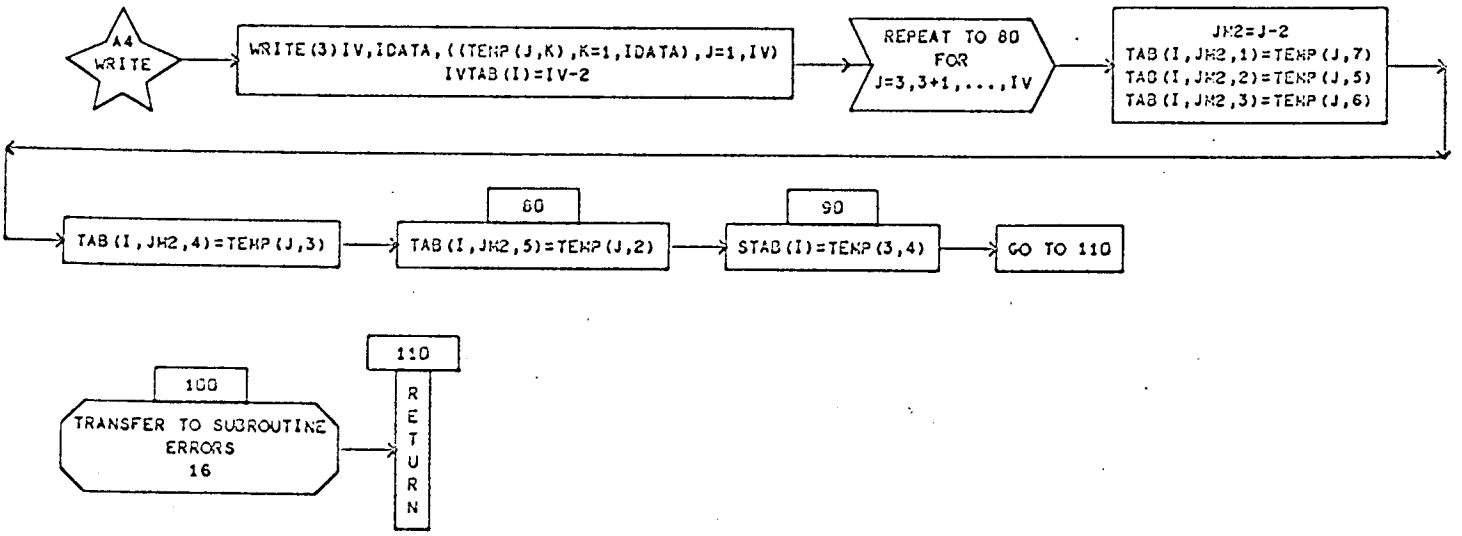
COMMON/CONTRL/
COMMON/DATAR/
COMMON/HEAD/
COMMON/TAPEFO/
UTILITY - None

METHOD OF SOLUTION

The gas name, (ALPHA(I)), specified on the input data is compared with available cases on the thermochemical data tape until a match is found. This particular case is then read in and immediately rewritten on the MOC flow field tape.

SUBROUTINE GASTAP




A4
WRITE
WRITE(3)IV,IDATA,((TEMP(J,K),K=1,IDATA),J=1,IV)
IVTAB(I)=IV-2
REPEAT TO 80
FOR
J=3,3+1,...,IV
JM2=J-2
TAB(I,JM2,1)=TEMP(J,7)
TAB(I,JM2,2)=TEMP(J,5)
TAB(I,JM2,3)=TEMP(J,6)
TAB(I,JM2,4)=TEMP(J,3)
80
TAB(I,JM2,5)=TEMP(J,2)
90
STAB(I)=TEMP(3,4)
GO TO 110
100
TRANSFER TO SUBROUTINE
ERRORS
16
110
RETURN

SUBROUTINE NAME: HYPER

DESCRIPTION

This subroutine calculates the balanced pressure at a corner point (i.e., at the intersection of a nozzle lip and the pressure boundary). The pressure balance is determined for either the over or under expanded case with impact or ambient freestream pressure.

CALLING SEQUENCE

CALL HYPER (PB, I, K, ITYPE)

where (PB) is the boundary pressure, (I, K) locates the boundary point, and (ITYPE) indicates if upper or lower boundary is involved.

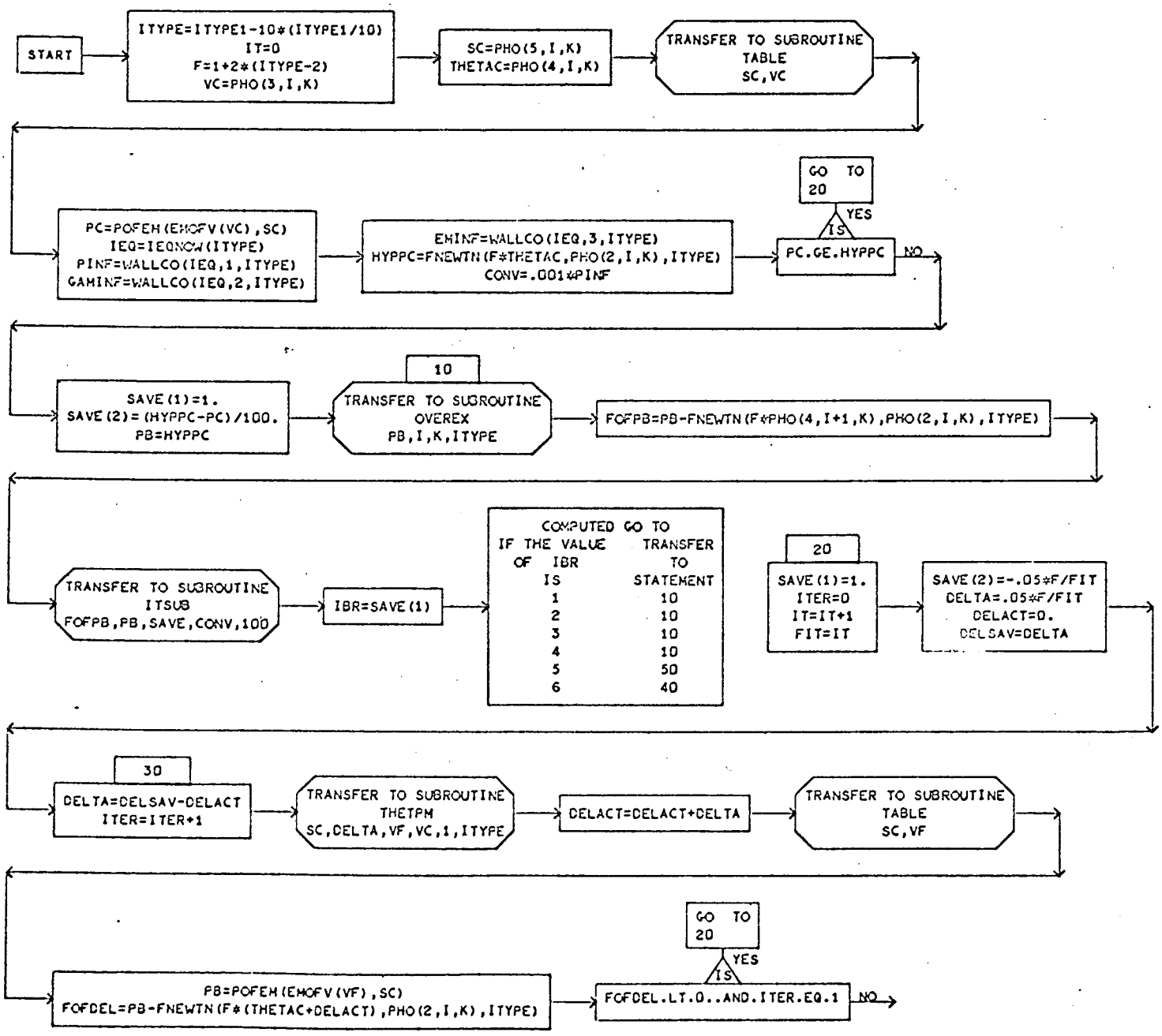
UTILITY ROUTINES AND COMMON REFERENCES

COMMON/DATAR/
TABLE
POFEM
FNEWTN
OVEREX
ITSUB
THETPM
ERRORS

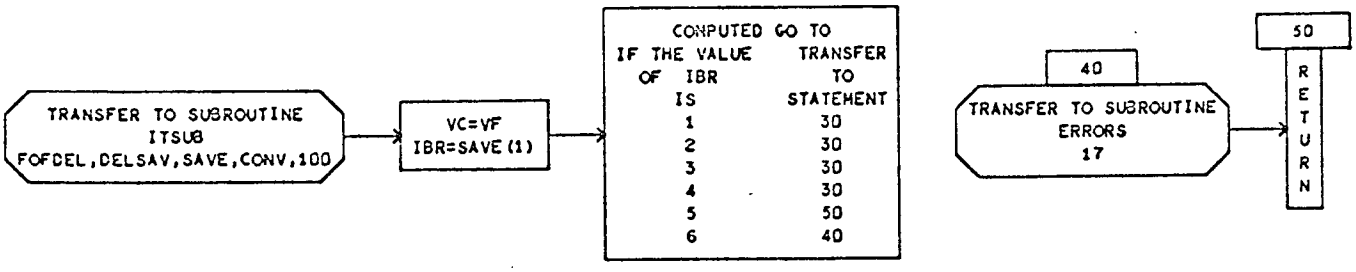
METHOD OF SOLUTION

The freestream pressure (may be impact or ambient) is compared to static pressure within the plume. Depending on whether the comparison indicates the flow is over or under expanded, a branch is made to (OVEREX) or (THETPM). In either of these routines an iterative process produces the balanced boundary pressure.

SUBROUTINEHYPER(PB,I,K,ITYPE1)



SUBROUTINEHYPER(PB,I,K,ITYPE1)



SUBROUTINE NAME: IDTAPE

DESCRIPTION

This subroutine writes the gas properties which were input via cards on the flow field program tape. The format used to write them on tape is compatible with that used for real gas.

CALLING SEQUENCE

CALL IDTAPE (UNITS)

where (UNITS) indicates whether the gas properties are being read in with English (ENG) or MKS units.

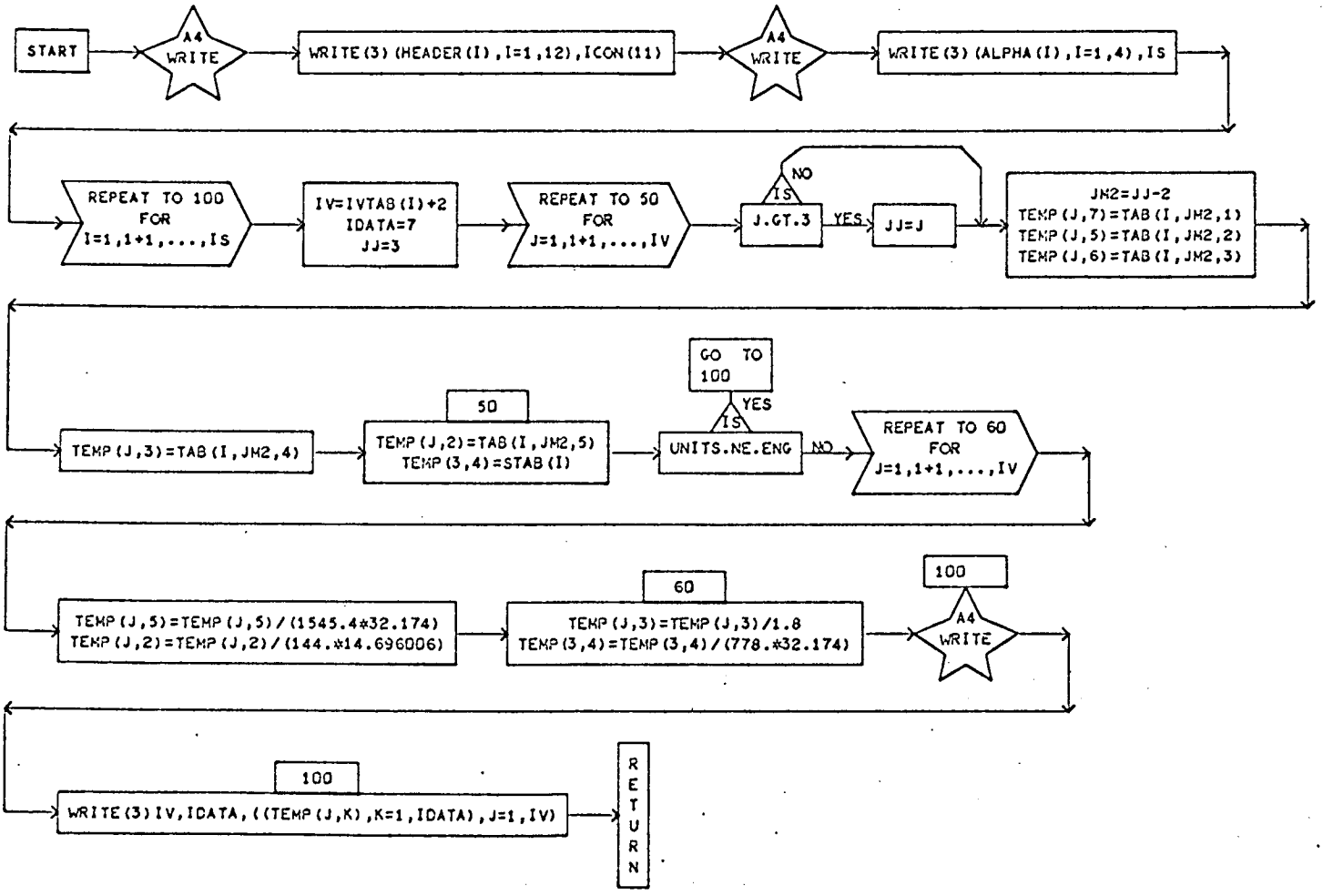
UTILITY ROUTINES AND COMMON REFERENCES

COMMON/DATAR/
COMMON/TAPEFO/
COMMON/CONTRL/
COMMON/HEAD/
UTILITY - None

METHOD OF SOLUTION

Gas property data is read in from cards. If not already in MKS units, the data is converted. This converted data is then written on the flow field tape (tape 3).

SUBROUTINE IDTAPE(UNITS) PAGE 1



SUBROUTINE NAME: INITP

DESCRIPTION

This subroutine initializes the values of certain control parameters, thereby providing for proper activation of the program. These initial values include:

1. the number of the initial upper and lower boundary equations,
2. the number of the first characteristic line,
3. the initial number of degrees per Prandtl-Meyer ray,
4. convergence criteria,
5. maximum number of iterations.

CALLING SEQUENCE

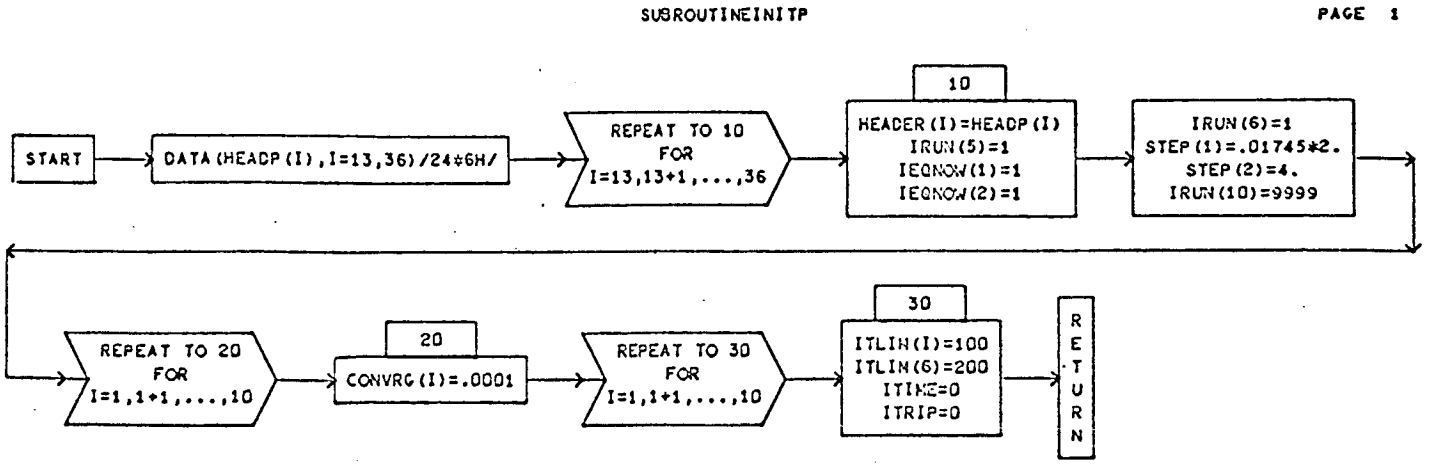
CALL INITP

UTILITY ROUTINES AND COMMON REFERENCES

COMMON/CONTRL
COMMON/CRITER
COMMON/DATAR
COMMON/HEAD
COMMON/STEPC
UTILITY - None

METHOD OF SOLUTION

Not applicable.



SUBROUTINE NAME: INRSCT

DESCRIPTION

This subroutine finds the intersection of two straight lines.

CALLING SEQUENCE

CALL INRSCT (R1, X1, BETA1, R2, X2, BETA2, R3, X3)

where (R1, X1, BETA1) and (R2, X2, BETA2) define the equations of the two straight lines which intersect at (R3, X3).

UTILITY ROUTINES AND COMMON REFERENCES

None

METHOD OF SOLUTION

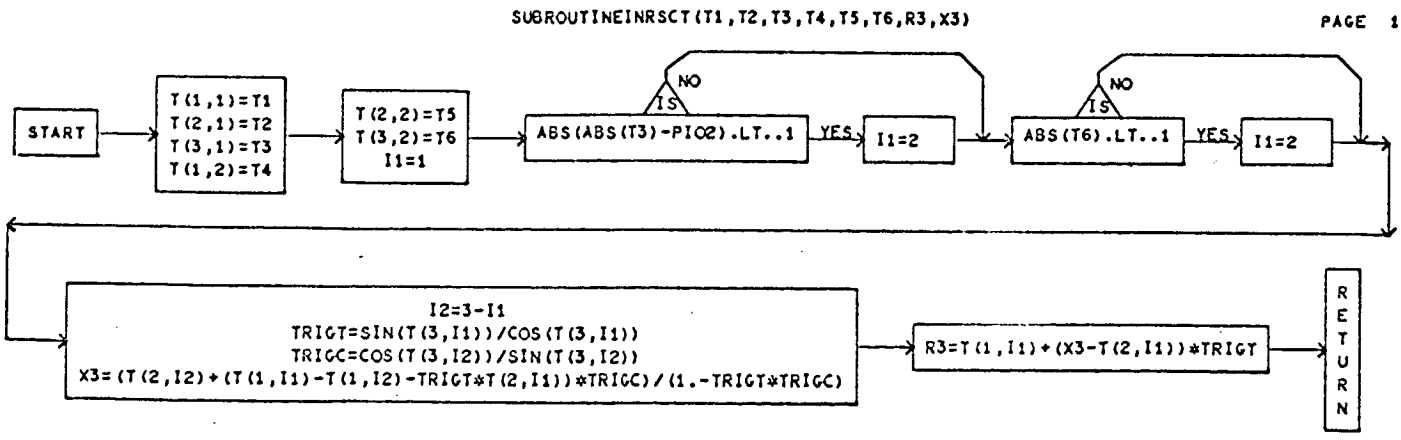
The equations of the straight lines are written

$$r = \tan\beta_1 (x - x_1) + r_1$$

and

$$x = \cot\beta_2 (r - r_2) + x_2$$

These equations are solved for x but a test on the slopes is made to prevent indeterminate forms. If an indeterminate form is possible, the points are mapped one onto another, thus precluding the possibility of indeterminancy except when the lines are parallel.



FUNCTION NAME: ITERM

DESCRIPTION

ITERM tests each characteristic point to determine if it is within the predefined problem limits. If the point falls outside the limits, the present characteristic line is terminated and a new line started.

CALLING SEQUENCE

FUNCTION = ITERM (IP, K)

where (IP) identifies the characteristic point on the new (K) line.

UTILITY ROUTINES AND COMMON REFERENCES

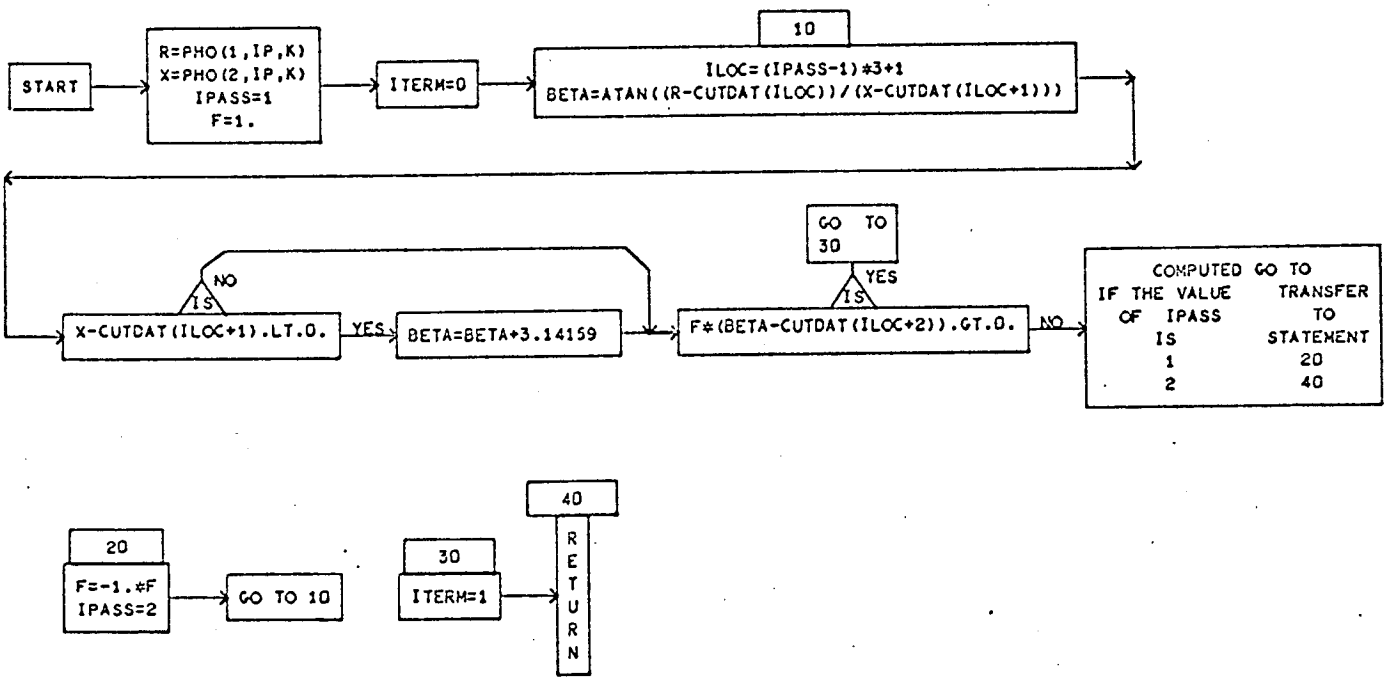
COMMON/CUTFO/
COMMON/DATAR/
UTILITY - None

METHOD OF SOLUTION

The angular orientation of a line drawn from the upper or lower cutoff coordinates to the characteristic point is determined. Comparing this angle to the angle of the upper or lower cutoff line determines if the point is inside or outside the problem limits.

FUNCTION ITERM(IP,K)

PAGE 1



SUBROUTINE NAME: ITSUB

DESCRIPTION

This subroutine controls the iterative solution of any set of equations which can ultimately be expressed as a function of one variable. The routine can also be used to control an integration loop.

CALLING SEQUENCE

CALL ITSUB (FOFX, X, SAVE, CONV, NTIMES)

(FOFX) - function of X which is driven to zero

(X) - variable which is iteratively solved for

(SAVE) - program control, i.e., SAVE(1) is control counter, SAVE(2) is X increment

(CONV) - convergence criteria

(NTIMES) - maximum number of iterations

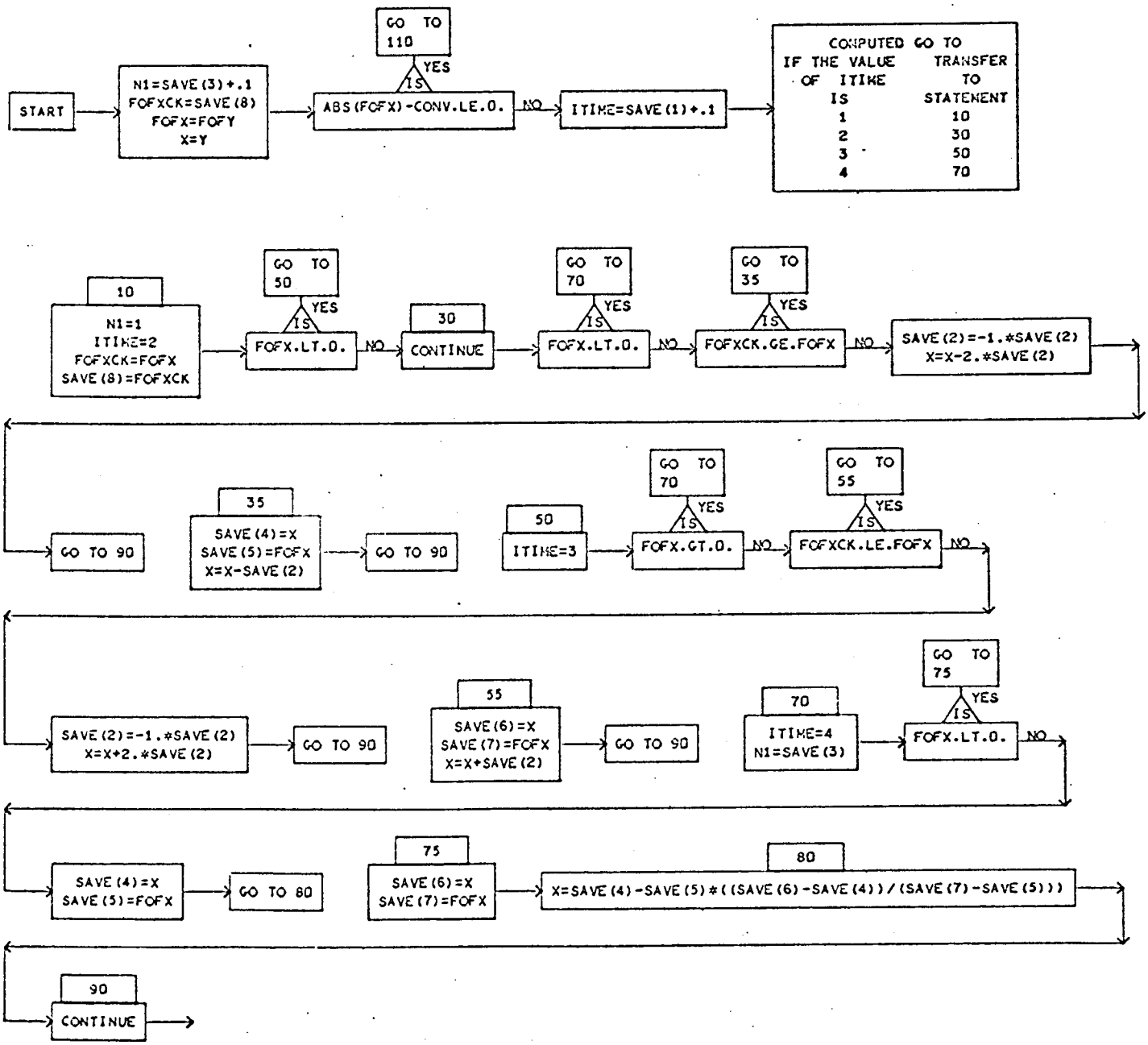
UTILITY ROUTINES AND COMMON REFERENCES

None

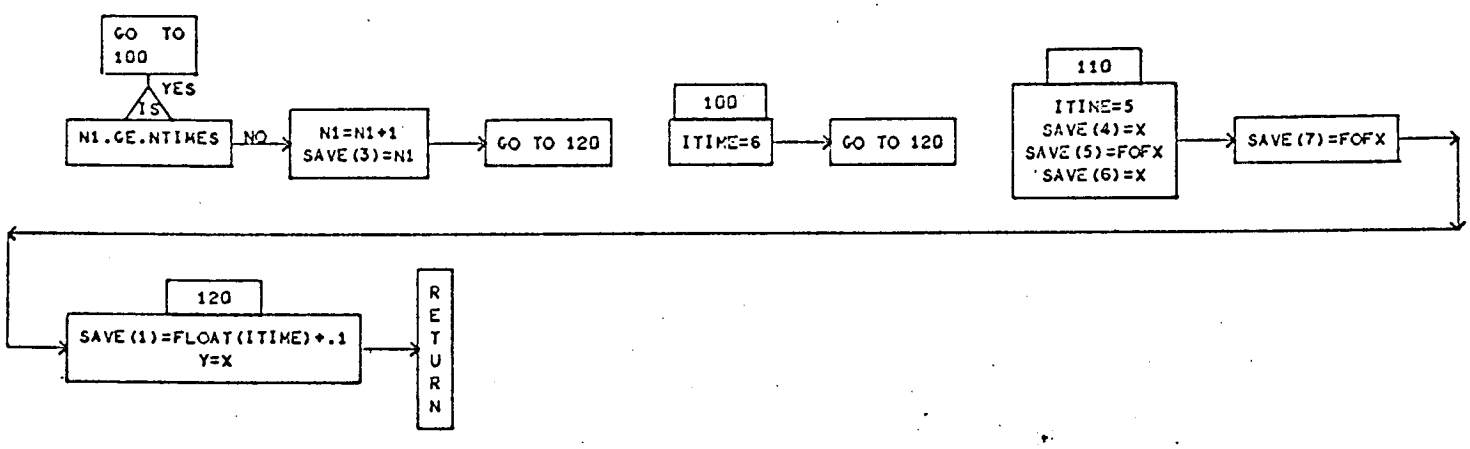
METHOD OF SOLUTION

ITSUB modifies (X) in the proper direction by the decrement value (SAVE(2)) until the root has been bracketed. The method of false position is then used to modify X until the solution is reached. Immediately after entering ITSUB each time, the function is inspected for convergence. If the function has converged, a program control is set, and computer control is transferred to the calling routine.

SUBROUTINE ITSU3 (FOFY,Y,SAVE,CONV,NTIMES)



SUBROUTINE ITSUB (FOFY,Y,SAVE,CONV,NTIMES)



SUBROUTINE NAME: KIKOFF

DESCRIPTION

This subroutine allows control to return to the Main program if an error in the calculation is encountered. It also reads in the plot request data if SC 4020 plots are desired.

CALLING SEQUENCE

CALL KIKOFF

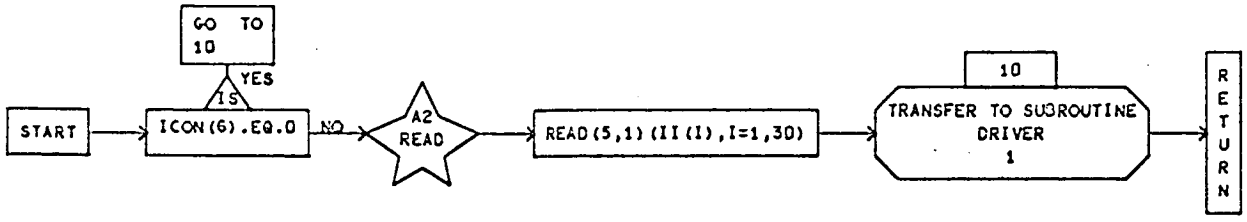
UTILITY ROUTINES AND COMMON REFERENCES

COMMON/CONTRL/
DRIVER

METHOD OF SOLUTION

Not applicable.

SUBROUTINE KIKOFF



SUBROUTINE NAME: LIMITS

DESCRIPTION

This subroutine tests the new boundary point to determine if it is within the limits of the current boundary equation. Depending on the test, the options are:

1. remain on the current boundary equation,
2. advance to the next boundary equation, or
3. the current equation is the last one specified.

CALLING SEQUENCE

CALL LIMITS (I, K, ITYPE, IOK)

where (I, K) represents the location of the boundary point in the PHO array, (ITYPE) tells if an upper or lower boundary is to be considered, and (IOK) is a control indicating if option 1, 2, or 3 is to be used.

UTILITY ROUTINES AND COMMON REFERENCES

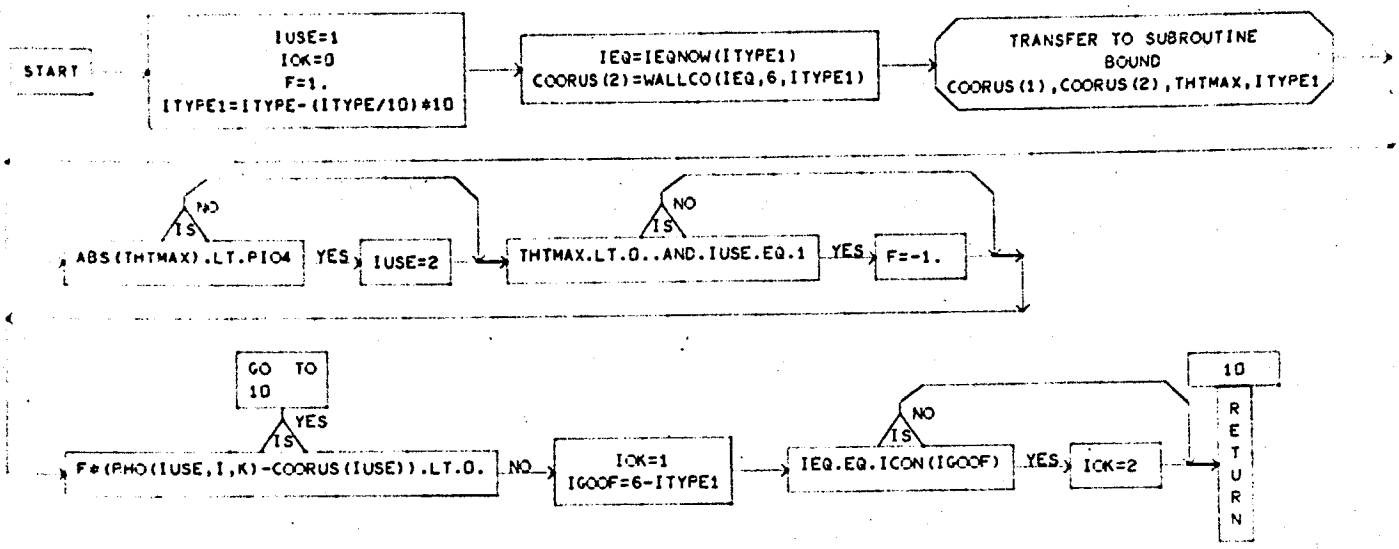
COMMON/CONTRL
COMMON/DATAR
UTILITY - None

METHOD OF SOLUTION

The radius (RMAX) and boundary angle (THETAMAX) at the limiting axial value is calculated in (BOUND). (RMAX) or (XMAX) is compared to (R) or (X) for the point in question. The results of the comparison determine if option 1, 2 or 3 is to be used.

SUBROUTINE LIMITS(I,K,ITYPE,IOK)

PAGE 1



SUBROUTINE NAME: LIPIN

DESCRIPTION

LIPIN calculates information for the starting line points when the simplified straight start line option is used (i.e., when ICON(2) = 0).

CALLING SEQUENCE

CALL LIPIN (COOR, S, INTOT, DELM)

where (COOR) is the starting line information array, (S) is the entropy level of the start line, (INTOT) is the total number of input points specified (50 MAX), and (DELM) is the change in Mach number along the start line.

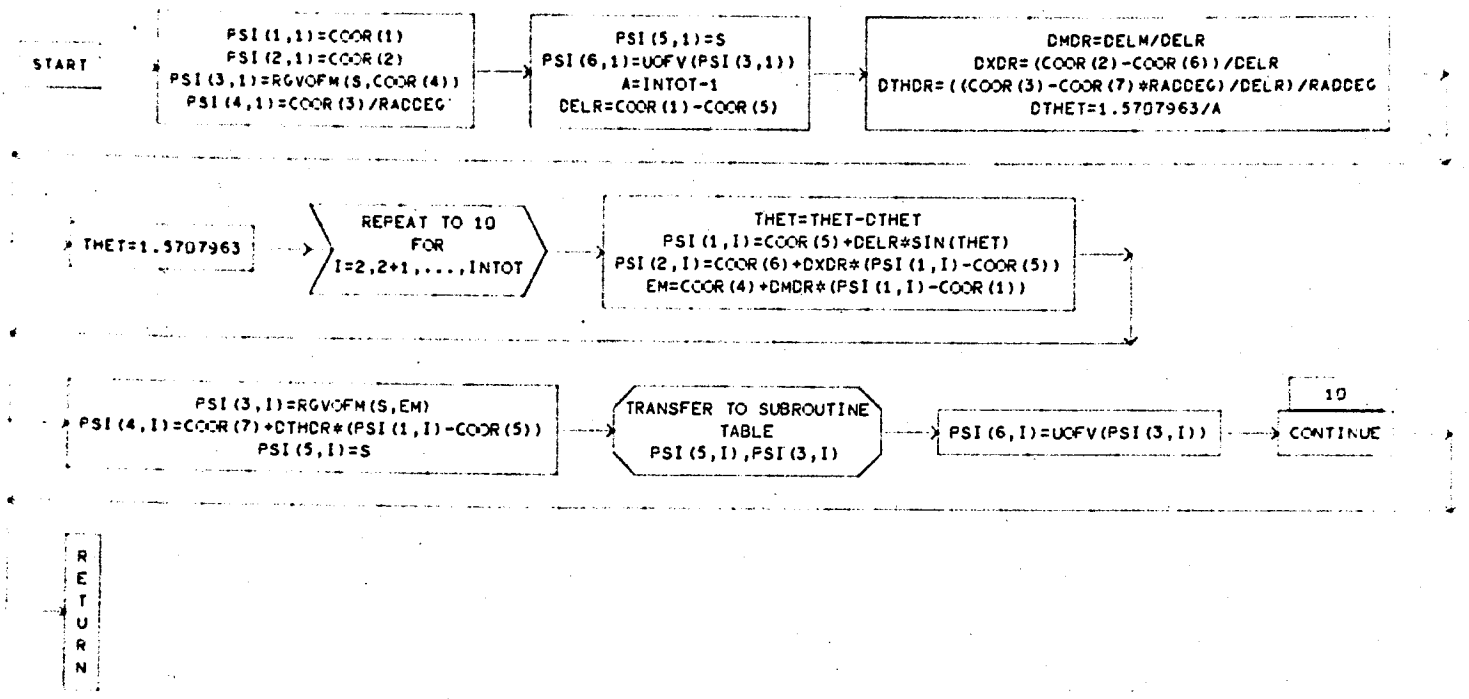
UTILITY ROUTINES AND COMMON REFERENCES

COMMON/INPUT/
TABLE
RGVOFM
UOFV

METHOD OF SOLUTION

The start line input data is divided into the specified number of increments. Radial gradients in Mach number, X, θ, are calculated. A quarter circle is divided into the specified increments and data transferred, considering gradients, to the start line.

SUBROUTINE LIFIN(COOR,S,INTOT,DELM) PAGE 1



SUBROUTINE NAME: MASCON

DESCRIPTION

This subroutine calculates the Mach number distribution at an area downstream of the throat such that total mass flow is conserved. Mass flow, calculated at the throat, is used as the constant for comparison.

CALLING SEQUENCE

CALL MASCON (E, SE, DELM)

where (E) is the input line array (CORLIP), (SE) is the exit entropy level, and (DELM) is the Mach number gradient along the start line.

UTILITY ROUTINES AND COMMON REFERENCES

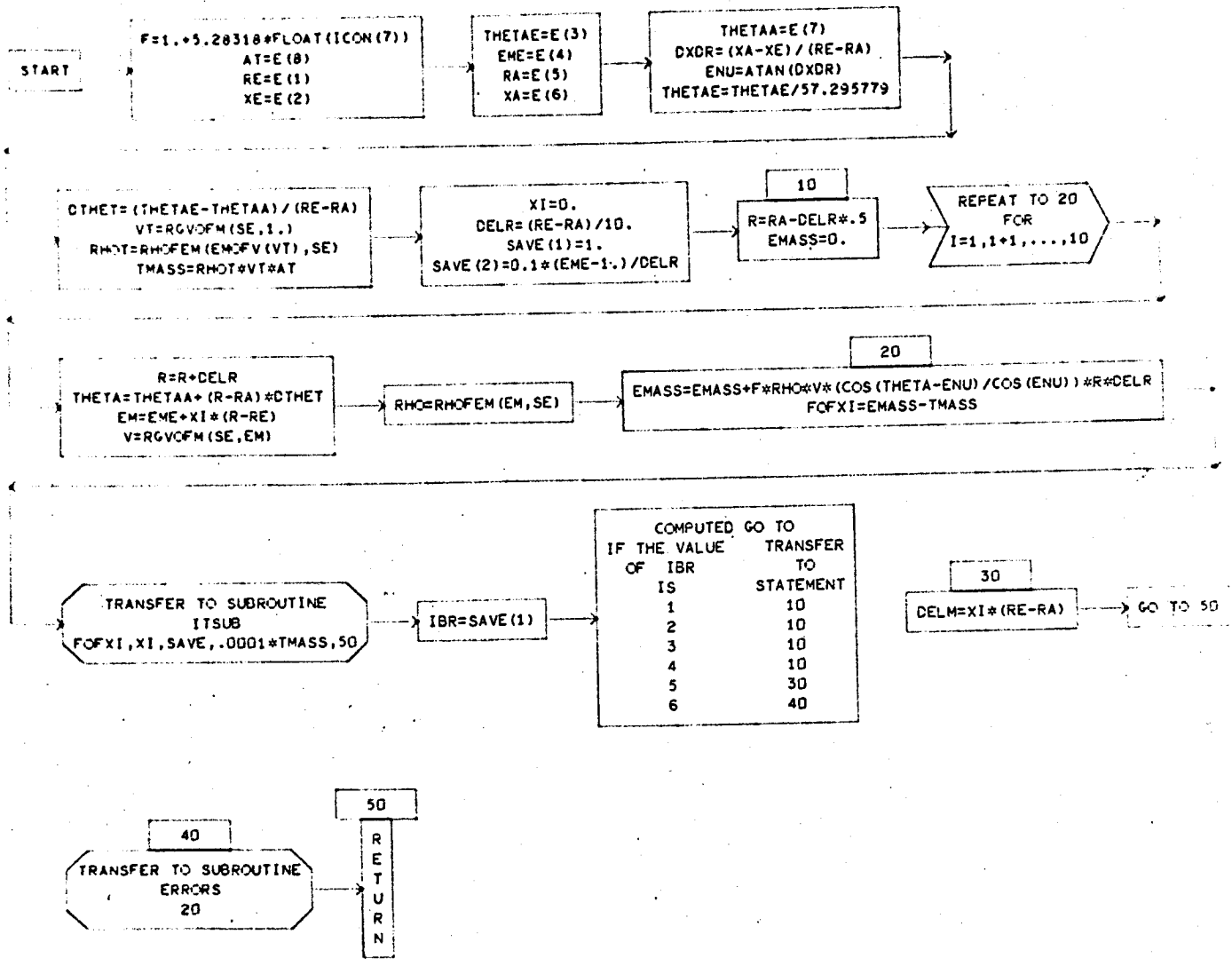
COMMON/CONTRL/
RGVOFM
RHOFEM
ERRORS

METHOD OF SOLUTION

The mass flow rate at the throat ($\dot{M}^*$) is calculated. This ($\dot{M}^*$) is compared to that at the exit area for a given Mach number distribution. The Mach number distribution is perturbed until mass flow is conserved.

SUBROUTINE MASCON(E,SE,DELM)

PAGE 1



SUBROUTINE NAME: MASSCK

DESCRIPTION

This subroutine keeps a running check on the mass flow. Mass flow at the starting line is calculated and compared with that crossing each characteristic line downstream.

CALLING SEQUENCE

CALL MASSCK (ILAST, ISTART, K)

where (ILAST) is the last point on the previous line, (ISTART) is the first input point or axis point, and (K) represents the new characteristic line.

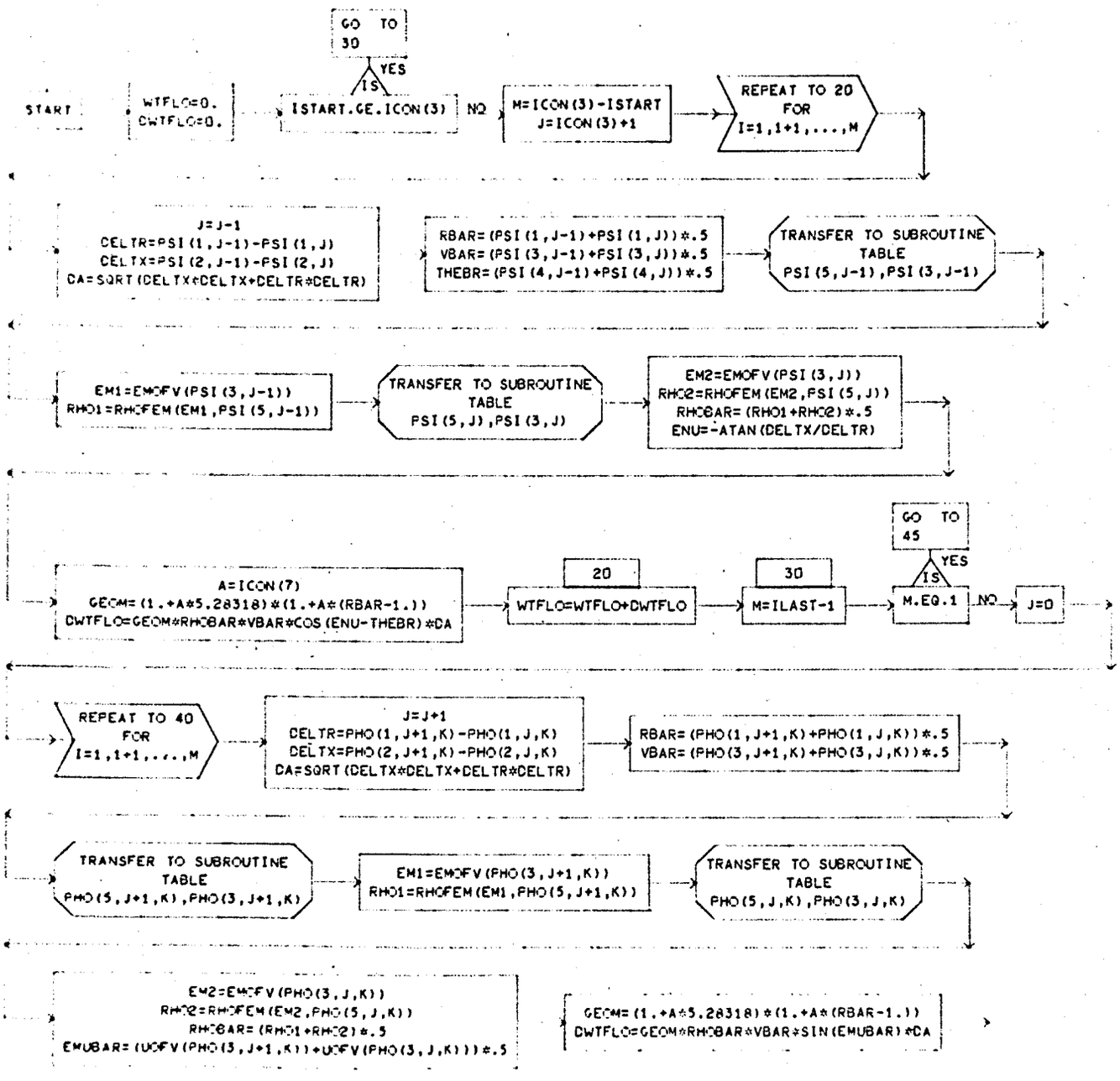
UTILITY ROUTINES AND COMMON REFERENCES

COMMON/DATAR/
COMMON/INPUT/
COMMON/CONTRL/
COMMON/STEPC/
TABLE
EMOFV
RHOFEM
UOFV

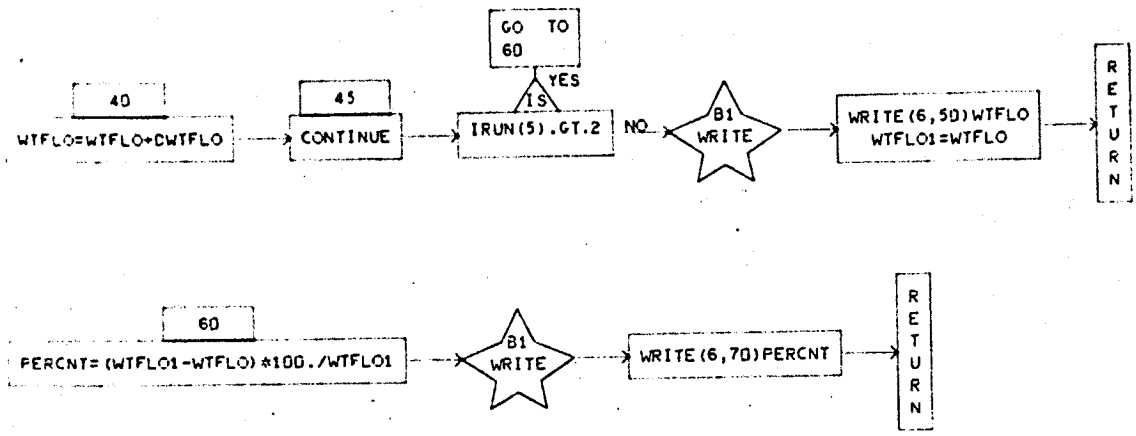
METHOD OF SOLUTION

The mass flow through the start line/second characteristic line is calculated and stored. Mass flow through lines downstream are calculated and their values compared with the initial value. A percent change in mass flow is printed for each characteristic line.

SUBROUTINE MASSCK(ILAST,ISTART,K)



SUBROUTINE MASSCK(ILAST,ISTART,K)



SUBROUTINE NAME: MOCSOL

DESCRIPTION

This subroutine provides all two dimensional or axisymmetric method-of-characteristics solutions. The new point being solved for may be one of five possible types:

1. interior point
2. upper wall point
3. upper free boundary point
4. lower wall point
5. lower free boundary point

CALLING SEQUENCE

CALL MOCSOL (I, K, I1, K1, I2, K2, IFLAG, ITYPE)

where (I, K) identifies the storage location for the new point to be computed, (I1, K1) identifies the right running (or upper boundary) known point, and (I2, K2) identifies the left running (or lower boundary) known point. (IFLAG) is an error indicator and (ITYPE) selects the type calculation.

UTILITY ROUTINES AND COMMON REFERENCES

COMMON/CONTRL/	BOUND
COMMON/CRITER/	ROTERM
COMMON/DATAR/	VOFEM
COMMON/GASCON/	RGMOFP
TABLE	FNEWTN
INRSCT	UOFV
	ERRORS

METHOD OF SOLUTION

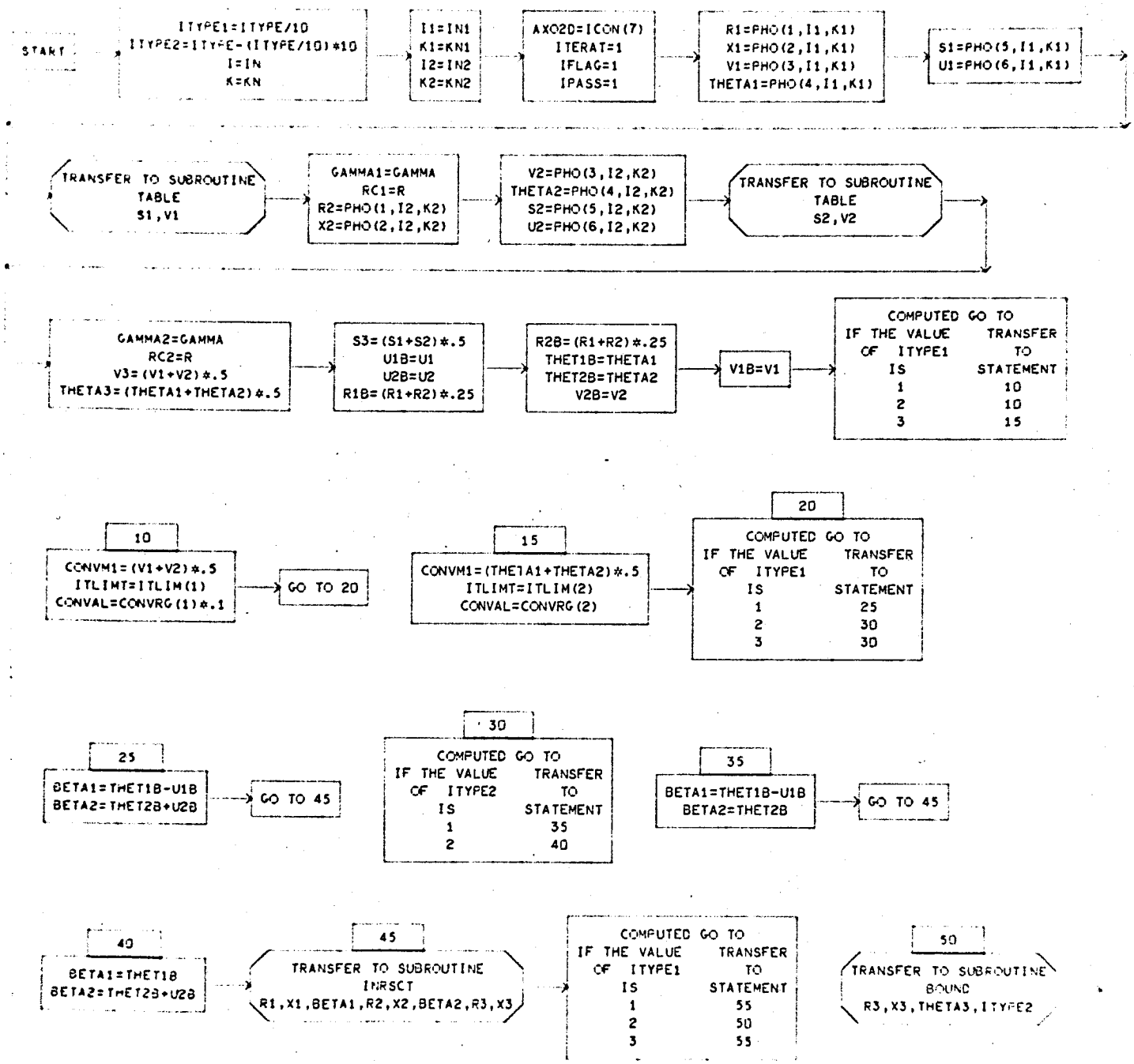
The four characteristic equations are written as a function of five variables (R, X, θ, V, S). An additional relationship is obtained by assuming

the entropy (S) varies linearly between known data points. Using these characteristic equations in finite difference form, the routine solves for a new mesh point, knowing two mesh points of opposite family.

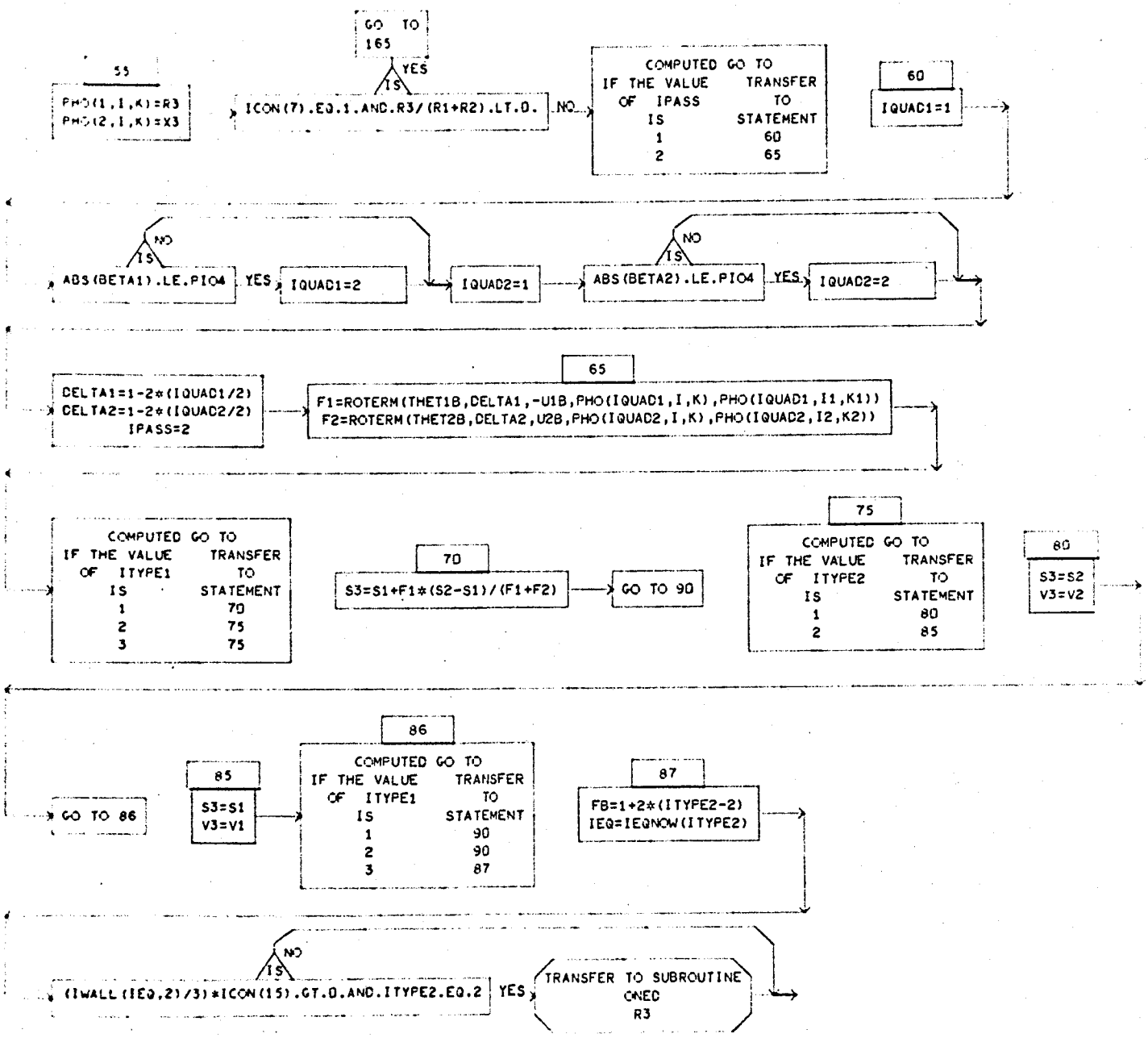
The solution is begun by setting the average values of properties over the step length equal to the known values at the base points. Subsequent passes in the iterative solution result in "updated" average values. The iterative solution is continued until the desired convergence on velocity or flow angle is reached or until the maximum number of iterations is exceeded.

For a detailed derivation of the characteristic equations and a description of their application in finite difference form to the solution of the characteristic mesh, see Section 6, Reference 1.

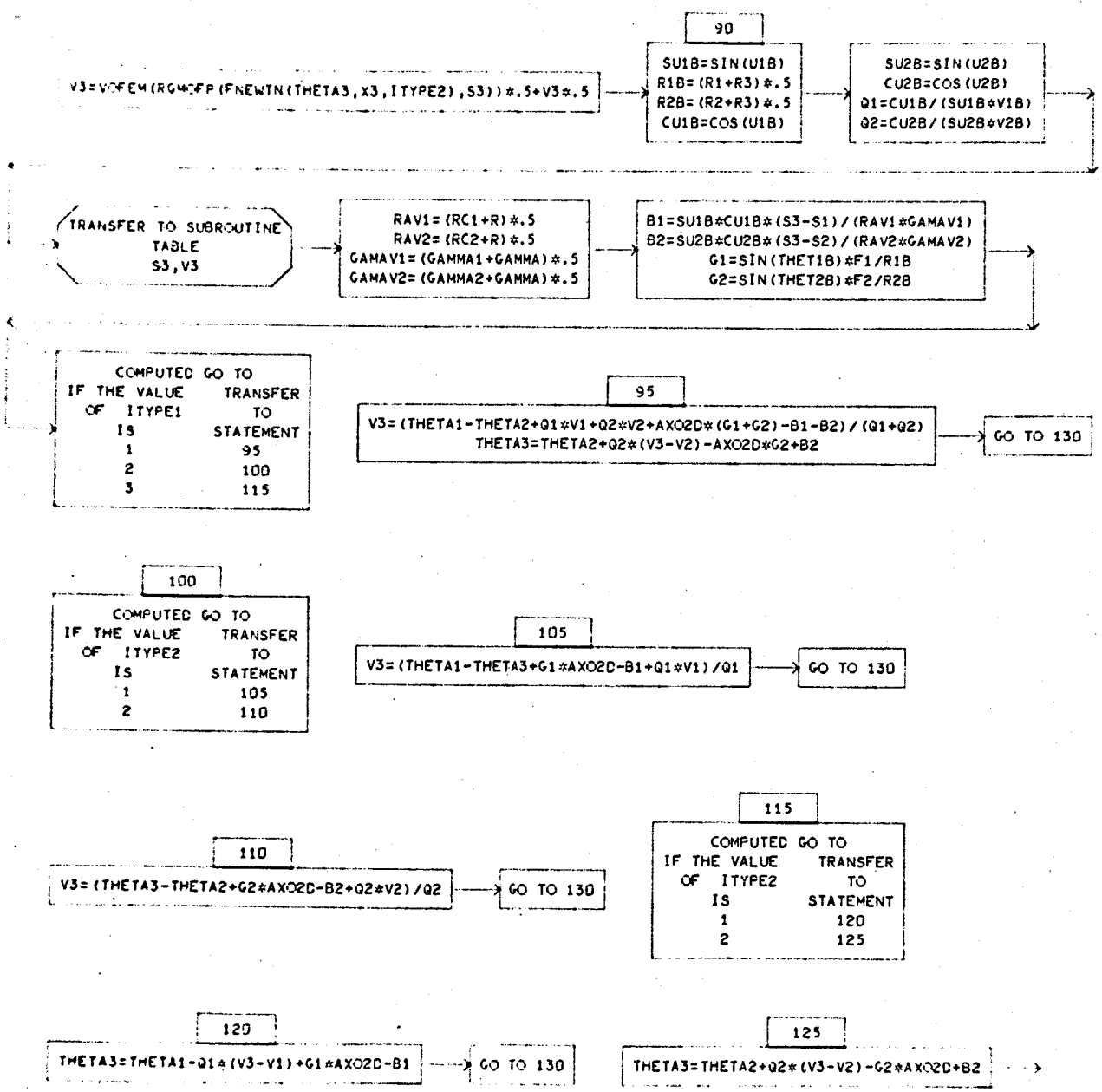
SUBROUTINEMOCSOL(IN,KN,IN1,KN1,IN2,KN2,IFLAG,ITYPE) PAGE 1 OF 5

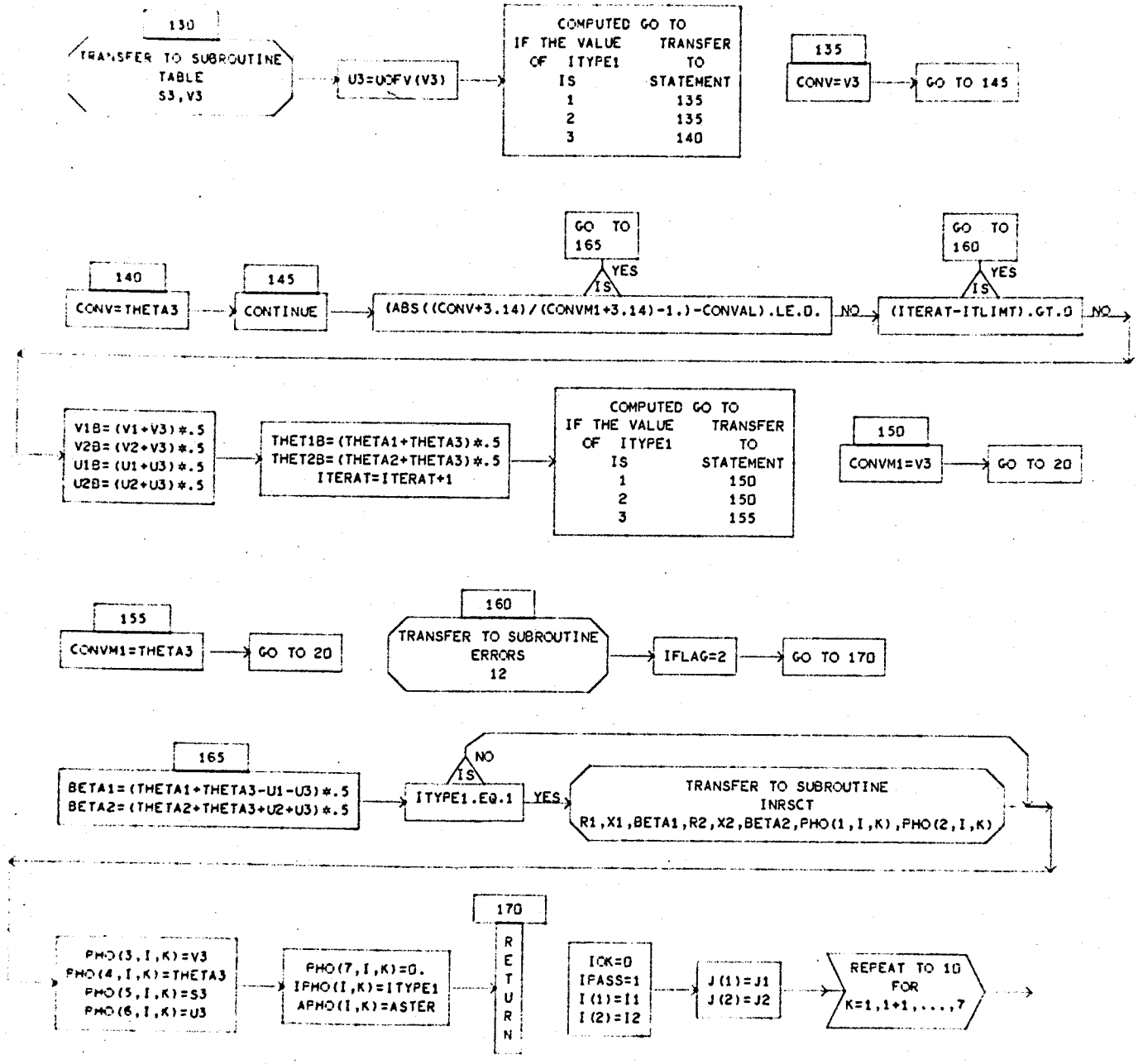


SUBROUTINEMOCSOL(IN,KN,IN1,KN1,IN2,KN2,IFLAG,ITYPE)

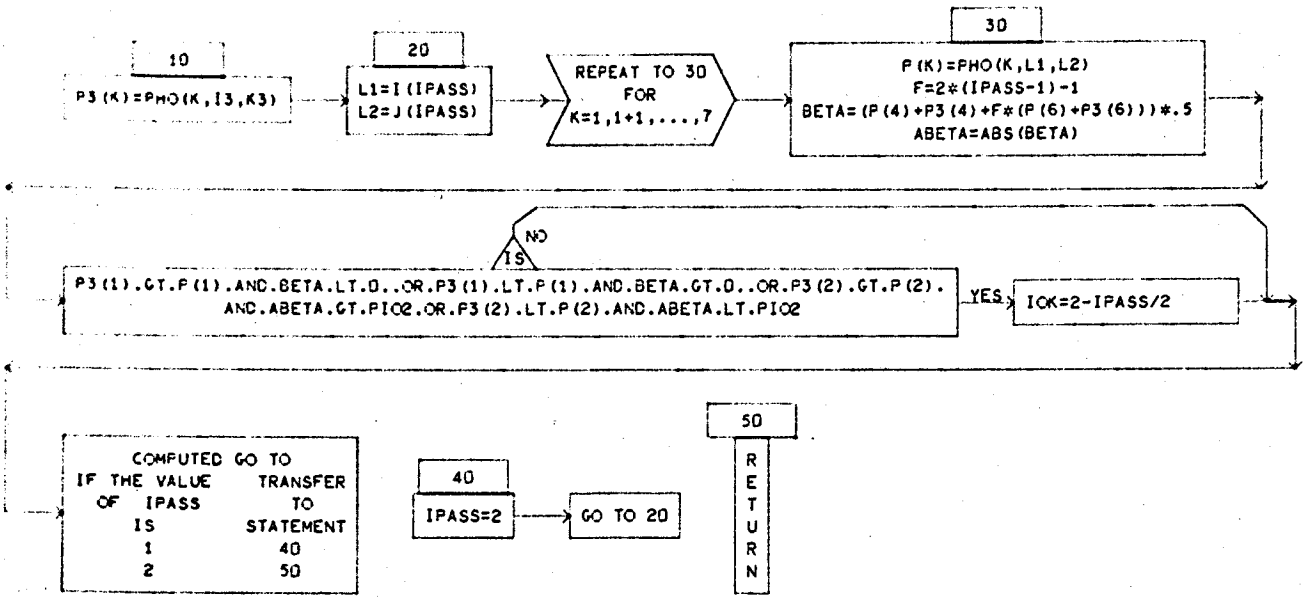


SUBROUTINEMOCSOL(IN,KN,IN1,KN1,IN2,KN2,IFLAG,ITYPE)




130
TRANSFER TO SUBROUTINE TABLE S3,V3
U3=UCFV(V3)
COMPUTED GO TO
IF THE VALUE OF ITYPE1 IS
TRANSFER TO STATEMENT
1 135
2 135
3 140
135
CONV=V3
GO TO 145
140
CONV=THETA3
145
CONTINUE
(ABS((CONV+3.14)/(CONVM1+3.14)-1.)-CONVAL).LE.0.
IS
YES
GO TO 165
NO
(ITERAT-ITLIMT).GT.0
IS
YES
GO TO 160
NO
V1B=(V1+V3)*.5
V2B=(V2+V3)*.5
U1B=(U1+U3)*.5
U2B=(U2+U3)*.5
THET1B=(THETA1+THETA3)*.5
THET2B=(THETA2+THETA3)*.5
ITERAT=ITERAT+1
COMPUTED GO TO
IF THE VALUE OF ITYPE1 IS
TRANSFER TO STATEMENT
1 150
2 150
3 155
150
CONVM1=V3
GO TO 20
155
CONVM1=THETA3
GO TO 20
160
TRANSFER TO SUBROUTINE ERRORS 12
IFLAG=2
GO TO 170
165
BETA1=(THETA1+THETA3-U1-U3)*.5
BETA2=(THETA2+THETA3+U2+U3)*.5
ITYPE1.EQ.1
IS
NO
YES
TRANSFER TO SUBROUTINE INRSCT
R1,X1,BETA1,R2,X2,BETA2,PHO(1,I,K),PHO(2,I,K)
PHO(3,I,K)=V3
PHO(4,I,K)=THETA3
PHO(5,I,K)=S3
PHO(6,I,K)=U3
PHO(7,I,K)=0.
IPHO(I,K)=ITYPE1
APHO(I,K)=ASTER
170
RETURN
ICK=0
IPASS=1
I(1)=I1
I(2)=I2
J(1)=J1
J(2)=J2
REPEAT TO 10 FOR K=1,1+1,...,7

SUBROUTINEMOCSOL(IN,KN,IN1,KN1,IN2,KN2,IFLAG,ITYPE)



SUBROUTINE NAME: MONO

DESCRIPTION

This subroutine determines if the characteristic solution is monotonic along left or right running lines.

CALLING SEQUENCE

CALL MONO (I1, J1, I2, J2, I3, K3, IOK)

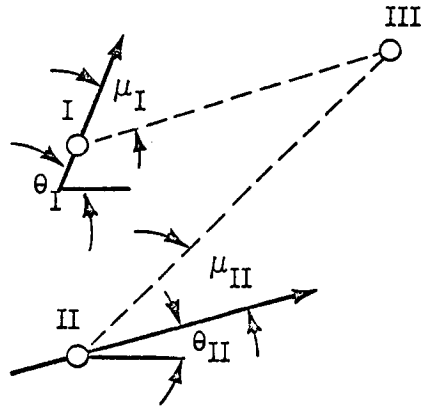
where (I1, J1), (I2, J2), (I3, K3) designate the right running base point, the left running base point, and the new characteristic point, respectively. IOK is a flag returned to the calling program which is (0) if solution is monotonic, (1) if a non-monotonic condition has occurred along the right running characteristic, and (2) if one has occurred along a left running line.

UTILITY ROUTINES AND COMMON REFERENCES

COMMON/DATAR/
UTILITY - None

METHOD OF SOLUTION

Envelope shock waves are detected in a method-of-characteristics solution by crossing of characteristic lines which, mathematically, causes a discontinuity in the flow properties. This discontinuity is interpreted as a shock wave. This routine is supplied the two base points used and the resultant new mesh point. Using this information, a discontinuity, if it exists, is detected.



Now

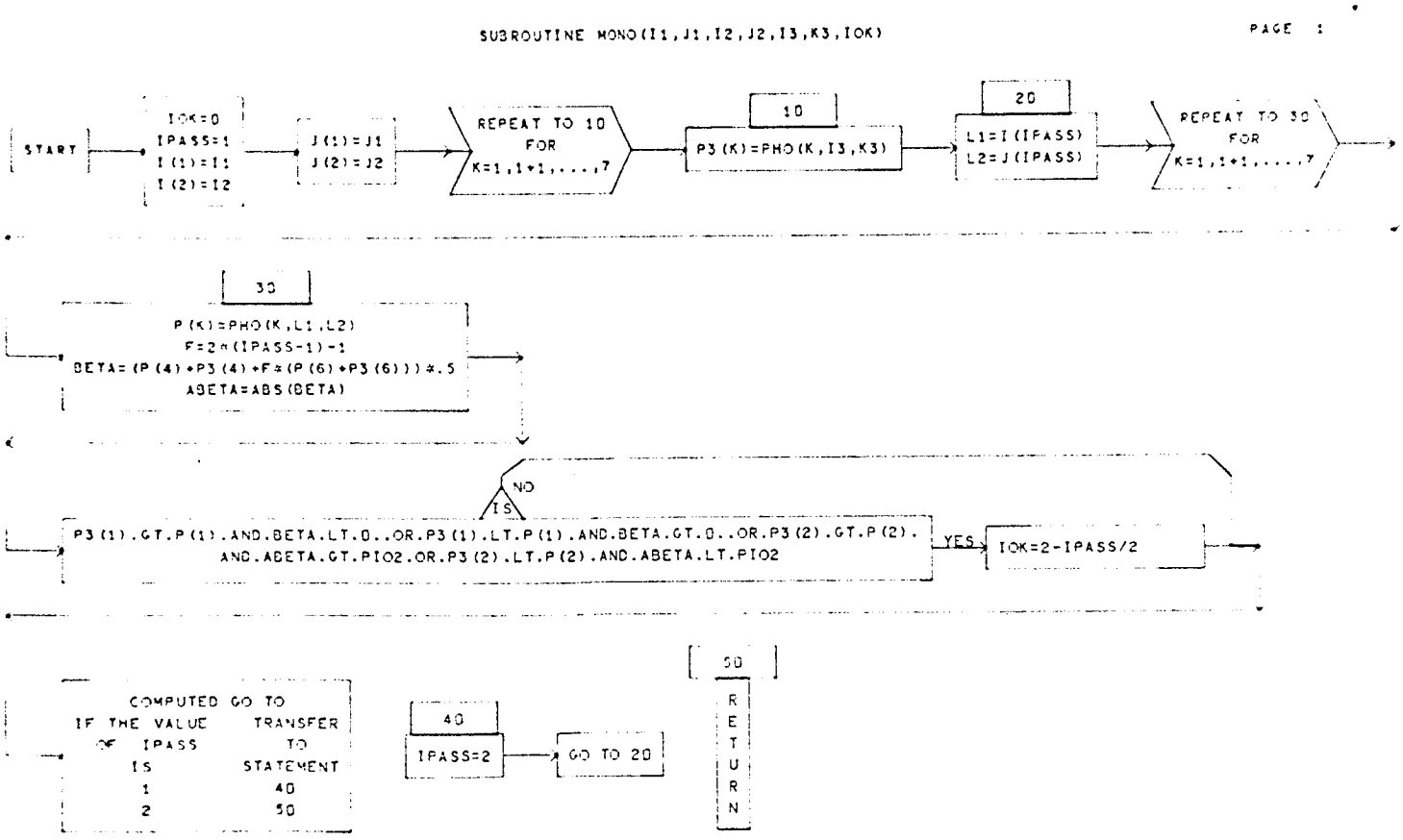
$$\overleftarrow{r}_{III} = \overleftarrow{r}_{II} + \lambda_I \left\{\cos(\overline{\theta}_I - \overline{\mu}_I)\overleftarrow{i} + \sin(\overline{\theta}_I - \overline{\mu}_I)\overleftarrow{j}\right\}$$

and

$$\overleftarrow{r}_{III} = \overleftarrow{r}_{II} + \lambda_{II} \left\{\cos(\overline{\theta}_{II} + \overline{\mu}_{II})\overleftarrow{i} + \sin(\overline{\theta}_{II} + \overline{\mu}_{II})\overleftarrow{j}\right\}$$

Effectively, this routine checks the sign of $\lambda_{I,II}$ and sets IOK accordingly.

e.g.,	if	$\lambda_I, \lambda_{II} \geq 0$	IOK = 0
	if	$\lambda_I < 0$	IOK = 1
	if	$\lambda_{II} < 0$	IOK = 2



SUBROUTINE NAME: OUT

DESCRIPTION

This subroutine writes the calculated data at characteristic points along with the corresponding title and headings.

CALLING SEQUENCE

CALL OUT (I1, I2, K)

where (I1, I2) refer to the point numbers of the points to be output (any number of points may be output at one time). (K) represents the current characteristic line (takes on the value 1 or 2).

UTILITY ROUTINES AND COMMON REFERENCES

COMMON/CONTRL/
COMMON/DATAR/
COMMON/GASCON/
COMMON/GASTAB/
COMMON/HEAD/
PAGE
TABLE

METHOD OF SOLUTION

Not applicable.

SUBROUTINE OUT (I1,I2,K)

START

```
DATA(A(I,1),I=1,3)/6HINPU,6HTPOIN,6HT/
DATA(A(I,2),I=1,3)/6H,6H,6H/
DATA(A(I,3),I=1,3)/6HWALL,6H,6H/
DATA(A(I,4),I=1,3)/6HFREE,6HBOUND,6HARY/
DATA(A(I,5),I=1,3)/6HUPST,6HREAMS,6HHOCK/
DATA(A(I,6),I=1,3)/6HPRAN,6HDTL-ME,6HYER/
DATA(A(I,7),I=1,3)/6HDOWN,6HSTREAM,6H/
J1=I1
```

```
J2=I2
ISHOCK=1
IOMIT=ICON(8)/10
LINES=ICON(4)-10*IOMIT
```

LHIGH=IRUN(5)

IRUN(4).LT.55 — YES: GO TO 40 — NO:

20: TRANSFER TO SUBROUTINE PAGE IRUN(4)

B1 WRITE

WRITE(6,2)
IRUN(4)=IRUN(4)+2

COMPUTED GO TO

IF THE VALUE OF LINES IS	TRANSFER TO STATEMENT
1	40
2	30
3	30

30: B1 WRITE

30: WRITE(6,3)
IRUN(4)=IRUN(4)+1

LINES.LT.3 — YES: GO TO 40 — NO:

B1 WRITE

WRITE(6,8)
IRUN(4)=IRUN(4)+1

40: REPEAT TO 100 FOR I=J1,J1+1,...,J2

REPEAT TO 50 FOR L=1,1+1,...,7

50: P(L)=PHO(L,I,K)

TRANSFER TO SUBROUTINE TABLE P(5),P(3)

```
P(4)=RADDEG*P(4)
P(3)=EMCFV(P(3))
P(7)=RADDEG*P(7)
M=IPHO(I,K)+1
```

M.EQ.2.AND.IOMIT.EQ.1 — YES: GO TO 110 — NO:

M.NE.5 — YES: GO TO 57 — NO:

COMPUTED GO TO

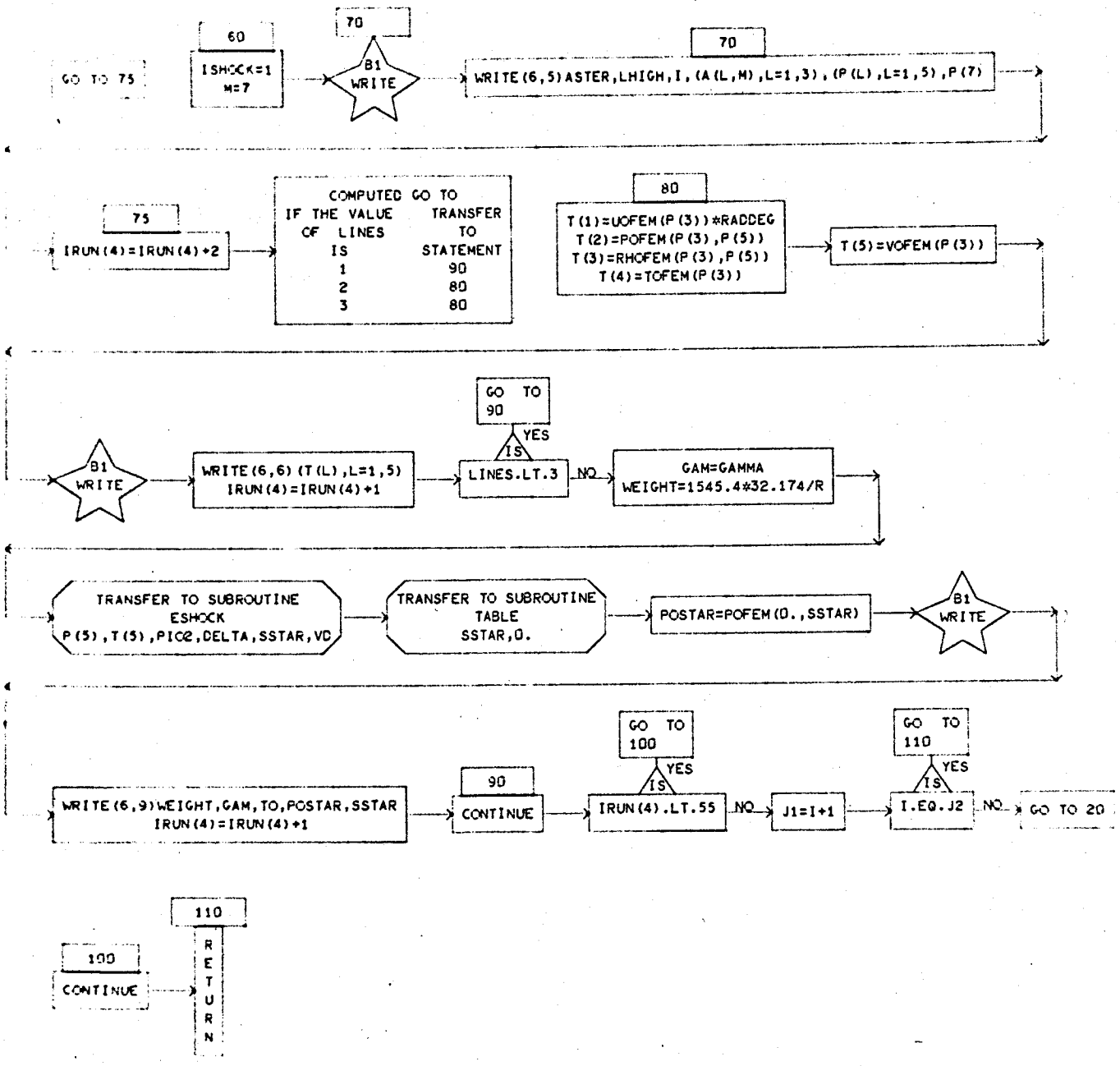
IF THE VALUE OF ISHOCK IS	TRANSFER TO STATEMENT
1	55
2	60

55: ISHOCK=2

57: B1 WRITE

57: WRITE(6,4)ASTER,LHIGH,I,(A(L,M),L=1,3),(P(L),L=1,5)

SUBROUTINE OUT (I1,I2,K)



SUBROUTINE NAME: OUTBIN

DESCRIPTION

This subroutine writes the calculated characteristic point data on the binary output tape. This is done for any number of characteristic points.

CALLING SEQUENCE

CALL OUTBIN (I1, I2, J)

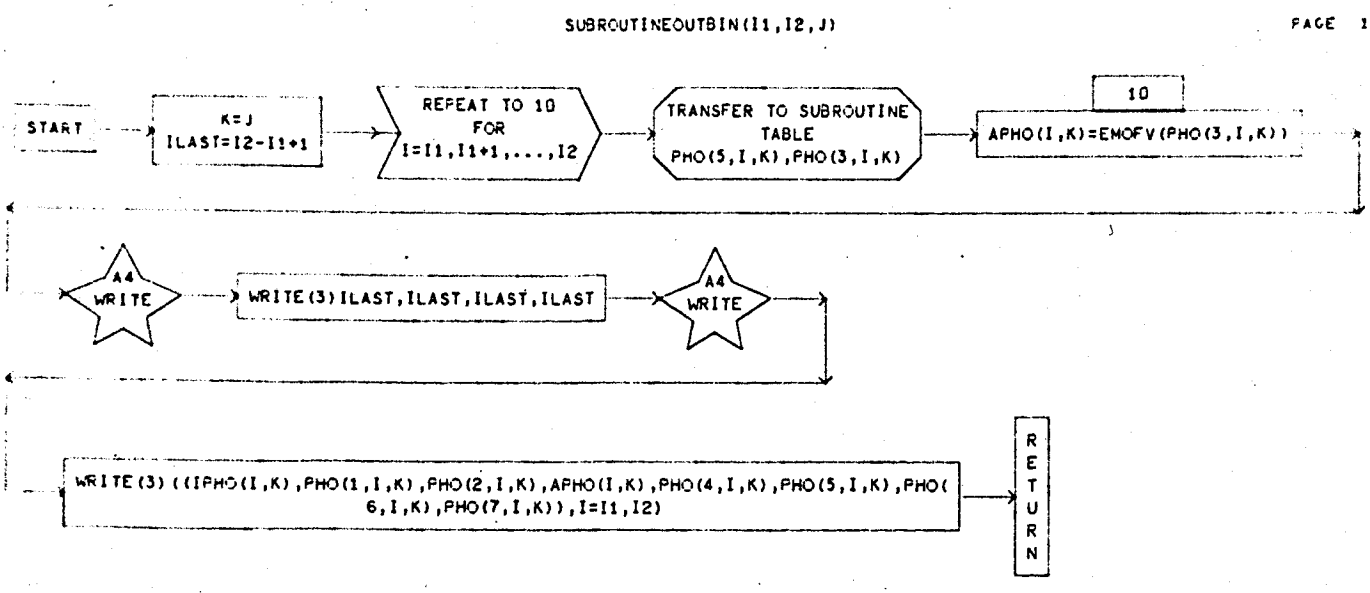
where (I1, I2) identifies the range of points to be written on tape (I1 is first point, I2 is last). (J) represents the current characteristic line (1 or 2).

UTILITY ROUTINES AND COMMON REFERENCES

COMMON/DATAR/
TABLE
EMOFV

METHOD OF SOLUTION

Not applicable.



SUBROUTINE NAME: OVEREX

DESCRIPTION

This subroutine solves for the shock angle at the nozzle lip when the flow is over expanded. Provisions are made to calculate the shock angle for an upper or lower lip point. Real gas effects are considered in calculating flow properties downstream of the shock.

CALLING SEQUENCE

CALL OVEREX (PB, I, K, ITYPE)

where (PB) is the freestream pressure at the boundary, (I, K) define the location of the lip point in the characteristic data (PHO) array and (ITYPE) indicates whether an upper or lower boundary is to be considered.

UTILITY ROUTINES AND COMMON REFERENCES

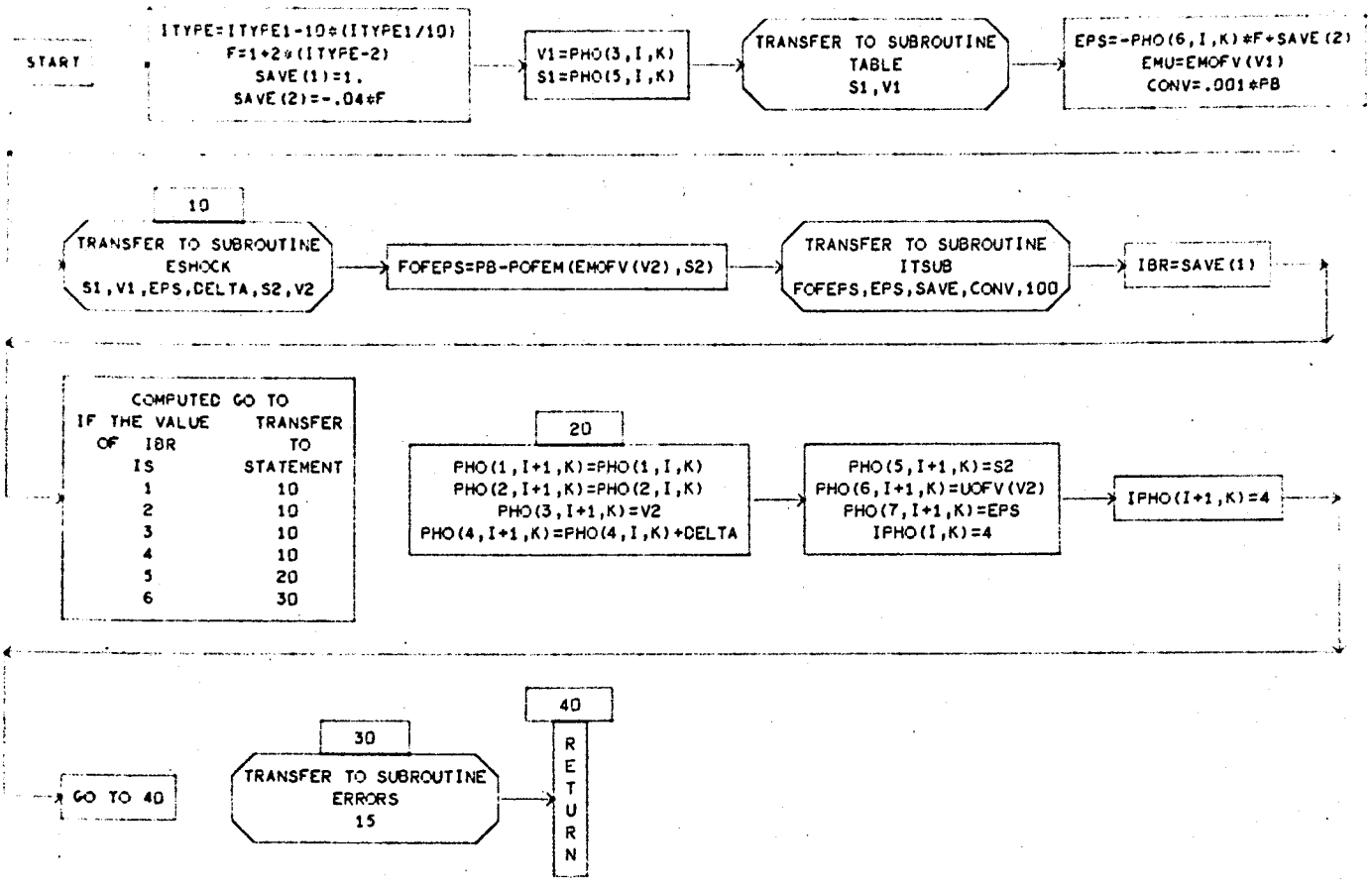
COMMON/DATAR/
TABLE
ESHOCK
ITSUB

METHOD OF SOLUTION

An initial shock angle is guessed. This shock angle is perturbed in ITSUB and the result used to calculate flow properties downstream of the shock, including static pressure. The calculated static pressure is compared with the boundary pressure and the arbitrary difference function (FOFEPS) is driven sufficiently close to zero by successive iterations for the convergence criteria to be met.

SUBROUTINEOVEREX(PB,I,K,ITYPE1)

PAGE 1



SUBROUTINE NAME: PAGE

DESCRIPTION

This subroutine page ejects and writes the header comments and page number on each page of printout.

CALLING SEQUENCE

CALL PAGE (LCNT)

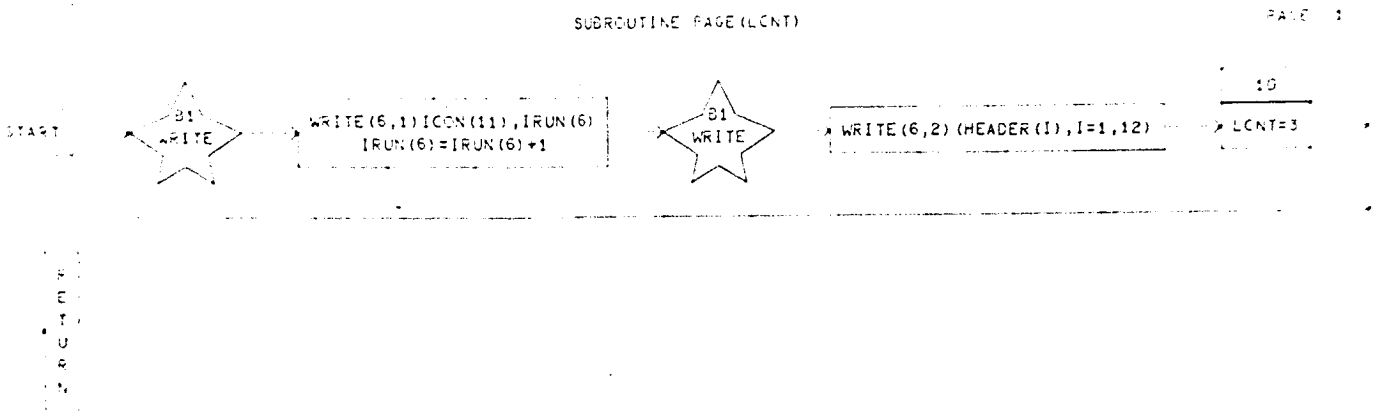
where (LCNT) is a counter which monitors the number of lines of printed output per page. (LCNT) is re-initialized in PAGE.

UTILITY ROUTINES AND COMMON REFERENCES

COMMON/HEAD/
COMMON/CONTRL/
UTILITY - None

METHOD OF SOLUTION

When the maximum number of lines per page have been output, (PAGE) is called to page eject. It then prints the identifying information and the page number, increments the page number and re-initializes the line counter.



SUBROUTINE NAME: PHASE1

DESCRIPTION

This subroutine provides the necessary logic to successively employ the proper calculation at the proper time in order to describe the entire characteristic mesh. Direction is given to calculate the flow field throughout the nozzle and plume, and termination is achieved when a right running shock intersects the boundary or problem limits have been reached.

CALLING SEQUENCE

CALL PHASE1 (IFINIS)

where (IFINIS) is a flag to bring in an additional logic routine (non-existant for present setup) for additional calculations after Phase 1 is through. Currently (IFINIS) remains zero and represents growth potential only.

UTILITY ROUTINES AND COMMON REFERENCES

COMMON/CONTRL/	HYPER
COMMON/DATAR/	POFEM
COMMON/INPUT/	EMOFV
COMMON/STEPC/	RGMOFP
TABLE	VOFEM
OUT	THETPM
THRUST	MONO
OUTBIN	TURN
MOCSOL	OVEREX
LIMITS	ERRORS
BOUND	SHOCK
PRANDT	MASSCK

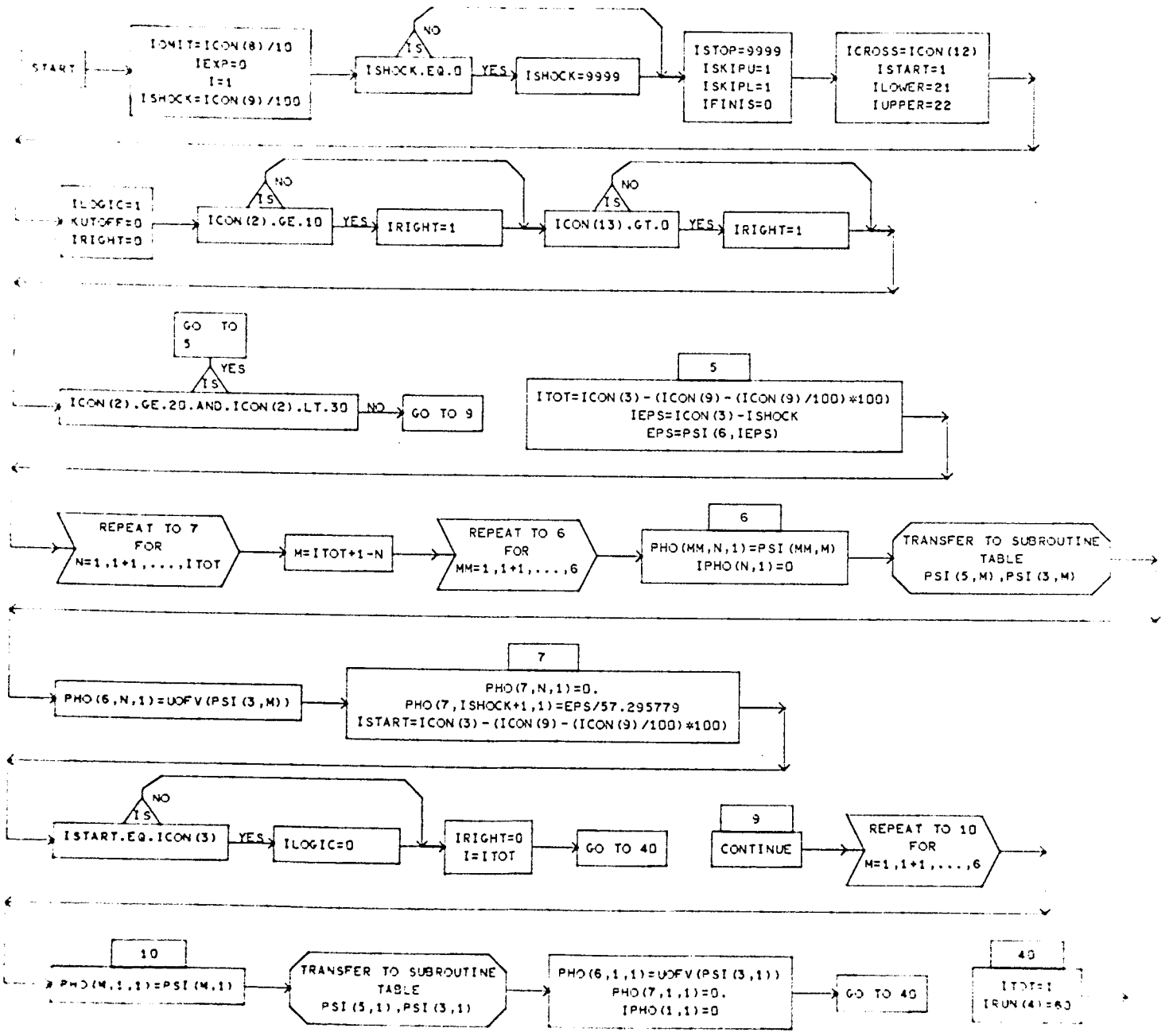
METHOD OF SOLUTION

In general terms, the flow properties at an unknown characteristic point may be expressed as some operation (ψ) on some number ($\Phi_1, \Phi_2, \ldots, \Phi_m$) of known points. These operations (ψ) differ according to the type of unknown point to be calculated. Presently, the six types of unknown points dealt with or six operations (ψ) performed are:

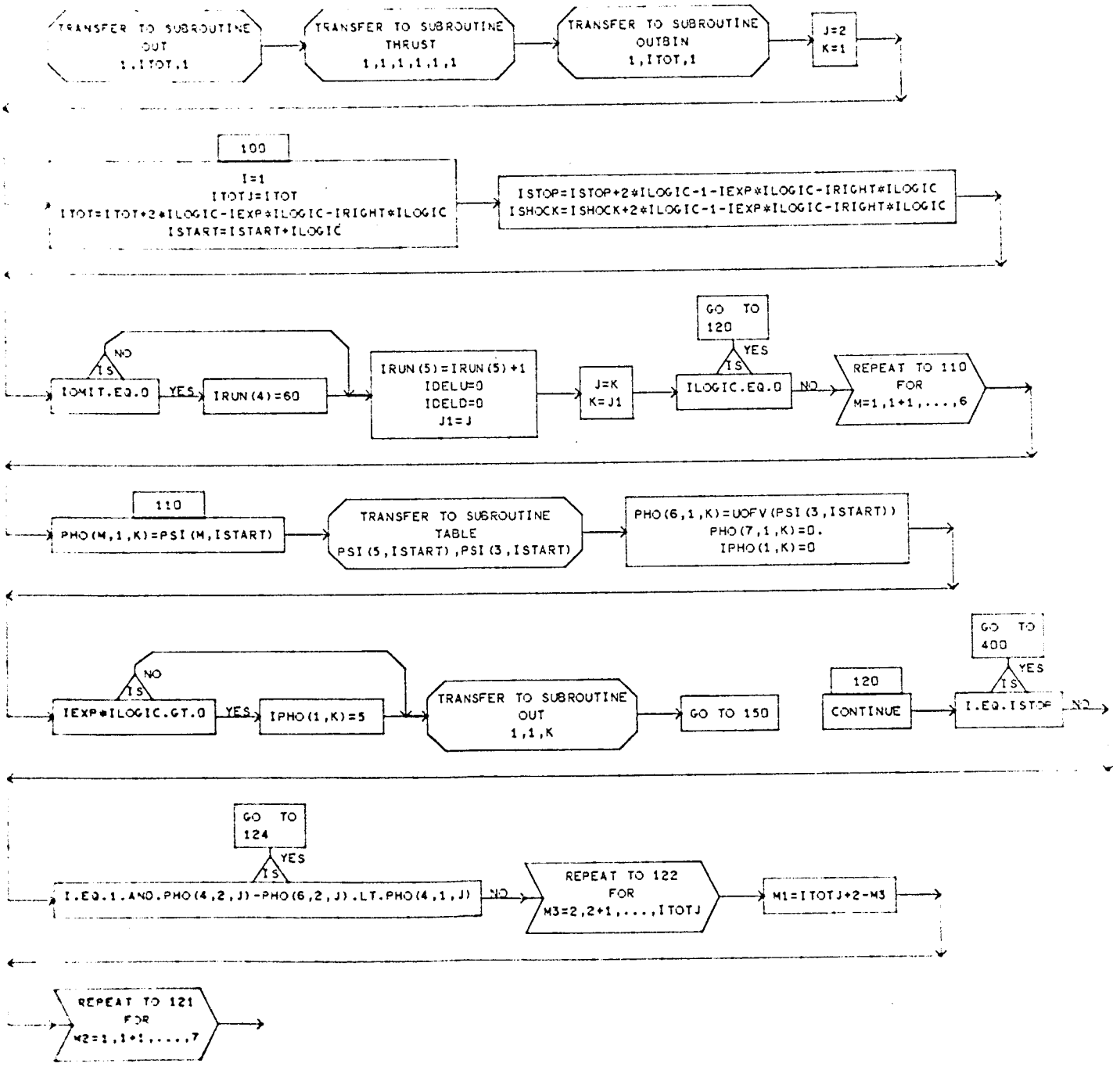
1. starting line point (ψ_0)
2. interior point (ψ_I)
3. boundary point (upper or lower) (ψ_B)
4. attached shock point (ψ_{AS})
5. shock point (ψ_S)
6. Prandtl-Meyer point (upper or lower, solid or free) (ψ_{PM})

Basically, PHASE1 contains the fixed point arithmetic necessary to perform the above mentioned calculations. Through this system of fixed point arithmetic, the necessary types of calculations are performed on the proper known characteristic points to produce the new characteristic point. For a detailed description of the fixed point arithmetic and examples of its use, see Section 10 of Reference 1.

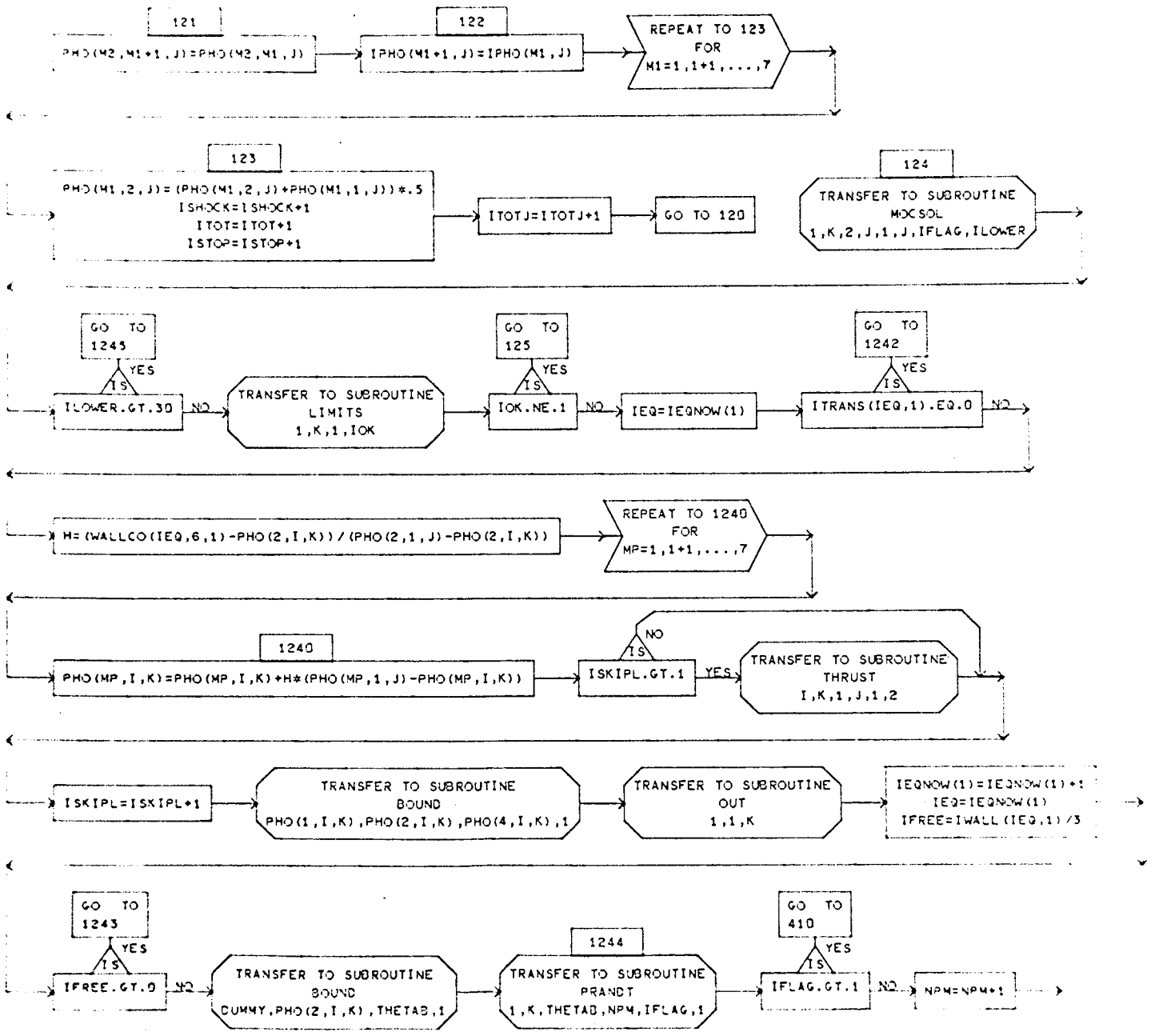
SUBROUTINE PHASE1 (IFINIS)



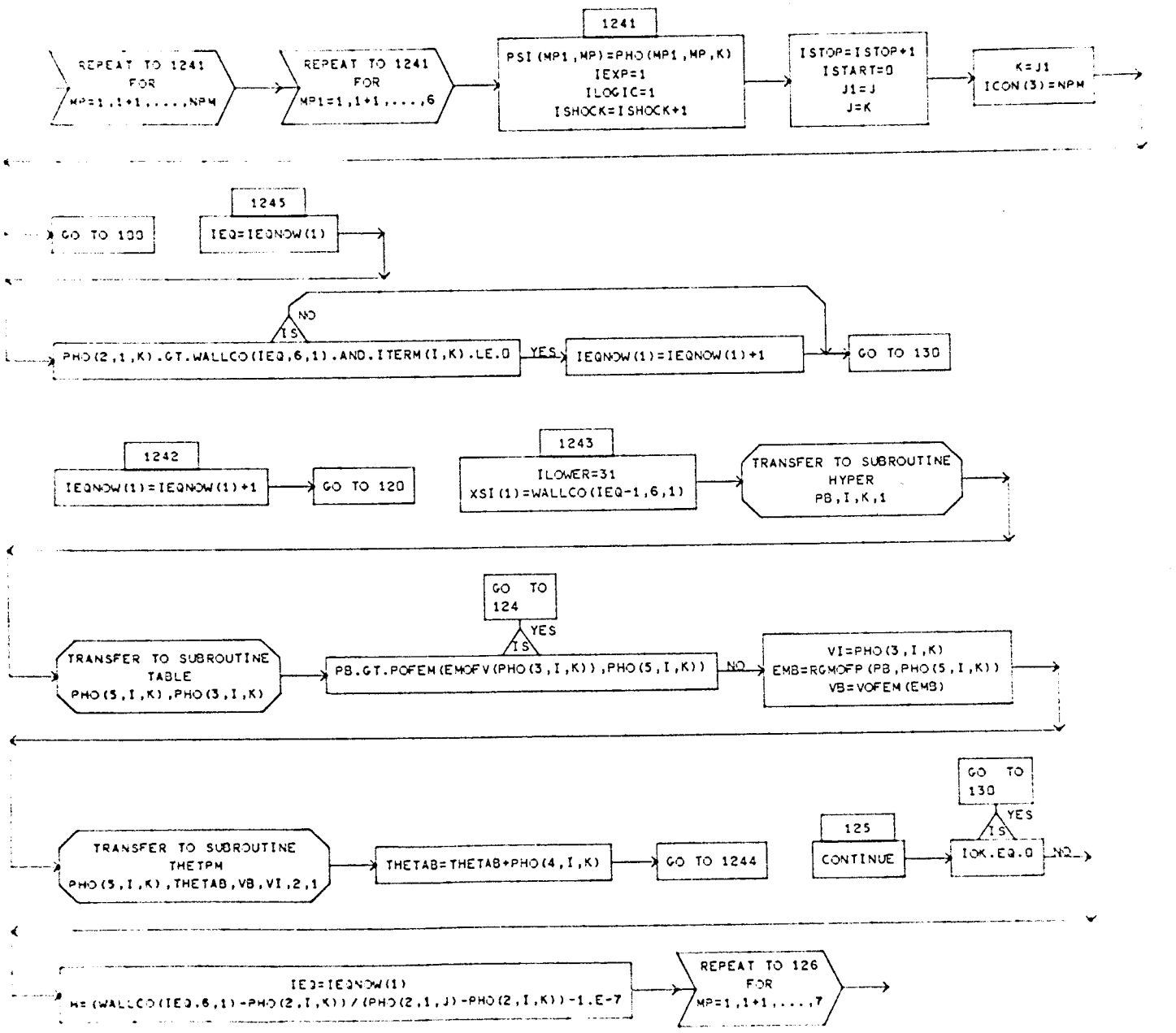
SUBROUTINE PHASE1 (IFINIS)

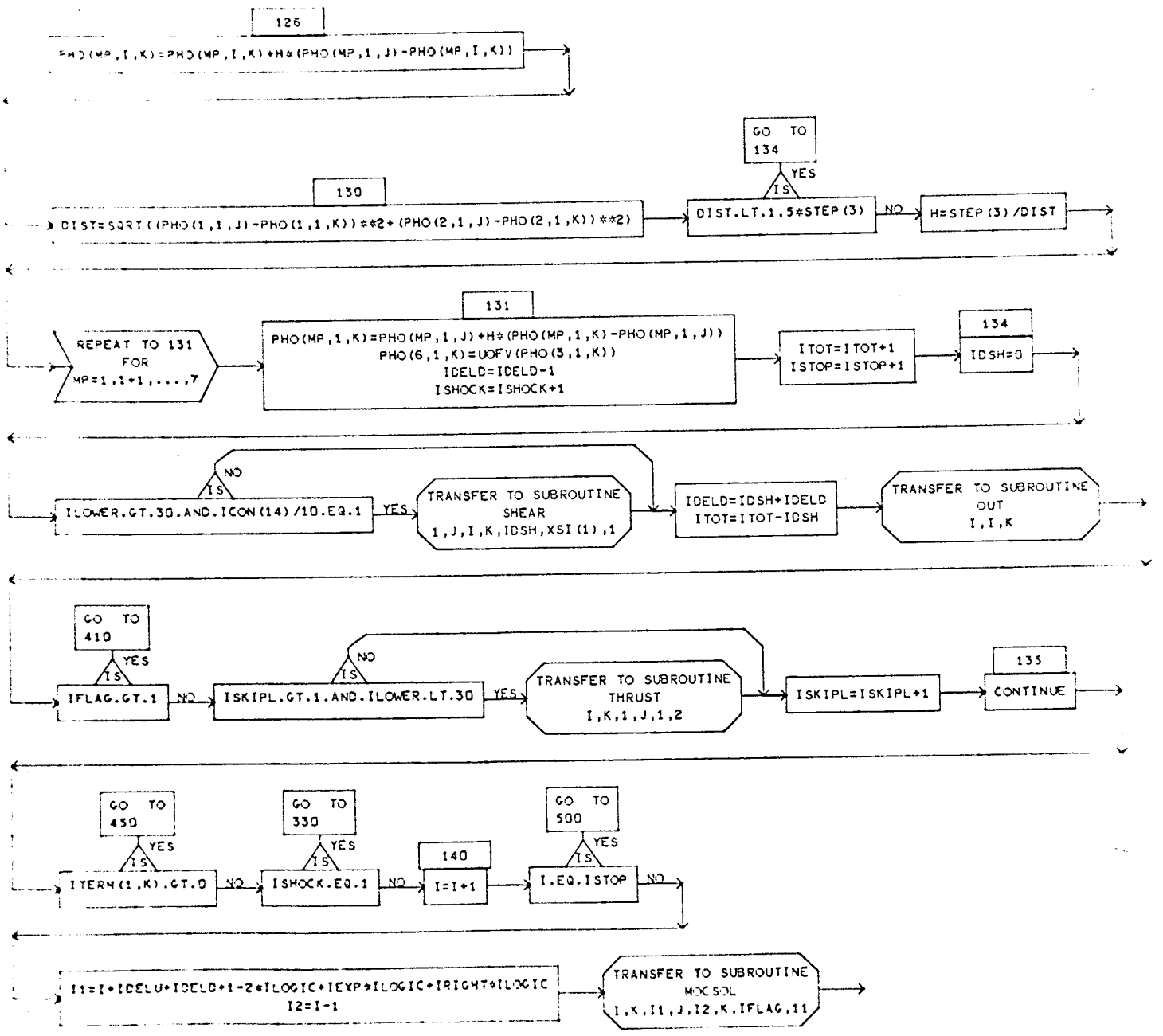


SUBROUTINE PHASE1 (IFINIS)

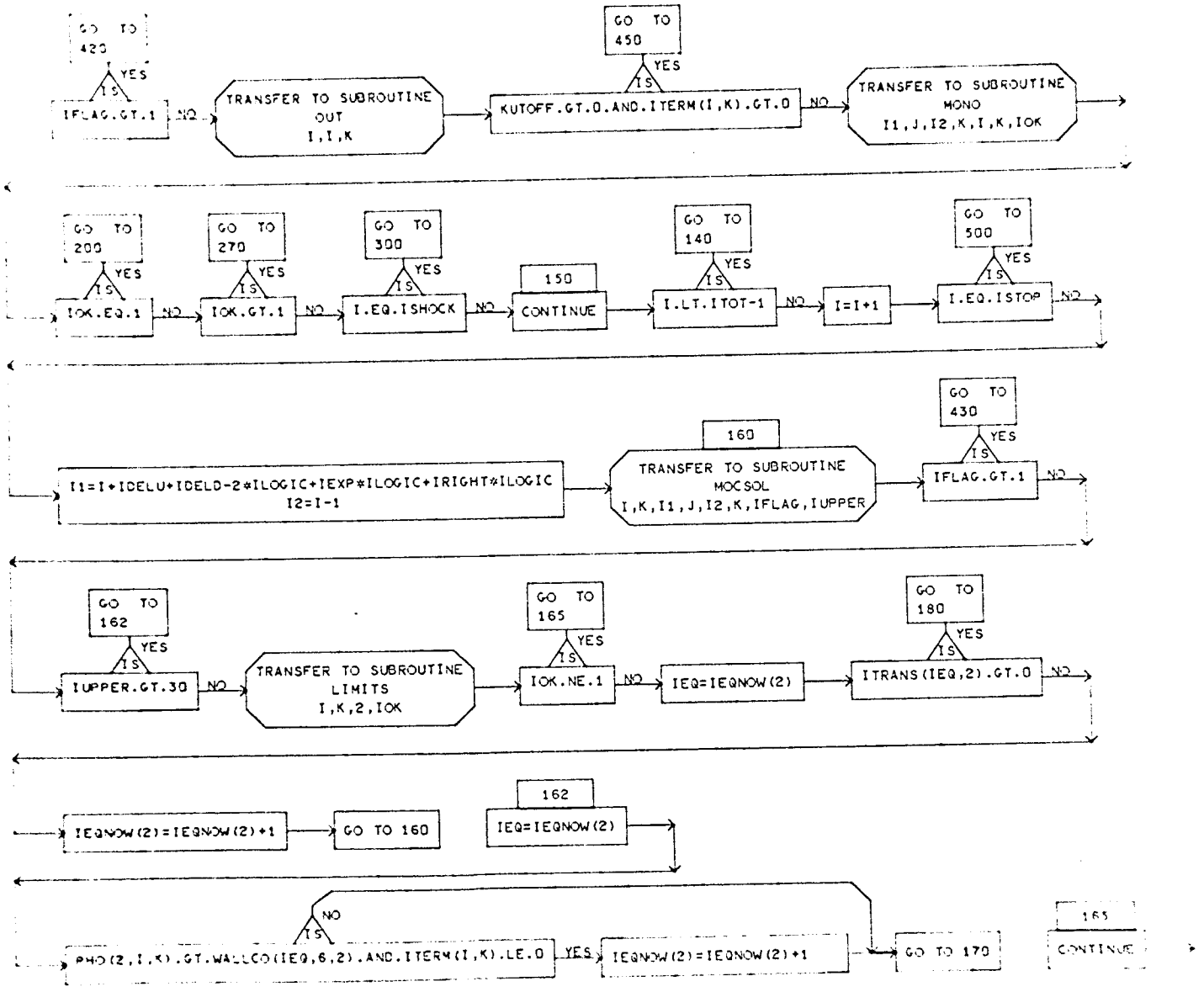


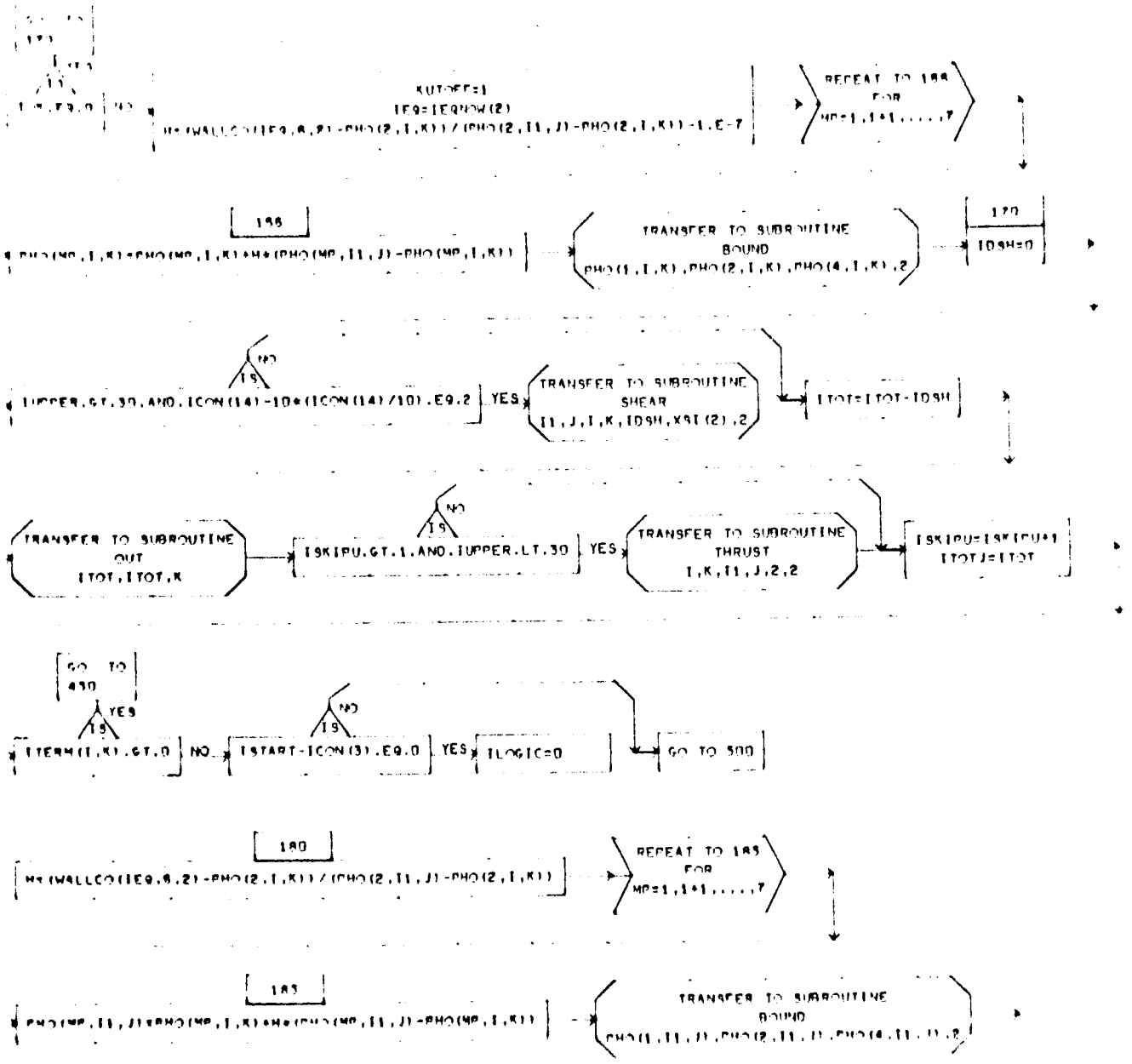
SUBROUTINE PHASE1 (IFINIS)

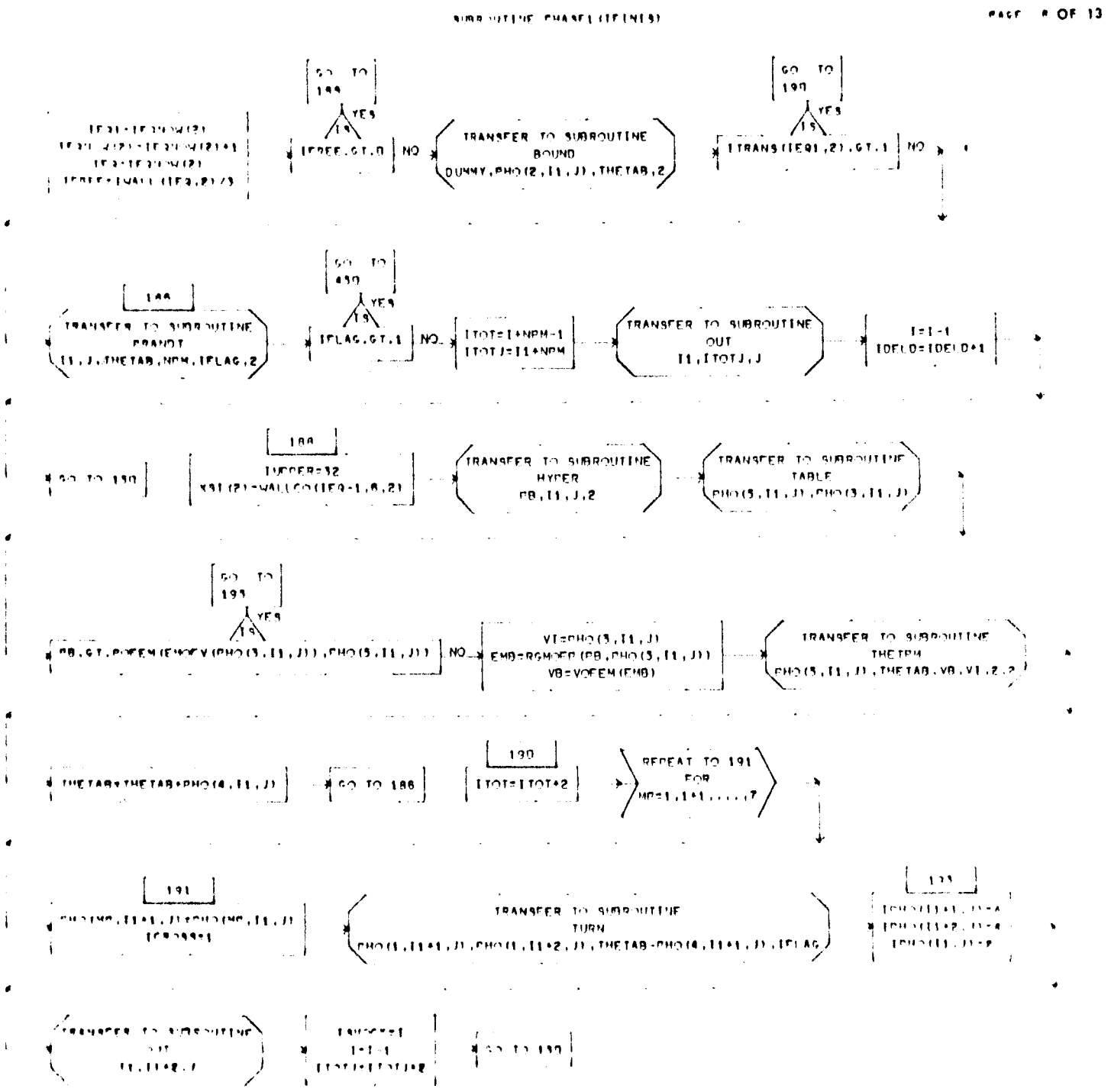


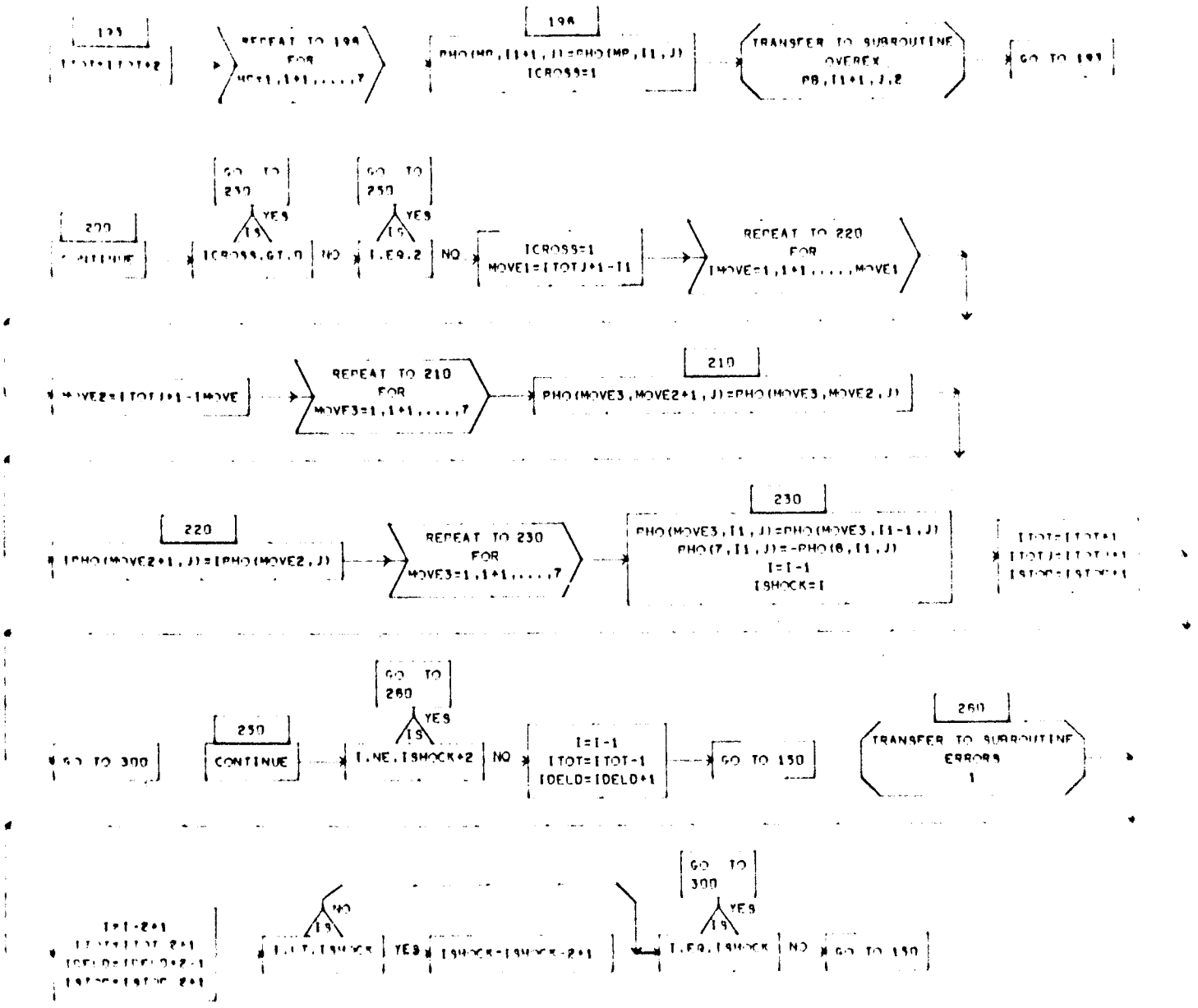

126
PHO(MP,I,K)=PHO(MP,I,K)+H*(PHO(MP,1,J)-PHO(MP,I,K))
GO TO 134
YES
IS
130
DIST=SQRT((PHO(1,1,J)-PHO(1,1,K))**2+(PHO(2,1,J)-PHO(2,1,K))**2)
DIST.LT.1.5*STEP(3)
NO
H=STEP(3)/DIST
REPEAT TO 131 FOR MP=1,1+1,...,7
131
PHO(MP,1,K)=PHO(MP,1,J)+H*(PHO(MP,1,K)-PHO(MP,1,J))
PHO(6,1,K)=UOFV(PHO(3,1,K))
IDELD=IDELD-1
ISHOCK=ISHOCK+1
ITOT=ITOT+1
ISTOP=ISTOP+1
134
IDSH=0
NO
IS
ILOWER.GT.30.AND.ICON(14)/10.EQ.1
YES
TRANSFER TO SUBROUTINE SHEAR 1,J,I,K,IDSH,XSI(1),1
IDELD=IDSH+IDELD
ITOT=ITOT-IDSH
TRANSFER TO SUBROUTINE OUT I,I,K
GO TO 410
YES
IS
IFLAG.GT.1
NO
NO
IS
ISKIPL.GT.1.AND.ILOWER.LT.30
YES
TRANSFER TO SUBROUTINE THRUST I,K,1,J,1,2
ISKIPL=ISKIPL+1
135
CONTINUE
GO TO 450
YES
IS
ITERM(1,K).GT.0
NO
GO TO 330
YES
IS
ISHOCK.EQ.1
NO
140
I=I+1
GO TO 500
YES
IS
I.EQ.ISTOP
NO
I1=I+IDELU+IDELD+1-2*ILOGIC+IEXP*ILOGIC+IRIGHT*ILOGIC
I2=I-1
TRANSFER TO SUBROUTINE MOCSOL I,K,I1,J,I2,K,IFLAG,11

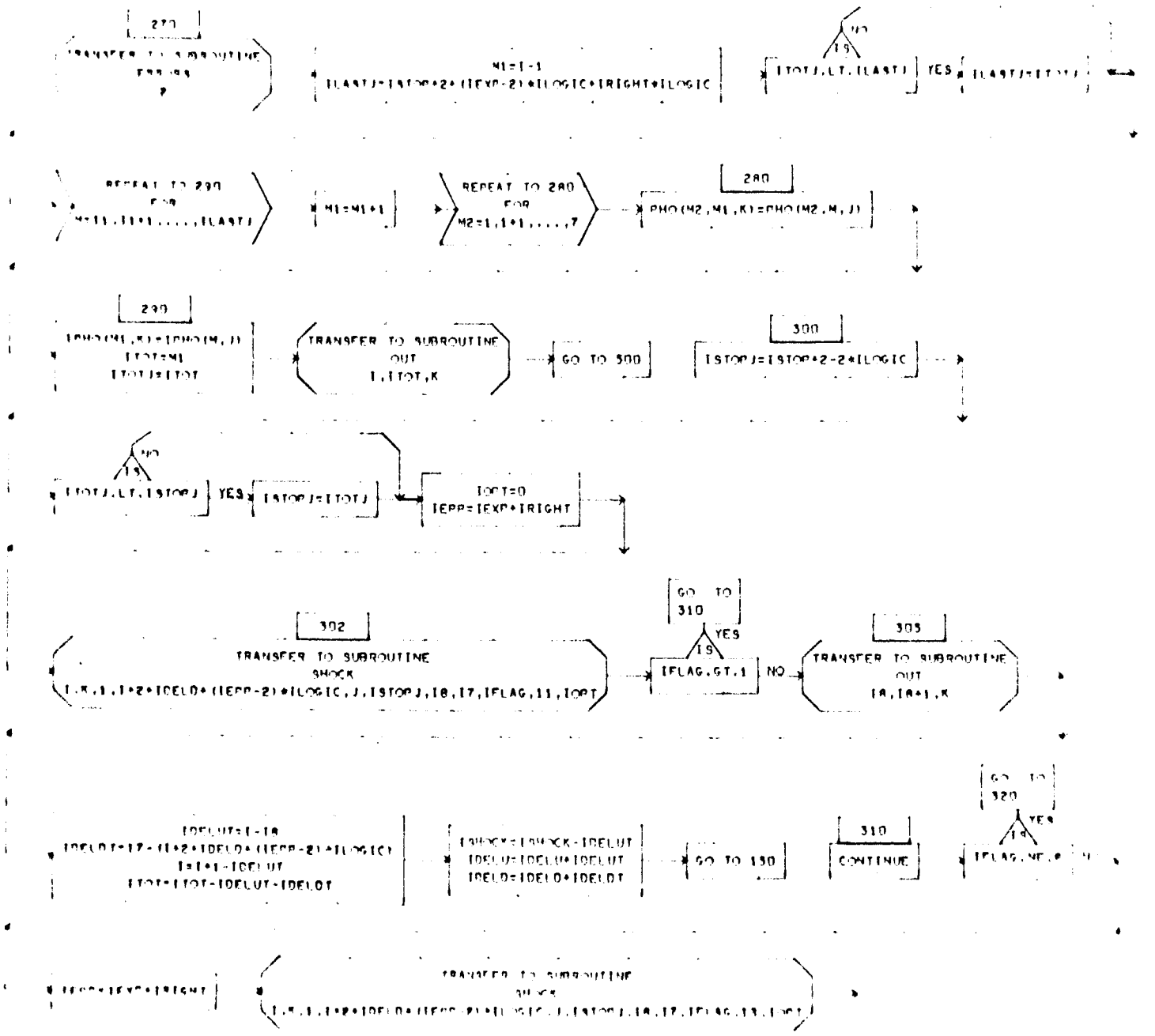
SUBROUTINE PHASE1(IFINIS)

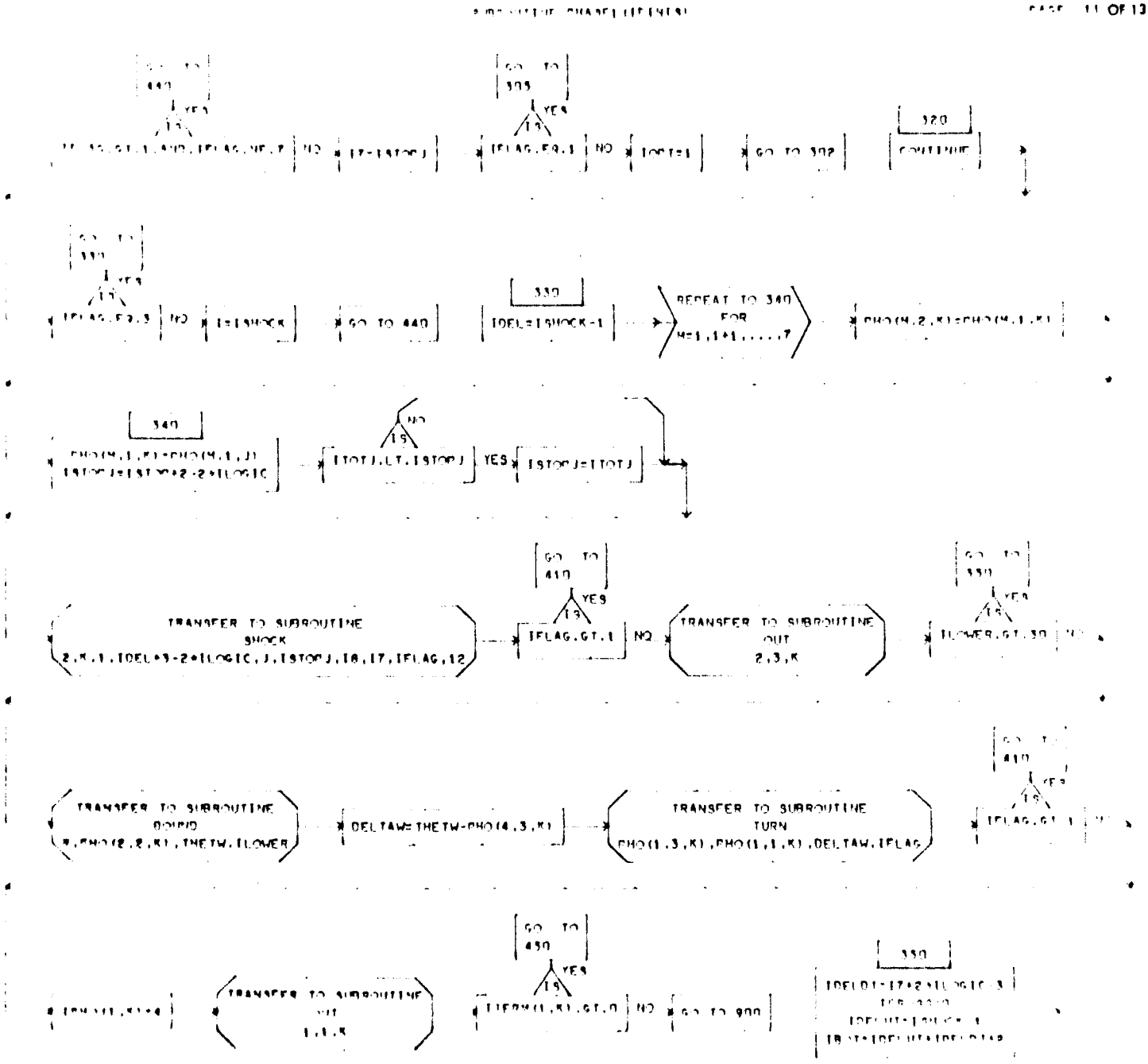


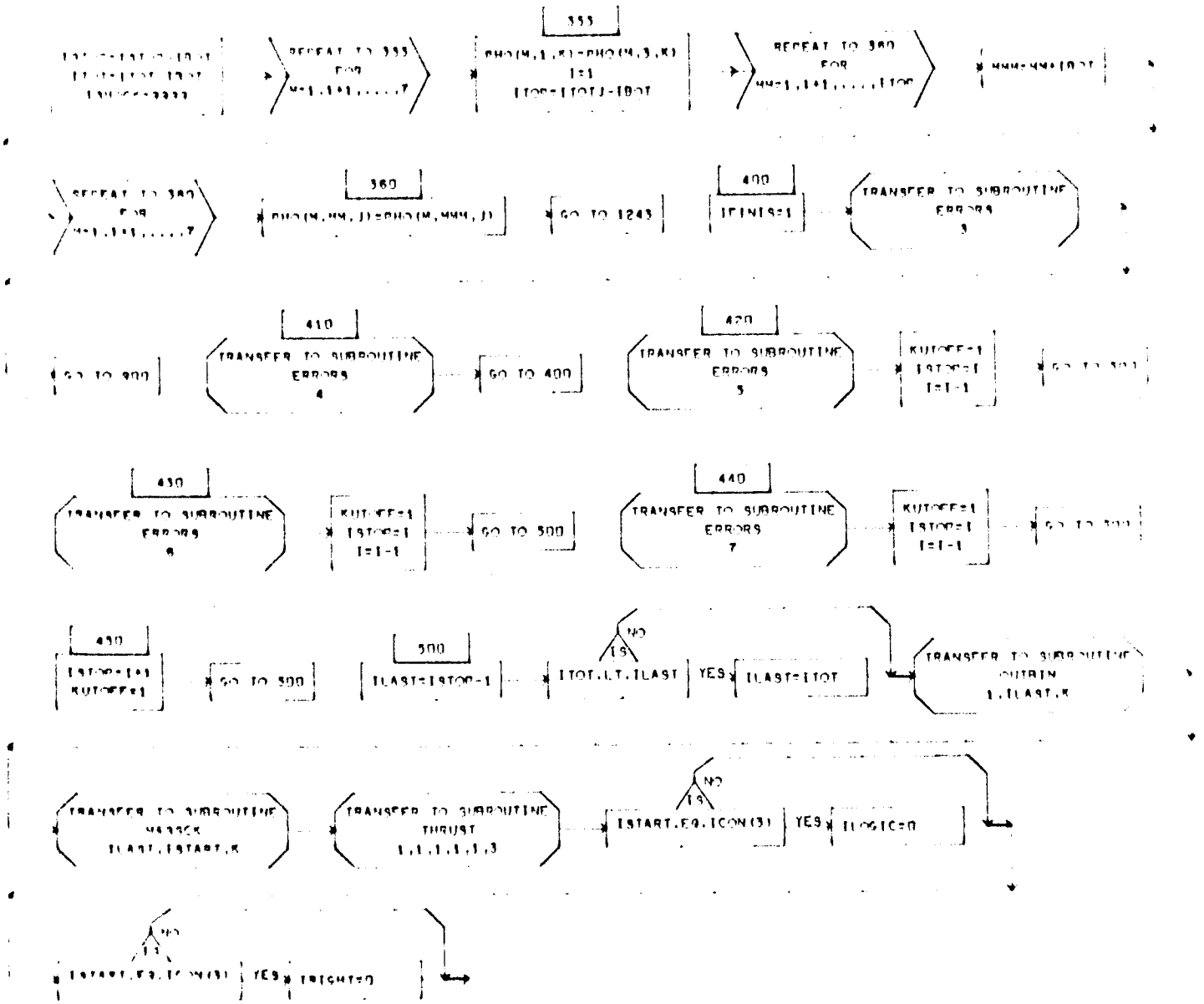

KUTOFF=1
IEQ=IEQNOW(2)
H=(WALLCO(IEQ,6,2)-PHO(2,I,K))/(PHO(2,I1,J)-PHO(2,I,K))-1.E-7
REPEAT TO 185 FOR MP=1,1+1,....,7
185
PHO(MP,I,K)=PHO(MP,I,K)+H*(PHO(MP,I1,J)-PHO(MP,I,K))
TRANSFER TO SUBROUTINE BOUND PHO(1,I,K),PHO(2,I,K),PHO(4,I,K),2
170
IDSH=0
IUPPER.GT.30.AND.ICON(14)-10*(ICON(14)/10).EQ.2
YES
TRANSFER TO SUBROUTINE SHEAR I1,J,I,K,IDSH,XSI(2),2
ITOT=ITOT-IDSH
TRANSFER TO SUBROUTINE OUT ITOT,ITOT,K
ISKIPU.GT.1.AND.IUPPER.LT.30
YES
TRANSFER TO SUBROUTINE THRUST I,K,I1,J,2,2
ISKIPU=ISKIPU+1
ITOTJ=ITOT
GO TO 490
ITERM(I,K).GT.0
NO
ISTART-ICON(3).EQ.0
YES
ILOGIC=0
GO TO 500
180
H=(WALLCO(IEQ,6,2)-PHO(2,I,K))/(PHO(2,I1,J)-PHO(2,I,K))
REPEAT TO 185 FOR MP=1,1+1,....,7
185
PHO(MP,I1,J)=PHO(MP,I,K)+H*(PHO(MP,I1,J)-PHO(MP,I,K))
TRANSFER TO SUBROUTINE BOUND PHO(1,I1,J),PHO(2,I1,J),PHO(4,I1,J),2

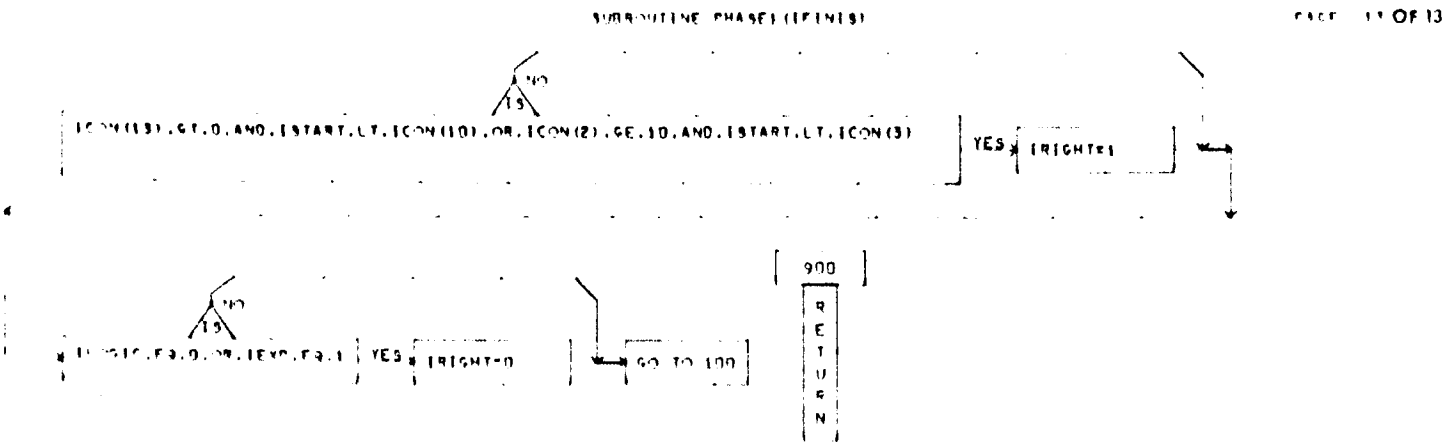

SUBROUTINE CHASE1(IFINIS)
PAGE 8 OF 13
GO TO 189
YES
IS
IFREE.GT.0
NO
TRANSFER TO SUBROUTINE BOUND DUMMY,PHO(2,I1,J),THETAB,2
GO TO 190
YES
IS
ITRANS(IEQ1,2).GT.1
NO
186
TRANSFER TO SUBROUTINE PRANDT I1,J,THETAB,NPM,IFLAG,2
GO TO 430
YES
IS
IFLAG.GT.1
NO
ITOT=I+NPM-1
ITOTJ=I1+NPM
TRANSFER TO SUBROUTINE OUT I1,ITOTJ,J
I=I-1
IDELD=IDELD+1
GO TO 130
188
IUPPER=32
XSI(2)=WALLCO(IEQ-1,8,2)
TRANSFER TO SUBROUTINE HYPER PB,I1,J,2
TRANSFER TO SUBROUTINE TABLE PHO(5,I1,J),PHO(3,I1,J)
GO TO 193
YES
IS
PB.GT.POFEM(EMOFV(PHO(3,I1,J)),PHO(5,I1,J))
NO
VI=PHO(3,I1,J)
EMB=RGMOFP(PB,PHO(3,I1,J))
VB=VOFEM(EMB)
TRANSFER TO SUBROUTINE THETPM PHO(5,I1,J),THETAB,VB,VI,2,2
THETAB=THETAB+PHO(4,I1,J)
GO TO 186
190
ITOT=ITOT+2
REPEAT TO 191 FOR MP=1,1+1,....,7
191
PHO(MP,I1+1,J)=PHO(MP,I1,J)
ICROSS=1
TRANSFER TO SUBROUTINE TURN PHO(1,I1+1,J),PHO(1,I1+2,J),THETAB-PHO(4,I1+1,J),IFLAG
193
TRANSFER TO SUBROUTINE OUT I1,I1+2,J
I=I-1
GO TO 130


190
REPEAT TO 199
FOR
MP=1,I+1,....,7
199
PHO(MP,I1+1,J)=PHO(MP,I1,J)
ICROSS=1
TRANSFER TO SUBROUTINE
OVEREX
PB,I1+1,J,2
GO TO 193
GO TO
230
YES
IS
ICROSS.GT.0
NO
GO TO
250
YES
IS
I.EQ.2
NO
ICROSS=1
MOVE1=ITOTJ+1-I1
REPEAT TO 220
FOR
IMOVE=1,I+1,....,MOVE1
MOVE2=ITOTJ+1-IMOVE
REPEAT TO 210
FOR
MOVE3=1,I+1,....,7
210
PHO(MOVE3,MOVE2+1,J)=PHO(MOVE3,MOVE2,J)
220
IPHO(MOVE2+1,J)=IPHO(MOVE2,J)
REPEAT TO 230
FOR
MOVE3=1,I+1,....,7
230
PHO(MOVE3,I1,J)=PHO(MOVE3,I1-1,J)
PHO(7,I1,J)=-PHO(8,I1,J)
I=I-1
ISHOCK=I
ITOT=ITOT+1
ITOTJ=ITOTJ+1
ISTOP=ISTOP+1
GO TO 300
250
CONTINUE
GO TO
260
YES
IS
I.NE.ISHOCK+2
NO
I=I-1
ITOT=ITOT-1
IDELD=IDELD+1
GO TO 150
260
TRANSFER TO SUBROUTINE
ERRORS
1
I=I-2+1
ITOT=ITOT-2+1
IDELD=IDELD+2-1
ISTOP=ISTOP-2+1
NO
IS
I.LT.ISHOCK
YES
ISHOCK=ISHOCK-2+1
GO TO
300
YES
IS
I.EQ.ISHOCK
NO
GO TO 190


270
TRANSFER TO SUBROUTINE
M1=I-1
ILAST=ISTOP+2*(IEXP-2)*ILOGIC+IRIGHT*ILOGIC
IS
NO
ITOTJ.LT.ILAST
YES
REPEAT TO 290
FOR
M=I1,I1+1,...,ILAST
M1=M1+1
REPEAT TO 280
FOR
M2=1,1+1,...,7
280
PHO(M2,M1,K)=PHO(M2,M,J)
290
PHO(M1,K)=PHO(M,J)
ITOT=M1
ITOTJ=ITOT
TRANSFER TO SUBROUTINE
OUT
I,ITOT,K
GO TO 300
300
ISTOPJ=ISTOP+2-2*ILOGIC
IS
NO
ITOTJ.LT.ISTOPJ
YES
ISTOPJ=ITOTJ
IOPT=0
IEPP=IEXP*IRIGHT
302
TRANSFER TO SUBROUTINE
SHOCK
I,K,1,1+2*IDELD*(IEPP-2)*ILOGIC,J,ISTOPJ,I8,I7,IFLAG,I1,IOPT
GO TO
310
YES
IS
IFLAG.GT.1
NO
305
TRANSFER TO SUBROUTINE
OUT
I8,I8+1,K
IDELOT=I-I8
IDELDT=I7-(I+2*IDELD*(IEPP-2)*ILOGIC)
I=I+1-IDELOT
ITOT=ITOT-IDELOT-IDELDT
IDHOCK=IDHOCK-IDELOT
IDELU=IDELU+IDELOT
IDELD=IDELD+IDELDT
GO TO 130
310
CONTINUE
GO TO
320
YES
IS
IEPP=IEXP*IRIGHT
TRANSFER TO SUBROUTINE
SHOCK
I,K,1,1+2*IDELD*(IEPP-2)*ILOGIC,J,ISTOPJ,I8,I7,IFLAG,I1,IOPT


GO TO 440
YES
IS
NO
I7=ISTOPJ
GO TO 305
IFLAG.EQ.1
IOPT=1
GO TO 302
320
CONTINUE
GO TO 330
IFLAG.EQ.3
I=ISHOCK
GO TO 440
330
IDEL=ISHOCK-1
REPEAT TO 340 FOR M=1,1+1,....,7
PHO(M,2,K)=PHO(M,1,K)
340
PHO(M,1,K)=PHO(M,1,J)
ISTOPJ=ISTOPJ+2-2*ILOGIC
ITOTJ.LT.ISTOPJ
ISTOPJ=ITOTJ
TRANSFER TO SUBROUTINE SHOCK
2,K,1,IDEL+3-2*ILOGIC,J,ISTOPJ,I8,I7,IFLAG,12
GO TO 410
IFLAG.GT.1
TRANSFER TO SUBROUTINE OUT
2,3,K
ILOWER.GT.30
TRANSFER TO SUBROUTINE BOUND
PHO(2,2,K),THETW,ILOWER
DELTAW=THETW-PHO(4,3,K)
TRANSFER TO SUBROUTINE TURN
PHO(1,3,K),PHO(1,1,K),DELTAW,IFLAG
IFLAG.GT.1
TRANSFER TO SUBROUTINE OUT
1,1,K
GO TO 450
ITERM(1,K).GT.0
GO TO 900
350


REPEAT TO 355 FOR M=1,1+1,....,7
355
PHO(M,1,K)=PHO(M,3,K)
I=1
ITOP=ITOTJ-IBOT
REPEAT TO 360 FOR MM=1,1+1,....,ITOP
MMM=MM+IBOT
REPEAT TO 380 FOR M=1,1+1,....,7
360
PHO(M,MM,J)=PHO(M,MMM,J)
GO TO 1243
400
IFINIS=1
TRANSFER TO SUBROUTINE ERRORS 3
GO TO 900
410
TRANSFER TO SUBROUTINE ERRORS 4
GO TO 400
420
TRANSFER TO SUBROUTINE ERRORS 5
KUTOFF=1
ISTOP=I
I=I-1
430
TRANSFER TO SUBROUTINE ERRORS 6
KUTOFF=1
ISTOP=I
I=I-1
GO TO 500
440
TRANSFER TO SUBROUTINE ERRORS 7
KUTOFF=1
ISTOP=I
I=I-1
450
ISTOP=I+1
KUTOFF=1
GO TO 500
500
ILAST=ISTOP-1
ITOT.LT.ILAST
NO
IS
YES
ILAST=ITOT
TRANSFER TO SUBROUTINE OUTBIN 1,ILAST,K
TRANSFER TO SUBROUTINE MASSCK ILAST,ISTART,K
TRANSFER TO SUBROUTINE THRUST 1,1,1,1,1,3
ISTART.EQ.ICON(3)
NO
IS
YES
ILOGIC=0
ISTART.EQ.ICON(3)
NO
IS
YES
TRIGHT=0


SUBROUTINE PHASE1 (IFINIS)
PAGE 11 OF 13
ICON(13).GT.0.AND.ISTART.LT.ICON(10).OR.ICON(2).GE.10.AND.ISTART.LT.ICON(3)
IS
NO
YES
IRIGHT=1
IS
NO
YES
IRIGHT=0
GO TO 100
900
RETURN

SUBROUTINE NAME: PLUMIN

DESCRIPTION

This subroutine reads in the input data (input via cards) necessary to complete the method-of-characteristics solution. This input information is routed by PLUMIN to various supporting routines depending on the options selected.

CALLING SEQUENCE

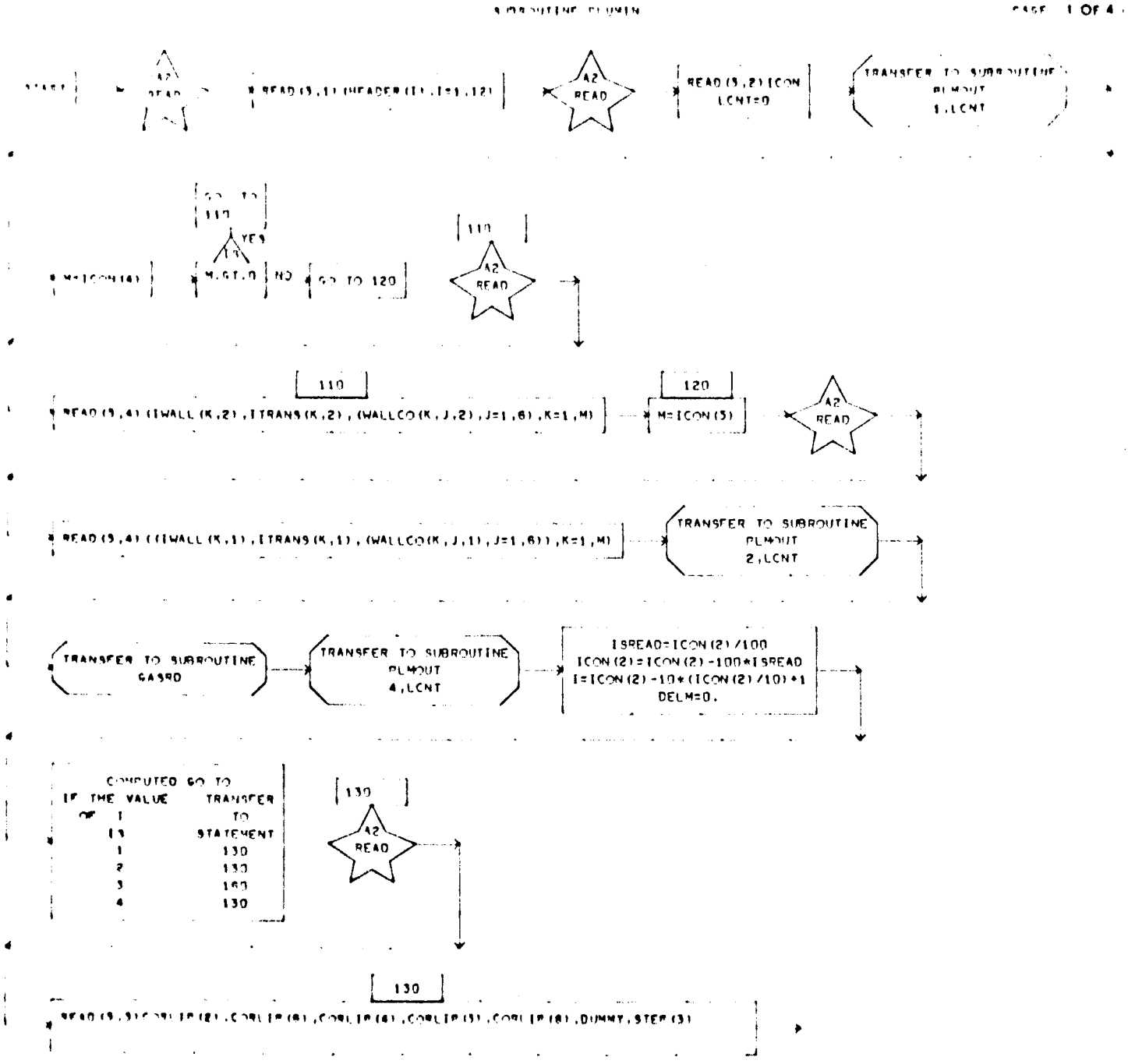
CALL PLUMIN

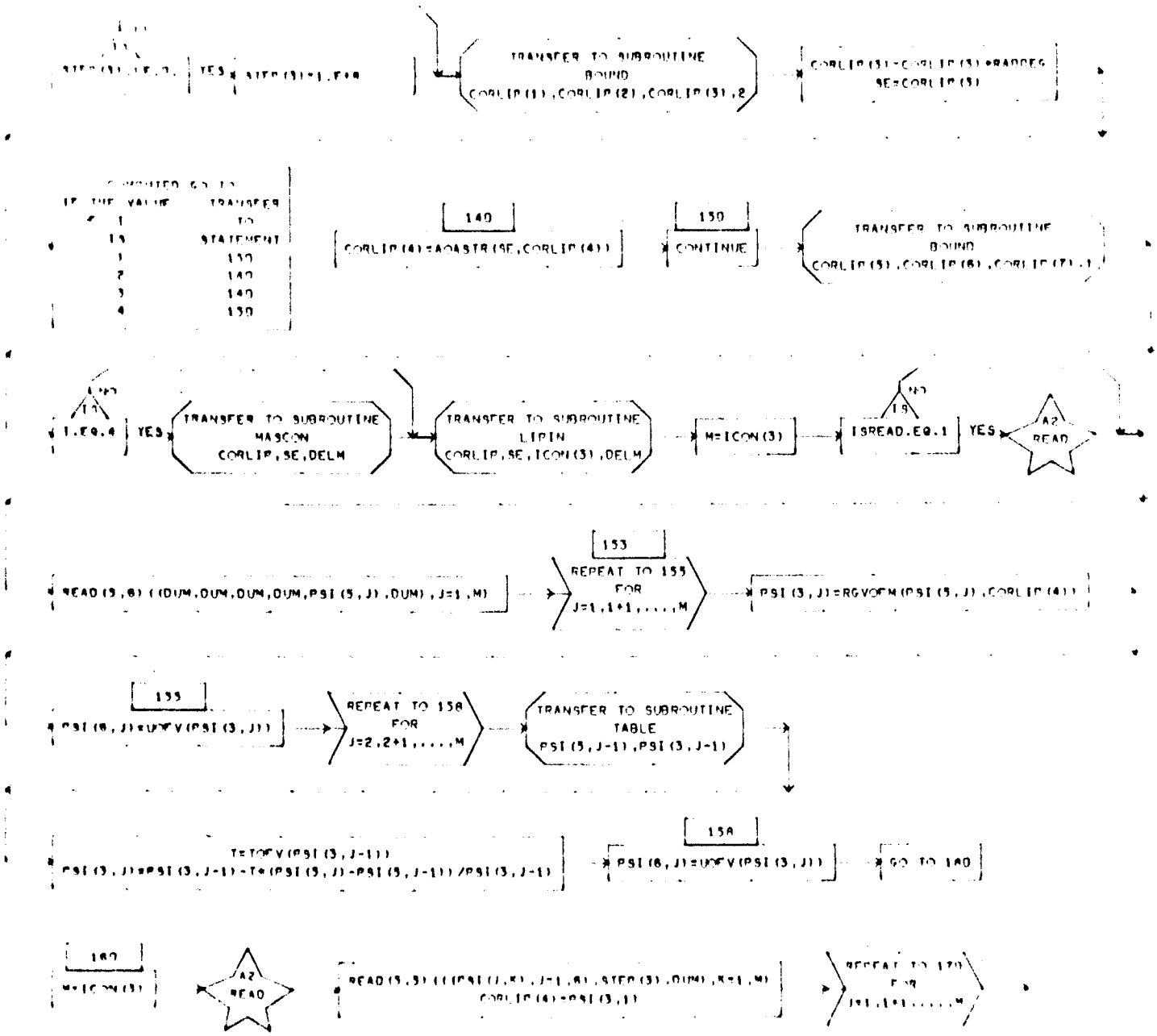
UTILITY ROUTINES AND COMMON REFERENCES

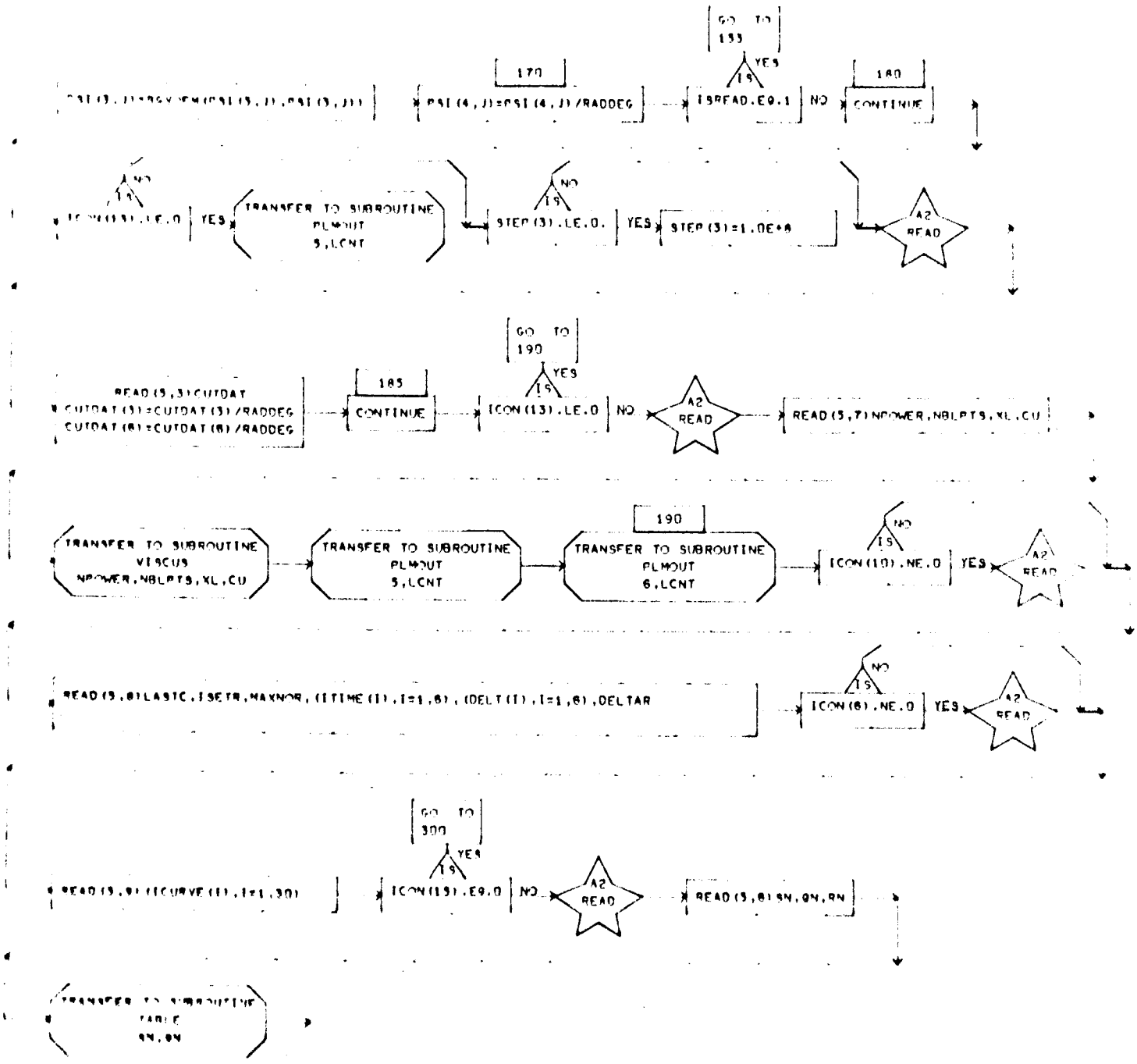
COMMON/COONED/	GASRD
COMMON/CONTRL/	BOUND
COMMON/CUTFO/	LIPIN
COMMON/DATAR/	AOASTR
COMMON/GASCON/	MASCON
COMMON/HEAD/	RGVOFM
COMMON/INPUT/	UOFV
COMMON/JUBCOM/	TABLE
COMMON/STEPC/	TOFV
PLMOUT	EMOFV
	POFEM

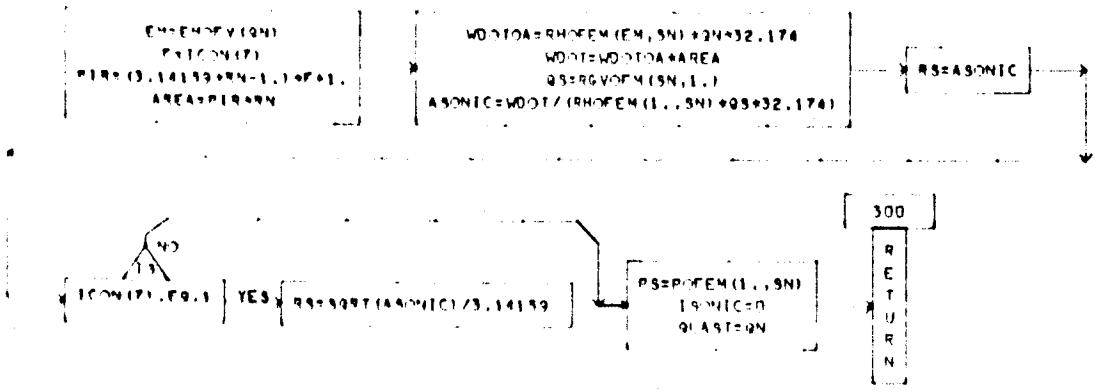
METHOD OF SOLUTION

Not applicable.


SUBROUTINE PLOMIN
PAGE 1 OF 4
A2 READ
READ(5,1)(HEADER(I),I=1,12)
A2 READ
READ(5,2)ICON
LCNT=0
TRANSFER TO SUBROUTINE
PLMOUT
1,LCNT
M=ICON(4)
M.GT.0
YES
NO
GO TO 120
110
A2 READ
110
READ(5,4)((IWALL(K,2),ITRANS(K,2),(WALLCO(K,J,2),J=1,6),K=1,M)
120
M=ICON(5)
A2 READ
READ(5,4)((IWALL(K,1),ITRANS(K,1),(WALLCO(K,J,1),J=1,6)),K=1,M)
TRANSFER TO SUBROUTINE
PLMOUT
2,LCNT
TRANSFER TO SUBROUTINE
GASRD
TRANSFER TO SUBROUTINE
PLMOUT
4,LCNT
ISREAD=ICON(2)/100
ICON(2)=ICON(2)-100*ISREAD
I=ICON(2)-10*(ICON(2)/10)+1
DELM=0.
COMPUTED GO TO
IF THE VALUE OF I IS
TRANSFER TO STATEMENT
1 130
2 130
3 130
4 130
130
A2 READ
130
READ(5,3)(CORLIP(2),CORLIP(3),CORLIP(4),CORLIP(5),CORLIP(6),DUMMY,STEP(3)


TRANSFER TO SUBROUTINE BOUND CORLIP(1),CORLIP(2),CORLIP(3),2
CORLIP(3)=CORLIP(3)*RADDEG SE=CORLIP(3)
140
CORLIP(4)=AOASTR(SE,CORLIP(4))
150
CONTINUE
TRANSFER TO SUBROUTINE BOUND CORLIP(5),CORLIP(6),CORLIP(7),1
I.EQ.4
YES
TRANSFER TO SUBROUTINE MASCON CORLIP,SE,DELM
TRANSFER TO SUBROUTINE LIPIN CORLIP,SE,ICON(3),DELM
M=ICON(3)
ISREAD.EQ.1
YES
A2 READ
153
REPEAT TO 155 FOR J=1,1+1,...,M
PSI(3,J)=RGVOFM(PSI(5,J),CORLIP(4))
155
PSI(6,J)=UOFV(PSI(3,J))
REPEAT TO 158 FOR J=2,2+1,...,M
TRANSFER TO SUBROUTINE TABLE PSI(5,J-1),PSI(3,J-1)
T=TOFV(PSI(3,J-1))
PSI(3,J)=PSI(3,J-1)-T*(PSI(5,J)-PSI(5,J-1))/PSI(3,J-1)
158
PSI(6,J)=UOFV(PSI(3,J))
GO TO 180
160
M=ICON(3)
A2 READ
CORLIP(4)=PSI(3,1)


SUBROUTINE PLUMIN
PAGE 3 OF 4
GO TO 133
YES
IS
170
PSI(4,J)=PSI(4,J)/RADDEG
ISREAD.EQ.1
NO
180
CONTINUE
NO
IS
ICON(13).LE.0
YES
TRANSFER TO SUBROUTINE PLMOUT 5,LCNT
NO
IS
STEP(3).LE.0.
YES
STEP(3)=1.0E+8
A2 READ
GO TO 190
YES
IS
READ(5,3)CUTDAT
CUTDAT(3)=CUTDAT(3)/RADDEG
CUTDAT(6)=CUTDAT(6)/RADDEG
185
CONTINUE
ICON(13).LE.0
NO
A2 READ
READ(5,7)NPOWER,NBLPTS,XL,CU
TRANSFER TO SUBROUTINE VISCUS NPOWER,NBLPTS,XL,CU
TRANSFER TO SUBROUTINE PLMOUT 5,LCNT
190
TRANSFER TO SUBROUTINE PLMOUT 6,LCNT
NO
IS
ICON(10).NE.0
YES
A2 READ
READ(5,8)LASTC,ISETR,MAXNOR,(ITIME(I),I=1,6),(DELT(I),I=1,6),DELTAR
NO
IS
ICON(6).NE.0
YES
A2 READ
GO TO 300
YES
IS
READ(5,9)(ICURVE(I),I=1,30)
ICON(15).EQ.0
NO
A2 READ
READ(5,8)SN,QN,RN
TRANSFER TO SUBROUTINE TABLE SN,QN


EM=EMOFV(9N)
F=ICON(7)
PIR=(3.14159*RN-1.)*F+1.
AREA=PIR*RN
WDOTOA=RHOFEM(EM,SN)*2N*32.174
WDOT=WDOTOA*AREA
QS=RGVOFM(SN,1.)
ASONIC=WDOT/(RHOFEM(1.,SN)*QS*32.174)
RS=ASONIC
ICON(7).EQ.1
NO
YES
RS=SQRT(ASONIC)/3.14159
RS=ROFEM(1.,SN)
IRONIC=0
QLAST=QN
300
RETURN

SUBROUTINE NAME: PLMOUT

DESCRIPTION

This subroutine prints the data read by (PLUMIN).

CALLING SEQUENCE

CALL PLMOUT (KP, LCNT)

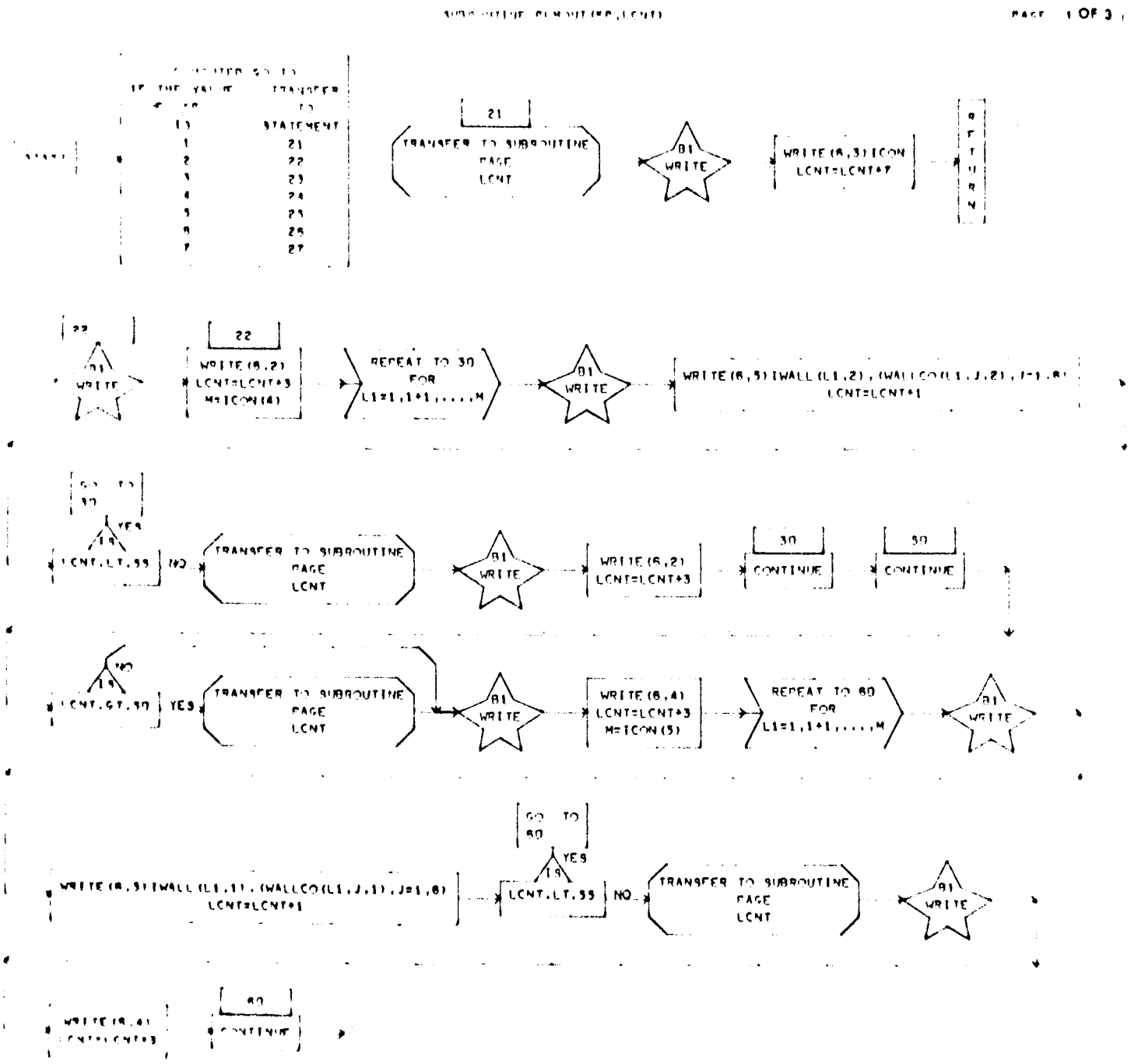
where (KP) is a control parameter which is set in PLUMIN, and (LCNT) is the printed line counter.

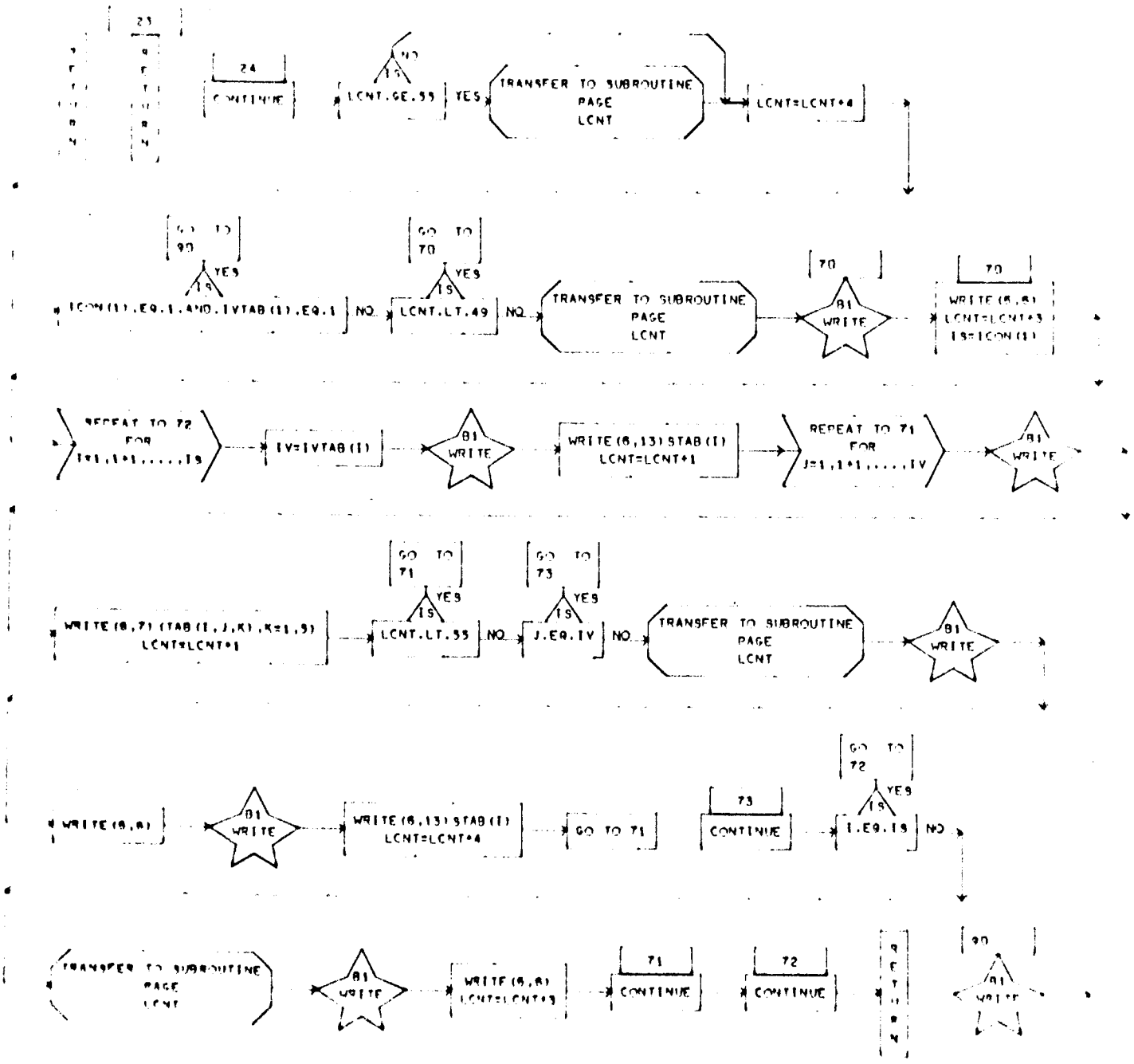
UTILITY ROUTINES AND COMMON REFERENCES

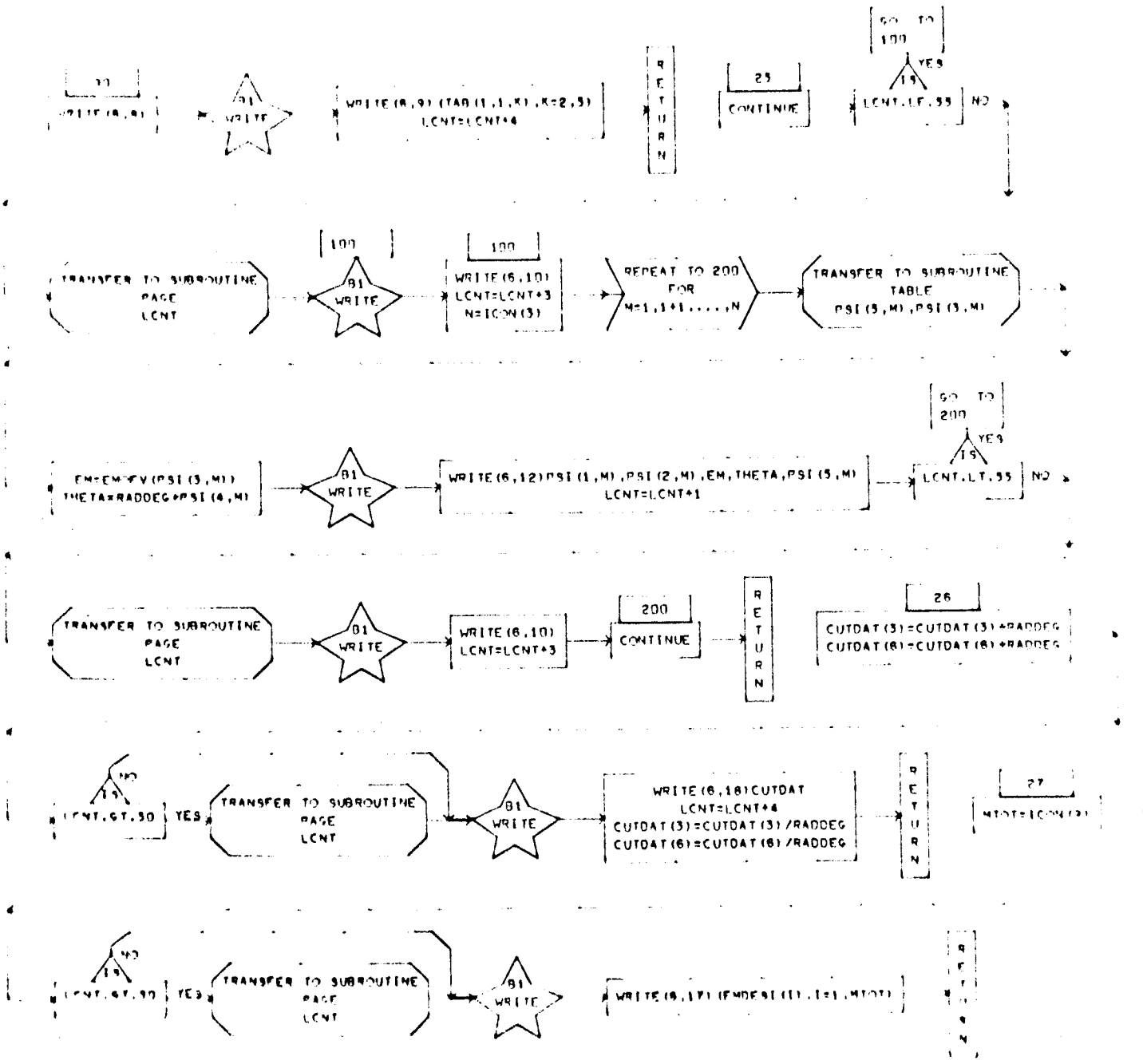
COMMON/CONTRL/
COMMON/CUTFO/
COMMON/DATAR/
COMMON/EMCURV/
COMMON/GASCON/
COMMON/HEAD/
COMMON/INPUT/
PAGE
TABLE
EMOFV

METHOD OF SOLUTION

Not applicable.


PAGE 1 OF 3
IF THE VALUE
TRANSFER TO STATEMENT
1 21
2 22
3 23
4 24
5 25
6 26
7 27
21
TRANSFER TO SUBROUTINE
PAGE
LCNT
B1 WRITE
WRITE(6,3)ICON
LCNT=LCNT+7
RETURN
22
B1 WRITE
WRITE(6,2)
LCNT=LCNT+3
M=ICON(4)
REPEAT TO 30
FOR
L1=1,1+1,....,M
B1 WRITE
WRITE(6,5)IWALL(L1,2),(WALLCO(L1,J,2),J=1,8)
LCNT=LCNT+1
GO TO 30
LCNT.LT.55
YES
NO
TRANSFER TO SUBROUTINE
PAGE
LCNT
B1 WRITE
WRITE(6,2)
LCNT=LCNT+3
30
CONTINUE
50
CONTINUE
LCNT.GT.50
NO
YES
TRANSFER TO SUBROUTINE
PAGE
LCNT
B1 WRITE
WRITE(6,4)
LCNT=LCNT+3
M=ICON(5)
REPEAT TO 80
FOR
L1=1,1+1,....,M
B1 WRITE
WRITE(6,5)IWALL(L1,1),(WALLCO(L1,J,1),J=1,8)
LCNT=LCNT+1
GO TO 80
LCNT.LT.55
YES
NO
TRANSFER TO SUBROUTINE
PAGE
LCNT
B1 WRITE
WRITE(6,4)
LCNT=LCNT+3
80
CONTINUE


23
RETURN
24
CONTINUE
LCNT.GE.55
NO
YES
TRANSFER TO SUBROUTINE
PAGE
LCNT
LCNT=LCNT+4
GO TO 90
ICON(I).EQ.1.AND.IVTAB(I).EQ.1
YES
NO
GO TO 70
LCNT.LT.49
YES
NO
TRANSFER TO SUBROUTINE
PAGE
LCNT
70
B1
WRITE
70
WRITE(6,8)
LCNT=LCNT+3
IS=ICON(I)
REPEAT TO 72
FOR
I=1,I+1,....,IS
IV=IVTAB(I)
B1
WRITE
WRITE(6,13)STAB(I)
LCNT=LCNT+1
REPEAT TO 71
FOR
J=1,J+1,....,IV
B1
WRITE
WRITE(6,7)(TAB(I,J,K),K=1,5)
LCNT=LCNT+1
GO TO 71
LCNT.LT.55
YES
NO
GO TO 73
J.EQ.IV
YES
NO
TRANSFER TO SUBROUTINE
PAGE
LCNT
B1
WRITE
WRITE(6,8)
B1
WRITE
WRITE(6,13)STAB(I)
LCNT=LCNT+4
GO TO 71
73
CONTINUE
GO TO 72
I.EQ.IS
YES
NO
TRANSFER TO SUBROUTINE
PAGE
LCNT
B1
WRITE
WRITE(6,8)
LCNT=LCNT+3
71
CONTINUE
72
CONTINUE
RETURN
90
B1
WRITE


WRITE(6,9)
B1 WRITE
WRITE(6,9)(TAB(I,1,K),K=2,5)
LCNT=LCNT+4
RETURN
25
CONTINUE
GO TO 100
YES
LCNT.LE.55
NO
TRANSFER TO SUBROUTINE
PAGE
LCNT
100
B1 WRITE
100
WRITE(6,10)
LCNT=LCNT+3
N=ICON(3)
REPEAT TO 200
FOR
M=1,1+1,....,N
TRANSFER TO SUBROUTINE
TABLE
PSI(5,M),PSI(3,M)
GO TO 200
YES
LCNT.LT.55
NO
EM=EM*FV(PSI(3,M))
THETA=RADDEG*PSI(4,M)
B1 WRITE
WRITE(6,12)PSI(1,M),PSI(2,M),EM,THETA,PSI(5,M)
LCNT=LCNT+1
TRANSFER TO SUBROUTINE
PAGE
LCNT
B1 WRITE
WRITE(6,10)
LCNT=LCNT+3
200
CONTINUE
RETURN
26
CUTDAT(3)=CUTDAT(3)*RADDEG
CUTDAT(6)=CUTDAT(6)*RADDEG
NO
LCNT.GT.50
YES
TRANSFER TO SUBROUTINE
PAGE
LCNT
B1 WRITE
WRITE(6,18)CUTDAT
LCNT=LCNT+4
CUTDAT(3)=CUTDAT(3)/RADDEG
CUTDAT(6)=CUTDAT(6)/RADDEG
RETURN
27
NO
LCNT.GT.50
YES
TRANSFER TO SUBROUTINE
PAGE
LCNT
B1 WRITE
WRITE(6,17)(FMDESI(I),I=1,MTOT)
RETURN

FUNCTION NAME: POFEM

DESCRIPTION

This function computes the local static pressure as a function of Mach number and entropy.

CALLING SEQUENCE

P = POFEM (EM, S)

where (P) is the resultant static pressure found from the Mach number (EM) and entropy (S). NOTE: The appropriate values of the gas properties must be stored in common upon entry to this routine.

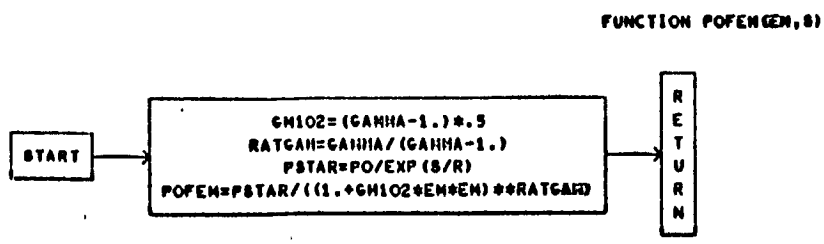
UTILITY ROUTINES AND COMMON REFERENCES

COMMON/GASCON/
UTILITY - None

METHOD OF SOLUTION

Thermally perfect gas relationships are used to find the pressure.

$$p = p_o e^{-S/R} \left(1 + \frac{\gamma - 1}{2} M^2\right)^{-\frac{\gamma}{\gamma - 1}}$$



SUBROUTINE NAME: PRANDT

DESCRIPTION

This subroutine computes the Prandtl-Meyer expansion angle for a given boundary angle and divides this angle into a series of expansion "rays." The flow properties at each angular increment are set and stored in the Characteristic Data (PHO) array.

CALLING SEQUENCE

CALL PRANDT (I, J, THETAB, NPM, IFLAG, ITYPE)

where

(I) - represents the corner point
(J) - indicates a characteristic line
(THETAB) - is the boundary angle
(NPM) - number of Prandtl-Meyer increments (calculated in PRANDT)
(IFLAG) - error flag
(ITYPE) - indicates if upper (2) or lower (1) boundary

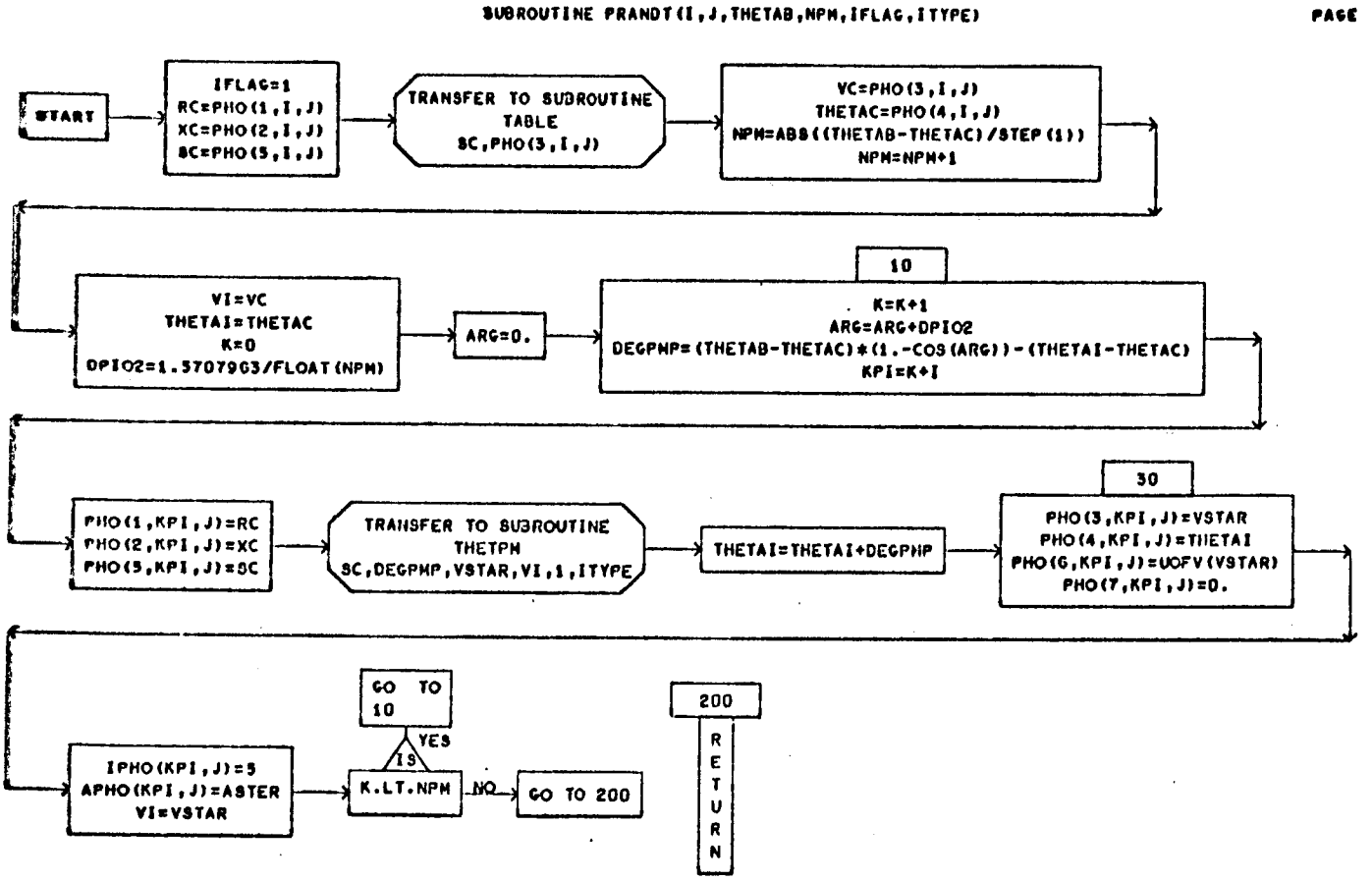
UTILITY ROUTINES AND COMMON REFERENCES

COMMON/CRITER/
COMMON/DATAR/
COMMON/GASCON/
COMMON/STEPC/
TABLE
THETPM
UOFV

METHOD OF SOLUTION

The routine is entered with known flow properties and a known corner and boundary flow angle. From the known angles and the preset number of degrees per ray, the number of increments is calculated. The number of

degrees per ray is then adjusted by a weighting function. Subroutine (THETPM) is entered with known initial conditions and the adjusted number of degrees per ray and returns with a final velocity. These new conditions are then set into the (PHO) array.



FUNCTION NAME: RGMOFP

DESCRIPTION

This subroutine finds Mach number as a function of pressure and entropy. The difference between this routine and EMOFP is that in this case the gas properties are not known prior to entry.

CALLING SEQUENCE

EM = RGMOFP (P, S)

where (EM) is the resultant Mach number and (P) is the local static pressure, while (S) is the local entropy.

UTILITY ROUTINES AND COMMON REFERENCES

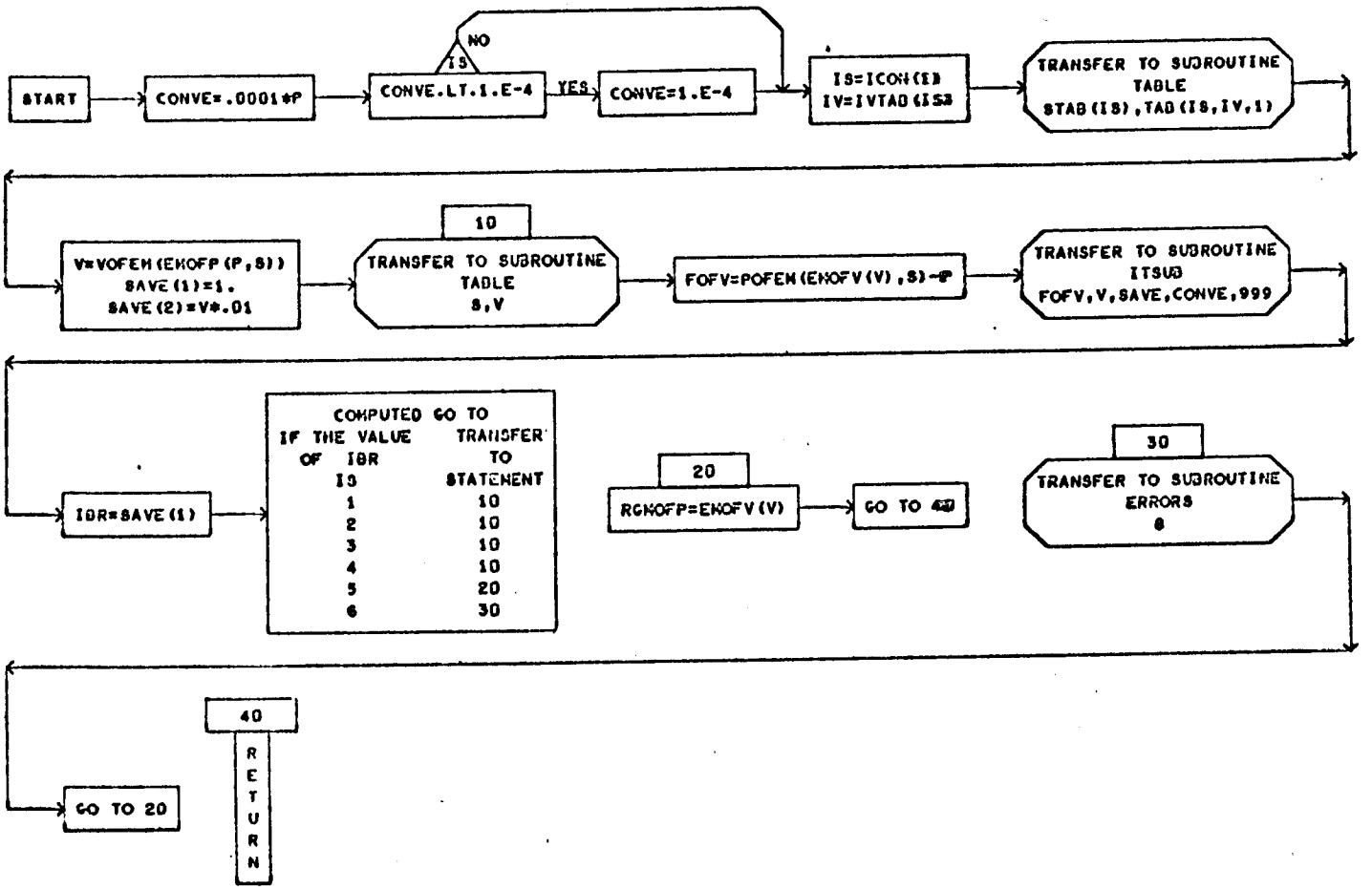
COMMON/GASTAB/
COMMON/GASCON/
POFEM
EMOFV
ITSUB
TABLE

METHOD OF SOLUTION

The real gas tables have, as independent variables, entropy and velocity. If the velocity is not known, an iterative solution must be employed to find Mach number from pressure and entropy.

FUNCTION RGNOFP (P,S)

PAGE 1



FUNCTION NAME: RGVOFM

DESCRIPTION

This subroutine finds velocity as a function of Mach number and entropy. The difference between this routine and VOFEM is that the gas properties are not known prior to entry.

CALLING SEQUENCE

V = RGVOFM (S, EM)

where V is the resultant velocity formed from entropy (S) and Mach number (EM).

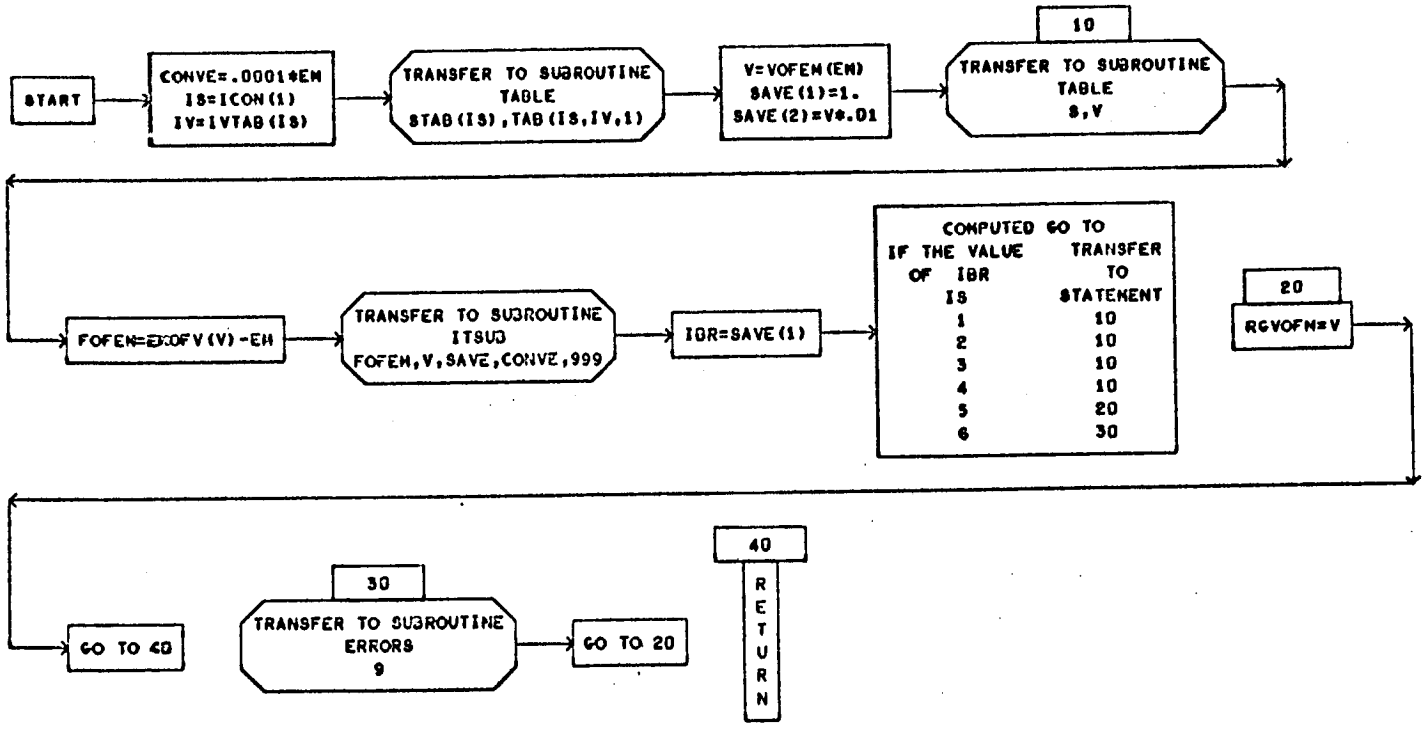
UTILITY ROUTINES AND COMMON REFERENCES

COMMON/GASTAB/
TABLE
VOFEM
EMOFV
ITSUB

METHOD OF SOLUTION

The real gas tables have, as independent variables, entropy and velocity. If the velocity is not known, an iterative solution must be employed to find the velocity from Mach number and entropy.

FUNCTIONRGVOFN(S,EN)



FUNCTION NAME: RHOFEM

DESCRIPTION

This function computes the local density as a function of Mach number and entropy.

CALLING SEQUENCE

RHO = RHOFEM (EM, S)

where RHO is the resultant density found from local Mach number and local entropy. NOTE: The appropriate values of the gas properties must be stored in common upon entry to this routine.

UTILITY ROUTINES AND COMMON REFERENCES

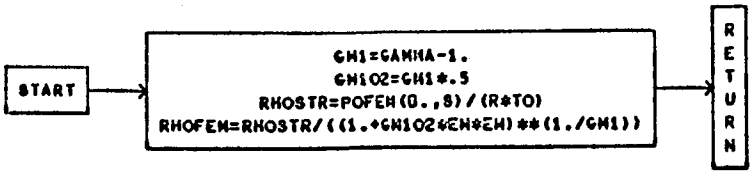
COMMON/GASCON/
POFEM

METHOD OF SOLUTION

Thermally perfect gas relationships are used to find the density.

$$\rho = \rho_o^* \left(1 + \frac{\gamma - 1}{2} M^2\right)^{\frac{-1}{\gamma - 1}}$$

FUNCTION RHOFEM(EM,S)



FUNCTION NAME: ROTERM

DESCRIPTION

This routine computes the rotational term (F_I, F_{II}) used in the method-of-characteristics routine (MOCSOL).

CALLING SEQUENCE

F = ROTERM (THETA, DELTA, EMU, R3, RI)

where (THETA) is $\bar{\theta}_I$ or $\bar{\theta}_{II}$ (flow angles of the known points)
(DELTA) selects quadrant
(EMU) is $\bar{\mu}_I$ or $\bar{\mu}_{II}$ (Mach angles of the known points)
(R3) is $\bar{r}_{III}$ or x_{III} (coordinates of new point)
(RI) is r_I or x_I (coordinates of known point)

UTILITY ROUTINES AND COMMON REFERENCES

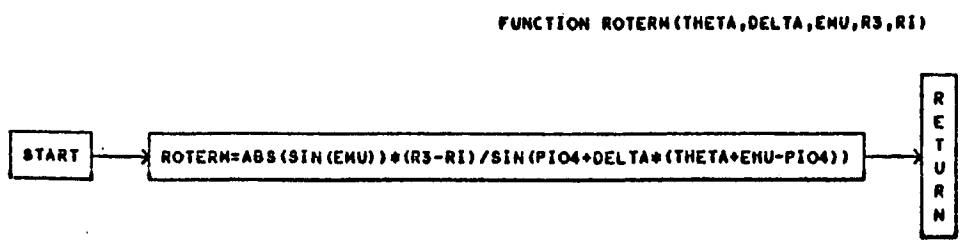
None

METHOD OF SOLUTION

The method-of-characteristics solution uses this routine to determine a coefficient needed in its solution. This term (see Equation (6-29), Section 6 of Reference 1) can be written as:

$$F = \frac{\left|\sin\mu\right| (d_{III} - d)}{\sin\left(\frac{\pi}{4} + \delta\left(\bar{\theta} + \bar{\mu} - \frac{\pi}{4}\right)\right)}$$

By the proper choice of d (r or x), δ and the sign of μ, indeterminant forms are eliminated in the evaluation.



FUNCTION NAME: SHOCK

DESCRIPTION

This subroutine iteratively adjusts the shock strength in order to satisfy the oblique shock relations and the flow field properties simultaneously. The six different options are:

1. interior right running shock wave
2. interior left running shock wave
3. right running shock wave at wall
4. left running shock wave at wall
5. right running shock reflected from wall
6. left running shock reflected from wall

CALLING SEQUENCE

CALL SHOCK (IN, KN, IKL, IN1, JN, IJH, I8FIN, I7FIN, IFLAG, ITYPE)

where	(IN, KN)	is the location of the virtual point
	IKL	is the first point on the KN array
	(IN1, JN)	is the location of the known shock point
	IJH	is the last point on the JN array
	I8FIN	is the final location of the upstream shock point
	I7FIN	is the final location of the base point on the downstream side
	IFLAG	is an error flag
	ITYPE	selects the type of calculation

ITYPE =
11 for case (1)
12 for case (2)
21 for case (3)
22 for case (4)
31 for case (5)
32 for case (6)

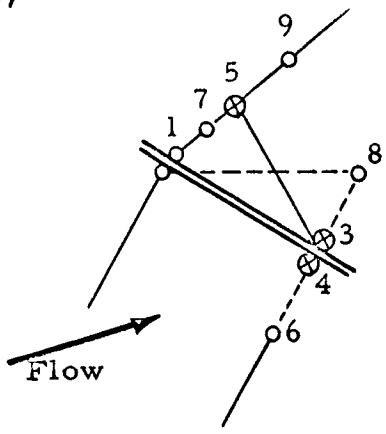
UTILITY ROUTINES AND COMMON REFERENCES

COMMON/CONTRL/	EMOFV
COMMON/CRITER/	DELTAF
COMMON/GASCON/	ENTROP
COMMON/DATAR/	UOFV
INRSCT	MOSCOL
TABLE	ROTERM
	ITSUB

METHOD OF SOLUTION

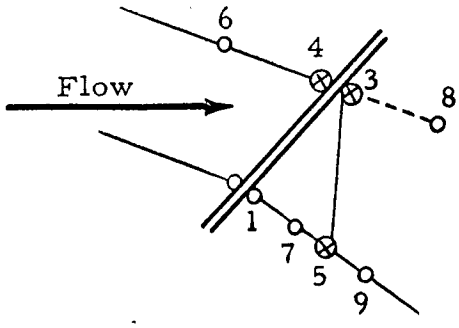
This subroutine is used to calculate the properties across an oblique shock wave as a function of the local characteristic lattice. In its operation, this routine instructs the calling routine as to the necessity of adjusting the counting scheme for network construction due to the presence of the shock wave. Diagrams for the six options are given below.

(1)



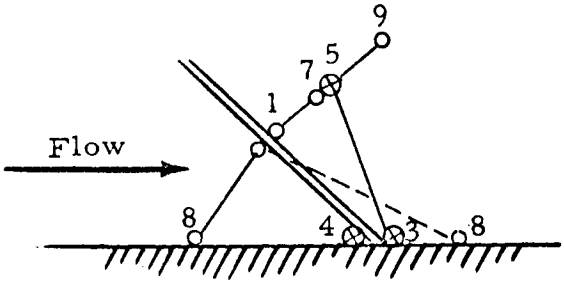
Case (1), ITYPE = (11)

(2)

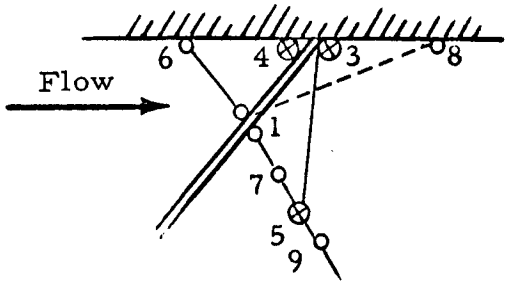


Case (2), ITYPE = (12)

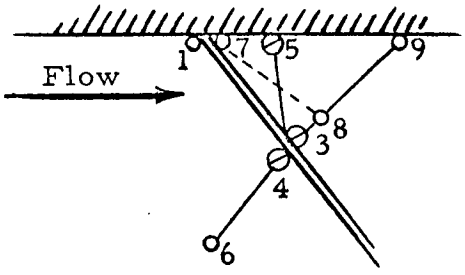
(3)



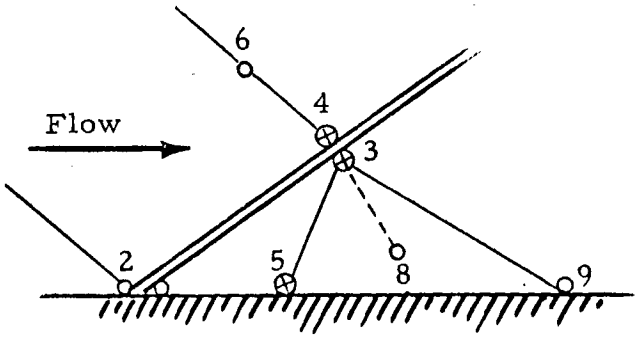
Case (3), ITYPE = (21)



CASE (4), ITYPE = (22)

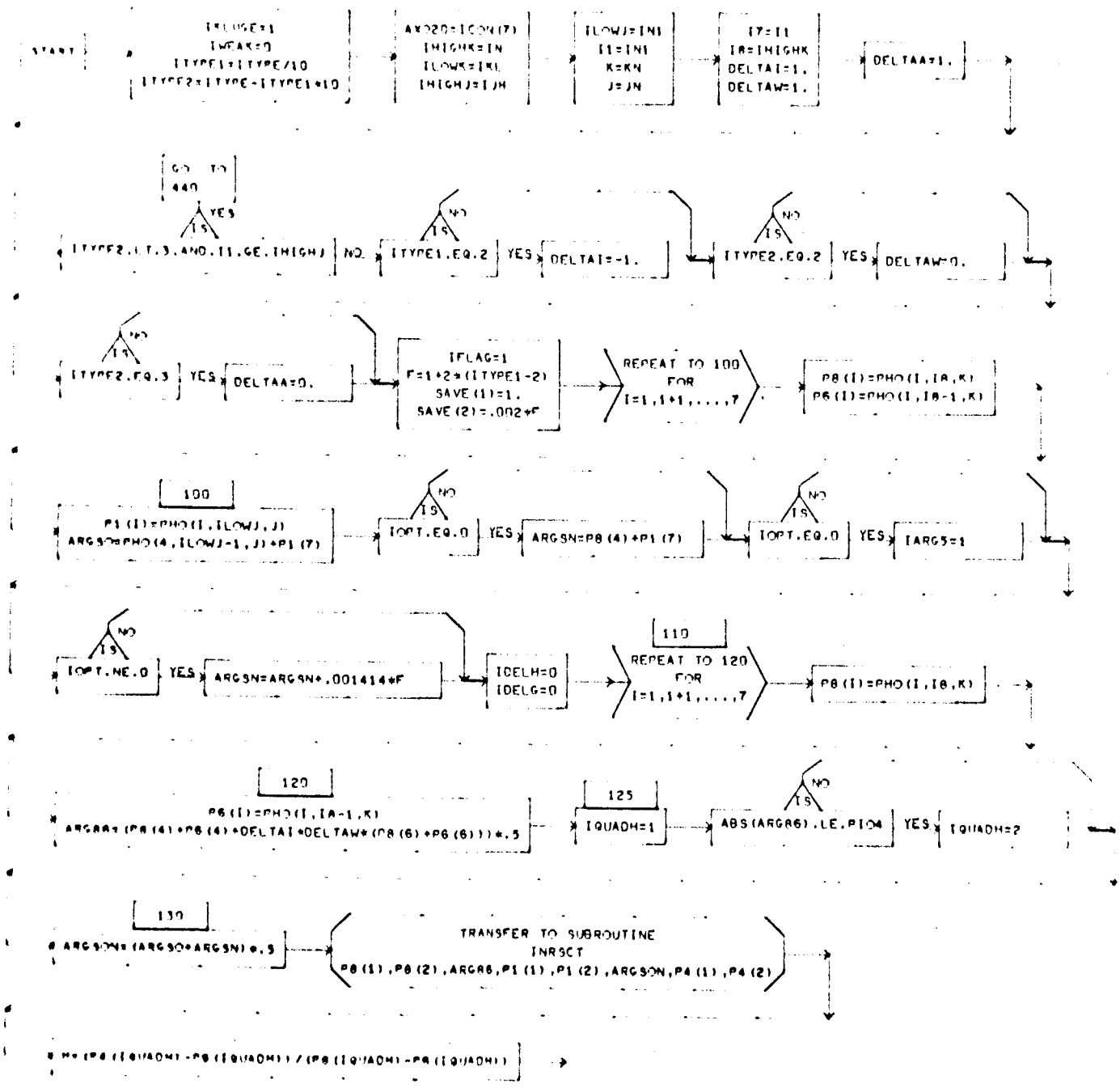


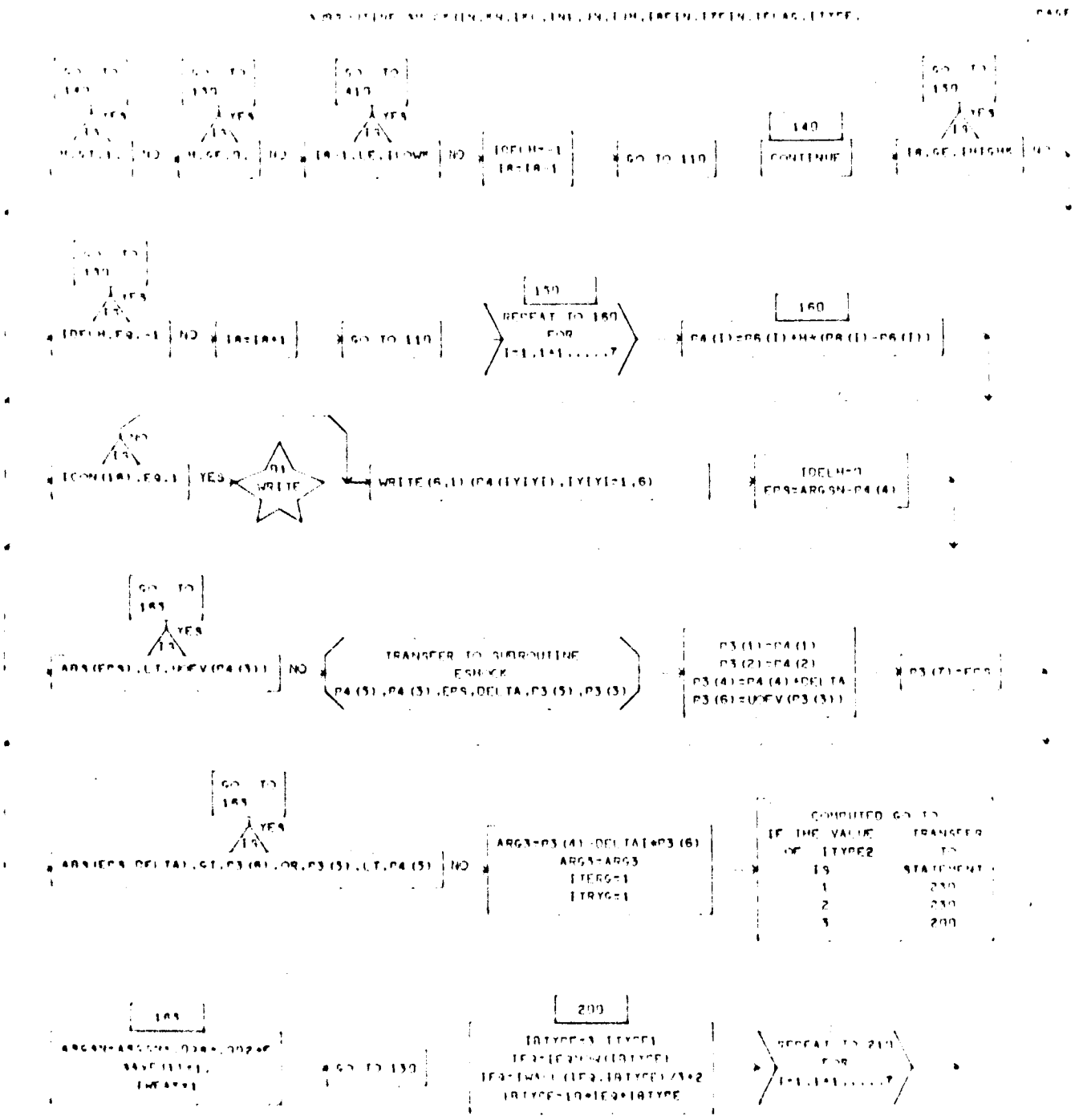
Case (5), ITYPE = (31)

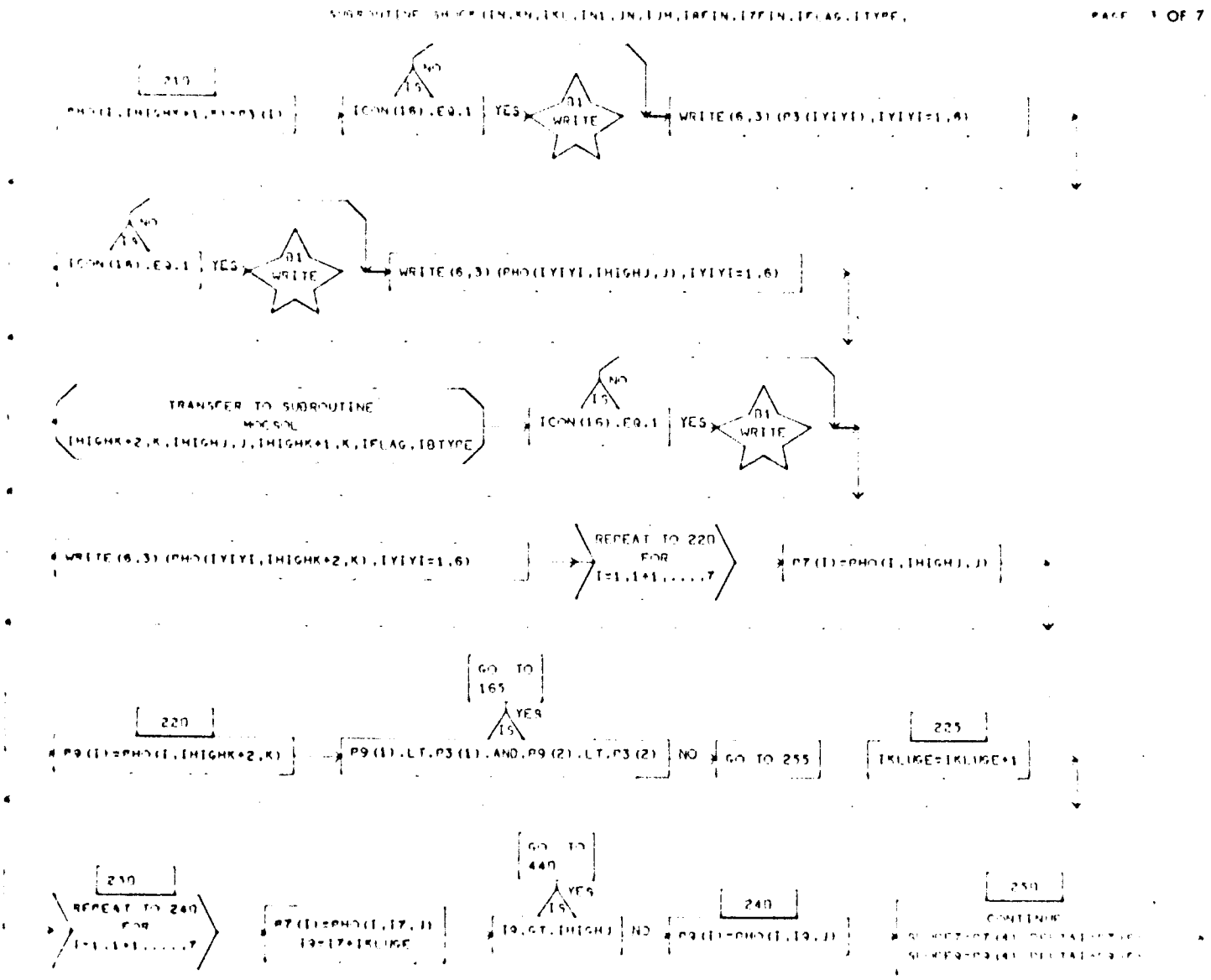


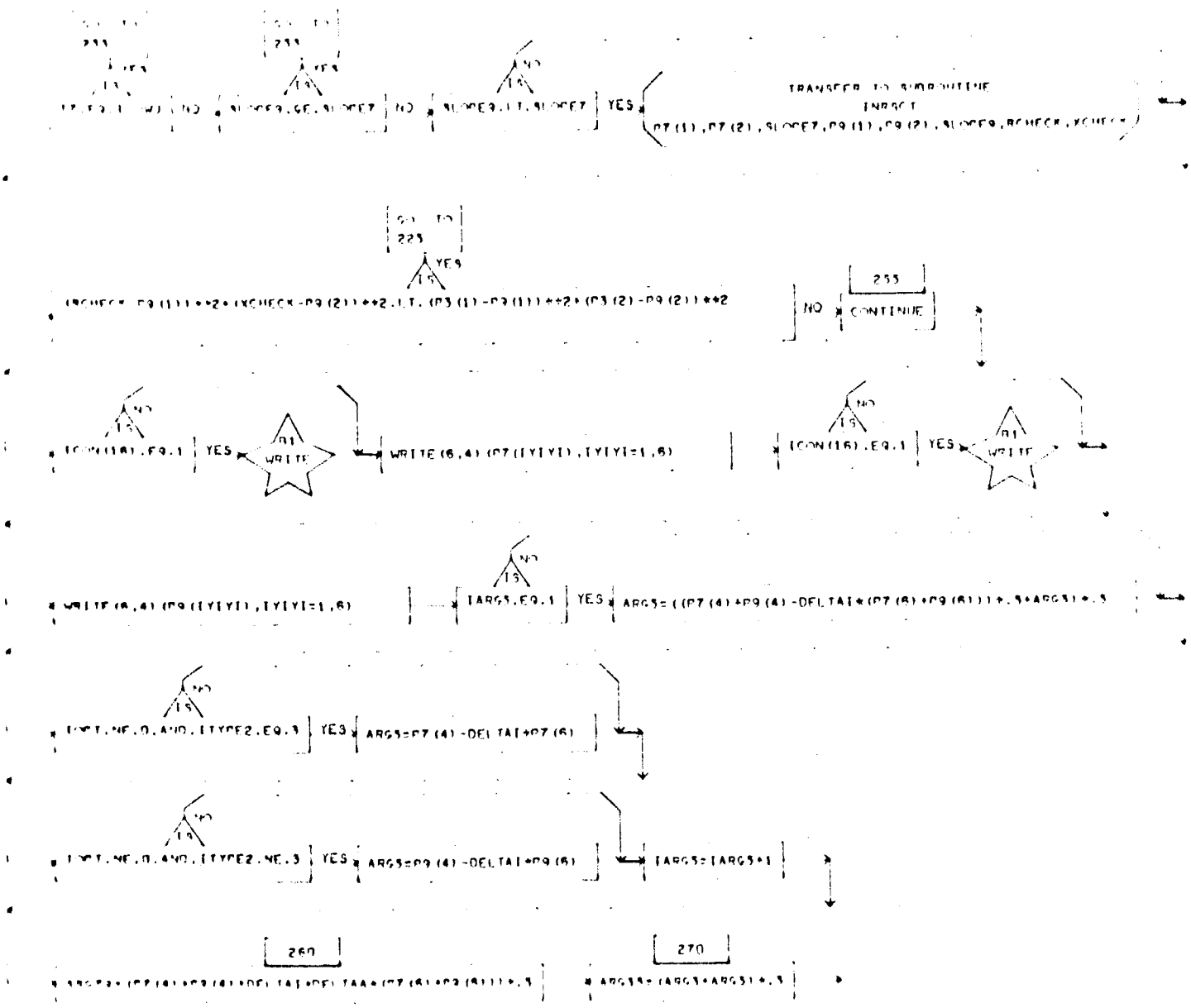
Case (6), ITYPE = (32)

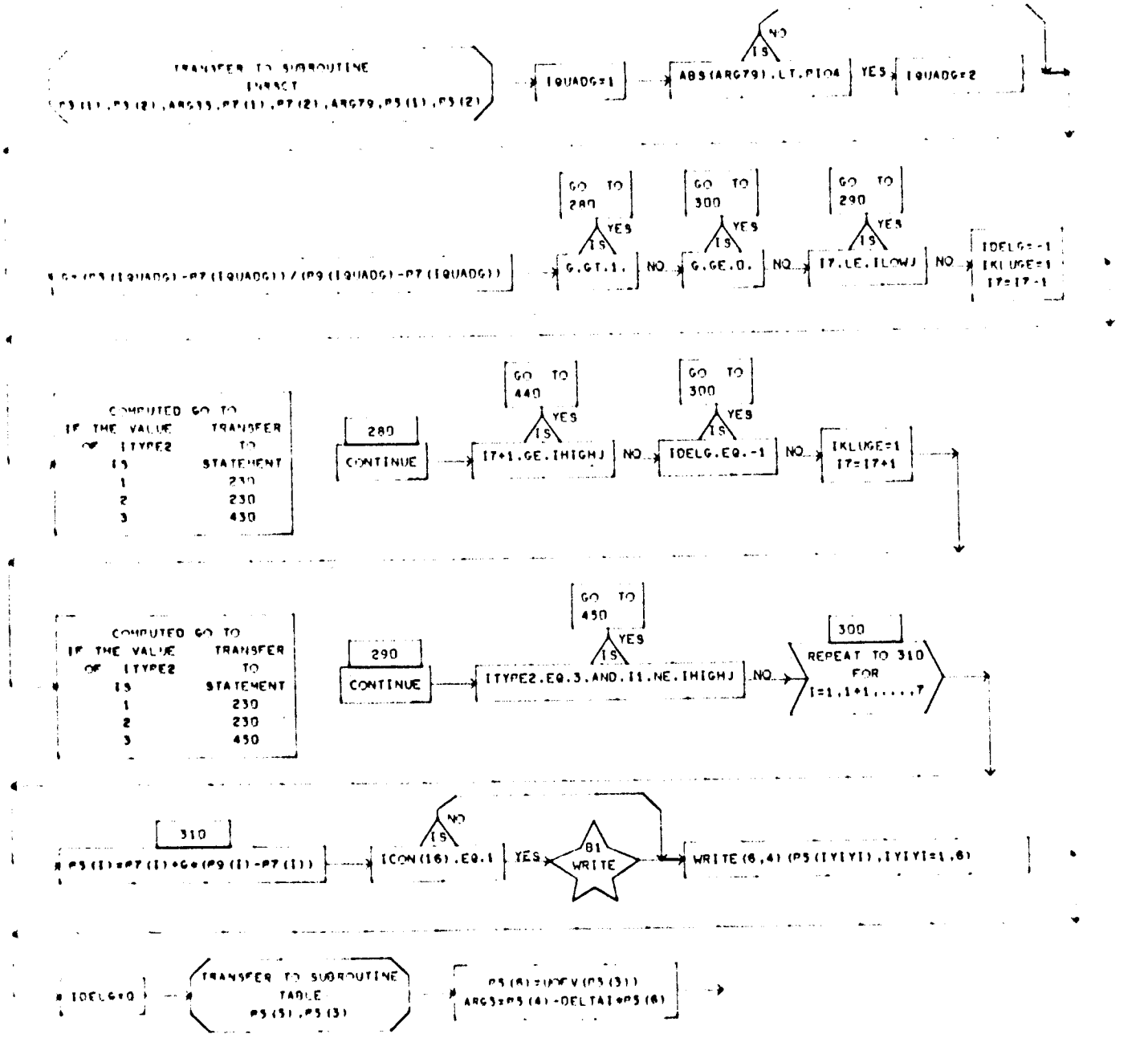
SUBROUTINE SHOCK(IN,KN,IKL,INI,JN,IJH,IRFIN,ITFIN,IFLAG,ITYPE,

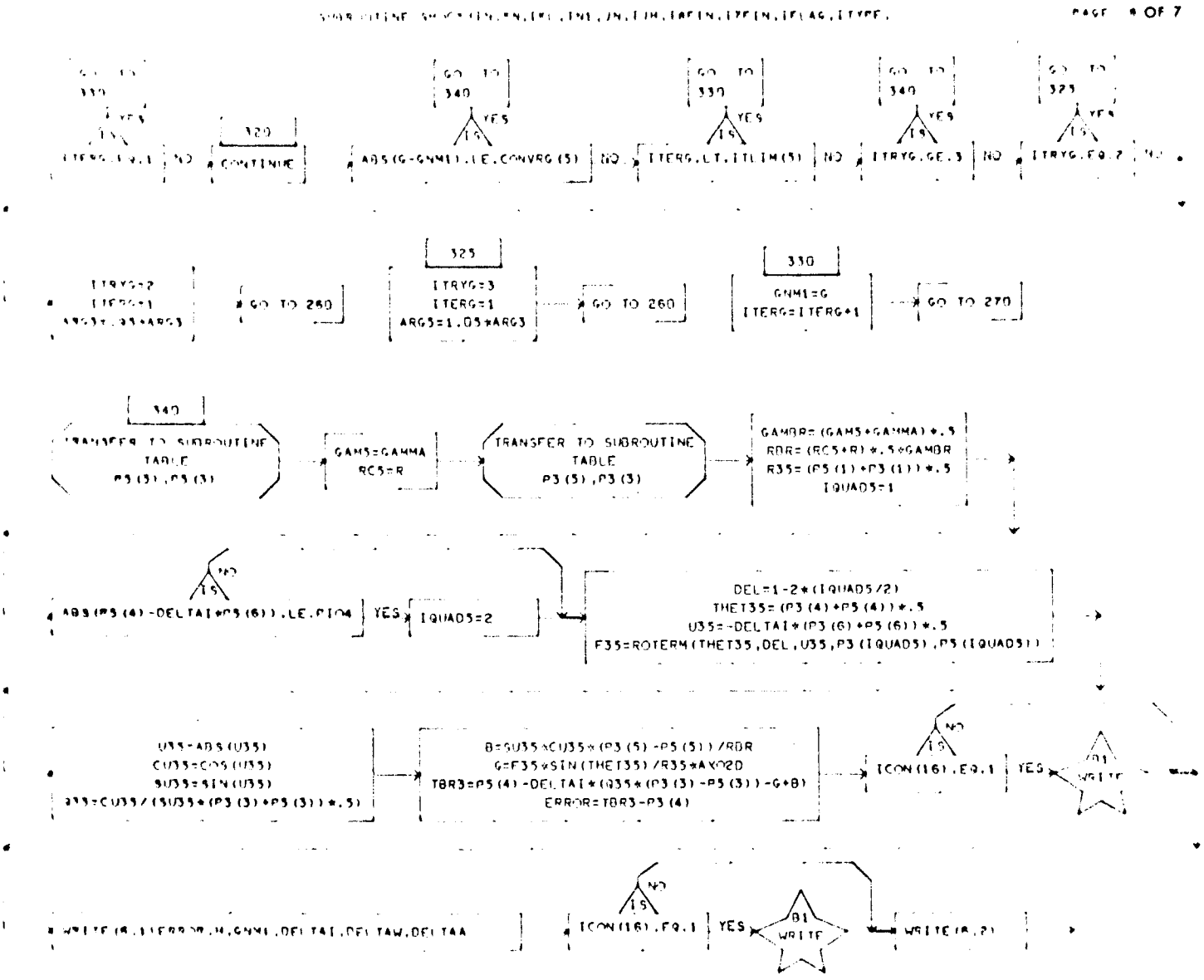


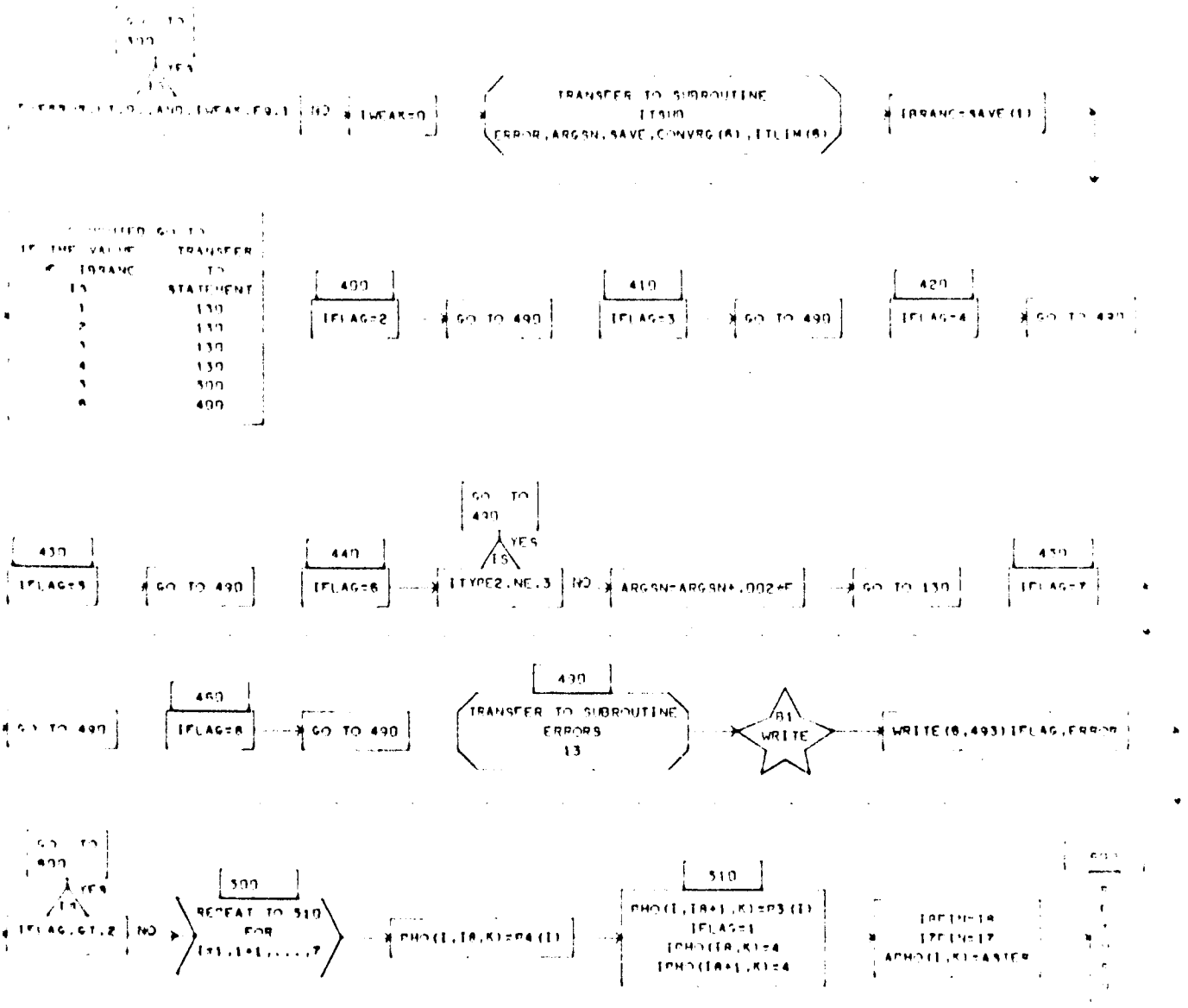

GO TO 140
GO TO 130
GO TO 410
YES
IS
NO
IB=IB-1
GO TO 110
140
CONTINUE
IB.GE.IHIGHK
IDELH.EQ.-1
IB=IB+1
150
REPEAT TO 160
FOR
I=1,1+1,....,7
160
P4(I)=P6(I)+H*(P8(I)-P6(I))
ICON(IB).EQ.1
WRITE
WRITE(6,1)(P4(IYIYI),IYIYI=1,6)
IDELH=0
EPS=ARGSN-P4(4)
GO TO 165
ABS(EPS).LT.UOFV(P4(3))
TRANSFER TO SUBROUTINE
ESHOCK
P4(5),P4(3),EPS,DELTA,P3(5),P3(3)
P3(1)=P4(1)
P3(2)=P4(2)
P3(4)=P4(4)+DELTA
P3(6)=UOFV(P3(3))
ARG3=P3(4)-DELTA*P3(6)
ARG3=ARG3
ITERG=1
ITRYG=1
COMPUTED GO TO
IF THE VALUE OF ITYPE2 IS
TRANSFER TO STATEMENT
1 230
2 230
3 200
185
GO TO 130
200
REPEAT TO 210
FOR
I=1,1+1,....,7


SUBROUTINE SHOCK(IN,KN,IKL,IN1,JN,IJH,IRFIN,IZFIN,IFLAG,ITYPE,
PAGE 1 OF 7
210
PHO(I,IHIGHK+1,K)=P3(I)
IS
NO
ICON(16).EQ.1
YES
B1
WRITE
WRITE(6,3)(P3(IYIYI),IYIYI=1,6)
IS
NO
ICON(16).EQ.1
YES
B1
WRITE
WRITE(6,3)(PHO(IYIYI,IHIGHJ,J),IYIYI=1,6)
TRANSFER TO SUBROUTINE
MOCSOL
IHIGHK+2,K,IHIGHJ,J,IHIGHK+1,K,IFLAG,IBTYPE
IS
NO
ICON(16).EQ.1
YES
B1
WRITE
WRITE(6,3)(PHO(IYIYI,IHIGHK+2,K),IYIYI=1,6)
REPEAT TO 220
FOR
I=1,1+1,....,7
P7(I)=PHO(I,IHIGHJ,J)
GO TO
165
220
P9(I)=PHO(I,IHIGHK+2,K)
IS
YES
P9(1).LT.P3(1).AND.P9(2).LT.P3(2)
NO
GO TO 255
225
IKLUGE=IKLUGE+1
230
REPEAT TO 240
FOR
I=1,1+1,....,7
P7(I)=PHO(I,I7,J)
I9=I7+IKLUGE
GO TO
440
IS
YES
I9.GT.IHIGHJ
NO
240
P9(I)=PHO(I,I9,J)
250
CONTINUE


233
YES
NO
SLOPE9.GE.SLOPE7
SLOPE9.LT.SLOPE7
TRANSFER TO SUBROUTINE
INRSCT
P7(1),P7(2),SLOPE7,P9(1),P9(2),SLOPE9,RCHECK,XCHECK
225
(XCHECK-P9(1))**2+(XCHECK-P9(2))**2.LT.(P3(1)-P3(1))**2+(P3(2)-P9(2))**2
NO
CONTINUE
ICON(16).EQ.1
YES
WRITE
WRITE(6,4)(P7(IYIYI),IYIYI=1,6)
ICON(16).EQ.1
YES
WRITE
WRITE(6,4)(P9(IYIYI),IYIYI=1,6)
IARGS.EQ.1
YES
ARGS=((P7(4)+P9(4)-DELTAI*(P7(6)+P9(6)))*.5+ARGS)*.5
ICNT.NE.0.AND.ITYPE2.EQ.3
YES
ARGS=P7(4)-DELTAI*P7(6)
ICNT.NE.0.AND.ITYPE2.NE.3
YES
ARGS=P9(4)-DELTAI*P9(6)
IARGS=IARGS+1
260
ARGS2=((P7(4)+P9(4)+DELTAI+DELTAA*(P7(6)+P9(6)))*.5
270
ARGS3=(ARGS3+ARGS2)*.5


PAGE 1 OF 7
TRANSFER TO SUBROUTINE INRSCT
P3(1),P3(2),ARG35,P7(1),P7(2),ARG79,P5(1),P5(2)
IQUADG=1
ABS(ARG79).LT.PIO4
IQUADG=2
G=(P3(IQUADG)-P7(IQUADG))/(P9(IQUADG)-P7(IQUADG))
G.GT.1.
G.GE.0.
I7.LE.ILOWJ
IDELG=-1
IKLUGE=1
I7=I7-1
COMPUTED GO TO
IF THE VALUE OF ITYPE2 IS
TRANSFER TO STATEMENT
1 230
2 230
3 430
280
CONTINUE
I7+1.GE.IHIGHJ
IDELG.EQ.-1
IKLUGE=1
I7=I7+1
COMPUTED GO TO
IF THE VALUE OF ITYPE2 IS
TRANSFER TO STATEMENT
1 230
2 230
3 450
290
CONTINUE
ITYPE2.EQ.3.AND.I1.NE.IHIGHJ
300
REPEAT TO 310 FOR I=1,1+1,....,7
310
P5(I)=P7(I)+G*(P9(I)-P7(I))
ICON(16).EQ.1
B1 WRITE
WRITE(6,4)(P5(IYIYI),IYIYI=1,6)
IDELG=0
TRANSFER TO SUBROUTINE TABLE
P5(5),P5(3)
P5(6)=UDFV(P5(3))
ARG3=P5(4)-DELTAI*P5(6)


SUBROUTINE SHOOT(IN,FN,IRL,INL,JN,IJH,IRFIN,IZFIN,IFLAG,ITYPE,
PAGE 4 OF 7
GO TO 330
ITERG.EQ.1
YES
NO
320
CONTINUE
GO TO 340
ABS(G-GNM1).LE.CONVRG(5)
YES
NO
GO TO 330
ITERG.LT.ITLIM(5)
YES
NO
GO TO 340
ITRYG.GE.3
YES
NO
GO TO 325
ITRYG.EQ.2
YES
NO
ITRYG=2
ITERG=1
ARG3=.95*ARG3
GO TO 280
325
ITRYG=3
ITERG=1
ARG3=1.05*ARG3
GO TO 280
330
GNM1=G
ITERG=ITERG+1
GO TO 270
340
TRANSFER TO SUBROUTINE
TABLE
P5(5),P5(3)
GAM5=GAMMA
RC5=R
TRANSFER TO SUBROUTINE
TABLE
P3(5),P3(3)
GAMBR=(GAM5+GAMMA)*.5
RBR=(RC5+R)*.5*GAMBR
R35=(P5(1)+P3(1))*.5
IQUAD5=1
ABS(P5(4)-DELTAI*P5(6)).LE.PI04
NO
YES
IQUAD5=2
DEL=1-2*(IQUAD5/2)
THET35=(P3(4)+P5(4))*.5
U35=-DELTAI*(P3(6)+P5(6))*.5
F35=ROTERM(THET35,DEL,U35,P3(IQUAD5),P5(IQUAD5))
U35=ABS(U35)
CU35=COS(U35)
SU35=SIN(U35)
A35=CU35/(SU35*(P3(3)+P5(3))*.5)
B=SU35*CU35*(P3(5)-P5(5))/RBR
G=F35*SIN(THET35)/R35*AX02D
TBR3=P5(4)-DELTAI*(U35*(P3(3)-P5(3))-G+B)
ERROR=TBR3-P3(4)
ICON(16).EQ.1
NO
YES
B1
WRITE
WRITE(8,1)ERROR,H,GNM1,DELTAI,DELTAW,DELTAA
ICON(16).EQ.1
NO
YES
B1
WRITE
WRITE(8,2)


TRANSFER TO SUBROUTINE
ITSUB
ERROR,ARGSN,SAVE,CONVRG(8),ITLIM(8)
IWEAK=0
IBRANC=SAVE(1)
IF THE VALUE IBRANC IS
TRANSFER TO STATEMENT
1 130
2 130
3 130
4 130
5 300
6 400
400
IFLAG=2
GO TO 490
410
IFLAG=3
GO TO 490
420
IFLAG=4
GO TO 490
430
IFLAG=5
GO TO 490
440
IFLAG=6
GO TO 490
YES
IS
ITYPE2.NE.3
NO
ARGSN=ARGSN+.002*F
GO TO 130
IFLAG=7
GO TO 490
460
IFLAG=8
GO TO 490
490
TRANSFER TO SUBROUTINE
ERRORS
13
B1
WRITE
WRITE(6,493)IFLAG,ERROR
GO TO 800
YES
IS
IFLAG.GT.2
NO
500
REPEAT TO 510
FOR
I=1,I+1,....,7
PHO(I,I8,K)=P4(I)
510
PHO(I,I8+1,K)=P3(I)
IFLAG=1
IPHO(I8,K)=4
IPHO(I8+1,K)=4
I8FIN=I8
I7FIN=I7
APHO(I,K)=ASTER

SUBROUTINE NAME: TABLE

DESCRIPTION

This subroutine utilizes real or ideal gas information obtained from a master tape or input cards to calculate properties locally in the flow. The maximum size of the array used by (TABLE) is limited to five gas properties (V, R, γ, T_o, P_o) at thirteen velocity "cuts" for each of nine entropy cuts.

CALLING SEQUENCE

CALL TABLE (SS, VV)

where (SS) is the local entropy and (VV) is the local velocity at the point of interest.

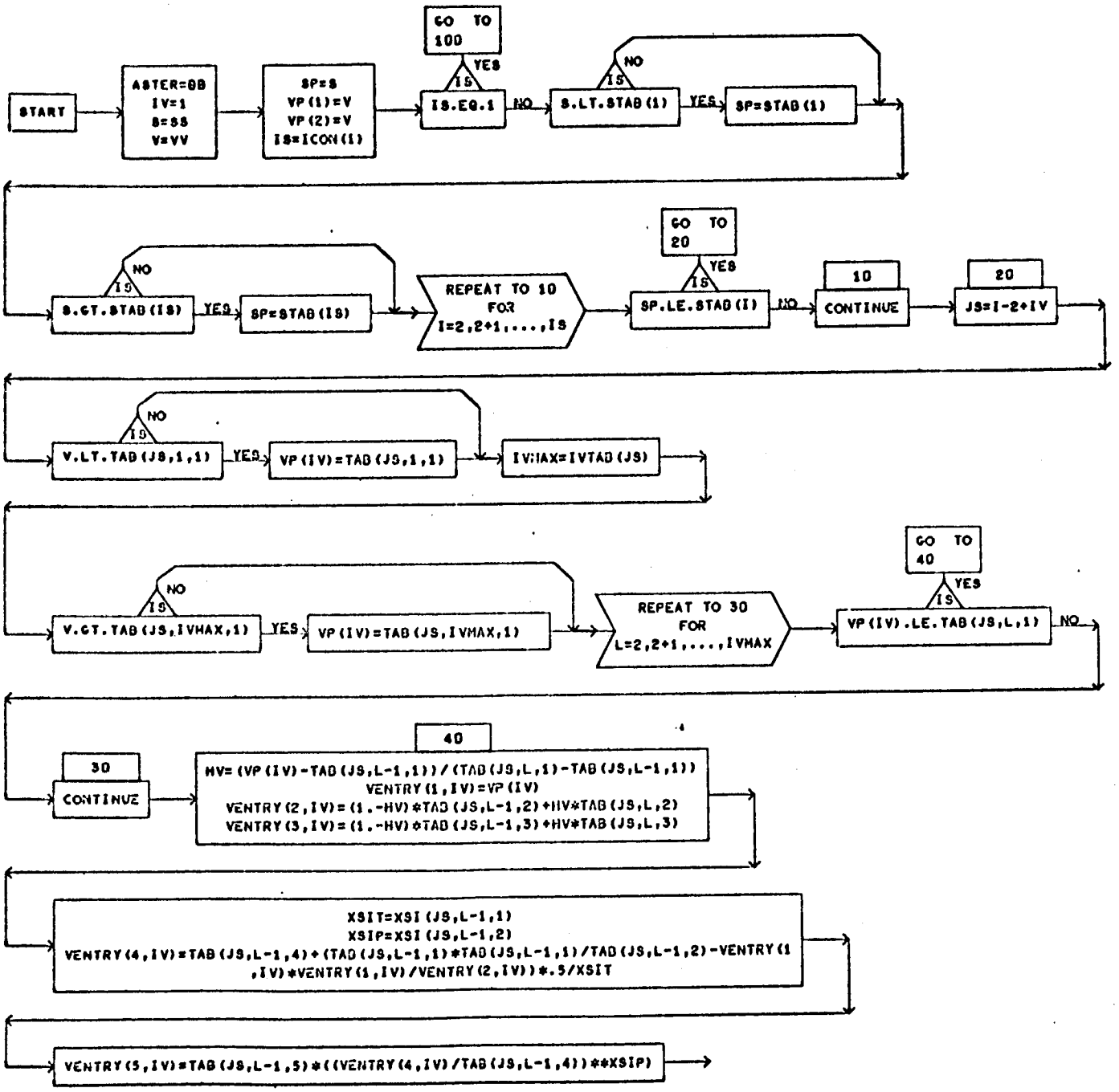
UTILITY ROUTINES AND COMMON REFERENCES

COMMON/XSICOM/
COMMON/CONTRL/
COMMON/DATAR/
COMMON/GASCON/
TOFV
POFEM

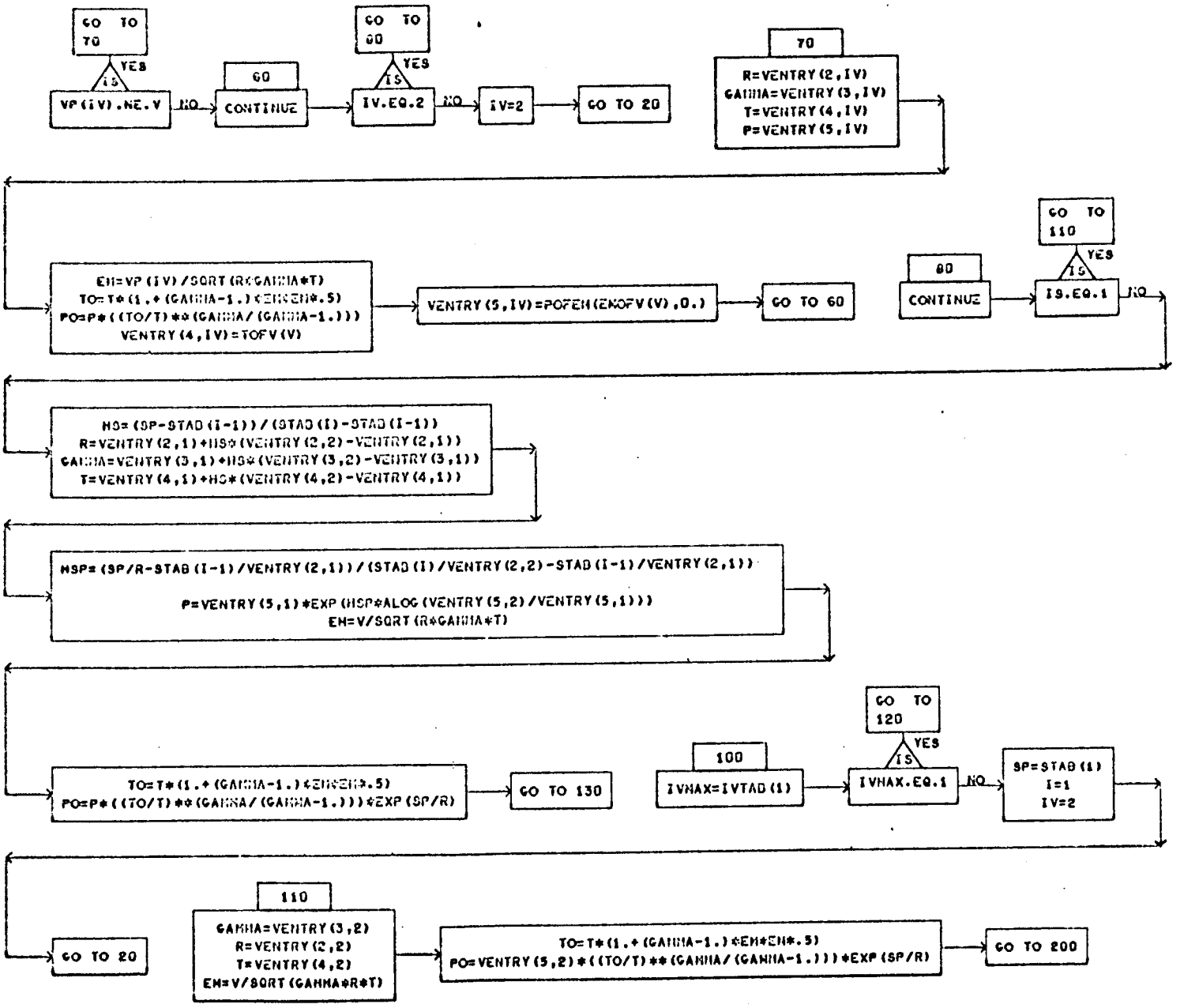
METHOD OF SOLUTION

The routine is entered with the local entropy (SS) and velocity (VV). A test is then made to determine if the gas is real or ideal. If the test indicates an ideal gas, the local properties are set to those stored in the (TAB) common array. If the test indicates real gas, a double interpolation scheme is utilized to locate gas properties between tabulated values of velocity and entropy. In the case of an entry velocity beyond the range of the table, an ideal gas extrapolation from the last table value is made to locate the gas properties.

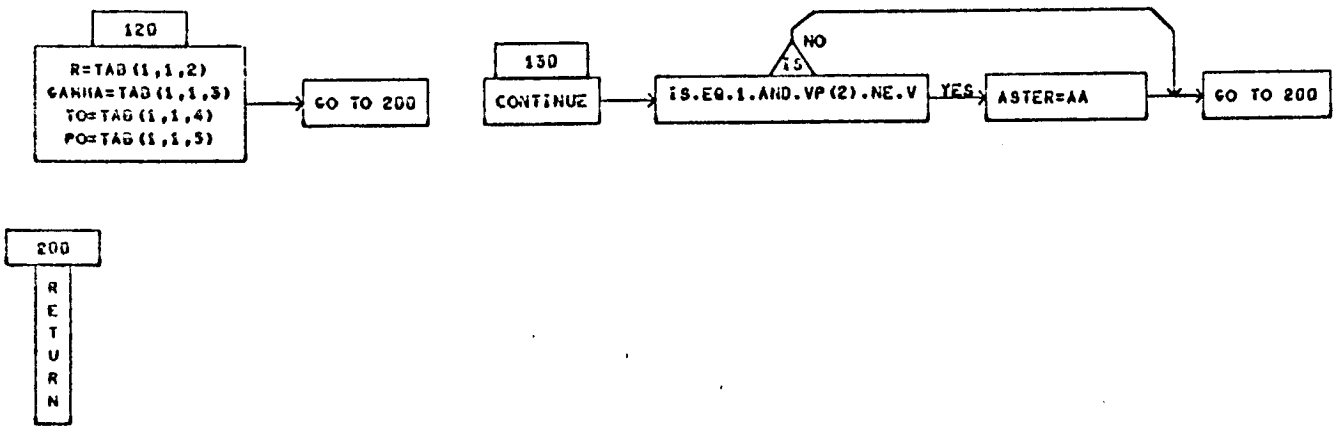
SUBROUTINE TABLE(SS,VV)



SUBROUTINE TABLE(SS,VV)



SUBROUTINE TABLE(SS,VV)



SUBROUTINE NAME: THETPM

DESCRIPTION

This subroutine performs a numerical integration to calculate properties through a Prandtl-Meyer expansion. Either the case of known final velocity or known final expansion angle may be handled.

CALLING SEQUENCE

CALL THETPM (S, DELTA, VF, VI, IT, ITYPE)

where	(S)	is the local entropy level
	(DELTA)	is the total expansion angle
	(VF)	is the final velocity downstream of the expansion
	(VI)	is the initial velocity upstream of the expansion
	(IT)	is a control parameter indicating if expansion to a solid wall or free boundary is taking place
	(ITYPE)	indicates if upper (2) or lower (1) boundary

UTILITY ROUTINES AND COMMON REFERENCES

COMMON/GASCON/
COMMON/STEPC/
TABLE
ITSUB

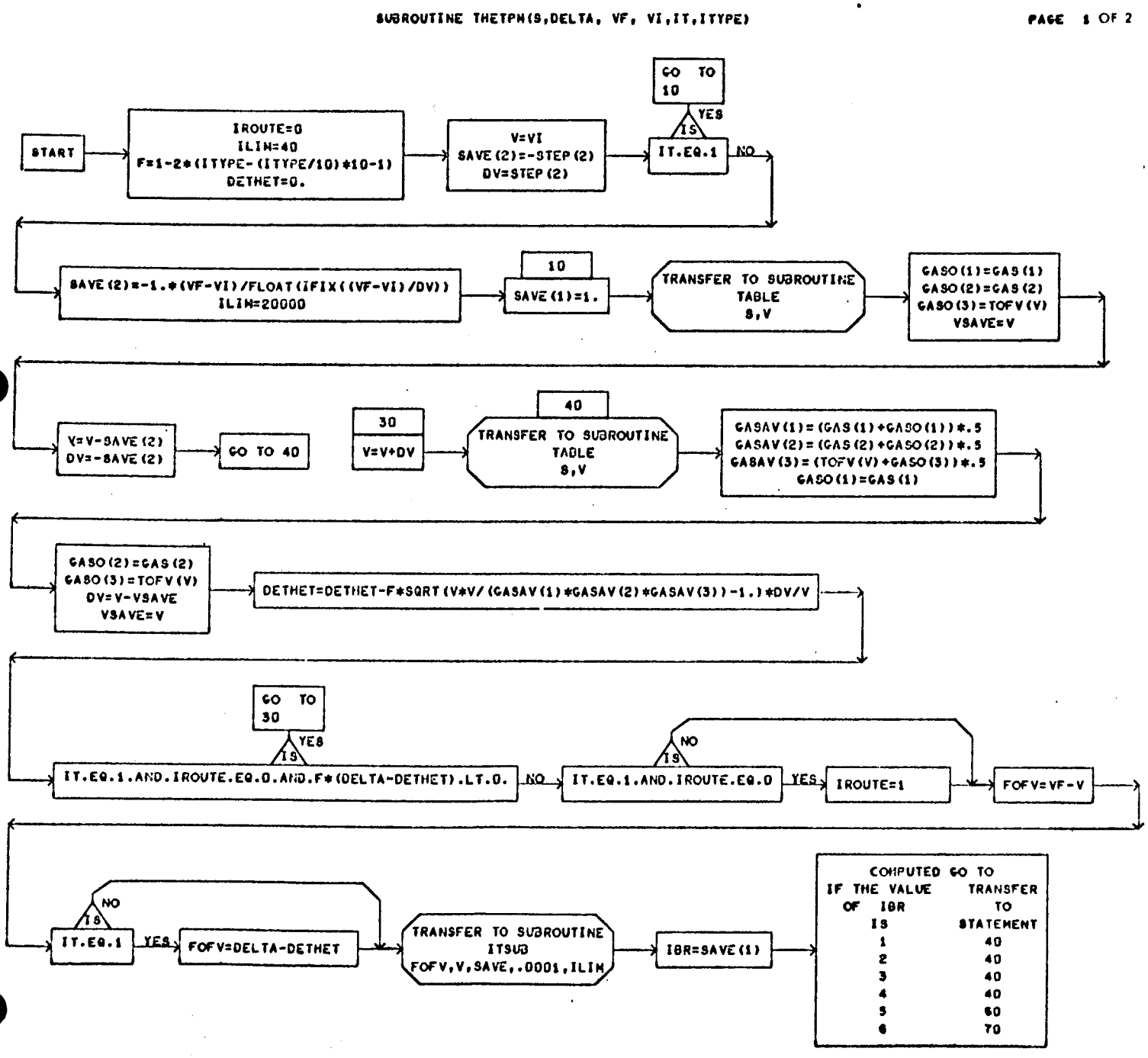
METHOD OF SOLUTION

The integral equation

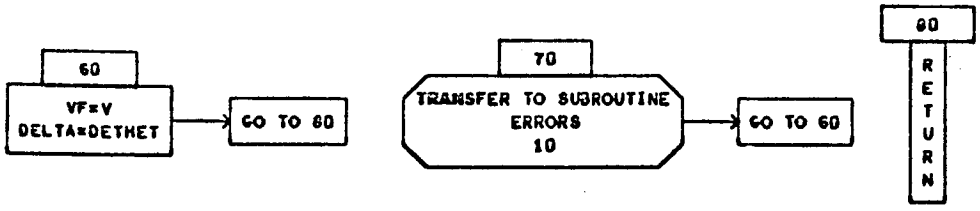
$$\int_{V_1}^{V_F} \sqrt{M^2 - 1}\,\frac{dV}{V} - \Delta\theta = f(V_F) = 0$$

$$(M^2 = V^2/\gamma RT)$$

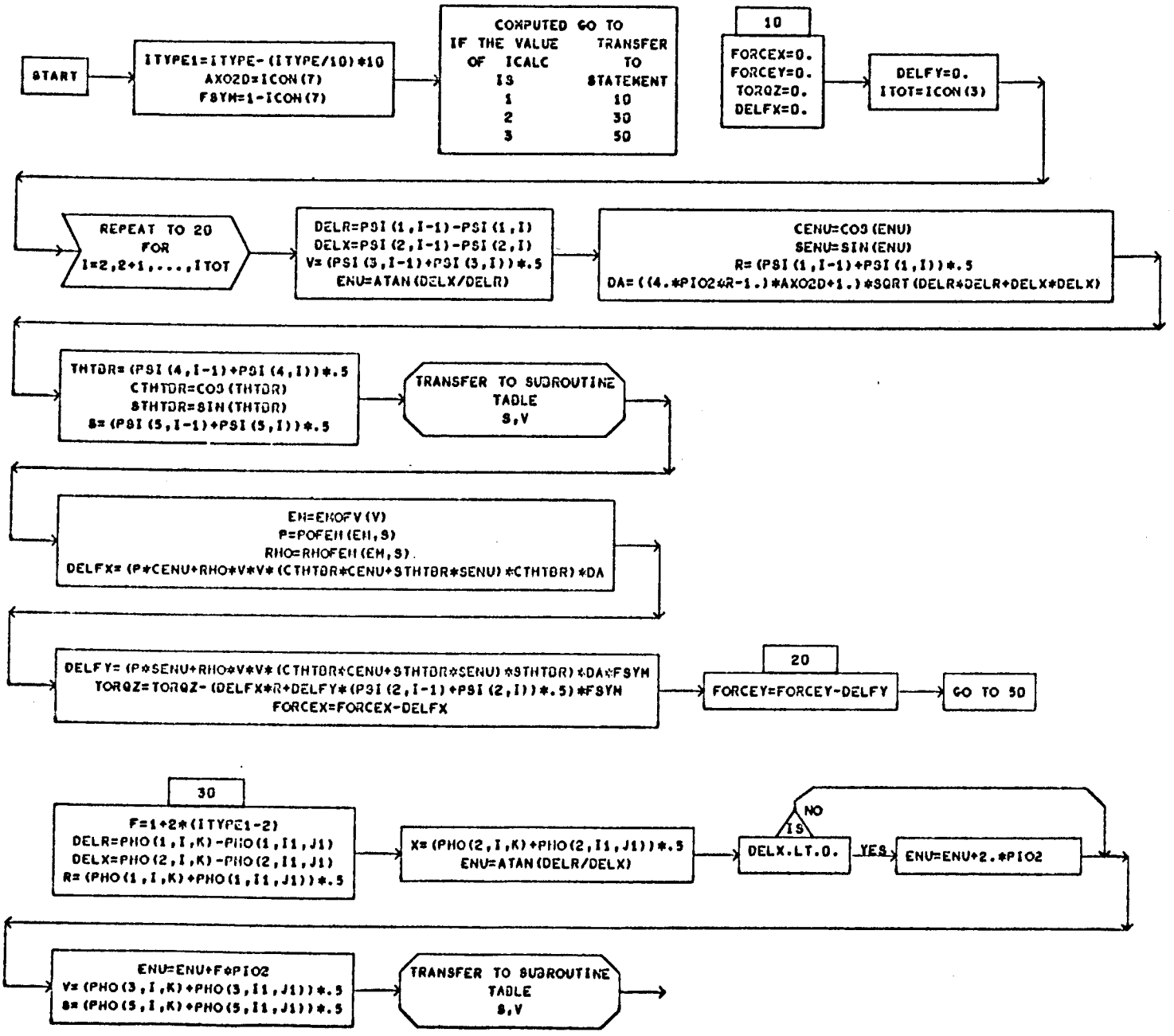
is solved knowing either the final velocity (V_F) or the expansion angle ($\Delta\theta$). As can be seen, if the final velocity (V_F) is known, the integration progresses straightforwardly to a solution. However, if the expansion angle is known, an iterative procedure must be employed to pick the velocity which produces the desired expansion angle.



SUBROUTINE THETPM(S,DELTA, VF, VI,IT,ITYPE)



SUBROUTINE THRUST(I,K,I1,J1,ITYPE,ICALC)



SUBROUTINE NAME: THRUST

DESCRIPTION

This routine computes the vacuum thrust produced by a two-dimensional or axisymmetric nozzle. Addition of the momentum term at the throat and the pressure term computed along the nozzle yields the final thrust.

CALLING SEQUENCE

CALL THRUST (I, K, I1, J1, ITYPE, ICALC)

where (I, K) designates the unknown characteristic point and (I1, J1) is the known characteristic point. (ITYPE) specifies if the point is on the upper or lower boundary and (ICALC) is a counter with the values of 1, 2 or 3. (1 specifies integration at the throat, 2 - along the nozzle and 3 - at the exit.)

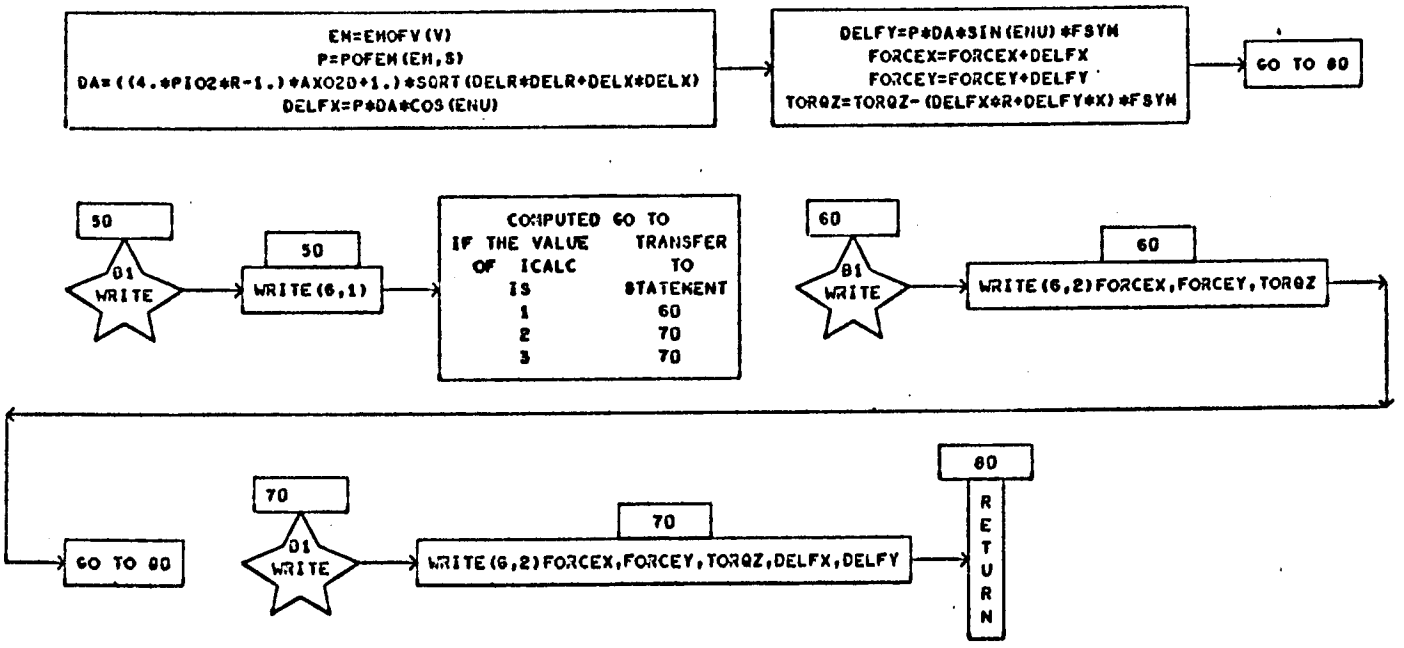
UTILITY ROUTINES AND COMMON REFERENCES

COMMON/CONTRL/
COMMON/DATAR/
COMMON/FORCE/
COMMON/INPUT/
TABLE
EMOFV
POFEM
RHOFEM

METHOD OF SOLUTION

Thrust is found by first computing the momentum thrust in the sonic area or throat of the nozzle. The static pressure is then integrated along the nozzle wall and the total thrust found by summation of the pressure and momentum terms. Inclusion of a factor in the incremental force term accounts for either two-dimensional or axisymmetric flow.

SUBROUTINE THRUST(I,K,I1,J1,ITYPE,ICALC)



FUNCTION NAME: TOFEM

DESCRIPTION

This function computes the local static temperature as a function of Mach number. The gas properties at the point of interest are known prior to entry. TOFEM and TOFV are quite similar; the difference being if Mach number or velocity is the known quantity.

CALLING SEQUENCE

$$T = \text{TOFEM (EM)}$$

where (T) is the one-dimensionally calculated local static pressure which exists at the Mach number (EM).

UTILITY ROUTINES AND COMMON REFERENCES

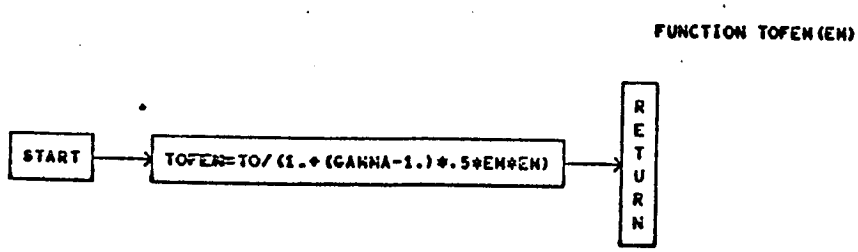
COMMON/GASCON/

METHOD OF SOLUTION

The calorically perfect gas relationship

$$T = \frac{T_o}{1 + \frac{\gamma - 1}{2} M^2}$$

is solved for static temperature at the local Mach number.



FUNCTION NAME: TOFV

DESCRIPTION

This function computes the local static temperature as a function of velocity. The gas properties at the point of interest are known prior to entry. TOFV and TOFEM are quite similar; the difference being if Mach number or velocity is the known variable.

CALLING SEQUENCE

$$T = TOFV\ (V)$$

where (T) is the one-dimensionally calculated local static pressure which exists at the velocity (V).

UTILITY ROUTINES AND COMMON REFERENCES

COMMON/GASCON/

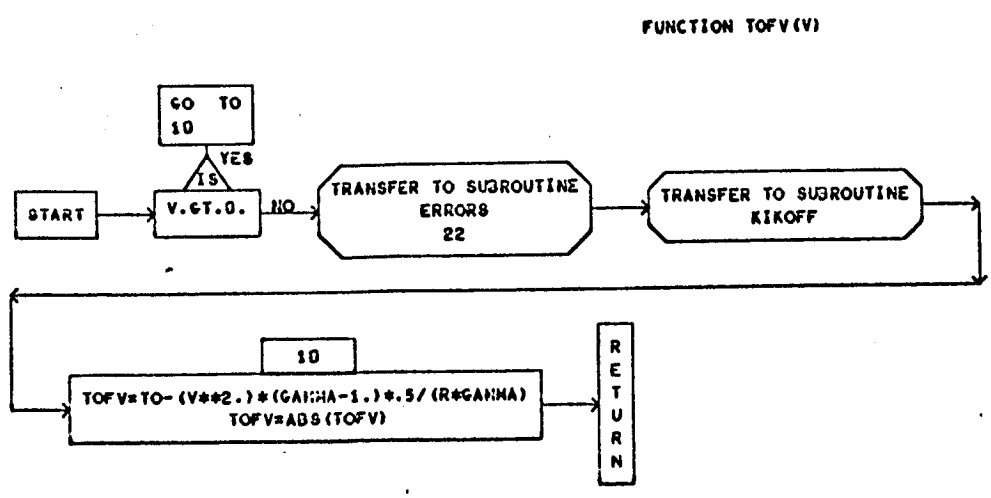
UTILITY - None

METHOD OF SOLUTION

The calorically perfect gas relationship

$$T = T_o - \frac{V^2}{2R}\left(\frac{\gamma - 1}{\gamma}\right)$$

is solved for static temperature at the local velocity.



SUBROUTINE NAME: TURN

DESCRIPTION

This subroutine solves for a shock wave which has a known turning angle (δ). A condition of known turning angle exists when the flow is turned through a compression corner on a solid boundary. Real gas effects are considered in calculating conditions downstream of the shock.

CALLING SEQUENCE

CALL TURN (PU, PD, DELTA, IFLAG)

where (PU, PD) represent flow conditions upstream and downstream of the shock, (DELTA) is the turning angle, and (IFLAG) indicates if the solution will converge or not.

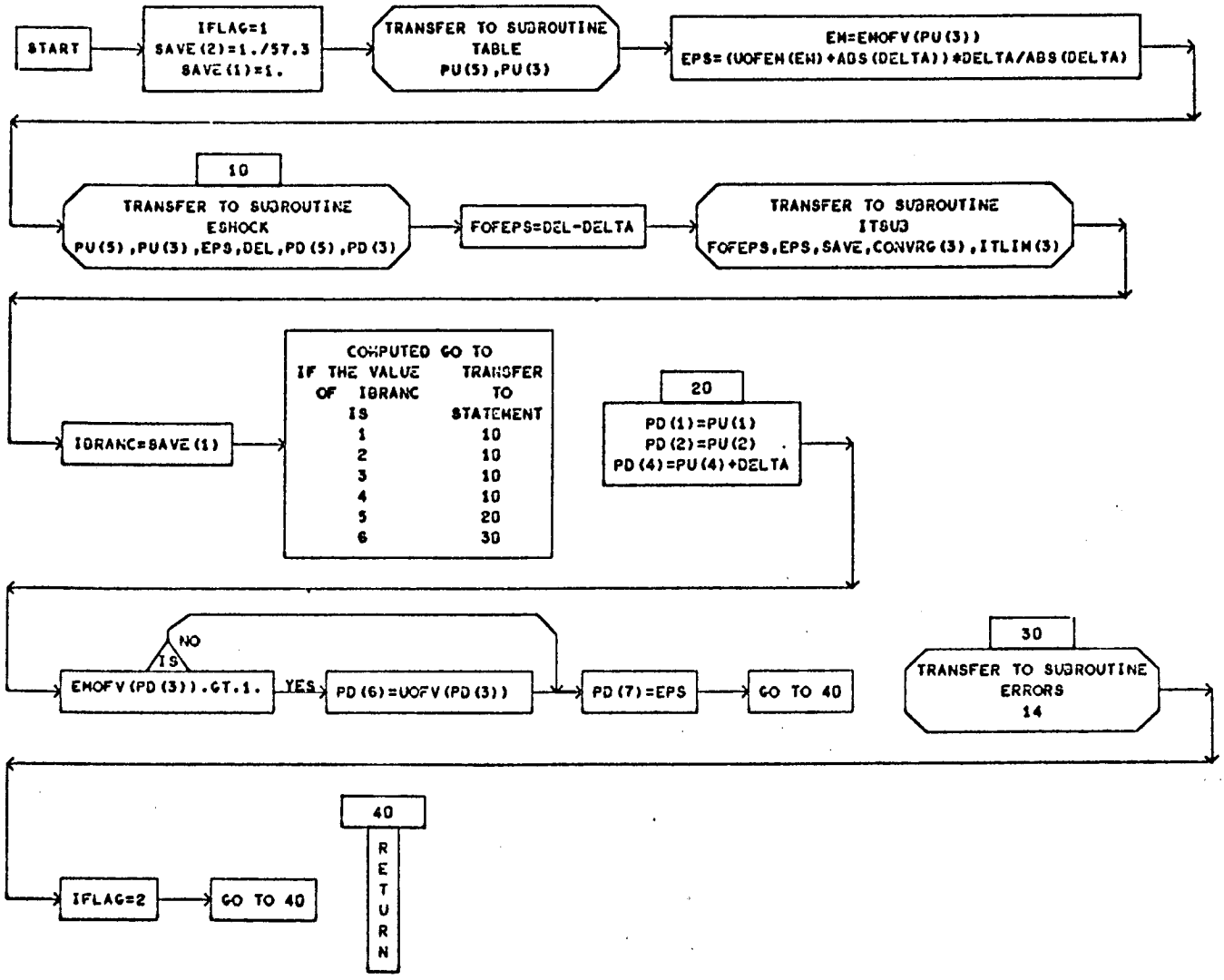
UTILITY ROUTINES AND COMMON REFERENCES

COMMON/CRITER/
TABLE
EMOFV
UOFEM
ESHOCK
ITSUB

METHOD OF SOLUTION

An initial shock angle is guessed. This shock angle is used to calculate a turning angle. The calculated turning angle is compared to the known turning angle and successive iterations on shock angle are performed until the turning angle difference is sufficiently close to zero.

SUBROUTINE TURN(PU,PD,DELTA,IFLAG) PAGE 1



FUNCTION NAME: UOFEM

DESCRIPTION

This function computes the Mach angle at a local Mach number. A test is made to ensure that the Mach number is greater than one; prior to the calculation.

CALLING SEQUENCE

EMU = UOFEM (EM)

where (EMU) is the Mach angle which exists at the local Mach number (EM).

UTILITY ROUTINES AND COMMON REFERENCES

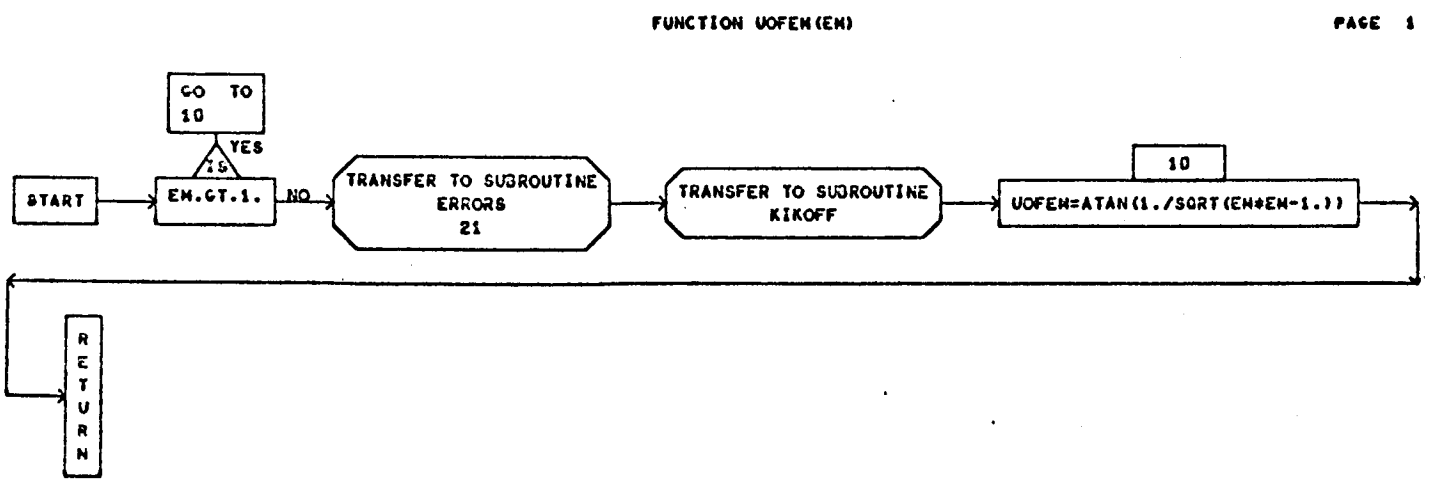
None

METHOD OF SOLUTION

The following equation

$$\mu = \tan^{-1}\left(\frac{1}{\sqrt{M^2 - 1}}\right)$$

is solved for the local Mach angle.



FUNCTION NAME: UOFV

DESCRIPTION

This function computes the Mach angle at a local velocity.

CALLING SEQUENCE

EMU = UOFV (V)

where (EMU) is the Mach angle which exists at the local velocity (V).

UTILITY ROUTINES AND COMMON REFERENCES

COMMON - None

UOFEM

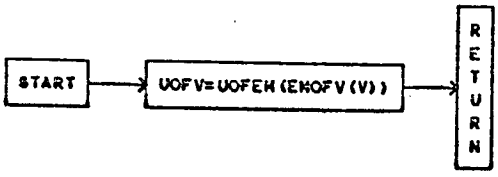
EMOFV

METHOD OF SOLUTION

The local velocity is converted into a Mach number using (EMOFV). Function (UOFEM) is then entered with the calculated Mach number and the Mach angle obtained from the following equation.

$$\mu = \tan^{-1}\left(\frac{1}{\sqrt{M^2 - 1}}\right)$$

FUNCTION UOFV(V)



SUBROUTINE NAME: VISCUS

DESCRIPTION

This subroutine calculates the laminar or turbulent boundary layer thickness and velocity distribution at the nozzle exit. This boundary layer adjustment is made on the exit plane starting line. Only the supersonic portion of the boundary layer is considered.

CALLING SEQUENCE

CALL VISCUS (N, NBL, XL, CU)

where (N) is the power of the velocity profile ($V/V_{edge} = (y/y_{edge})^{1/N}$). (NBL) is number of boundary layer points specified. (XL) is a characteristic length (usually the nozzle length). (CU) is a conversion factor for mixed units of length in the boundary layer calculation.

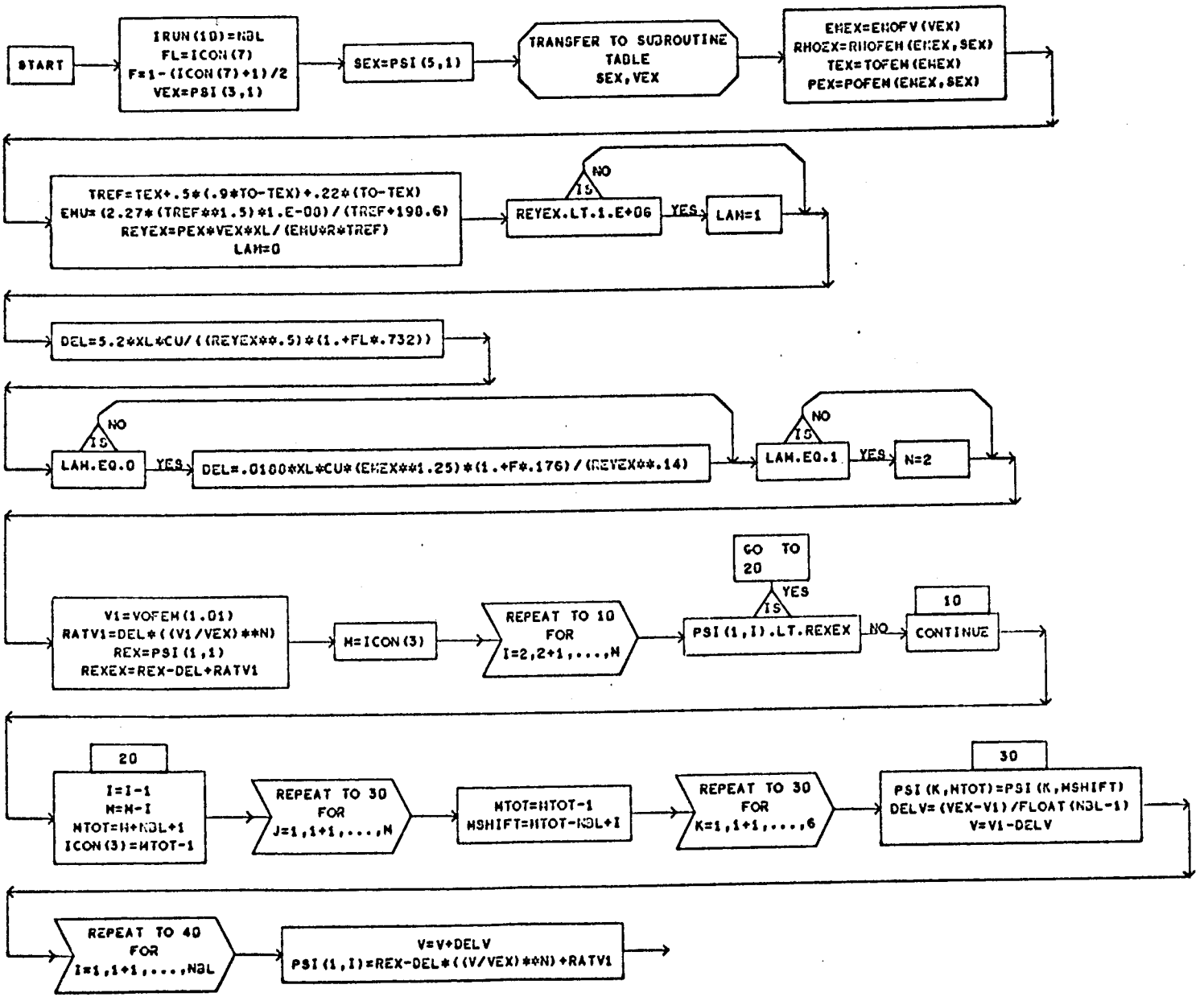
UTILITY ROUTINES AND COMMON REFERENCES

COMMON/INPUT/	EMOFV
COMMON/CONTRL/	TOFEM
COMMON/GASCON/	POFEM
TABLE	VOFEM
	UOFV

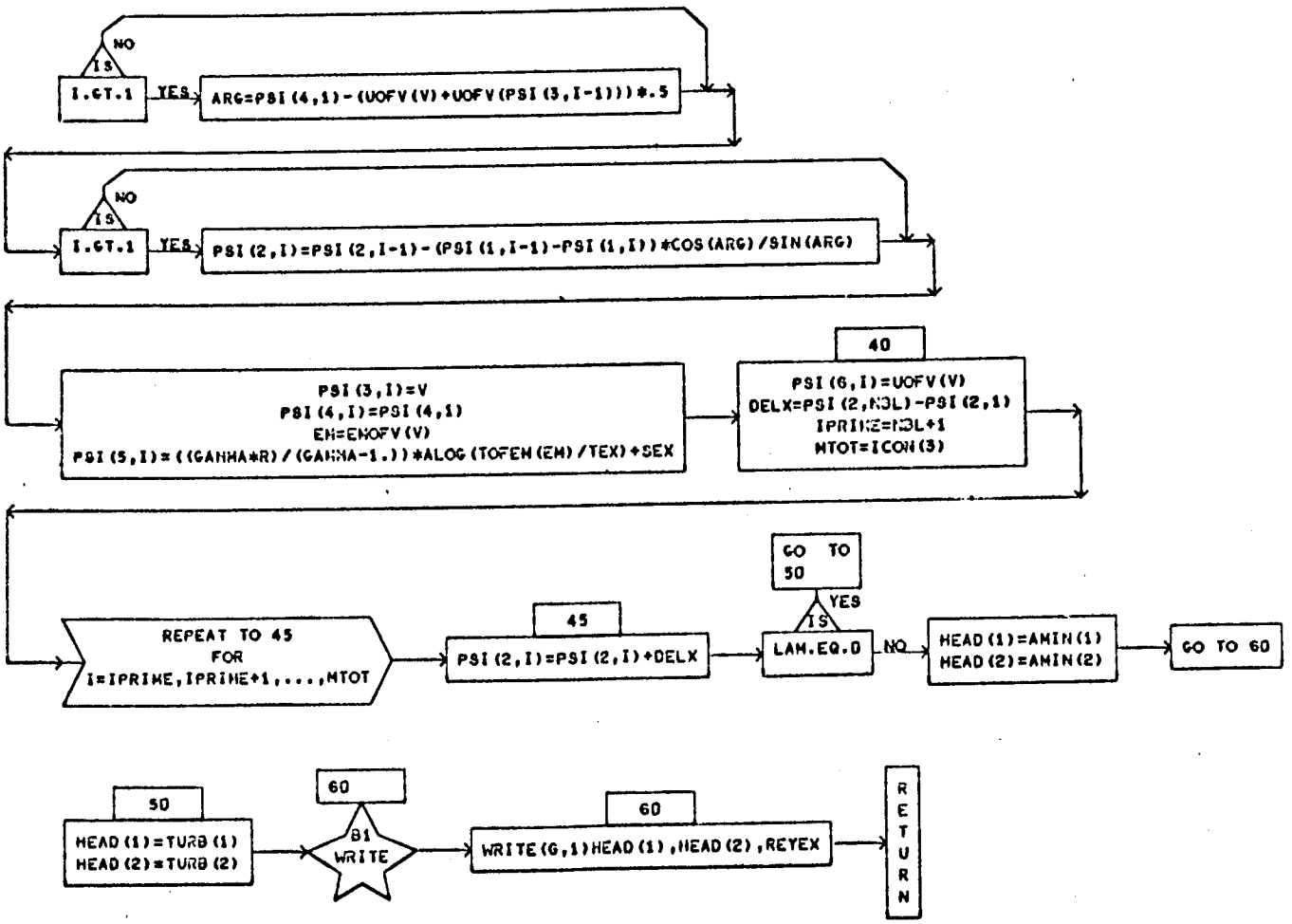
METHOD OF SOLUTION

The number of starting line points within the supersonic portion of the boundary layer is specified. The velocity profile for a laminar or turbulent boundary layer is calculated and distributed to the starting line points. These points are then transferred to a right running characteristic line and the remaining inviscid portion of the starting line is attached.

SUBROUTINE VISCUS(N,NBL,XL,CU)



SUBROUTINE VISCUS(N,NBL,XL,CU)



FUNCTION NAME: VOFEM

DESCRIPTION

This function computes velocity as a function of Mach number. Ideal gas relations are used and the gas properties are known prior to entry.

CALLING SEQUENCE

$$V = \text{VOFEM (EM)}$$

where (V) is the local velocity which corresponds to the local Mach number (EM).

UTILITY ROUTINES AND COMMON REFERENCES

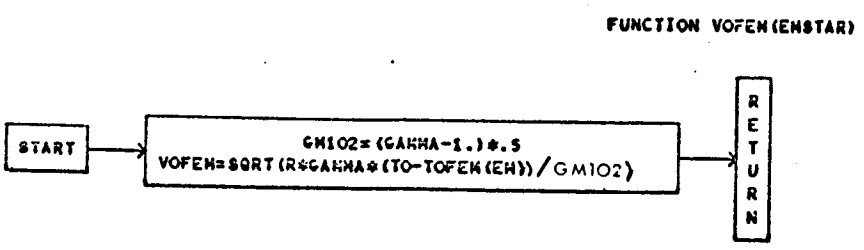
COMMON/GASCON/

METHOD OF SOLUTION

The ideal gas relationship

$$V = \sqrt{\frac{R\gamma(T_o - T)}{\left(\frac{\gamma - 1}{2}\right)}}$$

is solved for velocity. Local static temperature (T) is obtained from the input Mach number.



SUBROUTINE NAME: WEAK

DESCRIPTION

This subroutine determines the independent variables (SD, VD) downstream of a weak oblique shock. The gas properties upstream of the shock are known prior to entry.

CALLING SEQUENCE

CALL WEAK (SU, VU, ERS, DELTA, SD, VD)

where (SU, VU) are the upstream entropy and velocity, (EPS, DELTA) are the shock angle and turning angle, and (SD, VD) are the downstream entropy and velocity.

UTILITY ROUTINES AND COMMON REFERENCES

COMMON/GASCON/
TABLE
EMOFV
POFEM
RHOFEM
ENTROP
DELTAF

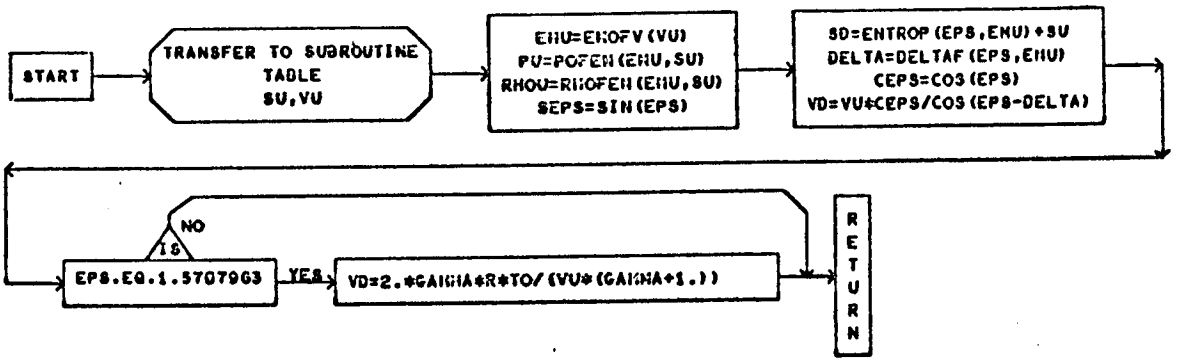
METHOD OF SOLUTION

From the known upstream entropy and velocity, the local gas properties, pressure, density, and upstream Mach number are calculated. The entropy rise across the shock is added to the upstream entropy to get total downstream entropy. Downstream velocity is calculated from the following relationship.

$$V_D = \frac{V_u \cos(\xi)}{\cos(\xi - \delta)}$$

PAGE 1

SUBROUTINEWEAK (SU,VU,EPS,DELTA,SD,VD)



FUNCTION NAME: WOFA

DESCRIPTION

This function computes the weight flow per unit area as a function of Mach number. This calculation is only used in function AOASTR.

CALLING SEQUENCE

WEIGHT FLOW = WOFA (EM)

where (EM) is the local Mach number.

UTILITY ROUTINES AND COMMON REFERENCES

COMMON/GASCON/

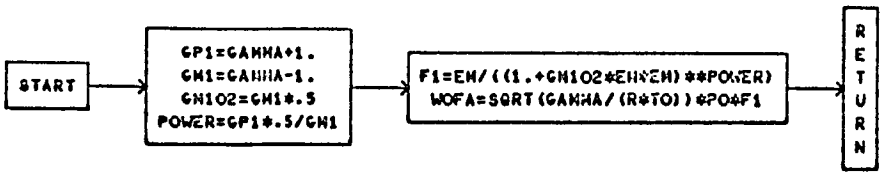
UTILITY - None

METHOD OF SOLUTION

Weight flow per unit area ($\dot{W}/A$) is calculated from ideal gas relations. The equation used is

$$\frac{\dot{W}}{A} = \sqrt{\frac{\gamma}{RT_o}} \left\{ \frac{P_o M}{\left[1 + \frac{\gamma - 1}{2} M^2\right]^{\frac{\gamma+1}{2(\gamma-1)}}} \right\}$$

PAGE 1 FUNCTION WOFA (EM)



		Page
3.4	INPUT/OUTPUT GUIDE	
3.4.1	Detailed Guide for Input Data	3-135
3.4.2	Description of Program Output	3-140

3.4.1 Detailed Guide for Input Data

CARD No. 1		Problem Title or Identification
Format:	12A6	
Cols. 1-72	HOL	Comment card, header information such as problem title may go on this card. It is printed at the top of each page of output.
CARD No. 2	Run Control Card	
Format:	16I5	
Col 5	ICON(1)	1 Read cards for gas properties 2 Read tape 10 (A6) for gas properties
Col 9	ICON(2)	0 Normal start line 1 Right running characteristic start line 2 Left running characteristics start line
Col 10	ICON(2)	0 Straight start line M given 1 Source start line A/A^* given 2 Starting line input 3 Starting line calculated by conservation of mass
Cols 14, 15	ICON(3)	Number of starting line points (50 max)
Cols 19, 20	ICON(4)	Number of upper boundary equations (100max)
Cols 24, 25	ICON(5)	Number of lower boundary equations (100max)
Col 30	ICON(6)	0 No SC-4020 plots N Number of parameters to be plotted
Col 35	ICON(7)	0 Two dimensional solution 1 Axisymmetric solution
Col 39	ICON(8)	0 Full output 1 Limited output (no interior points)
Col 40		1 One line output (R, X, M, THETA, S, Shock Angle) 2 Two lines, above plus (Mach Angle, P, Density, T, V) 3 Three lines, above plus (MWT, GAMMA, TO^*, PO^*, S^*)
Cols 41-43	ICON(9)	No. of left running points up to and including upstream shock point. Used when ICON(2) $\geq$ 20 and shock crosses starting line.
Cols 44-45	ICON(9)	Number of regular start line points if ICON(2) $\geq$ 20
Col 50	ICON(10)	0 Radiance tape not desired 1 Radiance tape desired (1 tape) 2 Radiance tape desired (2 tapes)
Cols 51-55	ICON(11)	Case number (prints at tope of each page)

Col 60	ICON(12)	0 Calculate shock wave 1 No rotation option
Cols 61-65	ICON(13)	1 Use viscous boundary layer
Cols 66-80	ICON(14-16)	Not presently used

CARD(S) No. 3 — Describes physical boundaries of the flow field

Format: I1, 3X, I1, 5X, 6E10.6

Col 1	IWALL	1, Conic equation R=A*(SQRT(B+C*X+D*X**2)+E)
	IWALL	2 Polynomial equation R=A*X**4+B*X**3+C*X**2+D*X+E
	IWALL	3 Free boundary equation P=PINF*(1+EX)*(1+GAMMAINF*(MINF*SIN*(THETAB-THETAINF))**2)
Col 5	ITRANS	0 No discontinuity follows this equation
	ITRANS	1 Expansion corner follows this equation
	ITRANS	2 Compression corner follows this equation
Cols 11-20	WALLCO	A(If IWALL = 1 or 2), PINF (If IWALL=3)
21-30	WALLCO	B(If IWALL = 1 or 2), GAMMAINF (If IWALL=3)
31-40	WALLCO	C(If IWALL = 1 or 2), MINF (If IWALL=3)
41-50	WALLCO	D(If IWALL = 1 or 2), THETAINF (If IWALL=3)
51-60	WALLCO	E(If IWALL = 1 or 2), E (If IWALL=3)
61-70	XMAX	Maximum X value for which this equation applies.

NOTE - The coefficients of each equation are contained on a single card. As many cards, i.e., equations, as necessary to describe the boundaries are input. The units of physical dimensions affect only the thrust calculations in which units of feet are assumed. Upper boundary information is given first. Program assumes that starting line is bounded by solid walls and that the equations are ordered with XMAX monotonically increasing.

CARD No. 4 — Gas Identification and Gas Property Input Control

Format: 4A6, 5X, A3, 7X, I1

Cols 1-24	ALPHA	Gas name, identification for real gas properties on tape. May be any name when gas properties are input via cards.
Cols 30-32	UNITS	ENG English units are to be input (cards only) MKS Metric units (cards or tape)
Col 40	IS	Number of entropy cuts (ignored for tape, 1 for ideal gas, 9 max for real gas via cards).

CARD(S) No. 5		Entropy value and number of velocity cuts. (Not input if ICON(1) = 2, i.e., gas properties via tape)
Format:	E10.6, 8X, 12	
Col 1-10	STAB	Entropy value
Col 19, 20	IVTAB	Number of Mach numbers for this entropy value 13 max, (1 if ideal gas)
CARD(S) No. 6		This card(s) gives the Mach number and associated gas properties at that Mach number and entropy.
Format:	5E10.6	
Cols 1-10	TAB	Mach number
Cols 11-20	TAB	Gas constant (R) if UNITS = ENG, Molecular weight (MWT) If UNITS = MKS.
Cols 21-30	TAB	GAMMA
Cols 31-40	TAB	Static temperature (TO) at this Mach number
Cols 41-50	TAB	Static pressure (TO) at this Mach number

NOTE - Cards 5 and 6 are omitted if gas properties are input via tape.

CARD No. 7		This card specifies the necessary information for the starting line.
Format:	5E10.6	
Cols 1-10	CORLIP	Axial coordinate of upper limit of start line.
Cols 11-20	CORLIP	Axial coordinate of lower limit of start line.
Cols 21-30	CORLIP	Mach number or A/A* for start line.
Cols 31-40	CORLIP	Entropy level of start line.
Cols 41-50	CORLIP	Area of nozzle throat (units consistant with boundary equations)
Cols 61-70	STEP(3)	Point insert criteria
CARDS No. 8		These cards are used to read in a known starting line (ICON(2) = 2), otherwise omitted.
Format:	5E10.6	
Cols 1-10	PSI	Radial coordinate of this point
Cols 11-20	PSI	Axial coordinate of this point
Cols 21-30	PSI	Mach number of this point
Cols 31-40	PSI	Flow angle of this point
Cols 41-50	PSI	Entropy level of this point
Cols 51-60	PSI	Shock angle of downstream shock point when ICON(2) $\geq$ 100

NOTE - As many of these cards are input as specified by ICON(3) on the run control card

CARD No. 9

This card contains the necessary information to limit the calculations to those areas of interest. An unusual scheme is employed in order to make these limits efficient for the many problem orientations which are possible.

Format: 6E10.6

Cols 1-10	CUTDAT	Radial coordinate defining upper cutoff.
Cols 11-20	CUTDAT	Axial coordinate defining upper cutoff.
Cols 21-30	CUTDAT	Angle cutoff line makes with horizontal.
Cols 31-40	CUTDAT	Radial coordinate defining downstream cutoff.
Cols 41-50	CUTDAT	Axial coordinate defining downstream cutoff.
Cols 51-60	CUTDAT	Angle cutoff line makes with horizontal.

CARD No. 10

This card contains the input information for the viscous boundary layer option

Format: I1, 2X, I2, 5X, 2E10.6

Col 1	NPOWER	Exponent of the velocity profile in the boundary layer
Cols 4-5	NBLPTS	Number of boundary layer points specified
Cols 11-20	XL	A characteristic length (usually nozzle length)
Cols 21-30	CU	Conversion factor for mixed units of length

CARD No. 11

This card is used when ICON (10) equals 1 or 2. Its purpose is to "juggle" the method of characteristics output such that gas properties in the flow field can be determined at designated points and saved on binary output tapes.

Format: 9I5

Col 5	LASTC	0 Juggle case other than last or only case
	LASTC	1 Last or only juggle case
Col 10	ISETR	0 Radial value at intersection of juggled axial location and left running characteristic.
	ISETR	1 Use constant radial increments, interpolating between aforementioned intersections.
Col 15	MAXNOR	Maximum number of radial increments (used only if ISETR = 1, maximum number allowable is 100 DELTA RS)
Col 20	ITIME(1)	Number of times first DELTA X is used
	ITIME(2)	Number of times second DELTA X is used
	ITIME(3)	Number of times third DELTA X is used

	ITIME(4)	Number of times fourth DELTA X is used
	ITIME(5)	Number of times fifth DELAT X is used
Col 45	ITIME(6)	Number of times sixth DELTA X is used

NOTE - Up to a maximum of six DELTA X changes are allowed but not always necessary

CARD No. 12 — Continuation of Card No. 10

Format: 7E10.6

Col 1-10	DELT(1)	Length of first DELTA X increment.
Col 11-20	DELT(2)	Length of second DELTA X increment.
Col 21-30	DELT(3)	Length of third DELTA X increment.
Col 31-40	DELT(4)	Length of fourth DELTA X increment.
Col 41-50	DELT(5)	Length of fifth DELTA X increment.
Col 51-60	DELT(6)	Length of sixth DELTA X increment.
Col 61-70	DELTAR	Radial increment used if ISETR = 1

NOTE - Total length of summation of DELTA X must be greater than, or equal to axial cutoff value

CARD No. 13 — Plot control card

Format: 30I2

Col 2	(J)	1 Mach No.
Col 4		2 Press. static
Col 6		3 Temp. static
Col 8		4 Press (stag norm shock)
Col 10		5 GAMMA
Col 12		6 Mole wt
Col 14		7 Density
Col 16		8 Entropy

NOTE - The order of these parameters is arbitrary

NOTE - All units used are ENG. (except entropy) which may be either ENG. or MKS. depending on gas property units. Following is a list of units for specific parameters

PARAMETER	UNITS
X	Thrust calc. assumes ft. Otherwise
R	any scale acceptable
All Angles	Deg.
S	FT**2/SEC**2DEG. R=ENG. CAL/GRAMDEG. K=MKS
Density	LBM/FT**3
T	DEG. R=ENG, DEG. K=MKS
V	FT/SEC
P	PSFA=ENG, ATM=MKS
R	1545.4*32.17/MWT

3.4.2 Description of Program Output

The methods of characteristics program output is organized in a logical fashion with the data presented in an easily understood form. The initial pages consist of a printout of the input data including the real gas tables obtained from the master tape. Characteristic data are organized along left-running characteristic lines with all the pertinent information printed for each characteristic point on each characteristic line. Numbered flags on the example printout sheets (pp. 3-144 through 3-148) correspond to numbered comments listed below.

GROUP I - IDENTIFICATION

(1) Case Number: Appears on each page - may be a maximum of five digits.

(2) Title: Identifies particular run, appears on each page and may be 72 spaces.

GROUP 2 - RUN CONTROL

(3) Run Control Parameters: These 16 parameters control the execution of the program according to the options selected. (See input data guide for explanation of individual parameters.)

GROUP 3 - BOUNDARY EQUATIONS

(4) Type Equation: Identifies type of boundary equation selected. (1 - conic, 2 - poly, 3 - free bound)

(5) Coefficients: Apply to upper or lower boundary equations. (See input guide.)

(6) XMAX: Maximum value of (x) for which present equation applies.

GROUP 4 - GAS IDENTIFICATION

(7) Gas Identification: Identifies gas on master tape for which gas table is printed.

GROUP 5 - REAL/IDEAL GAS PROPERTIES

(8) Reference Entropy: This is lowest entropy level in the table. All other entropy levels are measured from this base.

(9) Entropy Cuts: May be nine maximum, value is relative to predefined base level.

(10) Velocity Cuts: May be 13 maximum at each entropy cut.

(11) "Gas Constant": Local value.

(12) Isentropic Exponent: Local value.

(13) Static Temperature: Local value.

(14) Static Pressure: Local value.

Note: Ideal gas format is similar, (S) and (V) are generally zero and only one value of R, γ, T_o, P_o is printed.

GROUP 6 - STARTING LINE INFORMATION

(15) R: Radial distance to characteristic point (may be any unit of length or non-dimensional).

(16) X: Axial distance to characteristic point. (may be any unit of length or non-dimensional).

Note: The only restriction on units for X and R is that they be consistant, however thrust and mass flow calculations assume feet.

(17) Mach Number: Local value (may be any supersonic value).

(18) Flow Angle: Local value (degrees).

(19) Entropy: Local value (ft^2/sec^2R^o)

Note: The starting line may be obtained using various options (see input guide); however, the format on the printout remains the same.

GROUP 7 - RUN CUTOFF INFORMATION

(20) R: Radial coordinate of upper cutoff (units same as R on starting line).

(21) X: Axial coordinate of upper cutoff (units same as X on starting line).

(22) THETA: Angle of upper cutoff line (degrees).

(23) R: Radial coordinate of lower cutoff.

(24) X: Axial coordinate of lower cutoff.

(25) THETA: Angle of lower cutoff line.

GROUP 8 - TYPICAL LEFT CHARACTERISTIC LINE

(26) Characteristic Line: Identifies line for which data is printed.

(27) Characteristic Point: Identifies point for which data is printed.

(28) Description: Describes the type of point. The options are:

a. input point
b. interior point (prints blank)
c. wall point
d. free boundary point
e. shock point
f. Prandtl-Meyer point

(29) R: Radial distance to the characteristic point.

(30) X: Axial distance to the characteristic point.

(31) M: Mach number at the characteristic point.

(32) Theta: Flow angle at the characteristic point.

(33) Entropy: Entropy level at the characteristic point.

(34) Shock Angle: Shock angle at the characteristic point (only prints when shock point).

(35) Mach angle: Mach angle at the characteristic point.

(36) Pressure: Static pressure at the characteristic point.

(37) Density: Static density at the characteristic point.

(38) Temperature: Static temperature at the characteristic point.

(39) Velocity: Velocity of flow at the characteristic point.

(40) Statements such as this appear when left or right characteristic lines cross. (See Subroutine (ERRORS) for all possible statements.)

(41) This is a comparison to the mass flow through the throat. The percent change should be near zero; any change is an indication of accumulated error in the calculation.

(42) This is a calculation of the components of net momentum thrust and pressure thrust at the particular wall point in the nozzle.

GROUP 1

(1) CASE NO.20001 PAGE 1

(2) EQUILIBRIUM DEMONSTRATION CASE LOX/ALCOHOL

GROUP 2

(3) RUN CONTROL PARAMETERS

ICON(1)	ICON(2)	ICON(3)	ICON(4)	ICON(5)	ICON(6)	ICON(7)	ICON(8)
2	0	20	3	1	0	1	2
ICON(9)	ICON(10)	ICON(11)	ICON(12)	ICON(13)	ICON(14)	ICON(15)	ICON(16)
-0	-0	20001	0	-0	-0	-0	-0

GROUP 3

UPPER BOUNDARY

(4) TYPE	(5) A	(5) B	(5) C	(5) D	(5) E	(6) MAX
1	-.10000+01	.40000+01	-.00000	-.10000+01	-.10440+02	.52071-00
2	-.00000	-.00000	-.00000	.26982-00	.83697+01	.40250+02
3	.19800+04	-.00000	-.00000	-.00000	-.00000	.10000+03

GROUP 3

LOWER BOUNDARY

(4) TYPE	(5) A	(5) B	(5) C	(5) D	(5) E	(6) MAX
2	-.00000	-.00000	-.00000	-.00000	-.00000	.10000+03

PLEASE MOUNT TAPE(S) INDICATED ON OPERATOR INSTRUCTION CARD

GROUP 4

(7) THE FOLLOWING GAS PROPERTIES IN ENGLISH UNITS ARE FOR O2/BOOZE,O/F=1.29,PC=214

THE REFERENCE ENTROPY IS (8) .73914+05

GROUP 5

REAL GAS PROPERTIES

(9) S	(10) V	(11) F	(12) GAMMA	(13) T	(14) P
-.00000					
	.00000	.23161+04	.11481+01	.54095+04	.30816+05
	.36696+04	.22984+04	.11569+01	.50642+04	.17651+05
	.50604+04	.22860+04	.11690+01	.47204+04	.10272+05
	.70255+04	.22729+04	.11973+01	.39384+04	.30816+04
	.82044+04	.22705+04	.12114+01	.32697+04	.10272+04
	.91335+04	.22702+04	.12161+01	.26439+04	.30816+03
	.97674+04	.22701+04	.12138+01	.21761+04	.10272+03
	.10302+05	.22701+04	.12053+01	.17659+04	.30816+02
	.10665+05	.22701+04	.11983+01	.14691+04	.10272+02
	.11021+05	.22690+04	.11999+01	.12037+04	.30816+01
.92457+03					
	.00000	.23213+04	.11446+01	.53668+04	.21600+05
	.36562+04	.23023+04	.11528+01	.50362+04	.12389+05
	.50499+04	.22885+04	.11649+01	.47039+04	.72000+04
	.70164+04	.22734+04	.11953+01	.39389+04	.21600+04
	.81975+04	.22705+04	.12109+01	.32735+04	.72000+03
	.91285+04	.22702+04	.12161+01	.26474+04	.21600+03
	.97635+04	.22701+04	.12138+01	.21790+04	.72000+02
	.10299+05	.22701+04	.12053+01	.17682+04	.21600+02
	.10663+05	.22701+04	.11983+01	.14709+04	.72000+01
	.11019+05	.22696+04	.12029+01	.12043+04	.21600+01
.17671+04					
	.00000	.23276+04	.11406+01	.53155+04	.14400+05
	.36599+04	.23071+04	.11482+01	.50012+04	.82735+04
	.50371+04	.22917+04	.11601+01	.46824+04	.48000+04
	.70049+04	.22742+04	.11926+01	.39388+04	.14400+04
	.81868+04	.22706+04	.12103+01	.32782+04	.48000+03

GROUP 5

(Continued)

CASE NO.20001 PAGE 2

EQUILIBRIUM DEMONSTRATION CASE LOX/ALCOHOL

REAL GAS PROPERTIES

S	V	P	GAMMA	T	P
.17671+04					
	.91221+04	.22702+04	.12160+01	.26520+04	.14400+03
	.97587+04	.22701+04	.12138+01	.21627+04	.48000+02
	.10295+05	.22701+04	.12154+01	.17712+04	.14400+02
	.10580+05	.22701+04	.11984+01	.14733+04	.48000+01
	.11016+05	.22699+04	.12046+01	.12058+04	.14400+01
.33851+04					
	.00000	.23390+04	.11342+01	.52222+04	.72000+04
	.36106+04	.23161+04	.11406+01	.49346+04	.41481+04
	.50123+04	.22980+04	.11515+01	.46394+04	.24000+04
	.69822+04	.22759+04	.11968+01	.39372+04	.72000+03
	.81714+04	.22709+04	.12088+01	.32674+04	.24000+03
	.91094+04	.22702+04	.12159+01	.26609+04	.72000+02
	.97468+04	.22701+04	.12139+01	.21901+04	.24000+02
	.10268+05	.22701+04	.12056+01	.17770+04	.72000+01
	.10674+05	.22701+04	.11984+01	.14780+04	.24000+01
	.11012+05	.22701+04	.12053+01	.12094+04	.72000-00
.45828+04					
	.00000	.23479+04	.11298+01	.51498+04	.43200+04
	.35880+04	.23235+04	.11352+01	.48806+04	.24936+04
	.49921+04	.23034+04	.11452+01	.46025+04	.14400+04
	.69629+04	.22775+04	[illegible]	.39341+04	.43200+03
	.81565+04	.22711+04	.12073+01	.32949+04	.14400+03
	.90984+04	.22702+04	.12157+01	.26687+04	.43200+02
	.97404+04	.22701+04	.12140+01	.21965+04	.14400+02
	.10261+05	.22701+04	.12057+01	.17620+04	.43200+01
	.10669+05	.22701+04	.11985+01	.14820+04	.14400+01
	.11007+05	.22701+04	.12052+01	.12128+04	.43200-00
.71743+04					
	.00000	.23680+04	.11212+01	.49873+04	.14400+04
	.35376+04	.23406+04	.11248+01	.47532+04	.83436+03
	.49439+04	.23170+04	.11324+01	.45096+04	.48000+03
	.69145+04	.22825+04	.11680+01	.39191+04	.14400+03
	.81160+04	.22719+04	.12024+01	.33125+04	.48000+02
	.90700+04	.22702+04	.12152+01	.26885+04	.14400+02
	.97166+04	.22701+04	.12142+01	.22130+04	.48000+01
	.10265+05	.22701+04	.12061+01	.17949+04	.14400+01
	.10655+05	.22701+04	.11986+01	.14925+04	.48000-00
	.10997+05	.22701+04	.12046+01	.12215+04	.14400-00
.88209+04					
	.00000	.23811+04	.11164+01	.48620+04	.72000+03
	.35051+04	.23525+04	.11190+01	.46670+04	.41807+03
	.49108+04	.23267+04	.11252+01	.44429+04	.24000+03
	.68791+04	.22869+04	.11580+01	.39021+04	.72000+02
	.80890+04	.22726+04	.11977+01	.33236+04	.24000+02
	.90465+04	.22703+04	.12147+01	.27033+04	.72000+01
	.97021+04	.22701+04	.12143+01	.22255+04	.24000+01
	.10252+05	.22701+04	.12063+01	.18048+04	.72000-00
	.10645+05	.22701+04	.11987+01	.15004+04	.24000-00

CASE NO.20001 PAGE 3

EQUILIBRIUM DEMONSTRATION CASE LOX/ALCOHOL

GROUP 5 (Concluded)

REAL GAS PROPERTIES

S	V	R	GAMMA	I	P
.88209+04	.10989+05	.22701+04	.12041+01	.12281+04	.72000-01

STARTING LINE

GROUP 6

(15) U	(16) X	(17) M	(18) THETA	(19) S
.84400+01	-.00000	.10100+01	-.00000	-.00000
.84112+01	.00000	.10100+01	.00000	-.00000
.83249+01	.00000	.10100+01	.00000	-.00000
.81817+01	.00000	.10100+01	.00000	-.00000
.79827+01	.00000	.10100+01	.00000	-.00000
.77291+01	.00000	.10100+01	.00000	-.00000
.74228+01	.00000	.10100+01	.00000	-.00000
.70657+01	.00000	.10100+01	.00000	-.00000
.66603+01	.00000	.10100+01	.00000	-.00000
.62095+01	.00000	.10100+01	.00000	-.00000
.57164+01	.00000	.10100+01	.00000	-.00000
.51840+01	.00000	.10100+01	.00000	-.00000
.46162+01	.00000	.10100+01	.00000	-.00000
.40170+01	.00000	.10100+01	.00000	-.00000
.33903+01	.00000	.10100+01	.00000	-.00000
.27405+01	.00000	.10100+01	.00000	-.00000
.20719+01	.00000	.10100+01	.00000	-.00000
.13892+01	.00000	.10100+01	.00000	-.00000
.69697-00	.00000	.10100+01	.00000	-.00000
.12655-05	.00000	.10100+01	.00000	-.00000

GROUP 7

RUN CUTOFF INFORMATION

(20)	(21) UPPER BOUNDARY			(22)	(23) LOWER BOUNDARY			(24)
R=	.30000+02	X=	-.10000+01	THETA=	.00000	R=	-.30000+02	X=	.10000+03	THETA=	.90000+02

CASE NO.20001

EQUILIBRIUM DEMONSTRATION CASE LOX/ALCOHOL

(26) LINE	(27) POINT	(28) DESCRIPTION	(29) F / (35) MACH ANGLE	(30) X / (36) PRESSURE	(31) M / (37) DENSITY	(32) THETA / (38) TEMPERATURE	(33) ENTROPY / (39) VELOCITY	(34) SHOCK ANGLE
50	1	WALL	-.00000	.26265+02	.24207+01	-.00000	-.00000	
			.24400+02	.18645+04	.22691-03	.36171+04	.76150+04	
50	2		.71551-01	.26422+02	.24170+01	-.61641-01	.00000	
			.24440+02	.18774+04	.22822-03	.36213+04	.76075+04	
50	3		.14735-00	.26591+02	.23982+01	-.49589-00	.00000	
			.24644+02	.19443+04	.23493-03	.36429+04	.75695+04	
50	4		.23438-00	.26784+02	.23965+01	-.35610-00	.00000	
			.24663+02	.19505+04	.23556-03	.36448+04	.75660+04	
50	5		.32709-00	.26989+02	.23953+01	-.28871-00	.00000	
			.24676+02	.19548+04	.23600-03	.36462+04	.75635+04	
50	6		.42427-00	.27203+02	.23948+01	-.23571-00	.00000	
			.24681+02	.19565+04	.23616-03	.36467+04	.75626+04	
50	7		.52473-00	.27424+02	.23951+01	-.18088-00	.00000	
			.24678+02	.19554+04	.23605-03	.36464+04	.75632+04	
50	8		.62721-00	.27648+02	.23961+01	-.12078+00	.00000	
			.24667+02	.19518+04	.23569-03	.36452+04	.75652+04	
50	9		.73048-00	.27874+02	.23977+01	-.55088-01	.00000	
			.24650+02	.19462+04	.23513-03	.36435+04	.75684+04	
50	10		.83321-00	.28098+02	.23997+01	.14968-01	.00000	
			.24628+02	.19369+04	.23440-03	.36412+04	.75725+04	
50	11		.93412-00	.28318+02	.24020+01	.88006-01	.00000	
			.24602+02	.19304+04	.23355-03	.36385+04	.75773+04	
50	12		.10317+01	.28530+02	.24046+01	.16184-00	.00000	
			.24574+02	.19212+04	.23262-03	.36355+04	.75825+04	
50	13		.11248+01	.28732+02	.24073+01	.23499-00	.00000	
			.24545+02	.19116+04	.23166-03	.36324+04	.75879+04	
50	14		.12118+01	.28920+02	.24100+01	.30551-00	.00000	
			.24515+02	.19021+04	.23070-03	.36293+04	.75934+04	
50	15		.12912+01	.29092+02	.24126+01	.37153-00	.00000	
			.24487+02	.18928+04	.22977-03	.36264+04	.75987+04	
50	16		.13618+01	.29244+02	.24150+01	.43163-00	.00000	
			.24461+02	.18843+04	.22891-03	.36236+04	.76036+04	
50	17		.14219+01	.29374+02	.24172+01	.48360-00	.00000	
			.24438+02	.18768+04	.22816-03	.36211+04	.76079+04	

LMSC/HREC A783573

CASE NO.20001 PAGE 135

EQUILIBRIUM DEMONSTRATION CASE LOX/ALCOHOL

LINE	POINT	DESCRIPTION	R MACH ANGLE	X PRESSURE	M DENSITY	THETA TEMPERATURE	ENTROPY VELOCITY	SHOCK ANGLE
50	18		.14704+01 .24[illegible]+02	.29478+02 .18797+04	.24189+[illegible] .22753-03	.52502-00 .36191+04	.00000 .76114+04	
50	19		.15059+01 .24405+02	.29554+02 .18661+04	.24203+01 .22757-03	.55734-00 .36176+04	.00000 .76141+04	
50	20		.15276+01 .24396+02	.29601+02 .18632+04	.24211+01 .22678-03	.57658-00 .36167+04	.00000 .76157+04	
50	21		.15350+01 .24393+02	.29617+02 .18623+04	.24214+01 .22669-03	.58330-00 .36164+04	.00000 .76163+04	
50	22		.31594+01 .23659+02	.33046+02 .16320+04	.24919+01 .20317-03	.20518+01 .35364+04	.00000 .77560+04	
50	23		.54634+01 .22593+02	.37721+02 .13234+04	.26024+01 .17074-03	.41687+01 .34131+04	.00000 .79665+04	
50	24		.81849+01 .21475+02	.42982+02 .10359+04	.27315+01 .13934-03	.64722+01 .32743+04	.00000 .81967+04	

(40) ILLEGAL CROSSING OF LEFT RUNNING CHARACTERISTICS RUN IS CONTINUED WITH REMAINDER OF LINE DELETED.

50	24		.81821+01 .21433+02	.42992+02 .10259+04	.27366+[illegible] .13922-03	.63184+01 .32689+04	.00000 .82056+04	
50	25		.11476+02 .20294+02	.49066+02 .78066+03	.28832+01 .11038-03	.87302+01 .31151+04	.00000 .84434+04	
50	26	UPSTREAM SHOCK	.14345+02 .19507+02	.54164+02 .63383+03	.29947+01 .92978-04	.10415+02 .30026+04	.00000 .86131+04	
50	27	DOWNSTREAM	.14345+02 .24571+02	.54164+02 .17944+04	.24049+01 .20639-03	-.59066+01 .36351+04	.27347+03 .75818+04	-.32105+02
50	28		.14630+02 .24784+02	.55015+02 .17755+04	.23855+01 .21368-03	-.64848+01 .36573+04	.26238+03 .75424+04	
50	29		.16469+02 .25425+02	.60699+02 .20409+04	.23292+01 .24130-03	-.78703+01 .37224+04	.18193+03 .74259+04	
50	30		.17354+02 .25174+02	.63437+02 .19937+04	.23509+01 .23734-03	-.69030+01 .36973+04	.14367+03 .74714+04	
50	31	FREE BOUNDARY	.17368+02 .25130+02	.63480+02 .19799+04	.23548+01 .23598-03	-.67679+01 .36928+04	.14308+03 .74795+04	

(41) THE PERCENT CHANGE IN MASS FLOW IS = -.124215+01

(42) PRESSURE INTEGRATION RESULTS

FORCEX	FORCEY	TORQZ	DELFX	DELFY
-.11158+[illegible]	.00000	-.00000	.00000	.00000