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PROJECT TECHNICAL REPORT

STEADY-STATE ATTITUDE CONTROL PROPULSION SYSTEMS COMPUTER PROGRAM DOCUMENTATION AND USER'S MANUAL
VOLUME I
MSC/TRW TASK 705-1

NAS 9-8166

June, 1971

Prepared for
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MANNED SPACECRAFT CENTER
HOUSTON, TEXAS

OFFICE OF PRIME RESPONSIBILITY

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TRW
SYSTEMS GROUP

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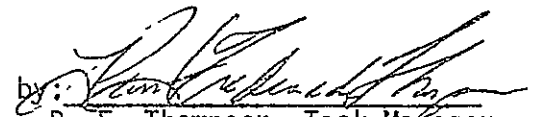NAS 9-8166   June, 1971

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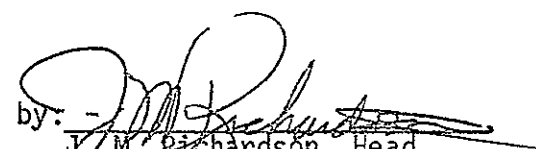Prepared by
P. F. Thompson
R. C. Turley
Propulsion Systems Section
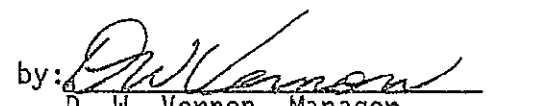Chemical and Mechanical Systems Section

Approved by: _____
P. F. Thompson, Task Manager
MSC/TRW Task 705-1

Approved by: _____
J. M. Richardson, Head
Propulsion Systems Section

Approved by: _____
D. W. Vernon, Manager
Chemical and Mechanical
Systems Department

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TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

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SUBROUTINE FLOW CHARTS

FIGURES

1.0 INTRODUCTION

The purpose of this document is to provide the user with a manual containing all information necessary to operate the Steady-State Attitude Control Propulsion System Computer Program (SSACPS). The SSACPS was developed as a general computer simulation model capable of modeling a large variety of attitude control propulsion systems (ACPS). This model has been developed under MSC/TRW Task 705-1 along with the ACPS Transient Computer Program.

The SSACPS was developed with the capability to simulate operation of ACPS components connected in a large variety of configurations. The components are connected within the program by the user, using data required to define initial and operating conditions. The component models consist of gas generators, combustors (monopropellant and bi-propellant), lines (adiabatic, isothermal, and heat transfer with friction-liquid/gas), heat exchangers, junctions, regulators, pressure boundaries, and liquid and gas valves. The system model uses hydrogen and oxygen properties from detailed NBS property subroutines. The data are input through the numerical input subroutine TRWLOD and the system equations are solved by the nonlinear equation solver, TRW BEGS. The constraint equations for each component set and the state variables are selected by the user. This allows a great deal of flexibility in solving for either fluid state points or component dimensions.

This document is comprised of two volumes and is to be used as a supplement to the Engineer's Manual, (Reference 1). Volume I contains the user's and programmer's information and Volume II (Reference 2) contains a copy of the program listing. Reference 1 contains more detailed information on each component model. The SSACPS was developed for use on MSC's UNIVAC 1108 computer.

1

2.0 PROGRAM DESCRIPTION

2.1 Program Definition

The SSACPS is a flexible steady-state attitude control propulsion simulation computer program. The program consists of engineering equations simulating the fluid states using properties of hydrogen and oxygen. The combustor gases are modeled using curve fit data. ACPS components are available for combination in any type of ACPS simulation.

The SSACPS program is stored on a PCF tape which contains the entire program. The program includes subroutines which model individual components, thermodynamic property data, a nonlinear equation solver, and a set of driver subroutines.

TRWLOD (card input) input is used to enter the component data and system configuration. TRWLOD is described in Section 4.8 and the description of the card inputs is presented in Section 3.1.3.

2.2 Method of Solution

The theory and mathematical derivations for this program are described in Reference 1.

3.0 USERS INFORMATION

The following sections present detailed descriptions of the types of input data and its format.

3.1 Input Description

3.1.1 Solution of Nonlinear Equations: Input

For normal usage IFIN=0. IFIN≠0 means that the finishing procedure only is to be executed. The purpose of this procedure is to examine the function F in a neighborhood of a given point X_o, where, presumably, $F(X_o)$ is a minimum. This is accomplished by perturbing each component of X_o by plus and minus small amounts, evaluating the corresponding functions, and printing all information as output via the system output tape. The routine was designed such that BEGS may be called with IFIN=0, and then immediately called again with IFIN≠0 without changing any other parameters. This procedure allows the user to test the solution just obtained.

The parameters are defined in Section 3.1.1 for the normal usage option (IFIN=0), and in Section 3.1.2 for the finishing procedure. For either option the parameters H, BØUNDS, JVECTR, and EPSLIN may be zero upon entry; "reasonable" values will then be substituted by the program.

Printout of information concerning any difficulties encountered by the program in solving the equations can be obtained by setting EPSLIN<0.

3.1.1.1 Solution Normal Usage (IFIN=0)

STATE   = State variables X_λ ($X_1...X_m$) used in non linear equation solver; first value input is the name of the variable, second and third values are the location of the variables, and the fourth value is the users starting guess. (State output is the program solution)

5

·Example:

        STATE = WDØTG, 1,1,5.,AREAT,1,1,.3
        flowrate WDØTG, line 1, node 1, 1st guess
        5.1bm/sec, area throat, combustor 1, Dummy
        value 1, 1st guess.3 square inches.

The following list presents the state variables used in the non-linear

equation solver:

WDOTG(II,JJ)	Flowrate, Line II, node JJ	lbm/sec
MACH(II,JJ)	Mach number, line II, node JJ	~
PG(II,JJ)	Pressure, line II, node JJ	lbm/in^2
XK(I)	Area of value I times discharge coefficient	in^2
PRE(I)	Discharge pressure of regulation I	lbm/in^2
DIALI(II)	Diameter, line II	in^2
TTEMP(II,JJ)	Temperature, line II, node JJ	deg-R
TTTEMP(II,JJ)	Total temperature, line II, node JJ	deg-R
PGPBL(I)	Pressure at Pressure Boundary I	lbm/in^2
ARINJ(I,II)	Area Injector, Combustor I, line II	in^2
PCI(I)	Combustor (I), Chamber pressure	lbm/in^2
AREAT(I)	Area throat Combustor I	$·in^2$
THRT(I)	Thrust Combustor I	lbf
PDELP(I)	Pressure rise through turbopump (I)	psia
LENGTH(I)	Length heat exchange tubes	in
RI(I)	Inner radius of concentric heat exchanger tubes	in
RØ(I)	Outer radius of concentric heat exchanger tubes	in
HR(I)	Hydraulic radius	in
P(I)	Accumulator Pressure	lbm/in^2
H	$(h_1,...,h_M)$ [input] is a vector of perturbations on X for the initial function evaluations. If $h_i = 0$, then $h_i = .01(x_i)$ will be automatically substituted; if $x_i = 0$, $h_i = .001$ will be substituted instead. H [output] is set to $(0,0,...,0)$.	

6

IBNDS	[input] is zero if the solution to the linear least squares solution by (LEGS) is to be unconstrained.
	IBNDS is nonzero if the least square solution is to be constrained by the use of BØUNDS (described below). The recommended usage here is IBNDS≠0, for the routine will evaluate BØUNDS and if too small, will increase its values to a size where they have no effect.
BØUNDS	$(b_1,...,b_M)$ [input] is the vector of constraints for bounding the least squares solution (IBNDS). If any $b_i=0$, then $b_i=10$ will be automatically substituted.
BØUNDS	[output] is set to $(0,0,...,0)$.
M	[input] is the number of variables.
N	[input] is the number of functions.
MAXIT	[input] is the maximum number of iterations allowable.
IDER	[input] is zero for the secant method. IDER is nonzero if the user computes the matrix of partial derivatives in Component Subroutines.
JVECTR	$(j_1,...,j_M)$ [input] is a vector of integers, which allow the user to hold fixed a particular combination of the variables. If $j_i≠0$, x_i will be disregarded in the iterative procedure, but will be present as input to FCØMP. If $j_i=0$, x_i is taken to be a true variable and is solved for.
EPSLN	[input] is a convergence test. The routine will exit if the following test is passed:

$$|\Delta\, x_i\,| \;<\; \varepsilon|\,x_i\,|\;,\; i = 1,M$$

$$\text{where } \varepsilon = \begin{cases} |\,\text{EPSLN}\,| & \text{if EPSLN} \neq 0 \\ 10^{-5} & \text{if EPSLN} = 0 \end{cases}$$

	Here $\Delta\, x_i$ is the newly computed correction to the current i-th component of the iterant. If EPSLN < 0 a message is printed out to indicate an unsuccessful secant iteration. See Step E in the Appendix.
BLØCK	is a FORTRAN vector used for temporary storage. The DIMENSION of this vector must be at least $(3M + 4)\,(M + 1) + N\,(2M + 1)$.
ITERS	[output] the magnitude of ITERS is the actual number of iterations completed before returning to the calling program. If ITERS = MAXIT, the "solution" should be regarded with suspicion. If ITERS is negative, iteration was terminated due to inability to find suitable function values.

7

CONSTRAINTS/F $(f_1,\ldots,f_N)$ [output] is $F(X)$ such that $||F||^2$ is a minimum.

FNØRM   [output] is the sum of the squares of f_i.

                 NOTE: If the process didn't converge, X and F correspond to the smallest value that was obtained for FNØRM.

3.1.1.2 Solution Using Finishing Technique (IFIN $\neq$ 0)

STATE   [output] is a trial solution to be tested by the finishing procedure. , If the perturbed state variable produces the best solution, the perturbed variable is used as the state variable for the next pass. If no better solution was found the original state variable is used.

H   [input] is a vector of small perturbations. If $h_i = 0$, then the value x_i will be substituted (see EPSLN, Section A.

                 H [output] = $(0,0,\ldots,0)$.

M   See Section 3.1.1

N   See Section 3.1.1

JVECTR   See Section 3.1.1 (one may bypass perturbing any of the variables).

EPSLN   See H [input2 above.

F   [output] is $F(X)$

FNØRM   is $||F||^2$

3.1.2 General Input

The SSACPS input is used in a way which defines the selected system. Each component is defined in the SYSCOM array. This array defines the order in which the program calculations will proceed. For example, calling SYSCOM=TANK,1, PIPLL,4, PBL,3 would set up an ordered three-component connection of a tank, liquid line and a constant pressure boundary. Each component must have all of the inlet connections defined by input prior to calling the component in the array SYSCOM. For example, before calling combustor 1, the following system setup must be set by input: SYSTEM =

PIPL,1, PIPL,2, CHAM,1. This represents the connection of pipes 1 and 2 to combustor 1. Prior to calling a turbopump the following information must be set by input: SYSCOM=PIPLL,1, PIPL,2, PIPL,3, TURBOP,1, PIPL,4. This turbopump input identifies a liquid line PIPLL at the inlet to the pump and PIPL 2 and 3 as the gas lines input to the gas generator (GG, modeled as one of the combustors, CHAM). Note that the GG is automatically connected to the turbine inlet of the turbopump. The order of the component selection is also the order which the calculation in the program will proceed. Both the individual components and their connections must be defined in detail.

The required inputs for each component are defined in Sections 3.1.4 through 3.1.15. The state variable (STATE), and functional constraints (FUNCT), defined in Section 3.1.2 are used in the program input. The state variables (STATE) are the unknowns in the system and the functional constraints (FUNCT) are the constraint equations used by the nonlinear equation solver to obtain a solution. An example of the input used to define the state variables are as follows:

STATE = ARINJ,1,1,.9, ARINJ,1,2,.8 AREAT,1,1.3.

The first value ARINJ represents the area of the injector in chamber 1, line 1 and the first guess used in the program value is 0.9 inches^2. ARINJ is the area of the injector connected to chamber 1 and line 2. AREAT is the area of the throat of chamber 1, the second value of 1 is a dummy value necessary for input only and the initial guess for the throat area is 3. inches^2. The associated functional constraints to go with the state variables defined above as follows:

FUNCT = CONCT,1, CONCT,2, CONCT,3

The first constraint, CONCT 1, is the injector area constraint for line 1 in the first combustor; CONCT 2, is the injector area constraint for line 2 combustor 1; and CONCT 3 is the throat area, chamber pressure or thrust constraints for combustor 1. Proper selection requires that the number of constraints match the number of state variables. A sample input case is presented in Section 3.2

The following represents the description of data cards for TRWLOD input package.

Input of Numerical Data may assume the following forms in columns 1-72;

(a)   User defined argument name = constant

(b)   User defined array name = set of constants (separated by commas)

(c)   User defined argument = subscript, set of constants (separated by commas) or

       User defined argument, subscript = set of constants (separated by commas)

(d)   User defined array name = dimension of variable, subscript, set of constants (separated by commas).

       The dimension should appear between slashes and indicate the number of rows in a two-dimensional array or the number of rows and columns in a three-dimensional array.

       The dimension and subscripts must follow the equal sign.

(e)   User defined array name = nRV (value V to be repeated n times)

(f)   User defined argument name = hollerith characters (alphanumeric only, first alphabetic)

(g)   User defined argument name = 'hollerith characters' (limited by apostrophes)

(h)   User defined argument name = octal constant

Any combination of the eight types of data input described above may be used in a data set. Data items must be separated by commas. The end of a data set is signified by ENDCAS. An exponential input format may be used, e.g., A = 1. E-15. If the decimal point is omitted and E, D, or sign appears in the value the number will be converted, assuming the decimal point is to the right of the last numerical character (in the base number). An absence of a decimal point, an E, a D, or an imbedded sign signifies an integer value. An asterisk following the data causes scanning of that data card to stop, permitting comments to be placed after the value. The scan of a card also terminates if an error is detected.

Data may be represented on Numerical Data cards in any of the following forms:

IA   = 123* THIS IS A COMMENT

X   = 1.23E1,2.9

X(2)   = 2.9, (1) 123-1

D   = /5/(2,3), 17.1* (where D is dimensioned (5,n), and
            17.1 is to be stored in D(2,3))

D   = /5,3/(2,2,3), 17.1* (where D is dimensioned (5,3,n)
            and 17.1 is to be stored in D(2,2,3))

DX   = 1.23D4

DX   = 123D2

DX   = 1.23D+04

A   = 3R14.1, 4R2*   (fields to be repreated may be real,
                             integer, double precision, hollerith, or
                             octal)

ICON   = 0040045000000

ICON   = 0040045* (twelve digit word is filled with six zeros

                to the right)

A   = ABCD* (one word is filled with the four characters

                followed by two blanks)

A   = 'bb(ABCD)bb' (two words as follows; bb(ABS and D)bbbb)

FUNCT   Functions array (2,N) Stored column-wise as name and
                subscript

SYSCØM   Component configuration input. The first value is the
                name of the system component, the second value is the
                number of the component.

NSYS   Total number of system components in Syscom.

3.1.3 <u>System Components</u>. The following is a list of system component
modules available in this program for compilation into any desired attitude
control propulsion system:

PBL   Pressure Boundary (6 press boundaries)

PIPL   Gas pipe line with friction and heat transfer (30
                lines maximum including PIPLL, ADIAB, ISOTH lines)

PIPLL   Liquid pipe line

ADIAB   Gas adiabatic pipe

ISOTH   Gas isothermal pipe

JUNCL   Junction (6 junctions)

CHAM   Bi propellant combustor or gas generator (6 combustors)
                including (CMON)

CMON   Mono propellant combustor

TANKD   Accumulator or storage tank (5 tanks)

TURBOP   Turbopump (5 turbopumps)

VALVL   Liquid valve (20 valves including VALVG)

VALVG   Gas valve

PREG   Pressure regulator (10 regs)

FEEDB   Feedback constraint subroutine (5 values)

HEATX   Heat Exchanger (5 each)

12

3.1.4 Constraints

The constraints (F) are incorporated in the system component models and are utilized by the nonlinear equation solver to obtain the smallest constraint such that $\| F \|^2$ is a minimum.

Symbol	Description	Dimensions
PB(I)	Pressure boundary constraint	6
JUN(I)	Flowrate at junction const raint	6
CONCT(I,J)	Combustor oxidizer flowrate constraint (1,J) Combustor fuel flowrate constraint (2,J) Combustor chamber pressure constraint (3,J)	3,6
POWC(I)	Turbopump power balance constraint (pump power = turbine power)	5
WTGC(I)	Turbine flowrate constraint (turbine flow = gas generator flow)	5
FBWC(I)	Feedback flowrate constraint	6
FBPC(I)	Feedback pressure constraint	6
FBTC(I)	Feedback temperature constraint	6
THØC(I)	Heat exchanger outlet temperature constraint	5
CGGTC(I)	Chamber (GG) combustion temeprature constraint to heat exchanger	6
CGTANK(I)	Gas inlet pressure constraint to tank	5
CPJU(I,J)	Junction inlet lines pressure constraints	10,5
CLTANK(I)	Inlet liquid pressure constraint to tank	5

3.1.5 PBL Pressure Boundary (Reference 1, Section 3.4.3.2)

Symbol	Description	Units	Dim.
PBL(I)	System component name for pressure boundary I		
IEND(I)	END to which pressure boundary I is connected (1=upstream, 2-downstream)		
IPB(I)	Tells which line is connected to pressure boundary I		6

Symbol	Description	Units	Dim.
PGPBL(I)	Pressure at pressure boundary	PSIA	6
TT(I)	Switch for total temperature input to PBM (=1 Input total temperature =2 Input fluid temperature		6
TTTEMP (II,JJ)	Static temperature	^{o}R	20,30
TTTEMP (II,JJ)	Total temperature	^{o}R	20,30
PB(I)	Pressure boundary downstream constraint		6

3.1.6 Junction input (Reference 1, Section 3.4.7)

Symbol	Description	Dimensions
JUNCL(I)	System component name for junction I	10
JUN(I)	Flowrate constraint in junction subroutine	10
NLINJU(I)	Number of pipes at the Ith junction	10
IJUNC(I,J)	Array which denotes connection to junction I of J lines, upstream lines must be input first positive and the downstream lines negative	10,6

3.1.7 Valve/Orifice (Reference 1, Section 3.4.5)

Symbol	Description	Units	Dim.
VALVG(I)	System component name gas valve I		20
VALVL(I)	System component name liquid valve I		20
VAD(I)	Line to which downstream end of valve is connected		20
VAI(I)	Line to which upstream end of valve is connected		20
XK(I)	Discharge coefficient times area of valve	In^{2}	20

3.1.8 Mono/Bi-Propellant Combustors (Reference 1, Section 3.4.11)

Symbol	Description	Units	Dim.
AREAT(I)	Chamber Throat Area	IN**2	6
ARINJ(I)	Area Injector	IN**2	6,2
PCI(2)	Chamber Pressure constraint	PSIA	6

Symbol	Description	Units	Dimensions
AJ(I)	Switch for input PDROP (AJ=1, Input PDROP)		6
PDROP(I)	Pressure drop across injector PSIA	PSIA	6
NCHAM(I)	Number of chambers		6
ICHAM(I,N)	Number of lines connected to the nth inlet of combustor I		6,2
CV(I,J)	Injector discharge coefficient		6,2
THRT	Engine Thrust constraint	lbf	6
PATM	Atmospheric pressure	PSIA	1
	Mono-Propellant Only		
CMON(I)	System component name for mono-propellant combustor I		
CTW	Constraint equation switch for combustor'		.1
	=1 Specific impulse constraint		
	=2 Chamber measure constraint		
	=3 Thrust constraint)		
LAMDA(I)	Divergence nozzle coefficient		6
CDC(I,J)	Chamber flowrate discharge coefficient		6,2
ISPI(I)	Specific impulse constraint	sec	6
AREAE(I)	Area exit chamber	in**2	6
	Bi-Propellant Only		
CHAM(I)	System component name for bi-propellant combustor I		
NCOEF	Number of coefficients in curve fits for propulsion parameters		1
MW2(I)	Molecular weight coefficients in curve fit equation combustor	Deg.R	4
TC2(I)	Temperature coefficients in curve fit equation		4

Symbol	Description	Units	Dim.
CP2(I)	Specific heat coefficients in curve fit equation		4
CS2(I)	CSTAR coefficients in curve fit equation	ft/sec	4
IS2(I)	ISP coefficients in curve fit equation	sec	4
CONCT(1,I)	Thruster (I) flowrate, $\dot{w}_o$, constraint equation	sec	3,6
CONCT(2,I)	Thruster (I) flowrate, $\dot{w}_f$, constraint equation	sec	3,6
CONCT(3,I)	Pc, thrust constraint equation	sec	3,6

3.1.9 PIPL Gas Line (Reference 1, Section 3.4.1)

Symbol	Description	Units	Dim.
ADIAB(I)	System component name adiabatic line I		30
PIPL(I)	System component name gas line I		30
PIPLL(I)	System component name liquid line I I		30
ISOTH(I)	System component name isothermal line I		30
ALPHA(II)	Angle line (II) makes with horizontal	Deg.	30
TH(II)	Wall thickness of line (II)	n.	4,20,30
NPIPL	Number of lines		1
DIALO(II)	Outside diameter line II	n.	30
GEE	Acceleration due to gravity	ft/sec^2	1
HNPR	Exponent on Prandtl number for line inner wall film coefficient		1
HNRE	Exponent on Reynolds number for line inner wall film coefficient equation		1
HOEX	Exponent on Prandtl+Grashof numbers for line outer film coefficient (stored 0.25)		1
TENV	Temperature of environment	Deg. R	1
WTHCON(I)	Wall thermal conductivity	$\frac{BTU}{ft\text{-}hr^\circ R}$	30
XLENGL(I)	Length of the Ith line	In.	30

Symbol	Description	Units	Dimensions
MACH(II,JJ)	Mach number line II node JJ		20,30
NPLINE(II)	Liquid in line II (1-OX, 2=Fuel)		30
HRS(I)	Switch for hydraulic resistance for Ith line I=0 program calculates HR =1 input HR(liquid line)		30
HR(I)	Hydraulic resistance (liquid line) of Ith line	$Sec^2/ft-in^2$	30
KLT(I)	Total loss coefficients for bends, contractions, etc. (liquid line)		30

3.1.10 Heat Exchangers (Reference 1, Section 3.4.15)

Symbol	Description	Units	Dimensions
HEATX(I)	System component name for heat exchanger		5
TYPE(I)	Type of heat exchanger, (3= crossflow, 2= parallel flow, 1= counter flow)		5
LI(I), LO(I)	Inner and outer fluid number (1= hydrogen) (2= oxygen) (3= H_2-O_2 at MR = 1.0)		5
XI, XO	Inner and outer fluid inlet quality		5
HEØI(I)	Number of the line connected to outer line of the Ith* heat exchanger inlet		5
HEII(I)	Number of the line connected to inner line of the Ith* heat exchanger inlet		5
HEØØ(I)	Number of the line connected to outer line of the Ith* heat exchanger outlet		5
HEIØ(I)	Number of the line connected to inner line of the Ith* heat exchanger outlet		5
HGII(I)	Number of combustors connected to Ith heat exchanger inside line		5
HGIØ(I)	Number of combustors connected to Ith heat exchanger outside line		5
THØC(I)	Temperature constraint for heat exchanger cold side discharge temperature		5

* If the heat exchanger is flowing into the line, the line number is input as a positive value, if the flowrate is going from the line into the heat exchanger, the flowrate is input as a negative value.

17

Counter Flow Heat Exchanger

Symbol	Description	Units	Dim.
P(I)	Pitch distance between tubes center to center	In	5
ARFL(I)	Flow area cross section of heat exchanger outer tube	IN^2	5
NT(I)	Number of tube wraps		5
DTB(I)	Diameter of tube bundle	In	5
HRS(I)	Switch for hydraulic input radius (=1 input, =0 calculated in program)		5
HR(I)	Hydraulic radius		5
KLT(I)	Loss for entrance, bends, and discharge coefficient		5
LT(I)	Length of inner tube	In	5
LS(I)	Heat exchanger shell length	In	5
DHYO(I)	Hydraulic dia for crossflow helicoil heat exchanger		5
DSI(I)	Diameter of heat exchanger shell (inside) total heat transfer for crossflow heat exchanger		

Parallel or Crossflow Heat Exchanger

Symbol	Description	Units	Dimensions
LENGTH(I)	Heat exchanger length	In	5
RI(I)	Inner tube radius	In	5
RO(I)	Outer tube radius	In	5
THICK(I)	Wall thickness of inner tube	In	5

3.1.11 Tank (Reference 1, Section 3.4.3)

TANKD(I)	System component name for accumulators/tanks I		
TIMEND	Time to end program	sec	1

18

Symbol	Description	Units	Dimensions
DELT	Time increment	1.0 sec	1
WDØTG(II,JJ)	Inlet liquid flowrate	lbm/sec	30,20
WDØTG(II,JJ)	Outlet liquid flowrate	lbm/sec	30,20
LDMI(I)	Number of lines, connected to tank gas inlet'		5
LDMO(I)	Number of lines, connected to tank gas outlet		5
LDWI(I)	Number of lines, connected to tank liquid inlet		5
LDWO(I)	Number of lines connected to tank liquid outlet		5
AVENT(I)	Relief valve flow area	in^2	5
CP1(I)	Specific heat C_p – species 1	B/lbm-^oR	5
CP2(I)	Specific heat C_p – species 2	B/lbm-^oR	5
R1(I)	Gas constant 1 – species 1	B/lbm-^oR	5
R2(I)	Gas constant 2 – species 2	B/lbm-^oR	5
PVENT(I)	Relief valve vent pressure	Psia	5
P(I)	Initial tank pressure	Psia	5
TTANK(I)	Initial tank temperature	^oR	5
TIN(I)	Inlet gas temperature- species 2	^oR	5
TIME	Time	sec	1
VTANK(I)	Tank volume	ft^3	5
WOL(I)	Initial mass of fluid	lbm	5
WDØTG(II,JJ)	Inlet gas flowrate line II, node JJ	lbm/sec	30,20
WDØTG(II,1)	Outlet gas flowrate line II, node JJ	lbm/sec	30,20
DQIN(I)	Heat rate into tank	Btu/sec	5

3.1.12 TURBOP Turbopump (Reference 1, Section 3.4.13)

Symbol	Description	Units	Dimensions
TURBOP(I)	System component name for the turbopump I		5
AREAT(I)	Area of turbine inlet throat (Same as GG throat) turbopump I	in^2	6
CEF1,CEF2(I)	Coefficients on turbine efficiency curve		
RPMD(I)	Pump RPM at design speed	rev/min	5
IPUMI(I)	Line connected to pump inlet		5
IPUMØ(I)	Line connected to pump outlet		5
DIAD(I)	Diameter pump design	in	5
DIAP(I)	Diameter pump actual	in	5
DIAT(I)	Diameter turbine	in	5
GR(I)	Pump to turbine gear ration		5
ATR(I)	Area turbine inlet	in^2	5
ATD(I)	Area turbine discharge	in^2	5
KTD(I)	Discharge coefficient turbine		5
KTI(I)	Discharge coefficient turbine inlet		5

3.1.13 PREG Pressure Regulator (Reference 1, Section 3.4.3.2)

Symbol	Description	Units	Dimensions
PREG(I)	System component name		10
PRIN(I)	Line connected to regulator inlet		10
PROU(I)	Line connected to regulator outlet		10
PRE(I)	Regulator pressure discharge	psia	10

3.1.14 Feedback Constraints (Reference 1, Section 3.4.18)

Symbol	Description	Units	Dimensions
FEEDB(I)	System component name		6
FBD(I)	Line connected to feedback subroutine downstream (flow going into feedback)		6

Symbol	Description	Units.	Dim.
WFB(I)	Line connected upstream		6
FBWC(I)	Flowrate feedback constraint equation		6
FBPC(I)	Pressure feedback constraint equation		6
FBTC(I)	Temperature feedback constraint equation		6

3.2 Output Description

The output description is given in the output processor subroutine, Section 4.1.

3.3. Typical Deck Set-up

A typical ACPS model (Figure 1) was formulated to exercise all the program options. The hydrogen (H_2) side of the ACPS was modeled in detail, and the oxygen (O_2) side was simulated as constant pressure boundaries. The system consists of a liquid hydrogen (LH_2) storage tank feeding a turbopump assembly. The turbopump increases the LH_2 pressure to 1421 psia and transmits the LH_2 to the heat exchanger which vaporizes the propellant. The heat exchanger and turbopump are driven by separate gas generators (gas-gas) which are operated in the feedback mode obtaining propellants from downstream of the heat exchanger. The heat exchanger also feeds an accumulator and three thrusters. The following listing represents a typical set of card input and represents the schematic as shown in Figure 1.
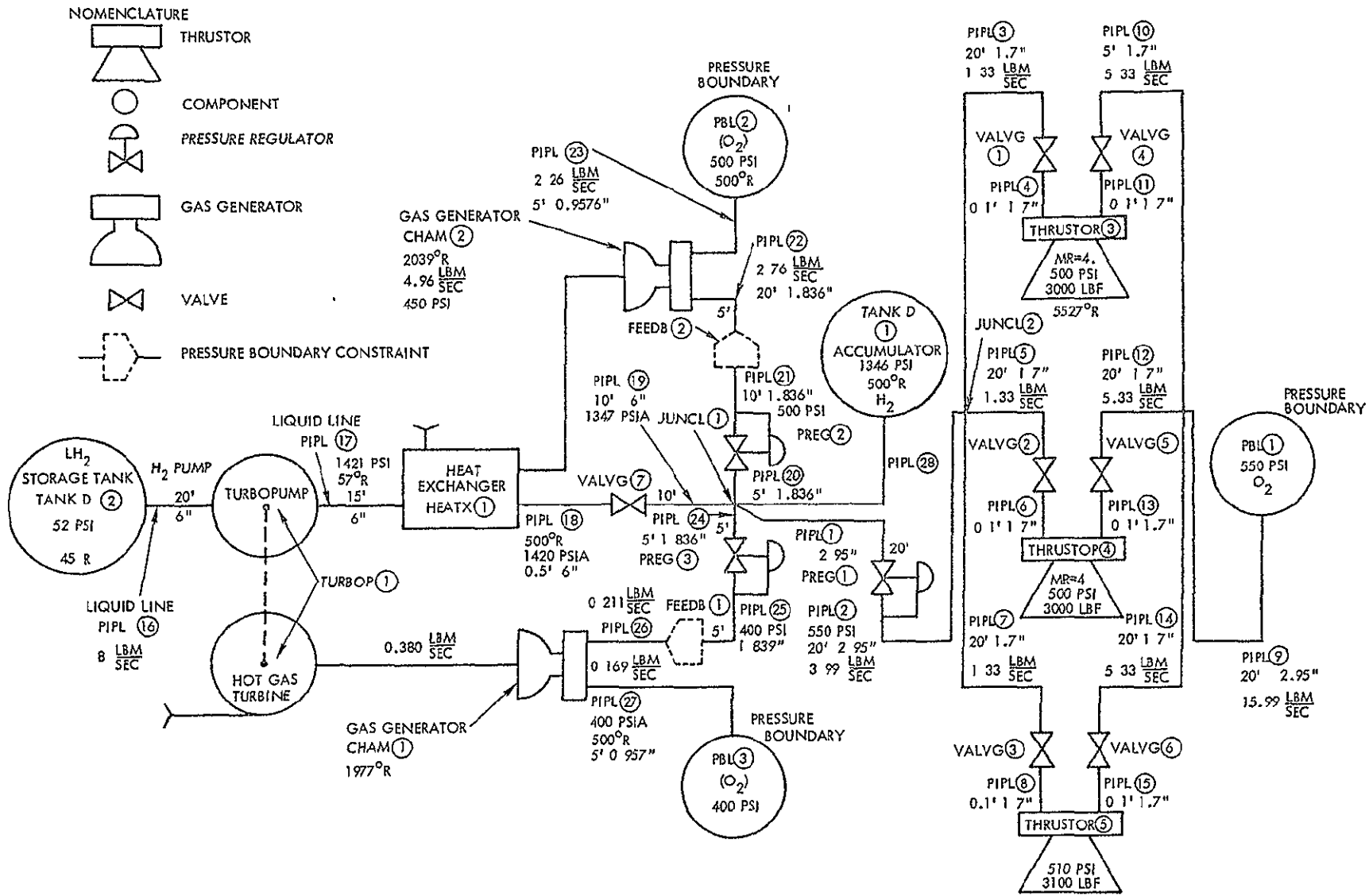
Figure 1. ACPS Demonstration Case

22

```
SYSCOM     =    TANKD,2,PIPLL,16,PBL,3,PIFL,27,PIPL,26,TURBOP,1,
                PIPLL,17,PIPL,22,PBL,2,PIPL,23,CHAM,2,HEATX,1,
                PIPL,18,VALVG,7,PIPL,19,JUNCL,1,PIPL,20,
                PREG,2,PIPL,21,FFEDB,2,PIPL,28,TANKD,1,
                PIPL,24,PREG,3,PIFL,25,FEEDB,1,
              PIPL,1,PREG,1,PIPL,2,JUNCL,2,PIPL,3,VALVG,1,PIPL,4,
                            PIPL,5,VALVG,2,PIPL,6,
                            PIPL,7,VALVG,3,PIPL,8,
              PBL,1,PIPL,9,JUNCL,3,PIPL,10,VALVG,4,PIPL,11,CHAM,3,
                            PIPL,12,VALVG,5,PIPL,13,CHAM,4,
                            PIPL,14,VALVG,6,PIPL,15,CHAM,5,
NSYS = 54   *
**
**    STATE VARIABLES + FUNCTIONAL CONSTRAINTS
FUNCT     =   CONCT,1,CONCT,2,POWC,1,
          CGTANK,1,
              CONCT,4,CONCT,5,
              CONCT,7,CONCT,8,CONCT,9,
              CONCT,10,CONCT,11,CONCT,12,CONCT,13,CONCT,14,CONCT,15,
              THOC,1       ,
              FBTC,1,FBTC,2, FBPC,1,FBPC,2 *
STATE     = ARINJ,1,1,0.031,ARINJ,1,2,0.15816,          PDELP,1,1,1050,,
              PG,26,1,399.9,P,1,1, 950.00,PG,22,1,500. ,
          ARINJ,2,1,0.031,ARINJ,2,2,0.158 ,
           ARINJ,3,1,0.63,ARINJ,3,2,0.94,AREAT,3,1,5.4 ,
           ARINJ,4,1,0.63,ARINJ,4,2,0.94,AREAT,4,1,5.4 ,
           ARINJ,5,1,0.63,ARINJ,5,2,0.94,AREAT,5,1,5.4 ,
          LENGTH,1,1,2000,,
              TTEMP,22,1,500,,TTEMP,26,1,500. *
**   SIMULTANEOUS EQUATION SOLVER
**
M = 20  *
N = 20  *
MAXIT = 80  *
**
**    7 VALVE INPUTS
**
XK   = 3R0.9399,3R0.945, 2.0
VAI    = 3,5,7,10,12,14,18 *
VAD    = 4,6,8,11,13,15,19 *
**
**
**    THREE COMBUSTORS + TWO GG'S
**
NCHAM      =  5 *
ICHAM      =/6/(1,1),26,(1,2),27,(2,1),22,(2,2),23,(3,1),4,(3,2),11,
              (4,1),6, (4,2),13,(5,1),8, (5,2),19 *
CV         =/6/12R1.*
PCI        = 350,,450,,2R500,,510. *
THRT(3)    = 2R3000,,3100. *
AREAT = 0.228,2.7*
NCOEF      = 4 *
```

23

```
##
##  JUNCTIONS
##
NLINJU = 5,4,4 #
IJUNC  =/10/(1,1),19,(1,2),-20,(1,3),-28,(1,4),-1,(1,5),-24,
           (2,1),2,(2,2),-3,(2,3),-5,(2,4),-7,
          -(3,1),9,(3,2),-10,(3,3),#12,(3,4),-14#
WDOTG =/30/(16,1),8,,(20,1),2,70,(24,1),,211,(25,1),1,0015#
##
##   LINES
##
XLENGL = 15,,15,,20,,0,1,20,,
         0,1,20,,5,1,5,0,5,0,
         0,1,5,0,0,1,5,0,0,1,
         20,,2,0,15,,15,,15,,
         5,0,10,,5,0,15,,10,,
         5,0,5,0,15,     #
EMIS   = 28R0,07#
EMIS(16)= 2R,0007#
DIALO  = 6,1,3,05,1,8,1,8,1,8,
         1,8,1,8,1,8,3,05,1,8,
         1,8,1,8,1,8,1,8,1,80,
         6,1,6,1,6,1,6,1,6,10,
         1,936,1,936,1,0576,6,1,1,936,
         1,936,1,0576,6,1#
TH     = 28R0,05
NODEL= 15R3, 2R2,11R3#
NPIPL  = 28 #
GEE    = 0,0#
HNPR   =  0,4#
HNRE   =  0,8#
HOEX   =  0,25#
TENV   = 600, #
NPLINE = 8R2,7R1,7R2,1,3R2,1,2#
WDOTG  =/30/(1,1),3,9975,(3,1),1,3325,(5,1),1,3325,(7,1),1,3325,
           (9,1),15,99,(10,1),5,33,(12,1),5,33,(14,1),5,33 #
TTEMP  =/30/(9,1),500,,(16,1),45,,(27,1),500,,(23,1),500, #
RGAS   = 48,2813,772,5#
KA   =  2R1,395     #
##
##   PRESSURE BOUNDARIES
##
PGPBL = 550,,500,,400, #
NPBL   = 3 #
IPB    = 9,23,27 #
IEND   = 1,1,1     #
##
##    TANK / ACCUMULATORS
##
VTANK   = 20,,200,
WOL     =   0,,1000,
TLIQ = 0,, 45, #
CP1     = ,25,3,45#
CP2     = ,25,3,45#
R1      =    2R,993#
```

```
R2        =       2R.993*
PVENT = 1500.,60.*
AVENT = 2R2.*
DGIN  = 2F0.*
LDMI  = 28,C*
LDWO  =  C.16*
P(2) = 52,*
TTANK =  50C.,45.*

**
**   HEAT EXCHANGER
**
TYPE   = 2*
LI     =  3 *
LC     =  1 *
XI     =  1,*
XC     =  1,*
THEC   =50C. *
HEOI   =-17 *
HEOO   = 18 *
HGII   =  2 *
RI     = 3, *
RC     = 4.34 *
THICK = 0.05 *
**
**   TURBOPUMP
**
CEF2   =  -8.6*
CEF1   =   5.2*
RPMD   = 50000.*
IPUMI = 16       *
IPUMO = 17       *
GR     = 1.      *
DIAD   = 1.      *
DIAP   = 1.      *
DIAT  = 24.8     *
ATI    = C.26    *
ATD    = 19.     *
KTD    = 1,      *
KTI    = 1.      *
WTHCON =   30F9.41 *
**
**   PRESSURE REGULATOR
**
PRE  = 550.,500.,400.*
PRIN  = 1,20,24 *
PROU  = 2,21,25 *
**
**   FEEDBACK LOOPS (PRESSURE,FLOWRATE FIXED THEREFORE FBWC /FBPC NOT
**                    REQUIRED FBTC ONLY)
FPI   = 25,21 *
FBD   = 26,22 *
WDOTG       = /30/(22,1),2.700,(23,1),2.260, (27,1), 0.169,(26,1),0.211*
RFLAG  = 7. *
ENDCAS
```

25

4.0 SUBROUTINES

This section contains a list of the subroutines utilized in the SSACPS program and a detailed discussion on the more complicated subroutines. Descriptions of the remaining subroutines may be obtained from the program listing.

Subroutine names and purpose follow:

ADIAB	Adiabatic gas line
BEGS	Nonlinear equation solver
BETA	Interpolation
BDCINT	Hollerith to integer conversion subroutine
BPROPG	Calculates the gas properties at saturated conditions
BPROPL	Calculates the liquid properties at saturated conditions
CDDATA	Data Record Processing
CHAM/TURBØP	Bi-propellant combustor or turbopump
CHOICE	Chooses heat exchanger configuration and calculation method
CMON	Monopropellant combustor
CWALL	Thermal conductivity of wall
DP2R	Double precision to Real Conversion Function
FCOMP1	Heat transfer with friction Mach number differential equation solved by Newton-Raphson iteration
FCOMP2	Isothermal pressure boundary differential equation by Newton-Raphson iteration
FCOMP3	Adiabatic Mach number differential equation solved by Newton-Raphson iteration
FEEDB	Feedback constraints
GATHER	Gathers routines in order to create system as input by user.
HEATEX	Heat exchanger calculations

HEATX	Connects input parameters and line connections to heat exchangers
INITAL	Tank initialization
INTEG	Integration
INTER2	Interpolation
INTERP	Interpolation
ISOTH	Isothermal gas line
JUNCL	Junction
LEGS	Single or double precision solution of an over-determined system of linear equations
NUSLET	Nusselt number
OUTPRC	Output processor
PACK	Character packing subroutine
PBL	Pressure boundary
PERFOR	Computes dimensions
PIPL/PIPLL	Gas or liquid line with heat transfer and frction
PREG	Pressure regulator
R2DP	Real to double precision conversion junction
SQZB	Blank Deletion Subroutine
SSPIPE	Main program driver
TAND	Tank driver
TANK	Tank/accumulator
TRWLOD	Numerical Data Input Subroutine
VALVG	Gas valve
VALVL	Liquid valve
WRITE	Writes output from heat exchanger

PROPERTY SUBROUTINES

Symbol	Description
BLK2	Initializes tables for use by PTHEAT
BPROPG	Calculates saturated gas properties (oxygen and hydrogen)
BPROPL	Calculates saturated liquid properties (oxygen and hydrogen)
HPTCV	Computes the specific heat of hydrogen at constant volume
HPTD	Computes density of hydrogen from NBS data
HPTCP	Computes specific heat for hydrogen at constant pressure
HPTTC	Computes thermal conductivity for hydrogen from NBS data
HPTV	Computes viscosity of hydrogen from NBS data
H2OH2	Calculates fluid properties of gas generator products (O_2/H_2 combustion)
LATENT	Calculates saturated gas and liquid enthalpies (hydrogen and oxygen)
PROPTY	Thermodynamic property lookups (density, viscosity, heat capacity, thermal conductivity, Prandtl Number)
PTHEAT	Computes specific heat of hydrogen at constant pressure or volume (NBS data)
SAT	Calculates the saturation temperature for hydrogen and oxygen
THERM	Computes thermodynamic properties of oxygen
TPOCB1	Initializes Weber's thermodynamic properties of oxygen
TPOCB2	Initializes Roder's thermodynamic properties of oxygen

Flowcharts 1 and 2 represent generalized flow charts of the SSACPS program logic showing the subroutine calling sequence.

Program Driver (SSPIPE)

START

Read data and
Initialize

Set up State Variables
X(I) = STATE(4,I)

Call GATHER selects
system components
models

Call BEGS for the solution
of ACPS component equations

Call ACPS components

Call OUTPRC for
case print output

TIME:TIMEND

≠

TIME = TIME + DELT

=

END
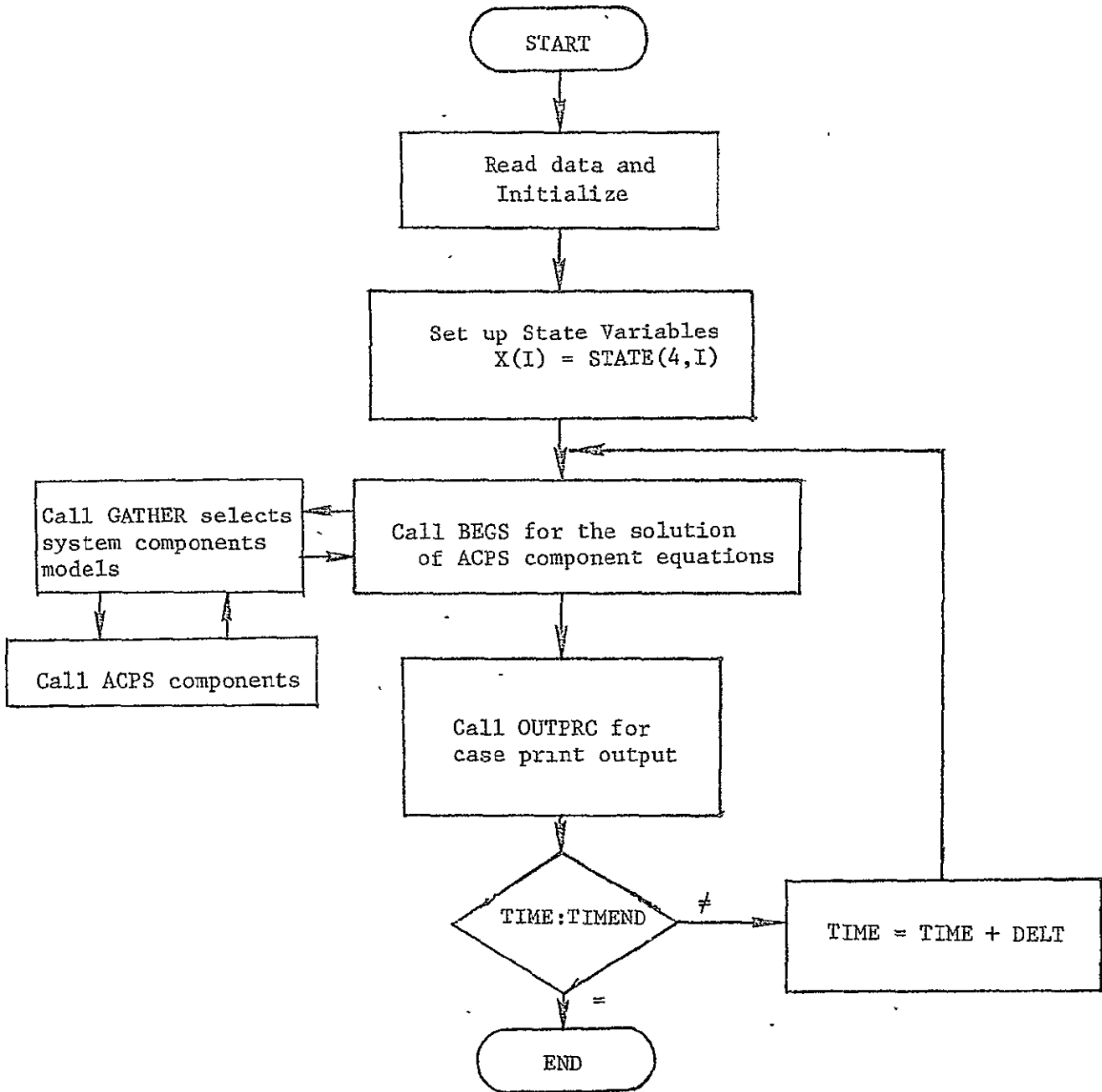
Flowchart 1.   ACPS General Flowchart
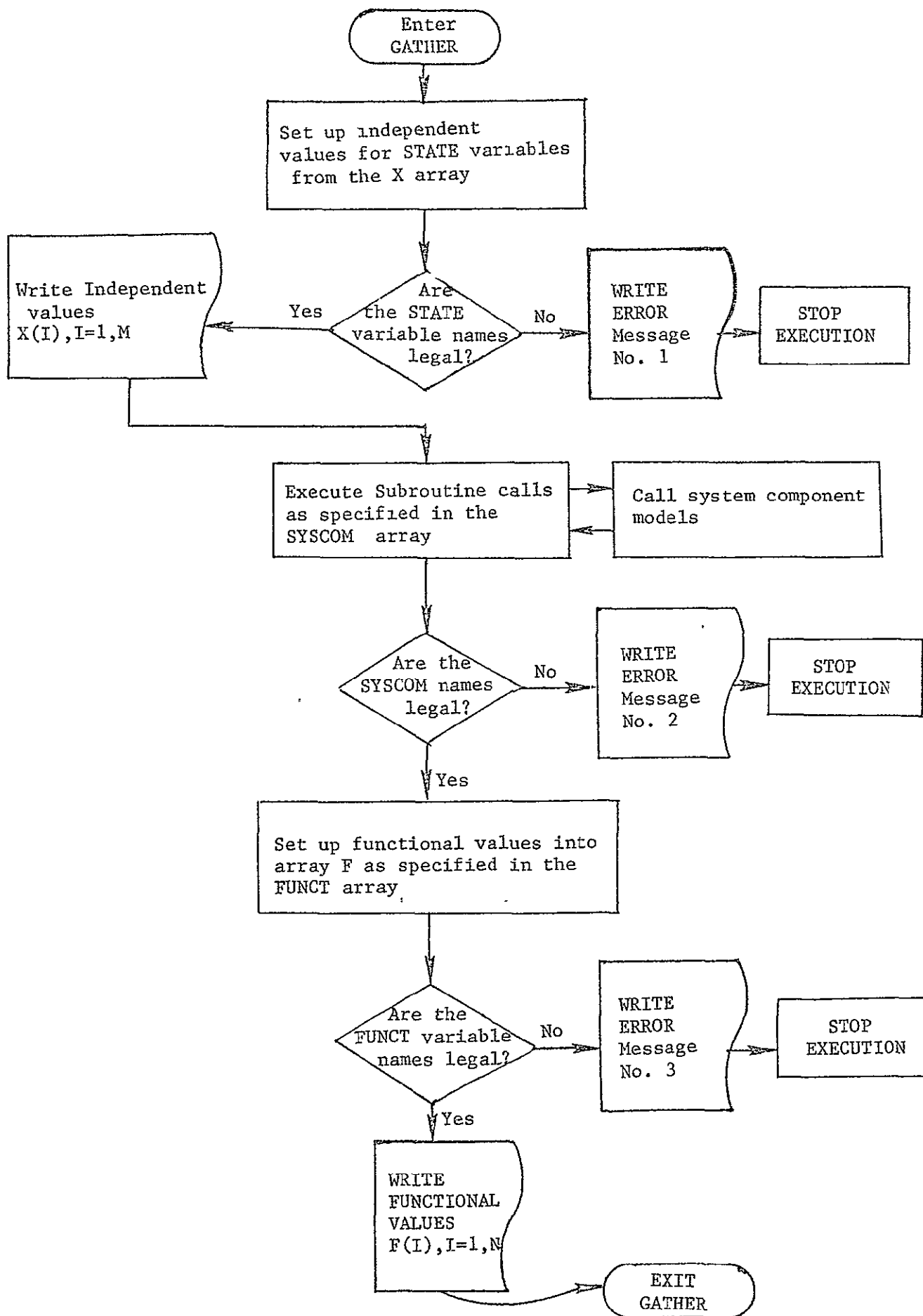
Flowchart 2 .   Flowchart for Subroutine GATHER
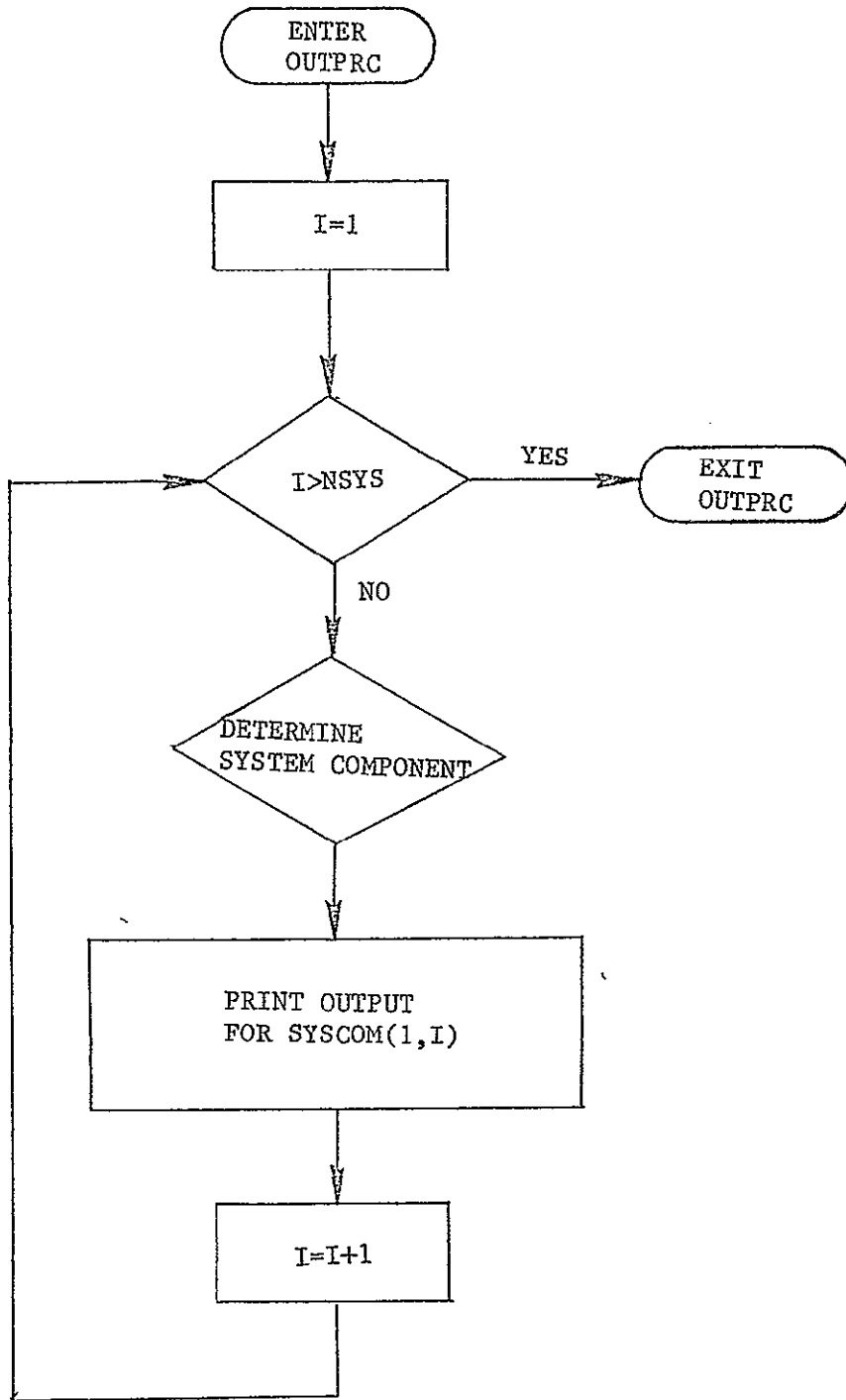
Flowchart 3 .   Flowchart for Subroutine OUTPRC

4.1 OUTPRC

Output Processor Subroutine

<u>Purpose</u>

The OUTPRC subroutine generates printed output at case termination for each of the user specified system component subroutines.

<u>Usage</u>

<u>Calling Sequence</u>

Ø UTPRC

Name Common Inputs	Definition	Units	Dimensions
AREAI(I,J)	Inside line cross section area (line I, node J)	in^2	6,2
AREAT(I)	Area of the combustor throat	in^2	6
ARINJ(I,J)	Area of combustor injectors (line I, node J)	in^2	6,2
ATD(I)	Area, turbine discharge	in^2	5
ATI(I)	Area, Turbine Inlet	in^2	5
CDC(I)	Discharge coefficient of the mono- propellant combustor injector	—	6
CF(I)	Thrust coefficient	—	6
CP(I)	Specific heat at constant pressure	$\frac{BTU}{lb-°R}$	6
CSTAR(I)	Characteristic exhaust velocity	ft/sec	6
CV(I)	Discharge coefficient of the bi- propellant combustor injector	—	6
CVEL(I)	Isentropic spouting velocity	ft/sec	5
DIALI(I)	Inside diameter of line	in	30
DIAT(I)	Diameter of turbine	in	5
DMVENT(I)	Gas Flowrate through the vent	lbm/sec	5
DQIN(I)	Heat into the accumulator/tank	BTU/sec	5
ETAT(I)	Turbine efficiency		5

33

Name Common Inputs	Definition	Units	Dimensions
FRL (I)	Friction	—	30
GR(I)	Pump to turbine gear ratio	—	5
HI(I)	Heat transfer coefficient, inside tube of the heat exchanger	$\dfrac{BTU}{in^2 sec°R}$	5
HØ(I)	Heat transfer coefficient, outside tube of the heat exchanger	$\dfrac{BTU}{in^2 sec°R}$	5
HRAD(I)	Equivalent heat transfer coefficient due to radiation	$\dfrac{BTU}{sec°R}$	5
ICHAM(I)	Number of the line connected to the nth inlet of combustor (I)	—	6
IEND(I)	End to which pressure boundary (I) is connected	—	6
IPB(I)	Used to identify which line is connected to pressure boundary I	—	6
IPUMI(I)	Line connected to pump inlet	—	5
IPUMØ(I)	Line connected to pump outlet	—	5
ISP(I)	Specific impulse of chamber (I)	$\dfrac{lb_f\text{-}sec}{lbm}$	6
KTHER(I)	Fluid conductivity line II	$\dfrac{BTU}{hr\text{-}ft°F}$	30
KTI(I)	Total loss coefficient (liquid line)	—	30
LAMDA(I)	Nozzle divergence coefficient	—	6
LDMI(I)	Line connected to gas inlet to tank	—	5
LDMØ(I)	Line connected to gas outlet from tank	—	5
LDWI	Number of lines connected to liquid inlet to tank	—	5
LDWØ(I)	Number of lines connected to liquid outlet to tank	—	5
MACH(II,JJ)	Mach number pipe II node JJ	—	20,30
MEX(I)	Chamber Mach number at exit	—	6
MR(I)	Mixture ratio	—	6
MWC(I)	Molecular weight of combustor combustion products	$\dfrac{lb}{lb\ mole}$	6

Name Common Inputs	Definition	Units	Dimensions
NLINJU(I)	Number of lines at junction (I)	--	10
NODEL(I)	Nodes in line I	--	30
NPR(I,J)	Prandtl number, line I, node J	-	30,2
NRE(I,J)	Reynolds number of line I, node J	-	30,2
NSYS	Number system components	--	1
P(I)	Pressure in tank I	psia	5
PCI(I)	Combustor chamber pressure (I)	psia	5
PCN(I)	Monopropellant combustor chamber pressure	psia	5
PDELP(I)	Pressure rise across turbopump	psia	5
PDRØP(I)	Pressure drop across injector	psia	5
PE(I)	Pressure at the exit of the combustor	psia	5
PG(I,J)	Pressure line I, node J	psia	30,20
PGPBL(I)	Pressure at pressure boundary	psia	6
PGT(I,J)	Total pressure line I, node J	psia	30,20
PØWP(I)	Turbopump power	$\frac{\text{ft-lb}_f}{\text{sec}}$	6
PØWT(I)	Turbine power	$\frac{\text{ft-lb}_f}{\text{sec}}$	6
PPI(I)	Pressure into turbopump	psia	5
PPØ(I)	Pressure out of turbopump	psia	5
PRIN(I)	Line connected to pump inlet	-	5
PROU(I)	Line connected to pump outlet	-	5
PTI(I)	Turbine inlet pressure	psia	5
PTØ(I)	Turbine outlet pressure	psia	5
PWØ(I)	Coefficients used to describe the pump pressure rise/flowrate relationship for turbopump I	-	4

Name Common Inputs	Definition	Units	Dimensions
R(I)	Turbine velocity ratio	–	5
RHØG(II,JJ)	Density of gas line II, node JJ	lbm/ft^3	30,20
RHØL(I)	Density of liquid	lbm/ft^3	30
RPMT(I)	Turbine speed	rev/min	5
SYSCØM(I,J)	System component names I component member J component member	–	4,150
TC(I)	Temperature of combustor	°R	6
THRT(I)	Combustor thrust	lbf	6
TTANK(I)	Initial temperature of accumulator/ tank	°R	5
TTEMP(II,JJ)	Fluid temperature line II, node JJ	°R	30,20
TTI(I)	Turbine temperature in	°R	5
TTØ(I)	Turbine temperature out	°R	5
TTTEMP(II,JJ)	Total temperature of fluid line II, node JJ	°R	30,20
TWALL(II,JJ)	Temperature of the wall line II, node JJ	°R	30,2
U(II,JJ)	Overall heat transfer coefficient of liquid	$\dfrac{BTU}{hr-°R}$	30,2
UAO(II,JJ)	Overall heat transfer coefficient of gas line II, node JJ	$\dfrac{BTU}{hr-°R}$	30,2
VAD(I)	Line connected to valve discharge	–	20
VAI(I)	Line connected to valve inlet	–	20
VEL(II,JJ)	Velocity fluid line II, node JJ	ft/sec	30,20
VISC(I)	Viscosity fluid	$\dfrac{lbm}{ft/sec}$	30
WDØTG(II,JJ)	Flowrate fluid line II, node JJ	lbm/sec	30,20
WI(I)	Flowrate into junction	lbm/sec	6
WNØZ(I)	Flowrate combustor nozzle	lbm/sec	6
WØ(I)	Flowrate out of junction	lbm/sec	6

Name Common Inputs	Definition	Units	Dimensions
WØL(I)	Weight of fluid in accumulator	lbm	5
WP(I)	Flowrate through pump	lbm/sec	5
WT(I)	Flowrate through turbine	lbm/sec	5
WTHCØN(II,J)	Fluid thermal conductivity, line II, node JJ	$\frac{BTU}{hr\text{-}ft\text{-}°R}$	30,2
XK(I)	Discharge coefficient times the area of the valve	in^2	20
XLENGL(I)	Length of each section of pipe	in	1

Subroutines Used

WRITE

   Subroutine OUTPRC is shown in Flowchart 3, page 32.

4.2 BDCINT

Hollerith-to-Integer Conversion Subroutine

Purpose

BCDINT computes an integer from an input array, in which each word consists of one left-justified hollerith character, 0 through 9 or a blank, with the remaining 5 characters being hollerith blanks.

Usage

Calling Sequence

        BCDINT   NCOL, INT, N

Input

Argument	Dimension	Definition
NCOL	N	Array in which all words contain one left-justified BCD character. The remaining five characters of each word are blank
N	1	The number of words in NCOL

Output

INT	1	An integer corresponding to the BCD characters of NCOL
N	1	The number of non-blank words in NCOL

Restrictions

Each word of NCOL must contain one of the BCD characters 0 to 9 or a blank left-justified with the remaining 5 characters also blank.

Subroutines Used

SQZB

Method

BCDINT first calls SQZB to adjust the non-blank words of NCOL to the front. Then each word of NCOL is compared to each of the integers 0 through 9 in BCD code. When a match is found, the value to be returned (INT) is increased appropriately. If a non-valid character is found, the value of N is returned negative, in which case the magnitude of N indicates the digit in error.

Subroutine BDCINT is shown in Flowchart 4, page 39.

38

ENTER
BCDINT

INPUT: ARRAY
OF BCD CHARACTERS
ONE PER WORD, SIZE
OF THIS ARRAY

USE SQZB TO ADJUST
ALL THE NON-BLANK
WORDS TO THE
FRONT OF THE ARRAY

ARE THERE
CHARACTERS OTHER
THAN 0 THROUGH 9
AND BLANK?

NO

YES

DETERMINE
THE CHARACTER
IN EACH WORD
AND INCREASE
THE VALUE
APPROPRIATELY

SET N
NEGATIVE

OUTPUT:
THE VALUE
COMPUTED

EXIT
BCDINT
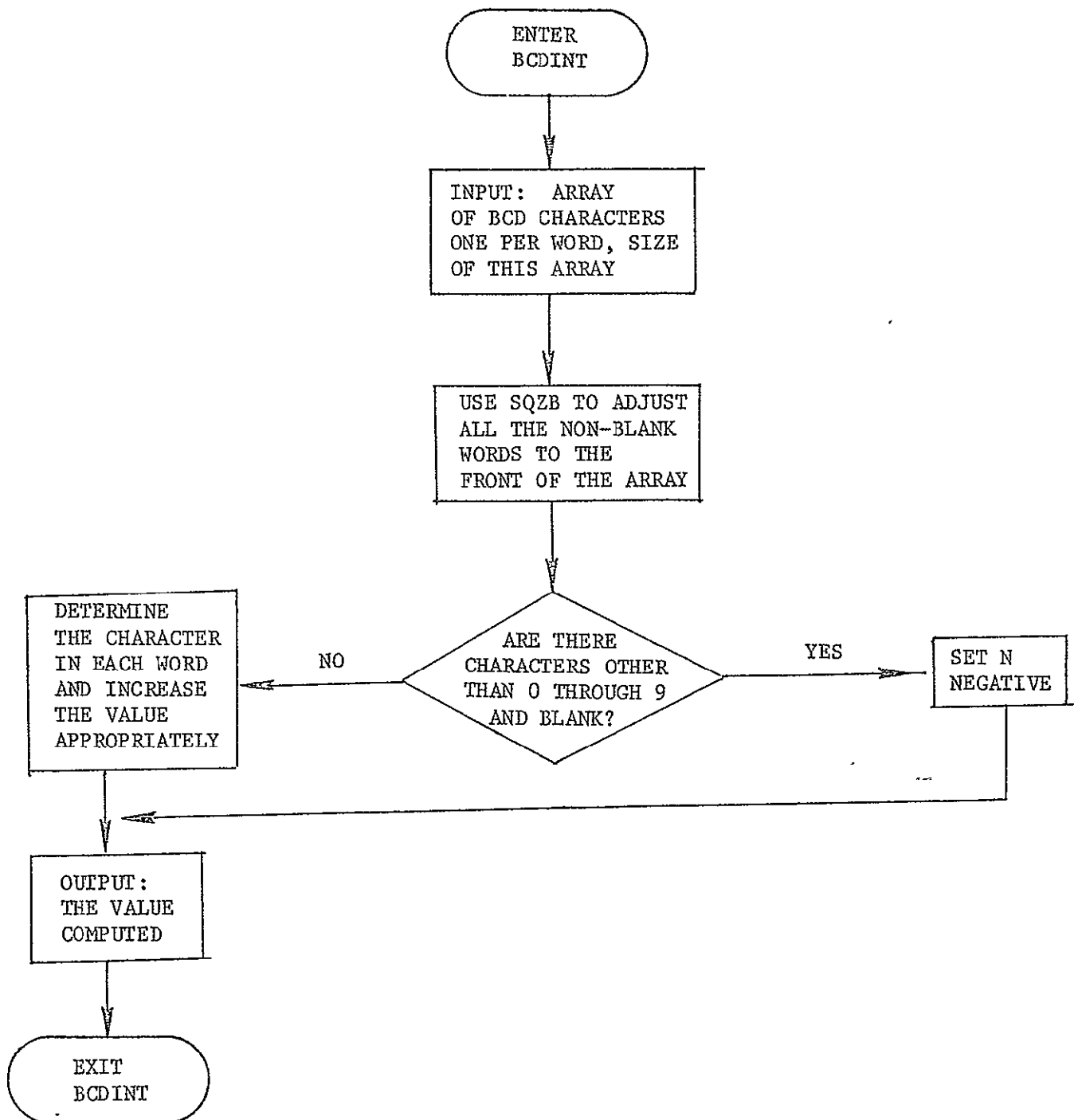
Flowchart 4.   Flowchart for Subroutine BCDINT

4.3 CDDATA

Data Record Processing Subroutine

Purpose

CDDATA reads an eighty character record in two parts. The first 72 characters may contain variable names, subscripts, data and other information while the remaining eight characters are available for sequencing or other user identification information.

Usage

CDDATA is called by TRWLØD for each input record. The record is read and resolved into the various fields, variable names, subscripts, control information, and individual data items. These fields are examined and categorized and loaded into a buffer (KRBF) with identifiers for use by TRWLØD. Numerous error checks are performed as the record is processed.

Calling Sequence

CDDATA ,

Input/Output

All input and output is through common.

Record Format

The records acceptable to CDDATA are free form in that the information may be in columns 1-72. Columns 73-80 may be used for sequencing or for miscellaneous information which is only read in and printed out on the user specified output unit.

All columns between two separators comprise a field. A separator may be an equal sign, a comma, an asterisk, a slash, a parenthesis, an R preceded by an integer, or apostrophes enclosing BCD characters. Blanks are permissible within all fields. An asterisk (*) except after an apostrophe for enclosing BCD characters terminates the scan, and speeds processing of the record.

Data information may be continued from one record to the next record by omitting the symbol name with storage of the information

40

continuing in the next consecutive cell. Data may be input for any location of a dimensioned variable (one-, two-, or three-dimensional array) by designating the subscript in parenthesis for a single dimensioned array (A = (3), 10.0), by designating the number of rows between slashes followed by the subscript for a two-dimensional array (B = /3/(3,3), 10.9), or by designating the number of rows and columns between slashes followed by the subscript for a three-dimensional array (C = /3,2/ (2,2,3), 9.99). A three-dimensional array is the largest accepted by subroutine CDDATA.

A BCD word preceding an equal sign (=) is a symbol, and all succeeding information is considered data for this symbol until the next symbol is encountered. Octal integers are input as ∅123456700000, where the number must be preceded by the letter ∅ and is stored from left to right as read.

The values of all symbols are stored in the buffer in the same format in which they appear in the record, i.e., BCD, integer, real, octal, or double precision. More than one symbol and its associated value(s) may appear in each record, i.e. X = 3.0, B = (2), 3.2, I = 4*.

Error/Action Messages

"ILLEGAL USE OF CHARACTER _____ IN OR AFTER COLUMN _____" This message is written when an illegal character is located in any of the various fields. A few of the possible errors are as follows:

a digit larger than 7 in an octal number, two periods in a real number, and a period in an exponent.

Restrictions

CDDATA will not store information in arrays having more than three dimensions.

Subroutines/Functions Used

BCDINT, PACK, SQZB

41

Method

CDDATA reads a record using a 72A1, A6, A2 format, prints this record image if requested, and processes the various fields while storing the information in a buffer to be returned to Subroutine TRWLOD. CDDATA scans the record until a field separator is located according to the separator of the field contents. The field and group type flags are defined as follows:

Field Type	Definition
1	Symbol followed by an equal sign (6 characters or less)
2	Single precision word (real)
3	Single precision word (integer)
4	Double precision word
5	BCD string preceded by an apostrophe
6	BCD string not preceded by an apostrophe
7	Octal integer

Group Type	Definition
20	Dimension group
30	Subscript group
40	Repeat group

The group type will always contain a field type 3, i.e., 23, 33, or 43, representing a dimension, subscript, or repeat integer, respectively.

When the type flag has been determined and the field processed, the type flag followed by the processed field is stored in the buffer. The procedure is repeated for all fields in the record until reaching an asterisk (*) or column 73, at which time a zero is stored in the next buffer cell signifying the end of the data. The number of buffer cells used for this record is stored in the buffer cell 109. The buffer has a storage capacity of 108 cells.

Each symbol requires three buffer cells, one for the type flag, one for the field (symbol name), and one for the symbol storage address. Each

double precision number used three buffer cells, one for the type flag and two for the field (value). Each BCD field uses two buffer cells plus the number of buffer cells (six record columns per cell) needed for the field (BCD string); one for the type flag, one indicating the number of BCD words in the field, and the rest for the field. All the other fields only require two buffer cells, one for the type flag and one for the field.

When a symbol is located, the table KSYMB is searched for this symbol, and if found, the address corresponding to the symbol is extracted from the table and stored in the buffer. If this symbol does not exist in the table KSYMB, it is an illegal input signified by a zero in the storage address cell of the buffer for this symbol.

Examples

Data record Y = /5/ (1,2) 29.4, (2,3) 100.9, 1.2, 7.6*

Buffer	Definition
KRBF(1) = 1	Type (symbol)
= Y	Field (symbol name)
= ____	Address of symbol
= 23	Type (dimension integer)
= 5	Field (number of rows)
= 33	Type (subscript integer)
= 1	Field (row subscript)
= 33	Type (subscript integer)
= 2	Field (column subscript)
= 2	Type (real)
= 9.4	Field (value of Y(1,2))
= 33	Type (subscript integer)
= 2	Field (row subscript)
= 33	Type (subscript integer)
= 3	Field (column subscript)
= 2	Type (real)
= 100.9	Field (value of Y(2,3))
= 2	Type (real)
= 1.2	Field (value of Y(3,3))
= 2	Type (real)

Buffer		Definition
KRBF(21)	= 7.6	Field (value of Y(4,3))
KRBF(22)	= 0	Type (end of record)
	⋮	
KRBF(109)	= 22	Number of buffer cells used for this record

Data record X = 123., THIS IS NOT A SYMBOL, 012, 1.D5*

Buffer		Definition
KRBF(1)	= 1	Type (symbol)
	= X	Field (symbol name)
	= ____	Address of symbol
	= 2	Type (real)
	= 123.	Field (value of X(1))
	= 6	Type (BCD string not preceded by an apostrophe)
	= 4	Field (number of BCD words)
	= THIS I	Field (value of X(2))
	= S NOT	Field (value of X(3))
	= A SYMB	Field (value of X(4))
	= OL	Field (value of X(5))
	= 7	Type (octal)
	= 120000000000_8	Field (value of X(6))
	= 4	Type (double precision)
	= }	Field } (value of X(7) and X(7)+1)
	= }	Field }
KRBF(17)	= 0	Type (end of record)
	⋮	
KRBF(109)	= 17	Number of buffer cells used for this record

A functional flowchart of this subroutine is shown in Flowchart 5, page 45.
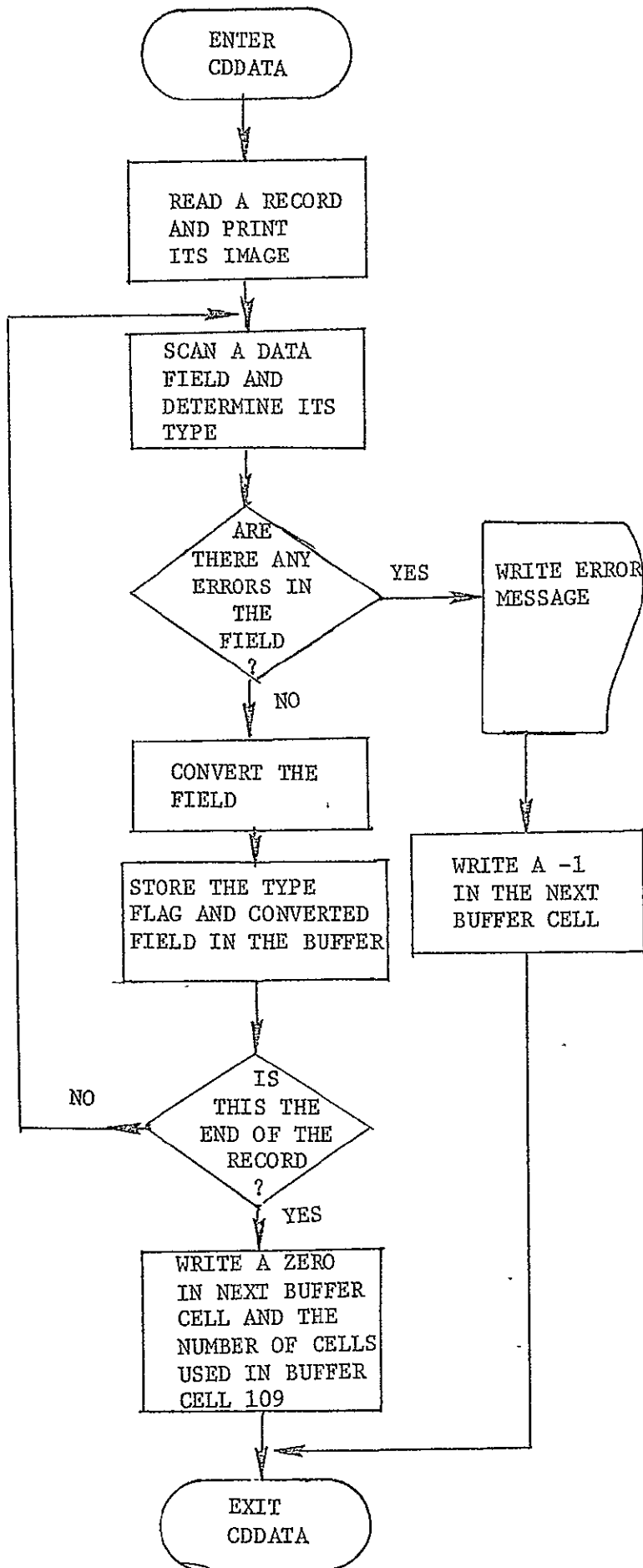
Flowchart 5. Flowchart for Subroutine CDDATA

45

4.4 DP2R

Double Precision to Real Conversion Function

Purpose

DP2R converts a double precision number stored in a type real variable
to a real number.

Functional Description

DP2R calls the intrinsic function SNGL to perform the conversion
from double precision to a real number.

Usage

Calling Sequence

DP2R   X

Input

Argument	Dimension	Definition
X	1	Value to be converted to real number

Output

Argument	Dimension	Definition
DP2R	1	Converted value

Error/Action Messages

None

Restrictions

None

4.5 R2DP

Real to Double Precision Convertion Function

Purpose

R2DP converts a real number to double precision to be stored in a type real variable.

Functional Description

R2DP calls the intrinsic function DBLE to perform the conversion from real to double precision.

Usage

Calling Sequence

     R2DP   X

Input

Argument	Dimension	Definition
X	1	Value to be converted to double precision

Output

Argument	Dimension	Definition
R2DP	1	Converted value

Error/Action Messages

None

4.6 PACK

Character Packing Subroutine

Purpose

    This subroutine packs BCD characters (one character per word) into an
array of six BCD characters per word.

Usage

    Calling Sequence

        PACK   NCARD, LWORD, N

    Input

Argument	Dimension	Definition
NCARD	N	An array in which all words have one left-justified BCD character. The remaining five characters per word are blanks.
N	1	The number of words in NCARD

    Output

Argument	Dimension	Definition
LWORD	$\left[\dfrac{N+5}{6} \right]$, where [ ] designated "greatest integer"	An array with six BCD characters. per word obtained by packing the input array NCARD
N	1	The number of words in LWORD

Error/Action Messages

    None

Restrictions

    None

Subroutines/Functions Used

    None

48

Method

PACK moves and combines BCD characters using bit manipulation and logical functions. The technique used to perform this function in the routine allows the subroutine to remain compatible for use on both the UNIVAC 1108 and the IBM 7094 computers. The following example shows a typical use of PACK: let NCARD be the eight word array (one left-justified BCD character per word) "EXAMPLES" (i.e., NCARD = Ebbbbb, Xbbbbb,etc.), on output, LWORD(1) = EXAMPL and LWORD(2) = ESbbbb. N should be input equal to 8, and it will be returned equal to 2. NCARD is not restricted to alphabetic characters but may contain any alphanumeric characters.

A flow chart indicating the logic used in Subroutine PACK is shown in Flowchart 6, page 50 .

```
                    ┌─────────────┐
                    │    ENTER    │
                    │    PACK     │
                    └─────────────┘
                           │
                           ▼
          ┌─────────────────────────────┐
          │  INPUT:  ARRAY WITH         │
          │  ONE BCD CHARACTER          │
          │  PER WORD LEFT-             │
          │  JUSTIFIED AND THE          │
          │  SIZE OF THE ARRAY          │
          └─────────────────────────────┘
                           │
                           ▼
          ┌─────────────────────────────┐
          │     DETERMINE SIZE          │
          │     OF OUTPUT               │
          │     ARRAY                   │
          │                             │
          └─────────────────────────────┘
                           │
                           ▼
          ┌─────────────────────────────┐
          │  USE BIT MANIPULATIONS      │
          │  AND LOGICAL FUNCTIONS      │
          │  TO PACK BCD CHARACTERS     │
          │  SIX PER WORD               │
          └─────────────────────────────┘
                           │
                           ▼
          ┌─────────────────────────────┐
          │  OUTPUT:  ARRAY OF          │
          │  SIX BCD CHARACTERS         │
          │  PER WORD WITH              │
          │  BLANK FILL IN LAST         │
          │  WORD AND THE SIZE          │
          │  OF THE ARRAY               │
          └─────────────────────────────┘
                           │
                           ▼
                    ┌─────────────┐
                    │    EXIT     │
                    │    PACK     │
                    └─────────────┘
```
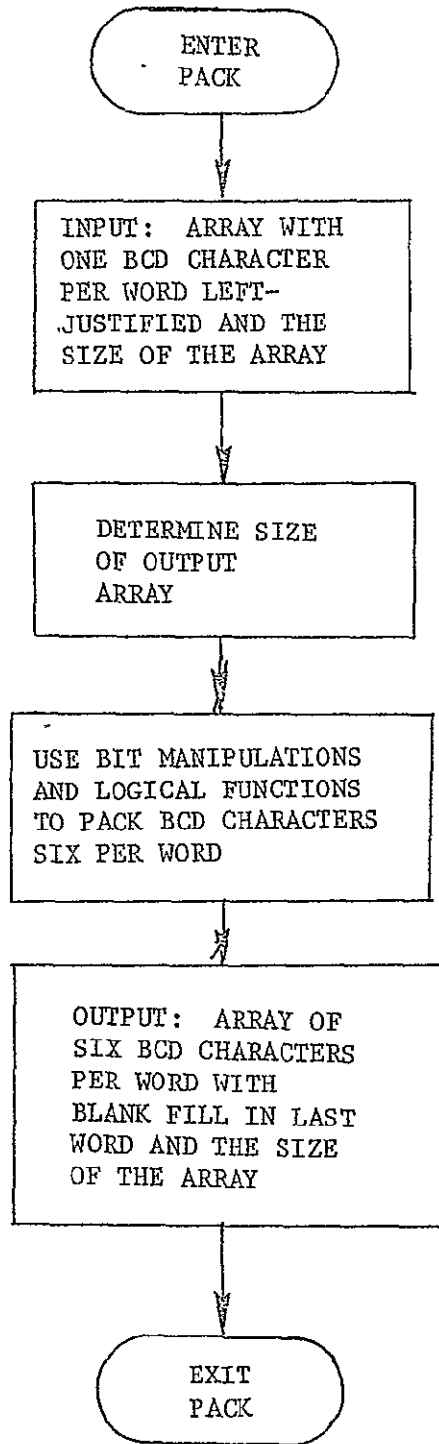
Flowchart 6.   Flowchart for Subroutine PACK

50

4.7 SQZB

Blank Deletion Subroutine

Purpose

The input language or numerical input may (in certain places), contain blanks which must be removed prior to processing. SQZB is called for this purpose.

Usage

Calling Sequence

SQZB   NCOL, N

Input

Argument	Dimension	Definition
NCOL	N	An array in which each word must be either all blanks or contain at least one non-blank BCD character
N	1	The number of words in the array NCOL

Output

Argument	Dimension	Definition
NCOL	N	If all the words of the NCOL array initially contained blanks or if all the words of the NCOL array contained at least one non-blank BCD character, then the NCOL array is unchanged. If, however, there is a mixture of the two, then the output NCOL array will have non-blank words at the beginning of the array and the remaining words of the array filled with blanks. See example in Method.
N	1	The number of non-blank words in the array NCOL

Error/Action Messages

None

None

Subroutines/Functions Used

None

Method

SQZB removes blanks from unpacked (one character per word) arrays of variable length. Non-blank words are left-justified in the array and the remaining words are blanked.

Example

Let the input array NCOL be ten words long with each word containing one BCD character (left-justified with blank fill): b, b, S, A, M, b, P, L, b, E (where "b" represents a blank). On return from SQZB the array NCOL will be: S, A, M, P, L, E, b, b, b, b, one character per word, with N=6.

A functional flowchart of this subroutine is shown in Flowchart 7, page 53.

```
                    ┌─────────────┐
                   (   ENTER       )
                   (   SQZB        )
                    └──────┬──────┘
                           │
                           ▼
         ┌─────────────────────────────────┐
         │  INPUT:   ARRAY                  │
         │  OF WORDS CONTAINING             │
         │  BLANKS AND/OR BCD               │
         │  CHARACTERS, AND THE             │
         │  ARRAY SIZE                      │
         └────────────────┬────────────────┘
                          │
                          ▼
         ┌─────────────────────────────────┐
         │  COUNT THE NUMBER                │
         │  OF NON-BLANK WORDS              │
         │         AND                      │
         │  LEFT-JUSTIFY THESE              │
         │  IN THE ARRAY                    │
         └────────────────┬────────────────┘
                          │
                          ▼
         ┌─────────────────────────────────┐
         │  OUTPUT:   THE ARRAY             │
         │  WITH NON-BLANK WORDS            │
         │  AT THE BEGINNING OF THE         │
         │  ARRAY AND REMAINING             │
         │  WORDS BLANKED, AND              │
         │  THE NUMBER OF NON-              │
         │  BLANK WORDS IN THE ARRAY        │
         └────────────────┬────────────────┘
                          │
                          ▼
                    ┌─────────────┐
                   (   EXIT SQZB   )
                    └─────────────┘
```
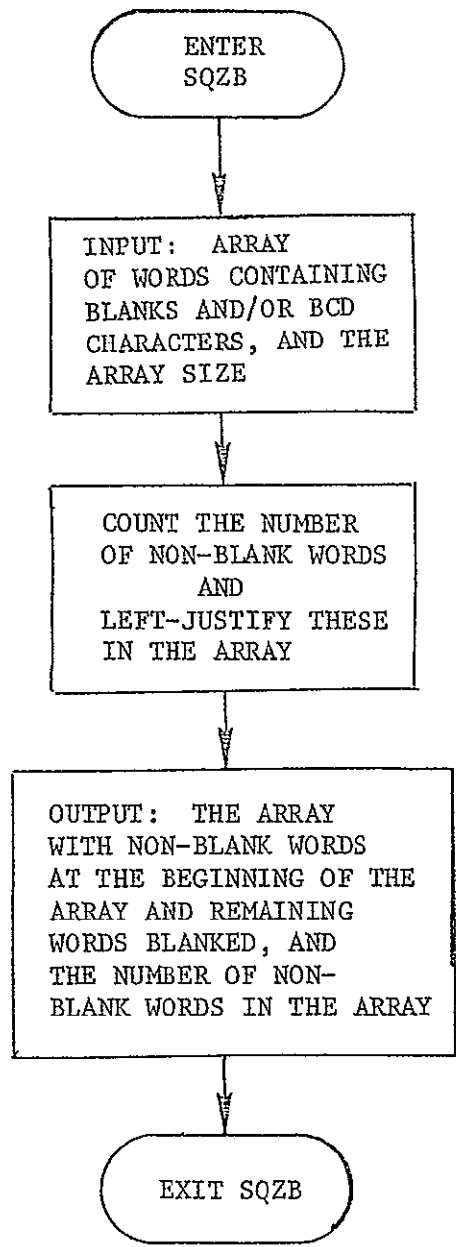
Flowchart 7.   Flowchart of Subroutine SQZB

4.8 TRWLOD

Numerical Data Input Subroutine

Purpose

TRWLOD is an input control routine which takes data contained by a buffer and stores the value(s) of each variable in specified core location(s).

Usage

Calling Sequence

TRWLOD   IIN, IØUT, K

Input

Argument	Dimension	Definition
IIN	1	Input BCD tape unit
IØUT	1	Øutput unit for record images. Suppress output if equal to 0.

Output

Argument	Dimension	Definition
K	1	Error flag = 2, indicates an error

Error/Action Messages

1) "ERROR IN SUBSCRIPT (SEE BUFFER WORD _____)"

    This error message is written for any of the following sub-
    script errors. The type flag from the buffer designates
    that a dimension integer is specified when the dimension
    has already been defined, the column subscript is being
    used without the number of rows having been specified, or
    the third subscript is being used without the number of
    columns being specified.

2) "INCORRECT DATA TYPE. NO CONVERSION POSSIBLE.
    _____ WAS EXPECTED, _____ FOUND ON CARD (SEE BUFFER WORD ___.)"

    This message is written when the type of the given value

is not consistent with the specifications in bits 18-20
of the address word NADR and the value cannot be converted
without changing its value.

3) "_____ IS AN ILLEGAL SYMBOL"

This message is written when the variable name in the
buffer is not a legal symbol.

4) "ILLEGAL DATA CARD CONTAINED IN BUFFER"

This message is written when the type flag is greater than
7, a symbol has not been defined (J=0) and the first buffer
cell contains a value other than a 1; i.e., the first data
card is a continuation card, or when non-integer subscript,
dimension, or repetition values have been used.

5) "ERROR INVOLVING REPETITION OF DATA FIELD (SEE BUFFER WORD ___)"
This message is written when either a negative or zero
number of repetitions have been requested or repetition of
a non-repeatable field is indicated; i.e., symbol name,
subscript, etc.

Subroutines Used

CDDATA

Functions Used

DP2R, R2DP

Method

TRWLOD calls Subroutine CDDATA to process a data record and returns
the information contained by a buffer. TRWLOD processes this information
storing the value(s) in the location(s) specified according to the given
subscript(s) (if any). TRWLOD checks the type of the value in the buffer
with the type specified for each variable, and if the types are not com-
patible, the value is converted providing the conversion can be accomplished
without altering the values. For instance, integers will be converted to
real numbers and real numbers converted to integers when conversion does
not cause truncation of the fractional part.

If the type flag from the buffer designates that a symbol is in the next buffer location, the symbol is stored in the variable "NAME." The buffer cell (stored in "NADR") following the symbol has the storage address in bits 21-35 and the type (real, integer, BCD, octal, etc.) of the value(s) expected in bits 18-20 (stored in "LL"). If the storage address is zero and the symbol is not "ENDCAS," this is an illegal symbol, and error message number 3 is written. If the symbol was "ENDCAS," control is returned to the calling subroutine.

A type flag equal to a two, three, four, five, six, or seven (type real, integer, double precision, BCD characters limited by apostrophes, BCD characters, or octal, respectively) designates the type of the value in the next buffer cell. If this type does not agree with "LL," the value is converted, if possible, without changing its value, e.g., integer to real; otherwise, error message number 2 is written. For any value being converted, the message "INPUT VALUE _____ CONVERTED TO _____" is written. If the type flag is the same as the value of "LL," "LL" is equal to zero, or if the value has been converted, the value is stored according to its subscripts (if any). A type flag equal to 1 causes error message number 4 to be written.

A type flag of 33 or 23 (type subscript integer or dimension integer, respectively) designates a subscript or dimension information is contained in the next buffer cell. When receiving subscript or dimension information, the subscript or dimension is determined, and if not correctly specified, error message number 1 is written.

A type flag of 43 (repeat integer) signified repetition of the following field is to take place the number of times specified in the next buffer location (location following the 43).

If "LL" is equal to zero, the values are stored as they are input without any conversion. A type flag equal to zero in the buffer indicates that all the information in the buffer has been processed.

After any error message is written, the buffer is dumped for use in diagnosing the error.

A functional flowchart of this subroutine is shown in Flowchart 8, page 57.

56

Flowchart 8. Flowchart for Subroutine TRWLOD

A

IS THE DATA THE CORRECT TYPE ?

YES

NO

CAN THE DATA BE CONVERTED ?

NO → WRITE ERROR MESSAGE 2

YES

D

CONVERT THE DATA TO THE CORRECT TYPE

ARE THERE ANY OTHER ERRORS ?

YES → WRITE ERROR MESSAGE 4

NO

STORE THE DATA IN THE SPECIFIED LOCATION

WRITE THE BUFFER

IS REPETITION COMPLETE ?

NO → A

YES

IS THIS THE END OF THE DATA?

NO → G

YES

IS THIS THE END OF THE CASE ?

NO → B

YES
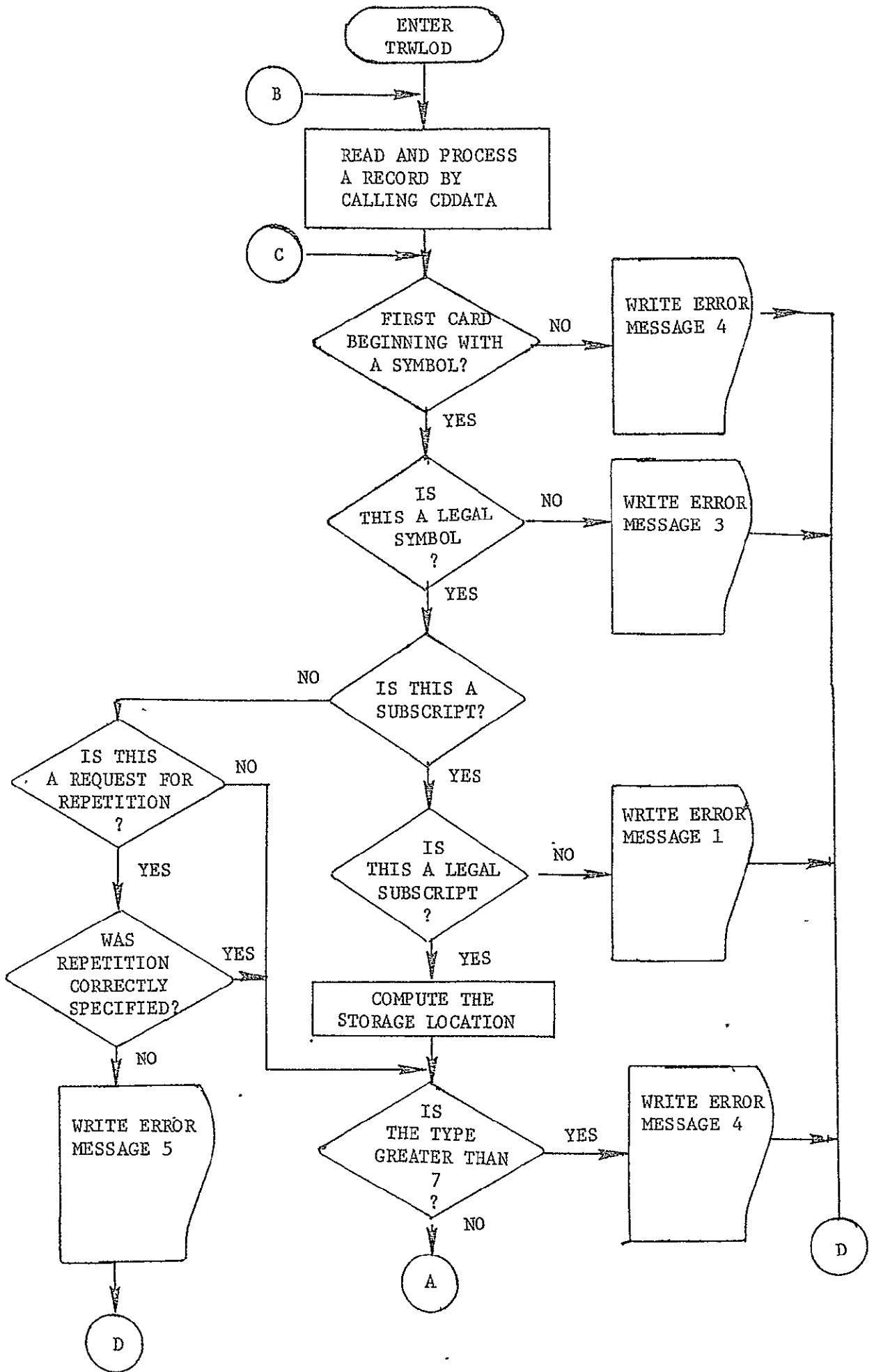
EXIT TRWLOD
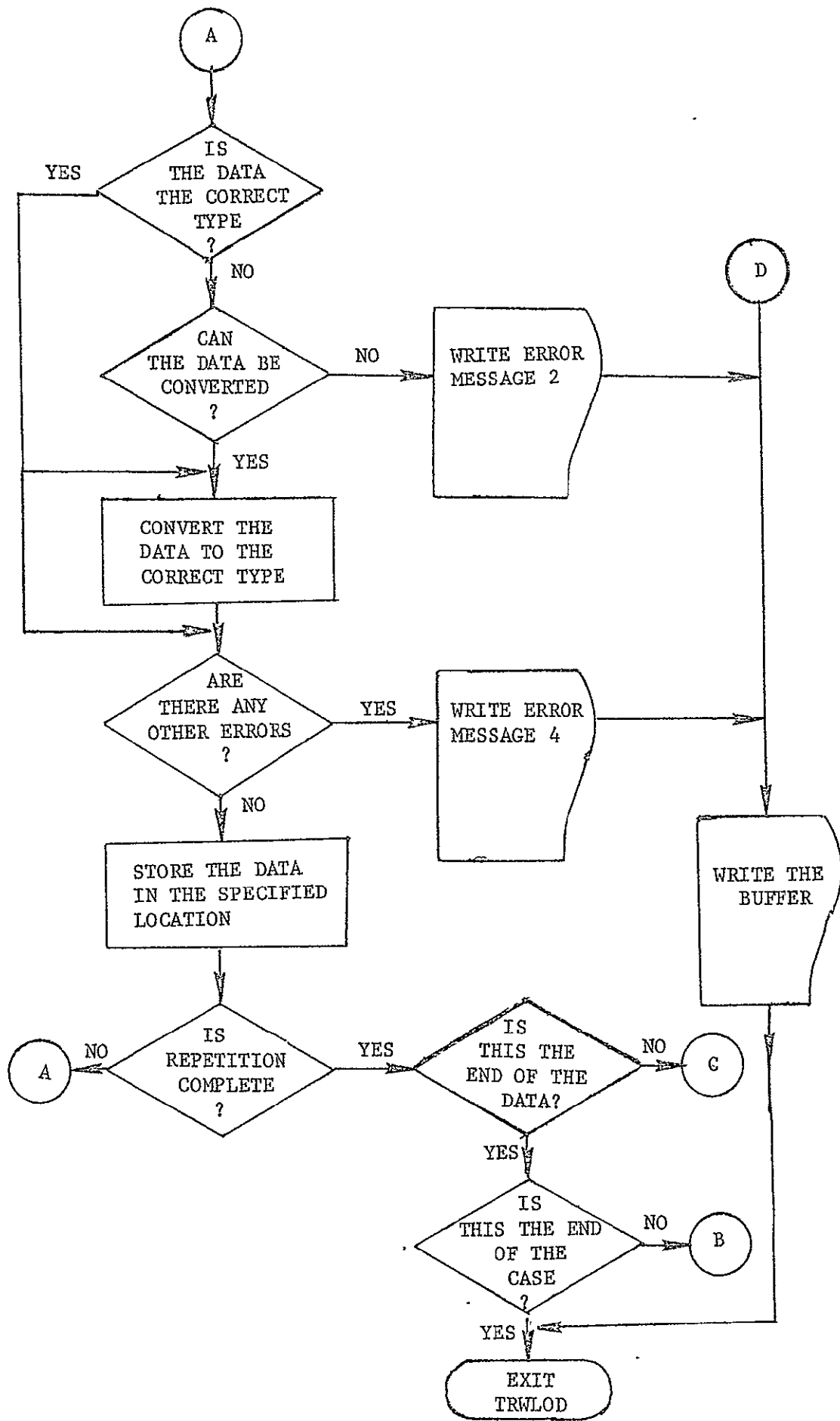
Flowchart 8. Flowchart for Subroutine TRWLOD (Continued)

4.9 PIPL/PIPLL

Fluid line subroutine simulating heat transfer and friction.

Purpose

Subroutine PIPL calculates the gas line properties and PIPLL calculates liquid line fluid properties that result from flowing through a line having heat transfer and friction.

Usage

Calling sequence:

PIPL   II

Input:

Argument	Dimension	Definition
II	1	Gas line number

Entry Point

PIPL	II

Output:

Argument	Dimension	Definition
II	1	Liquid line number

Name Common Variables	Dimension	Name Common Variables	Dimension
ALPHA	30	FRL	30,20
AREAI	30	GC	1
AREAK	30	GEE	1
AREAØ	30	HI	30,2
CP	30	HNPR	1
DIALI	30	HNRE	1
DIALØ	30	HØ	30,2
EMIS	30	HØEX	1
FB	1	HR	5

Name Common Variables	Dimension	Name Common Variables	Dimension
HRAD	30,2	PI	1
HRS	5	RFLAG	1
KA	2	RGAS	2
KLT	5	RHØG	30,20
KTHER	30	RHØL	3
LENGTH	5	TENV	1
MACH	30,20	TTEMP	30,20
NGR	30,2	TTTEMP	30,20
NØDEL	20	TWALL	30,2
NPLINE	30	UAØ	30,2
NPR	30,2	VEL	30,2
NRE	30,2	VISC	30
PG	30,20	WDØTG	30,20
PGT	30,20	WTHCØN	30

Subroutines/Functions used

ØPTCP, ØPTCV, ØPTTC, ØPTV, HPTCP, HPTCV, HPTTC, HPTV, ØPTD, HPTD, FCØMP1

Flowchart 9, page 61, shows the logic used in Subroutines PIPL/PIPLL.
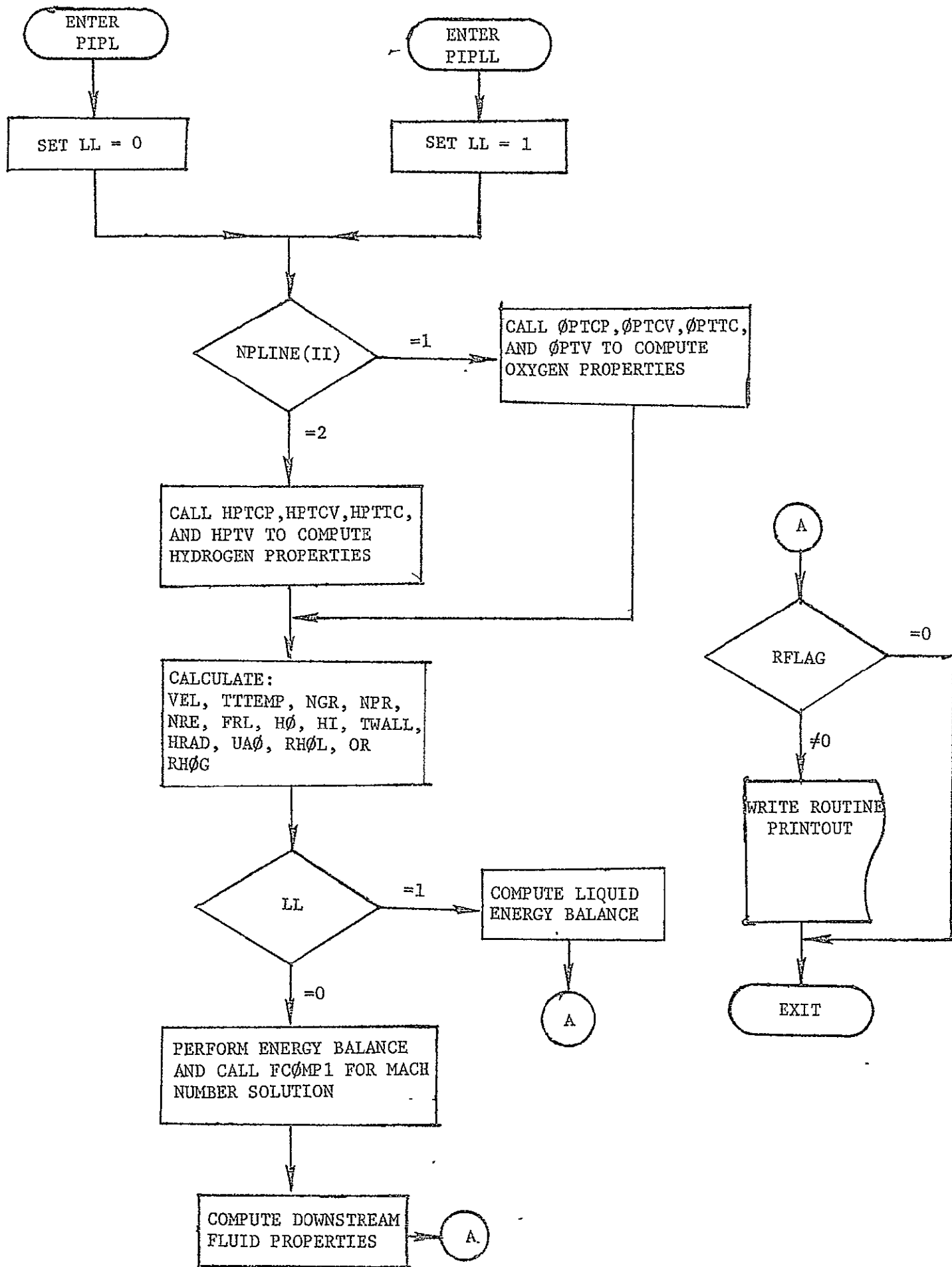
Flowchart 9. Flowchart for Subroutine PIPL/PIPLL

61

4.10 HEATEX

Heat Exchanger Subroutine

<u>Purpose</u>

This subroutine calculates the heat exchanger outlet conditions given
the fluid inlet conditions. The heat exchanger calculations are automatically
performed at twenty (20) segments along the heat exchanger.

<u>Usage</u>

<u>Calling Sequence</u>

HEATEX   LN,LI,LØ,TI1,TØ1,TI2,TØ2,PI1,PØ1,PI2,PØ2,WDI,WDØ,QT,XI1,XØ1

<u>Input</u>

<u>Argument</u>	<u>Dimension</u>
LN	1
LI	1
.LØ	1
TI1	1
TØ1	1
PI1	1
PØ1	1
WDI	1
WDØ	1
XI1	1
XØ1	1

<u>Øutput</u>

<u>Argument</u>	<u>Dimension</u>
TI2	1
TØ2	1
PI2	1
PØ2	1
QT	1

Name Common Variables	Dimension		Name Common Variables	Dimension
ARFL	5		PHI1	1
CPI	21		PHI2	1
CPØ	21		PHI3	1
DHYØ	5		PI	21
DIST	21		PØ	21
DSI	5		PRI	21
DTB	5		PRØ	21
FD	5		Q	21
FN	5		QUALI	21
HE	21		QUALØ	21
HI	21		REI	21
HØ	21		REØ	21
HW	21		RI	5
KI	21		RØ	5
KØ	21		SUI	21
KW	21		SVØ	21
LENGTH	5		THICK	5
LT	5		TI	21
MUI	21		TØ	21
MUØ	21		TWI	21
NT	5		TWØ	21
P	5		TYPE	5

Subroutines/Functions Used

PRØPTY, SAT, LATENT, BPRØPL, BPRØPG, NUSLET, CWALL

Flowchart 10, page 64, shows the logic used in HEATEX.
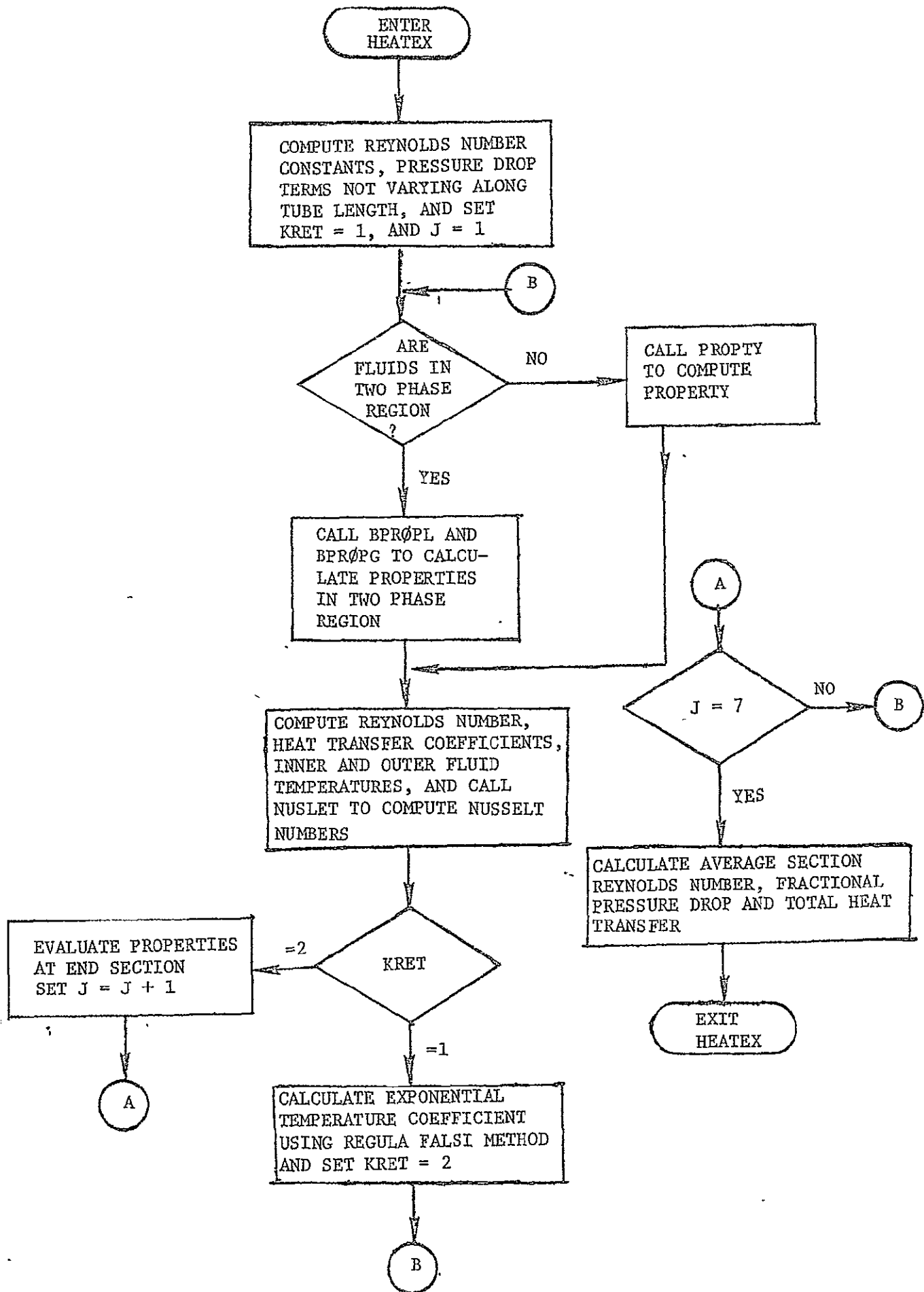
Flowchart 10.   Flowchart for Subroutine HEATEX

ENTER HEATEX

COMPUTE REYNOLDS NUMBER CONSTANTS, PRESSURE DROP TERMS NOT VARYING ALONG TUBE LENGTH, AND SET KRET = 1, AND J = 1

B

ARE FLUIDS IN TWO PHASE REGION ?

NO

CALL PROPTY TO COMPUTE PROPERTY

YES

CALL BPRØPL AND BPRØPG TO CALCULATE PROPERTIES IN TWO PHASE REGION

A

J = 7

NO

B

YES

CALCULATE AVERAGE SECTION REYNOLDS NUMBER, FRACTIONAL PRESSURE DROP AND TOTAL HEAT TRANSFER

COMPUTE REYNOLDS NUMBER, HEAT TRANSFER COEFFICIENTS, INNER AND OUTER FLUID TEMPERATURES, AND CALL NUSLET TO COMPUTE NUSSELT NUMBERS

EVALUATE PROPERTIES AT END SECTION SET J = J + 1

=2

KRET

=1

A

EXIT HEATEX

CALCULATE EXPONENTIAL TEMPERATURE COEFFICIENT USING REGULA FALSI METHOD AND SET KRET = 2

B

64

4.11   ADIAB

Adiabatic Gas Line Subroutine

Purpose

The purpose of this subroutine is to calculate fluid properties in a line where no heat is transferred.

Usage

Calling Sequence

ADIAB   II

Input

Argument	Dimension
II	1
CP	30
DIALI	30
FB	1
FRL	30, 20
GC	1
KA	2
MACH	30, 20

Name Common Variables	Dimension
NPLINE	30
NRE	30, 2
PG	30, 20
PGT	30, 20
RFLAG	1
RGAS	2
RHØG	30, 20
TTEMP	30, 20
TTTEMP	30, 20
VEL	30, 2
VISC	30
WDØTG	30, 20
XLENGTH	30

Subroutines/Functions Used

ØPTCP, ØPTCV, ØPTV, HPTCP, HPTCV, HPTV, FCØMP3

Flowchart 11, page 67, shows the logic used in Subroutine ADIAB.
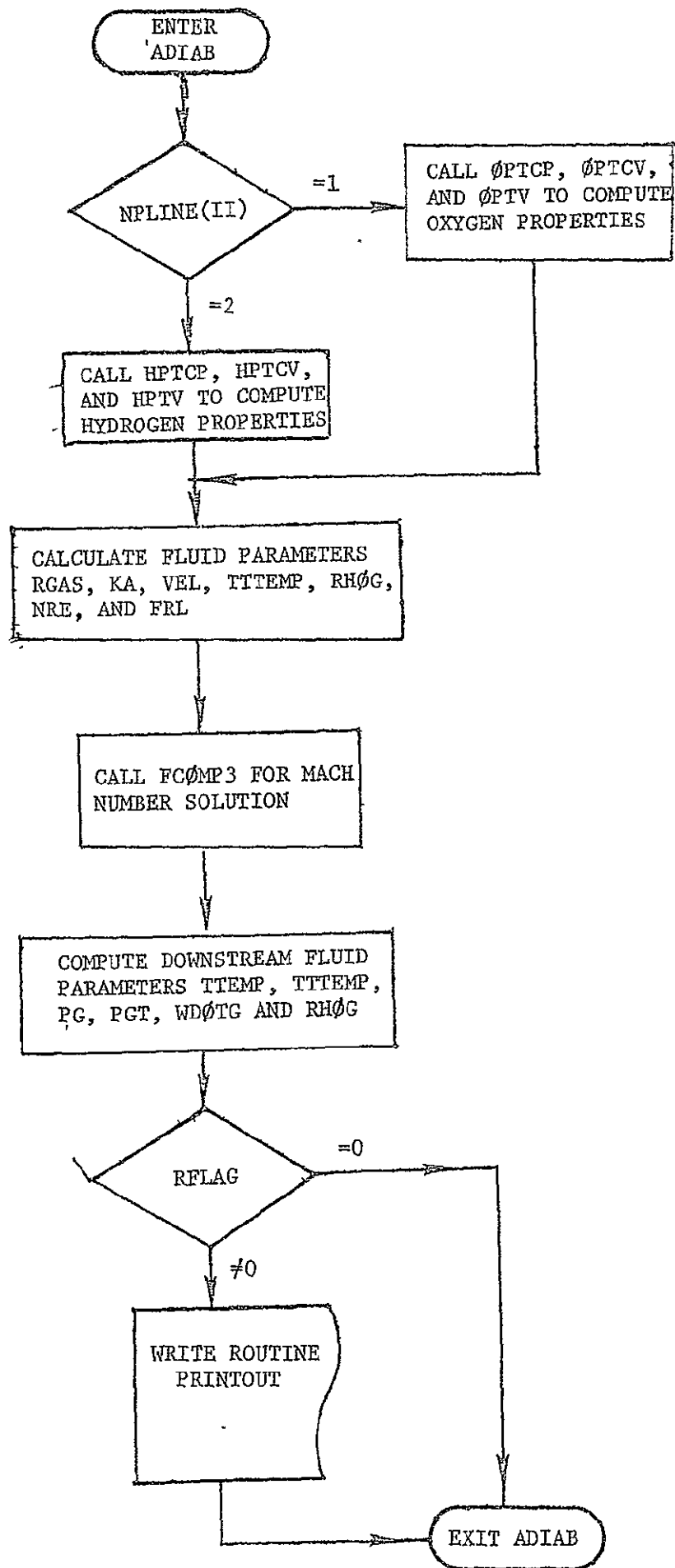
Flowchart 11. Flow Chart for Subroutine ADIAB

67

4.12   CMON

Monopropellant Combustion Subroutine

Purpose

The purpose of this routine is to calculate the combustion parameter
for a monopropellant combustor assuming a constant ratio of specific heats.

Usage

Calling Sequence

CMON   I

Input

Argument	Dimension
I	1

Name Common Variables	Dimension	Name Common Variables	Dimension
AJ	1	NØDEL	20
AREAE	6	NPLINE	30
AREAT	6	PATM	1
ARINJ	6, 2	PCI	6
CDC	6	PCN	6, 2
CTW	1	PDRØP	6
CV	6, 2	PE	6
GC	1	PG	30, 20
ICHAM	6, 2	PGT	30, 20
ICMØN	1	RGAS	2
ISP	6	RFLAG	1
ISPI	6	THRT	6
KA	2	TTEMP	30, 20
LAMDA	6	TTTEMP	30, 20
MEX	6	WDØTG	30, 20
NCHAM	1	WNØZ	6

Subroutines/Functions Used

OPTCP, OPTCV, HPTCP, HPTCV

Flowchart 12, page 70, shows the logic used in Subroutine CMON.

```
                        ┌─────────────┐
                        │   ENTER     │
                        │   CMØN      │
                        └─────────────┘
                               │
                               ▼
        ┌──────────────────────────────────────────┐
        │ COMPUTE OXYGEN AND HYDROGEN                │
        │ PROPERTIES BY CALLING ØPTCP,               │
        │ ØPTCV, HPTCP, HPTCV                        │
        └──────────────────────────────────────────┘
                               │
                               ▼
        ┌──────────────────────────────────────────┐
        │ CALCULATE EXIT MACH NUMBER                 │
        │ OF ALL CHAMBERS BY NEWTON                  │
        │ RAPHSON METHOD                             │
        └──────────────────────────────────────────┘
                               │
                               ▼
  ┌────────────────┐   ≠1  ◇ AJ ◇   =1   ┌────────────────┐
  │ CALCULATE      │◄──────        ──────►│ CALCULATE AREA │
  │ CHAMBER        │                      │ OF INJECTION   │
  │ PRESSURE       │                      │                │
  └────────────────┘                      └────────────────┘
          │                                        │
          ▼                                        ▼
```
```
  ┌──────────────────────┐  =2   ◇ CTW ◇  =1  ┌──────────────────────┐
  │ CALCULATE CONSTRAINT  │◄────         ────►│ CALCULATE CONSTRAINT  │
  │ EQUATION FOR CHAMBER  │                    │ EQUATION FOR SPECIFIC │
  │ PRESSURE              │                    │ IMPULSE               │
  └──────────────────────┘                    └──────────────────────┘
          │                   │ =3                        │
          │                   ▼                           │
          │        ┌──────────────────────┐               │
          │        │ CALCULATE CONSTRAINT  │               │
          │        │ EQUATION FOR THRUST   │               │
          │        └──────────────────────┘               │
          │                   │                           │
          ▼                   ▼                           ▼
                      ◇ RFLAG ◇    ≠0   ┌──────────────────┐
                          │       ─────►│ WRITE ROUTINE    │
                          │             │ PRINTOUT         │
                          │ =0          └──────────────────┘
                          ▼                      │
                     ┌─────────┐                 │
                     │  EXIT   │◄────────────────┘
                     └─────────┘
```

Flowchart 12.   Flowchart for Subroutine CMØN   70

4.13 CHAM/TURBØP

Bi-propellant Combustor and Turbopump Subroutines

Purpose

The bi-propellant combustor models either a LO_2/H_2 gas generator or a LO_2/H_2 combustor. The combustor performance data is calculated based on curve fit data input as a function of mixture ratio for the propellants combining into the combustor. The combustor can operate as a gas generator and therefore be connected to either the turbopump or the heat exchanger model. The turbopump model simulates a pump connected through a gear box driven by a gas turbine.

Usage

Calling Sequence

CHAM   I

Input

Argument	Dimension
I	1

Entry Point

TURBØP   I

Input

Argument	Dimension
I	1

Name Common Variables	Dimension	Name Common Variables	Dimension
AJ	1	CØNCT	3,6
AREAT	6	CP	30
ARINJ	6,2	CPCX	6
ATD	5	CP2	5
ATI	5	CSTAR	6
CEF1	5	CS2	4
CEF2	5	CV	6,2
CF	6	CVEL	1

| Name Common Variables	Dimension	Name Common Variables	Dimension
DIAD	5	PØWT	5
DIAP	5	PØW1	5
DIAT	5	PØW2	5
ETAT	1	PØW3	5
FB	1	PPI	5
GC	1	PPØ	5
GR	5	PTI	5
ICHAM	6,2	PWØ	5
IPUMI	5	PWØ	5
IPUMØ	5	PW1	5
ISP	6	PW2	5
ISPT	6	R	1
IS2	4	RFLAG	1
KA	2	RGAS	2
KTD	5	RHØL	3
KTI	5	RPMD	5
MR	6	RPMT	5
MWC	6	TC	
MW2	4	TC2	4
NCØEF	1	THRT	6
NØDEL	20	TTEMP	30, 20
NPLINE	30	TTI	5
PCI	6	TTØ	5
PDELP	5	TTTEMP	30, 20
PDRØP	6	U	1
PG	30,20	WDØTG	30, 20
PGT	30,20	WNØZ	6
PMR	6	WP	5
PØWC	5	WT	5
PØWO	5	WTGC	5
PØWP	5		

72

Subroutines/Functions Used

ØPTCP, ØPTCV, HPTCP, HPTCV

Flowchart 13, page 74, shows the logic used in Subroutine CHAM/TURBØP.
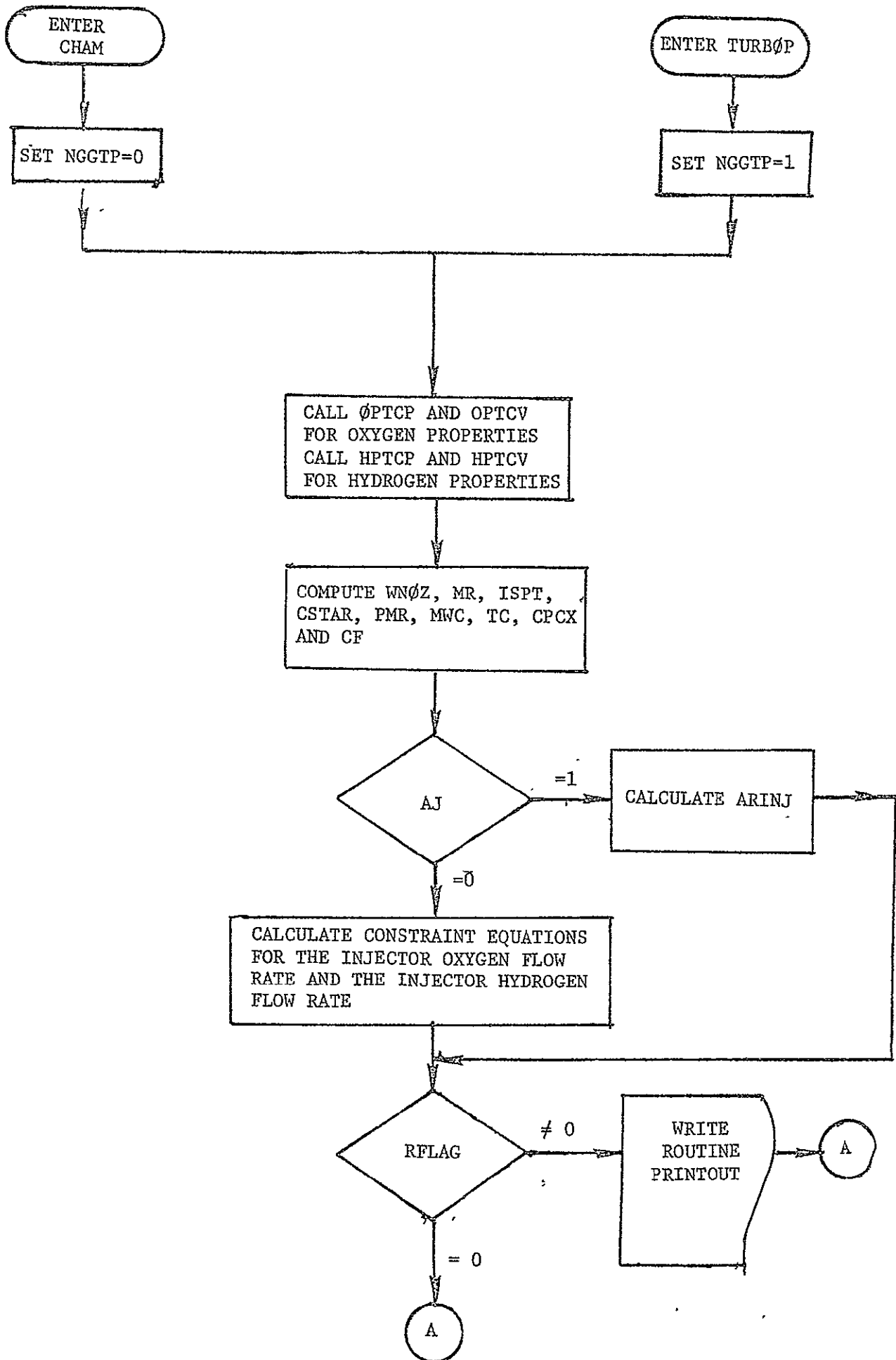
Flowchart 13.   Flowchart for Subroutine CHAM
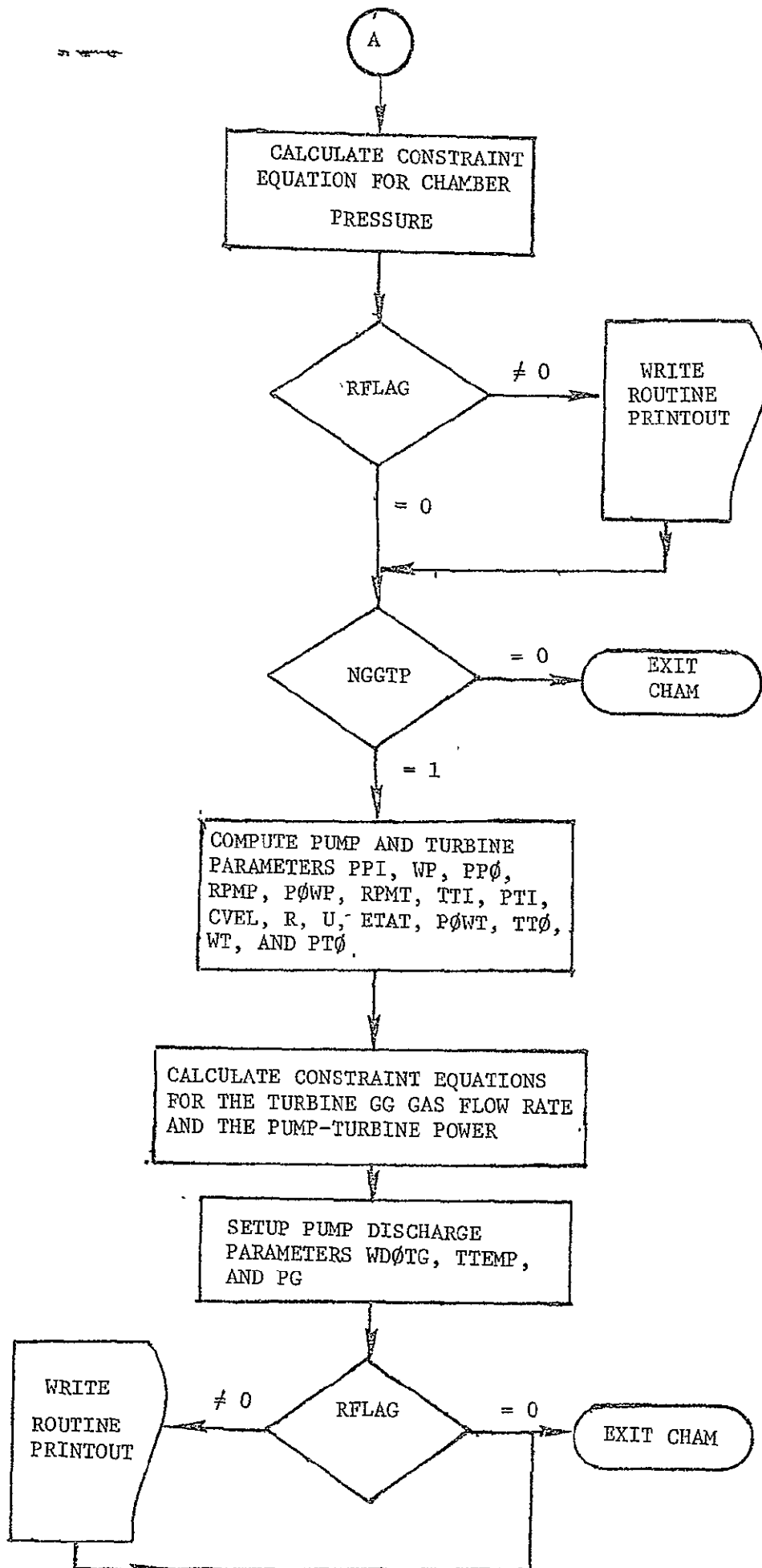
Flowchart 13. Flowchart for Subroutine CHAM (Continued)

4.14   ISØTH

Isothermal Gas Line Subroutine

Purpose

This subroutine simulates an isothermal gas line and determines downstream fluid conditions.

Usage

Calling Sequence

ISØTH   II

Input

Argument	Dimension
II	1

Name Common Variables	Dimension	Name Common Variables	Dimension
CP	30	PGT	30,20
DIALI	30	RFLAG	1
FB	1	RGAS	2
FRL	30,20	RHØG	30,20
GC	1	TTEMP	30,20
KA	2	TTTEMP	30,20
MACH	30,20	VEL	30,2
NPLINE	30	VISC	30
NRE	30,2	WDØTG	30,20
PG	30,20	XLENGL	30

Subroutines/Functions Used

ØPTCP, ØPTLP, ØPTV, HPTCP, HPTCV, HPTV, FCØMP2

Flowchart 14, page 77, shows the logic used for the Subroutine ISOTH.
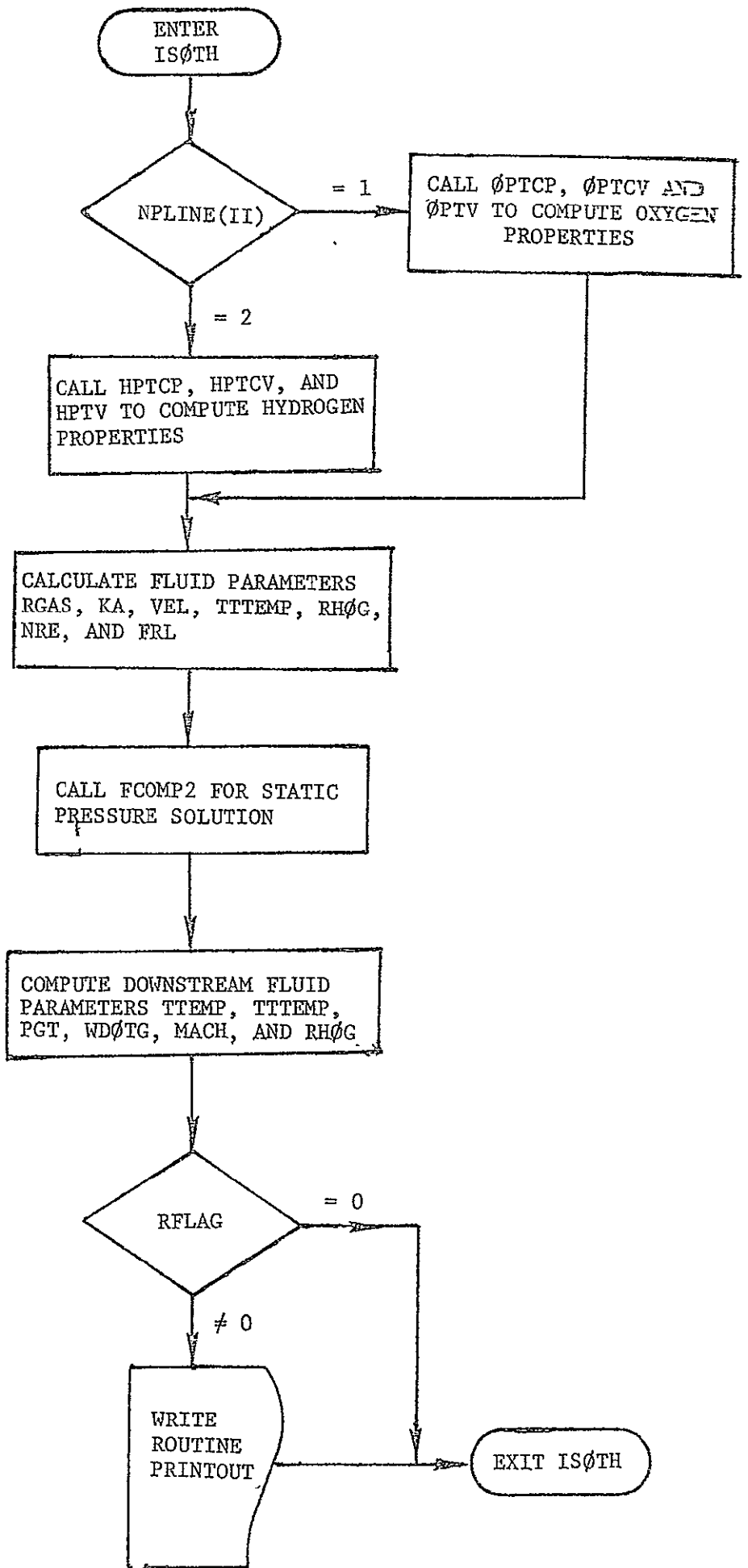
Flowchart 14. Flowchart for Subroutine ISØTH

5.0 NOMENCLATURE

SYMBOLS	DESCRIPTION	UNITS
ARINJ	Oxidizer area injector	in^2
ALPHA	Angle line makes with horizontal	deg
AREAI	Inside area of line	in^2
AREAT(I)	Combustor throat area combustor I	
AREG(I)	Maximum area of regulator assuming sonic flow of regulator (I)	in^2
ATD(I)	Turbine duct diaxhage area	in^2
AVENT(I)	Flow area vent valve tank (I)	in^2
CDC(I,J)	Discharge coefficient through injector monopropellant	
CEFI(I)	Turbine efficiency coefficient curve	–
CEF2(I)	Turbine efficiency coefficient curve	–
CP	Specific heat at constant pressure	BTU/lbm-°R
CPO, CPOG, CPI	Specific heat at constant pressure outside, gas, inside in heat exchanger	BTU/lbm-°R
CP1, 2(I)	Specific heat at constant pressure of tank I	BTU/lbm-°R
CSTAR (I)	Characteristic exhaust velocity combustor I	ft/sec
CV	Specific heat at constant volume of tank I	BTU/lbm-°R
CV(I,J)	Discharge coefficient through injector, bipropellant	
CVEL(I)	Isentropic spouting velocity of turbopump (I)	ft/sec
DELXL(II)	Line segment (line II)	ft
DHYO	Hydraulic diameter of heat exchanger	lbm/in-sec
DIAD(I)	Pump design diameter of turbopump (I)	in
DIALI, DIALØ(II)	Diameter line, inside, outside (line II)	in

SYMBOLS	DESCRIPTION	UNITS
DIAP(I)	Pump diameter of turbopump (I)	in
DIAT(I)	Turbine rotor diameter	in
DX	Length of heat exchanger	in
EMIS	Emissivity	-
ENTH,O,I,G,L	Enthalpy outside, inside, gas, liquid in heat exchanger	BTU/lbm
EP(I)	Pump efficiency of turbopump (I)	-
ETAT(I)	Turbine efficiency	-
FBPC(I)	Pressure constraint of junction (I)	-
FBWC(I)	Flowrate constraint of junction (I)	-
FFACTI, O	Friction factor inside, outside in heat exchanger	-
FRL	Friction factor	-
GAM	Specific heat ratio C_p/C_v	-
GC	32.174	$lbm\text{-}ft/sec^2 lbf$
HE	Equivalent heat transfer coefficient in heat exchanger	$BTU/in^2\text{-}{}^\circ R\text{-}hr$
HI	Inside film coefficient	$BTU/hr\text{-}ft^2\text{-}{}^\circ R$
HI, O	Heat transfer coefficient inside, outside in heat exchanger	$BTU/in^2\text{-}sec\text{-}{}^\circ R$
HØ	Outside film coefficient	$BTU/ft^2\text{-}{}^\circ R\text{-}hr$
HR	Hydraulic Resistance	$sec^2/ft\text{-}in^2$
HRAD	Radiation heat transfer coefficient	$BTU/hr\text{-}ft^2\text{-}{}^\circ R$

ISP(I)	Vacuum specific impulse combustor I	sec
K	Fluid thermal conductivity in heat exchanger	BTU/in-sec-^{o}R
KA	Specific heat ratio	–
KAY	Ratio of specific heats combustor	–
KLT	Total loss coefficients; bends, contractions, etc.	–
KTD(I)	Turbine discharge coefficients of turbopump (I)	–
KTHER	Fluid thermal conductivity	BTU/sec-ft-^{o}R
KTI(I)	Turbine inlet coefficient of turbopump(I)	–
MACH(II, JJ)	Mach number down pipe, line II, node JJ	^{o}R
MARTO(I)	Martinelli parameter	–
MR(I)	Mixture ratio combustor I	lbm/sec
MUI	Viscosity fluid in heat exchanger	lbm/in-sec
NGR	Grashof number	–
NLINJU(I)	Number of inlet or outlet lines at junction (I)	–
NPR	Prandtl number	–
NRE	Reynolds number	–
P	Fluid pressure in heat exchanger	psia
P	Pressure in tank I	psia
PB(I)	Pressure boundary constraint equation in the Ith pressure boundary	–
PCI(I)	Chamber pressure, combustor I	psia
PCORI, O	Pressure drop correction for two phase flow, inside, outside in heat exchanger	–
PDROP(I,J)	Pressure drop through injector J, combustor I	psia

PG(II,JJ)	Pressure, line II, node JJ	psia
PG(II,JJ)	Pressure, line II, node JJ	psia
PHI1	Correction for two phase flow boiling in heat exchanger	-
PHI2	Entrance effects correction in heat exchanger	-
PHI3	Asymmetric heating correction in heat exchanger	-
PHI4	Surface roughness correction in heat exchanger	-
POW,0,1,2,3 (I)	Coefficients in pump power design curve	-
POWP(I)	Pump power of turbopump (I)	ft-lbf/sec
POWT(I)	Turbine power of turbopump (I)	ft-lbf/sec
PRE(I)	Pressure regulator downstream of regulator I	psia
PW0,1,2, (I)	Coefficients in pump pressure design curve	-
Q	Heat flux in heat exchanger	BTU/sec-in^2
R(I)	Gas constant in tank I	B/lb-^{o}R
RGAS(I)	Gas constant in line	$\dfrac{ft-lbm}{lbf-^oR}$
RHOG,RHOL(II,JJ)	Fluid density, gas, liquid (line II, node JJ)	lbm/ft^3
RHOL(I)	Density in tank I	lbm/ft^3
RI, RO	Heat exchanger radius	in
RPMD(I)	Pump design speed	RPM
RPMP(I)	Pump speed of turbopump (I)	RPM
RPMT(I)	Turbine Speed	RPM
SVO, O,I,G,L	Specific volume outside, inside, gas, liquid in heat exchanger	in^3/lbm

SVBAR	Change in specific volume average in heat exchanger	in^3/lbm
T	Average gas temperature in tank	^oR
TC(I)	Chamber temperature combustor I	^oR
TENV	Temperature environment	^oR
THICK	Wall thickness in heat exchanger	in
THRT(I)	Thrust, combustor I	lbf
TIME	Time	Sec
TIN(I)	Gas inlet temperature in tank I	^oR
TPI(I)	Pump inlet temperature of turbopump (I)	^oR
TP∅(I)	Pump discharge temperature of turbopump (I)	^oR
TTEIS	Turbine isentropic discharge temperature of turbopump (I)	^oR
TTEMP(II,JJ)	Static temperature fluid line II, node JJ	^oR
TTI(I)	Turbine inlet temperature of turbopump(I)	^oR
TTO(I)	Turbine discharge temperature of turbo-pump (I)	^oR
TTTEMP(II,JJ)	Total temperature stagnation fluid, line II, node JJ	^oR
TWI,TWO	Discharge temperature in heat exchanger, inside, outside	^oR
TWALL	Wall temperature	^oR
UA∅	Overall heat transfer coefficient	$\dfrac{BTU}{^oR\ sec}$
VEL(II,JJ)	Velocity fluid, line II node JJ	ft/sec
VISC	Viscosity	lbm/ft-sec
VTANK(I)	Volume of tank I	ft^3

W	Flowrate	lbm/sec
W(I,1)	Oxidizer flowrate combustor I	lbm/sec
W(I,2)	Fuel flowrate combustor I	lbm/sec
WD, WDØTG(II,JJ)	Flowrate, line II, node JJ	lbm/sec
WGASI, WGASØ	Flowrate in heat exchanger, inside, outside	lbm/sec
WNØZ(I)	Nozzle flowrate combustor I	lbm/sec
WOL(I)	Mass of liquid in tank (I)	lbm
WP (I)	Pump flowrate	lbm/sec
WT (I)	Turbine flowrate	lbm/sec
XK (1)	Cross sectional area of valve times valve discharge coefficient of valve I	in^2
α	Mass ratio, $m_2/(m_1 + m_2)$	-
0.1714×10^8	Stefan-Boltzmann constant	$\dfrac{BTU}{hr \ ft^2 \ ^\circ R^4}$

6.0 REFERENCES

1. P. F. Thompson, T. J. Walsh, "Characterization of Attitude Control Propulsion System, MSC/TRW Task 705-1," TRW Technical Report Number 17618-H179-R0-00, June 1971.

2. P. F. Thompson, R. C. Turley, "Steady State Attitude Control Propulsion Systems Computer Program Documentation and User's Manual," TRW Technical Report 17618-H179-R0-00, Volume II.

6.0 REFERENCES

1. P. F. Thompson, T. J. Walsh, "Characterization of Attitude Control Propulsion System, MSC/TRW Task 705-1," TRW Technical Report Number 17618-H179-R0-00, June 1971.

2. P. F. Thompson, R. C. Turley, "Steady State Attitude Control Propulsion Systems Computer Program Documentation and User's Manual," TRW Technical Report 17618-H179-R0-00, Volume II.

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