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FINAL REPORT

SHUTTLE CRYOGENICS SUPPLY SYSTEM

OPTIMIZATION STUDY

VOLUME V B-1

PROGRAMMERS MANUAL
FOR
MATH MODELS

CONTRACT NAS9-11330

Prepared for Manned Spacecraft Center
by
Manned Space Programs, Space Systems Division

LOCKHEED MISSILES & SPACE COMPANY, INC.
A SUBSIDIARY OF LOCKHEED AIRCRAFT CORPORATION

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FOREWORD

This Final Report provides the results obtained in the Shuttle Cryogenics Supply System Optimization Study, NAS 9-11330, performed by Lockheed Missiles & Space Company (LMSC) under contract to the National Aeronautics and Space Administration, Manned Spacecraft Center, Houston, Texas. The study was under the technical direction of Mr. T. L. Davies, Cryogenics Section of the Power Generation Branch, Propulsion and Power Division. Technical effort producing these results was performed in the period from October 1970 to June 1973.

The Final Report is published in eleven volumes*:

Volume I	–	Executive Summary
Volumes II, III, and IV	–	Technical Report
Volume V A-1 and V A-2	–	Math Model – Users Manual
Volume V B-1, V B-2, V B-3, and V B-4	–	Math Model – Programmers Manual
Volume VI	–	Appendices

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*The Table of Contents for all volumes appears in Volume I only. Section 12 in Volume III contains the List of References for Volumes I through IV.

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Section 1

INTRODUCTION TO THE CRYOGENIC INTEGRATED MATH MODEL PROGRAM (TCIMM)

1.1 PROGRAM DESCRIPTION

The Integrated Math Model for Cryogenic Systems is a flexible, broadly applicable systems parametric analysis tool. The program will effectively accommodate systems of considerable complexity involving large numbers of performance dependent variables such as are found in the individual and integrated cryogen systems. Basically, the program logic structure pursues an orderly progression path through any given system in much the same fashion as is employed for manual systems analysis.

The system configuration schematic is converted to an alpha-numeric formatted configuration data table input starting with the cryogen consumer and identifying all components, such as lines, fittings, valves, etc., each in its proper order and ending with the cryogen supply source assembly. Then, for each of the constituent component assemblies, such as gas generators, turbo machinery, heat exchangers, accumulabors, etc., the performance requirements are assembled in input data tabulations. Systems operating constraints and duty cycle definitions are further added as input data coded to the configuration operating sequence. Characteristic performance data over the range of temperatures, pressures and flow rates of interest for each of the functional component assemblies, is input to the program or table lookup data arrays to be called as needed in the analysis sequences. The use of table lookup data combined with closed-form solution analysis, where needed, permits the rapid computation of the desired parameters as the analysis proceeds through the system configuration.

The program will size the system to fit the operating demands and constraints and produces as output the component and system hardware size and weight, propellant (or reactant) weight, vented fluid weight, and such analytical information (i.e., computed performance values) as may be desired. The analytical results are displayed both as time dependent data tabulations and summary table data.

1.1.1 Program Purpose

The intended purpose of the program is to provide an analytical tool which permits rapid parametric evaluation of the various types of cryogenics spacecraft systems currently under study in the national space program. The mathematical techniques built into the program provides the capability for in-depth analysis (combined with rapid problem solution) for the production of a larger quantity of soundly based trade-study data than normally would be obtained in hand calculations. Program flexibility in accommodating advanced systems resides in its modular type programming which permits program growth with simple addition of new subroutines and the addition of variables to existing common banks. Conversely, the program is easily dismantled if it is desired to limit analysis to only one or two systems and utilize a smaller computing machine.

In summary, the purpose of the program may be said to be that of providing an improved general analysis tool for cryogen technology applications.

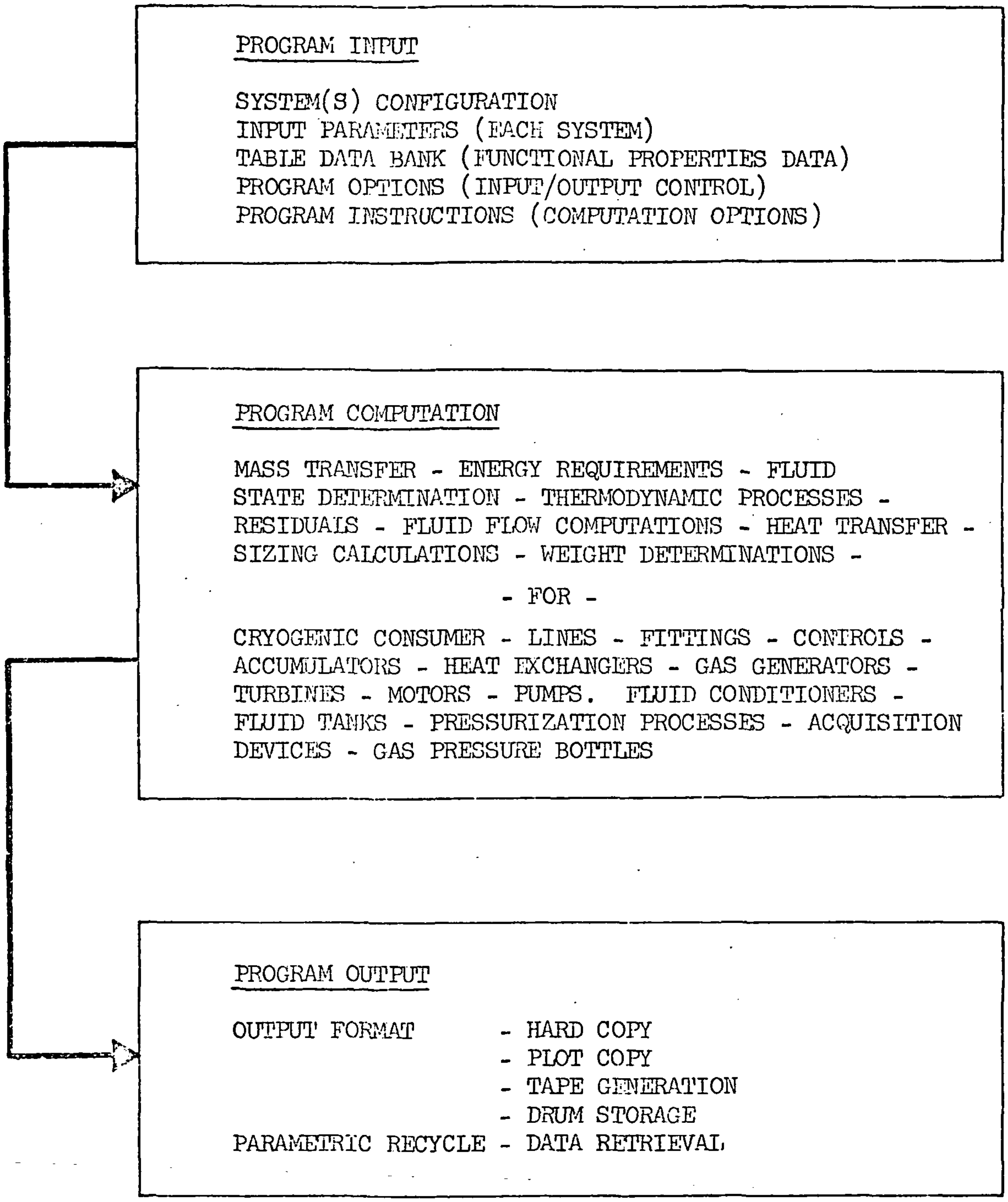
1.2 PROGRAM STRUCTURE

The Integrated Math Model for Cryogenic Systems consists essentially of three major sections as illustrated in Figure 1.2-1. Within each of the major sections the structure is further broken into block subsections, each of which is reserved for specific functions of data management, data utilization or analytical data display.

1.2.1 Program Input Data Logic

Of necessity, the program requires a rather large data bank capable of providing characteristic performance data for the wide variety of component assemblies found in typical cryogen systems.

Program data requirements for the Integrated Math Model are divided into two types. The first type consists of the "semi-permanent" data tables which the program employs to compute performance, weight, property, and other characteristics as a function of up to four variables per run.



PROGRAM INPUT

SYSTEM(S) CONFIGURATION
INPUT PARAMETERS (EACH SYSTEM)
TABLE DATA BANK (FUNCTIONAL PROPERTIES DATA)
PROGRAM OPTIONS (INPUT/OUTPUT CONTROL)
PROGRAM INSTRUCTIONS (COMPUTATION OPTIONS)

PROGRAM COMPUTATION

MASS TRANSFER - ENERGY REQUIREMENTS - FLUID STATE DETERMINATION - THERMODYNAMIC PROCESSES - RESIDUALS - FLUID FLOW COMPUTATIONS - HEAT TRANSFER - SIZING CALCULATIONS - WEIGHT DETERMINATIONS -

- FOR -

CRYOGENIC CONSUMER - LINES - FITTINGS - CONTROLS - ACCUMULATORS - HEAT EXCHANGERS - GAS GENERATORS - TURBINES - MOTORS - PUMPS. FLUID CONDITIONERS - FLUID TANKS - PRESSURIZATION PROCESSES - ACQUISITION DEVICES - GAS PRESSURE BOTTLES

PROGRAM OUTPUT

OUTPUT FORMAT - HARD COPY
- PLOT COPY
- TAPE GENERATION
- DRUM STORAGE
PARAMETRIC RECYCLE - DATA RETRIEVAL

FIGURE 1.2-1 MAJOR PROGRAM STRUCTURE

The table data bank contains the necessary component performance characterization data for the system configurations to be considered, as well as the required cryogen properties data and required material properties data.

The "source data", as obtained, is verified as being authoritative, and is then processed into a formatted tabular array which specifies the table name, ID codes, the dependent variables, and the independent variables – in order of use. The tabulated array data is carefully ordered such that curve fitting routines can extrapolate data points with good accuracy and speed. The prepared data array is punched into data card decks and verified for correctness. The procedure is illustrated in Figure 1.2-2. All data tables are logged as to reference, source, date of data acquisition, and pertinent data limitations such as range of application, etc.

Since a large volume of table data can be required by the program, a unique data management set of subroutines is employed to retrieve any particular table and extract the required information with remarkably high speed and accuracy. Additionally, a machine plotted and/or printed tabulation "echo" of the tables can be requested for easy table input checking.

The program currently contains forty-six tables and currently will accommodate up to fifty tables for a total of 7000 words.

The second type of input data is "variable" and contains the variable input parameters which may be perturbated for parametric system studies. These data include duty cycle characteristics, configuration description, and operational requirements of the system being studied. The variable input values are printed out just prior to the system computed data output as a means of input verification.

The general program input data requirements by type of data and source is illustrated in Figure 1.2-3.

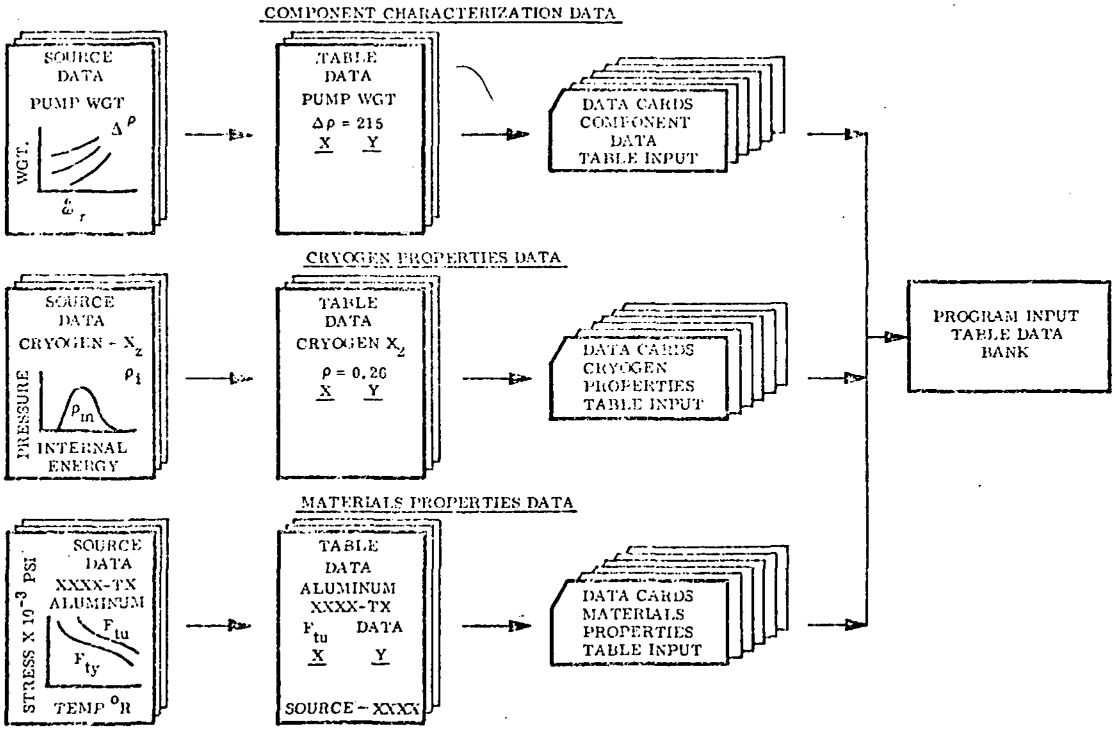


FIGURE 1.2-2 SOURCE DATA PREPARATION SEQUENCE

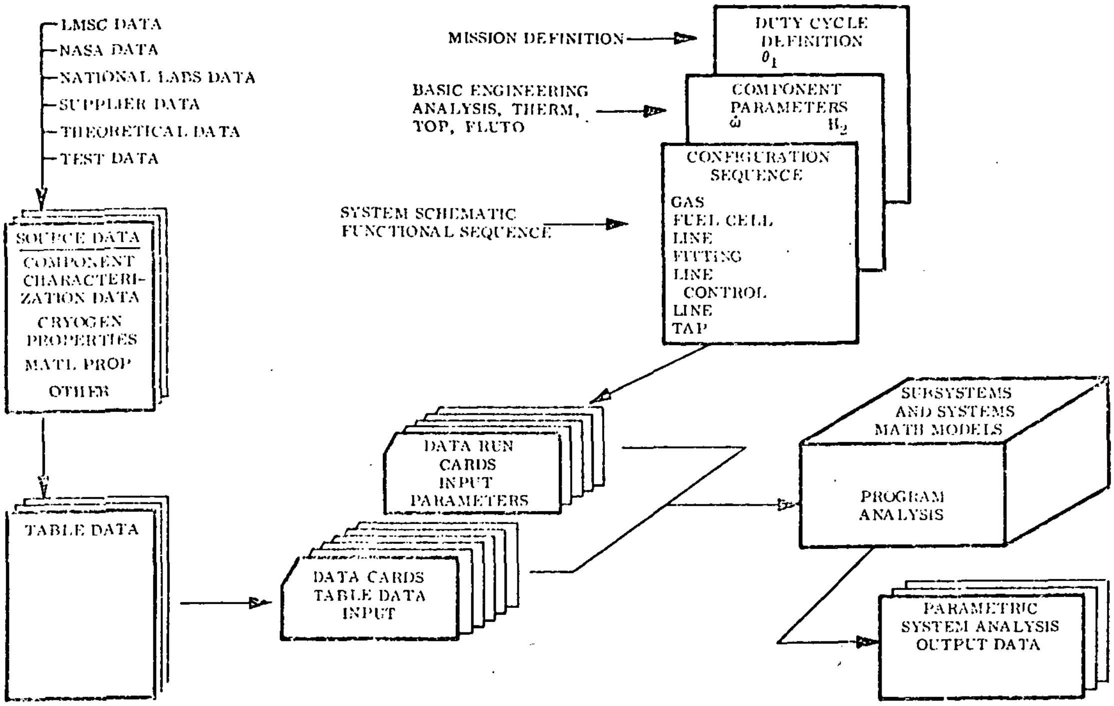


FIGURE 1.2-3 PROGRAM INPUT REQUIREMENTS BY TYPE OF DATA

1.2.2 PROGRAM COMPUTATION LOGIC

In order for the Integrated Math Model to accommodate the possible range of cryogenic systems likely to be considered and perform as a general systems analysis tool, the following three premises are established:

(1) Any logical combination of supply tanks, lines, fittings, valves, regulators, heat exchangers, gas generators, pumps, accumulators, and "cryogen-consumer" components can be specified as a system configuration point.

(2) The "cryogen-consumer" component may be any of the components being supplied with cryogenic fluids.

(3) An integrated cryogenic system may contain a number of similar and/or different cryogen subsystems to be fed from a common cryogen supply source.

Although these premises appear to force the generation of a very large program, an examination of the six basic individual cryogen system concepts reveals a marked similarity and commonality of components by kind. Table 1.2-1 illustrates adequately the fact that there are less than twenty-five kinds of major component assemblies to be considered, additionally, the temperatures, pressures, and flow rates are for the most part within reasonable range spans, thus further reducing the quantity of data to be manipulated.

1.3 CØMMØN DESCRIPTION

The program makes use of a number of defined common storage blocks in order to provide for the relatively large amount of data input, storage and transfer which occurs in the various subprograms. These CØMMØN blocks are defined only once in FØRTRAN PRØCEDURE DEFINITIØN PRØCESSØRS (PDP's) and thereafter are transferred to any using subprogram by the use of the FØRTRAN INCLUDE statement. The form of the FØRTRAN procedure employed is described in the following paragraph.

> FORTRAN PROCEDURE. A FORTRAN procedure contains FORTRAN source language that is to be included in a compilation by use of the FORTRAN INCLUDE statement. Athena FORTRAN V includes the COMPILER statement which allows the searching of other files for the procedure(s). The form of the statement is: COMPILER (LIB = FN1, FN2,...., FNN) where FN1 is of standard file-name form QUAL*FILE1/KEY1/KEY2. This causes FN1,..., FNN to be searched after the file containing the source input and before the library. If no definition is found in the search of these files, the compiler gives an error indication.

COMPONENT LIST	ACPS		APU		FUEL CELL		EC/LSS		OMS	
	SUBCR	SUPCR	SUBCR	SUPCR	SUBCR	SUPCR	SUBCR	SUPCR	P.A.E.	P.A.T.
ENGINE (MAIN)									●	●
ENGINE (AUXILIARY)	●	●								
TURBINE - GENERATOR			●	●						
FUEL CELL					●	●				
CABIN ATMOSPHERE							●	●		
ENVIRONMENT CONTROL							●	●		
LINES	●	●	●	●	●	●	●	●	●	●
FITTINGS	●	●	●	●	●	●	●	●	●	●
VALVES	●	●	●	●	●	●	●	●	●	●
REGULATORS	●	●	●	●	●	●	●	●		
ACCUMULATORS	●	●	●	●						
HEAT EXCHANGERS	●	●	●	●	●	●	●	●		
HEAT SOURCES			●	●	●	●	●	●		
GAS GENERATORS	●	●	●	●						●
TURBINES	●									●
MOTORS			●							
PUMPS	●		●							●
TANKAGE	●	●	●	●	●	●	●	●		
THERMAL CONDITIONING UNIT	●		●						●	●
PRESSURE CONTROL	●	●	●	●		●	●	●	●	●
ACQUISITION	●		●						●	●
GAS STORAGE			●						●	●
CIRCULATION PUMPS				●		●				

TABLE 1.2-1 CRYOGEN SYSTEMS - COMPONENT SIMILARITY BY KIND

The FORTRAN procedure has the form:

```
    @PDP,LFI      EL
    AA*    PROC            .bENTRY point must begin in column 1.
    .
           (FORTRAN statements)
    .

    .
    END                    .bEND statement must begin in column 2.
```

An entry will be made in the program-file FORTRAN procedure table for the label AA.

The PDP's employed in the program together with the data of latest update are listed in Figure 1.3-1. An example of the FØRTRAN PRØCEDURE TABLE in which the compiler has specified the LINK and LØCATIØN for the PCP's is illustrated in Fig. 1.3-2.

The PCP will contain, usually, PARAMETER statements, declaration statements for REAL or INTEGER variable names, CØMMØN definitions and LABELS, LOGICAL statements, DIMENSIØN and EQUIVALENCE statements, and, quite often a series of CØMMENT cards which may conveniently define the variable set listed in the labeled CØMMØN. An example of a program PDP is given in Fig. 1.3-3.

```
635717*TPF$ ELEMENT TABLE

D   NAME            VERSION          TYPE          DATE
    CACCUM                         FOR PROC      13 MAR 73
    CAPU                           FOR PROC      13 MAR 73
    CCNFIG                         FOR PROC      13 MAR 73
    CCNTRL                         FOR PROC      13 MAR 73
    CDCYCL                         FOR PROC      13 MAR 73
    CENG                           FOR PROC      13 MAR 73
    CFLRAT                         FOR PROC      13 MAR 73
    CFLUID                         FOR PROC      13 MAR 73
    CHEX                           FOR PROC      13 MAR 73
    CHTX                           FOR PROC      13 MAR 73
    CHSORC                         FOR PROC      13 MAR 73
    CIOUNT                         FOR PROC      13 MAR 73
    CKEYS                          FOR PROC      13 MAR 73
    CMATRL                         FOR PROC      13 MAR 73
    CMOTOR                         FOR PROC      13 MAR 73
    CONST                          FOR PROC      13 MAR 73
    CPAGE                          FOR PROC      13 MAR 73
    CPUMP                          FOR PROC      13 MAR 73
    CSYSWT                         FOR PROC      13 MAR 73
    CTAB                           FOR PROC      13 MAR 73
    CTABA                          FOR PROC      13 MAR 73
    CTANK                          FOR PROC      13 MAR 73
    CTURBN                         FOR PROC      13 MAR 73
    DUMMY                          FOR PROC      13 MAR 73
    SPUMP                          FOR PROC      13 MAR 73
    TABLOK                         FOR PROC      13 MAR 73
    TANKWT                         FOR PROC      13 MAR 73
    CECLSS                         FOR PROC      28 MAR 73
    CFUEL                          FOR PROC      28 MAR 73
    CNAMES                         FOR PROC      28 MAR 73
```

Figure 1.3-1   Table of Fortran Procedure Definition Processors

```
                FORTRAN PROCEDURE TABLE


D NAME              LOCATION          LINK
  CACCUM               50178             1
  CCNTRL               53174             4
  CENG                 53734             6
  CFUEL               172538           266
  CHTX                 54742            10
  CMATRL               55386            14
  CONST                55918            16
  CSYSWT               56758            19
  CTANK                57262            22
  SPUMP                58242            25

D NAME              LOCATION          LINK
  CAPU                 50570             2
  CDCYCL               53454             5
  CFLRAT               54014             7
  CHEX                 54126             9
  CIOUNT               55218            12
  CMOTOR               55862            15
  CPAGE                55974            17
  CTAB                 56926            20
  CTURBN               57794            23
  TABLOK               58298            26

D NAME              LOCATION          LINK
  CCNFIG               51970             3
  CECLSS              172006           265
  CFLUID               54098             8
  CHSORC               54854            11
  CKEYS                55358            13
  CNAMES              162906           262
  CPUMP                56198            18
  CTABA                57206            21
  DUMMY                58158            24
  TANKWT               58326            27
```

Figure 1.3-2 Fortran Procedure Tables

```
@PDP,IFL     .CFUEL
CFUEL* PROC
C
      PARAMETER  LFC = 12. LFD = 2
C
      REAL MRFC
C
      COMMON /CIFUEL/ SRCFC , MRFC   , POWTOT. WRFORP . WOCONS, WHCONS.
     1                PKWMAX, OFCTOT, QDTFC , TF21IN . TF21OU, TFOFC .
     2                TFHFC . PFOFC , PFHFC . QTOTR  . OEXCES, WF21MX.
     3                DQAMIN, TKOMAX, TKHMAX, QMXTKO . QMXTKH. WDTCFO.
     4                WDTCFH, WOCMP , WHCMP . POWMAX . DELTCP, WRRSRV.
     5                WORSRV, WHRSRV, QLEAKO. QLEAKH . WVHO   . WVHH   .
     6                WOVENT, WHVENT, SPWT1 . SPWT2 , NFCOP , NFCSTB ,
     7                SPWTFC, FCWGT , PRFCOP
C
      COMMON /CVFUEL/ WRF    (LFC),WDTFCO(LFC),WDTFCH(LFC),WDOTMX(LFD).
     1                QAVAIL(LFC),WDTF21(LFC),PRFCMN(LFD).TFCNOM(LFD).
     2                TKO2WD(LFC),TKH2WD(LFC).PCWDO2(LFC).PCWDH2(LFC).
     3                RHOTO2(LFC),RHOTH2(LFC),DQDWO (LFC),DQDWH (LFC).
     4                TKO    (LFC),TKH    (LFC).HTKO   (LFC).HTKH   (LFC).
     5                Q1ODTR(LFC),Q1HDTR(LFC).WDT1FO(LFC),WDT1FH(LFC).
     6                Q2ODTR(LFC),Q2HDTR(LFC).WDT2FO(LFC).WDT2FH(LFC).
     7                CSBVFO(LFC),CSBVFH(LFC),PHIFO2(LFC),PHIFH2(LFC).
     8                QSUMR (LFC),DQANET(LFC).RHOFIL(LFD),RHOFIN(LFD).
     9                WTRES (LFD),VOLTNK(LFD).AREATK(LFD).QLKO   (LFC).
     T                QLKH (LFC).WRTOTL(LFD). DIATK (LFD).DIAVJ (LFD).
     1                WCIRCP(LFD),RHOFTU(LFD).WTPVT (LFD).WTVJ   (LFD).
     2                WORFP (LFC), WHRFP(LFC)
C
C      *****
C         *
C         *
C      *****
C
 END
```

FIGURE 1.3-3 FORTRAN PROCEDURE DEFINITION PROCESSOR CFUEL

1.4 PROGRAM OPERATIONAL SEQUENCE

The program capability for accommodating a number of different kinds of systems analysis, derives from the use of built-in sequencing indices. The indices are stored as data statements in subroutine ST0DTA, and are readily available to a programmer or knowledgeable program-user for restructuring, if necessary. The indices are used by the various system analysis subprogrms to direct the analysis from one set of procedural steps to the next in a preprogrammed manner. The details of the program operational sequence for the various systems to be analyzed are explained in the following subparagraphs.

1.4.1 PROGRAM INITIATION AND CONTROL

Program initiation is accomplished through by the driver subroutine C0NTRL. This subroutine initializes the data storage subroutines and reads the first card of the input data deck for the user's name and program title. Following this a call to subroutine INTAB reads in table data deck (or file) to storage. As a check on the correctness of the data table input, subroutine INTAB causes an "echo" printout of the selected table numbers to be printed for visual reference. A typical "echo" print is illustrated in Table 1.4-1. Note that the echo" also permits verification of the number of words in any given table, thus aiding the user in troubleshooting incomplete table entries. C0NTRL then reads in the name and type of system to be evaluated. This is followed by a call to subroutine C0MPIL which reads into core the cryogen system input data deck containing the system duty cycle, configuration sequence, and pertinent system and component parametric information.

TABLE 1.4-1

DATA TABLE SELECTION "ECHO"

TABLE NUMBER	TITLE OF TABLE	NUMBER OF DIMENSIONS	NUMBER OF SUBTABLES	NUMBER OF WORDS
1	RCS-THRUSTER WEIGHT	4	6	122
2	RCS-VAC. SP. IMPULSE	3	3	68
3	SPEC.HT/LB OF O2 REMOVED	3	5	206
4	SPEC.HT/LB OF H2 REMOVED	3	5	184
5	TEMP. /LB. OF O2 REMOVED	3	5	184
6	TEMP. /LB. OF H2 REMOVED	3	5	192
7	RR/ VS PGG,M/R,PAMB,PCHP	5	12	95
8	KK VS PGG,M/R,PAMB,PCHP	5	12	95
9	OMS ENGINE WEIGHT	3	3	50
10	OMS VAC. SP. IMPULSE	3	3	68
11	HEX HOT GAS FLOW - LO2	5	24	133
12	HEX HOT GAS FLOW - LH2	5	12	71
13	GAS GENERATOR WEIGHT	4	10	220
14	LO2 TRANSFER PUMP WEIGHT	5	8	130
15	LH2 TRANSFER PUMP WEIGHT	5	8	138
16	MOTOR WEIGHT	3	5	120
17	VAC.JAC.DIA.VS.WEIGHT	2	1	34
18	PHI - HYDROGEN	3	5	172
19	TEMP. OF N2 VS RHO F(P)	3	5	180
20	HT.XFER.COEF.-H2	3	4	106
21	HT.XFER.COEF.-O2-N2	3	4	138
22	FTU OF 321/347 ST.STEEL	2	1	32
23	FTU OF 2219-T87 ALUM.	2	1	36
24	FTU OF 6061-T6 ALUMINUM	2	1	30
25	FTU OF INCONEL-718	2	1	30
26	FTU OF TI-6AL-4V	2	1	30
27	HEAD COEFFICIENT VS NS	2	1	34
28	ADIABATIC EFF. VS NS	2	1	44
29	EFFIC. QUOT.VS IMP. DIAM	2	1	46
30	BASE LINE STAGE WT VS DI	2	1	28
31	SATURATED STEAM. T.VS P.	2	1	46
32	SP.HT. OF O-H COMB.PROD.	3	4	114
33	OXYGEN INTERNAL ENERGY	3	5	166
34	HYDROGEN INTERNAL ENERGY	3	5	216
35	OXYGEN INTERNAL ENERGY	3	5	142
36	OXYGEN VAPOR PRESSURE	3	5	166
37	HYDROGEN VAPOR PRESSURE	3	5	216
38	OXYGEN VAPOR PRESSURE	3	5	142
39	ENTHALPY OF LO2	2	1	46
40	ENTHALPY OF LH2	2	1	24
41	ENTHALPY OF HELIUM	3	5	142
42	OXYGEN ENTHALPY (GAS)	3	5	98
43	HYDROGEN ENTHALPY (GAS)	3	5	122
44	BETA FACTOR	2	1	28
45	SIGMA-DELTAP FOR HEXELC	3	5	172
46	BETA VALUES FOR H2	3	5	168

TOTAL TABLE STORAGE = 5024

Subroutine C0NTRL next calls subroutine CRYC0N to process the calculations required for the system being considered. Completion of the required calculations causes program control to return from CRYC0N TO C0NTRL. Subroutine C0NTRL then tests to see if additional system data decks are to be read in, if so, it does and repeats the cycle; if not, C0NTRL calls EXIT and terminates the run.

Brief flow-charts for C0NTRL, C0MPIL, and CRYC0N are presented in Figure 1.4-1, -2, and -3.

1.4.2 Program Sequencing Subroutine. The mechanism for controlling the analysis sequencing is set up in Subroutine CRYC0N. This subroutine performs the major branching functions of calling in the various subprograms needed for each specific system type analysis. Key variables used by CRYC0N to effect this control over the analysis sequencing are SYSNUM and SCRIT. For each cryogen system (and system kind) there exists a preprogrammed set of induces stored on a data statement KSUBC (SYSNUM, I) which defines the order in which the major analytical subroutines will be called. This set of indices are used in CRYC0N for sequencing purposes.

1.4.2.1 Program Calculations Sequence. The initiation of specific system calculations occurs in Subroutine CRYC0N. For any of the five cryogen systems, CRYC0N will obtain from labeled common CCNTRL, the values for SYSNUM and SCRIT. This permits access to the indices stored in the preprogrammed set of data statements KSUBC (SYSNUM, I). The branching index JKM (see Fig 1.4-3). then can assume the value of each stored sequencing index in a given KSUBC data statement as CRYC0N cycles through its "I" loop. Concurrently, as each JKM index is picked up, CRYC0N tests to see if the specified subprogram requires a "user signalled" diagnostic switch to be turned "ON" or left "OFF." This is an especially useful feature when debugging changes to subprogram coding. Values for MDTRC, the diagnostic indices, are entered by the user in the system run data deck (see Section 1.5). The KSUBC data statements are physically located in Subroutine STODTA and are available through labeled common CCNTRL via an INCLUDE statement.

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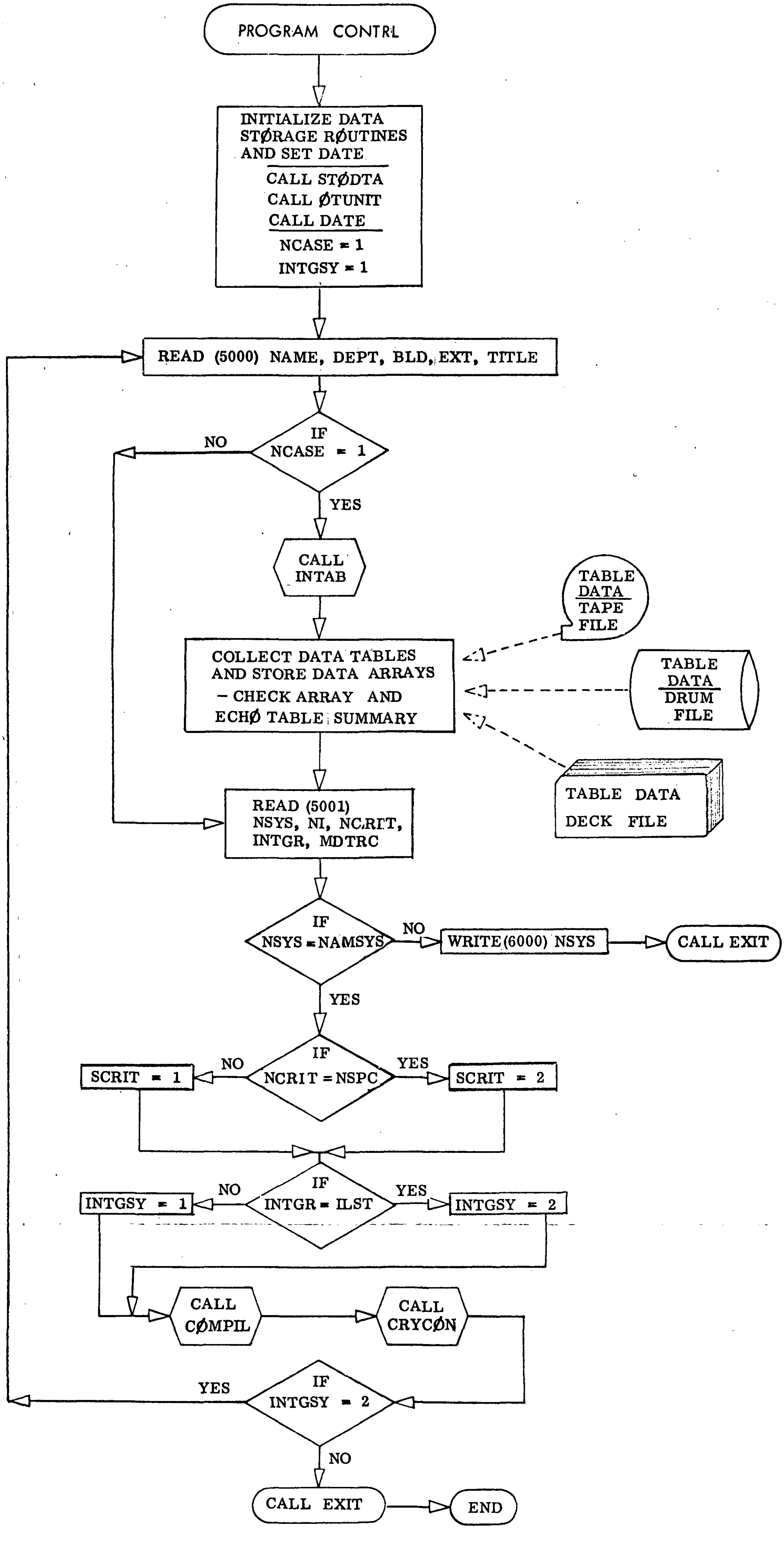

Fig. 1.4-1 Flow Chart for Subroutine CØNTRØL

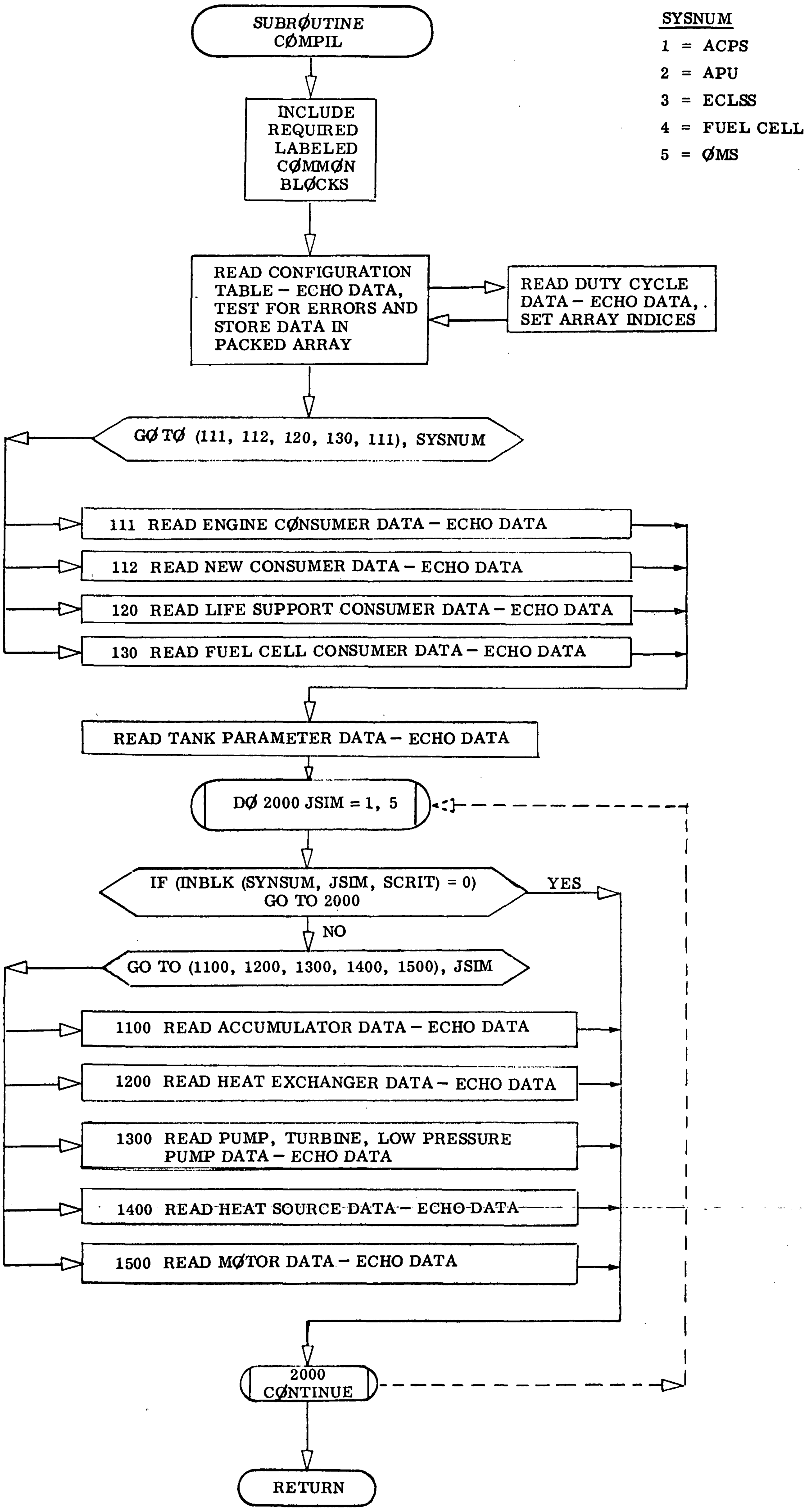

Fig. 1.4-2 Flow Chart for Subroutine CØMPIL (Simplified)

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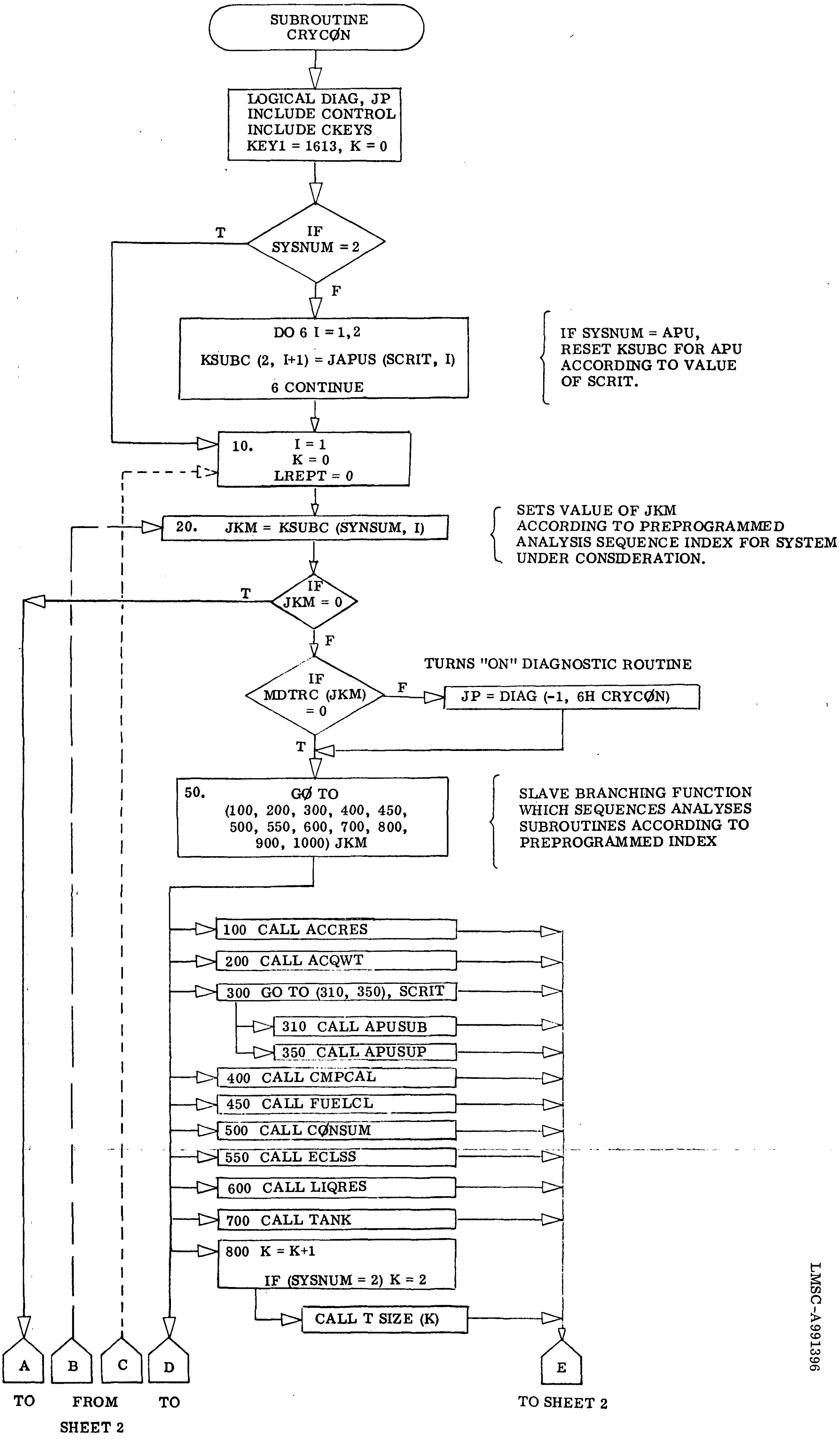

Fig. 1.4-3 Flow Chart for Subroutine CRYCØN
(Sheet 1)

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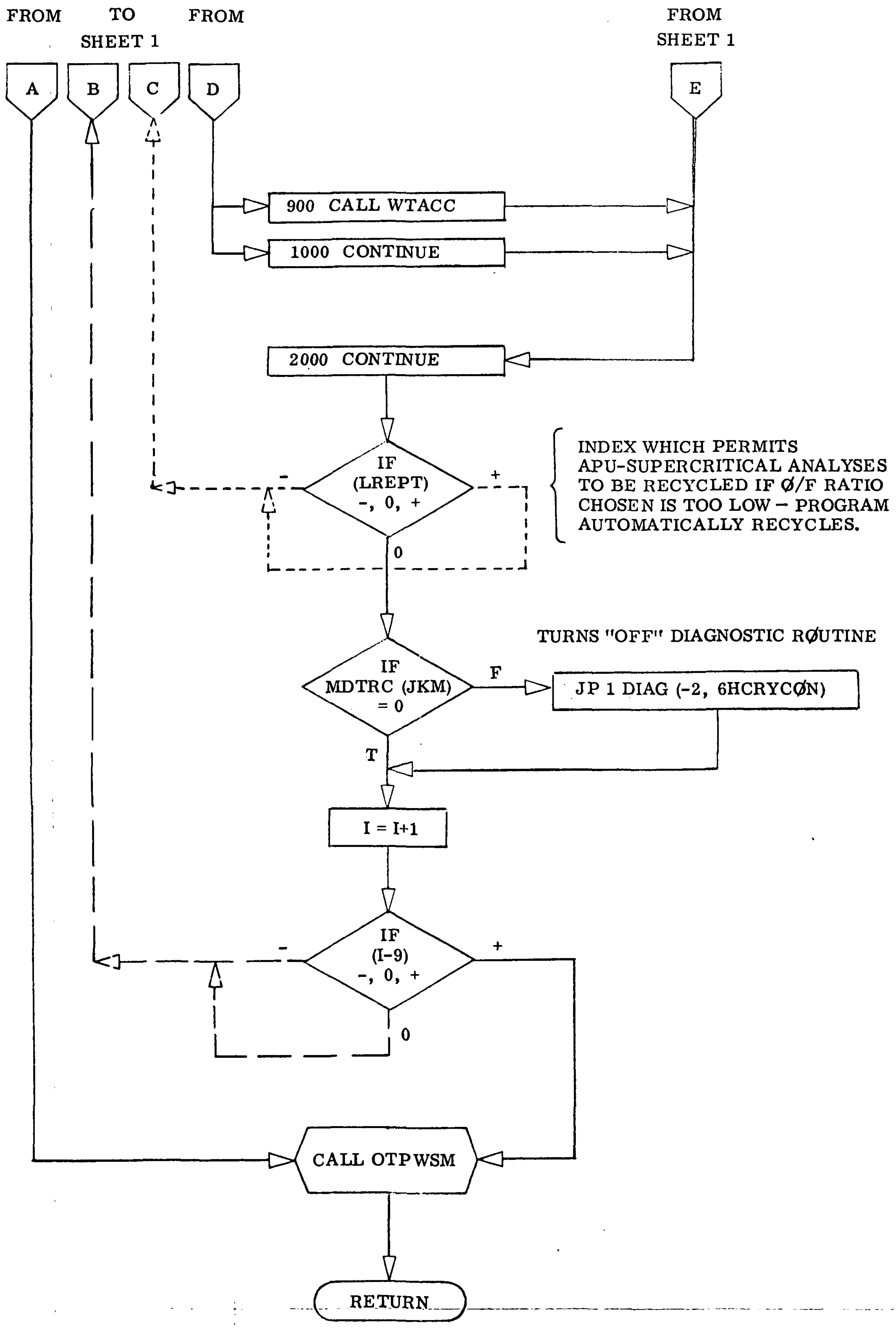

Fig. 1.4-3 Flow Chart for Subroutine CRYCØN (Sheet 2)

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The index "K" employed in CRYC0N is used to indicate initial or final conditions for subroutine TSIZEI (K). For the specific requirements of an Auxiliary Power System analysis (APU), the value of "K" can only be set equal to two (2). For all other system analysis "K" is set equal to one (1) the first time called and set equal to two (2) the second time called.

The index "LREPT" is employed, by CRYC0N, only when processing a supercritical APU system. Its use permits the recycling (starting over again) of subroutine APUSUP when that subprogram determines that the fuel mixture ratio (O/F) input value is too low and yields impossible temperature values. At that point the subprogram incrementally raises the O/F ratio and reruns the analysis. If three attempts fail, the subprogram quits and terminates the analysis.

The manner in which the sequential execution of CRYC0N can vary is explained in the subsections which follow.

1.4.2.2 ACPS – OMS Systems Calculation Sequence. If, for example, a subcritical cryogenic reaction control system (ACPS) had been chosen for analysis, the following would be the sequence of events executed by subroutine CRYC0N. The values assigned to SYSNUM, SCRIT, and KSUBC (SYSNUM, I) would be:

SYSNUM = 1	(For ACPS)
SCRIT = 1	(Subcritical System)
KSUBC (1, I)	(KSUBC for ACPS)

and the preprogrammed Data Statement to be used would be:

```
DATA (KSUBC (1,I)   I = 1, NBRSR)/6, 4, 10, 9, 8, 1, 10, 11, 2/
```

where "NBRSR" is defined as 9 in PDP-CCNTRL.

There are, therefore, nine subprograms to be called in the reaction control system analysis.

Referring to the CRYC0N Flow Chart (Fig. 1.4-3), note that statement 10 sets I = 1 for the first pass in the calculation loop. Statement 20 then sets JKM = KSUBC (SYSNUM, I), or, literally equal to KSUBC (1, I) which is the first of the nine values defined in the data statement body. Thus JKM = 6 in the first loop pass. Statement 50 is a "computed" GO TO statement which in this instance literally says

GO TO the JKM (6th) value within the parenthesis, or GO TO Statement 500, which calls subroutine C0NSUM. Thus, the order of subprogram execution, in sequence, by subroutine CRYC0N for a reaction control system analysis would be as shown in the table below:

Table 1.4-2

CRYC0N EXECUTION SEQUENCE FOR ACPS ANALYSIS

Loop Pass	JKM Value	G0 T0 Statement	Subprogram Called
1	6	500	C0NSUM
2	4	400	CMPCAL
3	10	800	TSIZEI(1)
4	9	700	TANK
5	8	600	LIQRES
6	1	100	ACCRES
7	10	800	TSIZEI(2)
8	11	900	WTACC
9	2	200	ACQWT

The above table holds true for an orbit maneuvering system (subcritical cryogen) as well, since the only significant differences are larger engines and fewer, but larger, component parts.

Upon completion of nine loop passes through CRYCON, accomplishing all of the calculations required by the respective subprograms, the final step is a call to subroutine OTPWSM which extracts from the labeled common storage, the values needed for a system weight summary and outputs these data in a formatted weight summary table. Program control returns to subroutine CONTRL for either execution of a second case (system analysis) or termination. A general flow chart for a typical reaction control system analysis is presented in Figure 1.4-4.

1.4.2.3 APU System Calculations Sequence. For the Auxiliary Power System analysis, two operating system types are possible; a subcritical cryogen fluid supply subsystem and a supercritical cryogen fluid supply subsystem.

It is therefore necessary to provide a means of altering the preprogrammed values to accommodate both cryogen fluid supply subsystems. This is accomplished by preprogramming KSUBC (2,I) for the more likely supercritical fluids case, and modifying the data statement when considering the subcritical cryogen fluid supply subsystem. This data statement adjustment is automatically taken care of in subroutine CRYCON DO6 loop as shown in the Flow Chart (Ref. Fig. 1.4-3). The DO6 loop will reverse the second and third values of the data stored as KSUBC(2,I) depending upon the value assigned to SCRIT. JAPUS (SCRIT, I) is the variable accomplishing the switch in value. The data statements defining JAPUS are stored in subroutine STODTA.

Subcritical Analysis: For an APU system requiring a subcritical cryogen fluid supply subsystem, the values assigned, via input, to the variables SYSNUM, SCRIT and KSUBC (SYSNUM, I) would be

SYSNUM = 2 (For APU)
SCRIT = 1 (For Sub critical)

and KSUBC(2,I)

The preprogrammed data statement stored in core is
KSUBC(2 I) I = 1,9)/6 3 4 10 11 2 0 0 0/ which is actually the sequence for a

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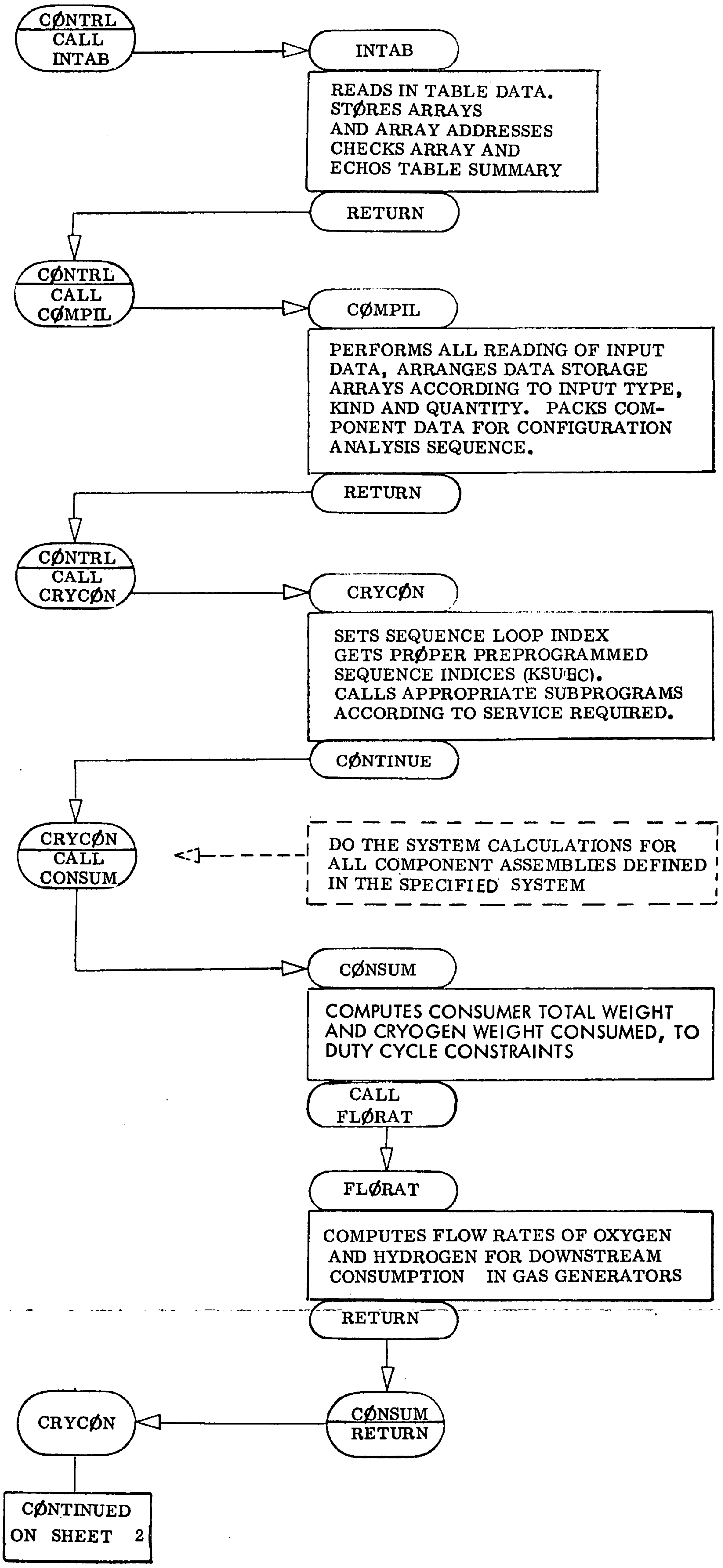

Fig. 1.4-4 General Flow Chart for ACPS-OMS System Analysis (Sheet 1)

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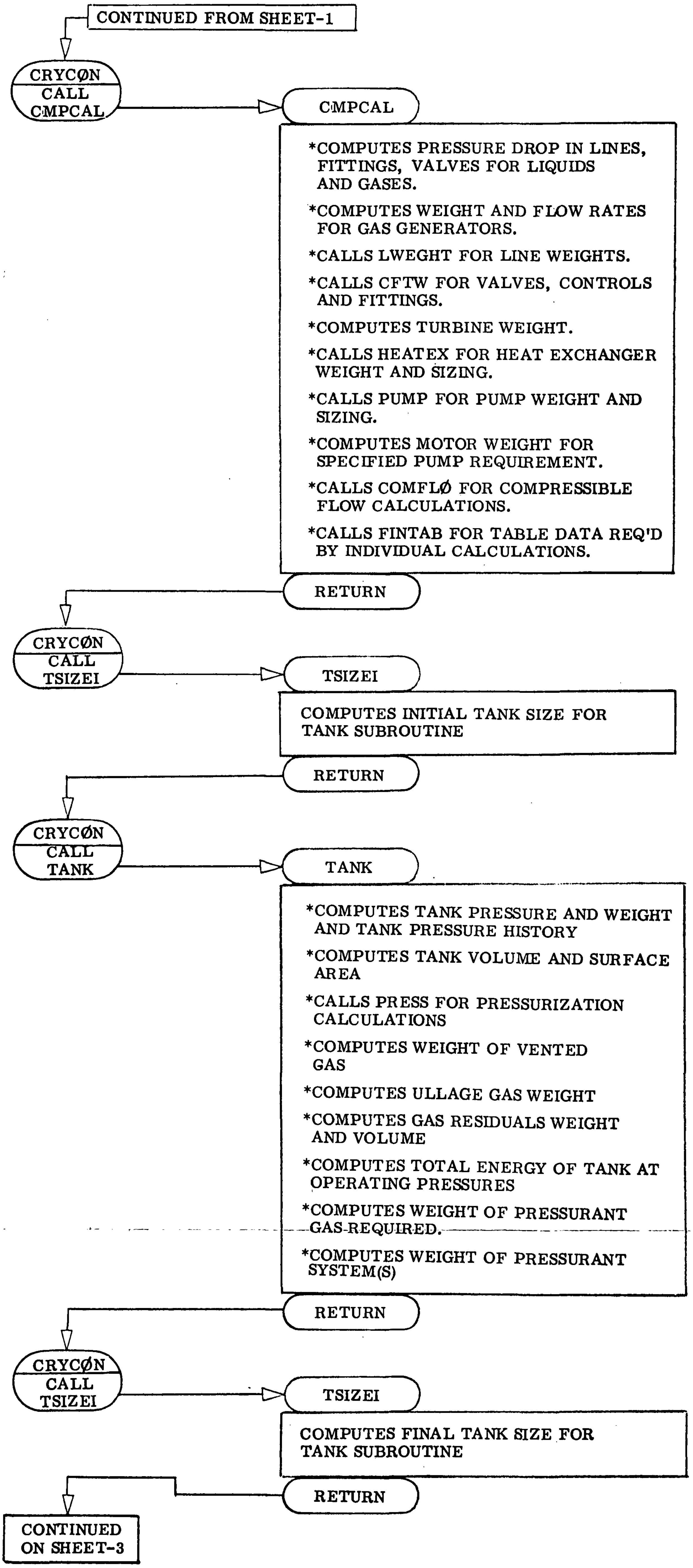

Fig. 1.4-4 General Flow Chart for ACPS-OMS System Analysis (Sheet 2)

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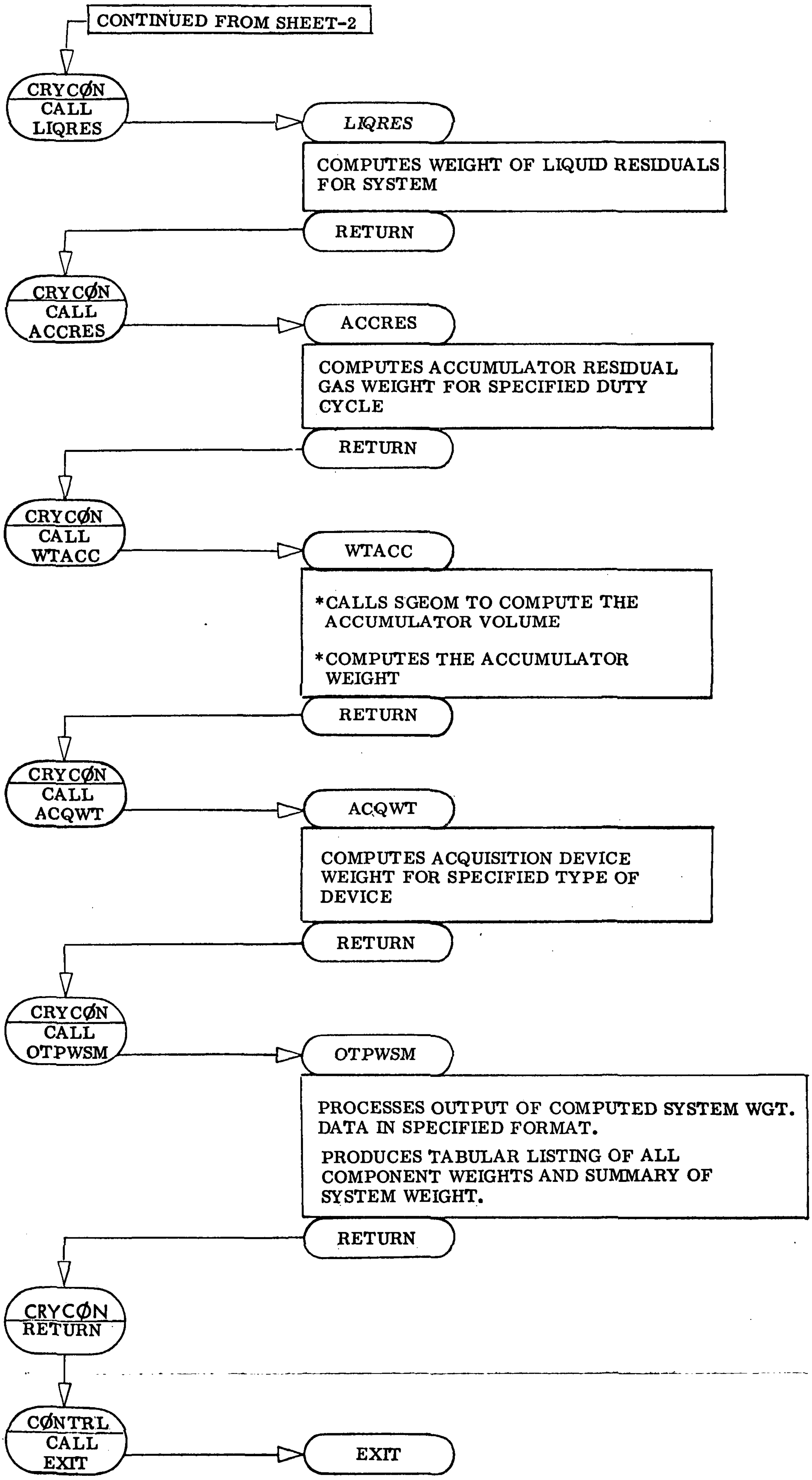

Fig. 1/4-4 General Flow Chart for ACPS-OMS System Analysis (Sheet 3)

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supercritical subsystem. Therefore, the first action by CRYC0N is to reset the second and third values in a two-step loop as follows:

1st; KSUBC(2,2) = JAPUS(1,1) = 4
2nd; KSUBC(2,3) = JAPUS(1,2) = 3

and the reversed data statement becomes:

KSUBC(2,I),F = 1,9/6, 4, 3, 10, 11, 2, 0, 0, 0/

Note that only six subprograms are called in an APU analysis. The order of subprogram execution, in sequence, is presented in the following table.

Table 1.4-3

CRYCON EXECUTION SEQUENCE FOR AN APU SUBCRITICAL SYSTEM ANALYSIS

Loop Pass	JKM Value	G0 T0 Statement	Subprogram Called
1	6	500	C0NSUM
2	4	400	CMPCAL
3	3	300	APUSUB
4	10	800	TSIZEI(2)
5	11	900	WTACC
6	2	200	ACQWT
7	0	2200	Terminates Loop

Upon leaving the sequence loop subroutine CRYCON calls subroutine OTPWSM to output the component and system weight summary. Program execution returns to subroutine CONTRL which checks to see if another case (same system, or, new one) is to be run, or if program termination is in order.

Super-critical Analysis:

For an APU system requiring a super-critical cryogen fluid supply subsystem, the input values assigned to the variables SYSNUM, SCRIT and KSUBC (SYSNUM, I) would be:

SYSNUM = 2 (For APU)
SCRIT = 2 (For Super-critical)

and KSUBC(2, I)

Assuming, for example, that the supercritical case is run as the second case in a multi-case run (not necessarily so) the preprogrammed data statement in core would still be, KSUBC(2, I), I = 1, 9)/6, 4, 3, 10, 11, 2, 0, 0, 0/. The first activity in CRYCON, since SYSNUM = 2, will be to reset the second and third value of the KSUBC data in a two-step loop as follows: (SCRIT = 2)

1st KSUBC(2,2) = 3
2nd KSUBC(2,3) = 4

and the revised data statement becomes;

KSUBC(2,I), I = 1, 9)/6, 3, 4, 10, 11, 2, 0, 0, 0/.

The order of sub-program execution, in sequence, is presented in the following table:

Table 1.4-4

CRYC0N EXECUTION SEQUENCE FOR AN APU SUPERCRITICAL SYSTEM ANALYSIS

Loop Pass	JKM Value	G0 T0 Statement	Subprogram Called
1	6	500	C0NSUM
2	3	300	APUSUP
3	4	400	CMPCAL
4	10	800	TSIZEI(2)
5	11	900	WTACC
6	2	200	ACQWT
7	0	2200	Terminates Loop

Upon leaving the sequence loop CRYC0N calls subroutine 0TPWSM to output the component and system weight summary, and then return program execution to subroutine C0NTRL.

1.4.2.4 Life Support System Calculation Sequence. For the Life Support System analysis, the cryogen fluid supply subsystem is by definition a supercritical subsystem with a relatively simple and straightforward plumbing structure. It is also unique among the other systems, in that the cryogen fluids employed are oxygen and nitrogen. Because of this fact, and the need to maintain overall program variable storage requirements at a level that will fit into core, it was decided not to expand the program variable arrays to accommodate a third cryogen fluid, but instead, to use those portions of the arrays normally used for the hydrogen fluid to store the nitrogen fluid parameter values. Consequently, the Life Support subprogram became a fairly large self-contained subprogram, designated as subroutine ECLSS. Hence, subroutine CRYC0N makes only one call for the subprogram. In the case of a Life Support System analysis, the values assigned, via input, to the variables SYSNUM, SCRIT and KSUBC (SYSNUM, I) would be,

SYSNUM = 3

SCRIT = 2

and KSUBC (3,I).

The preprogrammed data statement stored in core for this system analysis is, (KSUBC(3,I), I = 1,9)/7, 0, 0, 0, 0, 0, 0, 0, 0/. And the order of subprogram execution by subroutine CRYCON is as shown in the following table:

Table 1.4-5

CRYCON EXECUTION SEQUENCE FOR A LIFE SUPPORT SYSTEM ANALYSIS

LOOP PASS	JKM VALUE	GO TO STATEMENT	SUB-PROGRAM CALLED
1	7	550	ECLSS
2	0	2200	Terminates Loop

As stated previously CRYCON calls subroutine OTPWSM, outputs the weight summaries and returns to CONTRL for a new case, or termination of the program.

1.4.2.5 Fuel Cell System Calculation Sequence. The cryogen fuel cell system as defined by this study is a fuel cell array fed by a supercritical fluids storage and supply subsystem. Further, the energy required for conditioning the reactant fluids and maintaining their super-critical condition in storage is wholly derived from the reject heat of the fuel cells. The subprogram which characterizes the fuel cell system is subroutine FUELCL. This rather large sub-program performs the system sizing calculations based upon the mass and energy transfer requirements of the input performance and duty cycle constraints.

The individual fluid circuit components and line segments are sized and weighed by subroutine CMPCAL which additionally supplys pressure drop calculations for the main reactant circuits.

For a fuel cell analysis, subroutine CRYC0N has the values assigned, via input data, for SYSNUM, SCRIT and KSUBC (SYSNUM, I), as follows:

SYSNUM = 4
SCRIT = 2

and KSUBC (4,I)

The preprogrammed data statement stored in core for fuel cell system analysis is, (KSUBC(4,I),I = 1,9)/5, 4, 0, 0, 0, 0, 0, 0, 0/.

The order of sub-program execution is as given in the following table

Table 1.4-6

CRYC0N EXECUTION SEQUENCE FOR A FUEL CELL SYSTEM ANALYSIS

Loop Pass	JKM Value	G0 T0 Statement	Subprogram Called
1	5	450	FUELCL
2	4	400	CMPCAL
3	0	2200	Terminates Loop

When the internal loop is terminated CRYCON calls subroutine OTPWSM, outputs the weight summaries and returns to CONTRL for a new case, or termination of the program.

1.4.2.6 Orbit Maneuvering System Calculation Sequence The orbit maneuvering system (OMS) employed in this study was defined to be a subcritical cryogen fluids pump-fed system. The OMS and ACPS analysis procedures are quite similar programwise, with the principal differences being engine size, component size and the fact that the OMS has fewer, though larger components.

For an OMS analysis, SYSNUM, SCRIT and KSUBC (SYSNUM, I) will have the following values:

SYSNUM = 5
SCRIT = 1

and KSUBC (5,I).

The preprogrammed data statement stored in core for OMS analysis is:
(KSUBC(5,I),I = 1,9)/6, 4, 10, 9, 8, 1, 10, 11, 2/

The order of sub-program execution by sub-routine CRYCON is identical to the order given in Table 1.4-2 , and the subsequent remarks following that table.

1.5 INPUT DATA

The input data deck structure will vary according to the system to be analyzed and the type of fluid storage system employed. All input data cards are read within the body of subroutine CONTRL. The segments of input data to be read are generally divided into two groups; (1) input data common to all system analyses and (2) input data specific to a given system analysis. Necessarily a variety of read statement formats must be used and these are defined in labeled card formats given later in this discussion.

In general, a data input deck, for any system to be analyzed, will be made up of a set of card groups from the following group list:

(a) User Identification Card (First Header Card)
(b) Case Title Card (Second Header Card)
(c) Table Data Echo Control Card
(d) Add-File Card - To cause loading of "Table Data" file - or - Actual "Table Data" Deck may be placed here, replacing the Add-File card
(e) System Definition Card
(f) Configuration Definition Data Cards
(g) Duty Cycle Definition Data Cards
(h) Consumer Characterization Data Cards
(i) Fluid Storage Tanks Characterization and Configuration Data Cards
(j) Fluid Accumulator Characterization Data Card
(k) Heat Exchanger Characterization Data Cards
(l) Pump and Turbine Characterization Data Cards
(m) Heat Source Characterization Data Cards
(n) Motor Characterization Data Cards

Cards (a), (b), and (e) are read directly by subroutine CONTRL. Cards (c) and (d) are read by subroutine INTAB, called by CONTRL. Cards (f) through (n) are read by subroutine COMPIL, called by CONTRL.

1.5 1 Input Data - Card Definition and Description

Data definition and input card descriptions for data contained in the fourteen data card groups are presented in detail in the following subsections. Card data formats are presented in Subsection 1.2.

1.5.1.1 User I.D. and Case Title Cards.

Gp(a) Card-1

The User I. D. card identifies the analyst making the program run. This card is required in every run deck. The card contains the following information:

Name, Dept., Bldg., Extension

Gp(b) - Card-1

A case title card is to be provided for every system data deck as a means of providing run identification for the system being evaluated. Seventy-two (72) spaces are provided for the title. Short titles are to be centered in the 72 spaces.

1.5.1.2 Table Data Input Cards.

Gp(c) - Card-1

This card is the Table Data Echo control card. The variables contained on the card are: IFT, OFT, NPRT, NPRT2

IFT = Table Data Input Drum Unit
OFT = Table Data Output Drum Unit
NPRT = Table Data Echo Print Control
= 0, Print All Tables, One Table per Page
= 1, Print No Table Output
= 2, Print All Tables with no page eject - Table Dump

NPRT2 = Control for Table Summary

$\left.\begin{array}{l}\text{NPRT} = 1\\ \text{NPRT2} = 1\end{array}\right\rangle$ Print Brief Table Summary

Gp(d) - Card-1 (Normal Setup)

If the Table Data has been entered and stored as a DATA File, then the Data File may be assigned and Card-1 here will be a simple:

```
@ ADD,P  FILNAM
```

where

FILNAM is the Data File nemonic.

If the Table Data is on cards to be read in at this time, then the Gp(d) cards will be the actual table data card sets as described in detail in Subsection 1.5.6.

Alternate Table Deck Input: (N-sets)

Gp(d) Card-1

The Table I.D. and Control Card will contain the following information:

Title – Table Title (Description)
ND – Number of Dimensions in Table (MAX = 7, MIN = 2)
NC – Number of Comment Cards in Table
IP – Plot Option (O = No Plot, 1 = Plot Table)
NT – Table Number

GP(d) Card-2

Table Comment Card - Gives further description of table data and data reference sources. There may be NC comment cards.

Gp(d) Card-3

Table Subset Variable Card - Specifies additional variable and its values for Table Data Subsets.

LABV – Variable Label
NP – Number of Values to be used (is also number of data subsets)
TAB – Value, Value_z, $\cdots \text{Value}_{np}$

There must be (ND-2) of these cards present in Table Set. (ND = Number of dimensions in Table)

Gp(d) Card-4

Table Plot Control Card - Contains X-axis label, Y-axis label, X-MIN value, X-MAX value. One card is required for each Table Set.

Gp(d) Card-5

Table Data Subset Characterization Card - card contains:

NV – Number of Data Point Sets (X,Y) or Number of coefficients
TYPE – Type of Data in Table
= 0, Coefficients of polynomial
= 1, Discrete data points from curve
= 2, Equation
NIP – Number of points to be used for data interpolation
$\leq$ NV
$>$ 1
= 2, Linear Interpolation
= 3, parabolic or hyperbolic interpolation

There must be one of these cards for each data sub-set in the Table Set.

Gp(d) Card-6

Table Data Card - :
For discrete data there are three data sets (X,Y) per card arranged in order of increasing values of X, for NV sets of points.

For coefficients; coefficients are arranged in order of power and NV coefficients are read. (For example: $C_1X^2 + C_2X + C_3 = 0$; Input as C_1, C_2, C_3 and NV = 3)

There are NV/3 discrete data cards required, or NV/6 coefficient data cards required.

There will be N sets of the Gp(d) table card sets, where N equals the number of Table Data sets required for the program.

1.5.1.3 System Definition Card

Gp(e) Card-1

The system definition card provides the system identification; specifies whether the system has a subcritical or super-critical fluid supply subsystem; specifies whether or not additional systems are to be read in for additional case consideration; and, specifies which subprogram diagnostic switches are to be activated. The variables which are read are:

NSYS – First three letters of system name
N1 – Additional six alpha spaces for rest of system name
NCRIT – First three letters of subcritical or super-critical
MDTRC – Diagnostic switch for eleven subprograms
    0, or, blank for NO Diagnostics
    1, turns ON Diagnostic switch as defined in PDP-CCNTRL

There must be one system definition card in each system input deck.

1.5.1.4 System Configuration Definition Data Cards

Gp(f) Card-1

The system configuration definition data represents the program image of the system schematic diagram. Only one (1) card format is employed which functions as a data input card, and as a configuration table END card. The flexibility of the data format card in providing different kinds of information resides in the technique of reading the array and changing the variable name to correspond to the value entered at any point in the array. Since each data card represents a specific item, such as, fluid, component, or line segment, and their associated parameters, the data array is conveniently manageable.

The variables which are allocated to the card are as follows:

CFUNCT – Six alpha characters which specify either the fluid, consumer assembly, or system component item, currently being considered. The allowable names are defined in DATA (FNAME) located in subroutine STODTA, and further described in PDP-CCNFIG

CFTYPE – A single, or, two digit number which characterizes the type or kind of fluid, consumer assembly, or system component item

CNOPER – Single digit number - for number of consumer assemblies, or component items operating in parallel; or, in the case of a fluid, the digit specifies the fluid state (i.e., 1 = gas; 2 = liquid)

CNSTBY – Single digit number - for the number of consumer assemblies or component items in parallel standby condition (not operating)

CMTYPE – Single Digit Number which specifies the material type for the system component item. CMTYPE values are defined in PDP- CCNFIG.

FRCOEF – Variable containing the friction coefficient applicable to the system component item being considered

LOD – Length over Diameter Ratio, or, Length applicable to the system component item under consideration (Real Number)

DIAM – Diameter (I.D. or Port) applicable to system component item being considered

CITYPE – Integer defining Insulation Type employed for system component item being considered

ITHICK – Insulation thickness (Real Number) for system component item under consideration

NBAR – Number (Real) of insulation layers per inch of thickness for component item being considered

CODE – Six alpha character code name for component item under consideration. (i.e., PS02, etc.)

There must be one card for; (a) each fluid and fluid state change, (b) each fluid system consumer, (c) each fluid system component item, and (d) each fluid system line segment item. The cards are arranged starting with the oxidizer fluid system side and working from the consumer toward the fluid supply source. This is followed by the same arrangement for the fuel fluid side of the system. A typical configuration table is illustrated in the Input Data Deck Example given in Subsection 1.5.5. The very last card in the configuration data set must have END entered in the CFUNCT field, since this is required in subroutine COMPIL to terminate the READ loop. (It is also advisable to use card columns 73-80 to number the configuration data cards.)

1.5.1.5 System Duty Cycle Definition Data Cards

Gp(g) Card-1

The system duty cycle definition data cards contain the cyclic operating interval data required for each analysis. The variables employed are as given below. Note that the variable DCYCLE is in an array in which are stored alternate values of operating and non-operating time intervals:

DCYCLE(I) – Operating Time Interval

DCYCLE(I+1) – Non-operating Time Interval

PSI – Minimum Impulse Bit Degradation

NEOP – Number of Consumers Operating (Engines, Fuel Cells, etc.)

HP – Horsepower-Average Value In Interval

PAMB – Ambient Pressure-Average Value In Interval

PKW – Power (KW)-Average Value In Interval

RPRTIM – Time required per repressurization (cabin or airlock) during a given duty cycle Interval

There must be one card for each of the defined duty cycle interval periods in total missio span considered.

There must be a duty cycle end-card consisting of a negative number (i.e., -1) in the DCYCLE (I+1) field

1.5.1.6 Consumer Characterization Data Cards. The consumer characterization data cards are specific to the system undergoing analysis and contribute the only significant change in the input data decks for the respective systems. Aside from the differing input data for the five kinds of consumer systems further differences occur when a given system has a sub-critical fluid supply subsystem, or when it has a super-critical fluid supply subsystem. Thus, there are seven separate consumer characterization data card sets which cover the range of program analysis capability.

1.5.1.6 1 Engine Consumer Data Cards: (ACPS or OMS).

Gp(h-l) Card-1

The engine consumer data card is utilized for both ACPS and OMS engine data since the required parameters are identical and the same variable names are used. The variables employed are defined as follows:

NENG — Integer number of engines operating

GITEMP — Fluid Inlet Temperature to Engine(s)

GIPRES — Fluid Inlet Pressure to Engine(s)

THRUST — Developed Thrust per Engine

PSUBC — Engine Combustion Chamber Pressure

EXPRAT — Engine Nozzle Expansion Ratio

MIXRAT — Engine Oxidizer to Fuel Mixture Ratio (Real Number)

The single card is usually marked by placing the term ENG in card columns 78-80.

1.5.1.6.2 APU Consumer Data Cards. The APU Consumer input data requires two cards for either a subcritical or super-critical fluid fed system. The first card used in both cases is identical, while the second cards contain different information. The input cards required are as follows:

Gp(h-2) Card-1 (APU-Basic)

The following variables are input on the APU-Basic card:

NAPU – Integer number of APUs operating

HPR – Horsepower Rating of a single APU (Assumes all are identical)

FMR – Oxidizer to Fuel Mixture Ratio of Gas Generator Driving APU Turbine

PGG – Exit Pressure of Gas Generator driving APU Turbine

TIT – Turbine Inlet Temperature (Assumed also to be exhaust temperature of gas generator driving APU turbine)

TD – Exhaust discharge temperature from fluid conditioning heat exchangers

Gp(h-2) Card-2 (APU-Subcritical)

The variables input on the APU-Subcritical card are as follows:

MRGGCH – Oxidizer to fuel mixture ratio for the gas generator driving the fuel fluid conditioning heat exchanger

MRGGCØ – Oxidizer to fuel mixture ratio for the gas generator driving the oxidizer fluid conditioning heat exchanger

TDGGH – Discharge temperature of gas generator for fuel conditioning heat exchanger

TDGGØ – Discharge temperature of gas generator for oxidizer conditioning heat exchanger

TVH – Temperature of residual vapor in fuel storage tank

TVØ – Temperature of residual vapor in oxidizer storage tank

TENV – Environment temperature around APU System

Gp(h-2) Card-3 (APU-Supercritical)

The variables entered in the APU Supercritical data card are as follows:

FMRG – Oxidizer to fuel mixture ratio for supplementary gas generator

PFH – Final fuel tank pressure

PFØ – Final oxidizer tank pressure

TFH – Final fuel tank temperature

TFØ – Final oxidizer tank temperature

TG – Exit gas temperature from supplemental gas generator

DELPCP – Pressure rise (Delta-P) in tank circulating pump

TENV – Environmental temperature around APU system

1.5.1.6.3 Life Support Consumer Data Cards. The Life Support Consumer Data Input variables require four input cards in two different card formats. The variables by card format are as follows:

Gp(h-3) Card-1 (Ø2 = Oxygen, N2 = Nitrogen)

MDAYS — Integer number of days in mission

NCREW — Integer number of crewmen on board spacecraft

NRPRES — Integer number of cabin or airlock prepressurization planned for missi

NDARES — Integer number of days of reserve fluids required

Ø2FNØM — Metabolic oxygen requirement (lbs. per man-day)

GLKRAT — Spacecraft atmosphere leakage rate (lbs. per day)

TLSNØM — Nominal temperature of gases supplied for life support (1) = $Ø_2$; (2) = N2

RHØBEG — Loading density at stored life support fluids (1) = $Ø_2$; (2) = N2

TKFTEM — Final fluid tank temperatures (1) = $Ø_2$; (2) = N2

TKFPRS — Final fluid tank pressures (1) = $Ø_2$; (2) = N2

TENVR — Environment temperature around life support fluid storage tanks

CABVØL — Cabin (or airlock) volume

Gp(h-3) Card-2

LINDIA – Fluid line diameter entering fluid conditioning heat exchanger
(1) = 02; (2) = N2

HTRFLX – Heater rating (BTU/HR-sq. in. ret. temp.)
(1) For heaters in conditioning heat exchanger
(2) For fluid tank heaters

PLSN0M – Nominal pressure of delivered gaseous life support fluids
(1) = 02; (2) = N2

HTRDIA – Fluid tank heater diameter
(1) = 02; (2) = N2

HTRLNG – Fluid tank heater length
(1) = 02; (2) = N2

PSET1 – Lower pressure limit setting for 02 storage tank

PSET2 – Lower pressure limit setting for N2 storage tank

1.5.1.6.4 Fuel Cell Consumer Data Cards. The fuel cell consumer data input variables require four data cards in three different card formats. The variables arranged by card format are as follows:

Gp(h-4) Card-1

MRFC – Oxygen to hydrogen reactant mixture ratio for fuel cell

SRCFC – Specific reactant consumption (lbs/KWH @ rated power output)

QDTFC – Fuel cell heat rejection rate (BTU/KWH @ rated power output)

SPWTFC Fuel cell specific weight (LB/KW @ rated power output)

TFCNOM – Nominal fuel cell gas fired temperature
(1) = 02; (2) = H2

TF21IN – F21 coolant fuel cell exit temperature

TF210U – F21 coolant fuel cell inlet temperature

TF0FC – Final 02 reactant tank temperature

TFHFC – Final H2 reactant tank temperature

PF0FC – Final 02 reactant tank temperature

PFHFC – Final H2 reactant tank temperature

RH0FIL – Reactant tank fill densities
(1) = 02; (2) = H2

W0VENT – Estimated 02 vent quantity

WHVENT – Estimated H2 vent quantity

DELTCP – Pressure rise in reactant tank circulating compressor

TENV – Environment temperature around fuel cell system

PRFC0P – Fuel cell operating pressure

P0WN0M – Nominal fuel cell operating power level

Gp(h-4) Card-2

NFCØP – Integer number of fuel cells operating

NFCSTB – Integer number of fuel cells on standby

PLSET1 – Lower limit pressure setting for Ø2 reactant tank

PLSET2 – Lower limit pressure setting for H2 reactant tank

VJANUL – Vacuum jacket annulus spacing (inches)
(1) = Ø2; (2) = H2

TKMXDI – Maximum tank pressure vellel diameter permitted
(design constraint - inches)
(1) = Ø2; (2) = H2

Gp(h-4) Card-3

FCVØLT – Nominal fuel cell voltage

PRGRAT – Nominal fuel cell purge rate
(1) = Ø2; (2) = H2

PRGTIM – Nominal fuel cell purge time (duration each purge)
(1) = Ø2; (2) = H2

PRGINT – Purge interval in ampere hours
(1) = Ø2; (2) = H2

1.5.1.7 Fluid Tank Data Input Cards. The fluid tankage characterization data cards are common to systems encompassed in the major program. Variations which may occur in some systems are accommodated by simply entering zero values for the variables not used by the particular system considered. Tank geometry considerations are provided for in the program, with subprogram capability for calculating; spherical, cylindrical, cylindrical with hemispherical ends, cylindrical with conical ends, and combination tankage with a common bulkhead, hemispherical bottom and conical top with a hemispherical cap (such as the cryogen shuttle orbiter drop-tank). For special tank shapes having predetermined dimensions, the program will read in the dimensions and do the necessary calculations for volume and surface area. For simple spherical tanks, or, simple cylindrical tanks with hemispherical ends, the program skips the special geometry input cards, and they must not be present in the input deck. The conditions controlling this branching option are specified in the tank geometry characterization sub-paragraph.

1.5.1.7.1 Fluid Tank Characterization DATA CARDS. The variables which characterize the fluid tank conditions and constraints are as follows:

Gp(i-1) Cards 1-4

N0P – Number of tanks operating on line (same fluid)

SATYPE – Fluid acquisition device type

SITYPE – Tankage insulation type

SMTYPE – Tank construction material type

SPTYPE – Tank pressurization system type

SITEMP – Tank initial fluid temperature

SIPRES – Tank initial pressure

SPGTEM – Pressurant gas temperature (inlet condition)

S0PRES – Tank operating pressure
SVPRES – Tank vent pressure setting

SHFLUX – Heat leak flux into tank (BTU/HR-Sq. Ft.) (Optional)

SITHIK – Tank insulation thickness (inches)

FLDL0D – Wgt. of fluid loaded into tank (optional)

SULGPC – Percent ullage (initial value for tank)

SMDIAM – Maximum tank diameter (ft.)

SH0TEM – Tank conditioning heat exchanger cold fluid outlet temperature

SHDELP – Tank conditioning heat exchanger cold fluid pressure drop (psi)

SPDELP – Tank circulating pump pressure rise (psi)

SG0TEM – Tank conditioning heat exchanger gas-generator outlet temperature

SGGPC – Tank conditioning heat exchanger gas-generator chamber pressure (outlet pressure)

SGMRAT – Tank conditioning heat exchanger gas-generator mixture ratio (0/F).

SNBAR – Number of layers per inch of tank insulation material. (multilayer insulation only)

Two sets of the above cards are read; the first set contains the data for the oxidizer tankage, and the second set contains the data for the fuel tankage. Two sets (8-cards) must be present in the data deck, even if one set is blank.

1.5.1.7.2 Fluid Tank Geometry Data Cards.

Gp(i-2) Card-5

Tank Option Card – Provides branching option to tank geometry subprograms when required for special tank shapes.

IWØP – Integer number specifying tank geometry option

NØSHAP – Integer number specifying number of tank shape cards to follow

Option Definitions

If IWOP = 1	Subprogram will compute tank volume for a spherical tank. If diameter of spherical tank exceeds value of SMDIAM, subprogram will add a cylindrical section between hemispheres with diameter equal to SMDIAM to accommodate tank volume required. Subprogram prints out requirement for cylindrical tank giving length of cylinder and diameter.
If IWØP = 2	Subprograms will compute all parameters for a "Specific General Tank Configuration" - to be specified on input cards following this card.
If IWØP = 3	Subprograms will compute all parameters for a "Fitted General Tank Configuration" in which all tank segments are specified except the length of the major cylindrical section. This "Length" will be computed by the subprograms to "fit" the required tank volume generated by system fluid consumption computations.

If, IWØP < 2, and N0SHAP = 0, the IWØP = 1 Option is executed automatically, and there are no tank shape cards following the option card. If, IWØP ≥ 2, then NØSHAP must specify the number of tank shapes involved and that many "shape cards" will have to be present following the Tank Option Card.

Gp(i-3) Card-6

Tank shape card(s) - the tank shape cards specify the geometric shape(s) involved in the tank structure in their order of consideration, the fluid contained by the tank, and the dimensions associated with each shape segment. The variables input in this card are as follows:

JTKTYP – Integer value which specifies tank segment shape (see notes)

JFLTP – Integer value which specifies fluid contained in tank segment shape

XD – Shape "X" dimension (see notes)

YD – Shape "Y" dimension (see notes)

ZD – Shape "Z" dimension (see notes)

Notes: Variable Specifications

JTKTYP = 1, for cylinder
= 2, frustrum of cone
= 3, hemi-ellipsoid
= 4, cylinder plus hemi-ellipsoid
= -2, inverted frustrum of cone
= -3, inverted hemi-ellipsoid (bulkhead)

JFLTYP = 1, oxidizer fluid
= 2, fuel fluid
= -1 oxidizer at common bulkhead
= -2, fuel at common bulkhead

For JTKTYP = 1,
XD = Height (ft)
YD = Radius (ft)

For JTKTYP = 2, or, -2,
XD = height (ft.)
YD = radius of top (ft.)
ZD = radius of bottom (ft.)

For JTKTYP = 3, or, -3
XD = radius along axis of rotation (ft.)
YD = radius perpendicular to axis of rotation(ft.)

For JTKTYP = 4,
XD = radius (and cylinder height) along axis of rotation (ft.)
YD = radius perpendicular to axis of rotation (ft.)

One card is necessary for each tank segment shape and the order of input is from the tank "Bottom" to the tank "Top".

1.5 .1.8 Accumulator Data Input Cards. For those systems requiring an accumulator tank for the storage of gaseous fluid, provision is made for inputing the required accumulator dat The branching function permitting the reading of data specified in this and the following subsections is controlled by preprogrammed data statements called "INBLK", defined as DATA ((INBLK(SYSNUM, I, J), I = 1,5), J = 1,2). The five data statements, one for each major system, define which of five sets of major component input data cards are to be read for any given system. The five INBLK data statements will be found in subroutine ST0DTA, INBLK is defined in PDP-CCNTRL. If INBLK(SYSNUM, 1,J) is set equal to one (1), the system requires and will read in accumulator data; conversely, if INBLK (SYSNUM, 1,J) equals zero, no accumulator is required and the accumulator input cards will not be present in the input data deck.

The variables which are input in the accumulator data input cards are as follows: six cards (two sets) are required since the variables for each fluid accumulator are entered separatel The variables for the oxidizer accumulator are entered first, followed by the variables for the fuel fluid accumulator.

Gp(j) Cards 1-3

NA0P – Integer value for number of accumulators operating for one fluid

AITYPE – Accumulator insulation type

AMTYPE – Accumulator structural material type

ATEMP – Operating temperature for accumulator

APRES – Operating pressure for accumulator

AHFLUX – Heat leak rate into accumulator (Btu/hr-ft^2)

AITHIK – accumulator insulation thickness (inches)

AV0L – Accumulator volume (cu. ft.)

ADIAM – Accumulator maximum diameter (ft.)

ANDELP – Pressure drop swing allowed in accumulator (psi)

ANBAR – Number of insulation layers per inch of thickness (multilayer insulation only)

Note that if INBLK (SYSNUM, 1,J) is zero, then there will be no accumulator data cards in the input data deck.

1.5.1.9 Heat Exchanger Data Input Cards. A requirement for heat exchangers of one form or another usually exists in most of the cryogen systems one can envision, except for the liquid fed OMS system. And, (as described in subsection 1.5.1.8) if INBLK (SYSNUM, 2,J) = 1, then heat exchangers are required and input data cards must be present, otherwise they are deleted.

Heat exchangers in a two fluid system usually occur in pairs, except for the case where a single supplementary heat exchanger might be required to make up for a potential energy deficiency resulting from a limited heat source capability. For purposes of uniformity, heat exchanger data will always be input for pairs of exchangers even if one of the pair does not exist. In this case, the non-existent exchanger is represented by a dummy (or blank) data card.

The heat exchanger variables required for input employ only two card formats. The second card is repeated for each exchanger in sets of two. The first card contains data for the first oxidizer heat exchanger occuring upstream of the system consumer, and the second card contains data for its fuel side equivalent. Additional data sets are input for other heat exchangers encountered as the schematic layout progresses toward the fluid supply tanks. The variables which are input on the Heat Exchanger Data Input Cards are doubly subscripted and are stored in a double array.

For example, "HXCODE (4,1) = HX07" is the heat exchanger schematic code symbol for the oxidizer (4, 1) heat exchanger of the fourth (4, 1) set of heat exchangers occurring up-
↑ ↑
stream of the cryogen consumer.

The variables employed as input are as follows:

Gp(k) Card-1

NUMHEX = Integer value for number of pairs of heat exchangers being considered

One card is required if heat exchanger data is to be input.

Gp(k) Card-2

HEXHIT – Hot fluid inlet temperature (°R)

HEXHØT – Hot fluid outlet temperature (°R)

HEXCIT – Cold fluid inlet temperature (°R)

HEXC0T – Cold fluid outlet temperature (°R)

HEXHIP – Hot fluid inlet pressure (psia)

HEXH0P – Hot fluid outlet pressure (psia)

HEXCIP – Cold fluid inlet pressure (psia)

HEXC0P – Cold fluid outlet pressure (psia)

HXHDLP – Hot fluid pressure drop (psi)

HXCDLP – Cold fluid pressure drop (psi)

HXMRAT – Heat exchanger gas generator 0/F mixture ratio

HXC0DE – Heat exchanger identification code symbol

Two cards are required for each pair of exchangers; oxidizer unit first followed by fuel side unit, when data is to be input.

1.5.1.10 Pump and Turbine Data Input Cards. The requirement for pump, or turbine data for any of the systems considered is preprogrammed in the stored INBLK data. If INBLK (SYSNUM, 3, J) = 1, then either pump or pump and turbine data are required to be input, otherwise the data cards are deleted. The pump data input cards contain three separate sets of information; (a) Pump data (high pressure); (b) Transfer pump data; and (c) Turbine data.

The six cards which make up the pump and turbine data card set consist of two pump data cards (one for each fluid), two transfer pump data cards (one for each fluid), and two turbine data cards (one for each fluid). All six cards must be present if any of the data are required. Non-pertinent variables are simply left blank.

The variables required as input are as follows:

Gp (l) Cards 1-2

PTYPE – Interger value for pump type
PTYPE = 1, for pump only
PTYPE = 2, for turbopump assy

PEFF – Pump efficiency

PNPSH – Pump net positive suction head (psi)

PSSPED – Pump speed (rpm)

EPDELP – Estimated pump pressure rise (psi)

Gp (l) Cards 3-4

TPEFF – Transfer pump efficiency

TPNPSH – Transfer pump net positive suction head (psi)

TPDELP – Transfer pump pressure rise (psi)

TPWD0T – Transfer pump flow rate (lb/sec)

Gp (l) Cards 5-6

TEFF – Turbine efficiency

TITEMP – Turbine inlet temperature (^{o}R)

T0TEMP – Turbine outlet temperature (^{o}R)

TMRATØ – Turbine gas generator Ø/F mixture ratio

TGGPC – Exhaust pressure of turbine gas generator (psia)

Note: For high and medium pressure pumps subroutine PARPMP will calculate pump speed and net positive suction pressure required. Thus input values need only be nominal.

1.5.1.11 Heat Source Data Input Cards. The requirement for heat sources, usually in the form of gas generators, for any given cryogen system is usually associated with a requirement for heat exchangers and turbines where waste heat is not available, or, insufficient for the energy needed. For the defined cryogen systems, accommodated by the Math Model Program, the heat source requirements are imbedded in the stored INBLK data. Thus, if the value of INBLK (SYSNUM, 4, J) = 1, the heat source data are required, otherwise the data cards are deleted from the input deck.

Heat sources in a two fluid system usually occur in pairs, except for the case where a single supplementary heat source might be required to make up for an energy deficiency.

For purposes of uniformity in data handling, heat source data is always arranged such that data for a heat source in the oxidizer side of the system is input first, followed by the same data for the equivalent heat source in the fuel side of the system (i.e., paired sources). If one of the sources does not exist, then a dummy (or blank) card is entered in its place. The first pair of input data cards will contain data for the first pair of heat sources closest to the cryogen consumer. Additional data sets are then input for each pair of heat sources encountered while going through the system schematic toward the fluid supply tanks. As with the heat exchanger data, the variables are doubly subscripted and match the heat sources to the heat exchanger by position and fluid index.

The variables employed in heat source data input are as follows:

Gp (m) Card-1

NUMHS0 – Integer value for number of pairs of heat sources being considered

One card is required if heat source data is to be input.

GP (m) Card-2

HSTYPE – Integer value for heat source type
HSTYPE = 1, for gas generator only
HSTYPE = 2, for waste heat input only
HSTYPE = 3, for gas generator and waste heat combination

HSMRAT – Heat source 0/F mixture ratio

HS0TEM – Heat source outlet temperature (°R)

HSAEE – Heat source available energy (BTUs)

HSPRES – Heat source outlet pressure (psia)

Two cards are required for each pair of heat source units; oxidizer side unit first followed by fuel side unit – when data is to be input.

1.5.1.12 Electric Motor Data Input Cards. The requirement for motor driven pumps, transfer pumps, or compressors exists in some of the smaller cryogen systems where pumping horsepower needed is small, or the duty cycle is light. For the cryogen systems considered in this program, the requirement for using electric motor data has been embedded in the preprogrammed-stored INBLK data. If, for any specified system, the value of INBLK (SYSNUM, 5, J) = 1, the electric motor data are required; if otherwise, the data cards do not appear in the input data deck.

The variable employed for input at the electric motor data are as follows:

Gp (n) Card-1

MTYPE – Integer value for motor type

MEFF – Motor efficiency

MSS – Motor speed (rpm)

PDNSTY – Power density of battery driving electric motors

One card is used if motor data is required. If not required the card is deleted from the input deck.

1.5.2 Input Data Card and Card Format Description

The input data cards which make up the program input data deck are defined by the Read Statements located in Subroutines CØNTRØL, INTAB, and CØMPIL. This subsection presents a graphic description of each input card as an aid in visualizing and arranging the individual system input data decks needed for the analytical operation of the program. Included as aids, are several tables which explain and define the construction and insulation material types employed by the various subprograms. Included also as aids in program data setup are several tables which define and explain important variables that occur repeatedly. Table 1.5.2-1 presents the variable names employed for control, branching and switching purposes. Table 1.5.2-2 presents the configuration variable names and definition. Following the tables are the data sheets which present the input data card formats.

Table 1.5.2-1

VARIABLE NAMES EMPLOYED FOR CONTROL, BRANCHING, AND SWITCHING PURPOSES

1. System Identification: (Subroutine C0NTRL)

Variable Read	Alpha Input	Variable Equivalent	Integer Value	System Defined
NSYS	ACP	NAMSYS	1	Attitude Control Propulsion System (ACPS)
NSYS	APU	NAMSYS	2	Auxiliary Power Unit (APU)
NSYS	EC/	NAMSYS	3	Life Support System (EC/LSS)
NSYS	FUE	NAMSYS	4	Fuel Cell System (Fuel Cell)
NSYS	0MS	NAMSYS	5	Orbit Maneuvering System (0MS)

2. Control Variables: (Subroutine C0NTRL)

Control Variable		Integer Value	Description
SYSNUM	=	1	Controls Selection of Subprograms for ACPS
	=	2	Controls Selection of Subprograms for APU
	=	3	Controls Selection of Subprograms for ECLSS
	=	4	Controls Selection of Subprograms for Fuel Cell
	=	5	Controls Selection of Subprograms for OMS
SCRIT	=	1	Specifies Subcritical Fluid Supply
	=	2	Specifies Supercritical Fluid Supply

Table 1.5.2-1 (Cont'd)

3. Branching and Switching Variables:

MDTRC – Diagnostic Trace Switch, Read in by Subroutine CØNTRL, Used by CRYCØN. Defined in PDP-CCNTRL.

MDTRC ( ) = Diagnostic Trace Switch for CRYCØN (OFF = 0)
(1) = 1 Turn on ACCRES
(2) = 1 Turn on ACQWT
(3) = 1 Turn on APUSUB or APUSUP
(4) = 1 Turn on CMPCAL
(5) = 1 Turn on FUELCL
(6) = 1 Turn on CØNSUM
(7) = 1 Turn on ECLSS
(8) = 1 Turn on LIQRES
(9) = 1 Turn on TANK
(10) = 1 Turn on TSIZEI
(11) = 1 Turn on WTACC

MDTRC(1) is Card Column 70,---MDTRC(11) is Card Column 80 of the System Specification Card

INBLK – Controls input data selection in subroutine CØMPIL via preprogrammed set of switches.

System Specification
Input Selection Index
INBLK (SYSNUM, I, SGRIT)
Fluid Subsystem Type

DATA STATEMENT DEFINITION:

```
DATA  ((INBLK(1,I,J),I = 1,5),J = 1,2)/1,1,1,1,0,      1,1,0,1,0/
DATA  ((INBLK(2,I,J),I = 1,5),J = 1,2)/1,1,1,1,1,      1,1,0,1,0/
DATA  ((INBLK(3,I,J),I = 1,5),J = 1,2)/0,0,0,0,0,      0,1,0,0,0/
DATA  ((INBLK(4,I,J),I = 1,5),J = 1,2)/0,1,0,1,0,      0,1,1,0,1/
DATA  ((INBLK(5,I,J),I = 1,5),J = 1,2)/0,0,0,0,0,      0,0,1,0,0/
```

Table 1.5.2-1 (Cont'd)

For:

I = 1, Read Accumulator Data – If INBLK = 1
= 2, Read Heat Exchanger Data – If INBLK = 1
= 3, Read Pump Data – If INBLK = 1
= 4, Read Heat Source Data – If INBLK = 1
= 5, Read Motor Data – If INBLK = 1

KSUBC – Preprogrammed Branching Variable for specified system analysis program selection – Used in subroutine CRYCØN. Defined in STØDTA.

System Specification

Subprogram Index

KSUBC (SYSNUM, I)

DATA STATEMENT DEFINITION:

```
DATA (KSUBC(1,I), I = 1, NBRSR) /6,4,10,9,8,1,10,11,2/
DATA (KSUBC(2,I), I = 1, NBRSR) /6,3,4,10,11,2,0,0,0/
DATA (KSUBC(3,I), I = 1, NBRSR) /7,0,0,0,0,0,0,0,0/
DATA (KSUBC(4,I), I = 1, NBRSR) /5,4,0,0,0,0,0,0,0/
DATA (KSUBC(5,I), I = 1, NBRSR) /6,4,10,9,8,1,10,11,2/
```

JAPUS – Switching variable which reverses order of subprogram selection for APU subcritical or supercritical analysis. Used in subroutine CRYCØN, values defined in subroutine STØDTA.

Fluid Subsystem Type

Subprogram Reordering Index

JAPUS (SCRIT, I)

DATA STATEMENT DEFINITION:

```
DATA JAPUS(1,1), JAPUS (1,2) /4,3/
DATA JAPUS(2,1), JAPUS (2,2) /3,4/
```

Table 1.5.2-2

CONFIGURATION VARIABLE NAMES AND DEFINITIONS

(Used by Subroutine CØMPIL, CMPCAL and LSSCMP)

1. Defined Configuration Names:

Defined Variable	Input Alpha	Variable Equivalent	Integer Value	Component Item
CFUNCT	GAS	FNAME	1	FLUID
CFUNCT	ENGINE	FNAME	2	ENGINE
CFUNCT	LINE	FNAME	3	LINE
CFUNCT	CØNTRL	FNAME	4	CØNTRØL
CFUNCT	FITTING	FNAME	5	FITTING
CFUNCT	TAP	FNAME	6	FLUID TAP
CFUNCT	TEE	FNAME	7	TEE
CFUNCT	ELBOW	FNAME	8	ELBOW
CFUNCT	VALVE	FNAME	9	VALVE
CFUNCT	REG	FNAME	10	REGULATOR
CFUNCT	ACCUM	FNAME	11	ACCUMULATOR
CFUNCT	TANK	FNAME	12	TANK
CFUNCT	PUMP	FNAME	13	PUMP
CFUNCT	HEX	FNAME	14	HEAT EXCHANGER
CFUNCT	TRBINE	FNAME	15	TURBINE
CFUNCT	F-CELL	FNAME	16	FUEL CELL
CFUNCT	EC/LSS	FNAME	17	LIFE SUPPORT
CFUNCT	END	FNAME	18	END OF TABLE

Table 1.5.2-2 (Cont'd)

2. <u>Configuration Variable Definitions:</u>

CONFIGURATION FUNCTION CODE AND TYPE.

CFUNCT = 1, GAS CFTYPE-1 = OXYGEN 2 = HYDROGEN
CFUNCT = 2, ENGINE CFTYPE-1 = HI-PRESSURE 2 = LO-PRESSURE
CFUNCT = 3, LINE CFTYPE = 10A FIXED NUMBER

CFUNCT = 4, CONTROL USES TWO DIGIT INDEX AS FOLLOWS,
IDV = TENS DIGIT (10, 20, etc.)
CFTYPE = UNITS DIGIT (1, 2, etc.)
IDV = 10 FOR LIGHT WEIGHT CONTROL
= 20 FOR MEDIUM WEIGHT CONTROL
= 30 FOR HEAVY WEIGHT CONTROL
= 40 FOR EXTRA HEAVY WEIGHT CONTR
CFTYPE = 1 FOR VALVE
= 2 FOR REGULATOR
= 3 FOR ORIFICE
= 4 FOR FLOW METER

CFUNCT = 5, FITTING USES TWO DIGIT INDEX AS FOLLOWS,
LDV = TENS DIGIT (10, 20, etc.)
CFTYPE = UNIT DIGIT (1, 2, etc.)
LDV = 10 FOR USE IN LINE ONLY
= 20 FOR 4-WAY TEE
= 30 FOR 3-WAY TEE
CFTYPE = 1 FOR TEE

Table 1.5.2-2 (Cont'd)

CFUNCT = 6, TAP	USES TWO DIGIT INDEX AS FOLLOWS, LDV = TENS DIGIT (10, 20, etc.) CFTYPE = UNITS DIGIT (1, 2, etc.) LDV = 10 FOR USE IN LINE ONLY = 20 FOR 4-WAY TEE = 30 FOR 3-WAY TEE CFTYPE = 1 FOR TEE
CFUNCT = 7, TEE	USES TWO DIGIT INDEX AS FOLLOWS, LDV = TENS DIGIT (10, 20, etc.) CFTYPE = UNITS DIGIT (1, 2, etc.) LDV = 10 FOR USE IN LINE ONLY = 20 FOR 4-WAY TEE = 30 FOR 3-WAY TEE
CFUNCT = 8, ELBOW	USES TWO DIGIT INDEX AS FOLLOWS, LDV = TENS DIGIT (10, 20, etc.) CFTYPE = UNITS DIGIT (1, 2, etc.) LDV = 10 FOR USE IN LINE ONLY = 20 FOR 90 DEG ELBOW = 30 FOR 45 DEG ELBOW CFTYPE = 1 FOR ELBOW
CFUNCT = 9, VALVE	USES TWO DIGIT INDEX AS FOLLOWS, IDV = TENS DIGIT (10, 20, etc.) CFTYPE = UNITS DIGIT (1, 2, etc.) IDV = 10 FOR LIGHT WEIGHT CONTROL = 20 FOR MEDIUM WEIGHT CONTROL = 30 FOR HEAVY WEIGHT CONTROL = 40 FOR EXTRA HEAVY WEIGHT CONTROL CFTYPE = 1 FOR VALVE

Table 1.5.2-2 (Cont'd)

CFUNCT = 10, REGULATOR	USES TWO DIGIT INDEX AS FOLLOWS, IDV = TENS DIGIT (10, 20, etc.) CFTYPE = UNITS DIGIT (1, 2, etc.) IDV = 10 FOR LIGHT WEIGHT CONTROL = 20 FOR MEDIUM WEIGHT CONTROL = 30 FOR HEAVY WEIGHT CONTROL = 40 FOR EXTRA HEAVY WEIGHT CONT CFTYPE = 1 FOR REGULATOR
CFUNCT = 11, ACCUM	NO OPTIONS
CFUNCT = 12, TANK	(SEE TANK ROUTINE)
CFUNCT = 13, PUMP	USES TWO DIGIT INDEX AS FOLLOWS, JOPTN = TENS DIGIT (10, 20, etc.) CFTYPE = UNITS DIGIT (1, 2, etc.) JOPTN = 10 FOR MINIMUM POWER PUMP = 20 FOR MINIMUM WEIGHT PUMP CFTYPE = 1 FOR HI-PRESSURE PUMP CFTYPE = 2 FOR LO-PRESSURE PUMP
CFUNCT = 14, HEX	CFTYPE = 1 FOR HI-PRESSURE = 2 FOR LO-PRESSURE
CFUNCT = 15, TURBINE	NO OPTIONS
CFUNCT = 16, FUEL CELL	NO OPTIONS
CFUNCT = 17, ECLSS	NO OPTIONS
CFUNCT = 18, END	NO OPTIONS

Table 1.5.2-2 (Cont'd)

CMTYPE – CONFIGURATION MATERIAL TYPE

CMTYPE = 1, 321/347 STAINLESS STEEL
= 2, 2219-T87 ALUMINUM ALLOY
= 3, 6061-T6 ALUMINUM ALLOY
= 4, INCONEL-718 ALLOY
= 5, TITANIUM Ti-6Al-4V ALLOY
= 6, CRES VACUUM JACKETED LINE
= 7, 2219 VACUUM JACKETED LINE

CITYPE – CONFIGURATION INSULATION TYPE

CITYPE = 1, DOUBLE ALUMINUM MYLAR/SILK NET
= 2, DOUBLE GOLD MYLAR/SILK NET
= 3, DOUBLE ALUMINUM MYLAR/TISSUE GLASS
CITYPE = 4, CRINK DOUBLE ALUMINUM MYLAR
= 5, NRC-2 CRINKLED ALUMINIZED MYLAR
= 6, SUPERFLOC
= 7, MICROSPHERES (104-135 MICRON)
= 8, POLYURETHANE FOAM
= 9, FIBERGLASS BATTING (JM)

CNOPER – NUMBER OF OPERATIONAL UNITS (CFUNCT)

CNSTBY – NUMBER OF STANDBY UNITS (CFUNCT)

CONFIG – CONFIGURATION TABLE

COLUMN 1	CONTAINS THE ABOVE SIX (6) VARIABLES PACKED ONE PER BYTE IN THE ORDER THEY ARE LISTED FROM LEFT TO RIGHT IN THE WORD.
COLUMN 2	CONTAINS THE FLOW FRICTION COEFFICIENT
COLUMN 3	CONTAINS THE LENGTH OF A LINE OR THE EFFECTIVE L/D FOR OTHER COMPONENTS
COLUMN 4	CONTAINS THE DIAMETER OF A LINE
COLUMN 5	CONTAINS THE INSULATION THICKNESS FOR A LINE

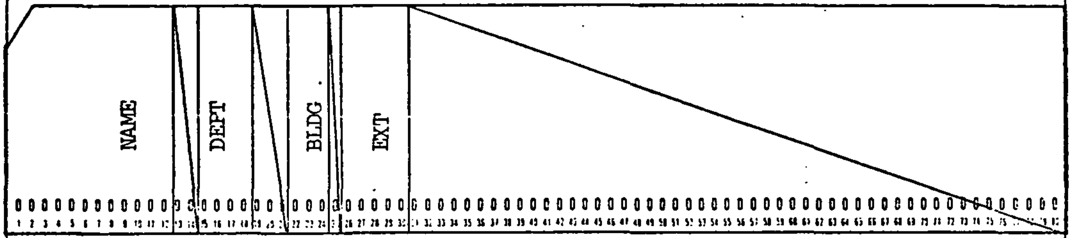
Prepared by:	Date	LOCKHEED MISSILES & SPACE COMPANY. INC.	Page Temp. Form.
Checked by:	Date	Title USER ID CARD CASE TITLE CARD	Model
Approved by:	Date		Report No. 1.5.2.1

CARD TYPE - G_p(a) CARD-1

CARD FUNCTION - User Identification Card

READ BY - Subroutine CØNTRL

CARD FORMAT (2AC, 2XA4, 3XA3, 1XA5)

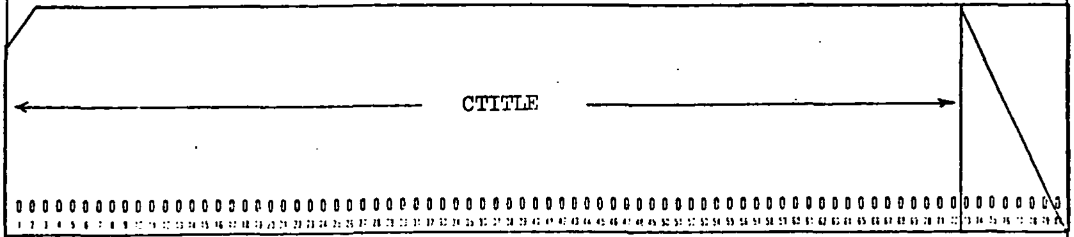


CARD TYPE - G_p(b) CARD-1

CARD FUNCTION - Case Title Card

READ BY - Subroutine CØNTRL

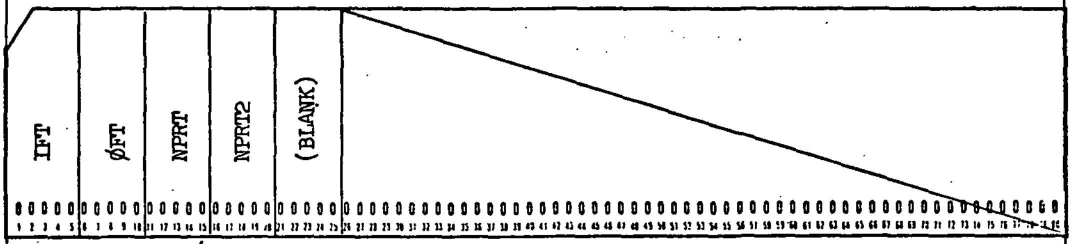
CARD FORMAT - (12AC)



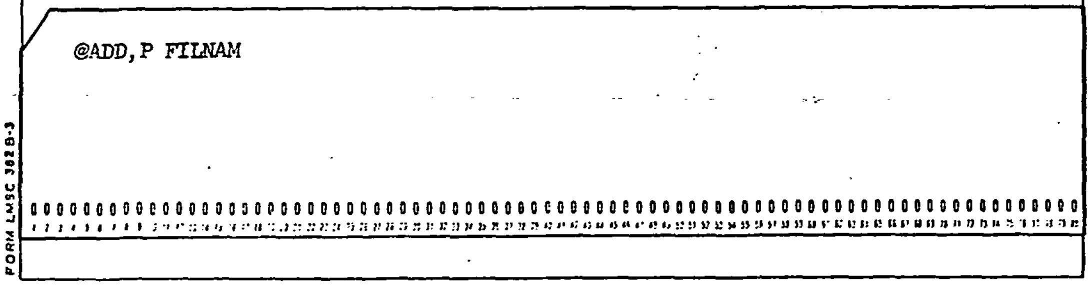
FORM LMSC 382 B-3

Prepared by:	Date	LOCKHEED MISSILES & SPACE COMPANY. INC.	Page Temp. Perm.
Checked by:	Date	Title TABLE DATA CARDS (FOR STORED TABLE FILE)	Model
Approved by:	Date		Report No. 1.5.2.2

CARD TYPE - G_p(c) CARD-1
CARD FUNCTION - TABLE DATA ECHO CONTROL CARD
READ BY - SUBROUTINE INTAB
CARD FORMAT - (5I5)

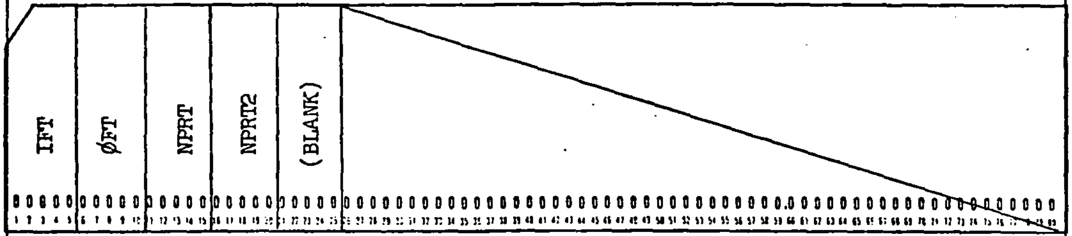


CARD TYPE - G_p(d) CARD-1
CARD FUNCTION - TABLE DATA FILE - ADD CARD
READ BY - SUBROUTINE INTAB
CARD FORMAT - QADD,P FILNAM
REF. - UNIVAC-1108 MANUAL

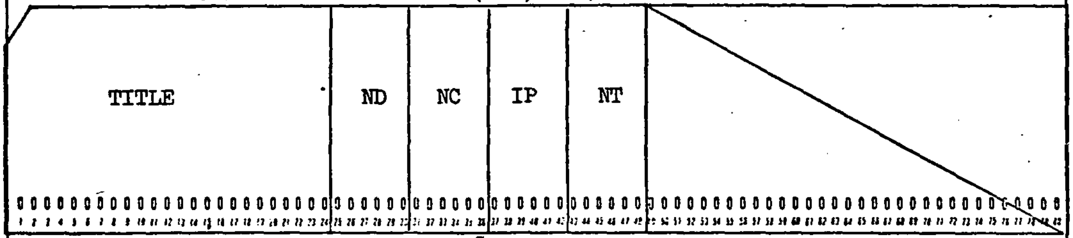


Prepared by:	**Date**	LOCKHEED MISSILES & SPACE COMPANY, INC.	**Page** Temp. Perm.
Checked by:	**Date**	**Title** ALTERNATE TABLE DATA INPUT -TABLE DATA DECKS-	**Model**
Approved by:	**Date**		**Report No.** 1.5.2.3

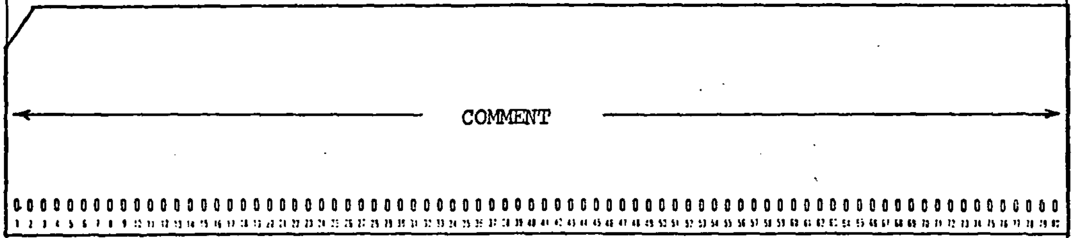
CARD TYPE - $G_p(c)$ CARD-1
CARD FUNCTION - TABLE DATA DECK ECHO CONTROL CARD
READ BY - SUBROUTINE INTAB
CARD FORMAT - (5I5)



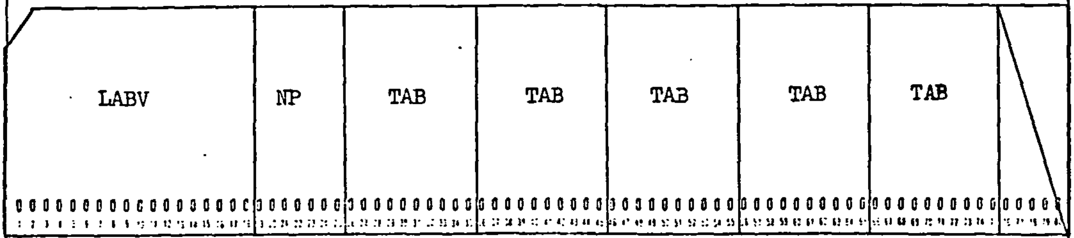
CARD TYPE - $G_p(d)$ CARD-1
CARD FUNCTION - TABLE I.D. AND CONTROL CARD
READ BY - SUBROUTINE INTAB
CARD FORMAT - (4AL, 4IC)



CARD TYPE - $G_p(d)$ CARD-2
CARD FUNCTION - TABLE COMMENT CARD
CARD FORMAT - (13AL, A2)



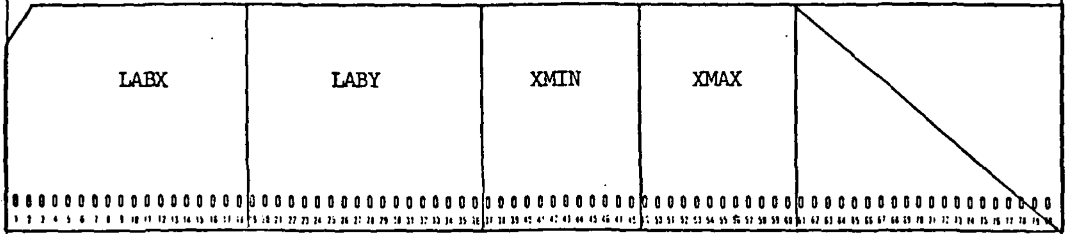
CARD TYPE - $G_p(d)$ CARD-3
CARD FUNCTION - TABLE SUBSET VARIABLE CARD
CARD FORMAT - (3AL, I7, 5E10.0)



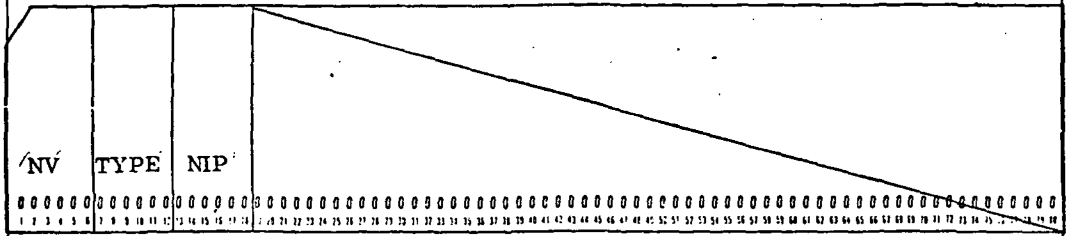
FORM LMSC 382B-3

Prepared by:	Date	LOCKHEED MISSILES & SPACE COMPANY, INC.	Page Temp. Perm.
Checked by:	Date	Title ALTERNATE TABLE DATA INPUT - TABLE DATA DECKS -	Model
Approved by:	Date		Report No. 1.5.2.4

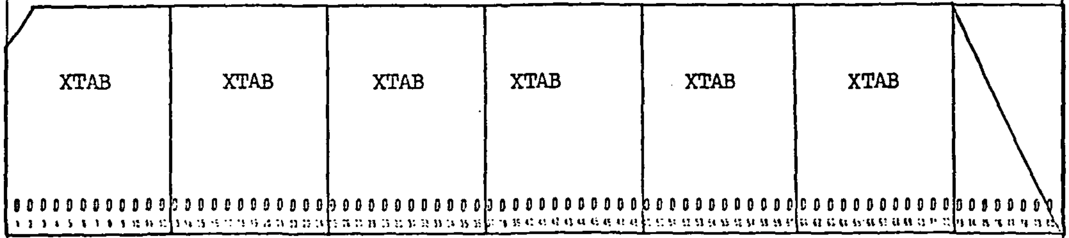
CARD TYPE - $G_p(d)$ CARD-4
CARD FUNCTION - TABLE PLOT CONTROL CARD
READ BY - SUBROUTINE INTAB
CARD FORMAT - (3AL, 3AL, 2E12.0)



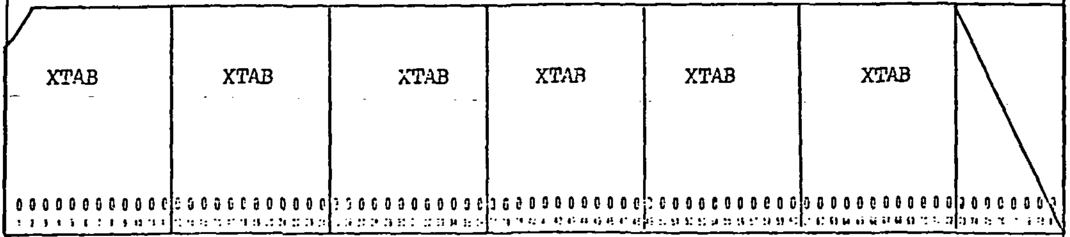
CARD TYPE - $G_p(d)$ CARD-5
CARD FUNCTION - TABLE SUBSET DATA CARD
CARD FORMAT - (3I6)



CARD TYPE - $G_p(d)$ CARD-6
CARD FUNCTION - TABLE DATA CARD (POLY NOMIAL COEFFICIENTS)
CARD FORMAT - (6E12.0)



CARD TYPE - $G_p(d)$ CARD-6
CARD FUNCTION - TABLE DATA CARD (DISCRETE DATA)
CARD FORMAT - (6E12.0)



FORM LMSC 382 B-3

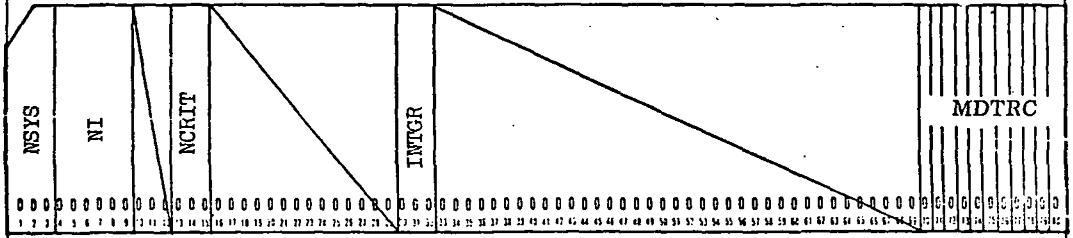
Prepared by:	Date	LOCKHEED MISSILES & SPACE COMPANY. INC.	Page Temp. Perm.
Checked by:	Date	Title SYSTEM DEFINITION INPUT CARD	Model
Approved by:	Date		Report No. 1.5.2.5

CARD TYPE - $G_p(e)$ CARD-1

CARD FUNCTION - SYSTEM DEFINITION CARD

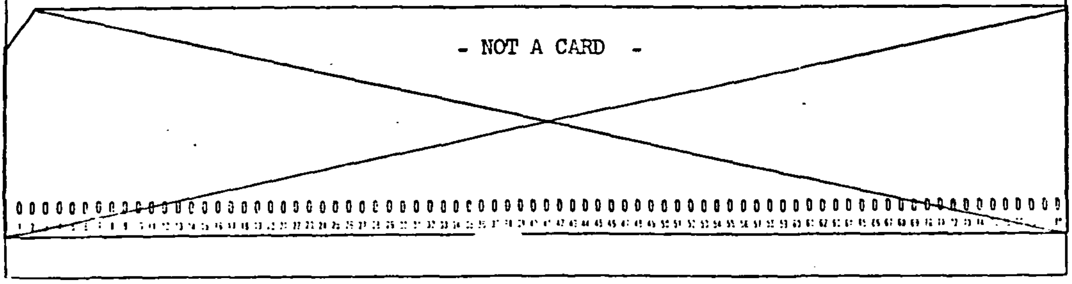
READ BY - SUBROUTINE CONTRL

CARD FORMAT - (A3, A6, 3X, A3, 14X, A3, 37X, 11I1)



- THIS IS A BLANK SPACE -

GO TO NEXT PAGE



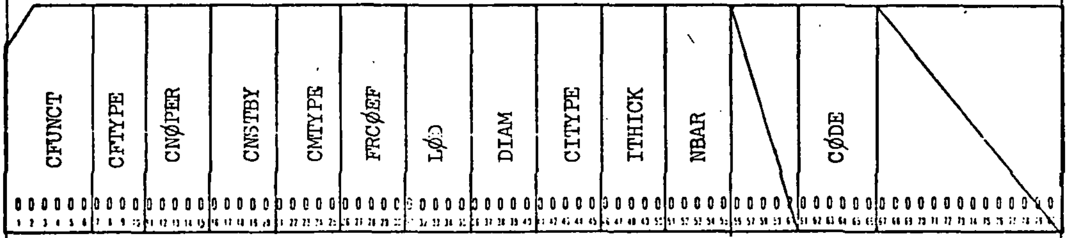
Prepared by:	Date	LOCKHEED MISSILES & SPACE COMPANY. INC.	Page Temp. Form.
Checked by:	Date	Title CONFIGURATION DEFINITION DATA CARDS	Model
Approved by:	Date		Report No. 1.5.2.6

CARD TYPE - $G_p(f)$ CARD-1

CARD FUNCTION - CONFIGURATION DATA CARD

READ BY - SUBROUTINE CØMPIL

CARD FORMAT - (A6, I4, 3I5, 3F5.0, I5, 2F5.0, 5X, A6)

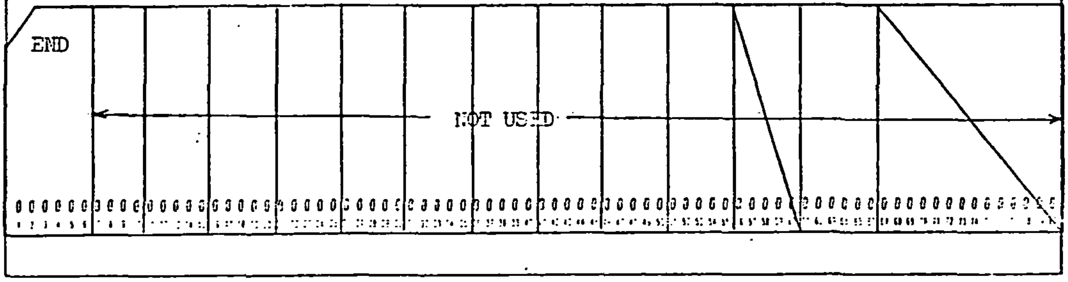


CARD TYPE - $G_p(f)$ CARD-2

CARD FUNCTION - CONFIGURATION DATA END CARD

READ BY - SUBROUTINE CØMPIL

FORMAT - (A6, I4, 3I5, 3F5.0, I5, 2F5.0, A6)



FORM LMSC 3628-3

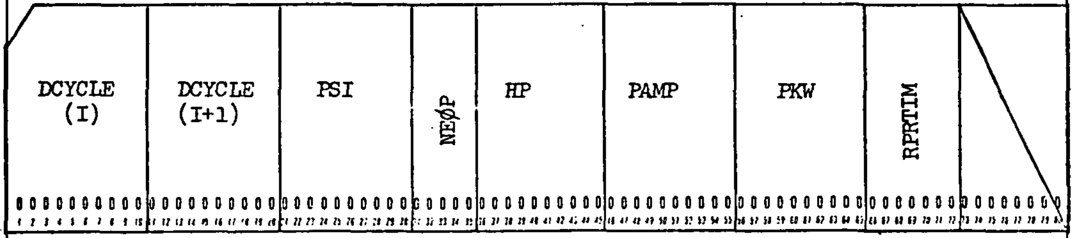
Prepared by:	Date	LOCKHEED MISSILES & SPACE COMPANY. INC.	Page Temp. Perm.
Checked by:	Date	Title DUTY CYCLE DEFINITION DATA CARD	Model
Approved by:	Date		Report No. 1.5.2.7

CARD TYPE - $G_p(g)$ CARD-1

CARD FUNCTION - DUTY CYCLE DATA CARD

READ BY - SUBROUTINE CØMPIL

CARD FORMAT - FØRMAT (3F10.0, I5, 3F10.0, F7.0)

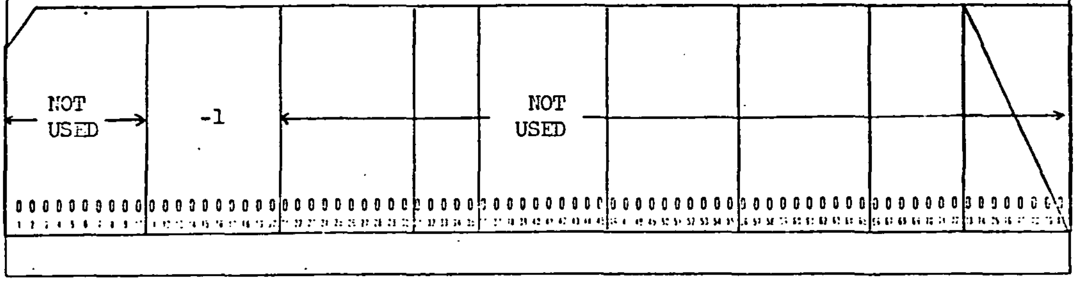


CARD TYPE - $G_p(g)$ CARD-1

CARD FUNCTION - DUTY CYCLE DATA END CARD

READ BY - SUBROUTINE CØMPIL

CARD FORMAT - (3F10.0, I5, 3F10.0, F7.0)



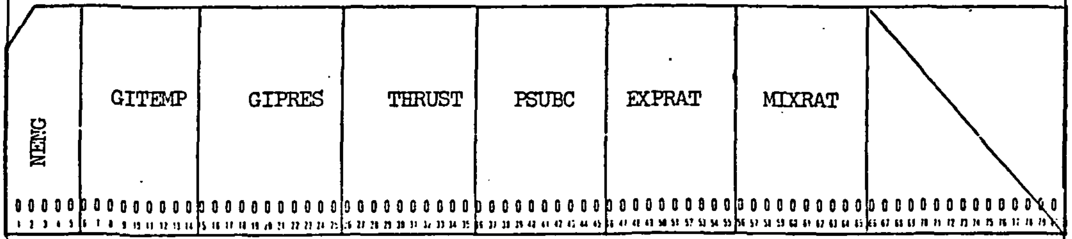
Prepared by:	Date	LOCKHEED MISSILES & SPACE COMPANY. INC.	Page Temp. Perm.
Checked by:	Date	Title ENGINE CONSUMER DATA CARDS	Model
Approved by:	Date		Report No. 1.5.2.8

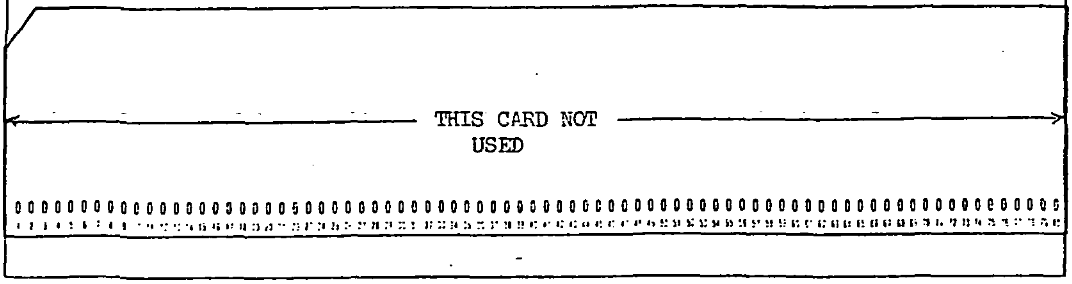
CARD TYPE - G_p(h-1) CARD-1

CARD FUNCTION - ENGINE CONSUMER INPUT DATA CARD

READ BY - SUBROUTINE CØMPIL

CARD FORMAT - (I5, 6F10.0)

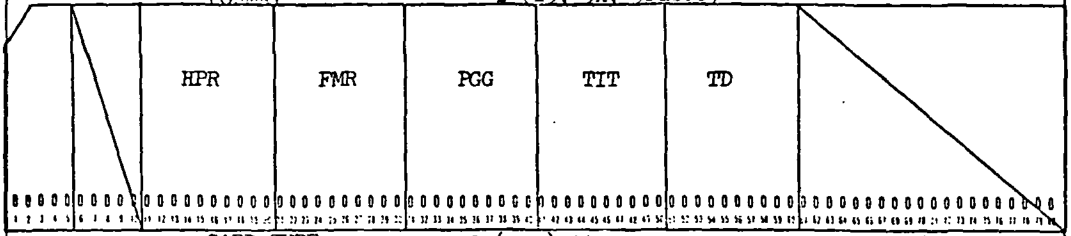




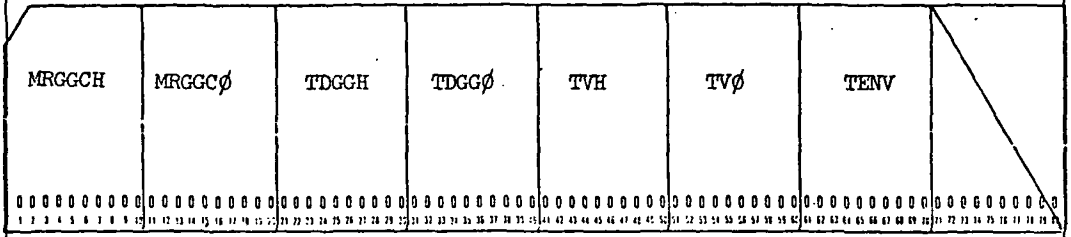
FORM LMSC 362B-3

Prepared by:	Date	LOCKHEED MISSILES & SPACE COMPANY, INC.	Page Temp. Perm.
Checked by:	Date	Title APU CONSUMER DATA CARDS	Model
Approved by:	Date		Report No. 1.5.2.9

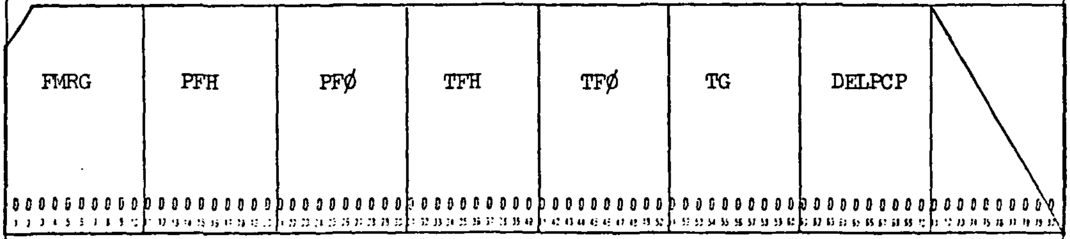
CARD TYPE - G_p(h-2) CARD-1
CARD FUNCTION - APU CONSUMER INPUT DATA CARD - APU BASIC DATA
READ BY - SUBROUTINE CØMPIL
FORMAT - (I5, 5X, 5F10.0)

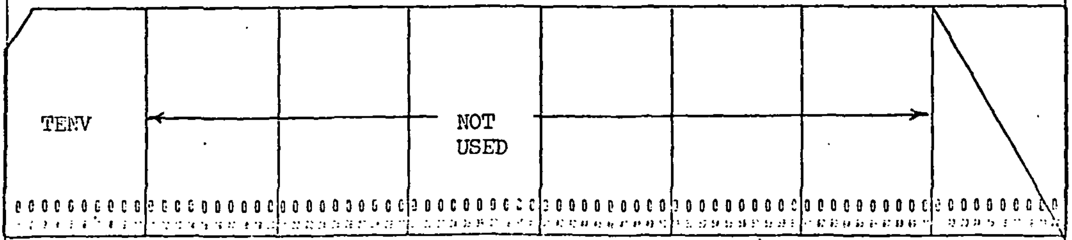


CARD TYPE - G_p(h-2) CARD-2
CARD FUNCTION - APU CONSUMER INPUT DATA CARD-APU SUBCRITICAL DATA
FORMAT - (7F10.0)



CARD TYPE - G_p(h-2) CARD-3
CARD FUNCTION - APU CONSUMER INPUT DATA CARD - APU SUPERCRITICAL DATA
CARD FORMAT - (7F10.0)

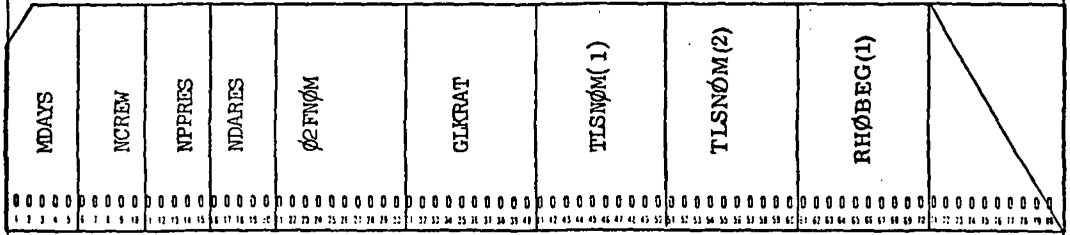


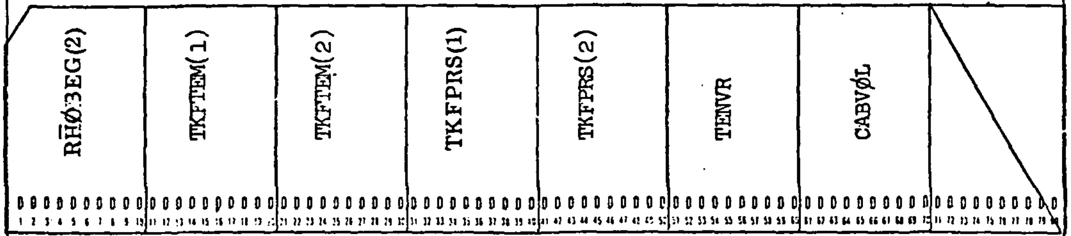


FORM LMSC 362 B-3

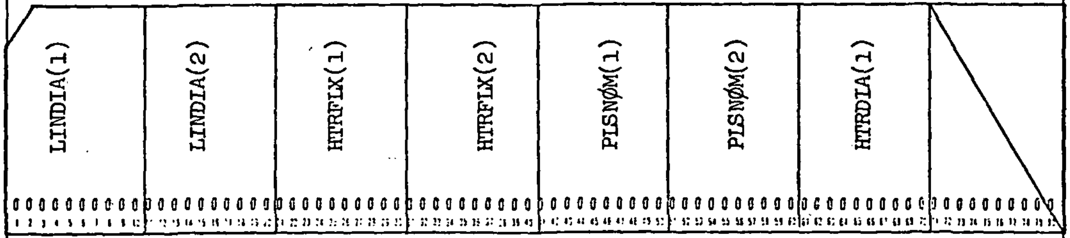
Prepared by:	Date	LOCKHEED MISSILES & SPACE COMPANY. INC.	Page Temp. Perm.
Checked by:	Date	Title LIFE SUPPORT CONSUMER DATA CARDS	Model
Approved by:	Date		Report No. 1.5.2.10

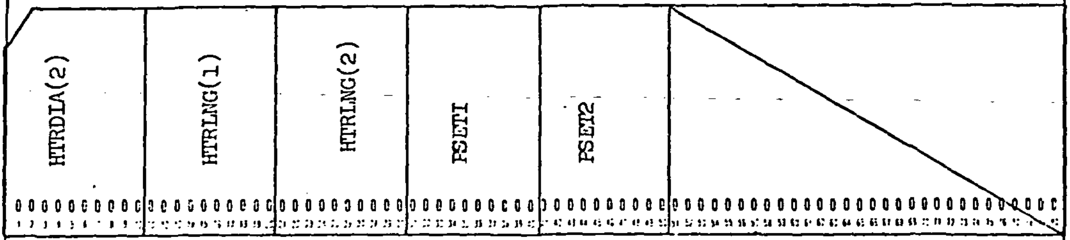
CARD TYPE - G_p (h-3) CARD-1
CARD FUNCTION - LIFE SUPPORT INPUT DATA CARDS
READ BY - SUBROUTINE CØMPIL
FORMAT - (4I5, 5F10.0/(7F10.0)





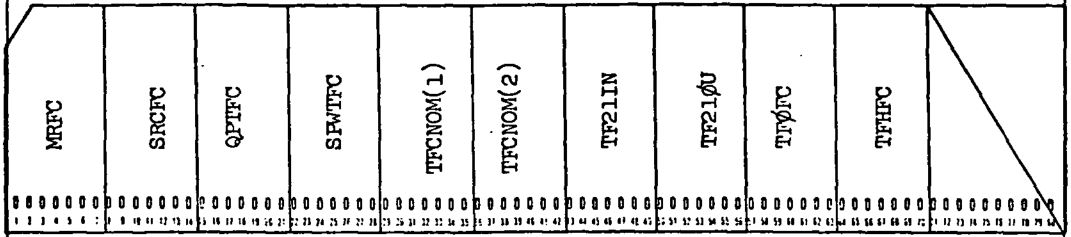
CARD TYPE - G_p(h-3) CARD-2
CARD FUNCTION - LIFE SUPPORT INPUT DATA
CARD FORMAT - (7F10.0/5F10.0)



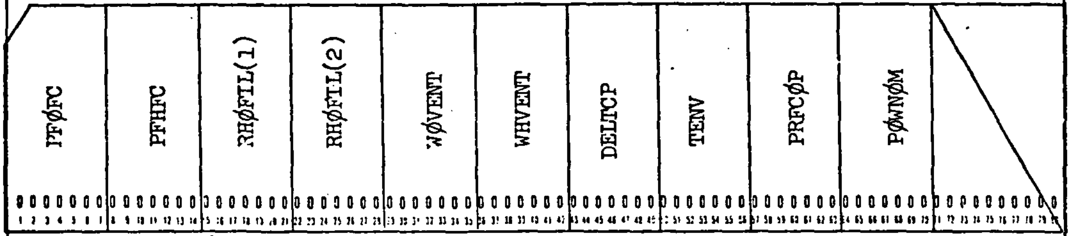


Prepared by:	Date	LOCKHEED MISSILES & SPACE COMPANY. INC.	Page Temp. Perm.
Checked by:	Date	Title FUEL CELL CONSUMER DATA CARDS	Model
Approved by:	Date		Report No. 1.5.2.11

CARD TYPE - G_p(h-4) CARD-1
CARD FUNCTION - FUEL CELL INPUT DATA CARDS
READ BY - SUBROUTINE CØMPIL
CARD FORMAT - (10F7.0)

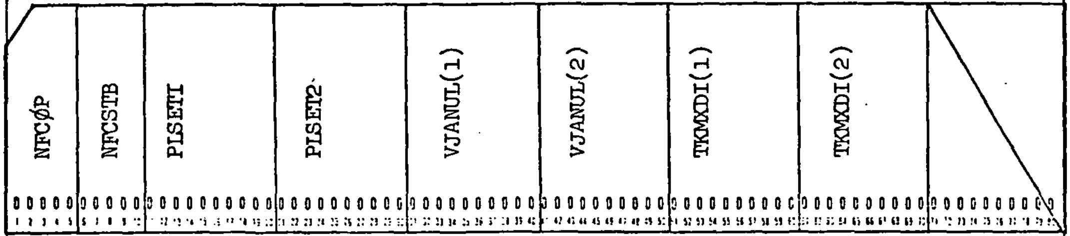


MRFC	SRCFC	QPTFC	SPWTFC	TFCNOM(1)	TFCNOM(2)	TF21IN	TF21ØU	TTØFC	TFHFC



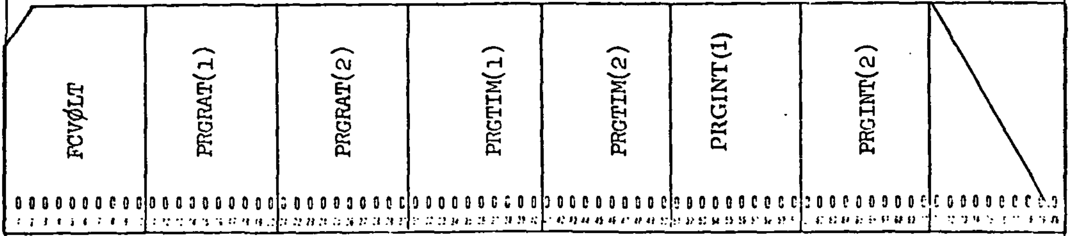
PFØFC	PFHFC	RHØFTL(1)	RHØFTL(2)	WØVENT	WHVENT	DELTCP	TENV	PRFCØP	PØWNØM

CARD TYPE - G_p(h-4) CARD-2
CARD FUNCTION - FUEL CELL INPUT DATA
CARD FORMAT - (2I5, 6F10.0)



NFCØP	NFCSTB	PISET1	PISET2	VJANUL(1)	VJANUL(2)	TKMXDI(1)	TKMXDI(2)

CARD TYPE - G_p(h-4) CARD-3
CARD FUNCTION - FUEL CELL INPUT DATA
CARD FORMAT - (7F10.0)



FCVØLT	PRGRAT(1)	PRGRAT(2)	PRGTIM(1)	PRGTIM(2)	PRGINT(1)	PRGINT(2)

FORM LMSC 3628-3

Prepared by:	Date	LOCKHEED MISSILES & SPACE COMPANY, INC.	Page Temp. Perm.
Checked by:	Date	Title TANK CHARACTERIZATION INPUT DATA	Model
Approved by:	Date		Report No. 1.5.2.12

CARD TYPE - $G_p(i-1)$ CARD-1
CARD FUNCTION - TANK CHARACTERIZATION INPUT DATA CARDS
READ BY - SUBROUTINE CØMPIL
CARD FORMAT - (5I5)

NØP	SATYPE	SITYPE	SMTYPE	SPTYPE

CARD TYPE - $G_p(i-1)$ CARD-2
CARD FUNCTION - TANK DATA
CARD FORMAT - (8F10.0)

SITEMP	SIPRES	SPGTEM	SØPRES	SVPRES	SHFLUX	SITHIK	FLDLØD

CARD TYPE - $G_p(i-1)$ CARD-3
CARD FUNCTION - TANK DATA
CARD FORMAT - (8F10.0)

SULGPC	SMDIAM	SHØTEM	SHDELP	SPDELP	SGØTEM	SGGPC	SGMRAT

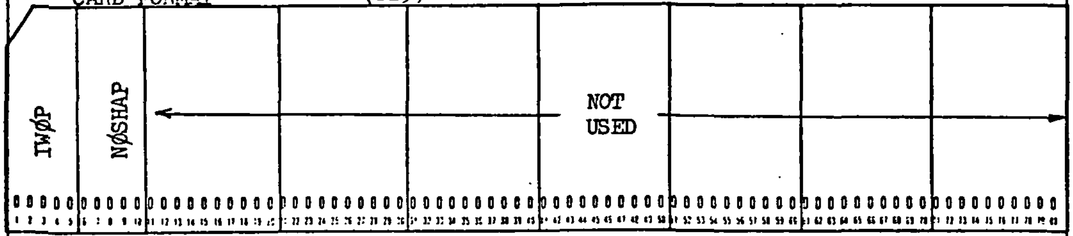
CARD TYPE - $G_p(i-1)$ CARD-4
CARD FUNCTION - TANK DATA
CARD FORMAT - (F10.0)

SNBAR

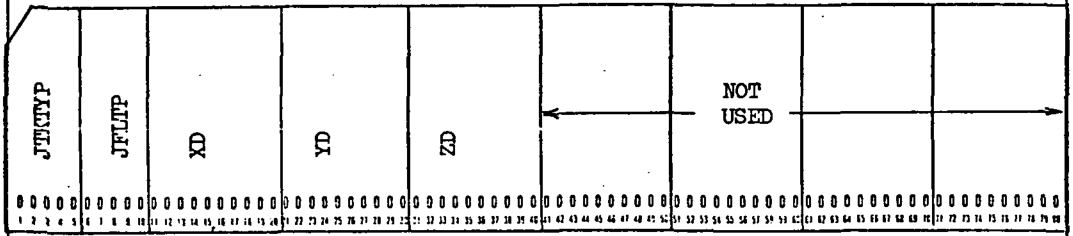
NOTE: TWO SETS OF THE ABOVE CARDS ARE REQUIRED

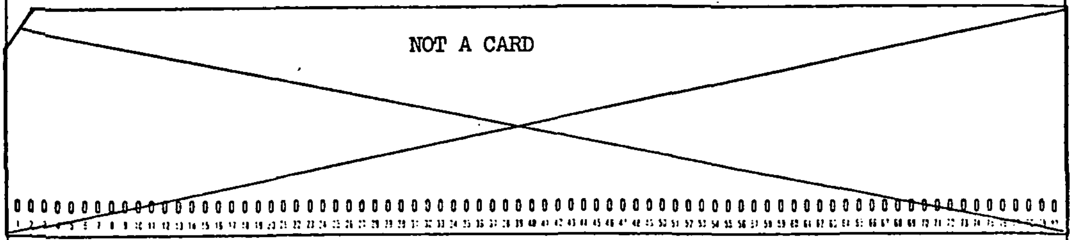
Prepared by:	Date	LOCKHEED MISSILES & SPACE COMPANY. INC.	Page Temp. Perm.
Checked by:	Date	Title TANK GEOMETRY INPUT DATA CARDS	Model
Approved by:	Date		Report No. 1.5.2.13

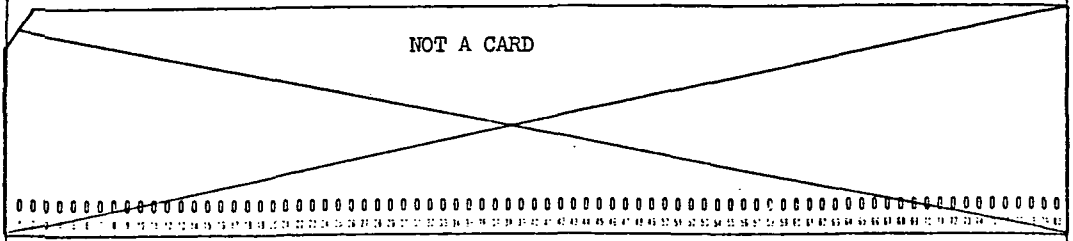
CARD TYPE - $G_p(i-2)$ CARD-5
CARD FUNCTION - TANK GEOMETRY OPTION CARD
READ BY - SUBROUTINE CØMPIL
CARD FORMAT - (2I5)



CARD TYPE - $G_p(i-3)$ - CARD-6
CARD FUNCTION - TANK SEGMENT SHAPE CARD
CARD FORMAT - (2I5, 7F10.0)





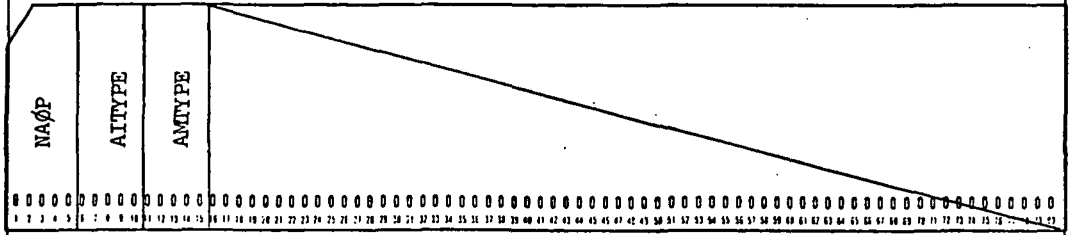


FORM LMSC 352B-3

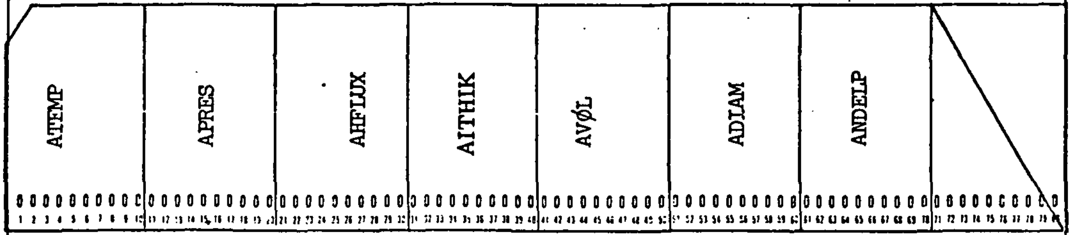
Prepared by:	Date	LOCKHEED MISSILES & SPACE COMPANY, INC.	Page Temp. Perm.
Checked by:	Date	Title ACCUMULATOR CHARACTERIZATION INPUT DATA CARDS	Model
Approved by:	Date		Report No. 1.5.2.14

CARD TYPE - $G_p(j)$ CARD-1

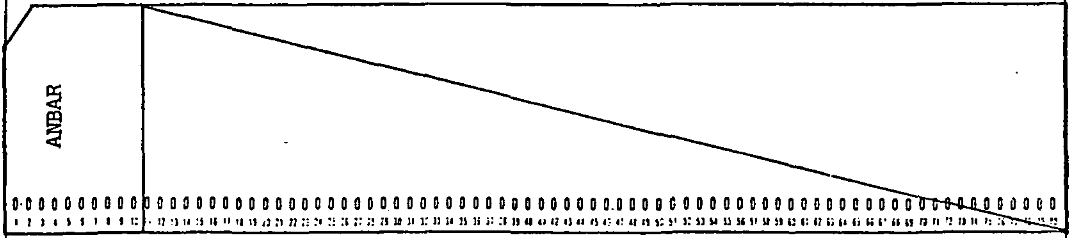
CARD FUNCTION - ACCUMULATOR DATA INPUT CARDS
READ BY - SUBROUTINE CØMPIL
CARD FORMAT - (3I5)



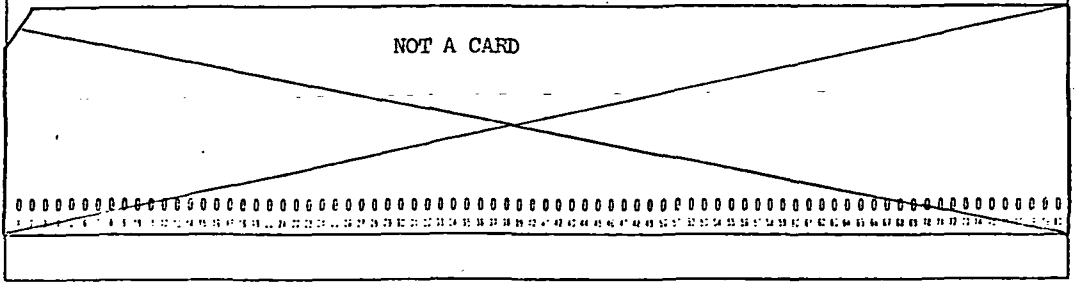
CARD TYPE - $G_p(j)$ CARD-2
CARD FUNCTION - ACCUMULATOR DATA
CARD FORMAT - (F10.0)



CARD TYPE - $G_p(j)$ CARD-3
CARD FUNCTION - ACCUMULATOR DATA
CARD FORMAT - (10.0)



NOTE: TWO SETS OF THE ABOVE CARDS ARE NEEDED IF ACCUMULATOR DATA IS REQUIRED.



FORM LMSC 3828-3

Prepared by:	Date	LOCKHEED MISSILES & SPACE COMPANY. INC.	Page Temp. Frim.
Checked by:	Date	Title HEAT EXCHANGER CHARACTERIZATION DATA INPUT CARDS	Model
Approved by:	Date		Report No. 1.5.2.15

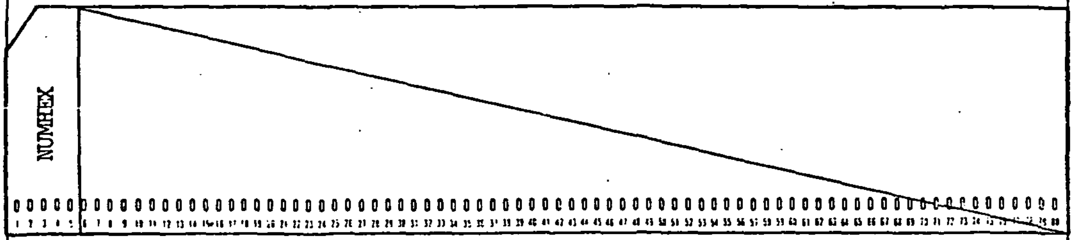
Heat Exchanger Data Input (when required) will always be in pairs. Use dummy blank card if one heat exchanger does not exist. Oxidizer side unit will be entered first followed by fuel side unit.

CARD TYPE - $G_p(k)$ CARD-1

CARD FUNCTION - HEAT EXCHANGER DATA INPUT CARDS

READ BY - SUBROUTINE CØMPIL

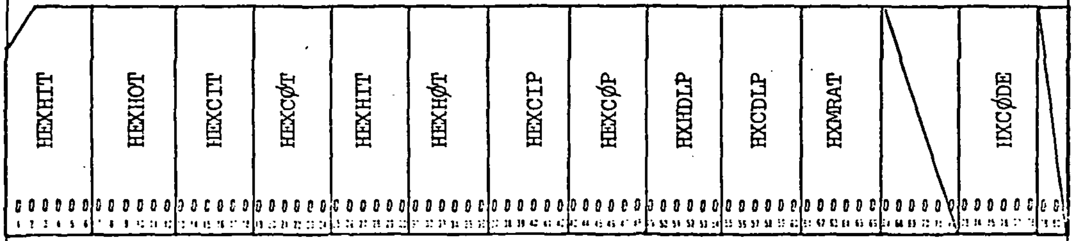
CARD FORMAT - (I5)



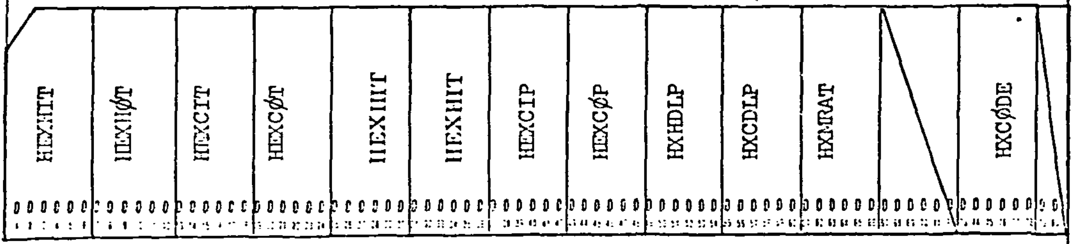
CARD TYPE - $G_p(k)$ CARD-2

CARD FUNCTION - HEAT EXCHANGER DATA

CARD FORMAT - (11F6.0, 6X,A6) (OXIDIZER SIDE)



(FUEL SIDE)



FORM LMSC 362 B-3

Prepared by:	Date	LOCKHEED MISSILES & SPACE COMPANY, INC.	Page Temp. Perm.
Checked by:	Date	Title PUMP AND TURBINE CHARACTERIZATION DATA INPUT CARDS	Model
Approved by:	Date		Report No. 1.5.2.16

Pump and turbine input data (when required) will always be input in pairs. Six cards (3 pair sets) are always required. Non-pertinent variables will be left as blanks. If no data are required, then all cards are omitted from input data deck.

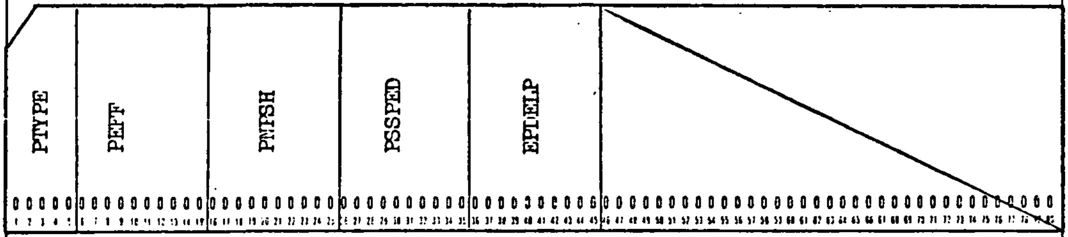
CARD TYPE - $G_p(1)$ CARD-1-2

CARD FUNCTION - PUMP AND TURBINE INPUT DATA CARDS

READ BY - SUBROUTINE CØMPIL

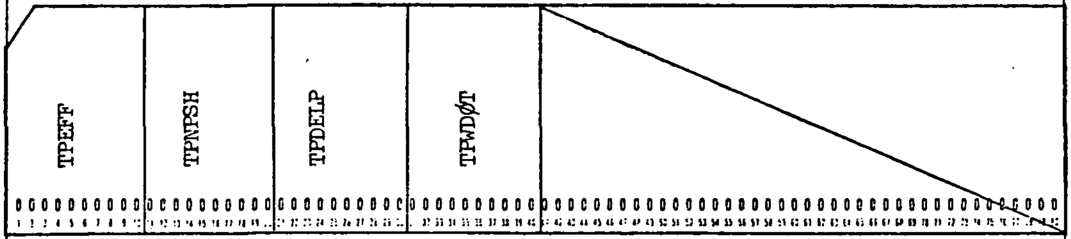
CARD FORMAT - (I5, 4F10.0)

1. OXIDIZER SIDE
2. FUEL SIDE



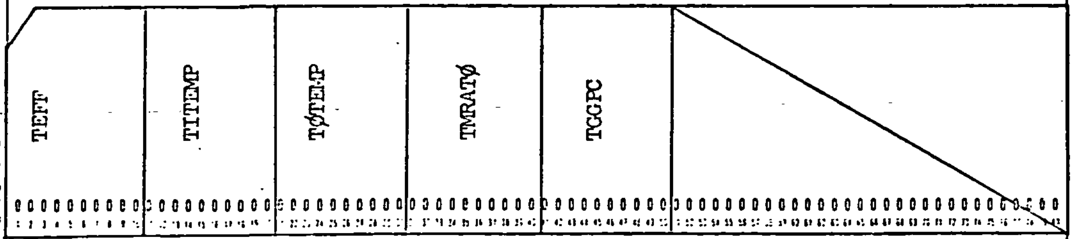
CARD TYPE - Gp(1) CARDS 3-4
CARD FUNCTION - TRANSFER PUMP DATA
CARD FORMAT - (4F10.0)

3. OXIDIZER SIDE
4. FUEL SIDE



CARD TYPE - $G_p(1)$ CARDS 5-6
CARD FUNCTION - TURBINE DATA
CARD FORMAT - (5F10.0)

5. OXIDIZER SIDE
6. FUEL SIDE



Prepared by:	Date	LOCKHEED MISSILES & SPACE COMPANY, INC.	Page Temp. Perm.
Checked by:	Date	Title HEAT SOURCE CHARACTERIZATION DATA INPUT CARDS	Model
Approved by:	Date		Report No. 1.5.2.17

Heat source data input (when required) will always be in sets of two cards, one each for oxidizer and fuel sides of system. Use dummy (blank) card when one unit does not exist. Oxidizer side unit will be entered first followed by fuel side unit.

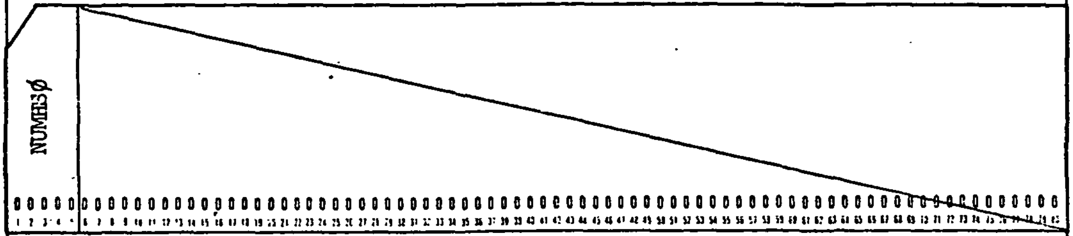
HEAT SOURCE INPUT DATA CARDS

CARD TYPE - $G_p(m)$ CARD-1

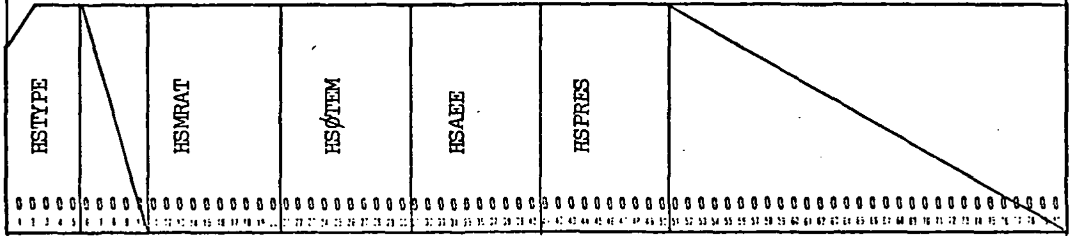
CARD FUNCTION - HEAT SOURCE DATA

READ BY - SUBROUTINE CØMPIL

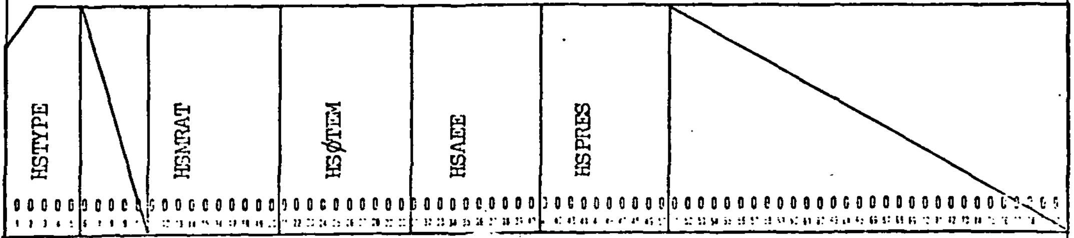
CARD FORMAT - (I5)



CARD TYPE - $G_p(m)$ CARD-2
CARD FUNCTION - HEAT SOURCE DATA
CARD FORMAT - (I5,5X, 4F10.0) (OXIDIZER SIDE)



CARD TYPE - $G_n(m)$ CARD-2
CARD FUNCTION - HEAT SOURCE DATA
CARD FORMAT - (I5, 5X, 4F10.0) (FUEL SIDE)



Prepared by:	Date	LOCKHEED MISSILES & SPACE COMPANY. INC.	Page Temp. Perm.
Checked by:	Date	Title MOTOR CHARACTERIZATION DATA INPUT CARD	Model
Approved by:	Date		Report No. 1.5.2.18

Electric Motor Data (when required) is input currently with a single card. If additional motor types and characteristics are to be added, the data input will need to be expanded. When adding variables, take care to insure proper dimensioning is accomplished in the appropriate PDP.

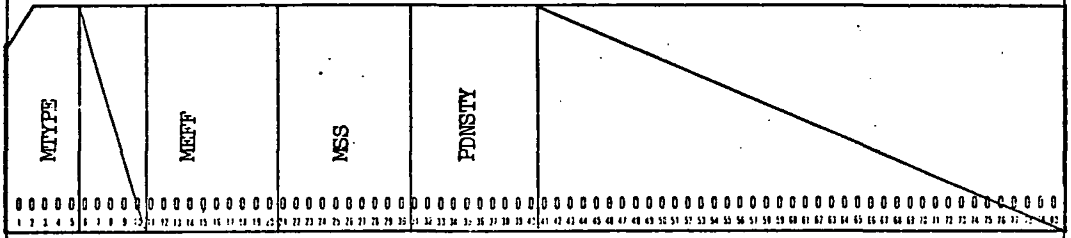
MOTOR INPUT DATA CARD

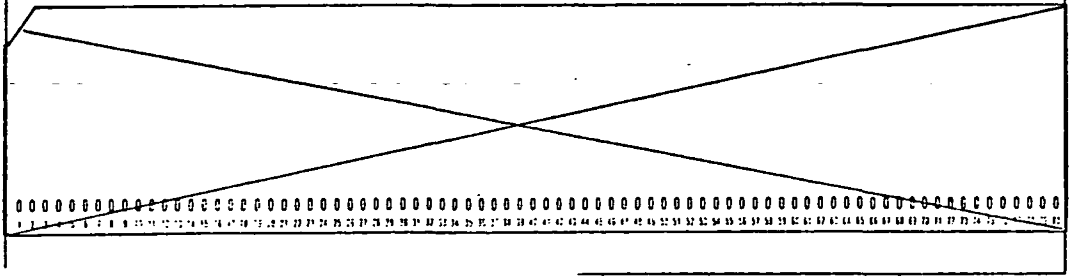
CARD TYPE - $G_p(n)$ CARD-1

CARD FUNCTION - MOTOR INPUT DATA

READ BY - SUBROUTINE CØMPIL

CARD FORMAT - (I5, 5X, 3F10.0)





1.5.3 Table Data Cards

The use of semi-permanent table data and the general means of acquiring such data has been previously discussed in subsection 1.2.2, and graphically outlined in Fig. 1.2-2. However, the use of an actual example will serve better to illustrate, and demonstrate, the procedure to be used in setting up tables for the users own specific applications.

The example chosen is the Electrical Heat Exchanger Heat Transfer Performance Data for Hydrogen Gas utilized in Data Table 20 of the current program table set. The data (Ref. 1.5-1) is presented in graphic form in Figure 1.5.3-1 and represents a typical data source obtained from study reports. The heat transfer coefficient as a function of hydrogen gas mass velocity, over a given range, is given for four pressures. The data is given for a one inch square section of a specific flow element diagram which is described in detail in the referenced (Ref. 1.5-1).

In translating curve data to table data, the limitations of computer data array manipulation must be kept in mind. Normally, if a computer independent variable is slightly off the end of a curve, the analyst simply takes a ships curve, or straight-edge and fits the curve to extend the graphic function. But a computer table look-up program will only see the first or last value in the curve point data array and (if programmed) states that the value currently considered is out of range for the table. This problem is avoided by extending (extrapolation) each curve in the set (both ends) to insure that the resulting table is adequate for the data range required in the planned analysis. For the example it was determined that the range for the independent variable (mass velocity) should be 0.1 to 6.0 lbs/hr-sq.in. The resulting points taken from the curve are given in the following table.

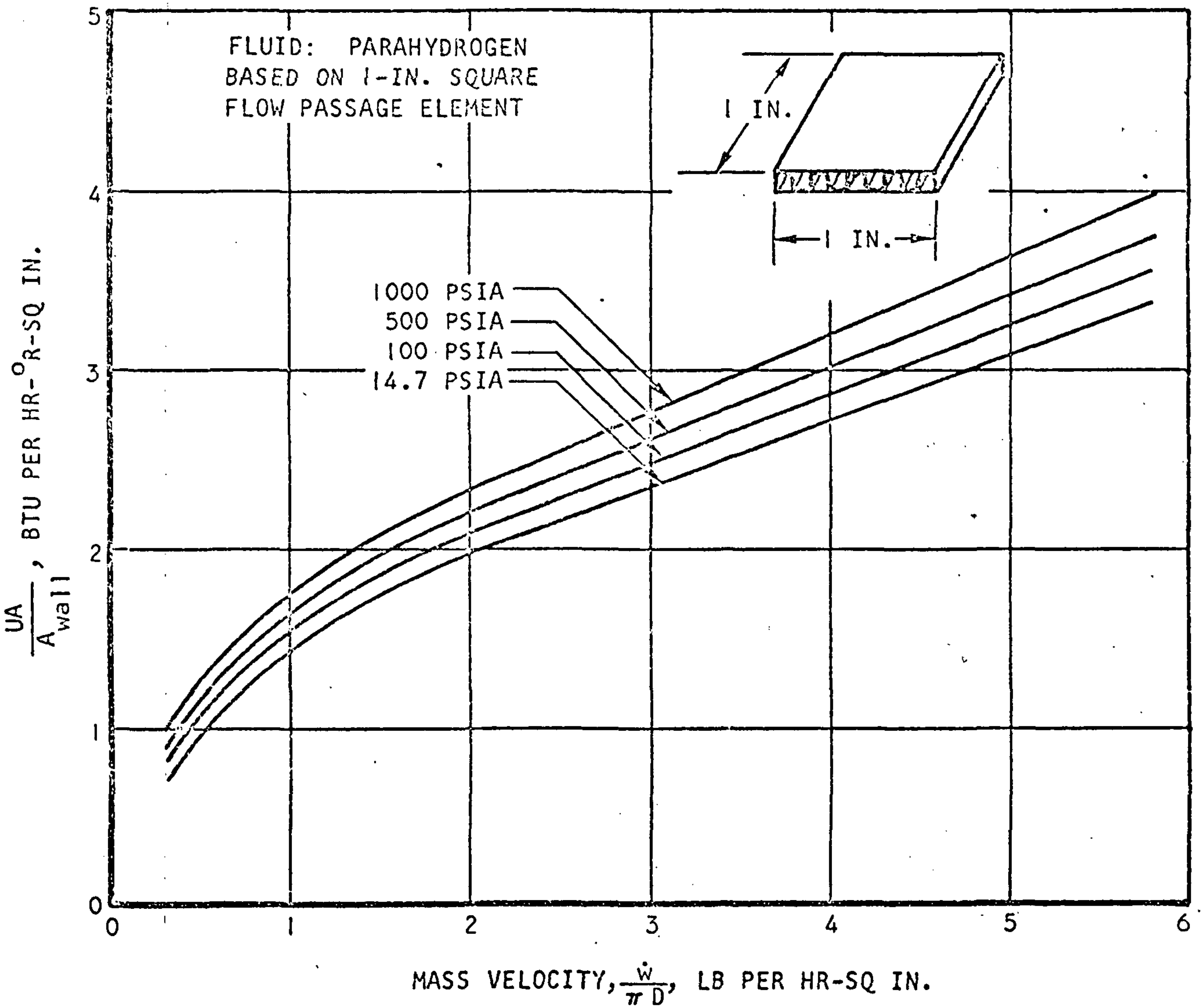


Figure 1.5.3-1 Hydrogen Electrical Heater Heat Transfer Performance

Table 1.5.3-1

ELECTRICAL HEAT EXCHANGER – HEAT TRANSFER PERFORMANCE FOR HYDROGEN GAS (REF. FIG. 1.2.3-1)

Mass Velocity (lb/hr-sq. in.)	Heat Transfer Coefficient (BTU/Hr-°R-Sq. In.) at:			
	14.7 (psia)	100 (psia)	500 (psia)	1000 (psia)
0.10	.27	.35	.45	.50
0.30	.70	.78	.88	.99
0.50	.96	1.10	1.20	1.30
0.75	1.21	1.35	1.45	1.55
1.00	1.42	1.53	1.65	1.76
1.50	1.75	1.85	1.96	2.08
2.00	1.97	2.09	2.22	2.34
3.00	2.35	2.48	2.61	2.78
4.00	2.73	2.87	3.04	3.22
5.00	3.09	3.25	3.42	3.65
6.00	3.45	3.65	3.82	4.09

Translation of the data from Table 1.5.3-1 into the table data card format then consists of assigning the program variable names and values in the order illustrated in Fig. 1.5.3-2.

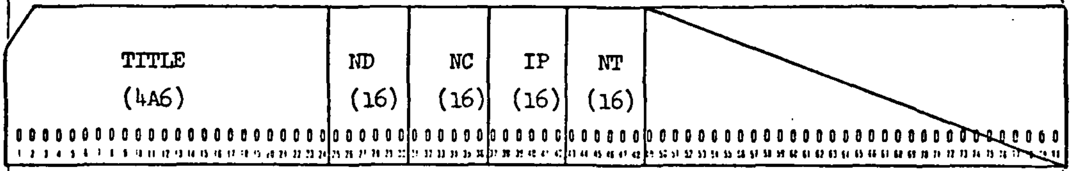
Taking the variables as they appear for each of the table cards shown in Figure 1.5.3-2, the following assignments are made:

Card-1, Title Card

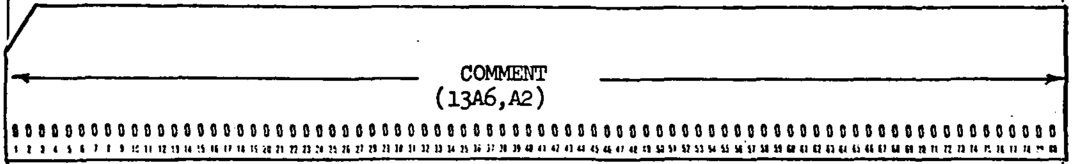
Title = HEAT XFER.COEFF.-H2
ND = 3 (Number of variables in table)
NC = 4 (Number of command cards)
IP = (Blank) (Table will not be plotted)
NT = 20 (Table I.D. number)

Prepared by:	Date	LOCKHEED MISSILES & SPACE COMPANY. INC.	Page Temp. Perm.
Checked by:	Date	Title TABLE DATA INPUT CARD FORMAT Figure 1.5.3-2	Model
Approved by:	Date		Report No.

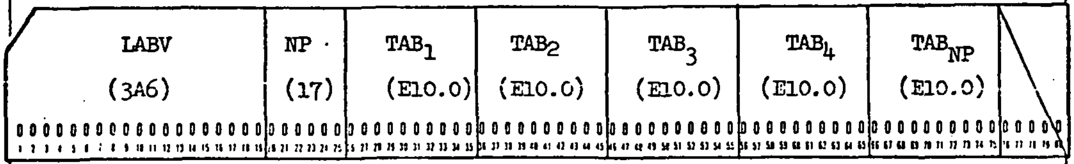
CARD TYPE - G_p(d) CARD-1
CARD FUNCTION - TABLE IDENTIFICATION AND CONTROL CARD



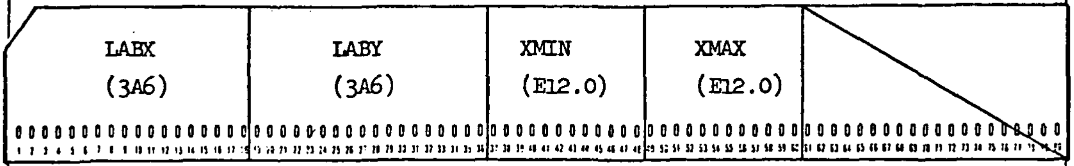
CARD TYPE - G_p(d) CARD-2
CARD FUNCTION - TABLE COMMENT CARD



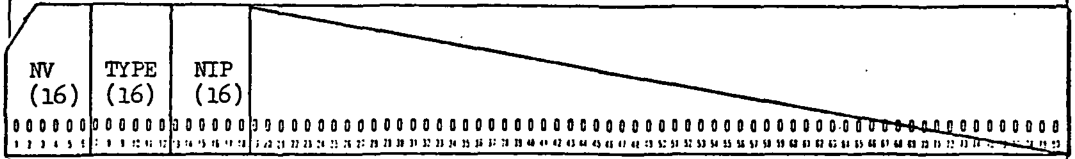
CARD TYPE - G_p(d) CARD-3
CARD FUNCTION - TABLE SUBSET VARIABLE CARD



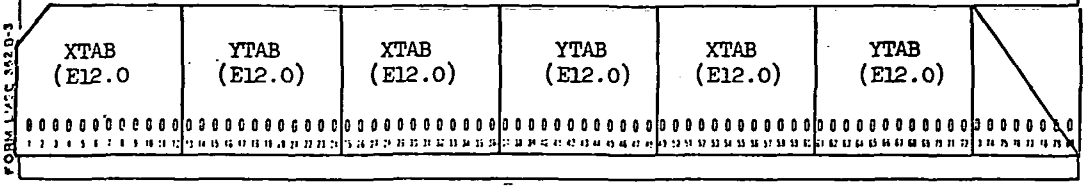
CARD TYPE - G_p(d) CARD-4
CARD FUNCTION - TABLE DATA PLOT CONTROL CARD



CARD TYPE - G_p(d) CARD-5
CARD FUNCTION - TABLE SUBSET DATA CARD



CARD TYPE - G_p(d) CARD-6
CARD FUNCTION - TABLE DATA CARD (DISCRETE DATA)



Card-2, Command Card

Four Command Cards are used (NC = 4). Three cards contain description of table and source data reference, while the fourth card is simply used as a spare card.

Card-3, Table Subset Variable Card

This card contains the names of the third variable in Table 1.5.3-1, the number of values the variable can take on, and the values themselves.

LABV = Pressure (psia) (Third variable)
NP = 4 (Four pressure values)
TAB_1 = 14.7 (First value)
TAB_2 = 100 (Second value)
TAB_3 = 500 (Third value)
TAB_4 = 1000 (Fourth value)

Card-4, Table Plot Control Card

This card is used to enter the X-AXIS and Y-AXIS labels and the X value minima and maxima for plot output of table data.

LABX = MASS VELOCITY (X variable)
LABY = HEAT TRANS. COEF. (Y variable)
XMIN = 0.1 (if used)
XMAX = 6.0 (if used)

Card-5, Table Subset Data Card

There will be a subtable of X and Y values for each value that LABV can assume. Since NP = 4, there will be four subtables arranged in the increasing order of TAB_i. Each subtable will have a Card 5 giving the number of X, Y sets of points in the subtable, the "type" of data, and the number of points to be used for interpolation.

NV = 11 (Eleven sets of X,Y values per table subset)

TYPE = 1 (Discrete data points from curve)

NIP = 3 (Use 3 points for interpolation since curve is somewhat parabolic)

Card-6, Table Data Card

Use 4 data cards per table-subset, entering three sets of X,Y data per card with the last card having two sets of X,Y data (NV = 11). Thus, the first table-subset card starts with Mass Velocity and Heat Transfer Coefficient values for the 14.7 psia pressure curve.

$XTAB_1$ = 0.10

$YTAB_1$ = 0.27

$XTAB_2$ = 0.30

$YTAB_2$ = 0.70

$XTAB_3$ = 0.50

$YTAB_3$ = 0.96

The completed Table 20 is illustrated as a card listing in Table 1.5.3-2.

Table 1.5.3-2

HEAT TRANSFER PERFORMANCE DATA FOR HYDROGEN

DATA TABLE NUMBER 20

```
HT.XFER.COEF.-H2                    3     4            20
  OVERALL HEAT TRANSFER COEFFICIENT FOR H2 ELECTRIC POWERED HEX AS A
  FUNCTION OF MASS VELOCITY AND FLUID INLET PRESSURE.
  REF. AR-71-7535.

  PRESSURE (PSIA)         4      14.7        100.         500.       1000.
MASVEL(LB/HR-IN)   U (BTU/HR-R-SQ.IN)
    11       1       3
    .10             .27          .30          .70          .50          .96
    .75            1.21         1.00         1.42         1.50         1.75
   2.00            1.97         3.00         2.35         4.00         2.73
   5.00            3.09         6.00         3.45
    11       1       3
    .10             .35          .30          .78          .50         1.10
    .75            1.35         1.00         1.53         1.50         1.85
   2.00            2.09         3.00         2.48         4.00         2.87
   5.00            3.25         6.00         3.64
    11       1       3
    .10             .45          .30          .88          .50         1.20
    .75            1.45         1.00         1.65         1.50         1.96
   2.00            2.22         3.00         2.61         4.00         3.04
   5.00            3.42         6.00         3.82
    11       1       3
    .10             .50          .30          .99          .50         1.30
    .75            1.55         1.00         1.76         1.50         2.08
   2.00            2.34         3.00         2.78         4.00         3.22
   5.00            3.65         6.00         4.09
```

1.5.4 Use of Program Files and Data Files

In the use of the Math Model Program as an operational analysis tool, it can be quite inconvenient to have to load the entire program, data tables, and problem deck each time a run is to be made. It is therefore recommended that the program and data tables be maintained on stored files in the facility FASTRAND drum or DISC storage.

1.5.4.1 Program File. The Math Model Program as currently structured contains approximately 16,000 source cards including the thermodynamic properties subprograms. The program therefore is usually maintained on a master tape which takes quite awhile to read into core. It is considerably more convenient to maintain the program file on FASTRAND Drum or DISC storage and simply call in the file and copy it for use in a run.

For the UNIVAC-1108, the procedure in setting up a mass-storage file and using it are generally as follows:

Creating a Program File

Assume that the mnemonic TCIMM is used as the program file name, then the file creation cards are as follows: (A Master Tape and Program File will be created)

```
 @ RUN      \
             >  varies with facility operating procedures
 @ LID      /

 @ DELETE,C     TCIMM TAPE.          (Purges tape name)
 @ DELETE,C     TCIMM.               (Purges file record)
 @ ASG,UP       TCIMM TAPE.,T        (Assigns tape requirement)
 @ ASG,UP       TCIMM.,FD4           (Assigns file on DISC)
[@ PDP,IFL      CACCUM            ]  Source Deck
[@ FØR,IS       ACCRES, ACCRES    ]  Cards for
[@ FØR,IS       ZFIND,ZFIND       ]  Entire Program
```

```
@ CØPY          TPF$.,TCIMM.           (Creates program file)
@ TIC           TCIMM.,TCIMM TAPE.     (Makes tape label)
@ CØPØUT        TCIMM.,TCIMM TAPE.     (Writes tape)
@ FREE          TCIMM TAPE.            (Frees tape)
@ FREE          TCIMM.                 (Frees TCIMM file)

@ FIN or @ EØF                         (Ends run)
```

A run is made and the Program File and Program Master Tape are created and logged in the Facility Program Library. The user is now protected in the event of a system crash which causes the loss of the stored program file since the Master Tape is a backup file.

Using the Program File

The stored Program File (TCIMM.) may be called in for use in the following fashion:

```
@ RUN
@ LID

@ ASG,A         TCIMM.                 (Assigns file)
@ COPY,P        TCIMM.,TYPF$           (Copy file to user free of core)

@ FREE          TCIMM.                 (Free file to storage)
```

(Reference Figure 1.5.4-1)

1.5.4.2 Data Table File. Similarly, for the DATA TABLES which currently require approximately 1,300 source cards and could reach several thousand cards for newer systems, it is advisable to maintain a stored file and backup tapes. In this case a DATA file is preferred for the storage mechanism since file editing can be easily done from a DEMAND terminal, if the facility is so equipped.

The creation of a data file in the UNIVAC-1108 (EXEC-8) is accomplished as follows:

Creating a DATA File

Assume TNUMBAG. will be the file name chosen for TABLE DATA DECK.

```
@ RUN CARD  \
             >  Varies with facility operating procedures
@ LID CARD  /
@ DELETE,C      TNUMBAG.          (Deletes slot file
@ ASG,UP        TNUMBAG.,FO4      (Disc storage)
@ DATA,IL       TNUMBAG.          (Data processor)
[ TABLE DATA DECK ]
[ FOLLOWED BY     ]
[ ONE BLANK CARD  ]
@ END
@ FIN or @ EOF
```

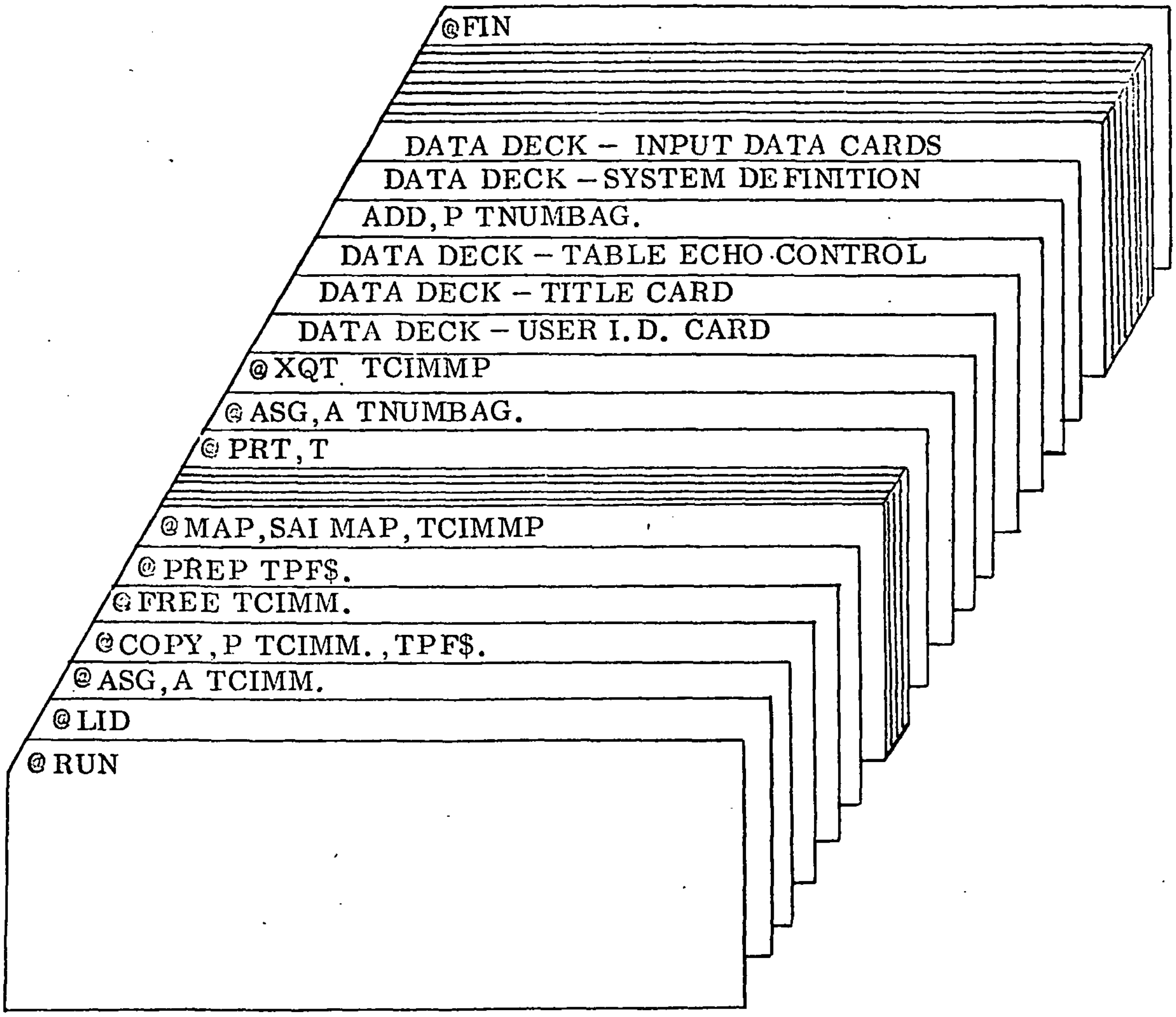
A run is made and is listed by the Data Processor. File is now stored on disc or drum.

Using the Data File

The stored data file (TNUMBAG.) may be called in for use by placing an ASG card just before the program execution card and an ADD file card after the third card in the problem data input deck, as follows:

```
@ ASG,A         TNUMBAG.
@ XQT
  DATA DECK     USER CARD
                TITLE Header Card
                TABLE ECHO CONTROL CARD
@ ADD           TNUMBAG.
                SYSTEM DEFINITION CARD
                .
                (Rest of data deck)
@ FIN or   EØF
```

(Reference Figure 1.5.4-1)



```
@FIN
DATA DECK - INPUT DATA CARDS
DATA DECK - SYSTEM DEFINITION
ADD,P TNUMBAG.
DATA DECK - TABLE ECHO CONTROL
DATA DECK - TITLE CARD
DATA DECK - USER I.D. CARD
@XQT TCIMMP
@ASG,A TNUMBAG.
@PRT,T
@MAP,SAI MAP,TCIMMP
@PREP TPF$.
@FREE TCIMM.
@COPY,P TCIMM.,TPF$.
@ASG,A TCIMM.
@LID
@RUN
```

FIG. 1.5.4-1 TCIMM RUN DECK SET UP TO USE PROGRAM FILE AND DATA TABLE FILE

1.5.4.3 Input Deck Data File. For the case where a group of analyses are desired for a given cryogen system and the "run to run" changes in the data deck are relatively few, it is often advantageous to place the input data deck into a data file and simply use change cards to alter the file when it is called in. Or, if the facility has a DEMAND system with terminals, it is possible to use the system EDITØR processor and alter the data file prior to calling it in for a run.

The use of change cards to alter the data deck is a simple procedure however, and the original Input Deck Data file can be preserved for repeated use simply by creating a temporary file containing the changes. Assume the nemonic ACPSDATA. to be the file name for the ACPS Data Input Deck file. It is desired to change the value of NPRT2 to zero to suppress all table output on the TABLE ECHO CONTROL CARD. This requires a zero in column 20 of the card. The new file will be temporary for one run only and for this purpose use TACPS DATA. on the temporary file name.

The procedure and deck setup to be used, follows:

(a) Before the run XQT card, insert these cards:

```
@ASG,A      ACPSDATA.
@ASG,T      TACPSDATA.
@DATA,L     ACPSDATA.,TACPSDATA.
 -3,3
        10     1     0
```

(b) After the XQT card, and in place of a data input deck, insert this card:

```
@ADD,P      TACPSDATA.
```

The program will now run using the temporary TACPSDATA. file, and, will list TACPSDATA. as a record of the temporary input data used in the run. The temporary file vanishes and the original unchanged file is still available for use.

1.5.5 Sample Input Data Deck Listing

As an aid in following the information presented in subsections 1.2.1 through 1.2.4, a listing of a typical Math Model data input deck is provided. The listing presented is the Attitude Control Propulsion System test problem which will be discussed in depth in Section 2.0 of this manual. Table 1.2.5-1 contains the complete test problem data input deck.

1.5.6 Data Table Deck List

The Data Tables currently employed in the program were set up to permit development and checkout of the subprograms required for the basic five types of system analysis. It, therefore, must be recognized that for systems which are more advanced, new data tables will probably be required. Direct substitution of tables is easily accomplished provided the table contains the same number of variables, arranged in the same order as used in the original table.

As an aid to future users of the program, a complete listing is presented of the current table to illustrate the diversity of table forms accommodated by the Math Model.

TABLE 1.5.5-1

ACPS INPUT DATA DECK LISTING

```
 USERS NAME    6213    104 30235
                              ACPS - TEST DEMONSTRATION PROBLEM
          10     1     1
*ADD             TNUMBAG.
ACPS            SUBCRITICAL       LAST CARD

GAS        1     1     0                                                    O2-VAP       CONFIG 1
ENGINE     0     3     0                                                    ENG1         CONFIG 2
LINE      10     3     0     1.0095 110.  2.0      4    .5   30.          LN01         CONFIG 3
TEE       21     1     0     1.0095126.3                                    FT01         CONFIG 4
LINE      10     1     0     1.0095150.0  2.0      4    .5   30.          LN02         CONFIG 5
TAP       31     1     0     1.0095 10.5                                    FT02         CONFIG 6
LINE      10     1     0     1.0095 24.0  2.0      4    .5   30.          LN03         CONFIG 7
VALVE     31     1     0     1.0095 10.5                                    IV01         CONFIG 8
LINE      10     1     0     1.0095 12.0  2.0      4    .5   30.          LN04         CONFIG 9
VALVE     21     1     0     1.0095135.0                                    CV02         CONFIG10
LINE      10     1     0     1.0095 40.0  2.0      4    .5   30.          LN05         CONFIG11
TAP       31     1     0     1.0095 10.5                                    FT03         CONFIG12
LINE      10     1     0     1.0095 20.0  2.0      4    .5   30.          LN06         CONFIG13
REG       32     1     0     1.0095336.8                                    PR01         CONFIG14
LINE      10     1     0     1.0095 30.0  2.0      4    .5   30.          LN07         CONFIG15
ACCUM      0     1     0     1                     4   2.0   30.          AC01         CONFIG16
LINE      10     1     0     1.0095 24.0  2.0      4    .5   30.          LN08         CONFIG17
HEX        1     1     0     1                                              HX01         CONFIG18
GAS        1     2     0                                                    O2-LIQ       CONFIG19
LINE      10     1     0     1.0180 12.0  1.0      4    .5   30.          LN09         CONFIG20
VALVE     31     1     0     1.0180                                         CV01         CONFIG21
LINE      10     1     0     1.0180 12.0  1.0      4    .5   30.          LN10         CONFIG22
PUMP      21     1     0     1                                              HP01         CONFIG23
LINE      10     1     0     1.0180160.0  1.5      4    .5   30.          LN11         CONFIG24
VALVE     21     1     0     1.0150 6.67                                    SV01         CONFIG25
LINE      10     1     0     1.0150 12.0  2.5      4    .5   30.          LN12         CONFIG26
TAP       31     1     0     1.0150 6.67                                    FT04         CONFIG27
LINE      10     1     0     1.0150 24.0  2.5      4    .5   30.          LN13         CONFIG28
TANK       0     1     0     2                     4   2.0   30.          TK01         CONFIG29
GAS        2     1                                                          H2-VAP       CONFIG30
ENGINE     0     3     0                                                    ENG1         CONFIG31
LINE      10     3     0     1 .011 110. 1.75      4   2.0   30.          LN21         CONFIG32
TEE       21     1     0     1 .011 109.                                    FT21         CONFIG33
LINE      10     1     0     1 .011 150. 1.75      4   2.0   30.          LN22         CONFIG34
TAP       31     1     0     1 .011   9.                                    FT22         CONFIG35
LINE      10     1     0     1 .011  24. 1.75      4   2.0   30.          LN23         CONFIG36
VALVE     31     1     0     1 .011   9.                                    IV02         CONFIG37
LINE      10     1     0     1 .011  12. 1.75      4   2.0   30.          LN24         CONFIG38
VALVE     21     1     0     1 .011  86.                                    CV04         CONFIG39
LINE      10     1     0     1 .011  40. 1.75      4   2.0   30.          LN25         CONFIG40
TAP       31     1     0     1 .011   9.                                    FT23         CONFIG41
LINE      10     1     0     1 .011  20. 1.75      4   2.0   30.          LN26         CONFIG42
REG       32     1     0     1 .011336.4                                    PR02         CONFIG43
LINE      10     1     0     1 .011  30. 1.75      4   2.0   30.          LN27         CONFIG44
ACCUM      0     1     0     1                     4   2.0   30.          AC02         CONFIG45
LINE      10     1     0     1 .011  24. 1.50      4   2.0   30.          LN28         CONFIG46
HEX        1     1     0     1                                              HX03         CONFIG47
GAS        2     2                                                          H2-LIQ       CONFIG48
LINE      10     1     0     1 .011  12. 1.50      4   2.0   30.          LN29         CONFIG49
VALVE     31     1     0     1 .011   9.                                    CV03         CONFIG50
LINE      10     1     0     1 .011  12. 1.50      4   2.0   30.          LN30         CONFIG51
```

TABLE 1.5.5-1

ACPS INPUT DATA DECK LISTING (CONTD)

```
PUMP     21     1     0     1                                        HP02        CONFIG52
LINE     10     1     0     1 .018 120.   2.0     4  2.0  30.        LN31        CONFIG53
VALVE    21     1     0     1 .018   5.6                             SV02        CONFIG54
LINE     10     1     0     1 .018  12.   2.0     4  2.0  30.        LN32        CONFIG55
TAP      31     1     0     1 .018   5.6                             FT24        CONFIG56
LINE     10     1     0     1 .018  24.   2.0     4  2.0  30.        LN33        CONFIG57
TANK      0     1     0     2                     4  2.0  30.        TK02        CONFIG58
END                                                                              ENDCFG59

    4.58        540.         .9       3                                           DCYL01
    6.15       7975.         .9       3                                           DCYL02
    3.58       2094.         .9       3                                           DCYL03
   38.80        536.         .9       3                                           DCYL04
    7.43       2061.         .9       3                                           DCYL05
    3.58        593.         .9       3                                           DCYL06
   66.10        536.         .9       3                                           DCYL07
   32.30        714.         .9       3                                           DCYL08
  104.10        568.         .9       3                                           DCYL09
   31.90       1876.         .9       3                                           DCYL10
   16.16     571048.         .9       3                                           DCYL11
  100.00       9584.         .9       3                                           DCYL12
                 -1.                                                              ENDINPUT

    3     350.       400.      1750.      250.       40.       4.                  ENGINE

    1    1     2     2     2                                                    SMAL.TK.02
  165.         16.        170.       26.7      31.7       .2        2.
   3.          5.066

    1    1     2     2     2                                                    SMAL.TK.H2
   37.         16.         40.       19.1      24.1       .3        2.
   3.          5.

    1    0                                                                      IWOP ' 1

    1    4     1                                                                 ACCUM-O2
      350.      2000.         .1        2.       2.5       2.05       .500.    ACCUM-O2

    1    4     1                                                                 ACCUM-H2
      350.      2000.         .2        2.      72.5       5.20       .500.    ACCUM-H2

    1                                                                            NUMHEX
 2000. 1100.  173.  350.  245.  215. 2030. 2000.   30.   30.    1.               HX01    1
 2000. 1028.   42.  350.  500.  470. 2010. 2000.   30.   10.    1.               HX03    1

    2     .52       8.7      20000.      2023.                                     PUMP1
    2     .54       1.1      70000.      2023.                                     PUMP2

                                                                                 TRPUMP 1
                                                                                 TRPUMP 2

     .55      2000.      1160.       .891       250.                             TURBN  1
     .36      2000.      1160.       .891       500.                             TURBN  2

    1                                                                            NUMHSO
    1               1.0     2060.                245.                            HSORC  1
    1               1.0     2060.                500.                            HSORC  2
```

1.5.6.1 LISTING OF THE DATA TABLES

DATA TABLE -1

```
RCS-THRUSTER WEIGHT             4      5              1
 HIGH PRESSURE APS THRUSTER
 REGEN. SLOT TYPE CU. CHAMBER
 QUAD REDUNDANT VALVES, RAD. NOZZLE
 EXPANSION RATIO SET TO 40 FOR THIS DEMONSTRATION TABLE

  TO = TF (R)               2 200.     500.
 PC (PSIA)                  3 100.     300.       500.
  THRUST (LB-F)   TCA WEIGHT (LB-M)
      8        1    2
100.          19.1        300.         29.         600.         40.3
1000.         54.         1500.        70.         3000.        118.
6000.0        234.0       10000.0      475.0
      8        1    2
100.          15.9        300.         20.9        600.         26.8
1000.         33.5        1500.        41.         3000.         64.
6000.0        118.0       10000.0      218.0
      8        1    2
100.          15.         300.         18.9        600.         23.1
1000.         28.2        1500.        33.9        3000.        49.8
6000.0        81.0        10000.0      131.0
      8        1    2
100.          19.1        300.         29.         600.         40.3
1000.         54.         1500.        70.         3000.        118.
6000.0        234.0       10000.0      475.0
      8        1    2
100.          15.9        300.         20.9        600.         26.8
1000.         33.5        1500.        41.         3000.         64.
6000.0        118.0       10000.0      218.0
      8        1    2
100.          15.         300.         18.9        600.         23.1
1000.         28.2        1500.        33.9        3000.        49.8
6000.0        81.0        10000.0      131.0
```

DATA TABLE -2

```
RCS-VAC. SP. IMPULSE          3      4              2
 HIGH PRESSURE APS THRUSTER
 THEORETICAL PERFORMANCE FOR GASEOUS HYDROGEN/GASEOUS OXYGEN
 EXPANSION RATIO SET TO 40 FOR THIS DEMONSTRATION TABLE

PROPELLANT TEMP,          3 100.     250.       540.
MIXTURE RATIO(O/F)ISP(LBF-SEC/LBM)
      9        1    3
1.            360.        1.5          392.        2.           418.
2.5           435.5       3.           445.5       3.5          451.
4.            454.        5.           455.        7.           442.
      9        1    3
1.            398.        1.5          425.        2.           441.5
2.5           451.        3.           457.5       3.5          461.5
4.            463.5       5.           463.5       7.           448.
      9        1    3
1.            429.        1.5          447.        2.           459.
2.5           467.        3.           472.        3.5          474.
4.            474.        5.           470.5       7.           452.
```

DATA TABLE -3

```
SPEC.HT/LB OF O2 REMOVED        3    4           3
   SPECIFIC HEAT PER LB. OF O2 WITHDRAWN
     (SPEC. HEAT) VS (DENSITY) AT A GIVEN PRESSURE
       DENSITY = F (PCT,WITHDRAWN,PF/(ZF*TF))

   PRESSURE (PSIA)         5     700.      1000.      1500.      2000.      3000.
  PLOT LABEL
    23      !     3
    2.056     235.88         2.241     212.94           2.402      196.04
    2.590     179.47         2.811     163.24           3.285      163.24
    3.527     126.64         4.059     108.76           4.567       95.90
    5.097      85.38         7.168      59.81           8.578       50.10
     10.          44.        15.          33.7           20.         29.1
     25.          28.8       30.          31.5           35.         38.
     40.          47.5       45.          59.5           50.         75.
     60.         115.        70.126     164.
    20      !     3
    2.917     235.24         3.109     217.76           3.412      194.90
    3.784     172.64         4.254     151.02           4.871      129.96
    5.058     124.75         7.041      87.87           9.068       67.80
     10.          60.        15.          45.8           20.         39.5
     25.          37.9       30.          39.6           35.         44.8
     40.          53.5       45.          64.9           50.         80.
     60.         119.5       70.126     166.9
    17      !     3
    4.312     233.81         5.061     192.89           5.967      159.50
    7.047     132.88         8.113     114.61           9.143      101.45
   10.235      90.65        14.772      64.65          19.854       53.02
     25.          51.        30.          51.1           35.         55.
     40.          62.2       45.          72.5           50.         85.7
     60.         121.7       70.126     170.
    17      !     3
    5.657     232.12         6.046     214.14           7.022      179.50
    8.140     152.18         9.022     136.45          10.150      121.05
   12.662      97.93        15.476      82.05          19.617       68.68
     25.          64.7       30.          63.2           35.         65.3
     40.          70.9       45.          79.9           50.         90.8
     60.         126.        70.126     174.
    15      !     3
    8.185     228.51         9.205     198.44          10.240      175.72
   12.818     139.40        14.457     126.25          16.553      113.42
     20.          99.        25.          86.1           30.         81.5
     35.          82.        40.          86.9           45.         95.6
     50.         107.4       60.         137.7           70.126     180.8
```

DATA TABLE -4

```
SPEC.HT/LB OF H2 REMOVED        3    4           4
   SPECIFIC HEAT PER LB. OF H2 WITHDRAWN
     (SPEC. HEAT) VS (DENSITY) AT A GIVEN PRESSURE
       DENSITY = F(PCT,WITHDRAWN,PF/(ZF*TF))

   PRESSURE (PSIA)         5     300.       500.       700.      1000.      1500.
  PLOT LABEL
    15      !     3
     .214     999.41          .313     565.51            .383      414.05
    .40      362.            .43      326.              .46       296.
     .5          274.        1.          151.            1.5        119.
    2.           111.        2.5         124.            3.0        153.
    3.5          192.        4.0         238.            4.365      272.
    15      !     3
     .218    1589.88          .420     786.88            .642      410.93
    .73      370.            .76      340.              .80       316.
     .86         293.        1.          245.            1.5        183.
    2.           162.        2.5         164.            3.0        185.
```

```
     3.5        217.        4.0        258.        4.365     292.
    17     1     3
     .213      2158.33      .318      1542.80       .423     1194.40
     .532       901.90      .647       674.37       .899      412.82
    .98        378.        1.03       360.         1.10      348.
     1.19        313.       1.5         256.        2.0       208.5
     2.5         202.       3.0         217.        3.5       245.
     4.0         282.      4.365        312.
    16     1     3
     .203      3208.73      .408      1683.98       .595     1209.78
     .821       798.49     1.02        571.99      1.27       425.33
  1.36         390.        1.40       378.         1.50      352.
     1.55        341.       2.0         283.5       2.5       261.5
     3.0         265.       3.5         284.        4.0       315.
    4.365        342.
    18     1     3
     .254      3654.70      .415      2264.82       .614     1642.97
     .815      1285.33     1.023       984.78      1.244      755.41
    1.400       647.35     1.723       505.19      1.876      455.42
   1.95        422.        2.00       414.         2.05      408.
     2.18        391.       2.5         363.        3.0       344.5
     3.5         347.5      4.0         369.       4.365      393.
```

DATA TABLE -5

```
TEMP. /LB. OF O2 REMOVED       3     4              5
    TEMPERATURE (DEG-R) PER LB. OF O2 WITHDRAWN
      (TEMP.) VS (DENSITY) AT A GIVEN PRESSURE
        DENSITY = F(PCT.WITHDRAWN,PF/(ZF)TF))

    PRESSURE (PSIA        5    700.        1000.       1500.       2000.       3000.
   PLOT LABEL
     21      1     3
     2.056    1000.          2.241     920.           2.402     860.
     2.590     800.          2.811     740.           3.285     640.
     3.527     600.          4.059     530.           4.567     480.
     5.097     440.          7.168     350.           8.578     320.
    10.209     300.         14.492     280.          18.617     276.19
    25.        276.19       36.171     276.19        44.345     270.
    51.605     255.         60.023     225.          72.252     160.
     18      1     3
     2.917    1000.          3.109     940.           3.412     860.
     3.784     780.          4.254     700.           4.871     620.
     5.056     600.          7.041     460.           9.069     390.
    10.000     370.         14.702     320.          21.749     300.
    26.969     295.         34.160     290.          42.970     280.
    51.612     260.         60.710     225.          72.510     160.
     15      1     3
     4.312    1000.          5.061     860.           5.967     740.
     7.047     640.          8.113     570.           9.143     520.
    10.235     480.         14.772     390.          19.854     350.
    25.288     330.         34.878     310.          42.293     295.
    51.137     270.         60.725     230.          72.926     160.
     15      1     3
     5.657    1000.          6.046     940.           7.022     820.
     8.140     720.          9.022     660.          10.150     600.
    12.662     510.         15.476     450.          19.617     400.
    26.117     360.         34.914     330.          45.084     300.
    50.769     280.         60.741     235.          72.559     165.
     12      1     3
     8.185    1000.          9.205     900.          10.240     820.
    12.818     680.         14.459     620.          16.553     560.
    20.909     480.         31.139     390.          41.334     340.
    51.263     295.         60.791     245.          72.618     170.
```

DATA TABLE -6

```
TEMP. /LB. OF H2 REMOVED        3     4            6
   TEMPERATURE (DEG-R) PER LB. OF H2 WITHDRAWN
     (TEMP) VS (DENSITY) AT A GIVEN PRESSURE
       DENSITY = F(PCT.WITHDRAWN,PF/(ZF*TF))

   PRESSURE (PSIA)         5     300.       500.        700.       1000.       1500.
  PLOT LABEL
     17      1      3
      .214    260.0           .313      180.0           .333      150.0
     .40     148.            .43       130.            .46       124.
     .50     115.            .75       89.            1.00        78.5
     1.25         73.        1.5          69.8          2.          66.
     2.5          64.3       3.           62.           3.5         58.
     4.           51.        4.365        43.5
     16      1      3
      .218    420.0           .420      220.0           .642      150.0
     .73     130.            .76       127.            .80       123.5
      .85         120.       1.           107.8         1.25        95.5
     1.5          87.5       2.           79.           2.5         73.3
     3.           68.3       3.5          62.3          4.0         54.7
     4.365        48.5
     18      1      3
      .213    600.0           .318      400.0           .423      300.0
      .532    240.0           .647      200.0           .899      150.0
     .98     132.            1.03      128.5           1.10      123.0
     1.2          119.        1.25        116.          1.5         104.8
     2.0          90.5       2.5          80.8          3.0         74.2
     3.5          66.5       4.           58.           4.365       51.
     16      1      3
      .203    900.0           .408      440.0           .559      320.0
      .621    220.0          1.02       180.0          1.27       150.0
    1.36     140.5           1.40      138.0           1.50      131.0
     1.55         129.       2.           108.          2.5         94.4
     3.           84.1       3.5          74.4          4.          63.9
     4.365        55.5
     18      1      3
      .254   1100.            .415      650.0           .614      425.0
      .815    320.           1.023      250.0          1.244      215.0
     1.400    190.           1.723      160.           1.876      150.0
    1.95     143.0          2.0        139.0          2.05       137.0
     2.18         130.        2.5         117.          3.          101.
     3.5          86.9        4.0         73.9          4.365       65.
```

DATA TABLE -7

```
RR/ VS PGG,M/R,PAMB,PCHP      5      3              7
   REFERENCE REACTANT FLOW AT T.I.T.= 2060 DEG R.
   (RR)  VS (PCT.HP.) AT A GIVEN (PRES.OF GG),(MIX.RATIO),(P-AMBIENT)

PRES. GAS GEN PSIA        3     300.       600.        900.
MIXTURE RATIO             2      .5         1.0
AMBIENT PRESSURE          2      0.        14.7
PLOT RR1
      2        1        2
      0.                0.          100.           7.52
      2        1        2
      0.                1.23        100.           8.57
      2        1        2
      0.                0.          100.           9.60
      2        1        2
      0.                3.00        100.          10.47
      2        1        2
      0.                0.          100.           6.53
      2        1        2
      0.                 .84        100.           7.13
```

```
2       1       2
0.              0.          100.          8.58
2       1       2
0.               .780       100.          9.30
2       1       2
0.              0.          100.          6.42
2       1       2
0.               .762       100.          6.65
2       1       2
0.              0.          100.          8.45
2       1       2
0.               .81        100.          8.70
```

DATA TABLE -8

```
KK VS PGG,M/R,PAMB,PCHP       5     4            8
   (RR)  REFERENCE REACTANT AT T.I.T. = 2060 DEG R
    KK -- CONVERSION FACTOR FOR REFERENCE REACTANT RR
   (KK) VS (PCT,HP.) AT A GIVEN (PRES OF GG),(MIX,RATIO),(P-AMBIENT)

PRES. GAS GEN PSIA          3    300.       600.       900.
MIXTURE RATIO               2     .5         1.0
AMBIENT PRESSURE            2     0.        14.7
PLOT K1
     2       1       2
     0.              1.078      100.          1.078
     2       1       2
     0.              1.037      100.          1.069
     2       1       2
     0.              1.062      100.          1.062
     2       1       2
     0.              1.035      100.          1.055
     2       1       2
     0.              1.087      100.          1.087
     2       1       2
     0.              1.05       100.          1.082
     2       1       2
     0.              1.067      100.          1.067
     2       1       2
     0.              1.044      100.          1.064
     2       1       2
     0.              1.09       100.          1.09
     2       1       2
     0.              1.052      100.          1.088
     2       1       2
     0.              1.068      100.          1.068
     2       1       2
     0.              1.047      100.          1.068
```

DATA TABLE -9

```
ONS ENGINE WEIGHT              3     4           9
  ADIABATIC WALL ENGINE
  EXPANSION RATIO FIXED AT 40.
  REFERENCE - AEROJET PARAMETRIC DATA FOR LIQUID BIPROP, ENGINES.6-2-69.

  PC (PSIA)               3 100.     250.      500.
 THRUST (LB-F)      ENG.WGT. (LB-M)
     6       1       2
   200.             13.0     1500.           42.5     3000.          77.5
  4500.            112.0     6000.          147.0     8000.         186.5
     6       1       2
   200.              6.0     1500.           21.4     3000.          36.8
  4500.             52.5     6000.           67.8     8000.          88.5
     6       1       2
   200.              4.6     1500.           14.6     3000.          21.0
  4500.             34.0     6000.           43.7     8000.          57.0
```

DATA TABLE -10

```
OMS VAC. SP. IMPULSE          3     4           10
 PUMP FED ENGINE
 EXPANSION RATIO FIXED AT 40.
 REFERENCE - AEROJET PARAMETRIC DATA FOR LIQUID BIPROP. ENGINES,6-2-69.

  PC (PSIA)                  3 100.    250.      500.
MIXTURE RATIO(O/F)ISP(LBF-SEC/LBM)
     9     1     3
    1.0        290.0        1.2        296.2        1.4        300.4
    1.6        300.5        1.8        298.5        2.0        296.0
    2.2        292.0        2.4        287.5        2.6        282.5
     9     1     3
    1.0        293.5        1.2        302.0        1.4        308.0
    1.6        309.7        1.8        310.5        2.0        308.5
    2.2        306.0        2.4        301.2        2.6        299.5
     9     1     3
    1.0        297.0        1.2        306.5        1.4        312.8
    1.6        316.5        1.8        318.0        2.0        318.5
    2.2        315.8        2.4        310.8        2.6        314.1
```

DATA TABLE -11

```
HEX HOT GAS FLOW - LO2         5      8            11
HEAT EXCHANGER HOT GAS FLOW TO PROVIDE CONDITIONED OXYGEN - HIGH PRESSURE
     SCALED FROM AEROJET PRESENTATION DATA OF 1/30/70

                     HOT GAS SIDE                     COLD GAS SIDE

  TIN                    2000 R                          175 R
  TOUT                    700 R                        AS SHOWN
  PIN                  150-250 PSIA                    PARAMETER
PIN COLD (PSIA)          4 250.     450.      650.       1200.
TOUT HOT (R)             2 500.     1000.
TOUT COLD (R)            3 200.     300.      400.
LO2 FLOW (LB/SEC) G.G. FLOW (LB/SEC)     0.          14.
     2     0
.005928     0.
     2     0
.048        0.
     2     0
.086428     0.
     2     0
.005928     0.
     2     0
.048        0.
     2     0
.086428     0.
     2     0
.005614     0.
     2     0
.045428     0.
```

```
      2      0
 .081857      0.
      2      0
 .005614      0.
      2      0
 .045428      0.
      2      0
 .081857      0.
      2      0
 .005114      0.
      2      0
 .041428      0.
      2      0
 .074571      0.
      2      0
 .005114      0.
      2      0
 .041428      0.
      2      0
 .074571      0.
      2      0
 .003714      0.
      2      0
 .030142      0.
      2      0
 .054142      0.
      2      0
 .003714      0.
      2      0
 .030142      0.
      2      0
 .054142      0.
```

DATA TABLE -12

```
HEX HOT GAS FLOW - LH2         5      8             12
HEAT EXCHANGER HOT GAS FLOW TO PROVIDE CONDITIONED HYDROGEN - HIGH PRESSURE
     SCALED FROM AEROJET PRESENTATION DATA OF 1/30/70

                   HOT GAS SIDE                 .      COLD GAS SIDE

  TIN                       2000 R                           50 R
  TOUT                       700 R                        AS SHOWN
  PIN                    150,200 PSIA            250,450 - 1200 PSIA
PIN COLD (PSIA)             2 100.       1000.
TOUT HOT (R)                2 500.       1000.
TOUT COLD (R)               3 200.       300.       400.
LH2 FLOW (LB/SEC) G.G. FLOW (LB/SEC)       0.            14.
      2      0
 .255714      0.
      2      0
 .411428      0.
      2      0
 .599285      0.
      2      0
 .255714      0.
      2      0
 .411428      0.
      2      0
 .599285      0.
      2      0
```

```
.255714     0.
    2       0
.411428     0.
    2       0
.599285     0.
    2       0
.255714     0.
    2       0
.411428     0.
    2       0
.599285     0.
```

DATA TABLE -13

```
GAS GENERATOR WEIGHT            4      7            13
GAS GENERATOR ASSEMBLY WEIGHT AS A FUNCTION OF GAS GENERATOR FLOW RATE
                    GAS GENERATOR ASSEMBLY WEIGHT CONSIDERS -

               1. BIPROPELLANT POPPET VALVES AND ACTUATORS WITH IGNITER
                  ASSEMBLY AND EXCITER BOX AND CABLE.

               2. MIXTURE RATIO OF 1.1 AND FUEL INLET TEMPERATURE OF 350 R.
   TOUT (R)               2 1000.    3000.
  PC (PSIA)               5 100.     200.       250.0      300.0      500.
G.G. FLOW (LB/SEC)G.G.A. WEIGHT (LB)
       9        1     3
0.             15.          2.          26.         4.            38.2
5.             46.1         6.          58.6        7.            78.
9.0            117.         11.0        161.        12.           179.
       9        1     3
0.             15.          2.          22.4        4.            30.9
5.             36.1         6.          42.8        7.            54.9
9.0            73.5         11.0        98.         12.           110.
       9        1     3
0.             15.          2.          20.1        4.            26.5
5.             30.7         6.          37.         7.            47.6
9.0            64.0         11.0        84.0        12.           95.0
       9        1     3
0.             15.          2.          19.1        4.            24.
5.             27.4         6.          32.3        7.            40.2
9.0            55.5         11.0        72.0        12.           81.0
       9        1     3
0.             15.          2.          17.6        4.            21.6
5.             24.3         6.          28.         7.            33.4
9.0            42.5         11.0        53.0        12.           58.5
       9        1     3
0.             15.          2.          26.         4.            38.2
5.             46.1         6.          58.6        7.            78.
9.0            117.         11.0        161.        12.           179.
       9        1     3
0.             15.          2.          22.4        4.            30.9
5.             36.1         6.          42.8        7.            54.9
9.0            73.5         11.0        98.         12.           110.
       9        1     3
0.             15.          2.          20.1        4.            26.5
5.             30.7         6.          37.         7.            47.6
9.0            64.0         11.0        84.0        12.           95.0
       9        1     3
0.             15.          2.          19.1        4.            24.
5.             27.4         6.          32.3        7.            40.2
9.0            55.5         11.0        72.0        12.           81.0
```

```
         9       1       3
0.             15.          2.           17.6         4.           21.6
5.             24.3         6.           28.          7.           33.4
9.0            42.5         11.0         53.0         12.          58.5
```

DATA TABLE -14

```
LO2 TRANSFER PUMP WEIGHT       5       2              14
                          ***** NOTE *****
THIS DATA IS AN APPROXIMATION ONLY AND WILL BE REPLACED
EFFICIENCY                   260.         80.
NPSH (PSI)                   20.          3.
HEAD RISE (PSI)              25.          50.
LO2 FLOW (LB/SEC) PUMP WEIGHT (LB)
         6       1       3
0              5.           5.           15.          10.          25.
20.            56.          30.          110.         70.          900.
         6       1       3
0.             5.           5.           24.          10.          47.
20.            122.         30.          260.         70.          2300.
         6       1       3
0              5.           5.           15.          10.          25.
20.            56.          30.          110.         70.          900.
         6       1       3
0.             5.           5.           24.          10.          47.
20.            122.         30.          260.         70.          2300.
         6       1       3
0              5.           5.           15.          10.          25.
20.            56.          30.          110.         70.          900.
         6       1       3
0.             5.           5.           24.          10.          47.
20.            122.         30.          260.         70.          2300.
         6       1       3
0              5.           5.           15.          10.          25.
20.            56.          30.          110.         70.          900.
         6       1       3
0.             5.           5.           24.          10.          47.
20.            122.         30.          260.         70.          2300.
```

DATA TABLE -15

```
LH2 TRANSFER PUMP WEIGHT       5       2              15
                          ***** NOTE *****
THIS DATA IS AN APPROXIMATION ONLY AND WILL BE REPLACED
EFFICIENCY                   2 60.        80.
NPSH (PSI)                   2 0.         3.
HEAD RISE (PSI)              2 5.         50.
LH2 FLOW (LB/SEC) PUMP WEIGHT (LB)
         6       1       3
0.             5.           5.           9.           10.          13.8
15.            19.4         20.          26.9         50.          120.
         7       1       3
0.             5.           5.           14.          10.          23.
15.            33.2         20.          47.          30.          80.25
50.0           150.0
         6       1       3
0.             5.           5.           9.           10.          13.8
15.            19.4         20.          26.9         50.          120.
         7       1       3
0.             5.           5.           14.          10.          23.
15.            33.2         20.          47.          30.          80.25
50.0           150.0
         6       1       3
0.             5.           5.           9.           10.          13.8
```

```
15.           19.4          20.           26.9          50.           120.
       7      1      3
0.            5.            5.            14.           10.           23.
15.           33.2          20.           47.           30.           80.25
50.0          150.0
       6      1      3
0.            5.            5.            9.            10.           13.8
15.           19.4          20.           26.9          50.           120.
       7      1      3
0.            5.            5.            14.           10.           23.
15.           33.2          20.           47.           30.           80.25
50.0          150.0
```

DATA TABLE -16

```
MOTOR WEIGHT                     3       8            16

               NOTE - BRUSHLESS D-C MOTOR WEIGHT INCLUDES
                      ELECTRONICS (FIXED SIZE FOR EACH POWER LEVEL)
                      ROTOR
                      STATOR
                      BEARINGS
                      SHAFT
                      HOUSINGS
HORSEPOWER            5 1.         5.          25.         100.       200.
SHAFT SPEED (RPM) MOTOR WEIGHT (LB)
    10       1     6
2.0       +0311.8       5.0      +038.5          7.5       +035.78
10.0      +035.28       15.0     +034.8          20.0      +034.58
30.0      +034.39       40.0     +034.25         50.0      +034.20
100.0     +034.20
    12       1     3
2.0       +0334.2       5.0      +0327.6         7.5       +0326.05
10.0      +0325.1       15.0     +0324.0         20.0      +0323.5
30.0      +0322.9       40.0     +0322.4         50.0      +0322.1
60.0      +0322.0       80.0     +0322.0         100.0     +0322.0
     9       1     6
2.        +03111.       5.       +0399.5         10.       +0394.
15.       +0391.        20.      +0390.          30.       +0388.65
40.       +0388.        50.      +0388.          100.      +0388.
     9       1     4
2.        +03289.       5.       +03265.         10.       +03255.7
15.       +03252.25     20.      +03250.7        30.       +03250.
40.       +03250.       50.      +03250.         100.      +03250.
     9       1     5
2.        +03502.       5.       +03462.         10.       +03440.
15.       +03435.5      20.      +03434.         30.       +03433.
40.       +03432.       50.      +03432.         100.      +03432.
```

DATA TABLE -17

```
VAC.JAC.DIA.VS.WEIGHT          2      3            17
VACUUM JACKET WEIGHT AS A FUNCTION OF VACUUM JACKET DIAMETER FOR
ALUMINUM HONEYCOMB. REF. LMSC A981608.

DIAMETER (INCHES) WEIGHT (LBS)
   15       1       3
   15.9            .396      24.0             .365      30.0             .355
   36.0            .350      42.0             .360      48.0             .370
   60.0            .400      72.0             .436      84.0             .478
   96.0            .520      108.0            .568      120.0            .618
  132.0            .660      144.0            .715      156.0            .762
```

DATA TABLE -18

```
PHI - HYDROGEN                             3    4          18
  ENERGY DERIVATIVE (PSIA-CU.FT./BTU) FOR HYDROGEN

  (PHI) VS (DENSTY) AT A GIVEN PRESSURE
   (DENSITY) = F(PCT.FLUID WITHDRAWN,PF/(ZF*TF))

  PRESSURE (PSIA)        5   200.          400.          600.          800.       1000.
RHO (LB/CU-FT)     PHI(PSIA-CUFT/BTU)
   15      1      3
   .08097       2.028         .09797        1.923          .1434         1.912
   .209         2.494         .311          3.415          .383          3.703
   .51          3.909         .656          4.017         1.133          3.909
  2.294         3.971        3.068          6.610         3.582          8.116
  4.007         9.493        4.305         10.480         4.466         11.088
   15      1      3
   .08258       2.168         .1233         2.149          .1605         2.053
   .2304        1.299         .476          2.933          .580          3.425
   .760         3.905        1.061          4.271         1.403          4.522
  2.329         5.293        3.100          6.817         3.467          7.779
  4.065         9.616        4.349         10.484         4.498         11.040
   15      1      3
   .0743        2.122         .1232         2.180          .1578         2.184
   .2038        2.143         .2611         2.033          .3221         1.945
   .4589        2.099         .9248         3.740         1.3910         4.479
  2.3077        5.511        3.098          6.878         3.517          7.879
  3.9630        9.117        4.231          9.943         4.459         10.716
   15      1      3
   .0743        2.035         .0988         2.129          .1634         2.193
   .2090        2.201         .260          2.174          .3024         2.123
   .4517        1.973         .7367         2.519         1.1753         3.832
  1.8787        4.952        3.1546         7.010         3.6572         8.163
  3.9463        8.944        4.1993         9.696         4.421         10.420
   15      1      3
   .0743        1.931         .0927         2.040          .1832         2.197
   .2278        2.213         .2789         2.215          .3466         2.175
   .4270        2.088         .7493         2.219         1.0274         2.919
  1.9648       .4.943        3.1912         7.044         3.7605         8.332
  4.0147        9.010        4.2447         9.691         4.4517        10.363
```

DATA TABLE -19

```
TEMP. OF N2 VS RHO F(P)       3     5            19
  TEMPERATURE OF NITROGEN AS A FUNCTION OF DENSITY AND PRESSURE.
   T VS RHO AT GIVEN PRESSURE
  REF - THERMO.PROPS.OF O2 AND N2 - PART 1 (N2), STEWART,JACOBSEN,MYERS,
        DATED 7-31-72, UNIV.OF IDAHO, NAS9-12078 FINAL REPT.

  PRESSURE                 5   100.         300.          600.         800.       1000.
RHO (LB/CU-FT)     TEMP (DEG-R)
   17      1      3
   0.26029  1000.            0.32550    800.            0.37226    700.
   0.43491   600.            0.52374    500.            0.65890    400.
   0.89566   300.            1.0076     270.            1.21764    230.
   1.32607   215.            1.41267    205.            1.51513    195.
   1.76471   176.882        43.65099    176.882        47.02511    160.
  50.44270   140.           51.97474    130.
   17      1      3
   0.77626  1000.            0.97151    800.            1.11245    700.
   1.30313   600.            1.57750    500.            2.01333    400.
   2.85722   300.            3.31995    270.            4.43380    230.
   5.31260   215.            5.90023    209.176        35.37826    209.176
  41.23298   190.           45.50434    170.           49.04794    150.
  50.64242   140.           52.13136    130.
   15      1      3
```

```
 1.53854  1000.          1.92725   800.           2.21038   700.
 2.59834   600.          3.17019   500.           4.12812   400.
 6.32072   300.          7.95007   270.          10.36763   250.
27.95726   230.         37.27237   210.          42.17850   190.
46.06018   170.         49.40493   150.          52.35831   130.
  15        1     3
 2.03884  1000.          2.55502   800.           2.93297   700.
 3.45464   600.          4.23447   500.           5.58290   400.
 9.04166   300.         12.32699   270.          19.38695   250.
32.02713   230.         38.28876   210.          42.72110   190.
46.40105   170.         49.63097   150.          52.50466   130.
  15        1     3
 2.53277  1000.          3.17489   800.           3.64719   700.
 4.30329   600.          5.29619   500.           7.06164   400.
12.07741   300.         17.61068   270.          26.07201   250.
33.93609   230.         39.12311   210.          43.21232   190.
46.72206   170.         49.84845   150.          52.64729   130.
```

DATA TABLE -20

```
HT.XFER.COEF.-H2                 3     4              20
 OVERALL HEAT TRANSFER COEFFICIENT FOR H2 ELECTRIC POWERED HEX AS A
  FUNCTION OF MASS VELOCITY AND FLUID INLET PRESSURE.
  REF. AR-71-7535.

  PRESSURE (PSIA)          4     14.7       100.       500.      1000.
MASVEL(LB/HR-IN)   U (BTU/HR-R-SQ.IN)
    11        1      3
    .10             .27          .30          .70          .50          .96
    .75            1.21         1.00         1.42         1.50         1.75
   2.00            1.97         3.00         2.35         4.00         2.73
   5.00            3.09         6.00         3.45
    11        1      3
    .10             .35          .30          .78          .50         1.10
    .75            1.35         1.00         1.53         1.50         1.85
   2.00            2.09         3.00         2.48         4.00         2.87
   5.00            3.25         6.00         3.64
    11        1      3
    .10             .45          .30          .88          .50         1.20
    .75            1.45         1.00         1.65         1.50         1.96
   2.00            2.22         3.00         2.61         4.00         3.04
   5.00            3.42         6.00         3.82
    11        1      3
    .10             .50          .30          .99          .50         1.30
    .75            1.55         1.00         1.76         1.50         2.08
   2.00            2.34         3.00         2.78         4.00         3.22
   5.00            3.65         6.00         4.09
```

DATA TABLE -21

```
 HT.XFER.COEF.-02-N2              3     4              21
  OVERALL HEAT TRANSFER COEFFICIENTS FOR 02 AND N2 ELECTRIC POWERED HEX
   AS A FUNCTION OF MASS VELOCITY AND FLUID INLET PRESSURE.
   REF. AR 71-7535

   PRESSURE (PSIA)         4      14.7      100.       500.      1000.
 MASVEL(LB/HR-IN)   U (BTU/HR-R-SQ.IN)
     15       1      3
     .2             .13         .4            .17          .6            .195
     .8             .22        1.0            .24         1.4            .27
    2.0             .31        4.0            .40         6.0            .49
    8.0             .57       12.0            .76        16.0            .935
   20.             1.1        25.            1.31        30.            1.53
     15       1      3
```

```
    .2           .14        .4           .18        .6           .205
    .8           .225      1.0           .245      1.4           .285
   2.0           .33       4.0           .42       6.0           .51
   8.0           .595     12.0           .78      16.0           .96
   20.          1.14      25.           1.35      30.           1.57
    15      1     3
    .2           .175       .4           .22        .6           .255
    .8           .27       1.0           .30       1.4           .34
   2.0           .38       4.0           .495      6.0           .60
   8.0           .700     12.0           .92      16.0          1.14
   20.          1.35      25.           1.615     30.           1.68
    15      1     3
    .2           .26        .4           .31        .6           .36
    .8           .39       1.0           .42       1.4           .47
   2.0           .52       4.0           .67       6.0           .82
   8.0           .96      12.0          1.255     16.0          1.56
   20.          1.835     25.           2.195     30.           2.555
```

DATA TABLE -22

```
FTU OF 321/347 ST.STEEL         2     3              22
EFFECT OF TEMPERATURE ON THE TENSILE STRENGTH OF 321/347 STAINLESS STEEL
REF. SEC.8-LMSC A981608,PAGE 8.1.1-8

TEMPERATURE (R)   ULT.STRENGTH (PSI)
    14      1     2
  36.7        266500.      59.7        251000.      159.7        207000.
 259.7        173000.     359.7        143000.      459.7        121000.
 559.7        108000.     659.7         91000.      859.7         75000.
1059.7         70000.    1259.7         66000.     1459.7         63000.
1659.7         50000.    1859.7         32000.
```

DATA TABLE -23

```
FTU OF 2219-T87 ALUM.           2     3              23
EFFECT OF TEMPERATURE ON THE TENSILE STRENGTH OF 2219-T87 ALUMINUM
REF. SEC.8-LMSC A981608,PAGE 8.1.1-8

TEMPERATURE (R)   ULT.STRENGTH (PSI)
    16      1     2
  36.7         94000.     100.0         82400.      150.0         76000.
 200.0         72000.     250.0         68500.      300.0         67800.
 350.0         67000.     400.0         66300.      450.0         65000.
 500.0         63800.     550.0         62000.      600.0         60000.
 650.          58000.     859.7         38400.     1059.7         16600.
1259.7          6400.
```

DATA TABLE -24

```
FTU OF 6061-T6 ALUMINUM         2     3              24
EFFECT OF TEMPERATURE ON THE TENSILE STRENGTH OF 6061-T6 ALUMINUM ALLOY
REF. MIL HANDBOOK -5

TEMPERATURE (R)   ULT.STRENGTH (PSI)
    13      1     3
  36.7         63840.     100.0         57330.      150.0         53340.
 200.0         50610.     250.0         48384.      300.0         46830.
 350.0         45696.     400.0         44940.      450.0         43848.
 500.0         42840.     550.0         41496.      600.0         40152.
 650.0         38556.
```

DATA TABLE -25

```
FTU OF INCONEL-718                 2      3                  25
EFFECT OF TEMPERATURE ON THE TENSILE STRENGTH OF INCONEL-718
REF. MIL HANDBOOK -5.

TEMPERATURE (R)   ULT.STRENGTH (PSI)
   13        1     3
  36.7        219600.      100.0       213660.      150.0       210240.
 200.0        206100.      250.0       201240.      300.0       196200.
 350.0        193140.      400.0       189000.      450.0       185400.
 500.0        182160.      550.0       179460.      600.0       177300.
 650.0        175140.
```

DATA TABLE -26

```
FTU OF TI-6AL-4V                  2      3                26
EFFECT OF TEMPERATURE ON THE TENSILE STRENGTH OF TITANIUM TI-6AL-4V
REF. MIL HANDBOOK -5.

TEMPERATURE (R)   ULT.STRENGTH (PSI)
   13        1     3
  36.7        288320.      100.        261600.      150.        244480.
 200.0        226880.      250.        212800.      300.        200960.
 350.0        190720.      400.        181280.      450.        173120.
 500.0        165280.      550.        158720.      600.        154240.
 650.0        145600.
```

DATA TABLE -27

```
HEAD COEFFICIENT VS NS          2      3                27

     HEAD COEF. VS NS  (SPEC. SPEED)

HEAD COEF
   15        1        2
    70.               .665         80.        .660          90.        .655
   100.               .65         200.        .639         400.        .619
   600.               .60        1000.        .571        2000.        .518
  3000.               .472       5000.        .400        6000.        .363
  7000.               .323       8000.        .281        9800.        .192
```

DATA TABLE -28

```
ADIABATIC EFF. VS NS            2      3                28

     ADIABATIC EFFICIENCY VS NS (SPEC. SPEED)

ADIAB. EFF
   20        1        2
    70.               .00          80.        .03           90.        .06
   100.               .08         127.        .20          200.        .30
   250.               .37         300.        .44          350.        .505
   400.               .555        500.        .635         600.        .695
   700.               .74         800.        .77         1000.        .81
  1500.               .845       2000.        .86         3000.        .875
  5000.               .887      10000.        .893
```

DATA TABLE -29

```
EFFIC. QUOT.VS IMP. DIAM      2      3              29

    EFFICIENCY QUOTIENT VS IMPELLER DIAMETER

EFF. QUOT.
   21      1      2
   .05          .0            .20        .30          .30         .42
   .40          .515          .50        .60          .70         .695
   .90          .755         1.20        .82         1.60         .88
  2.00          .918         2.40        .945        3.20         .975
  4.00          .985         5.0         .988        6.0          .991
  7.0           .994         8.0         .997        9.0          .999
 10.0           .9995       11.0         .9999      12.0         1.000
```

DATA TABLE -30

```
BASE LINE STAGE WT VS DI      2      3              30

    BASE LINE STAGE WEIGHT VS IMPELLER DIAMETER

STAGE WT.
   12      1      2
   .56          .40           .70        .415         .90          .44
  1.10          .48          1.50        .63         2.0          1.02
  2.50         1.72          3.5        3.8          5.0          9.0
  6.00        13.80          7.0       20.0          9.0         36.2
```

DATA TABLE -31

```
SATURATED STEAM, T.VS P.      2      3              31
SATURATED WATER VAPOR - SATURATION PRESSURE AND TEMPERATURE TABLE GIVING
TEMPERATURE AS A FUNCTION OF PRESSURE.

PSATWV (PSIA)       TSATWV (DEG.R)
   21      1      2
  .08854    492.0         .12170      500.0          .20        513.14
   .40      532.86        .60         545.21         .80        554.38
  1.0       561.74       2.0          586.08        4.0         612.97
  7.5       639.94      10.0          653.21       14.696       672.00
 30.0       710.33      50.0          741.01       60.0         752.71
 80.0       772.03     100.0          787.81      150.0         818.42
200.0       841.79     300.0          877.33      400.0         909.59
```

DATA TABLE -32

```
SP.HT. OF O-H COMB.PROD.      3      3              32
O/F RATIO FROM SP.HT. OF OXYGEN AND HYDROGEN COMBUSTION PRODUCTS AS A FUNCTION
OF TEMPERATURE  - FOR CONSTANT PRESSURE.

 TEMP. - DEG.R            4 700.      1500.      2500.      3500.
 OFRAT (RATIO)     CPBAR (BTU/LB-R)
   12        1     3
0.50       2.315        1.00        1.755        1.50        1.420
2.00       1.193        2.50        1.035        3.00        0.915
3.50       0.824        4.00        0.748        5.00        0.637
6.00       0.556        7.00        0.495        8.00        0.442
   12        1     3
0.50       2.420        1.00        1.845        1.50        1.705
2.00       1.270        2.50        1.098        3.00        0.980
3.50       0.892        4.00        0.817        5.00        0.703
6.00       0.626        7.00        0.561        8.00        0.512
```

```
      12        1      3
0.50         2.585        1.00          1.994         1.50          1.638
2.00         1.398        2.50          1.217         3.00          1.090
3.50         0.995        4.00          0.918         5.00          0.798
6.00         0.717        7.00          0.658         8.00          0.608
      12        1      3
0.50         2.805        1.00          2.185         1.50          1.795
2.00         1.540        2.50          1.353         3.00          1.207
3.50         1.102        4.00          1.023         5.00          0.898
6.00         0.810        7.00          0.758         8.00          0.710
```

DATA TABLE -33

```
OXYGEN INTERNAL ENERGY         3      2            33

OXYGEN INTERNAL ENERGY AS A FUNCTION OF VAPOR PRESSURE ALONG ISOCHORES
DENSITY (LB/CU FT)        5 40.         50.         60.         65.         70.
VAPOR PRESS (PSIA)INT.ENERGY(BTU/LB)
    16          1      2
    1.          -71.576       3.         -66.661       5.         -63.982
   10.          -59.824      20.         -54.901      40.         -48.963
   60.          -44.881      80.         -41.650     100.         -38.920
  250.          -26.086     400.         -16.568     650.          -4.123
 1100.           -0.169    1400.           4.516    2000.           5.423
 2600.            9.973
    14          1      2
    1.          -71.596       3.         -66.716       5.         -64.068
   10.          -59.982      16.         -56.820      20.         -55.189
   40.          -49.484      60.         -45.617      70.         -44.025
  100.          -43.469     550.         -42.716    1200.         -41.725
 1800.          -40.664    3000.         -38.575
    14          1      2
    1.          -71.594       3.         -66.709       5.         -64.056
   10.          -59.961      16.         -56.789      20.         -55.150
   40.          -49.415      60.         -45.518      80.         -42.462
  100.          -39.901     250.         -33.400     650.         -32.411
 1500.          -31.050    2600.         -28.379
    17          1      2
    1.          -71.586       3.         -66.690       5.         -64.027
   10.          -59.906      16.         -56.706      20.         -55.050
   40.          -49.234      60.         -45.264      80.         -42.137
  100.          -39.509     250.         -27.382     400.         -18.507
  700.          -15.264    1100.         -13.829    1400.         -12.766
 2000.          -10.666    2600.          -8.579
    11          1      2
    1.          -71.599       3.         -66.722       5.         -64.078
   10.          -60.000      16.         -56.847      20.         -55.222
   40.          -54.360     200.         -54.345    1000.         -53.411
 1500.          -52.714    2600.         -51.198
```

DATA TABLE -34

```
HYDROGEN INTERNAL ENERGY       3      2            34

HYDROGEN INTERNAL ENERGY AS A FUNCTION OF VAPOR PRESSURE ALONG ISOCHORES
DENSITY (LB/CU FT)        5 .5          1.0         3.0         4.0         4.4
VAPOR PRESS (PSIA)INT ENERGY(BTU/LB)
    23        1      2
   1.022     -130.455        3.00      -120.531         7.00       -106.738
12.5          -89.46       25.          -64.31        37.5          -40.23
50.           -18.76       62.5          2.34         75.           22.11
87.5          41.32        92.3          49.          100.          53.
112.5         59.5         125.          65.9         137.5         72.2
150.          78.8         162.5         85.1         175.          91.8
187.5         98.1         200.          104.6        500.          259.4
 800.          580.662     1000.          768.689
```

```
     24       1       2
    1.022    -131.786        3.0        -124.043        7.0         -114.008
 12.5        -102.97     25.            -85.48      37.5            -70.77
 50.         -57.48      62.5           -45.16      75.             -33.52
 87.5        -22.47      100.           -11.85      112.5           -1.
 125.        9.47        137.5          19.48       150.            30.07
 155.1       34.1        162.5          36.1        175.            39.6
 187.5       42.9        200.           46.1        240.            57.0
  500.        119.461     800.           197.957    1000.            271.725
     24       1       2
    1.022    -132.672        3.0        -126.385        7.0         -118.855
 12.5        -111.66     25.            -100.16     37.5            -91.4
 50.         -83.83      62.5           -77.12      75.             -70.92
 87.5        -65.1       100.           -59.58      112.5           -54.31
 125.        -49.23      137.5          -44.28      150.            -39.48
 151.7       -39.        162.5          -38.3       175.            -37.9
 187.5       -37.1       200.           -36.3       240.            -34.2
  500.        -20.858     800.            -6.132    1000.              2.862
     13       1       2
    1.0      -132.784        5.0        -122.649       10.0         -115.617
   20.0      -106.153       30.0         -98.897       40.0          -92.691
   50.0       -87.349      100.0         -85.024      200.0          -83.497
  350.        -78.572     500.           -76.946      800.           -67.869

 1000.        -62.404
     13       1       2
    1.0      -132.813        3.0        -126.757        5.0         -122.774
    7.0      -119.626       10.0        -115.839       15.0         -110.613
   35.0      -109.632      100.0        -108.846      200.0         -105.896
  350.       -102.346     500.           -99.733      800.           -93.689
 1000.        -89.093
```

DATA TABLE -35

```
OXYGEN INTERNAL ENERGY          3      3            35
OXYGEN INTERNAL ENERGY AS A FUNCTION OF VAPOR PRESSURE ALONG ISOCHORES
FOR LOW DENSITIES

DENSITY (LB/CU FT)        5 .1          .3          1.0         20.         40.
VAPOR PRESS (PSIA)INT.ENERGY(BTU/LB)
     5       1       2
    1.0      -50.134        5.          23.105       10.          46.217
  14.696      68.129       20.          93.279
     8       1       2
    1.0      -64.464        5.         -34.285       10.          -5.399
  14.696      18.785       20.          30.938       30.          46.280
  40.         61.659       50.          77.295
    13       1       2
    1.0      -70.286        5.0        -58.596       10.0        -49.953
  14.696     -43.418       20.0        -36.927       30.0        -26.125
  40.0       -16.442       50.0         -7.469       60.0           .999
  70.0         9.082       80.0         16.658       90.0         24.382
 100.0        29.474
    18       1       2
    1.       -71.522       3.          -66.518       5.          -63.757
   10.       -59.413      16.          -55.965      20.          -54.152
   40.       -47.608      60.          -42.970      80.          -39.212
  100.       -35.978     250.          -19.604     400.           -6.875
  500.         0.555     700.           16.127    1100.           22.634
 1400.        29.610    2000.           40.081    2600.           49.817
    16       1       2
    1.       -71.576       3.          -66.661       5.          -63.982
   10.       -59.824      20.          -54.901      40.          -48.963
   60.       -44.281      80.          -41.650     100.          -38.920
  250.       -26.086     400.          -16.568     650.           -4.123
 1100.        -0.169    1400.            4.516    2000.            5.423
 2600.         9.973
```

DATA TABLE -36

```
OXYGEN VAPOR PRESSURE          3      2            36

OXYGEN VAPOR PRESSURE AS A FUNCTION OF INTERNAL ENERGY ALONG ISOCHORES
DENSITY (LB/CU FT)          5 40.        50.         60.         65.         70.
INT.ENERGY(BTU/LB)VAPOR PRESS (PSIA)
    16        1     2
 -71.576       1.            -66.661      3.          -63.982       5.
 -59.824      10.            -54.901     20.          -48.963      40.
 -44.881      60.            -41.650     80.          -38.920     100.
 -26.086     250.            -16.568    400.           -4.123     650.
  -0.169    1100.              4.516   1400.            5.423    2000.
   9.973    2600.
    17        1     2
 -71.586       1.            -66.690      3.          -64.027       5.
 -59.906      10.            -56.706     16.          -55.050      20.
 -49.234      40.            -45.264     60.          -42.137      80.
 -39.509     100.            -27.382    250.          -18.507     400.
 -15.264     700.            -13.829   1100.          -12.766    1400.
 -10.666    2000.             -8.579   2600.
    14        1     2
 -71.594       1.            -66.709      3.          -64.056       5.
 -59.961      10.            -56.789     16.          -55.150      20.
 -49.415      40.            -45.518     60.          -42.462      80.
 -39.901     100.            -33.400    250.          -32.411     650.
 -31.050    1500.            -28.379   2600.
    14        1     2
 -71.596       1.            -66.716      3.          -64.068       5.
 -59.982      10.            -56.820     16.          -55.189      20.
 -49.484      40.            -45.617     60.          -44.025      70.
 -43.469     100.            -42.716    550.          -41.725    1200.
 -40.664    1800.            -38.575   3000.
    11        1     2
 -71.599       1.            -66.722      3.          -64.078       5.
 -60.000      10.            -56.847     16.          -55.222      20.
 -54.360      40.            -54.345    200.          -53.411    1000.
 -52.717    1500.            -51.198   2600.
```

DATA TABLE -37

```
HYDROGEN VAPOR PRESSURE        3      2            37

HYDROGEN VAPOR PRESSURE AS A FUNCTION OF INTERNAL ENERGY ALONG ISOCHORES
DENSITY (LB/CU FT)          5 .5          1.0          3.0          4.0          4.4
INT ENERGY(BTU/LB)VAPOR PRESS (PSIA)
    23        1       2
-130.455        1.022      -120.531        3.0        -106.738         7.0
-89.46       12.5          -64.31       25.           -40.23        37.5
-18.76       50.           2.34         62.5          22.11         75.
41.32        87.5          49.          92.3          53.           100.
59.5         112.5         65.9         125.          72.2          137.5
78.6         150.          85.1         162.5         91.8          175.
98.1         187.5         104.6        200.          259.4         500.
 580.662      800.          768.689     1000.
    24        1       2
-131.786        1.022      -124.043        3.0        -114.008         7.0
-102.97      12.5          -85.48       25.           -70.77        37.5
-57.48       50.           -45.16       62.5          -33.52        75.
-22.47       87.5          -11.58       100.          -1.           112.5
9.47         125.          19.48        137.5         30.07         150.
34.1         155.1         36.1         162.5         39.6          175.
42.9         167.5         46.1         200.          57.           240.
 119.461      500.          197.957      800.          271.725      1000.
```

```
      24        !      2
  -132.672          1.022       -126.385        3.          -118.855        7.0
  -111.6         12.5           -100.16       25.           -91.4         37.5
  -83.83         50.            -77.12        62.5          -70.92        75.
  -65.1          87.5           -59.58        100.          -54.31        112.5
  -49.23         125.           -44.28        137.5         -39.48        150.
  -39.           151.7          -38.3         162.5         -37.9         175.
  -37.1          187.5          -36.3         200.          -34.2         240.
   -20.858        500.             -6.132      800.            2.862      1000.
      13        !      2
  -132.784          1.          -122.649         5.         -115.617        10.
  -106.153         20.            -93.697       30.           -92.691       40.
   -87.349         50.            -85.024      100.           -83.497      200.
   -76.572        350.            -76.946      500.           -67.869      800.
   -62.404       1000.
      13        !      2
  -132.813          1.          -126.757         3.         -122.774         5.
  -119.626          7.          -115.839        10.         -110.613        15.
  -109.632         35.          -108.846       100.         -105.896       200.
  -102.346        350.            -99.733      500.           -93.689      800.
   -89.093       1000.
```

DATA TABLE -38

```
OXYGEN VAPOR PRESSURE              3      3              38
OXYGEN VAPOR PRESSURE AS A FUNCTION OF INTERNAL ENERGY ALONG ISOCHORES
FOR LOW DENSITIES

DENSITY                         5 .1          .4          1.6         20.          40.
INT.ENERGY(BTU/LB)VAPOR PRESS (PSIA)
    5       !      2
  -50.134      1.0          23.105       5.0           46.217        10.
   68.129     14.696        93.279      20.0
    8       !      2
  -64.464      1.0         -34.285       5.0           -5.399        10.
   18.785     14.696        30.938      20.0           46.280        30.
   61.657     40.0          77.295      50.0
   13       !      2
  -70.286      1.0         -58.596       5.0          -49.953        10.0
  -43.416     14.696       -36.927      20.0          -26.125        30.0
  -16.442     40.0          -7.469      50.0             .999        60.0
    9.082     70.0          16.858      80.0           24.382        90.0
   29.474    100.0
   18       !      2
  -71.522      1.          -66.518       3.           -63.757         5.
  -59.413     10.          -55.965      16.           -54.152        20.
  -47.608     40.          -42.970      60.           -39.212        80.
  -35.978    100.          -19.604     250.            -6.875       400.
    0.555    500.           16.127     700.           22.634       1100.
   29.610   1400.           40.081    2000.            49.817      2600.
   16       !      2
  -71.576      1.          -66.661       3.           -63.982         5.
  -59.824     10.          -54.901      20.           -48.963        40.
  -44.881     60.          -41.650      80.           -38.920       100.
  -26.086    250.          -16.568     400.            -4.123       650.
   -0.169   1100.            4.516    1400.             5.423      2000.
    9.973   2600.
```

DATA TABLE -39

```
ENTHALPY OF LO2                    2     2              39

ENTHALPY OF SATURATED LIQUID OXYGEN  -  REF. NBS TN 384, 7/1/71.
PSAI (PSIA)        H SUB L (BTU/LB)
   21        1     3
     .594     -73.599       1.102     -71.208       5.061      -64.007
   10.009     -59.977      20.200     -55.096      40.434      -49.310
   62.194     -45.093      85.013     -41.650     105.755      -39.018
  157.926     -33.588     201.664     -29.809     253.498      -25.852
  314.262     -21.640     348.270     -19.427     404.159      -15.937
  466.319     -12.166     511.521      -9.433     559.968       -6.438
  611.917      -3.028     650.000      -0.253     700.000        4.414
```

DATA TABLE -40

```
ENTHALPY OF LH2                 2     0     0    40
PSAI               H SUB L
    10        1      3
10.0         -115.02     20.0          -105.06     30.0          -97.32
40.0          -90.61     50.0           -84.51     60.0          -78.80
70.0          -73.35     80.0           -68.06     90.0          -62.86
100.0         -57.71
```

DATA TABLE -41

```
ENTHALPY OF HELIUM              3     3           41

ENTHALPY OF HELIUM AS A FUNCTION OF VAPOR PRESSURE ALONG CONSTANT
TEMPERATURE.  REF. NBS REPORT 9762,AUG.1970
TEMPERATURE (R)         5  30.        100.       200.      400.      600.
VAPOR PRESS (PSIA) ENTHALPY (BTU/LB)
   12       1       2
  0.01          43.53        1.           43.51       10.          43.29
 20.            43.06       30.           42.62       40.          42.59
 50.            42.36       60.           42.13       70.          41.90
 80.            41.67       90.           41.45      100.          41.23
   12       1       2
  0.01         130.38        1.          130.38       10.         130.41
 20.           130.44       30.          130.47       40.         130.51
 50.           130.54       60.          130.57       70.         130.60
 80.           130.63       90.          130.66      100.         130.69
   12       1       2
  0.01         254.44        1.          254.45       10.         254.53
 20.           254.61       30.          254.69       40.         254.76
 50.           254.84       60.          254.92       70.         255.00
 80.           255.08       90.          255.16      100.         255.24
   12       1       2
  0.01         502.58        1.          502.59       10.         502.68
 20.           502.77       30.          502.87       40.         502.96
 50.           503.06       60.          503.16       70.         503.25
 80.           503.35       90.          503.44      100.         503.54
   12       1       2
  0.01         750.71        1.          750.72       10.         750.81
 20.           750.91       30.          751.01       40.         750.11
 50.           750.20       60.          751.30       70.         751.40
 80.           751.50       90.          751.60      100.         751.69
```

DATA TABLE -42

```
OXYGEN ENTHALPY (GAS)             3     3               42
ENTHALPY OF OXYGEN GAS AS A FUNCTION OF VAPOR PRESSURE FOR SPECIFIED
DENSITIES. REF. NBS-TN-384,JULY 1971 AND NBS OXYGEN COMPUTER PROGRAM.

DENSITY (LB/CU FT)        5 .25          .60          1.0          1.6          2.0
VAPOR PRESS (PSIA)ENTHALPY (BTU/LB)
    5      1      2
  14.696       36.146       20.0        51.865        30.0         77.698
  40.0        103.937       50.0       129.235
    6      1      2
  14.696      -14.958       20.0         0.450        30.0         27.309
  40.0         43.431       50.0        54.171        60.0         63.633
    9      1      2
  14.696      -32.084       20.0       -21.990        30.0         -4.666
  40.0         11.291       50.0        26.360        60.0         40.453
  70.0         45.781       80.0        52.173       100.0         65.269
    9      1      2
  14.696      -41.717       20.0       -34.612        30.0        -22.653
  40.0        -11.812       50.0        -1.682        60.0          7.943
  70.0         17.183       80.0        26.116       100.0         41.214
    9      1      2
  14.696      -44.928       20.0       -38.820        30.0        -28.649
  40.0        -19.513       50.0       -11.029        60.0         -3.004
  70.0          4.673       80.0        12.076       100.0         26.243
```

DATA TABLE -43

```
HYDROGEN ENTHALPY (GAS)           3     3               43
ENTHALPY OF HYDROGEN GAS AS A FUNCTION OF VAPOR PRESSURE FOR SPECIFIED
DENSITIES. REF-NBS REPORT 9288 AND 9711.

DENSITY (LB/CU FT)        5 .05          .20          .50          1.0          2.0
 VAPOR PRESS (PSIA)ENTHALPY (BTU/LB)
   10      1      2
  10.0         93.266       20.0       185.4          30.0        281.128
  40.0        380.721       50.0       495.624        60.0        619.830
  70.0        747.701       80.0       880.510        90.0       1022.595
 100.0       1162.921
   10      1      2
  15.0         34.000       20.0        45.212        30.0         57.007
  40.0         92.852       50.0       115.055        60.0        138.126
  70.0        161.610       80.0       183.764        90.0        207.222
 100.0        230.212
   10      1      2
  15.0        -80.643       20.0       -74.984        30.0        -43.292
  40.0        -20.679       50.0          .944        60.0         20.952
  70.0         40.356       80.0        59.747        90.0         78.699
 100.0         90.340
   10      1      2
  15.0        -97.193       20.        -89.093        30.         -74.273
  40.0        -60.771       50.        -48.187        60.         -36.542
  70.0        -25.279       80.        -14.324        90.          -3.629
 100.0          6.833
   10      1      2
  15.        -105.468       20.        -99.849        30.         -89.764
  40.         -80.817       50.        -72.753        60.         -65.289
  70.         -58.097       80.        -51.360        90.         -44.792
 100.         -38.389
```

DATA TABLE -44

```
BETA FACTOR                          2     4          44
  CORRECTION FACTOR FOR PHITWO IN H2-O2-N2 ELECTRIC POWERER HEAT
  EXCHANGER.  BETA IS A FUNCTION OF CRITICAL PRESSURE RATIO.
  REF.  AM 71-7535.

P OVER PC             BETA
  12        !         2
  .01                .33          .1            .33           .12           .33
  .20                .35          .40           .39           .60           .44
  .80                .48         1.0            .52          1.4            .52
 1.8                 .52         2.2            .52          2.6            .52
```

DATA TABLE -45

```
SIGMA-DELTAP FOR HEXELC          3     4          45
  PRESENTS SIGMA-DELTAP AS A FUNCTION OF MASS VELOCITY AND HEAT
  EXCHANGER LENGTH.
  REF.  AM 71-7535.

  HEX-LENGTH (IN)           5      4.          8.          16.          32.          64.
MASVEL(LB/HR-IN)   SIG-DELTAP (PSI)
    15        !         3
    .10               .000032       .20        .00011        .40          .00042
    .60               .00094        .80        .00165       1.00          .0025
   2.00               .0095        4.00        .0360        6.00          .075
   8.00               .14         10.00        .200        20.00          .78
  30.                1.6          40.00       2.8          60.00         6.0
    15        !         3
    .10               .000052       .20        .00020        .40          .00078
    .60               .00165        .80        .00295       1.00          .0045
   2.00               .0170        4.00        .061         6.00          .140
   8.00               .230        10.00        .350        20.00         1.30
  30.00              2.9          40.00       4.7          60.00        10.0
    15        !         3
    .10               .000098       .20        .00037        .40          .00136
    .60               .0030         .80        .0050        1.00          .0080
   2.00               .0295        4.00        .115         6.00          .240
   8.00               .41         10.00        .64         20.00         2.40
  30.00              5.0          40.00       8.5          60.00        16.00
    15        !         3
    .10               .000165       .20        .00062        .40          .0024
    .60               .0054         .80        .0093        1.00          .0140
   2.00               .0540        4.00        .20          6.00          .43
   8.00               .76         10.00       1.2          20.00         4.30
  30.00              9.2          40.00      14.8          60.00        32.0
    15        !         3
    .10               .0003         .20        .00113        .40          .0043
    .60               .0095         .80        .0165        1.00          .0250
   2.00               .092         4.00        .35          6.00          .74
   8.00              1.3          10.00       2.0          20.00         7.60
  30.00             14.7          40.00      26.0          60.00        57.0
```

DATA TABLE -46

```
BETA VALUES FOR H2                  3     4          46
  VOLUME EXPANSIVITY (BETA) FOR HYDROGEN AS A FUNCTION OF PRESSURE AND
  TEMPERATURE.
  REF. - NBS-TN-617,APRIL 1972, NAT.BUR.STANDARDS,BOULDER,COLORADO.

  PRESSURE (PSIA)          5  50.0         100.0        200.0        300.0        400.0
TEMPERATURE(DEG-R) BETA (PER DEG-R)
   13        !        2
  30.0             .0068682       36.0        .0087034       42.0         .0120937
  45.406           .0154794       45.406      .0425479       60.0         .0214360
  60.0             .0140154      125.0        .0082872      200.0         .0050429
 340.0             .0029425      440.0        .0022710      540.0         .0018497
 700.0             .0014268
```

```
  15        1     2
  30.0      .0066720      40.0      .0101009     50.0       .0220225
  52.072    .0305221      50.072    .0669217     54.0       .0492883
  60.0      .0303448      70.0      .0203346     80.0       .0158545
 125.0      .0085774     200.0      .0050846    340.0       .0029435
 440.0      .0022692     540.0      .0018476    700.0       .0014250
  15        1     2
  30.0      .0063024      40.0      .0091823     50.0       .0166397
  58.0      .0595100      60.0      .6211455     62.0       .1125254
  66.0      .0484820      70.0      .0336912     90.0       .0157847
 125.0      .0091577     200.0      .0051645    340.0       .0029448
 440.0      .0022652     540.0      .0018431    700.0       .0014214
  15        1     2
  30.0      .0059902      40.0      .0084433      50.0      .0137881
  60.0      .0360359      64.0      .0856922      66.0      .1174762
  70.0      .0683492      80.0      .0282269      90.0      .0189064
 125.0      .0097206     200.0      .0052391     340.0      .0029450
 440.0      .0022609     540.0      .0018386     700.0      .0014177
  15        1     2
  30.0      .0056750      40.0      .0078461      50.0      .0119866
  60.0      .0229678      66.0      .0428049      70.0      .0600390
  75.0      .0514055      85.0      .0273007      95.0      .0186681
 125.0      .0102432     200.0      .0053075     340.0      .0029442
 440.0      .0022563     540.0      .0018339     700.0      .0014140
```

1.6 INPUT DECK SETUP

The Math Model Program has a built-in capability to process either a single system analysis run or multiple system runs. The multiple system runs can be several runs of the same system or different systems. Average system run times will vary from approximately 90 seconds (UNIVAC-1108, Exec 8) for an ACPS run to approximately 180 seconds for a fuel cell analysis.

1.6.1 Single System Deck Setup

For a single system setup the input deck setup is of the same general form as given in Fig. 1.5.4-1, where the system definition card continues the phrase, "LAST CARD" beginning in Field 4.

1.6.2 Multiple System Deck Setup

For a multiple system deck setup several adjustments are made to the input decks. First, since the Data Tables are only to be read-in once, only the first data deck will contain the ADD Card calling for Data Table input. Secondly, the System Definition card in each input deck, except the last one, will omit the phrase, "LAST CARD" (Field 4). This phrase must appear in the last deck in order to provide proper run termination. A typical multi-run deck setup is illustrated in Fig. 1.6.2-1, showing the card requirements. The illustration assumes the program and Data Tables are stored in files.

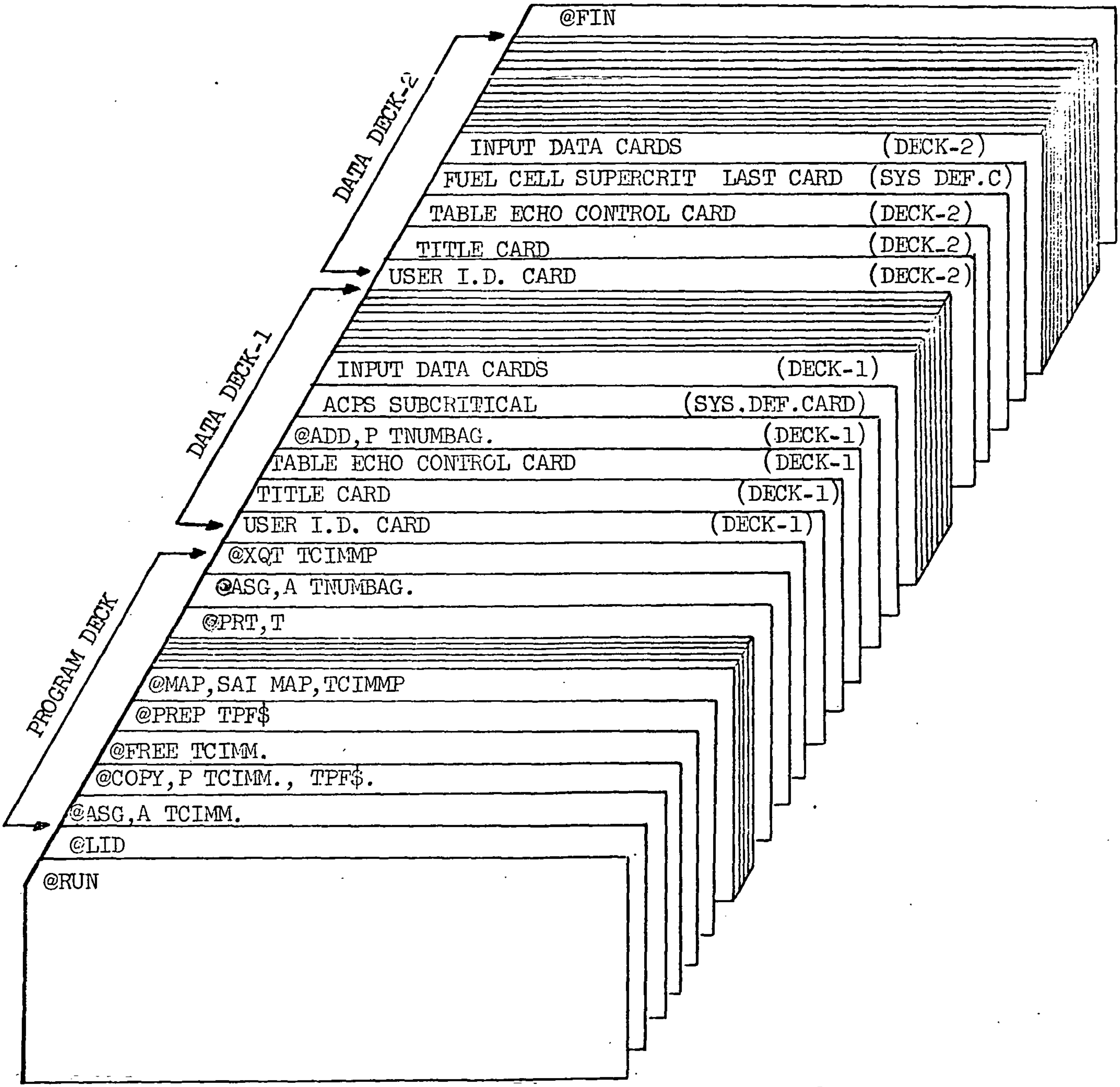


FIGURE 1.6.2-1 MULTI-SYSTEM DATA DECK

1.7 MATH MODEL PROGRAM MACHINE REQUIREMENTS

The program as it is currently configured requires in excess of 65,000 words of core storage for both the instruction and data banks. It is, therefore necessary, to either chain or overlay the program in order to avoid core overflow and truncation. Since the machine for which the program is intended is also a UNIVAC 1108 multiprocessor, operating under the EXEC-8 system, the option chosen is the use of a mapped program segment overlay. A third choice, of course, is to break the large program into two or three small programs which could each process one or two of the cryogen system analyses. For specialized analysis which concentrated on, for example, the life support and fuel cell systems, it would be preferrable to use only those subprograms required and reduce both core loading requirements and program run time.

The procedures required for developing a program segment overlay are documented in the UNIVAC manuals (Reference 1.7 -1), describing the COLLECTOR processor. The discussion given in this manual will be limited to the program segment overlay employed for the Math Model Program.

1.7.1 Segmented Overlay Procedure

The construction of a segmented overlay for a program is accomplished by manipulation of the order in which relocatable elements are collected by the computer operating system for the production of an executable absolute element. Under the EXEC-8 operating system, this function is accomplished by the COLLECTOR, a system processor designed to provide a user with a means of gathering relocatable elements from many sources (programs) which may then be used in the construction of overlay segments in order to produce an absolute element ready for execution. Optionally, the COLLECTOR can be used to produce one relocatable element from a collection of relocatable elements. The COLLECTOR may be called explicitly by the @MAP executive control statement, or, implicitly as a result of the user requesting execution (@XQT) of a program which is not in the absolute form. Only absolute elements procued by the COLLECTOR can be executed.

The procedure for structuring the overlay segments involved the use of the following control statements and directives:

(1) Setup the Entry Point Table (@PREP)

(2) Invoke the COLLECTOR with a @MAP control statement.

(3) Use the SEG directive to define each program segment in its preselected order.

(4) Use the IN directive to call explicitly the main or subprogram assigned in each segment.

(5) Use IN directives to call in BLOCK DATA elements where required in a segment.

(6) Use the END directive to define the end of source language statements to be processed.

The SEG directive, or control statement is used to define the relationship and contents of segments within a program. The format employed is SEG, NAME 1, NAME 2 where NAME 1 is the name of the segment and must be specified. NAME 2 gives the names of other segments to which the segment NAME 1 is being related. The first segment named in the source input is called the main segment and is not overlayed by other segments.

The IN directive, or control statement, allows the user to include any, or all, elements from any member of files in his collection specifically in the segment named by the preceding SEG statement.

The structured collection of source statements which make up the map for the Math Model Overlay is given in Table 1.7.1-1.

Table 1.7.1-1

MATH MODEL MAP OVERLAY

```
@MAP,LAI                       MAP, TCIMMP
C     MAPPING DECK FOR TCIMM PROGRAM
           SEG MAIN
            IN CONTRL
            IN SPHTDA
           SEG LVL1A*,(MAIN)
            IN INTAB
            IN COMPIL
           SEG LVL1B*,LVL1A
            IN CRYCON
           SEG LVL2A*,(LVL1B)
            IN ACCRES
            IN LIQRES
            IN TANK
            IN VENT
           SEG LVL2B*, (LVL1B)
            IN APUSUB,APUSUP
           SEG LVL2C*, (LVL1B)
            IN ECLSS
           SEG LVL2D*, (LVL1B)
            IN FUELCL
           END
```

When the COLLECTOR precessor is invoked by means of a @MAP control statement followed by a set of source statement mapping instructions, the collector will provide, as output, the starting addresses of all subprograms and common blocks in the order defined by the SEG and IN directives. An abbreviated illustration of segment loading addresses is given in Table 1.7.1-2.

Additionally, the collector presents a graphic representation of the segment MAP generated giving the quantity of work contained in each segment. The graphic representation generated for the Math Model Map is presented in Table 1.7.1-3.

TABLE 1.7.1-2

LOADING ADDRESSES FOR SEGMENTED OVERLAY

```
ADDRESS LIMITS     001000 064471        065000 154233
SEGMENT LOAD TABLE                      065000 065033
INDIRECT LOAD TABLE                     065034 065732
STARTING ADDRESS   011161

WORDS DECIMAL        26426 IBANK          28316 DBANK


SEGMENT MAIN                001000 011363     065733 132600


SEGMENT LVL1A*              011364 021155     132601 134317
FOLLOWS SEGMENT MAIN


SEGMENT LVL1B*              011364 056044     132601 151310
HAS THE SAME STARTING ADDRESS AS SEGMENT LVL1A


SEGMENT LVL2A*              056045 063416     151311 154233
FOLLOWS SEGMENT LVL1B


SEGMENT LVL2B*              056045 062401     151311 152114
FOLLOWS SEGMENT LVL1B


SEGMENT LVL2C*              056045 064436     151311 153765
FOLLOWS SEGMENT LVL1B


SEGMENT LVL2D*              056045 064471     151311 153544
FOLLOWS SEGMENT LVL1B
```

TABLE 1.7.1-3

COMPUTER DRAWN OVERLAY MAP

```
DBANK SEGMENTS DRAWN TO SCALE:   400 WORDS DECIMAL PER DASH

MAIN (18854)
-----------------------------------------------
                                               LVL1A* (847)
                                               --
                                               LVL1B* (7495)
                                               -------------------
                                                                  LVL2A* (1491)
                                                                  ----
                                                                  LVL2B* (388)
                                                                  -
                                                                  LVL2C* (1324)
                                                                  ---
                                                                  LVL2D* (1161)
                                                                  ---
IBANK SEGMENTS DRAWN TO SCALE:   400 WORDS DECIMAL PER DASH

MAIN (4340)
-----------
           LVL1A* (3962)
           ----------
           LVL1B* (18736)
           -----------------------------------------------
                                                          LVL2A* (2794)
                                                          -------
                                                          LVL2B* (2269)
                                                          -----
                                                          LVL2C* (3321)
                                                          --------
                                                          LVL2D* (3263)
                                                          --------
```

1.8 PROGRAM RESTRICTIONS

Program restrictions for the current version of TCIMM are largely self-imposed by the range of the data used in cryogenic system evaluation. Array size for many of the program variables can be conveniently changed by adjustment of the PARAMETER definition statements found in each of the Procedure Definition Processors which define the common arrays. The array dimensions as currently defined, however, are adequate for current system concepts.

1.8.1 Program Analytical Range

The program currently accommodates the use of four cryogen fluids: oxygen, hydrogen, helium, and nitrogen.

Temperature ranges extend to $800^{\circ}R$ for O_2, H_2, and He and to well over $1000^{\circ}R$ for N_2. Pressure ranges extend to 2500 psia for O_2, H_2, and N_2. In this respect all table data ranges can be extended by simply enlarging the tables.

The configuration table will currently accommodate one hundred components and can be extended by changing the appropriate PARAMETER statement in PDP-CCNFIG.

1.8.2 Table Data Limits

Current Table Data capacity is limited to 50 tables containing a total of 7000 words. The number of tables can be changed by altering the value of the NTBN in PDP-CTAB from 50 to the desired number of tables. The total number of table words can be changed by alterning the value of MXWRD in PDP-CTABA to the value desired. If MXWRD is changed, then the "error message" in FORMAT statement 6170 of subroutine INTAB should also be changed.

1.8.3 TAPE AND DRUM ASSIGNMENTS

For those facilities which have limited or no mass storage capability in the form of FASTRAND or DISC program storage, tape operation will be required for Program file and Data Table file loading only. The making of the files on tape will follow whatever local procedures are used compatible with local machine requirements. The program uses no scratch or intermediate tapes or drums for data storage, hence, there will be no requirement for mounting extra tapes.

1.8.4 Data Table Tape Preparation

Provisions have been made in the program to produce and use a binary data table tape, where this is preferred over Data Table Card input, or because of mass storage limitations.

A binary data table tape can be produced in the course of a normal program run utilizing existing coding in subroutine INTAB which is controllable from the input data, "Table Data Echo Control Card" (Ref. Gp(c) CARD-1, Sub.sec. 1.5.2.2).

The variables IFT and ØFT which occupy the first two fields of the Table Data Echo Control Card are utilized for the tape preparation and tape utilization functions.

The defined values to be used in the variables are as follows:

IF:	IFT = 0	Table Data Input is from Source Cards, or Mass Storage.
	IFT = 1 or 2	Table Data Input is from Binary Tape loaded from Tape Unit-15.

	IFT>2	Table Data Input is from Binary Tape loaded from Tape Unit IFT. Where IFT specifies tape unit number (Example: IFT = 17)
IF:	ØFT = 0	No binary data tape is to be made.
	ØFT = 1 or 2	Binary Data Table Tape will be produced on Tape Unit - 15.
	ØFT > 2	Binary Data Table Tape will be made on Tape Unit ØFT. Where ØFT specifies Tape Unit Number (Example: ØFT = 16)

To make a binary data tape of the Data Tables, the simplest procedure is as follows:

(a) Assign a blank tape to be loaded in Tape Unit 15, to be reserved.
(b) Set IFT = 0 in Table Data Echo Control Card.
(c) Set ØFT = 1 on Table Data Echo Control Card.
(d) Set NPRT = 1 } To print Table Echo Summary
NPRT2 = 1 }
(e) Load data Table Cards immediately following Table Data Echo Control Card.

The program will generate a binary data trap and those proceed with the execution of the run.

1.8.5 Data Table Tape Utilization

To use the binary data tape produced by the program, the following procedure applies:

(a) Assign the Data Table Tape to be read in on Tape Unit 15.

(b) Set IFT = 1 on Table Data Echo Control Card.

(c) Set ØFT = 0 on Table Data Echo Control Card.

(d) Set NPRT = 1 } To Print Table Echo Summary
NPRT2 = 1

(e) Omit Data Table Cards from Input Deck.

The program will now load in the Data Tables from Tape and procede to execute the run.

1.8.6 Drum and Disc Utilization

Where a facility is equipped with Drum and/or Disc file storage hardware, both the program and the Data Tables may be conveniently stored as files in mass storage. Assigning and calling in the files becomes a simple matter involving only a few control cards.

Detailed procedures for program file generation as well as DATA file generation are adequately described in the UNIVAC-1108 manuals.

1.8.7 ERROR MESSAGES

The size and relative complexity of the Math Model Program is such that the user must have some means other than the standard computer disgnostics and error messages to indicate and flag run problems.

Accordingly, several means of detecting run problems and error causing input values have been incorporated into the program itself. The two main techniques employed are out-of-range warning messages and built-in error termination. Troubleshooting the program is simplified by providing within the more sensitive subprograms, a built-in diagnostic trace technique which will output and flag intermediate values for the intermediate calculations not normally shown in the program output.

Normally, if no changes have been made in the subprogram coding, an error will usually be the result of an input data error, either as a wrong input value or the omission of the value. Since the input data decks are sometimes rather large, new decks should be very closely checked for keypunch errors and card omissions.

1.8.7.1 Built-in Diagnostic Trace

The built-in diagnostic trace technique consists of a set of diagnostic flag indices, a subprogram which verifies the flag and sets the "switch" position, and a set of diagnostic write statements placed in sensitive subprograms. The diagnostic flag index permits either single or multiple subprogram diagnosis as desired by the user.

1.8.7.2 <u>The Diagnostic Flag.</u> The diagnostic flag for any of the using subprograms is controlled through the variable "MDTRC" defined in Procedure Definition Processor CCNTRL. Input values for MDTRC are placed on the System Definition input data card described in subparagraph 1.5.2.4.

MDTRC may have a value of either zero or one, and is placed in specific system definition card positions to activate the diagnostic write statements in any of eleven (11) subprograms. The card columns utilized for MDTRC are as follows:

Card Column	MDTRC ( ) = DIAGNOSTIC TRACE SWITCH FOR CRYCØN (OFF = 0)
(70)	(1) = 1 Turn on ACCRES
(71)	(2) = 1 Turn on ACQWT
(72)	(3) = 1 Turn on APUSUB or APUSUP
(73)	(4) = 1 Turn on CMPCAL
(74)	(5) = 1 Turn on FUELCL
(75)	(6) = 1 Turn on CØNSUM
(76)	(7) = 1 Turn on ECLSS
(77)	(8) = 1 Turn on LIQRES
(78)	(9) = 1 Turn on TANK
(79)	(10) = 1 Turn on TSIZEI
(80)	(11) = 1 Turn on WTACC

MDTRC(1) is Card Column 70, ---MDTRC(11) is Card Column 80 of the System Definition Card.

The values for MDTRC are read in the main driver routine CØNTRL and are stored in CØMMØN/CCNTRL/ for later use in the executive sequencing subroutine CRYCØN.

1.8.7.3 Diagnostic Control Subprogram. The flag MDTRC is tested in subroutine CRYCØN as each of the analytical subprograms are sequenced. If MDTRC is not zero then subroutine CRYCØN will turn ON the diagnostic switch for the subprogram being sequenced. Any other routines or functions called by this subprogram will also yield diagnostics if equipped to do so. When the diagnostic switch is ON. a function routine called DIAG is also activated and prints as output the name of the subroutine being entered and states that a diagnostic trace is in progress. Each time in the subprogram that a diagnostic write statement is encountered, DIAG is tested and if found to be activated the write statement is executed. Upon leaving the subprogram the function DIAG again states the subprogram name and the fact that the subprogram has been exited.

An illustration of the diagnostic trace output is given in Fig.1.8-1 for a short trace used internally in the APU subprogram. The diagnostic trace was setup to be activated for an APU supercritical analysis, to examine the process of looking up ultimate strength values in Data Table 22.

```
                          NAME                 * * * * * * * * * * * * * * * * * * * * * PAGE   75
                          DEPT 6213            *      THE INTEGRATED MATH MODEL        * DATE 05 FEB 73
                          EXT. 30235           *                                       * TIME 10:10:01
                          BLD. 104             *                AT4307                 * CASE  .1
                          * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
                                           TEST CASE = SUPERCRITICAL APU PROBLEM, MIXRAT=0.90

**DIAGNOSTIC TRACE**
FINTAB ENTRED       22          2283
FINTAB EXITED        2             4                2                3                0                0
                                 .700000+03       .500000+03       .200000+03       .000000          .000000
                                 .150000+04       .100000+04       .300000+03       .000000          .000000
                                 .250000+04       .250000+03       .400000+03       .000000          .000000
                                 .350000+04       .300000+03       .000000          .000000          .000000
                                 .100000+04       .500000+03       .000000          .000000          .000000
MIPE   ENTRED        1             4                2                3                0                0
                                 .500000+03
LOCATE ENTRED      1     1 2284
LOCATE EXITED     14     1   2 2300     .367000+02       .185970+04       .266500+06       .320000+05
MIPE   EXITED        2             1                2                1                0                0
                                 .115761+06
FINTAB ENTRED       22          2283
FINTAB EXITED        2             4                2                3                0                0
                                 .700000+03       .500000+03       .200000+03       .000000          .000000
                                 .150000+04       .100000+04       .300000+03       .000000          .000000
                                 .250000+04       .250000+03       .400000+03       .000000          .000000
                                 .350000+04       .300000+03       .000000          .000000          .000000
                                 .100000+04       .500000+03       .000000          .000000          .000000
MIPE   ENTRED        1             4                2                3                0                0
                                 .500000+03
LOCATE ENTRED      1     1 2284
LOCATE EXITED     14     1   2 2300     .367000+02       .185970+04       .266500+06       .320000+05
MIPE   EXITED        2             1                2                1                0                0
                                 .115761+06
```

FIGURE 1.8-1   DIAGNOSTIC TRACE ILLUSTRATIONS

Since the only subprograms having diagnostic write statements within subroutine APUSUP were subroutines FINTAB, LØCAT and the function MIPE, the table look-up procedure examination was straightforward.

As noted in Fig. 1.8-1, DIAG caused the notation DIAGNOSTIC TRACE to be printed as subroutine FINTAB was called in. DIAG noted that FINTAB was entered and Data Table-22 was found and copied. FINTAB was exited and a summary of the X-array printed out. Function MIPE was then entered followed by a call to LØCAT which was entered to locate the X,Y subtable which bracketed the desired value of 500^oR. The array subtable limits were output and LØCAT was exited. Function MIPE then performed a linear interpolation of the X and Y arrays to obtain an ultimate stress value of 115761 psi at the desired temperature of 500^oR for the stainless steel oxygen accumulator tank material. MIPE was then exited with the required data. The sequence was repeated a second time for the hydrogen accumulator and since operating temperature and material selection was identical to the first accumulator, the answer obtained was the same as before. In this instance, the diagnostic output was not labeled by variable name, however, in other subprograms the diagnostic data appears in variable labeled format.

Diagnostic write statements will be easily recognized in the various subprograms since they all start with an IF statement, for example:

```
IF(DIAG(0,6HFLØRAT))WRITE(IØT,6020)WDØTI, etc.
```

which says, if the diagnostic switch is turned ON, write out that FLØRAT was entered and writeout the subroutine input variables starting with flowrate, etc.

1.8.8 Error Diagnostics

In addition to the diagnostic trace for checking out program computation procedures, there are a number of Error Diagnostics built into the various subprograms which give a warning if ranges are exceeded, or if things show up out of order. For example, subroutine CMPCAL computers pressure drops and keeps track of the required system pressure as the analysis proceeds to work its way toward the supply tanks. If, upon arriving at the tank, the subprogram finds the input tank pressure lower than the required pressure, it will reset the tank pressure equal to the calculated required pressure and print the following message:

> "DIAGNOSTIC* TANK INPUT PRESSURE IS LESS THAN THE REQUIRED PRESSURE. TANK PRESSURE SET = REQUIRED PRESSURE. TANK INPUT PRESSURE = -----. REQUIRED PRESSURE = ----.

Similar messages warn of the failure of data to converge, or the failure of data to match preset convergence ranges.

1.8.9 Preset Error Terminations

A number of preset error terminations are provided in the program, in order to prevent the generation of meaning less data and expenditure of costly run time. Typical conditions causing error terminations are as follows:

> Errors in naming the system on the System Definition Card will always abort the run. The system name must begin with the three alpha character mnemonics specified in DATA NAMSYS given in subroutine STØDTA.
>
> A negative temperature or pressure value will terminate the program in a number of subprograms.
>
> A temperature or pressure out of preset ranges will terminate the program in several of the thermodynamic property subprograms.

1.8.10 Errors in Reading Table Data

Subroutine INTAB is provided with a specific set of diagnostic messages in order to permit rapid isolation of problems in the DATA TABLE input. Usually the trouble occurs during table update or replacement, however, simple card juxtaposition can also cause a lot of trouble.

The following is a list of Table Data error messages and the table data cards to examine:

ERROR	THE NUMBER OF DIMENSIONS IS WRONG. ND = _______. (See Gp(d) CARD-1).
ERROR	THE NUMBER OF POINTS IS WRONG. NP = _______. (See Gp(d) CARD-3).
ERROR	THE NUMBER OF DATA POINTS IS WRONG. NV = _______. (See Gp(d) CARD-5).
ERROR	THE TABLE TYPE IS WRONG. TYPE = _______. (See Gp(d) CARD-5).
DIAGNOSTIC	THE NUMBER OF INTERPOLATION POINTS IS WRONG. NIP = _______. NIP IS SET EQUAL TO = _______. (See Gp(d) CARD-5).
ERROR	THE ABOVE TABLE NUMBER IS LESS THAN 0 AND GREATER THAN 50. (See Gp(d) CARD-1 (NT)).
DIAGNOSTIC	THE ABOVE TABLE HAS ALREADY BEEN INPUT. THIS TABLE SHALL REPLACE THE PREVIOUS TABLE. (Check table numbers-NT.)
ERROR	THE TOTAL SIZE OF THE TABLES HAS EXCEEDED 7000. THE REQUIRED SIZE IS _______. RUN TERMINATED.

Any of the foregoing messages requires action by the user to correct the Table Data Deck or File.

1.9 SUBROUTINE DESCRIPTIONS

This subsection of the manual contains descriptions of the major subroutines employed in Program TCIMM. The program currently contains one hundred and twenty-six (126) subroutines and function subprograms in addition to thirty (30) FORTRAN Procedure Definition Processors (PDP's). Of the one hundred and twenty-six subprograms, sixty-eight are required for computing fluid thermodynamics properties for Oxygen, Hydrogen, Helium and Nitrogen in either the liquid or gaseous states over the range of temperature and pressure covered by the cryogen systems considered. These five, only the more important major subprogram and a selection of the supporting subprograms have been included in this manual. The descriptions are arranged alphabetically by subroutine or function name.

1.9.1 Breakdown of Subprogram Description

SUBPROGRAM DESCRIPTION

Each subprogram is described and defined using the following format:

Description

Description briefly describes the subprogram.

MATHEMATICAL MODEL FOR SUBPROGRAM

Indicates whether a math model is supplied for the subprogram.

CALLING SEQUENCE

Calling Sequence will contain a description of the manner in which the subprogram is called, its calling arguments and pertinent comments regarding data transfer.

SIGNIFICANT VARIABLES

Significant Variables will contain the following elements:

Name	Type	I/O	Dimension	Description

Name is the name of the significant variable in the subprogram.

Type indicates the type of the variable; I – integer, R – real, or L – logical.

I/O indicates if the variable is input (I) to the routine through the calling sequence, output (O) from this routine through the calling sequence, or I/O if both; (C) indicates that the variable is computed, and (D) indicates that the variable is derived from a data statement.

SUBPROGRAMS REFERENCED IN THIS SUBPROGRAM

Name	Type	Reference

Name is the name of the subprogram

Type includes the elements S for subroutine, and F for function.

Reference is the page number where the referenced subprogram description can be found.

SUBPROGRAMS REFERENCING THIS SUBPROGRAM

Name	Type	Reference

The elements of Subprograms Referencing this Subprogram will be categorized as described under Subprograms Referenced in this Subprogram.

LISTING REFERENCE PAGE

The page number of the Appendix-B Listing where the subprogram may be found.

FLOW CHART

Flow Chart references the figure number of the applicable flow chart. Appendix A illustrates and explains the flow chart symbols.

The subprogram descriptions follow.

FUNCTI0N AFUNC

For a description of AFUNC see the writeup for "TKGE0M."   Page B-299

SUBROUTINE APUFL0

DESCRIPTION

The subroutine provides the starting point for APU subcritical and supercritical system analysis. The computation of pertinent APU parameters common to both subcritical and super-critical systems is accomplished including the following:

(a) % APU Power - Each Duty Cycle Point
(b) Propellant Temperature at APU Gas Generator Inlet
(c) Coefficients for Reference Propellant Flow Rate
(d) Reference Propellant Flow Rate (lbs/min)
(e) Propellant Flow Rate for Each Time Interval and Total Duty Cycle
(f) APU Exhaust Temperature during Each Time Interval
(g) Specific Heat of Combustion Products through Duty Cycle Intervals.

Input data to APUFL0 is read-in by Subroutine C0MPIL and stored in the Procedure Definition Processors, CAPU and CDCYCL, under labeled common statements /CIAPU/, /CVAPU/. Output data from APUFL0 is stored in the following labeled common statements; /CIAPU/, /CVAPU/ and /CENG/. Selected parametric values are output with appropriate titles in the analysis printout.

APUFL0 Mathematical Model

The equations, mathematical procedures, and necessary tables and constants required are presented in Appendix C.

CALLING SEQUENCE

APUFL0 is initiated by a simple call from Subroutine CRYC0N with no calling variables. Data transfer to APUFL0 is accomplished through INCLUDE statements as shown in the subroutine listing. Upon completion of its computations APUFL0 returns sequential program control to subroutine CRYC0N.

SIGNIFICANT VARIABLES

Significant variables processed in APUFL0 are as follows:

NAME	TYPE	I/0	DIMENSION	DESCRIPTION
NAPU	I	I	1	Number of APU's
HPR	R	I	1	Rated HP of APU
T0THPR	R	0	1	HPR*NAPU
PCTHP	R	0	20	%HP Demand each Cycle
TIT	R	I	1	Turbine Inlet Temp
TPF	R	0	1	Prop Temp into APU-G.G.
FMR	R	I	1	Fuel Mixture Ratio – APU
PGG	R	I	1	Gas Gen. Op. Pressure
PAMB	R	I	30	Ambient Pressure
WD	R	0	20	Total (02+H2) Flow Each Cycle
TIPWT	R	0	1	Total (02+H2) for APU Turbine
WDOTJ	R	0	20, 2	Flow Rate – Each Fluid (lb/sec)
WDOTI	R	0	20, 2	Max. Flow Rate - Each Fluid (lb/sec)
WDRH	R	0	20	Nom. Flow Rate - H2 (lb/min)
WDR0	R	0	20	Nom. Flow Rate - 02 (lbs/min)
WDT	R	0	20	Total Propellant Including Pressure
TE	R	0	20	Turbine Exhaust Temperature
D	R	0	20	Heat in Turbine Exhaust
HP	R	I	30	H.P. Required each Interval

SUBPROGRAMS REFERENCED IN APUFL0

NAME	TYPE	PURPOSE	REFERENCE
FINTAB	S	Table Lockup	Page B-747
MIPE	F	Table Data Extraction	Page B-221
CSUBPI	S	Cacl. Cp. for Exhaust Products	Page B-91
0PAPUF	S	Output Specific Values to Printer	Page B-234
CRYC0N	S	Sequential Control of Analysis	Page B-85

LISTING REFERENCE PAGE

The APUFL0 listing will be found in Appendix B, Page 5

FLOW CHART

A flow chart for APUFL0 is presented In Figure 1.9-1.

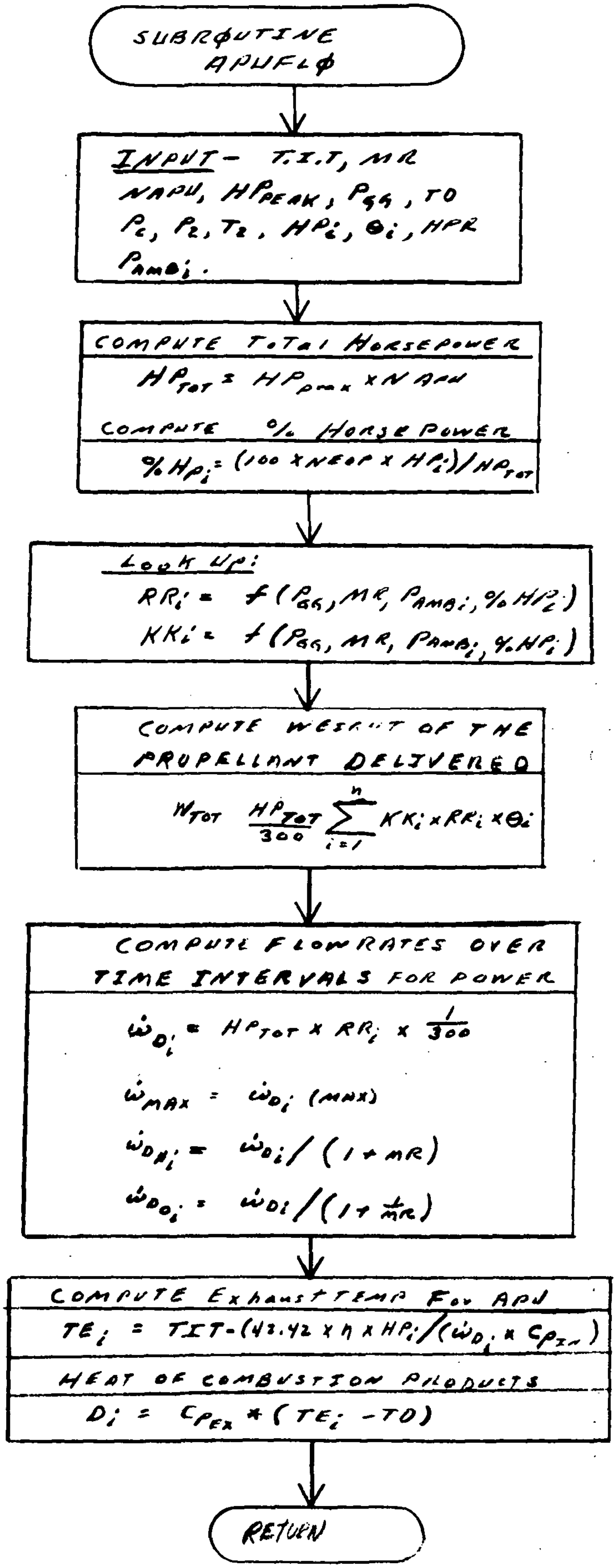


Fig. 1.9-1 APUFLØ
Flow Cha

SUBROUTINE APUSUB

DESCRIPTION:

The subroutine contains the equations and computational techniques required to perform an APU sub-critical system analysis. The subroutine accomplishes the computation of pertinent sub-critical system parameters required for the analysis and presents the calculated values in formatted output. The following are the principal computations contained in the subroutine.

(a) Sizes the heat exchangers between the accumulators and the APU gas generator.
(b) Establishes temperatures of exhaust gases from H2 and O2 conditioning gas generators.
(c) Sizes the H2 and O2 heat exchangers between the pumps and accumulators.
(d) Computes the total weight of O2 and H2 needed to operate the conditioning gas generators.
(e) Cumputes the volume of the O2 and H2 storage tanks.
(f) Computes the Weight of the O2 and H2 storage tank.
(g) Computes the weight of the O2 and H2 accumulator residual fluids.

System component weights and pressure drops for the max-flow conditions are calculated separately by subroutine CMPCAL.

Input data to APUSUB has previously been read-in by subroutine CØMPIL. This data, along with the values generated by subroutines APUFLØ and FLØRAT, are stored in labeled CØMMØN assigned storage defined by a set of Procedure Definition Processor elements. The labeled commons used for data transfer are:

```
CØMMØN / CACCUM/
CØMMØN / CIAPU/
CØMMØN / CVAPU/
CØMMØN / CDCYCL/
CØMMØN / CENG/
CØMMØN / DPUMP/
CØMMØN / CTANK/
```

APUSUB MATHEMATICAL MODEL

The equations, mathematical procedures, necessary tables, and constants required are presented in Appendix C.

CALLING SEQUENCE

APUSUB is initiated by a simple call from subroutine CRYCON with no calling variables. Data transfer to APUSUB is accomplished through INCLUDE statements as shown in the subroutine listing. Upon completion of the APUSUB computations, sequential control is returned to subroutine CRYCON.

SIGNIFICANT VARIABLES

Significant variables processed in APUSUB are as follows:

NAME	TYPE	I/Ø	DIMENSION	DESCRIPTION
Q4HDØT	R	Ø	20	H2-HEX QDØT for APU-G.G. Feed
QLØD4T	R	Ø	20	Ø2-HEX QDOT for APU-G.G. Feed
WDG	R	Ø	20	Hot Gas Flowrate for H2-HEX-APU
WDJ	R	Ø	20	Hot Gas Flowrate for Ø2-HEX-APU
TGGCH	R	Ø	1	G.G. Exhaust Temp for H2-Cond. HEX
TGGCØ	R	Ø	1	G.G. Exhaust Temp for Ø2-Cond. HEX
Q5HDØT	R	Ø	20	H2-HEX QDØT for H2 Conditioning
Q7ØD4T	R	Ø	20	Ø2-HEX QDØT for Ø2 Conditioning
WGGH	R	Ø	20	Total H2 Flowrate for Conditioning Fluids
WGGØ	R	Ø	20	Total Ø2 Flowrate for Conditioning Fluids
WTGGH	R	Ø	1	Total H2 Wgt For Conditioning Fluids
WTGGØ	R	Ø	1	Total Ø2 Wgt for Conditioning Fluids
VSTØ	R	Ø	1	Volume of Ø2 Storage Tank
VSTH	R	Ø	1	Volume of H2 Storage Tank
AREATØ	R	Ø	1	Surface Area Ø2 Storage Tank
AREATH	R	Ø	1	Surface Area H2 Storage Tank
WPTØT	R	Ø	2	Total Fluid Wgt by Species

NAME	TYPE	I/Ø	DIMENSION	DESCRIPTION
WPTTØ	R	Ø	1	Total Ø2 in Storage Tank
WPTTH	R	Ø	1	Total H2 in Storage Tank
WSRH	R	Ø	1	Wgt of Residual H2 in Tank
WSRØ	R	Ø	1	Wgt Residual Ø2 in Accumulator
WRSAH	R	Ø	1	Wgt Residual H2 in Accumulator
WRSAØ	R	Ø	1	Wgt. Residual Ø2 in Accumulator
TAH	R	I	1	H2 Accumulator Temp
TAØ	R	I	1	Ø2 Accumulator Temp
TSTH	R	I	1	Temp of Stored H2
TSTØ	R	I	1	Temp at Stored Ø2
PSTH	R	I	1	Pressure of Stored H2
PSTØ	R	I	1	Pressure of Stored Ø2
PGG	R	I	1	Gas Generator Pressure - APU
TPF	R	I	1	Prop Temp at Gas. Gen. Inlet - APU
D	R	I	20	Heat in Turbine Exhaust
MRGGCH	R	I	1	H2 Conditioning Gas Gen. Mix. Ratio
MRGGCØ	R	I	1	Ø2 Conditioning Gas Gen. Mix. Ratio
WDRH	R	I	20	H2 Nominal Flowrate
WDRØ	R	I	20	Ø2 Nominal Flowrate
PPDCH	R	I	2	Pump Discharge Pressure
TALSUM	R	I	1	Total Non-Operating Time

SUBPROGRAMS REFERENCED IN APUSUB

NAME	TYPE	PURPOSE	REFERENCE
CSUBP	S	Calc. Cp for Fluid	Page B-88
HYENTH	F	Calc H2 Enthalpy	Page B-193
ØXENTH	F	Calc Ø2 Enthalpy	Page B-238
CSUBP1	S	Calc Cp Exhaust Products	Page B-91
RHØLIQ	S	Calc. Liquid Fluid Densities	Page B-262
GSDNST	S	Calc Gaseous Fluid Densitieis	Page B-219

TC0ND	S	Calc Thermal Conductivity-Insulation	Page B-290
ZFIND	S	Calc Fluid Compressibility	Page B-335
ZGET	S	Calc Fluid Compressibility	Page B-336
0APUSB	S	Output Formatted Data to Printer (APUSUB)	Page B-226

SUBPROGRAMS REFERENCING APUSUB

NAME	TYPE	PURPOSE	REFERENCE
CRYC0N	S	Sequential Control of Analysis	Page B-85

LISTING REFERENCE PAGE

The APUSUB listing will be found in Appendix B, Page 8

FLOW CHART

A flow chart for APUSUB is presented in Figure 1.9-2.

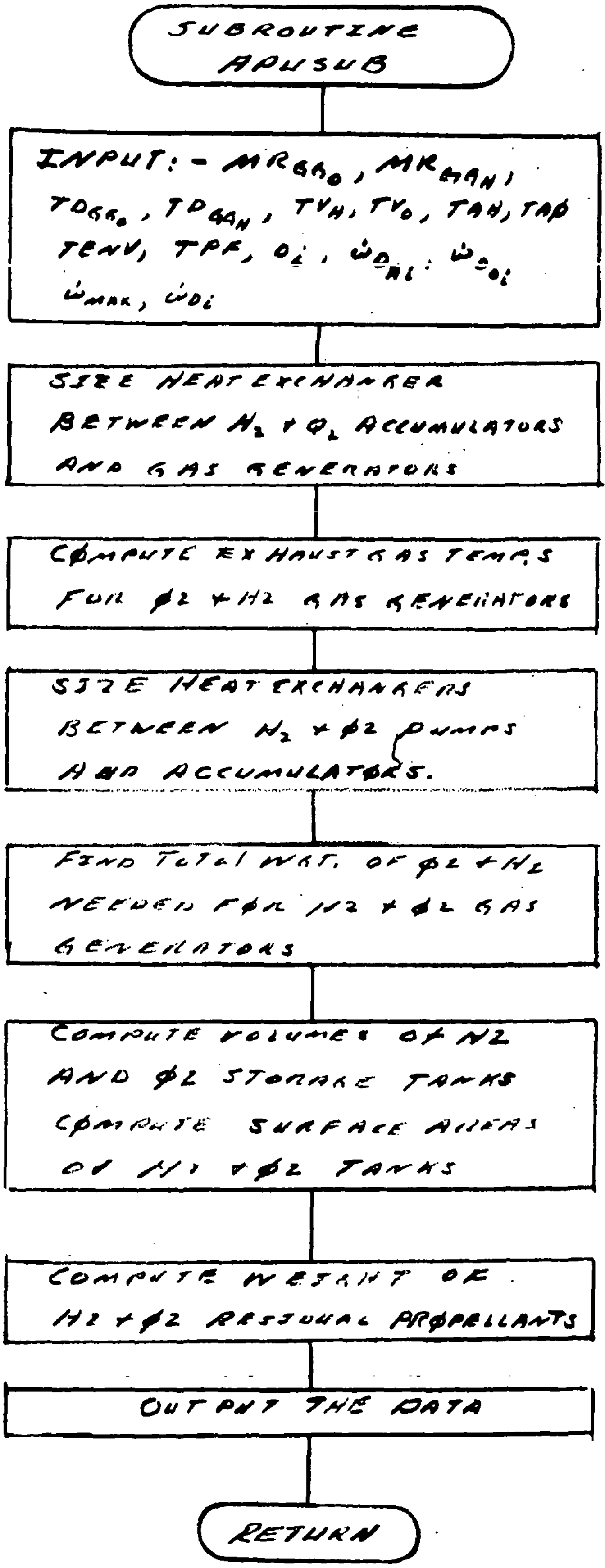


FIG. 1.9-2 APUSUB FLOW CHART

SUBROUTINE APUSUP

DESCRIPTION

This subroutine contains the necessary equations and computational procedures required to accomplish an APU super-critical system analysis. The subroutine follows procedures setup in a logical math model sequence to permit computation of the pertinent super-critical system parameters required for this analysis. The calculated values are presented in formatted print output for the analytical considerations. The following are the principle computations presented in the subroutine:

(a) Sizes Heat Exchangers located between fluid gas accumulators and APU gas generator.
(b) Determines initial fluid tank temperatures.
(c) Computes percent usable fluids withdrawn from tanks for all duty cycle intervals.
(d) Computes fluid densities as function of % withdrawn for all duty cycle intervals.
(e) Computes fluid temperatues in tanks for all duty cycle intervals.
(f) Computes specific heat input (THETA) of fluids in tanks for all duty cycle intervals.
(g) Computes required flow rate of exhaust gases and sizes heat exchangers located between the fluid tanks and accumulators.
(h) Computes energy derivative (PHI) for fluids in tanks as for all duty cycle intervals.
(i) Tests adequacy of APU turbine exhaust products for conditioning of fluids:

    (1) If adequate - subprogram proceeds to (j).
    (2) If inadequate - subprogram computes supplemental heat required and readjusts all fluid flows to compensate for additional fluids required to run supplemental gas generator for extra energy requirements. Subprogram computes corrected total Ø2 and H2 flowrates to the accumulators, and computes the total Enthalpy increment supplied by the supplementary gas generator.
    (3) If subprogram cannot provide sufficient energy from a supplementary gas generator to makeup for the deficiency in APU exhaust heat it will automatically recycle the program and reset the APU fuel mixture ratio as follows: FMR = FMR + 0.1

- (j) Computes the weight at the fluid tank heater circulating compressor (pump) and the maximum fluid flowrate the compressor must handle.
- (k) Computes the fluid tank venting requirements and quantity of fluids vented.
- (l) Computes volume, surface area, diameter and weight of fluid tanks.
- (m) Computes weight of fluid residuals in tank at end of mission.
- (n) Computes weight of fluid accumulators and weight of fluid residuals in accumulators.
- (o) Sums total fluid requirement for mission.
- (p) Presents pertinent data for analysis in formatted output.
- (q) Computes weight and pertinent characteristics of all heat exchangers and heat sources in the system and presents data in formatted output.
- (r) Returns sequential control to subroutine CRYCØN, which calls subroutine CMPCAL to compute system configuration component weights and pressure drop data.

Input data for APUSUP has previously been read in by subroutine CØMPIL. This data along with information generated by subroute APUFLØ are stored for use in labeled common storage areas defined by a set of Procedure Definition Processor elements. The labeled commons used for data transfer by APUSUP are:

```
CØMMØN/CACCUM/
CØMMØN/CIAPU/
CØMMØN/CVAPU/
CØMMØN/CDCYCL/
CØMMØN/CIFUEL/
CØMMØN/CUFUEL/
CØMMØN/CHEX/
CØMMØN/CMATRL/
CØMMØN/CONST/
CØMMØN/CPUMP/
CØMMØN/CTANK/
CØMMØN/TABLØK/
```

APUSUP MATHEMATICAL MODEL

The equations, mathematical procedures, necessary tables and constants required for the APU super-critical analysis are presented in Appendix C.

CALLING SEQUENCE

APUSUP is called from subroutine CRYCØN with no calling variables. Data transfer to APUSUP is accomplished through INCLUDE statements as shown in the rubroutine listing. Upon completion of APUSUP computations, sequential control is returned to subroutine CRYCØN.

SIGNIFICANT VARIABLES

Significant variables processed in APUSUP are as follows:

NAME	TYPE	I/Ø	DIMENSION	DESCRIPTION
QIHDØT	R	Ø	20	H2-Hex QDØT for APU-Gas Gen. Feed
WDA	R	Ø	20	Hot Gas Flow Rate in H2 HEX for APU-GG
Q1ØDØT	R	Ø	20	Ø2-HEX QDØT for APU - Gas Gen. Feed
WDD	R	Ø	20	Hot Gas Flow Rate in Ø2-HEX for APU-GG
TEMPØ2	R	Ø	1	Initial Temp. In Ø2-Tank
TEMPH2	R	Ø	1	Initial Temp. In H2-Tank
PCH2WD	R	Ø	20	Percent H2 withdrawn Each Duty Cycle
PCØ2WD	R	Ø	20	Percent Ø2 Withdrawn Each Duty Cycle
RHØCØ2	R	Ø	20	Ø2 Density f(% WD, Press) Each Duty Cycle
RHØCH2	R	Ø	20	H2 Density f(% WD, Press) Each Duty Cycle
TTH	R	Ø	20	H2 Tank Temp f (% WD, Pres) Each Duty Cycle
TTØ	R	Ø	20	Ø2 Tank Temp f (% WD, Pres) Each Duty Cycle
DQØDWH	R	Ø	20	Spec Heat Input - H2 as f (DENS, Pres.)
DQØDWØ	R	Ø	20	Spec Heat Input - Ø2 as f (DENS, Temp)
Q2ØDØT	R	Ø	20	H2-HEX QDØT for H2 conditioning
WDB	R	Ø	20	H2 Conditioning Hot Gas Flow Rate
Q2HDØT	R	Ø	20	Ø2-HEX QdØT for Ø2 Tank Conditioning
WDE	R	Ø	20	Ø2-Conditioning Hot Gas Flowrate
Q3HDØT	R	Ø	20	H2-HEX QDØT for H2 Tank Conditioning
WDC	R	Ø	20	H2-Tank Conditioning Hot Gas Flow Rate
Q3ØDØT	R	Ø	20	Ø2-HEX QDØT for Ø2 Tank Conditioning
WDF	R	Ø	20	Ø2 Tank Conditioning Hot Gas Flowrate
PHIØ2	R	Ø	20	Energy Derivative for Stored Ø2
PHIH2	R	Ø	20	Energy Derivative for Stored H2
WSUM	R	Ø	20	Summed Hot Gas Flowrates - Each Duty Cycle

NAME	TYPE	I/O	DIMENSION	DESCRIPTION
DWDB	R	0	20	Change in WDB Required to Balance Hot Gas Available
WGHC	R	0	20	Corr. H2 Flowrate Accounting for Suppl. Gas Gen.
WG0C	R	0	20	Corr 02 Flowrate accounting for Suppl. Gas Gen.
WD	R	0	20	Total Fluid (02 + H2) flowrate each Duty Cycle
WGH	R	0	20	Reference H2 Flowrate to Suppl. Gas. Gen.
WDBC	R	0	20	Corr. Hot Gas Flowrate for H2 Conditioning
WDCC	R	0	20	Corr. Hot Gas Flowrate for H2 Tank Cond.
WDEC	R	0	20	Corr. Hot Gas Flow Rate for 02 Conditioning
WDFC	R	0	20	Corr. Hot Gas Flowrate for 02 Tank Cond.
WT0	R	0	20	Corr. Total 02 Flow to Accumulator Each Duty Cycle
WTH	R	0	20	Corr. Total H2 Flow to Accumulator Each Duty Cycle
DELH	R	0	20	Enthalpy Increment Supplied by Suppl. Gas Gen.
Q2HDTC	R	0	20	Corr. QD0T in H2-HEX for H2 Conditioning
Q20DTC	R	0	20	Corr. QD0T in H2-HEX for 02 Conditioning
Q3HDTC	R	0	20	Corr. QD0T in H2-Tank HEX for Tank Cond.
Q30DTC	R	0	20	Corr. QD0T in 02-Tank HEX for Tank Cond.
TSIN	R	0	20	Suppl HEX Fluid Inlet Temperature
FMR	R	I	1	APU Fuel Mixture Ratio
LREPT	I	0	1	Subprogram Recycling Index
DQWMX0	R	0	1	02 Max. Spec. Heat Input Value
DQWMXH	R	0		H2 Max. Spec. Heat Input Value
W0MAX	R	0	1	02 Max. Flowrate to Accumulator
WHMAX	R	0	1	H2 Max. Flowrate to Accumulator
QMXTK0	R	0	1	Heat (BTU's) into 02 Tank at Max 02 Flow Rate
QMXFKH	R	0	1	Heat (BTU's) into H2 Tank at Max H2 flow Rate
RH0HF	R	0	1	Final H2 Density in H2 Tank
RH00F	R	0	1	Final 02 Density in 02 Tank
WDTCP0	R	0	1	02 Tank Circulating Compressor Flowrate Reqd

NAME	TYPE	I/O	DIMENSION	DESCRIPTION
WDTCPH	R	0	1	H2 Tank Circulating Compressor Flowrate Re
WCIRCP	R	0	2	Wgt of H2 or 02 Circulating Compressor
WTGH	R	0	1	Wgt H2 Reqd for Suppl Gas Generator
WTG0	R	0	1	Wgt 02 Reqd for Suppl Gas Generator
VTH	R	0	1	Wgt 02 Reqd for Suppl Gas Generator
VTH	R	0	1	Volume of H2 Tank
VT0	R	0	1	Volume of Q2 Tank
ATH	R	0	1	Surface Area of H2 Tank
AT0	R	0	1	Surface Area of 02 Tank
WV1H0	R	0	1	Wgt Vented H2 to Cool 02 Tank
WV1HH	R	0	1	Wgt Vented H2 to Cool H2 Tank
WVH	R	0	1	Weight of Vented H2
SMDIAM	R	0	2	Diameter of 02 or H2 Storage Tank
WGTHT	R	0	1	Weight of H2 Storage Tank
WGT0T	R	0	1	Weight of 02 Storage Tank
WRH	R	0	1	Wgt Residual H2 in H2 Storage Tank
WR0	R	0	1	Wgt Residual 02 in 02 Storage Tank
WAH	R	0	1	Wgt of H2 Accumulator
WA0	R	0	1	Wgt of 02 Accumulator
WRAH	R	0	1	Wgt of H2 Accmulator Residuals
WRA0	R	0	1	Wgt of 02 Accumulator Residuals
WPT0T	R	0	2	Total Weight of H2 or 02 Fluid
WHT0T	R	0	1	Total H2 Fluid Weight
W0T0T	R	0	1	Total 02 Fluid Weight
WHXT0T	R	0	10,2	Heat Exchanger Weight
HXCODE	R	I	10,2	Heat Exchanger I.D. Code
WD0MAX	R	0	1	02 Max. Flowrate to APU
WDHMAX	R	0	1	H2 Max. Flowrate to APU
TE	R	0	20	Temp of APU Exhaust Gases
TD	R	I	1	Temp of Hex Hot Gas Discharge
PGG	R	I	1	Pressure out of APU Gas Generator
TSINMN	R	0	1	Minimum Inlet Temp to Suppl Gas Gen.
APRES	R	I	2	Accumulator Operating Pressure
WTHMAX	R	0	1	Max. Corr. H2 Flow through H2 Cond. HEX
WT0MAX	R	0	1	Max. Corr. 02 Flow through 02 Cond. HEX

NAME	TYPE	I/O	DIMENSION	DESCRIPTION
PC0	R	I	1	Pressure of Conditioned 02
PCH	R	I	1	Pressure of Conditioned H2
HXCDLP	R	I	10,2	Cold Fluid Pressure Drop in HEX
DELPCP	R	I	1	Circulating Compressor Pressure Rise

SUBPROGRAMS REFERENCED IN APUSUP

NAME	TYPE	PURPOSE	REFERENCE
HYENTH	F	Calc. H2 Enthalpy	Page B-193
0XENTH	F	Calc. 02 Enthaly	Page B-238
FINTAB	S	Table Lookup	Page B-147
MIPE	F	Table Data Extraction	Page B-221
CSUBV	F	Calc. Cy For Fluid	Page B-93
ZFIND	S	Calc. Compressibility at Fluid	Page B-335
ZGET	F	Calc. Compresibility at Fluid	Page B-336
PHTH0N	S	Calc. THETA For Fluid	Page B-249
PHTH0N	S	Cal. PHI for Fluid	Page B-249
CSUBP1	S	Calc. Cp for Exhaust Products	Page B-91
CSUBP	S	Calc. Cp for Fluid	Page B-88
AMAXI	F	Finds Max. Value of 2 Values	System Routine
DENS0N	S	Calc. Density of 02 or N2	Page B-108
FINDR	F	Finds Fluid Gas Constant	Page B-140
CBRT	F	Calc. Cube Root of Value	System Routine
TC0ND	S	Calc. Thermal Conductivity for Insulation	Page B-290
SQRT	F	Calc. Square Root of Value	System Routine
0APUSP	S	Output S.R. for APUSUP	Page B-226
HEATEX	S	Calc. HEX Weight and Characteristics	Page B-177
GASGEN	S	Calc. Gas Gen Weight and Characteristics	Page B-172
AMINI	F	Find Min. Value of 2 values	System Routine
0PTHEX	S	Output S.R. for HEX and Gas. Gen. Data	Page B-226

SUBPROGRAMS REFERENCING APUSUP

NAME	TYPE	PURPOSE	REFERENCE
CRYCØN	S	Sequential Control of Analysis	Page B-85

LISTING REFERENCE PAGE

The APUSUP listing will be found in Appendix B, Page 12.

FLOW CHART

A flow chart for APUSUP is presented in Figure 1.9-3.

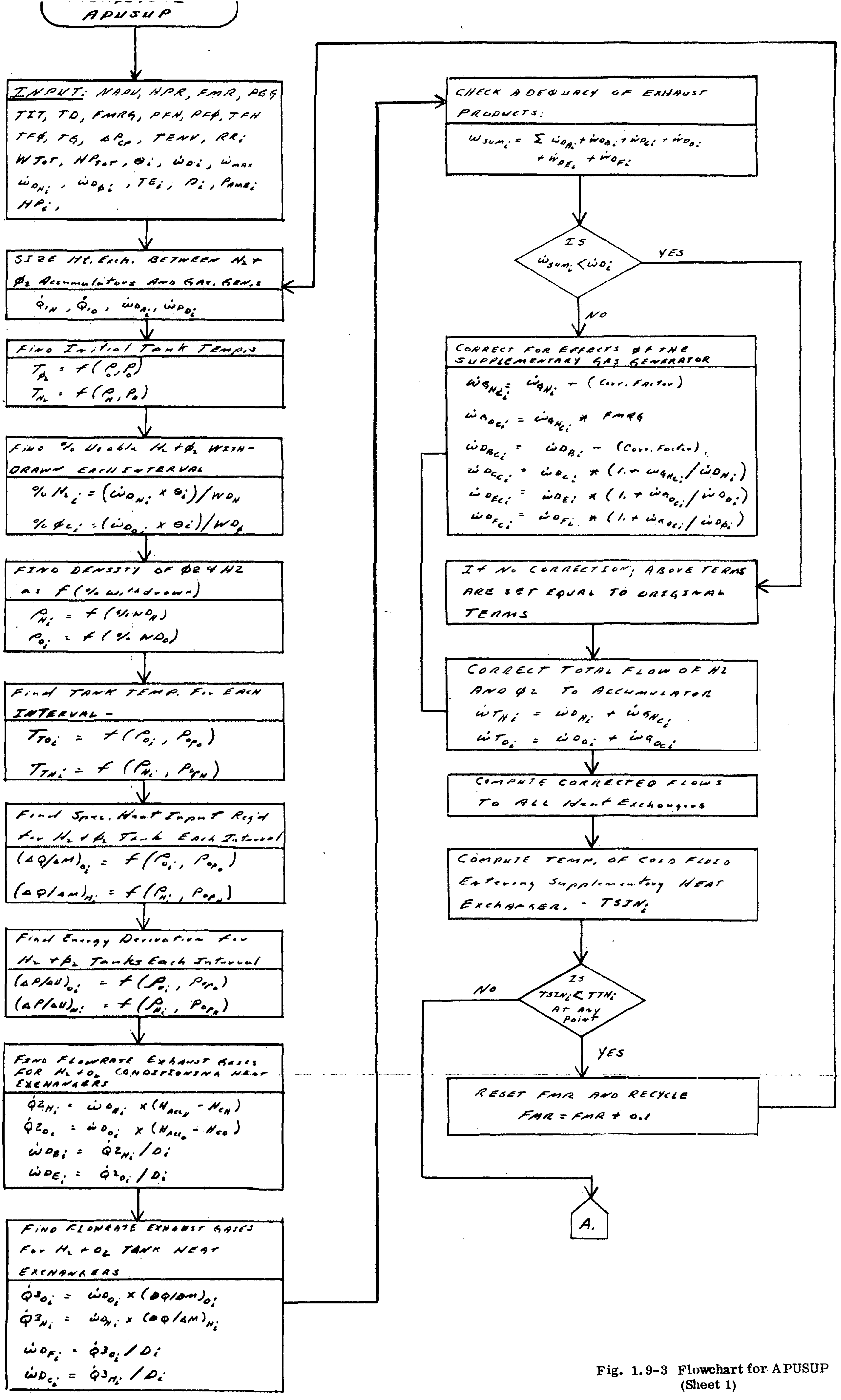


Fig. 1.9-3 Flowchart for APUSUP (Sheet 1)

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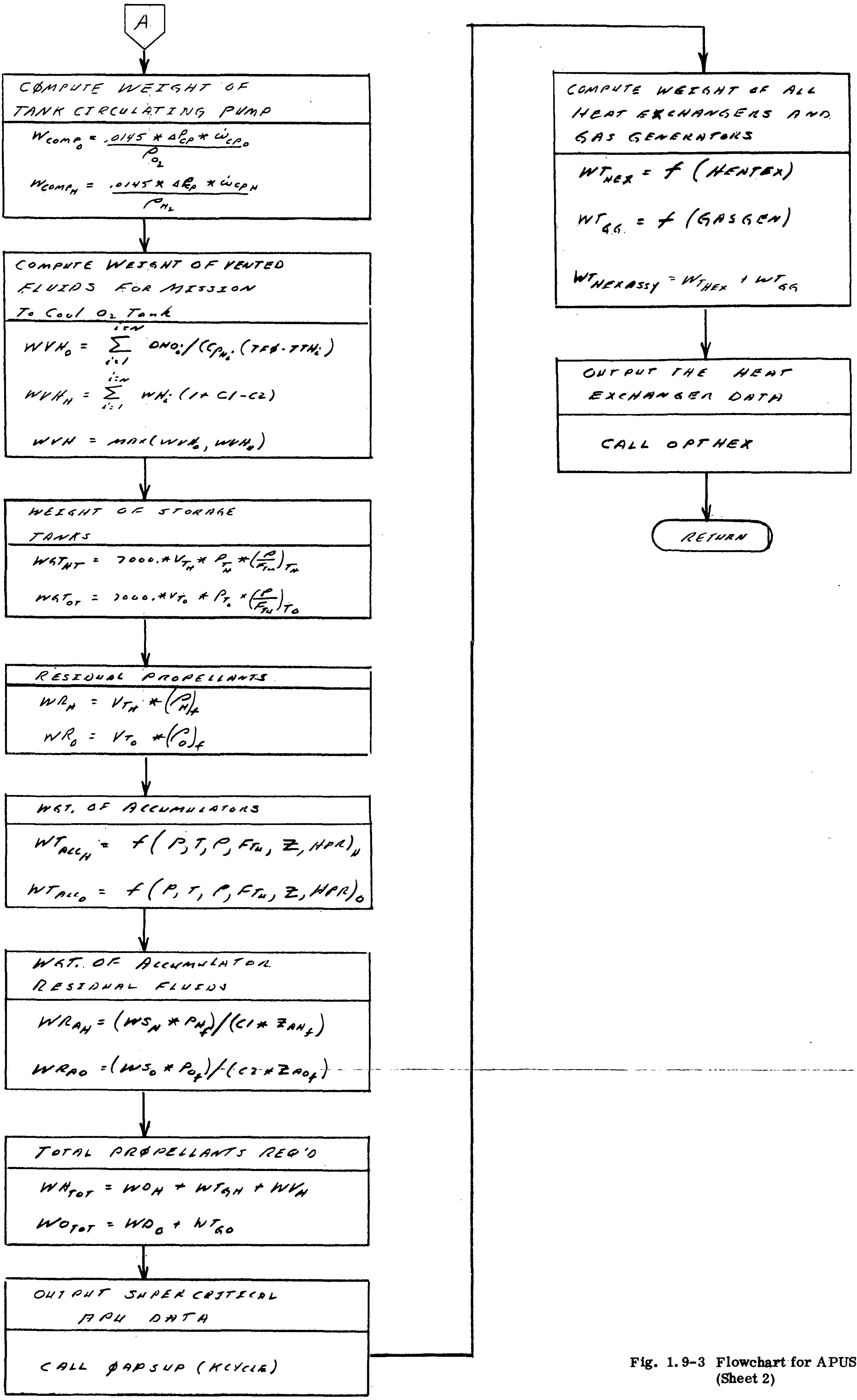

Fig. 1.9-3 Flowchart for APUSUP
(Sheet 2)

FUNCTI0N ARACYL

For a description of ARACYL see the writeup for "G0MTRY." Page B-175

FUNCTI0N AREAFR

For a description of AREAFR see the writeup for "G0MTRY." Page B-175

FUNCTI0N ARSPHR

For a description of ARSPHR see the writeup for "G0MTRY." Page B-175

FUNCTION ROUTINE CFTW

DESCRIPTION

The routine contains the equation for computation of weights for control devices such as pressure regulators, flow valves, check valves and pressure relief valves. The equations employed were developed from empirical data files assembled by AiResearch Mfg Company (Reference 1.9-1) covering a wide range of sizes and types of fluid handling devices. The data were reduced to a set of general curves from which the reference equations were developed. The control devices were categorized by the designations light, medium, heavy and extra heavy, based primarily upon the pressure range in which the devices are designed to operate.

The derived equations are based upon the weight being a function of the diameter cubed $(WT = f(D^3))$ for devices larger than 1 in. diameter, and the weight being a function of the diameter to the first power $(WT = f(D))$ for devices having a flow diameter of 1 in. and smaller. The general form of the equations are respectively:

$$WT = K(D^3) + C$$

and

$$WT = K(D) + C$$

where K and C are constants based upon actual device weights.

The constants developed from the Airesearch data and the categories to which they apply are as follows:

A. Flow Control Devices Larger Than One Inch:

Category	Pressure Range			
	$P_1 < 400$ psia		$P_1 > 1000$ psia*	
	K_1	C_1	K_2	C_2
Light	0.040	1.75	0.057	3.95
Medium	0.057	3.95	0.073	5.73
Heavy	0.073	5.73	0.090	8.91
Extra Heavy	0.090	8.91	0.107	12.35

*(Diameters less than 3.5 inches.)

B. Flow Control Devices Smaller Than One Inch:

Category	Pressure Range			
	$P_1 < 1000$ psia		$P_1 > 1000$ psia	
	K_3	C_3	K_4	C_4
Light	1.0	0.8	2.5	1.5
Medium	2.5	1.5	3.3	2.5
Heavy	3.3	2.5	5.5	3.5
Extra Heavy	5.5	3.5	7.7	4.5

The weight categories are defined to include the following flow control devices:

Category		Includes
Light	–	Check valves, quick disconnects of poppet and flapper types, and orifice assemblies.
Medium	–	Butterfly and poppet type, modulation, shutoff, fill, vent and isolation valves.
Heavy	–	Butterfly and poppet type, pressure regulators, flow controls, pressure relief and mixer values.
Extra Heavy	–	Solenoid butterfly type valves, solenoid poppet type valves, solenoid actuated ball valves.

The function routine is self-contained with the necessary input variables being brought in via the calling statement:

WGT = CFTW(D,P,IDV)

where

D = inlet port diameter (inches)
P = fluid inlet pressure (psia)
IDV = flow device category index (Reference PDP-CCNTRL)

All required constants and dimensioned variables are self-contained in the routine.

CFTW MATHMATICAL MODEL

No model is presented. Referenced data curves are to be found in Reference 1.9-1.

CALLING SEQUENCE

Function CFTW is called, with its specified input variables, each time the computations involve a flow control device, from subroutines CMPCAL and LSSCMP. Upon execution of the required computation program control returns to the calling subroutine.

SIGNIFICANT VARIABLES

Significant variables are as follows:

D – Inlet Port Diameter (inches)
P – Inlet Pressure (psia)
IDV – Category Index (see PDP-CCNTRL)
CFTW – Flow Control Device Weight (lb)

SUBPROGRAMS REFERENCED IN CFTW

None referenced.

SUBPROGRAMS REFERENCING CFTW

Name	Type	Purpose
CMPCAL	S	Component Weights, Pressure Drops and Flow Conditions
LSSCMP	S	Component Weights, Pressure Drops and Flow Conditions

LISTING REFERENCE PAGE

A listing of Function CFTW will be found in Appendix B, page 39.

FLOW CHART

None

SUBROUTINE CMPCAL

DESCRIPTION

The subroutine CMPCAL is designed to perform sizing and weight analysis for all of the component units which makeup the system configuration. The system configuration being defined as the computer image of the system main flow schematic diagram wherein all compoents and line segments are arranged in the normal logical sequence. The subroutine requires that each system or subsystem fluid segment begin with a data entry which flags the fluid kind and state and further requires that when a fluid state changes (i. e., gas to liquid), a second data entry must be available.

The subroutine currently will process systems which employ 02 and H2 as the cryogen fluids. The logic employed requires that the configuration data be entered starting with the cryogen consumer and working back to the fluid storage tanks, thus permitting the accumulation of pressure drop data in an orderly fashion.

Subroutine CMPCAL is normally employed for the evaluation of a two fluid system and normally processes the oxidizer side of the system fluid, followed by the fuel side. It can, however, process either side, or, just one side, depending upon the setting of the input fluid flag variables. The program calls-in required sub-programs as needed for the sizing and weighing of the individual components and line segments as they are encountered in the configuration sequence. The CMPCAL analysis procedure is based upon accomplishing a one-by-one analysis of the sequential component stream defined by the configuration table as read-in by subroutine C0MPIL. Based upon the input data, the subroutine accomplishes the computation of the individual component sizing, weight, pressure drop and flow constraint data and presents the calculated values in tabular formatted output as a "Summary of Computed System Configuration Parameters."

The principal computations accomplished in subroutine CMPCAL are as follows:

(a) Upon being called, the subroutine first initializes a set of flag and summation variables. It starts the configuration loop by calling for the decoding of first branching variable as entered in the first configuration data card. The primary branching control variables employed are CFUNCT and CFTYPE as defined in subroutine CØMPIL and PDP-CONFIG. The branching variable CFUNCT contains the coding for (in successive data entries), the fluid identification, consumer identification and, in turn, each component unit sequentially considered in the system. The secondary branching control variable CFTYPE successively contains the coding for, the fluid state, the consumer characteristic type, and, in turn, the controlling characteristics of each component unit sequentially considered in the system. Subroutine branching to the specified analysis region of the coding is accomplished via a computed GØ TØ statement, controlled by the variable CFUNCT.

(b) The subroutine identifies the fluid to be considered and identifies its state condition and then initializes the sequential indices.

(c) Identifies the cryogen consumer and sets up the consumer fluid flowrate, fluid pressure and fluid temperature with their respective sequential indices. At this point the actual configuration analysis has begun.

(d) The subroutine then processes a line segment (whenever called for by CFUNCT) through the sequence of the line analysis to compute - flow conditions, pressure drop and line weight. Fano-flow, compressible-flow, velocity effects, as well as minimum wall thickness are all taken into consideration in the analysis.

(e) Processes a control unit (valve, check valve, orifice, regulator, or flowmeter) through the sequence of the control analysis to compute flow conditions, pressure drop, and control weight. Mass characteristics as a function of pressure requirements for the control unit are specified in the "tens" digit of CFTYPE. Selection of the type of control unit is made via the "units" digit of CFTYPE, as defined in PDP-CCNFIG.

(f) The subroutine processes a fitting or tap in much the same fashion as for the line segment analysis, taking into account the flow geometry effects. Computes the flow conditions, pressure drop and fitting or tap weight.

(g) If the system requires an accumulator, the subroutine sets up the accumulator pressure, temperature and flowrate. The accumulator weight is computed separately by subroutine WTACC which has its own output, therefore the weight of the accumulator is not reported by CMPCAL.

(h) Processes a heat exchanger, sets up the fluid conditions, inlet and outlet cold fluid temperatures and pressures and heat source mixture ratios; then calls subroutine HEATEX to essentially design the heat exchanger and calculate pressure drop, hot fluid flowrates, and heat exchanger weight. If the heat source is a gas generator, CMPCAL calls subroutine GASGEN to size and weigh the unit. If the heat source is waste heat from another unit, the heat source characteristics are calculated elsewhere.

(i) If the system requires a high pressure pump, the subroutine searches ahead to locate the fluid tank and then works backwards to the pump, so as to provide both inlet and outlet pump pressures. The subroutine then calls subroutine PARPMP to essentially design the pump and permit computation of flow conditions, pressure drop and pump weight. The subroutine checks PTYPE and if the assembly is a turbopump, it calls TURBN to essentially design a turbine and compute the turbine hot gas requirements and turbine weight. The subroutine then computes the turbine gas flow rates and then sizes a gas generator to fit it and computes a gas generator weight. The pump, turbine and gas generator weights are summed to yield a weight for the complete assembly.

(j) If the system requires a low-pressure pump, the subroutine searches ahead to locate the fluid storage tank and then works backward to the pump, so as to permit the calculation of both inlet and outlet pump pressures. The subroutine then computes the low pressure pump weight (via table lookup) and procedes to look up a weight for an electric motor to drive the pump. The weights are summed to yield a combined motor-pump assembly weight.

(k) The subroutine then processes a fluid supply tank, first setting up the tank temperature and pressure. The actual tank weight for each fluid tank is calculated elsewhere either within a given system sub-program (i.e.,FUELCL) for which subroutine CMPCAL simple retrieves the weight value from storage, or, the tank weight may be calculated in subroutine TANK, in which case CMPCAL simple records the tank weight as zero and the weight and tank dimensions are found in the TANK output. CMPCAL does check to see if the tank pressure is adequate for the system pressure drop total at the tank outlet.

(l) CMPCAL then outputs the computed configuration component data in a tabular formatted output with all components identified and in the same sequence as given in the original system schematic.

Input data for use in subroutine CMPCAL is read-in at program initiation time via subroutine C0MPIL from the configuration data cards. Data from each card is stored in a packed array by subroutine ST0C0N using equivalenced array variables defined in the Procedure Definition Processor CCNFIG. Retrieval of the data is accomplished in CMPCAL via repeated calls to subroutine GETC0N which unpacks the data as needed.

The input data and computed parameter values are stored in various regions of the labeled C0MM0N storage defined by PDP elements. The labeled common storage employed by subroutine CMPCAL are as follows:

C0MM0N/CCACUM/
C0MM0N/CCNFIG/
C0MM0N/CCNTRL/
C0MM0N/CDCYCL/
C0MM0N/CENG/
C0MM0N/CHEX/
C0MM0N/CIFUEL/
C0MM0N/CVFUEL/
C0MM0N/CHS0RC/
C0MM0N/CI0UNT/
C0MM0N/CNAMES/
C0MM0N/CM0T0R/
C0MM0N/C0NST/
C0MM0N/CPAGE/
C0MM0N/CPUMP/
C0MM0N/CTANK/
C0MM0N/CTURBN/
C0MM0N/TABLOK/

CMPCAL MATHEMATICAL MODEL

The math model for subroutine CMPCAL presenting the equations, math logic, and procedures are presented in Appendix C.

CALLING SEQUENCE

Subroutine CMPCAL is initiated by a simple call statement with no calling variables from subroutine CRYCØN. The order in which CMPCAL is called relative to system analysis sub-programs is determined by the DATA statements labeled KSUBC found in subroutine STØDTA.

Data transfer to and from subroutine CMPCAL is effected through the use of INCLUDE statements which bring in the appropriate PDP element defining the required labeled CØMMØN storage areas. Upon completion of the CMPCAL computations, the program control returns to subroutine CRYCØN.

SIGNIFICANT VARIABLES

Significant variables employed in, and processed by, subroutine CMPCAL are defined in the following list:

NAME	TYPE	I/Ø	DIMENSION	DESCRIPTION
ICNF	I	I	1	Number of configuration data cards input
IDX	I	Ø	1	Configuration item index
ISIGN	I	Ø	1	Analysis directional index
CFUNCT	I	I	1	Integer Corresponding to Configuration Item Function
CFTYPE	I	I	1	Integer Corresponding to FunctionType
CMTYPE	I	I	1	Integer Corresponding to Material Type
CITYPE	I	I	1	Integer Corresponding to Insulation Type
CNOPER	I	I	1	Number of units operating
CNSTBY	I	I	1	Number of units on standby
FRCOEF	R	I	100	Characteristic Friction Factor for Flow Region
LØD	R	I	100	Length over Diameter, or, Length
DIAM	R	I	100	Diameter
ITHIK	R	I	100	Insulation Thickness
NBAR	R	I	100	Number of Layers of insulation per inch
CØDE	R	I	100	Identification Code for Config. Unit

NAME	TYPE	I/0	DIMENSION	DESCRIPTION
IGAS	I	I	1	Integer Corresponding to Fluid Kind
GSTATE	I	I	1	Integer Corresponding to Fluid State
PRES	R	0	100	Fluid Peessue at Each Point in System
TEMP	R	0	100	Fluid Temp at each point in System
WD0TN	R	0	100	Fluid Flowrate at each print in system
WD0TI	R	I	2	Input Fluid Max. Flow Rate at Consumer
PLSN0M	R	I	2	Input Fluid Pressure at Consumer
TLSN0M	R	I	2	Input Fluid Temperature at Consumer
FLD	R	0	1	$\frac{fL}{D}$ for Configuration Unit Considered
IDV	I	I	1	Integer Pointer for Control Mass Characteristic
LDV	I	I	1	Integer Pointer for Fitting and Tap Configuration
RH0	R	0	1	Fluid Density when a gas
DELP	R	0	1	Fluid Pressure Drop across Component
A	R	0	1	Cross Sectional Area of Flow Region
WEIGHT	R	0	1	Weight of Configuration Component Considered
APRES	R	I	2	Accumulator Pressure (if used)
INDXAC	I	0	2	Accumulator Index (if used)
INDXTK	I	0	2	Fluid Tank Index-Set to IDX
SIPRES	R	I	2, 1	Fluid Tank Initial Pressure
SITEMP	R	I	2, 1	Fluid Tank Initial Temperature
WTTOT	R	I	2	Fluid Tank Weight
WDOTCF	R	I	10, 2	Fluid Heat Exhanger Flow Rate
UC0DE	R	I	12, 2	Fluid Heat Exchanger I.D. Code
HEXCIT	R	I	10, 2	Fluid Heat Exchanger Cold Inlet Temp
HXCDLP	R	I	10, 2	Fluid Heat Exchanger Delta-P
WHXT0T	R	I	10, 2	Fluid Heat Exchanger Weight
MACH	R	0	100	Fluid Mach No.
MFLG	I	0	100	Fluid Mach No. Flag
J0PTN	I	I	1	Option for Minimum Wgt or Minimum Power Pump
PTEMP	R	0	2	Pump Fluid Inlet Temperature
PPRES	R	0	2	Pump Fluid Inlet Pressure
PPDCH	R	0	2	Pump Fluid Outlet Pressure
PPDEL	R	0	2	Pump DELTA-P (each fluid)
PPWDT	R	0	2	Pump Flow Rate (each fluid)
PPRH0	R	0	2	Pump Inlet Fluid Density
PNPSH	R	I	2	Pump NPSH for Each Fluid

NAME	TYPE	I/O	DIMENSION	DESCRIPTION
PMPEFF	R	0	2	Calculated Pump Efficiency (each fluid)
PMPV0L	R	0	2	Calculated Pump Volume (each fluid)
PMP0W	R	0	2	Calculated Pump Power (each fluid)
PSPD	R	0	2	Calculated Pump Speed (each fluid)
PSTAGE	R	0	2	Calc. Number Pump Stages (each fluid)
PNPSPR	R	0	2	Calc. NPSP Required (each fluid)
PWEGHT	R	0	2	Calculated Pump Weight (each fluid)
TWEGHT	R	0	2	Calculated Turbine Weight (each fluid)
TITEMP	R	I	2	Turbine Inlet Temperature (each fluid)
T0TEMP	R	I	2	Turbine Outlet Temperature (each fluid)
TMRAT0	R	I	2	Turbine Gas. Gen. Mixture Ratio (each fluid)
GWEGHT	R	0	2	Fluids Required to Run Turbine Gas Generator
WGTGGA	R	0	2	Weight of Gas Generator Assy (Each fluid)
TPDELP	R	I/0	2	Transfer Pump Delta-P (each fluid)
TPEFF	R	I	2	Transfer Pump Efficiency (each fluid)
TPNPSH	R	I	2	Transfer Pump NPSH (each fluid)
TPWD0T	R	I/0	2	Transfer Pump Flow Rate (each fluid)
TPWGHT	R	0	2	Transfer Pump Weight (each fluid)
HP	R	0	1	Calc Horse Power for Electric Motor
MSS	R	I	1	Input Motor Speed
MTYPE	I	I	1	Input Motor Type
PDNSTY	R	I	1	Battery Power Density
EMWGT	R	0	1	Electric Motor Weight
BWEGHT	R	0	1	Battery Weight
WCIRCP	R	0	2	Weight Fluid Circulating Pumps
WTT0T	R	I	2	Fluid Tank Weights (from Tank, etc)
WD0TCF	R	I	10, 2	Cold Fluid Flowrate - Heat Exchangers
UC0DE	R	I	10, 2	Heat Exchanger I.D. Code
HXC0DE	R	I	10, 2	Input Heat Exchanger I.D. Code
HXCIT	R	I	10, 2	Fluid Heat Exchanger Cold Inlet Temp
HXCDLP	R	I	10, 2	Fluid Heat Exchanger - Delta P
WHXT0T	R	0	10, 2	Fluid Heat Exchanger Weight
MACH	R	0	100	Fluid Mach Number
MFLG	I	0	100	Fluid Mach Number Flag

SUBPROGRAMS REFERENCED IN CMPCAL

NAME	TYPE	PURPOSE	REFERENCE
PAGE	F	Controls Pagination and Line Count	Page B-239
GETC0N	S	Unpacks Configuration Data Records	Page B-174
AMINI	F	Finds minimum of Two Real Values	System Library
GSDNST	S	Computes Density of Desired Gaseous Fluid at Stated Conditions	Page B-219
C0MFL0	S	Solves Compressible Flow Equations for Desired Gaseous Fluid at Stated Conditions for Pressure Drop and Mach Number	Page B-62
RH0LIQ	S	Computes Density of Desired Liquid Fluid at Stated Conditions	Page B-262
VGVS	S	Computes Mach Number for Desired Fluid at Stated Fluid Density using Velocity of Sound Equations	Page B-322
LWEGHT	S	Computes Weight of a Line Segment Considering Minimum Wall Thicknesses	Page B-215
CFTW	F	Computes weight of a Control Unit, Fitting, or Tap as specified	Page B-39
EXIT	S	Causes Program Termination - Used to Terminate from Error Condition	System Library
ABS	F	Computes Absolute Value of defined variable	System Library
PARPMP	S	Computes Weight and Characteristic Properties of a Pump--given Fluid, Delta P, Flowrate, Fluid Density and Estimated Net Position Suction Pressure	Page B-242
TURBN	S	Computes Turbine Weight given Fluid and Pump Characteristics	Page B-314
CSUBP1	S	Computes Cp for 02-H2 Combusion Products, given Temperature and Mixture Ratio	Page B-91
FINTAB	S	Table Location and Look-up	Page B-147
MIPE	F	Table Data Extraction	Page B-221
HEATEX	S	Computes Heat Exchanger Weight and Characteristic Properties give luid, HEX index, Flowrate, Inlet and Output Temperature and Pressures and Hot Gas Mixture Ratio	Page B-177
0TPPMP	S	Outputs Pump Data in Present Format	Page B-226
0TPTRB	S	Outputs Turbine Data in Preset Format	Page B-226

DATA TABLES REFERENCED IN CMPCAL

TABLE NUMBER	TITLE
13	Gas Generator Weight
14	L02 Transfer Pump Weight
15	LH2 Transfer Pump Weight
16	Motor Weight

SUBPROGRAMS REFERENCING CMPCAL

NAME	TYPE	PURPOSE	REFERENCE
CRYC0N	S	Sequential Control of Program Analysis	Page B-85

LISTING REFERENCE PAGE

The subroutine CMPCAL Listing will be found in Appendix B, Page 50.

FLOW CHART

A flow chart for subroutine CMPAL is presented in Figure 1.9-4.

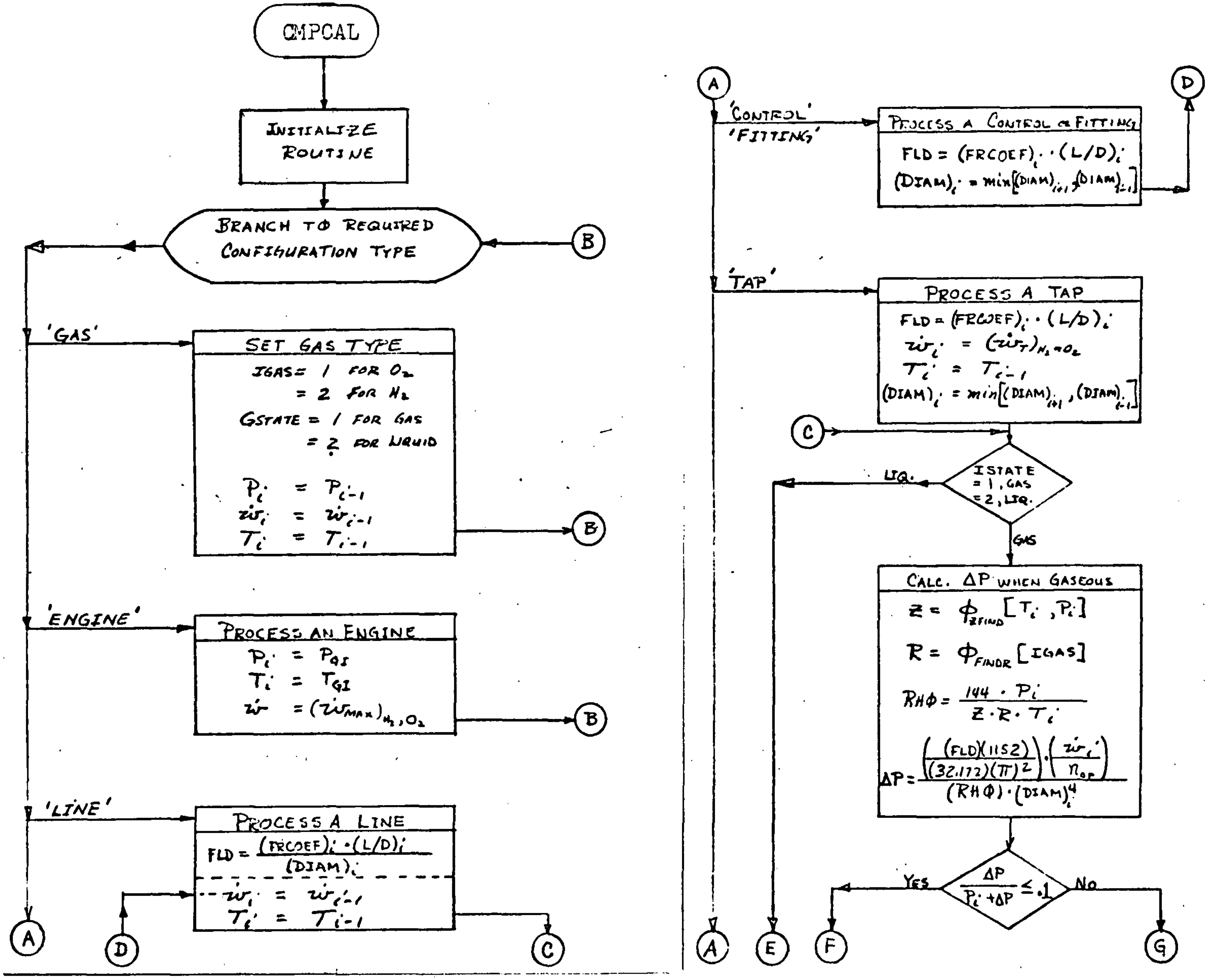

FIGURE 1.9-4 FLOW CHART FOR SUBROUTINE CMPCAL (SHEET 1/4)

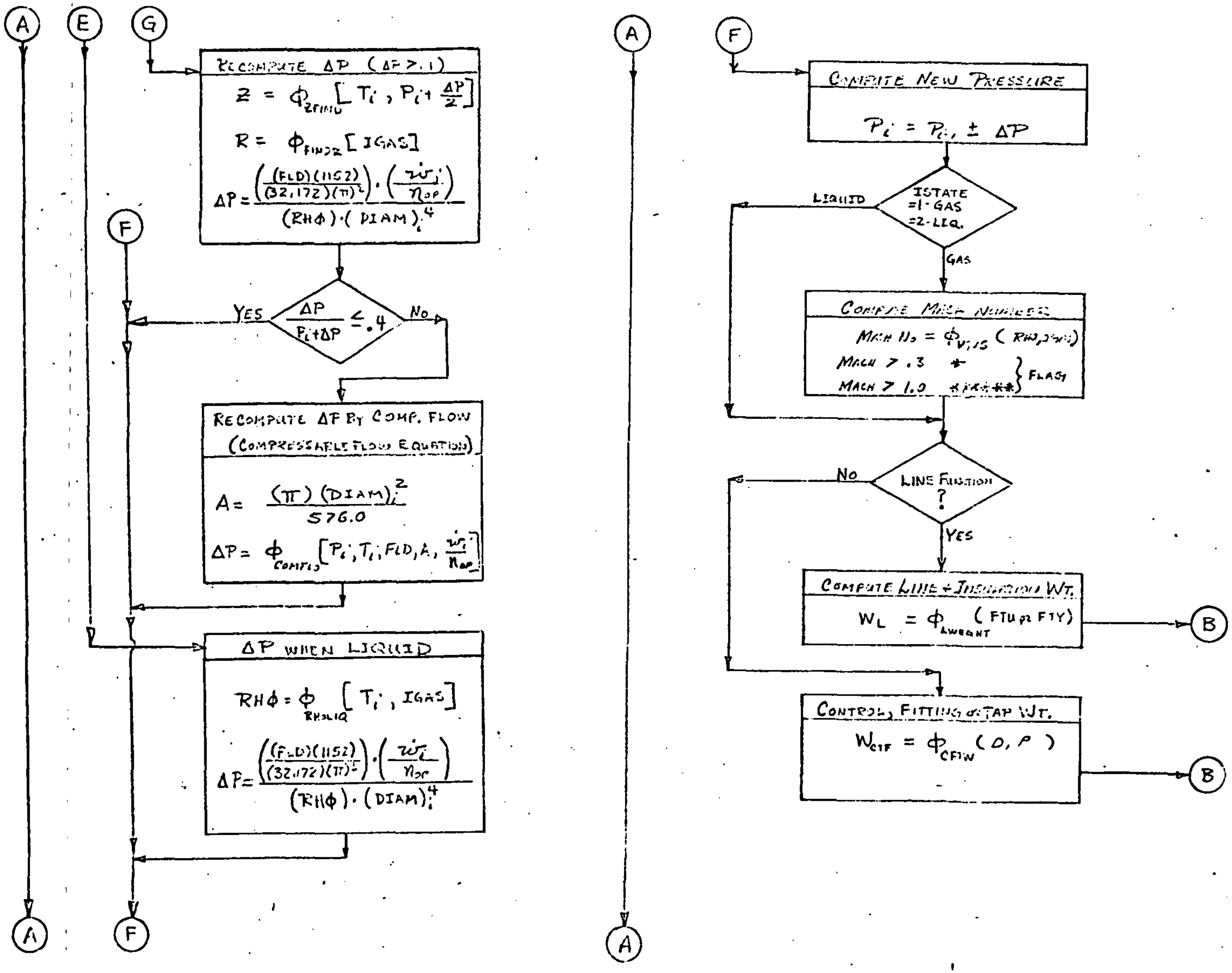

FIGURE 1.9-4 FLOW CHART FOR SUBROUTINE CMPCAL (SHEET 2/4)

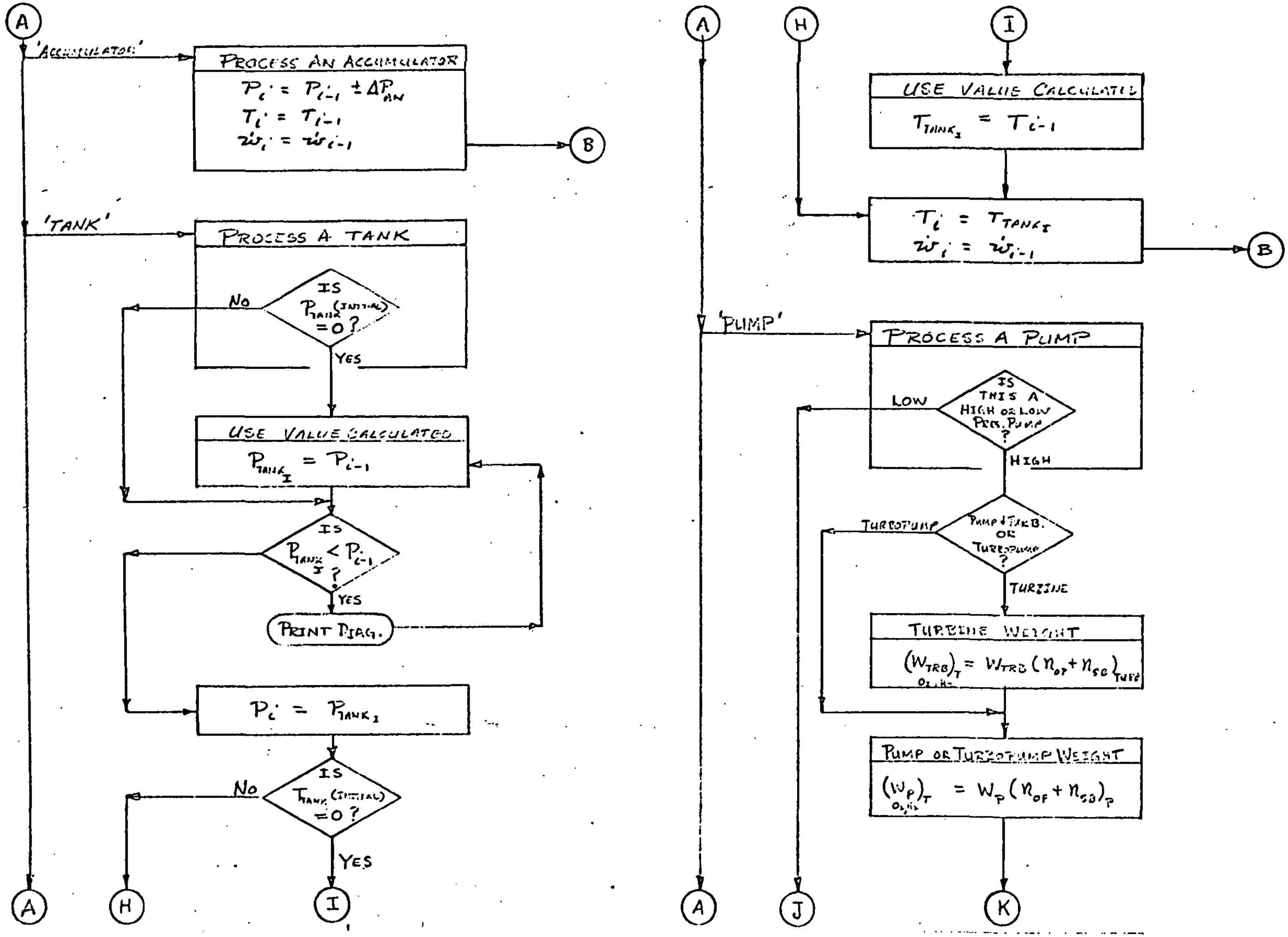

FIGURE 1.9-4 FLOW CHART FOR SUBROUTINE CMPCAL (SHEET 3/4)

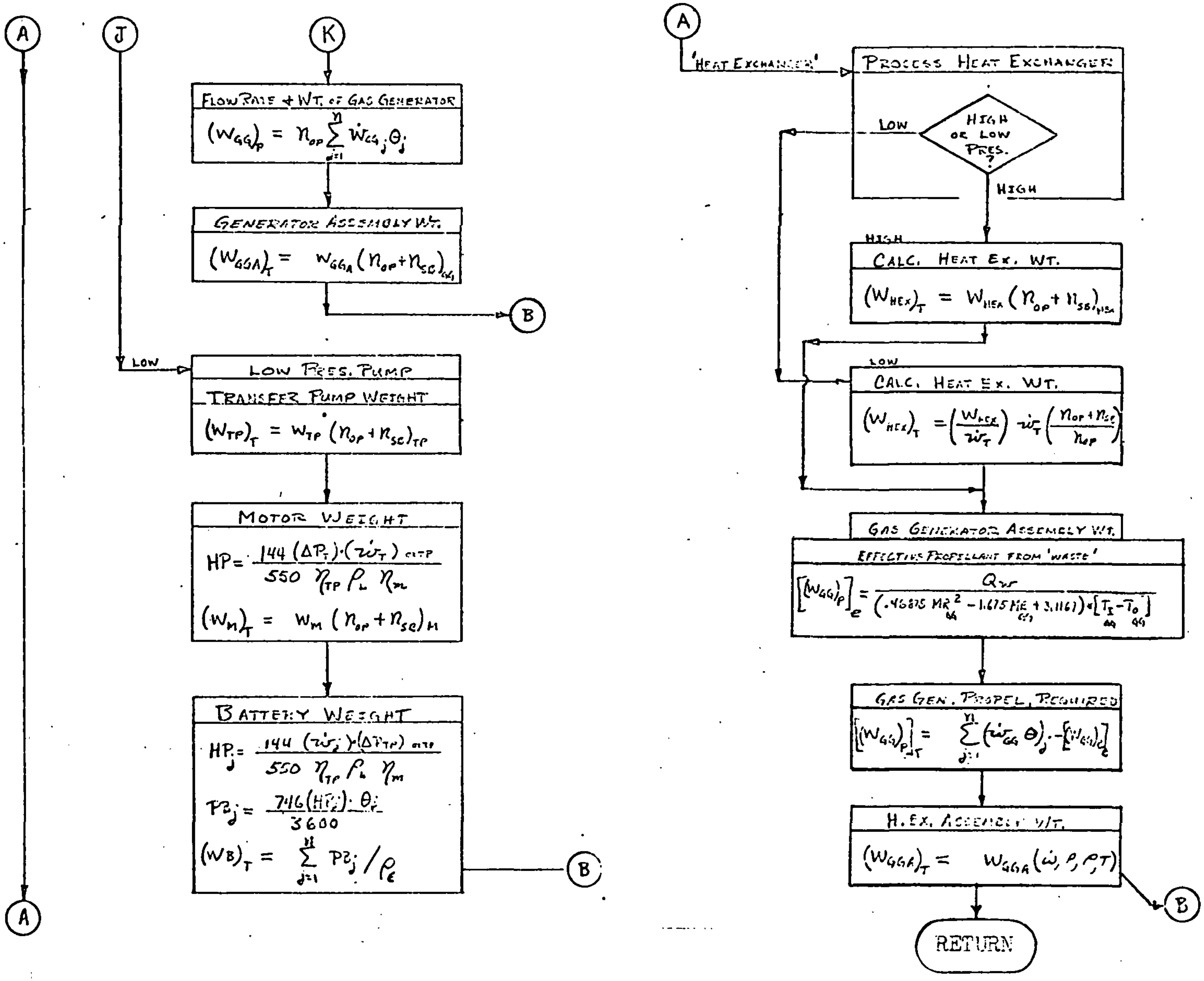

FIGURE 1.9-4 FLOW CHART FOR SUBROUTINE CMPCAL (SHEET 4/4)

SUBROUTINE COMFL0

DESCRIPTION

The subroutine solves the compressible through equations for the determination of pressure drop of gaseous fluids flowing in long ducts. Adiabatic flow is assumed.

Access to common storage blocks is provided for the following labeled common areas:

C0MM0N/CCNFIG/
C0MMON/CI0UNT/
C0MM0N/CONST/

MATHEMATICAL MODEL FOR COMFL0

A math model for subroutine COMFL0 is presented in Appendix C.

CALLING SEQUENCE

COMFL0 is called with eight calling arguments, seven of which are input values with the eigth argument returning the pressure drop value to the calling subroutine. The Mach number is sent to CCNFIG common storage via an INCLUDE statement.

SIGNIFICANT VARIABLES

Significant variables processed by COMFL0 are:

NAME	TYPE	I/O	DIMENSION	DESCRIPTION
IDX	I	I	1	Configuration Position Index
P	R	I	1	Downstream Pressure
T	R	I	1	Downstream Temperature
FLD	R	I	1	$= \frac{FL}{D}$
A	R	I	1	Cross-sectional area of duct
WD0T	R	I	1	Fluid flowrate
N	R	I	1	Fluid Identity: $1 = O_2$; $2 = H_2$; $17 = Ge$; $18 = N_2$
DELP	R	0	1	Pressure Drop Calculated Value
MACH	R	0	100	MACH Number
M1	R	C	1	Upstream MACH Number
M2	R	C	1	Downstream MACH Number
FLDMAX	R	C	1	$f\ (M_1)_{max}$
DF	R	C	1	$= FLDMAX + \frac{fL}{D}$

SUBPROGRAMS REFERENCED BY COMFL0

NAME	TYPE	PURPOSE	REFERENCES
DIAG	F	Diagnostic Writer	Page B-111
CSUBP	S	Cp for specified Fluid	Page B-88
CSUBV	F	Cv for Specified Fluid	Page B-90
HPTGAM	F	Compute for Hydrogen	Page B-189
SQRT	F	Square Root of Variable Value	System Routine
FL0DEQ	F	Computes F(M) MACH Numbers	Page B-148
ABS	F	Absolute Value of Variable	System Routine

SUBROUTINES REFERENCING COMFL0

NAME	TYPE	PURPOSE	REFERENCE
CMPCAL	S	Configuration Analysis	Page B-50
LSSCMP	S	Configuration Analysis	Page B-208

LISTING REFERENCE

A listing of subroutine COMFL0 will be found in Appendix-B, page 62.

FLOW CHART

No flow chart is presented for subroutine COMFL0.

PROGRAM CØNTRL

DESCRIPTION

Program CØNTRL is the initialization and driver routine which sets up TCIMM for any of the five cryogen system analyses. The routine initializes the data storage subroutines, establishes the date, reads in the data tables via subroutine INTAB and reads in the program data deck via subroutine CØMPIL. In so doing, CØNTRL sets up a number of index value relating to system type and kind and whether the input data deck is for a single case or multiple case run.

CØNTRL then calls subroutine CRYCØN and initiates the specified system analysis. Input data for CØNTRL is read from the first several cards of the input data deck. This data is used and transferred to storage in labeled common areas defined by Procedure Definition Processor elements. The labeled common areas used by CØNTRL are:

```
CØMMØN/CCNTRL/
CØMMØN/CIØUNT/
CØMMØN/CKEYS/
CØMMØN/CPAGE/
```

CØNTRL MATHEMATICAL MODEL

None.

CALLING SEQUENCE

CØNTRL is the TCIMM driver routine and as a main program it is not called.

SIGNIFICANT VARIABLES

NAME	TYPE	I/O	DIMENSION	DESCRIPTION
NAME	A	I	1	User Name
DEPT	I	I	1	User Department
BLD	I	I	1	Building Number
EXT	I	I	1	Phone Number
CTITLE	A	I	1	Case Title
NSYS	A	I	1	System Type Index
NI	A	I	1	Rest of System Name
NCRIT	I	I	1	System Kind
INTGR	A	I	1	Case Index
MDTRE	I	I	11	Diagnostic Switches
NAMSYS	I	I	5	System Names Index
SCRIT	I	I	1	System Kind Index

SUBPROGRAMS REFERENCED IN CONTRL

NAME	TYPE	PURPOSE	REFERENCE
STØDTA	S	Data Storage Routine	Page B-272
ØTUNIT	S	System Device Unit Selecting Routine	Page B-237
DATE	S	Finds Date	System Routine
INTAB	S	Loads Data Tables	Page B-198
CØMPIL	S	Loads Input Data	Page B-64
CRYCØN	S	System Analysis Sequencer Routine	Page B-85

SUBPROGRAMS REFERENCING CØNTRL

None.

LISTING REFERENCE PAGE

A listing of subroutine C0NTRL will be found in Appendix B, page 75.

FLOW CHART

The flow chart for subroutine C0NTRL is presented in Figure 1.4-1.

SUBROUTINE C0NSUM

DESCRIPTION

This subroutine, when called, provides access to subroutines ENGINE, APUFL0 and FL0RAT. It is essentially a switching subroutine used by subroutine CRYC0N.

Data transfer to C0NSUM is provided through the Procedure Definition Processor CCNTRL. The only labeled C0MM0N required is C0MM0N/CENTRL/.

C0NSUM MATHEMATICAL MODEL

None

SIGNIFICANT VARIABLES

NAME	TYPE	I/0	DIMENSION	DESCRIPTION
SYSNUM	I	I	1	System Number Index

CALLING SEQUENCE

C0NSUM is initiated via a simple call from subroutine CRYCON with no calling arguments. Data transfer to C0NSUM is accomplished through an INCLUDE statement.

SUBROUTINES REFERENCED IN C0NSUM

NAME	TYPE	PURPOSE	REFERENCE
ENGINE	S	Rocket Engine Parameter Calculations	Page B-138
FL0RAT	S	Flow Rate Calculations	Page B-149
APUFL0	S	APU Flow Rate Calculations	Page B-5

SUBROUTINES REFERENCING C0NSUM

NAME	TYPE	PURPOSE	REFERENCE
CRYCON	S	Program Sequential Control	Page B-85

LISTING REFERENCE PAGE

The subroutine C0NSUM listing will be found in Appendix B, page 74.

FLOW CHART

None.

SUBROUTINE CRYC0N

DESCRIPTION

This subroutine performs the major branching functions of calling in the various subprograms needed for each specified type of CRYOGEN system analysis. A detailed description of CRYC0N and its functions is given in subsection 1.4.2.

Input data transfer to CRYC0N is effected by the use of labeled common storage. The labeled common areas employed are:

C0MM0N/CCNTRL/
C0MM0N/CKEYS/

CRYC0N MATHEMATICAL MODEL

None

CALLING SEQUENCE

CRYC0N is called from C0NTRL with no calling arguments. Data transfer to CRYC0N is accomplished through INCLUDE statements as shown in the subroutine listing.

SIGNIFICANT VARIABLES

Significant variables processed by CRYC0N are:

NAME	TYPE	I/0	DIMENSION	DESCRIPTION
SYSNUM	I	I	1	System Number Index
SCRIT	I	I	1	System Kind Index
KSUBC	I	D	9	Subprogram Calling Index
LREPT	I	C	1	Recycling Index
MOTRC	I	I	11	Diagnostic Switch

SUBPROGRAMS REFERENCED IN CRYC0N

NAME	TYPE	PURPOSE	REFERENCE
DIAG	F	Diagnostic Print	Page B-111
ACCRES	S	Accumulator Residuals Calculations	Page B-2
AGQWT	S	Acquisition Device Weight Calculation	Page B-3
APUSUB	S	APU Subcritical Analysis	Page B-8
APUSUP	S	APU Supercritical Analysis	Page B-12
CMPCAL	S	Configuration Analysis	Page B-50
FUELCL	S	Fuel Cell Analysis	Page B-152
C0NSUM	S	Program Consumer Processor	Page B-74
ECLSS	S	Life Support Analysis	Page B-122
LIQRES	S	Liquid Residuals Calculations	Page B-204
TANK	S	Tank Propellant History Calculations	Page B-277
TSIZEI	S	Tank Sizing Analysis	Page B-310
WTACC	S	Accumulator Weight Analysis	Page B-330
OPTWSM	S	Configuration Weight Summary Output	Page B-226

SUBPROGRAMS REFERENCING CRYC0N

NAME	TYPE	PURPOSE	REFERENCE
C0NTRL	P	TCIMM Main Program	Page B-75

LISTING REFERENCE PAGE

A listing of subroutine CRYC0N is given in Appendix B, page 85.

FLOW CHART

A flow chart for subroutine CRYC0N is presented in Figure 1.4-3.

SUBR0UTINE CYLHED

For a description of CYLHED see the writeup for "SPHSEG". Page B-263

SUBR0UTINE CYMSPH

For a description of CYMSPH see the writeup for "SPHSEG." Page B-263

FUNCTI0N CYLNDR

For a description of CYLNDR see the writeup for "G0MTRY." Page B-175

FUNCTI0N CYLSPH

For a description of CYLSPH see the writeup for "G0MTRY." Page B-175

FUNCTION DIAG

DESCRIPTION

Function DIAG will print when a subroutine was entered or exited for diagnostic purposes. This routine is turned on by setting a value of MDTRC (I) equal to one (1) on the "System Definition Card" of the program input data deck.

CALLING SEQUENCE

JP = DIAG (NOPT, NAME)

Name	Type	I/0	Dimension	Description
NOPT	I	I		If NOPT = -1, DIAG will print the name of the routine exited. If NOPT = 0, no trace will be made. If NOPT = 1, DIAG will print the name of the routine entered.
NAME	A	I		Calling routine name

SIGNIFICANT VARIABLES

None

SUBPROGRAMS REFERENCED IN THIS SUBPROGRAM

None

SUBPROGRAMS REFERENCING THIS SUBPROGRAM

All major subprograms

LISTING REFERENCE PAGE

A listing of function DIAG will be found in Appendix B, page 111.

FLOW CHART

None

SUBROUTINE ECLSS

The ECLSS subroutine contains the system analysis logic, mathematical expressions and equations, and computational techniques required for a super-critical life-support system. The subroutine is structured to be nearly self-contained due to the fact that it considers a cryogenic oxygen and nitrogen supply system and nitrogen is not employed in the other five cryogen systems considered by the main program.

Based upon the input ECLSS data package, the subroutine accomplishes the computation of pertinent system parameters and presents the calculated values in tabular formatted output. The following are the principal computations accomplished in the subroutine:

(a) Computes quantity of fluids consumed for life support, vehicle leakage, airlock or cabin repressurization, and total fluid requirements.

(b) Computes the contingency reserve fluids required for the mission, and usable fluid consumables by species.

(c) Computes nominal fluid flow rates, repressurization flow rates, quantity of fluids consumed each duty cycle interval, and maximum flow rate of fluids for system sizing.

(d) Computes initial fluid tank conditions.

(e) Computes for each duty cycle interval; weight of fluids withdrawn from tanks, percent fluids withdrawn from tanks, density of fluids remaining in tanks, specific heat input required for fluids remaining in tanks, energy derivative for fluids remaining in tanks.

(f) Sizes fluid conditioning heat exchanbers (BTU's required), and, computes power required to provide energy for fluid conditioning heat exchangers.

(g) Sizes heat sources required for fluid tanks (BTU's required) and computes tank heater ratings based upon input heater diameter and length. Computes power required to provide energy needed in fluid tanks.

(i) Computes volume, surface area, and heat leak into fluid tanks. Computes quantity of fluids vented during mission duty cycle intervals and total fluids vented for mission.

(j) Computes total quantity of fluids to be loaded for mission.

(k) Computes fluid tank insulation weight, fluid tank pressure vessel weights, fluid tank vaccum jacket weights, and total weight of fluid tank assemblies.

(l) Computes weight of electrical fluid conditioning heat exchangers.

(m) Computes the individual fluid tank energy histories and the electrical heater OFF-ON duty cycle history in detail for ten-minute intervals of each major syste duty cycle interval.

System component weights and pressure drops for the maximum-flow operating conditions are computed by subroutine LSSCMP.

Input data for use in ECLSS is read in at program initation time via subroutine CØMPIL. The input data are stored in various regions of the labeled CØMMØN storage previously defined by Procedure Definition Processor (PDP) elements. The labeled CØMMØN areas employed by subroutine ECLSS for data storage and transfer are as follow

CØMMØN/CACCUM/
CØMMØN/CIAPU/
CØMMØN/CVAPU/
CØMMØN/CDCYCL/
CØMMØN/CILSS/
CØMMØN/CVLSS/
CØMMØN/CENG/
CØMMØN/CIFUEL/
CØMMØN/CVFUEL/
CØMMØN/CHEX/
CØMMØN/CHSØRC/
CØMMØN/CMATRL/
CØMMØN/CONST/
CØMMØN/CPUMP/
CØMMØN/CTANK/
CØMMØN/CIØUNT/
CØMMØN/TABLØK/

ECLSS MATHEMATICAL MODEL

The ECLSS Math Model consisting of analysis logic, equations, necessary tables and constants, procedures and the techniques required are presented in Appendix C.

CALLING SEQUENCE

Subroutine ECLSS is initiated by a simple call from subroutine CRYC0N, with no calling variables. Data transfer to ECLSS is accomplished through the use of INCLUDE statement as shown in the subroutine listing. Upon completion of the required ECLSS computation, sequential control of the program is returned to subroutine CRYC0N

SIGNIFICANT VARIABLES

Significant variables considered in, and processed by subroutine ECLSS are defined in the following list:

NAME	TYPE	I/0	DIMENSION	DESCRIPTION
MDAYS	I	I	1	Number of days in mission
NCREW	I	I	1	Number of personnel on board
NRPES	I	I	1	Number of repressurizations planned
NDARES	I	I	1	Number of days reserve fluids required
0FN0M	R	I	1	Metabolic Oxygen Consumption Rate
GLKRAT	R	I	1	Vehicle Atmosphere Leakage Rate
TLSN0M	R	I	2	Nominal Gaseous Fluid Delivery Temp
RH0BEG	R	I	2	Initial fluids loading densities
TKFTEM	R	I	2	Allowable Fluids Tank Final Temperature
TKFPRS	R	I	2	Allowable fluids Tank Final Pressure
TENVR	R	I	1	ECLSS System Environemtnal Temperature

NAME	TYPE	I/Ø	DIMENSION	DESCRIPTION
CABVØL	R	I	1	Cabin or Airlock Volume
LINDIA	R	I	2	Line Diameter entering Heat Exchangers
HTRFLX	R	I	2	Heater Rating (BTU/HR-Sq In.) @ T_{Ref}
PLSNØM	R	I	2	Nominal Pressure of Delivered Gaseous Fluids
HTRDIA	R	I	2	Tank Heater Diameter
HTRLNG	R	I	2	Tank Heater Length
PSETI	R	I	1	Ø2 Tank Lower Pressure Limit Setting
PSET2	R	I	1	N2 Tank Lower Pressure Limit Setting
SITYPE	I	I	2, 1	Fluid Tank Insulation Type
SMTYPE	I	I	2, 1	Fluid Tank Wall Material Type
SITEMP	R	I	2, 1	Initial Temp Fluids in Tank
SØPRES	R	I	2, 1	Fluid Tank Operating Pressures
SVPRES	R	I	2, 1	Fluid Tank Vent Pressures
SHFLUX	R	I	2, 1	Estimated Heat Leak Flux - Fluid Tanks
SITHIK	R	I	2, 1	Fluid Tank Insulation Thickness
SNBAR	R	I	2, 1	Number of Insulation Layers per Inch Thickness
DCYCLE	R	I	60	Duty Cycle Operating and Non-Operating Time Intervals - in sequential array
RPRTIM	R	I	12	Repressurization Period Duration - (NRPRES values entered in duty cyle array)
Ø2MCØN	R	Ø	1	Total Wgt Metabolic Ø2 - Consumed in Mission
Ø2LCØN	R	Ø	12	Metabolic Ø2 Wgt Consumed each duty cycle interval
Ø2LWT	R	Ø	12	Metabolic Ø2 Wgt of Leakage - each duty cycle interval
N2LWT	R	Ø	12	N2 Wgt lost by leakage - each duty cycle interval
N2LCØN	R	Ø	1	Total Wgt N2 Leakage - lost in mission
GASWGT	R	Ø	1	Weight of atmosphere lost in one depressurization
Ø2REPR	R	Ø	1	Wgt Ø2 required for all repressurizations
N2REPR	R	Ø	1	Wgt N2 required for all repressurizations
Ø2CØNS	R	Ø	1	Wgt Ø2 (metabolic + Leakage + Repressurization
N2CØNS	R	Ø	1	Wgt N2 (leakage + repressurization)
Ø2MRES	R	Ø	1	Wgt Ø2 (for metabolic reserve)
Ø2LRES	R	Ø	1	Wgt Ø2 for leakage reserve

NAME	TYPE	I/Ø	DIMENSION	DESCRIPTION
N2LRES	R	Ø	1	Wgt N2 for Leakage Reserve
Ø2RES	R	Ø	1	Wgt of Reserve Ø2 for Contingency
N2RES	R	Ø	1	Wgt of Reserve N2 for Contingency
Ø2TOTU	R	Ø	1	Wgt of Total Usable Ø2 on board
N2TØTU	R	Ø	1	Wgt of Total Usable N2 on board
WDØTØN	R	Ø	12	Nom. Ø2 Flow Rate - each duty cycle interval
WDØTNN	R	Ø	12	Nom. N2 Flow Rate - each duty cycle interval
WDØTØR	R	Ø	12	Ø2 Repressurization Flow Rate - each duty cycle interval
WDØTNR	R	Ø	12	N2 Repressurization Flow Rate - each duty cycle interval
WDTØ2	R	Ø	12	Total Ø2 Flow Rate - each duty cycle interval
WDTN2	R	Ø	12	Total N2 Flow Rate - each duty cycle interval
WTØ2	R	Ø	12	Total Wgt Ø2 used each duty cycle interval
WTN2	R	Ø	12	Total Wgt N2 used each duty cycle interval
WDTØMX	R	Ø	1	Max. Ø2 Flow Rate in any Interval
WDTNMX	R	Ø	1	Max. N2 Flow Rate in any interval
WDØTI	R	Ø	2	Max. Fluid Flow Rates in lbs per second
WDØTT	R	Ø	2	Saved values of WDØTI for other use
TEMPØ2	R	Ø	1	Initial Temp of Ø2 in Tank
TEMPN2	R	Ø	1	Initial Temp of N2 in Tank
TKØ2DP	R	Ø	12	Cum Wgt Ø2 removed from tank as f(time)
TKN2DP	R	Ø	12	Cum Wgt N2 removed from tank as f(time)
PCØXWD	R	Ø	12	Percent Ø2 removed from tank as f(time)
PCN2WD	R	Ø	12	Percent N2 removed from tank as f(time)
Ø2RHØ	R	Ø	12	Density of Ø2 in tank-end of each interval
N2RHØ	R	Ø	12	Density of N2 in tank-end of each interval
Ø2TEMP	R	Ø	12	Temp of Ø2 in tank-end of each interval
N2TEMP	R	Ø	12	Temp of N2 in tank-end of each interval
DØDMØ2	R	Ø	12	Spec Heat Input to Ø2-end of each interval
DØDMN2	R	Ø	12	Spec Heat Input to N2-end of each interval
DPDUØ2	R	Ø	12	Energy Derivative for Ø2 - end of each interval
DPDUN2	R	Ø	12	Energy Derivative for N2-end of each interval
Ø2H	R	Ø	12	Enthalpy of Ø2 at end of each interval
N2H	R	Ø	12	Enthalpy at N2 at end of each interval

NAME	TYPE	I/O	DIMENSION	DESCRIPTION
QDT0R	R	0	12	Heat Rate to Condition 02 at end of each interval
QDT0MX	R	0	1	Max. Heat Rate for Conditioning 02
QDTNR	R	0	12	Heat Rate to Condition N2 at end of each interval
QDTNMX	R	0	1	Max. Heat Rate for Conditioning N2
HWAT02	R	0	12	Energy Required for Heat to 02-end of each interv
HWT0MX	R	0	1	Max. Energy Reqd for Heat to 02-any interval
HWT0TT	R	0	1	Total Energy Reqd for Heat to 02-all intervals
HWATN2	R	0	12	Energy Reqd for Heat to N2-end of each interval
HWTNMX	R	0	1	Max. Energy Reqd for Heat to N2 - any interval
HWTNTT	R	0	1	Total Energy Reqd for Heat to N2-all intervals
QDTTK0	R	0	12	Heat Rate to Condition 02 Tank - each interval
QDTTKN	R	0	12	Heat Rate to Condition N2 Tank - each interval
HTRRA1	R	0	1	Heater Rating for 02Tank at Max. Heat Reqmt
HTRRA2	R	0	1	Heater Rating for N2 Tank at Max. Heat Reqmt
TWAT02	R	0	12	Energy Reqd for Heat Input to 02 Tank - each interval
TWT0MX	R	0	1	Max Energy for Heat Input to 02 Tank-any interval
TWT0TT	R	0	1	Total Energy for Heat Input to 02 Tank-all interv
TWATN2	R	02	12	Energy Reqd for Heat Input to N2 Tank-each interv
TWTNMX	R	0	1	Max. Energy for Heat Input to N2 Tank-any interva
TWTNTT	R	0	1	Total Energy for Heat Input to N2 Tank-all interv
T0TWMX	R	0	1	Max. Energy Rqmt all heat sources
T0TWAT	R	0	1	Total Energy Reqd - all heat sources-all interval
T0TP0W	R	0	1	Total Power Rqmts (KW-HRs)
RH0END	R	0	2	Fluid Densities at end of mission
WTRSID	R	0	2	Wgt Residual Fluids in Tanks
V0LTK	R	0	2	Volume of Fluid Storage Tanks
ARETK	R	0	2	Surface Area of Fluid Storage Tanks
Q02LK	R	0	12	Heat Leak into 02 Tank - each interval
QLK0TK	R	0	1	Cum. Heat Leak into 02 Tank - each interval
QN2LK	R	0	12	Heat Leak into N2 Tank - each interval
QLKNTK	R	0	1	Cum. Heat Leak into N2 Tank - all intervals
WTVNT0	R	0	12	Wgt of vented 02 - each interval

NAME	TYPE	I/0	DIMENSION	DESCRIPTION
WV02	R	0	1	Cum. Wgt of Vented 02 - all intervals
WTVNTN	R	0	12	Wgt of Vented N2 - each interval
WVN2	R	0	1	Cum. Wgt of Vented N2 - all intervals
T0TWTL	R	0	2	Total Weight of each Fluid Loaded
DITK	R	0	2	Diameter of each fluid tank
TIWT	R	0	2, 1	Tank Insulation Wgt - each Fluid Tank
DIVJ	R	0	2	Diameter of each Tank Vacuum Jacket
R0FTU	R	0	2	Tank Material Density/Ultimate Stress
WTPV	R	0	2	Weight of Pressure Vessel - each tank
WTVJ0	R	0	1	Weight of Vacuum Jacket - 02 Tank
WTVJN	R	0	1	Weight of Vacuum Jacket - N2 Tank
WTT0T	R	0	2	Total Tank Assy Wgt - Each Tank
WD0TX	R	0	10, 2	Fluid Flow Rate Into Heat Exchanger
UCODE	R	I	10, 2	Heat Exchanger I.D. Code
HEXCIT	R	0	10, 2	Cold Fluid Inlet Temperature
HEXC0T	R	0	10, 2	Cold Fluid Outlet Temperature
HEXCIP	R	0	10, 2	Cold Fluid Inlet Temperature
HSQREQ	R	0	10, 2	Heat Source Energy Required
ELCP0	R	0	10, 2	Electrical Energy for Heat source
JX	I	0	1	Heat Exchanger Index (Counter)
IGAS	I	0	1	Fluid Index
IFIN	I	I	1	Heat Exchanger-Heat Dissipation Fins Switch
WHXT0T	R	0	10, 2	Heat Exchanger Calculated Weight
HXCDLP	R	0	10, 2	Cold Fluid Pressure Drop through HEX
U0A	R	0	10,2	Heat Exchanger Heat Transfer Coefficient
DH	R	0	10,2	Heat Exchanger Diameter
HLNGTH	R	0	10, 2	Heat Exchanger Length
TIMINC	R	0	1	Time Increment defined as unity
PTANK1	R	I	1	02 Tank Pressure at Sub-interval time point
PTANK2	R	I	1	N2 Tank Pressure at Sub-interval time point
TIM	R	I	12	Duty Cycle Operating Time interval
TN0N0P	R	I	12	Duty Cycle Non-Operating Time interval
NPT	I	0	1	Number of sub-intervals in duty cycle interval
WDT030	R	0	1	02 Gas Flow during Sub-Interval
WDTN30	R	0	1	N2 Gas Flow during Sub-Interval

NAME	TYPE	I/Ø	DIMENSION	DESCRIPTION
K	I	Ø	1	Major duty cycle Index (counter)
LPRES	I	Ø	1	Index to locate repressurization interval
IK	I	Ø	1	Index for resetting sub-sub-interval examination of repressurization event back to leakage event sequence
TIME	R	Ø	1	Time Point of pressure history event (min)
TKØDP	R	Ø	1	Cum. Ø2 Tank Depletion at each time event
TKNDP	R	Ø	1	Cum. N2 Tank Depletion at each time event
RPTIME	R	Ø	1	Time Point of Repressurization History Event (mi
PCØXW	R	Ø	1	Percent Ø2 withdrawn as function of time
PCN2W	R	Ø	1	Percent N2 withdrawn as function of time
ØRHØ	R	Ø	1	Density of Ø2 in Tank at end of Sub-Interval
NRHØ	R	Ø	1	Density of N2 in tank at end of sub-interval
ØXTEM	R	Ø	1	Temp of Ø2 in Tank at End of Sub-Interval
N2TEM	R	Ø	1	Temp of N2 in Tank at End of Sub-Interval
DQDMI	R	Ø	1	Spec Heat Input to Ø2 - at end of sub-interval
DQDM2	R	Ø	1	Spec Heat Input to N2 - at end of sub-interval
DPDU1	R	Ø	1	Energy Derivative of Ø2 - at end of sub-interval
DPDU2	R	Ø	1	Energy Derivative of N2 - at end of sub-interval
QDTTK1	R	Ø	1	Heat Rate to Condition Ø2 Tank - For sub-interva
QDTTK2	R	Ø	1	Heat Rate to Condition N2 Tank - for sub-interva
Q1CUMØ	R	Ø	1	Cum. Heat Rqd to condition Ø2 Tank
Q2CUMN	R	Ø	1	Cum. Heat Reqd to condition N2 Tank
BETAØ	R	Ø	1	Volume Expansivity of Ø2 in Tank-at end of sub-interval
BETAN	R	Ø	1	Volume Expansivity of N2 in Tank-at end of sub-interval
CPØ	R	Ø	1	Spec Heat of Ø2 in tank-at sub-interval
CPN	R	Ø	1	Spec Heat of N2 in tank-at sub-interval
DELPI	R	Ø	1	Ø2 Tank Pressure Drop - sub-interval depletion
DELP2	R	Ø	1	N2 Tank Pressure Drop - sub-interval depletion
QHTR1	R	Ø	1	Ø2 Tank Heater Output (BTU/MIN)
QHTR2	R	Ø	1	N2 Tank Heater Output (BTU/MIN)
QELC1	R	Ø	1	Ø2 Tank Heat Req'd (BTU)
HTRØN1	R	Ø	1	Time Ø2-Heater is ON to provide QELCI
QELC2	R	Ø	1	N2 Tank Heat Req'd (BTU)
HTRØN2	R	Ø	1	Time N2-Heater is ON to provide QELC2

SUBPROGRAMS REFERENCED IN ECLSS

Name	Type	Purpose	Reference
PAGE	F	Controls Pagination and Line Count	Page B-239
FINTAB	S	Finds Designated Table of Data	Page B-147
MIPE	F	Table Data Extraction	Page B-221
CSUBV	F	Compute Cv for Desired Fluid and Conditions	Page B-93
ZGET	F	Compute Compressibility for Desired Fluid and Conditions	Page B-336
PHTH0N	S	Computes Specific Heat Input (THETA) and Energy Derivative (PHI) for Desired Fluid Conditions	Page B-249
OXENTH	F	Computes 02 Enthalpy at StatedConditions	Page B-238
NIENTH	F	Computes N2 Enthalpy at Stated Conditions	Page B-224
AMAXI	F	Finds Maximum of Two Real Values	System Library
DENSON	S	Computes Density for Desired Fluid at Stated Conditions	Page B-108
TC0ND	S	Compute Thermal Conductivity for Specified Insulation at Stated Conditions	Page B-290
HEXELC	S	Computes Heat Exchanger Weight and Characteristics	Page B-184
CSUBP	S	Compute Cp for Desired Fluid and Conditions	Page B-88
0PTHXE	S	Output Subroutine for Electric Heat Exhanger Data	Page B-229
OPTP0W	S	Output Subroutine for ECLSS Power Summary	Page B-230
LSSCMP	S	Computes Pressure drops and component weights for the ECLSS Configuration Analysis	Page B-208

SUBPROGRAMS REFERENCEING ECLSS

Name	Type	Purpose	Reference
CRYC0N	S	Sequential Control of Designated System Analysis	Page B-85

LISTING REFERENCE PAGE

A listing of subroutine ECLSS will be found in Appendix B, Page 122

FLOW CHART

The flow chart for subroutine ECLSS is presented in Figure 1.9-5

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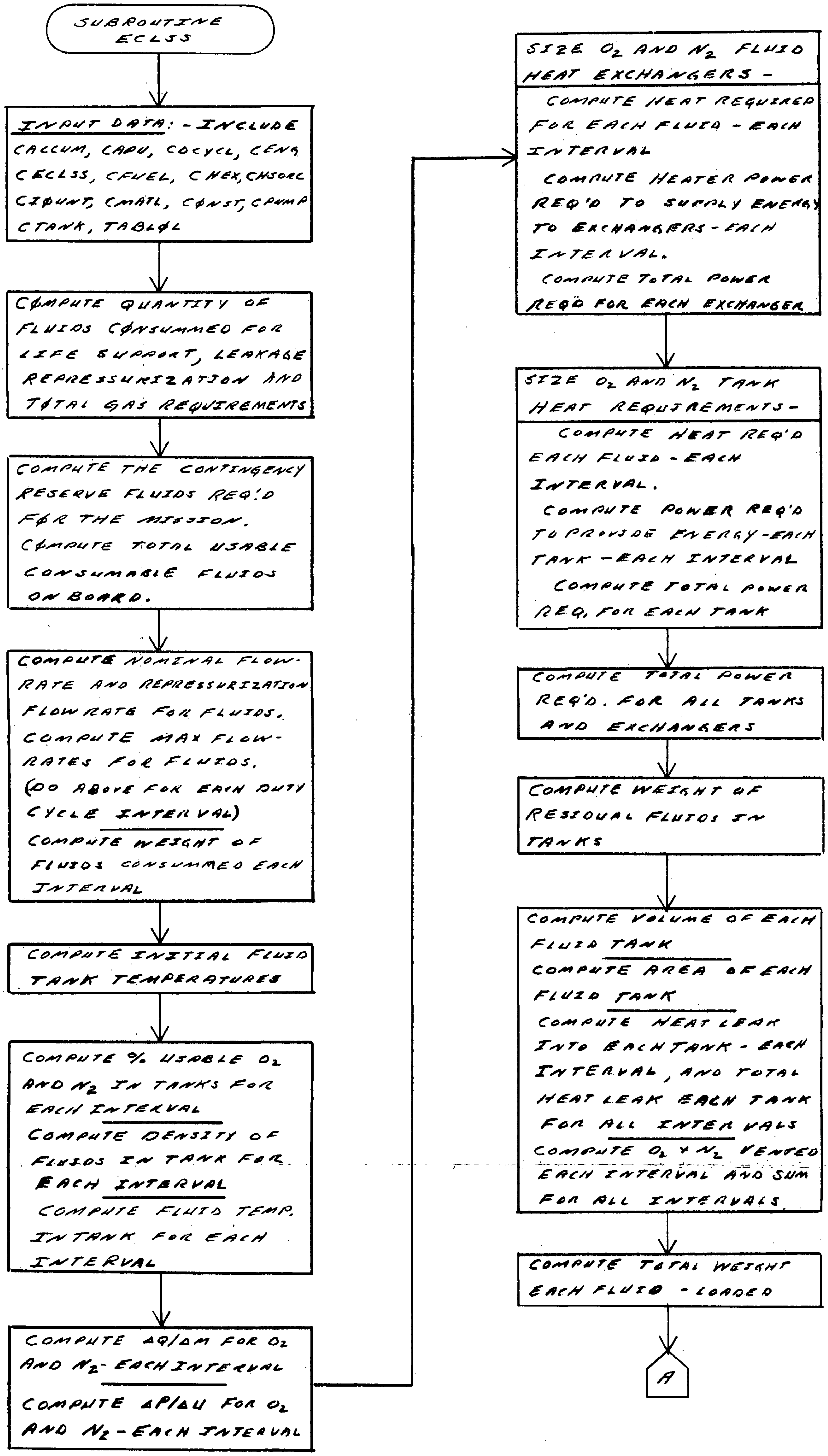

Fig. 1.9-5 Flowchart for Subroutine ECLSS
(Sheet 1/2)

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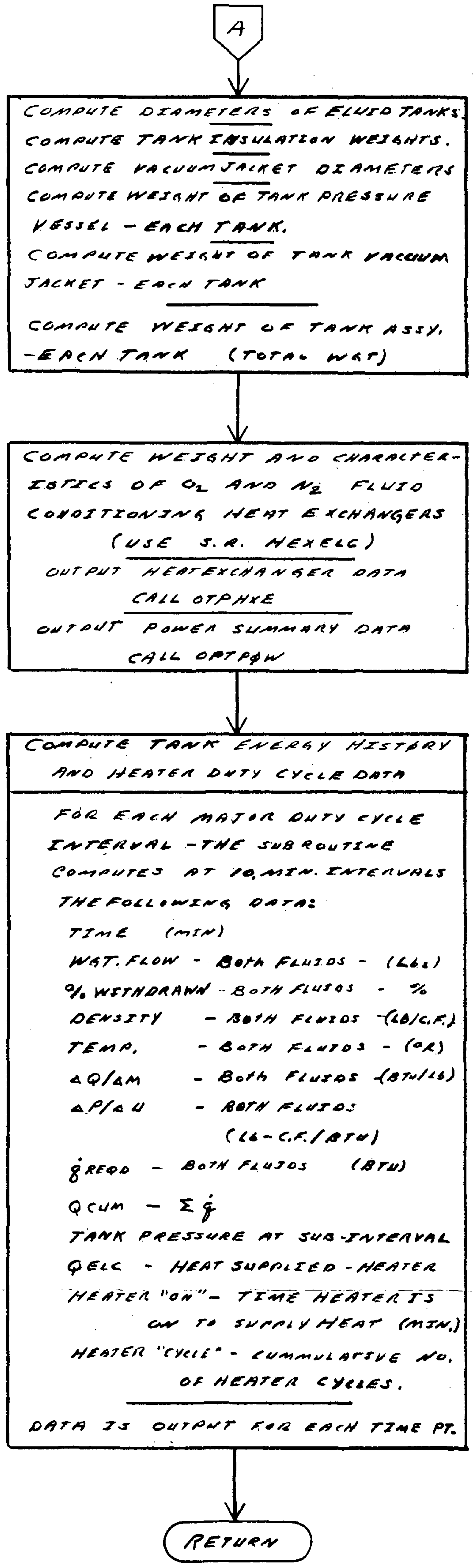

COMPUTE DIAMETERS OF FLUID TANKS.
COMPUTE TANK INSULATION WEIGHTS.
COMPUTE VACUUM JACKET DIAMETERS
COMPUTE WEIGHT OF TANK PRESSURE VESSEL – EACH TANK.
COMPUTE WEIGHT OF TANK VACUUM JACKET – EACH TANK

COMPUTE WEIGHT OF TANK ASSY. – EACH TANK (TOTAL WGT)

COMPUTE WEIGHT AND CHARACTERISTICS OF O_2 AND N_2 FLUID CONDITIONING HEAT EXCHANGERS (USE S.R. HEXELC)

OUTPUT HEATEXCHANGER DATA
CALL OTPHXE

OUTPUT POWER SUMMARY DATA
CALL OPTPØW

COMPUTE TANK ENERGY HISTØRY AND HEATER DUTY CYCLE DATA

FOR EACH MAJOR DUTY CYCLE INTERVAL – THE SUBROUTINE COMPUTES AT 10 MIN. INTERVALS THE FOLLOWING DATA:
TIME (MIN)
WGT. FLOW – BOTH FLUIDS – (Lbs)
% WITHDRAWN – BOTH FLUIDS – %
DENSITY – BOTH FLUIDS – (LB/C.F.)
TEMP. – BOTH FLUIDS – (°R)
$\Delta Q/\Delta M$ – BOTH FLUIDS – (BTU/LB)
$\Delta P/\Delta U$ – BOTH FLUIDS (LB-C.F./BTU)
$\dot{q}$ REQD – BOTH FLUIDS (BTU)
QCUM – $\Sigma \dot{q}$
TANK PRESSURE AT SUB-INTERVAL
QELC – HEAT SUPPLIED – HEATER
HEATER "ON" – TIME HEATER IS ON TO SUPPLY HEAT (MIN.)
HEATER "CYCLE" – CUMMULATIVE NO. OF HEATER CYCLES.

DATA IS OUTPUT FOR EACH TIME PT.

Fig. 1.9-5 Flowchart for Subroutine ECLSS (Sheet 2/2)

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SUBRØUTINE ELIPSG

For a description of ELIPSG see the writeup for "SPHSEG."   Page B-263

Subroutine FINTAB

DESCRIPTION

Subroutine FINTAB is called just prior to an interpolation on any table. This routine looks up the number of dimensions (ND) of the designated table and if it is greater than two. The routine transfers the (ND-2) "independent" variables from the master table array (TABLE) to a small two dimensional array TAB (6,5) . Then the routine FINTAB sets a pointer to the location of the first subtable of the designated major table.

Labeled Common Used

```
CØMMØN/CIØUNT/
CØMMØN/CTAB/
CØMMØN/CTABA/
```

Mathematical Model for FINTAB

None

Calling Sequence

FINTAB is called from any subprogram which uses table interpolation (or polynomial fit). It has one variable – the table ID# in its calling sequence. All other data is transferred through labeled common CTAB and CTABA.

Significant Variables

Name	Type	I/Ø	Dimension	Description
IDX1	I	Ø	1	Points to first location of subtables
ITAB	I	Ø	6,5	Contains the (ND-2) independent variable
ITABLE	I	I	7000	Main storage array for table data

Name	Type	I/0	Dimension	Description
JTABID	I	0	1	Table ID of designated table
TAB	R	0	6,5	Equivalent to ITAB
TABLE	R	I	7000	Equivalent to ITABLE
TLA	I	I	50	Contains location in TABLE of 1st word for each table

Subprograms Referenced by FINTAB

Name	Type	Purpose	Reference
DIAG		Prints diagnostic trace	Page B-111

Subprograms Referencing FINTAB

All routines which do table interpolation. Same as function MIPE. See MIPE Page

Listing Reference

A listing of FINTAB can be found in Appendix B, Page 147 .

Flow Chart

For flow chart of FINTAB see Figure 1.9-6

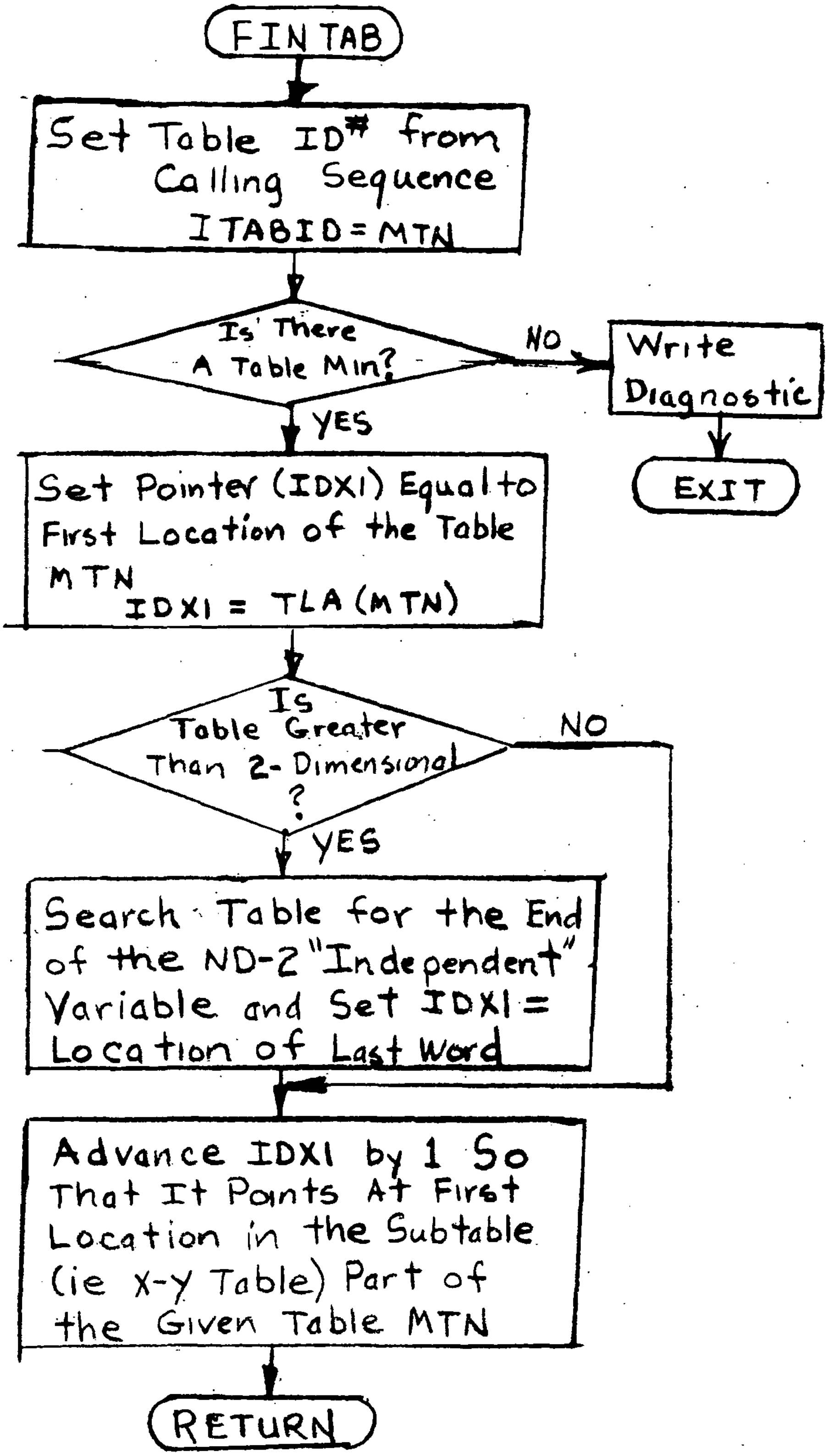

Fig. 1.9.6 Flowchart for FINTAB

SUBROUTINE FLØRAT

DESCRIPTION

This subroutine computes the flow rates for the support gas generation required by the system heat exchangers and turbopumps. The individual flow rates are stored in assigned variables and the total flow rate by fluid species is computed and stored for later use.

The following are the principal computations performed in the subroutine:

(a) Computes flow rate required for each gas generator in system main stream by fluid species.

(b) Sums flow rate by fluid species for heat exchanger gas generators.

(c) Sums flow rates by fluid species for turbopump gas generators (if required).

(d) Computes total flow rates by fluid species for cryogen consumer and all gas generators.

(e) Outputs flow rate data in predetermined format as part of analysis output.

Input data for FLØRAT has previously been read in by subroutine CØMPIL. This data, and data that has been computed by subroutine CØNSUM is available to FLØRAT through the labeled CØMMØN storage blocks. The labeled CØMMØN blocks used by FLØRAT are:

CØMMØN/CCNTRL/
CØMMØN/CENG/
CØMMØN/CFLRAT/
CØMMØN/CHEX/
CØMMØN/CPUMP/
CØMMØN/CTANK/
CØMMØN/CTURBN/
CØMMØN/CIQUNT/

FL0RAT MATHEMATICAL MODEL

The equations and computational procedures required in subroutine FL0RAT are presented in Appendix C.

CALLING SEQUENCE

FL0RAT is called from subroutine C0NSUM with no calling arguments. Data transfer is accomplished through INCLUDE statements as shown in the FL0RAT listing. Upon completion of the calculations, program control is returned to subroutine C0NSUM.

SIGNIFICANT VARIABLES

Significant variables processed in FL0RAT are as follows:

Name	Type	I/0	Dimensions	Description
HEXHIP	R	I	10,2	Heat exchanger hot inlet pressure
HXMRAT	R	I	10,2	Heat exchanger mixture ratio
HEXHCT	R	I	10,2	Heat exchanger hot outlet temperature
HEXHIT	R	I	10,2	Heat exchanger hot inlet temperature
CPHEX	R	C	1	HEX hot gas specific heat
ICIN	R	C	1	HEX cold fluid inlet enthalpy
IC0UT	R	C	1	HEX cold outlet fluid enthalpy
TITEMP	R	I	2	Turbine inlet temperature
TOTEMP	R	I	2	Turbine outlet temperature
WOOTI	R	I	2	Consumer flow rate
WDHXT0	R	C	2	HEX gas generator O_2 flow rate
WDHXTF	R	C	2	HEX gas generator H_2 flow rate
WDTPT0	R	C	2	Turbopump GG – O_2 flow rate
WDTPTF	R	C	2	Turbopump GG – H_2 flow rate
WD0TT	R	0	2	Total flow rate each fluid

SUBPROGRAMS REFERENCED IN FL0RAT

Name	Type	Purpose	Reference
DIAG	F	Diagnostic Print	Page B-111
CSUBPI	S	Specific heat at O_2 — H_2 Combustion Products	Page B-91
ENTH0H	S	Computes enthalpy of O_2 or H_2. (Entry point into subroutine MATHAX.)	Page B-218
RH0LIQ	S	Computes density of liquid O_2 or H_2.	Page B-262
OPTFLT	S	Output turbine gas generator data	Page B-226

SUBPROGRAMS REFERENCING FL0RAT

Name	Type	Purpose	Reference
C0NSUM	S	Computes consumer parameters	Page B74

LISTING REFERENCE PAGE

A listing of subroutine FL0RAT will be found in Appendix B, page 149.

FLOW CHART

Simple structure requires no flow chart.

FUNCTI0N FRC0NE

For a description of FRC0NE see the writeup for "G0MTRY." Page B-175

SUBR0UTINE FRHEAD

For a description of FRHEAD see the writeup for "SPHSEG". Page B-263

SUBROUTINE FUELCL

DESCRIPTION

The subroutine contains the equations and computational techniques required to perform a super-critical fuel cell system analysis. Based upon the input fuel cell data, the subroutine accomplishes the computation of pertinet system parameters and presents the calculated values in formatted output. The following are the principal computations contained in the subroutine.

(a) Computes the total electrical power supplied for themission.

(b) Computes the quantity of reactant consummed for power production for the mission (total and by species).

(c) Computes the flowrate of each reactant for each duty cycle interval in the mission. Determines maximum flowate for each reactant for system sizing calculations.

(d) Computes total heat rejected and heat rejected for each operating interval (duty cycle) by the fuel cells.

(e) Computes initial reactant storage tank temperature as a function of fill density and operating pressure.

(f) Computes percent of usable reactant withdrawn from tanks and resultant density for each mission interval defined by duty cycle.

(g) Computes for each reactant, the readout temperature, specific heat input (theta) and, the energy derivative (phi) for each operating duty cycle interval.

(h) Computes the Ø2 tank and H2 tank heat requirements and hot fluid flow rates for each duty cycle interval.

(i) Computes the Ø2 and H2 conditioning heat exchanger heat and hot fluid flow requirements for each duty cycle interval.

(j) Performs a heat balance to assure adequate supply of fuel cell reject heat to operate heat exchangers during each interval.

(k) Computes the maximum heat flow rate required for each reactant tank and worst tank circulating compressor conditions. Computes weight of circulating compressor for each reactant tank.

(l) Computes reserve reactant quantity required and weight of residual reactants at end of mission.

(m) Computes weight of H2 vented during the mission, if venting is required.

(n) Computes total reactants required for the mission. The reactant tank volumes, surface areas, and diameters.

(o) Computes tank insulation weights, tank pressure vessel weights, tank vacuum jacket weights, and total reactant tank weights. Flags tank diameters when maximum allowable diameter is exceeded.

(p) Computes the weight of the on-board fuel cells.

(q) Computes the weight of all system heat exchangers and their respective characteristic parameters.

(r) Additionally, the subroutine computes the individual reactant switch duty cycle history in detail for each duty cycle interval.

System component weights and pressure design for the max-flow conditions are calculated separately by subroutein CMPCAL.

Input data to FUELCL has previously been read-in by subroutine CØMPIL. The input data are stored in various sections of labeled CØMMØN previously defined by a set of Procedure Definition Processor (PDP) elements. The labeled CØMMØN areas used by FUELCL for data storage and transfer are:

```
CØMMØN/CACCUM/
CØMMØN/CIAPU/
CØMMØN/CVAPU/
CØMMØN/CDCYCL/
CØMMØN/CENG/
CØMMØN/CIFUEL/
CØMMØN/CVFUEL/
CØMMØN/CHEX/
CØMMØN/CHSØRC/
CØMMØN/CMATRL/
CØMMØN/CONST/
CØMMØN/CPUMP/
CØMMØN/CTANK/
CØMMØN/CIØUNT/
CØMMØN/TABLØK/
```

FUELCL MATHEMATICAL MODEL

The quations, mathematical logic, and procedures, necessary tables, and constants required are presented in Appendix C.

CALLING SEQUENCE

Subroutine FUELCL is initiated by a simple call from subroutine CRYCØN, with no calling variables. Data transfer to FUELCL is accomplished through INCLUDE statements as shown in the subroutine listing. Upon completion of the FUELCL computations, sequential control is returned to subroutine CRYCØN.

SIGNIFICANT VARIABLES

Significant variables processed in subroutine FUELCL are as follows:

NAME	TYPE	I/O	DIMENSION	DESCRIPTION
MRFC	R	I	1	Fuell Cell Mixture Ratio
SRCFC	R	I	1	Specific Restart Consumption
QDTFC	R	I	1	Fuel Cell Heat Rjection Rate
SPWTFC	R	I	1	Specific Weight for Fuel Cell
TFCNOM	R	I	2	Nominal Fuel Cell Gas Feed Temp
TF21IN	R	I	1	F21 Coolant Inlet Temperature
TF21ØU	R	I	1	F21 Coolant Outlet Temperature
TFØFC	R	I	1	Final Ø2 Tank Temperature
TFHFC	R	I	1	Final H2 Tank Temperature
PFØFC	R	I	1	Final Ø2 Tank Pressure
PFHFC	R	I	1	Final H2 Tank Pressure
RHØFIL	R	I	2	Reactant Fill Densities
WØVENT	R	I	1	Estimated Ø2 Vent Quantity
WHVENT	R	I	1	Estimated H2 Vent Quantity
DELTCP	R	I	1	Tank Circulating Compressor Delta-P
TENV	R	I	1	Fuel Cell System Environmental Temp
PRFCØP	R	I	1	Fuel Cell Operating Pressure
PØWNØM	R	I	1	Nom. Fuel Cell Operating Power Level
NFCØP	I	I	1	Number of Fuel Cells Operating
NFCSTB	I	I	1	Number of Fuel Cells Standby
SØPRES	R	I	2	Reactant Tank Operating Pressures
DCYCLE	R	I	100	Fuel Cell Operating + Non-Operating Time Intervals

NAME	TYPE	I/Ø	DIMENSION	DESCRIPTION
PKW	R	I	100	Constant Power Levels for Operating Intervals
PLSET1	R	I	1	Ø2 Tank Lower Pressure Limit Setting
PLSET2	R	I	1	H2 Tank Lower Pressure Limit setting
VJANUL	R	I	2	Fluid Tank Vacuum Jacket Annuli (Inches)
TKMXDI	R	I	2	Fluid Tank Maximum Diameters (Inches)
PØWTØT	R	Ø		Total Electric Power Supplied for Mission
WRFØRP	R	Ø	1	Wgt Reactants Consumed for Power Mission
WRP	R	Ø	12	Wgt Reactants Consumed for Power Each Interval
WØCØNS	R	Ø	1	Wgt Ø2 Consumed for Power - Mission
WHCØNS	R	Ø	1	Wgt H2 Consumed for Power - Mission
WØRFP	R	Ø	12	Wgt Ø2 for Power - each duty cycle interval
WHRFP	R	Ø	12	Wgt H2 for Power - each duty cycle interval
WDTFCØ	R	Ø	12	Ø2 Flow Rate - each duty cycle interval
WDTFCH	R	Ø	12	H2 Flow Rate - each duty cycle interval
PKWMAX	R	Ø	1	Max. Power drawin in any interval
WDTMX	R	Ø	2	Max Flow Rate Reactants - in any interval
WDØTI	R	Ø	2	Max. Flow Rates per Second for Component Sizir
TMF21	R	Ø	1	Mean Temp of F21 Hot fluid available
QF21	R	Ø	1	Specific Heat of F21 Hot Fluid
CF21	R	Ø	1	Heat Value of F21 Hot Fluid per lb.
QAVAIL	R	Ø	12	Heat (BTU's) available from F21 Hot Fluid
WDTF21	R	Ø	12	Flow Rate of F21 Hot Fluid
QFCTOT	R	Ø	1	Total BTU's available from F21 Hot Fluid
PCØFC	R	I	1	Operating Pressure Ø2 Reactant Tank
TEMPO2	R	Ø	1	Initial Temp of Ø2 Reactant in Tank
PCHFC	R	I	1	Operating Pressure H2 Reactant Tank
TEMPH2	R	Ø	1	Initial Temp of H2 Reactant in Tank
TKØ2WD	R	Ø	12	Ø2 Reactant Withdrawn - each duty cycle interv
TKH2WD	R	Ø	12	H2 Reactant Withdrawn - each duty cycle interv
PCWDØ2	R	Ø	12	Percent Ø2 Withdrawn - each duty cycle interva
PCWDH2	R	Ø	12	Percent H2 Withdrawn - each duty cycle interva
RHØTØ2	R	Ø	12	Density of Ø2 in Tank - each duty cycle interv
TKØ	R	Ø	12	Ø2 Temp in Tank - each duty cycle interval
TKH	R	Ø	12	H2 Temp in Tank - each duty cycle interval

NAME	TYPE	I/Ø	DIMENSION	DESCRIPTION
DQDWØ	R	Ø	12	Heat Input (BTU/lb) to Ø2 - each duty cycle interval
DQDWH	R	Ø	12	Heat Input (BTU/lb) to H2 - each duty cycle interval
QIØDTR	R	Ø	12	Heat Req'd for Ø2 Heat Exchanger-each interval
WDTIFØ	R	Ø	12	F21 Flow Rate for H2 Heat Exchanger-each interval
QIHDTR	R	Ø	12	Heat Req'd for H2 Heat Exchanger-each interval
WDTIFH	R	Ø	12	F21 Flow Rate for Ø Heat Exchanger-each interval
Q2ØDTR	R	Ø	12	Heat Required for Ø2 Tank Heat Exchanger-each interval
Q2HDTR	R	Ø	12	Heat Req'd for H2 Tank Heat Exhanger -each interval
WDTR2FØ	R	Ø	12	F21 Flowrate for Ø2 Tank Heat Exchanger - each interval
WDT2FH	R	Ø	12	F21 Flowrate for H2 tank heat exchanger - each interval
PHIFØ2	R	Ø	12	Energy Derivative for Ø2 In Tank - each interval
PHIFH2	R	Ø	12	Energy Derivative for H2 In Tank - each interval
QSUMR	R	Ø	12	Sum of all Heat Reqmts - each interval
DØANET	R	Ø	12	Difference between Available Heat and Heat Reqd
QTØTR	R	Ø	1	Total Heat Reqd over mission span
QEXCES	R	Ø	1	Difference Between Total available and total required
WF21MX	R	Ø	1	Max. Flowrate of F21 hot fluid
DØAMIN	R	Ø	1	Minimum value of DØANET
TKØMAX	R	Ø	1	Maximum value of Ø2 Tank Temp
TKHMAX	R	Ø	1	Maximum value of H2 Tank Temp
QMXTKØ	R	Ø	1	Max. Heat Reqmt for Ø2 tank
QMXTKH	R	Ø	1	Max. Heat Reqmt for H2 Tank
PRFCMN	R	I	2	Minimum Reactant Tank Pressures
WDTCFØ	R	Ø	1	Ø2 Tank Recirculation Max. Flow Rate
WDTCFH	R	Ø	1	H2 Tank Recirculation Max. Flow Rate
WØCMP	R	Ø	1	Weight of Ø2 Tank Circulating Compressor
WHCMP	R	Ø	1	Weight of H2 Tank Circulating Compressor
WCIRCP	R	Ø	2	Variable which saves Circulating Compressor Wgts
PØWMAX	R	Ø	1	100% Power over Mission Span
WRMAX	R	Ø	1	Reactant Based upon 20% of PØWMAX
WRRSRV	R	Ø	1	Total Reserve Reactant (lbs)

NAME	TYPE	I/O	DIMENSION	DESCRIPTION
WØRSRV	R	Ø	1	Total Ø2 Reserve Reactant (lbs)
WHRSRV	R	Ø	1	Total H2 Reserve Reactant (lbs)
WTRES	R	Ø	2	Residual Reactants in Tanks - end of missio
VOLTNK	R	Ø	2	Volume of Reactant Tanks
AREATK	R	Ø	2	Surface Area of Reactant
QLKØ	R	Ø	12	Heat Leak into Ø2 Tank -each non-oper inter
QLKH	R	Ø	12	Heat Leak into H2 Tank - each non-oper inte
QLEAKØ	R	Ø	1	Total Heat Leak into Ø2 Tank
QLEAKH	R	Ø	1	Total Heat Leak into H2 Tank
SNBAR	R	I	2	Number of Insulation Layers per Inch Thick
SITHIK	R	I	2,1	Insulation thickness in inches
WVHØ	R	Ø	1	Wgt Vented H2 Req'd to Cool Ø2 Tank
WVHH	R	Ø	1	Wgt Vented H2 req'd to Cool H2 Tank
WHVENT	R	Ø	1	Total Wgt of Vented H2
WRTØTL	R	Ø	2	Total Wgt of Reactants Loaded in Tanks
DIATK	R	Ø	2	Diameter of Reactant Tanks
TIWT	R	Ø	2, 1	Tank Insulation Weights
DIAVJ	R	Ø	2	Diameter of Tank Vacuum Jackets
SMTYPE	I	I	2, 1	Tank Material Designation
RHØFTU	R	Ø	2	Tank Material Density/Ultimate Stress
WTPVT	R	Ø	2	Wgt of Tank Pressure Vessels
WTVJ	R	Ø	2	Wgt of Tank Vacuum Jackets
WTTØT	R	Ø	2	Total Weight of Each Tank Assy
FCWGT	R	Ø	1	Total Weight of Fuel Cells
WDØTX	R	Ø	10,2	Cold Fluid Flow Rate
UCØDE	R	I	10, 2	Heat Exchanger Code Designation
HEXHIT	R	Ø	10,2	Hot Fluid Inlet Temp
HEXCIT	R	Ø	10, 2	Cold Fluid Inlet Temp
HEXHØT	R	Ø	10, 2	Hot Fluid Outlet Temp
HEXCØT	R	Ø	10, 2	Cold Fluid Outlet Temp
HEXCØP	R	Ø	10, 2	Cold Fluid Outlet Pressure
HEXCIP	R	Ø	10, 2	Cold Fluid Inlet Pressure
HSQREQ	R	Ø	10, 2	Heat Source BTU's Required
HSGCPE	R	Ø	10, 2	Heat Source Specific Heat
HSGTØT	R	Ø	10,2	Total Heat Trim Heat Source
WHXTØT	R	Ø	10, 2	Heat Exchanger Weight

NAME	TYPE	I/Ø	DIMENSION	DESCRIPTION
PSET1	R	Ø	1	Lower Limit Ø2 Tank Pressure Setting
PSET2	R	Ø	1	Lower Limit H2 Tank Pressure Setting
PTANK1	R	Ø	1	Ø2 Tank Pressure at Sub-Interval Time Point
PTANK2	R	Ø	1	H2 Tank Pressure at Sub-Interval Time Point
TIM	R	Ø	12	Time Duration of a Duty Cycle Interval
DTØ30	R	Ø	1	Subdivided Ø2 Flowrate for 10 min Period
DTH30	R	Ø	1	Subdivided H2 Flowrate for 10 min Period
NTP	I	Ø	1	Number of Time Sub-intervals in duty cycle interval
TIME	R	Ø	1	Time Sub-intervals in minutes
KØDP	R	Ø	1	Ø2 Tank Depletion (lbs)
KHDP	R	Ø	1	H2 Tank Depletion (lbs)
PCØXW	R	Ø	1	Percent Ø2 withdrawn from Tank
PCH2W	R	Ø	1	Percent H2 withdrawn from Tank
RHØ	R	Ø	1	Density of Remaining Ø2 in Tank
RHØ	R	Ø	1	Density of Remaining H2 in Tank
XTEM	R	Ø	1	Temp of remaining Ø2 in Tank
2TEM	R	Ø	1	Temp of remaining H2 in Tank
QDM1	R	Ø	1	Heat Input to Remaining Ø2 in Tank
QDM2	R	Ø	1	Heat Input to Remaining H2 in Tank
PDU1	R	Ø	1	Energy Deviation of Ø2 remaining in Tank
PDU2	R	Ø	1	Energy Derivation of H2 remaining in tank
1CUM	R	Ø	1	Cumulative Heat Reqd in Ø2 Tank
2CUM	R	Ø	1	Cumulative Heat Reqd in H2 Tank
ETAØ	R	Ø	1	Volume Expansivity of Ø2 in Tank
ETAH	R	Ø	1	Volume Expansivity of H2 in Tank
ELP1	R	Ø	1	Ø2 Tank Pressure Drop in Interval ITIM
ELP2	R	Ø	1	H2 Tank Pressure Drop in Interval ITIM
TRØN1	R	Ø	1	Time (min) for Heat Source to be ØN during ITIM period
TRØN2	R	Ø	1	Time (min) for Heat Source to be ØN duringITIM period
TANK1	R	Ø	1	Equals Q1CUM (Used to Calc. HTRØNI)
TANK2	R	Ø	1	Equals Q2CUM (Used to Calc. HTRØN2)
	I	Ø	1	Ø2 Heater Cycle Counter
	I	Ø	1	H2 Heater Cycle Counter

SUBPROGRAM REFERENCED IN FUELCL

NAME	TYPE	PURPOSE	REFERENCE
PAGE	F	Controls Page & Line Count-Output	Page B-23
CSPF21	F	Calculates Cp for F21 Hot Fluid	Page B-87
OXENTH	F	Calculates Ø2 Enthalpy	Page B-23
HYENTH	F	Calculates H2Enthalpy	Page B-19
FINTAB	S	Finds Designated Table of Data	Page B-14
MIPE	F	Table Data Extraction	Page B-22
CSUBV	F	Calculates Cv for Desired Fluid	Page B-93
ZFIND	S	Compute Compressibility for H2	Page
ZGET	F	Computes Compressibility for Ø2	Page B-33
PHTHØN	S	Computes THETA and PHI for Ø2	Page B-33
AMINI	F	Finds Minimum of two REAL values	System Li
AMAXI	F	Finds Maximum of two REAL Values	System Li
DENSØN	S	Calculates Density for Ø2 and N2	Page B-10
GSDNST	S	Calculates Gas Density for H2	Page B-21
CSUBP	S	Calculates Cp for Desired Fluid	Page B-88
TCØND	S	Computes thermal Conductivity for Insulation	Page B-29
SQRT	F	Computes Square Root of Variable	System Rou
HEXF21	S	Computes Heat Exchanger Weight for Desired Fluid	Page B-18
BETAB	S	Computes Volume Expansivity (Beta) for Desired Fluid	Page B-25
ØTPHXF	S	Output Subroutine for Freon Heat Exchangers	Page B-22

SUBPROGRAMS REFERENCING FUELCL

NAME	TYPE	PURPOSE	REFERENCE
CRYCØN	S	Sequential Control of Analysis	Page B-85

LISTING REFERENCE PAGE

A listing of subroutine FUELCL will be found in Appendix B, Page 152.

FLOW CHART

The flow chart for FUELCL is presented in Figure 1.9-7.

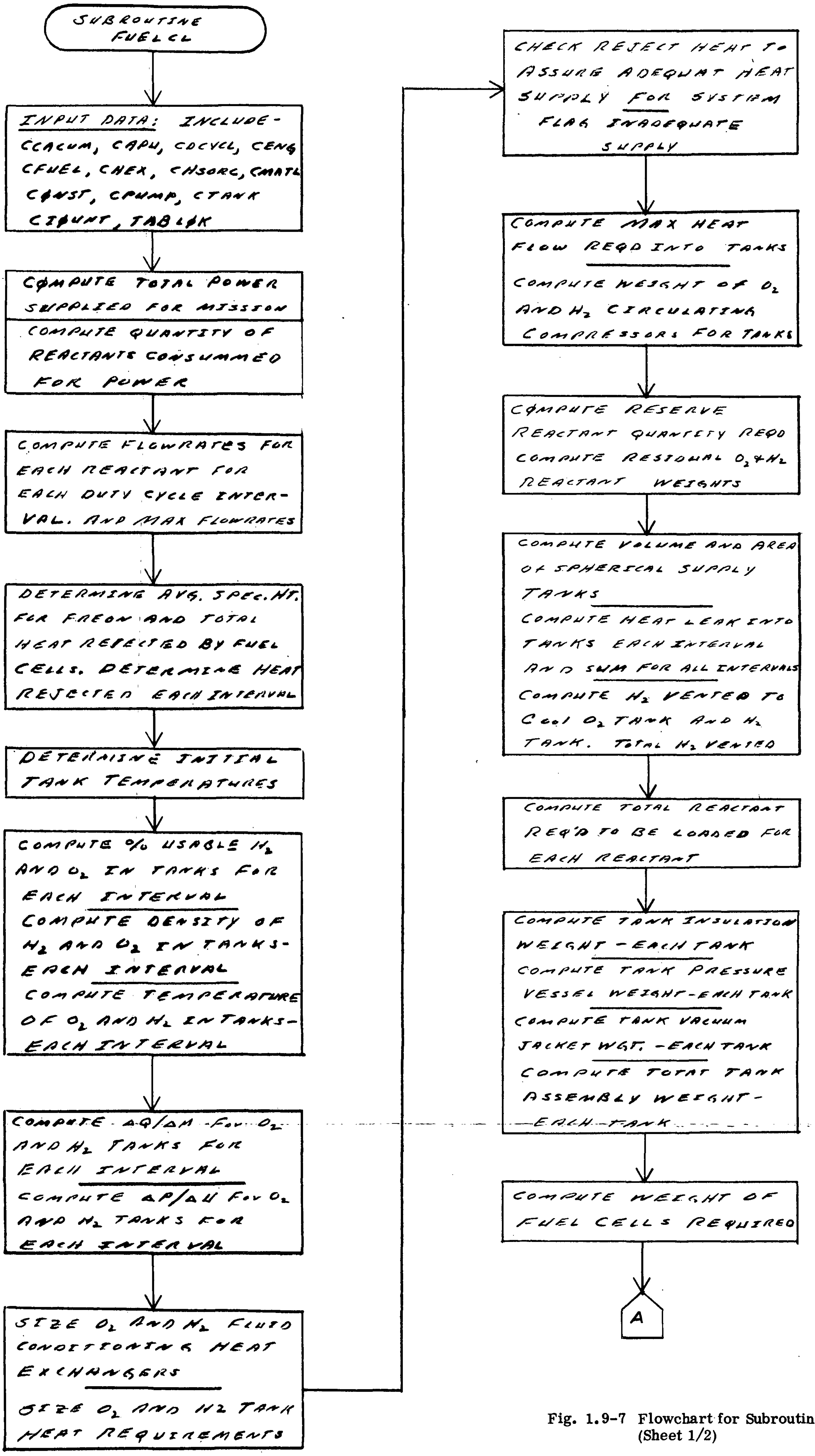

Fig. 1.9-7 Flowchart for Subroutine FUELCL
(Sheet 1/2)

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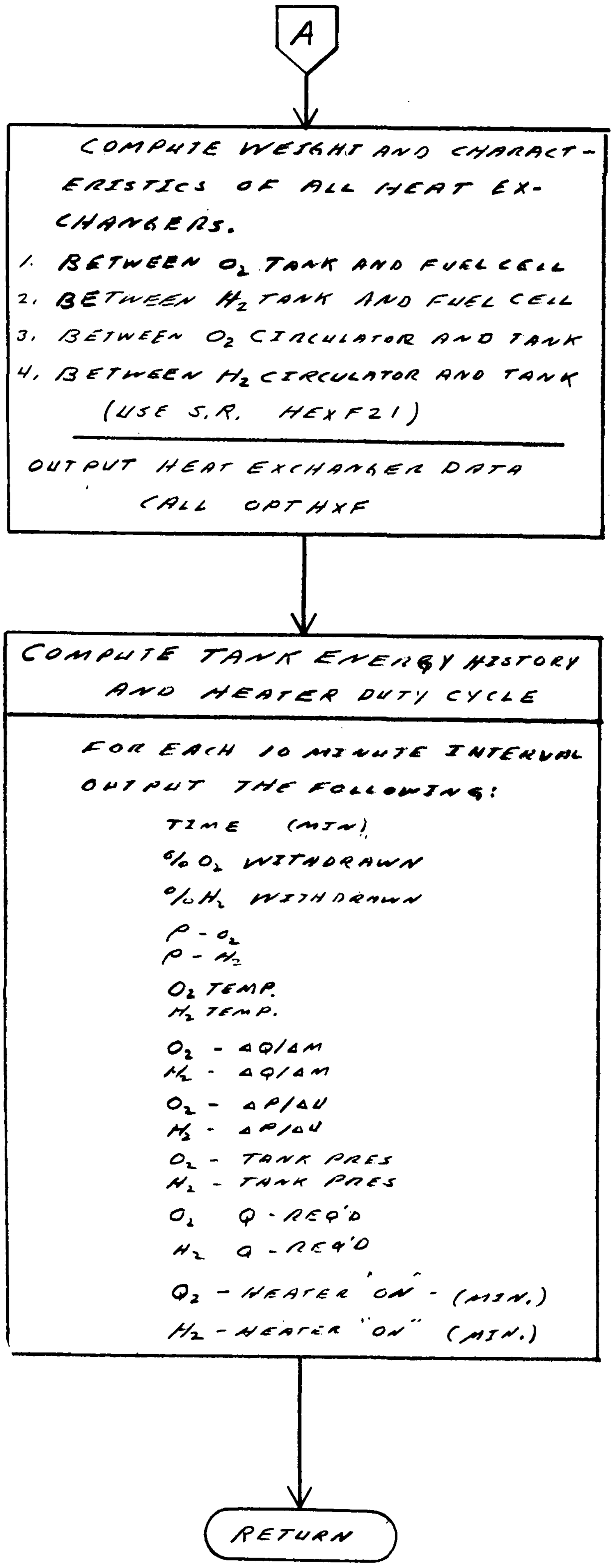

Fig. 1.9-7 Flowchart for Subroutine FUELCL
(Sheet 2/2)

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SUBROUTINE GASGEN

DESCRIPTION

Subroutine GASGEN computes the weight of a gas generator employed on a primary heat source for a cryogen heat exchanger. The routine additionally considers the cases where all or a part of the thermal energy required may be derived from waste heat rejected from another system.

The principal computations performed by GASGEN are as follows:

(a) Computes the weight of a gas generator functioning as the only heat source for a cryogen heat exchanger.

(b) Computes the thermal energy required by a heat exchanger where waste heat is the only heat source.

(c) Computes the weight of a gas generator which supplies makeup thermal energy to satisfy a deficit in available waste thermal energy.

The basic gas generator weight equations employed in GASGEN were derived from Reference 1.9-3.

Input data for use in GASGEN is derived from on-going calculations performed in the subprograms which call GASGEN through the labeled CØMMØN storage blocks. The labeled CØMMØN storage areas employed by GASGEN for data storage and transfer are as follows:

```
CØMMØN/CDCYCL/
CØMMØN/CHEX/
CØMMØN/CHSØRC/
CØMMØN/CTANK/
```

GAS GEN MATHEMATICA MODEL

The GASGEN math model presenting the equations and pertinent data is presented in Appendix C.

CALLING SEQUENCE

Subroutine GASGEN is called with two argments, JX and IGAS. Argument JX is the heat exchanger position-in-array index which directs all related data to the proper array position reserved for a particular heat exchanger.

Argument IGAS specifies the fluid processed by the heat exchanger under consideration. Input data, as stated above, is transferred through C0MM0N by the use of INCLUDE statements to bring in specific common blocks.

SIGNIFICANT VARIABLES

Significant variables employed in the routine are as follows:

Name	Type	I/0	Dimension	Description
JX	I	I	1	Heat exchanger data array index
IGAS	I	I	1	Index of fluid under consideration
HSGSUM	R	C	1	Summed thermal energy required over mission
WGGFU	R	C	10,2	Thermal energy available from waste heat over mission
WGGFX	R	C	10,2	Thermal energy to be supplied by gas generator
HSWGHT	R	0	10,2	Gas generator weight
HSASSY	R	0	11,2	Gas generator plus heat exchanger weight
HSQRQD	R	0	10,2	Waste thermal energy available
HSGCPE	R	0	10,2	Specific heat of waste hot fluid

SUBPROGRAMS REFERENCED IN GASGEN

None

SUBPROGRAMS REFERENCING GASGEN

Name	Type	Purpose	Reference
CMPCAL	S	Configuration Analysis	Page B-50
APUSUP	S	APU Supercritical Analysis	Page B-8

LISTING REFERENCE PAGE

A listing of subroutine GASGEN will be found in Appendix B, page 172.

FLOW CHART

None

Subroutine GETC0N

DESCRIPTION

Subroutine GETC0N unpacks the word in the first column of the configuration array C0NFIG designated by the cabling variable IDX. The first column of CONFIG contains data packed by subroutine ST0C0N and is in the format described in the writeup for that subroutine. GETC0N unpacks the six bytes of data and stores it in the same order in the six word array ICNFIG.

Labeled Common

C0MM0N/CCNFIG/
C0MM0N/CI0UNT/

Mathematical Model for GETC0N

None

Calling Sequence

ST0C0N is called by CMPCAL, LSSCMP and 0TRTNS and has one variable in its calling sequence. The variable is the location index for the component storage array. All other data is transferred thru labeled common CCNFIG.

Significant Variables

Name	Type	I/0	Dimension	Description
CONFIG	I	I	100,7	Packed data stored in first column of this array
ICNFIG	I	0	6	Output array of unpacked data
IDX	I	I	1	Location index in the array C0NFIG

Subprograms Referenced by GETC0N

Name	Type	Purpose	Reference
IPBYTE	F	Byte Manipulation Routine	LMSC Systems Routines

Subprograms Referencing GETC0N

Name	Type	Purpose	Reference
CMPCAL	S	Computes Weight, Pressure, etc., for given components	Page B-50
LSSCMP	S	Component configuration processing for EC/LSS	Page B-208
0TRTNS	S	Main output routine for system	Page B-226

Listing Reference

A listing of GETC0N can be found in Appendix B, Page 174.

Flow Chart

None

FUNCTION G0MTRY

DESCRIPTION

The subprograms labeled G0MTRY on its control card is actually a set of eight function subprograms using entry points under the heading function "CONE". The entry point names and their use are: (1) "CYLNDR" calculates volume of a right circular cylinder given a height and radius; (2) "CYLSPH" calculates the volume between a cylinder and an ellipsoid which has been inserted in the top end, inputs are height (same as axis of rotation for the ellipsoid) and radius; (3) "FRC0NE" calculates the volume of a frustrum of a right circular cone, given the height and the radius of the top and bottom ends; (4) "HSPHER" calculates the volume of half of an ellipsoid or hemisphere given the length of the semi-major and semi-minor axes (these are equal for a hemisphere; (5) "SPHERE" calculates volume of an ellipsoid or sphere given the lengths of the axes; (6) "ARACYL" calculates the area of a cylinder excluding the ends – given height and radius; (7) "AREAFR" computes the area of a frustrum of a cone excluding the "ends" – given the height and radius of the top and bottom; (8) "ARSPHR" calculates the area of half of an ellipsoid given the length of major or minor axes – (a hemisphere if axis lengths are same).

Labeled Common Used

C0MM0N/C0NST/

Mathematical Model of "G0MTRY"

For equations used, see Appendix C.

Calling Sequence

Each function entry point has a calling sequence as follows:

CYLNDR (Radius, Height)
CYLSPH (Radius on axis of rotation, radius perpendicular to first)

FRCONE (Radius of top, Height, Radius of Bottom)
HSPHER (Radius on rotation axis, radius perpendicular to first)
SPHERE (Radius on rotation axis, radius perpendicular to first)
ARACYL (Radius, Height)
AREAFR (Radius of Top, Height, Radius of Bottom)
ARSPHR (Radius on rotation axis, radius perpendicular to first)

Significant Variables

Name	Type	I/O	Dimension	Description
C0NE	R	0	1	The output volume or area of the function
E	R	I	1	Eccentricity of ellipse
H	R	I	1	Height of cylinder or frustrum of cone
R	R	I	1	Radius of cylinder, top of frustrum, or ellipse
RZ	R	I	1	Radius of bottom of frustrum
RR0T	R	I	1	Radius along rotation axis

Subprograms Referenced By G0MTRY

Name	Type	Purpose	Reference
AL0G	F	Calculates natural log	Univac 1108 system
ASIN	F	Calculates arc sine	Univac 1108 system
S0RT	F	Calculates spareroot	Univac 1108 system

Subprograms Referencing G0MTRY

Name	Type	Purpose	Reference
AFUNC	F	Controls calculation of areas.	Page B-299
TNKWTA	S	Controls calculation of tank geometry.	Page B-303
VFUNC	F	Controls calculation of volumes.	Page B-299

Listing Reference

A listing of "G0MTRY" can be found in Appendix B, Page 175.

Flow Chart

A flow chart of "G0MTRY" is presented in Fig. 1.9-8.

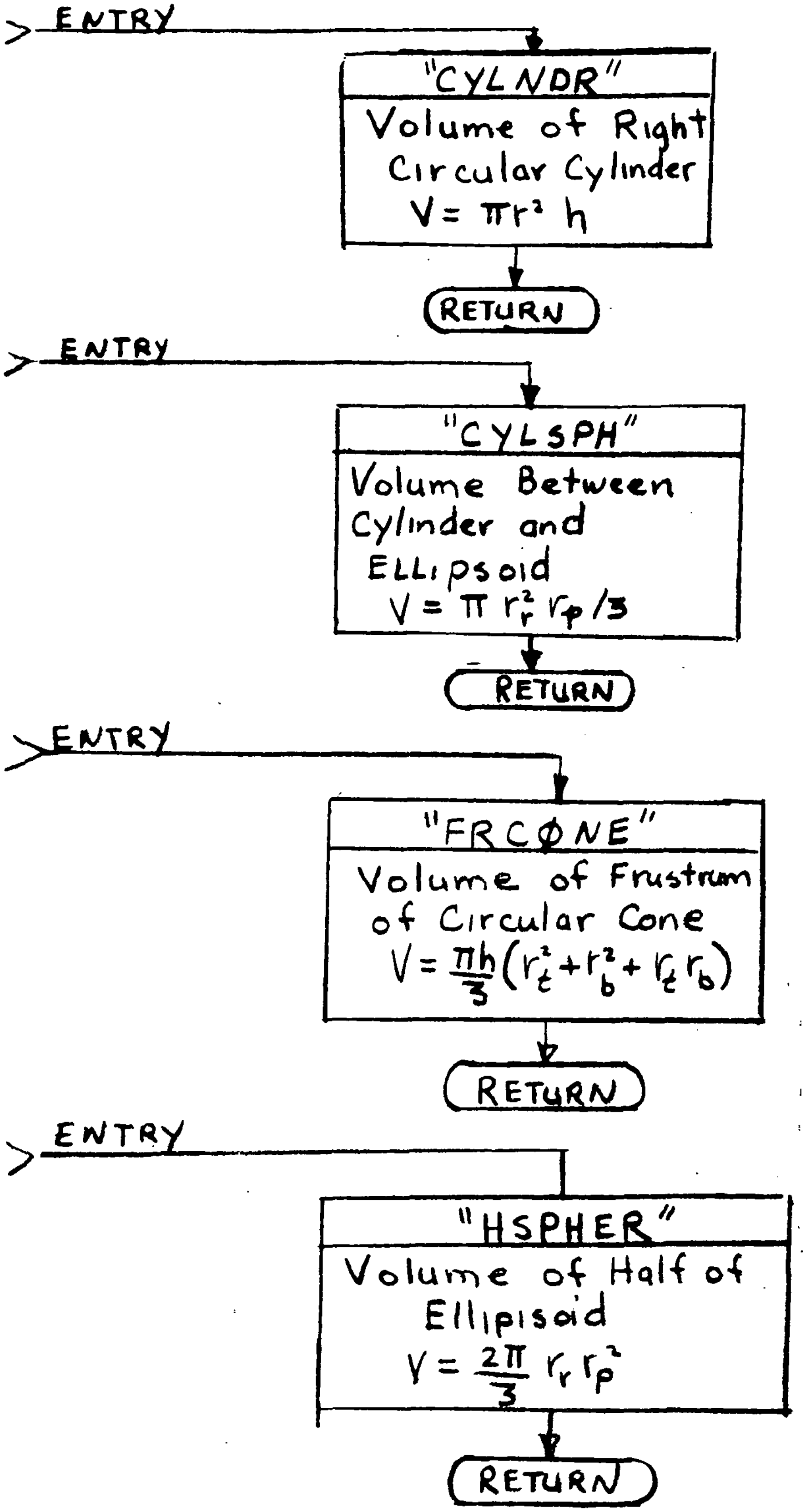


Fig. 1.9-8 Flowchart for GØMTRY

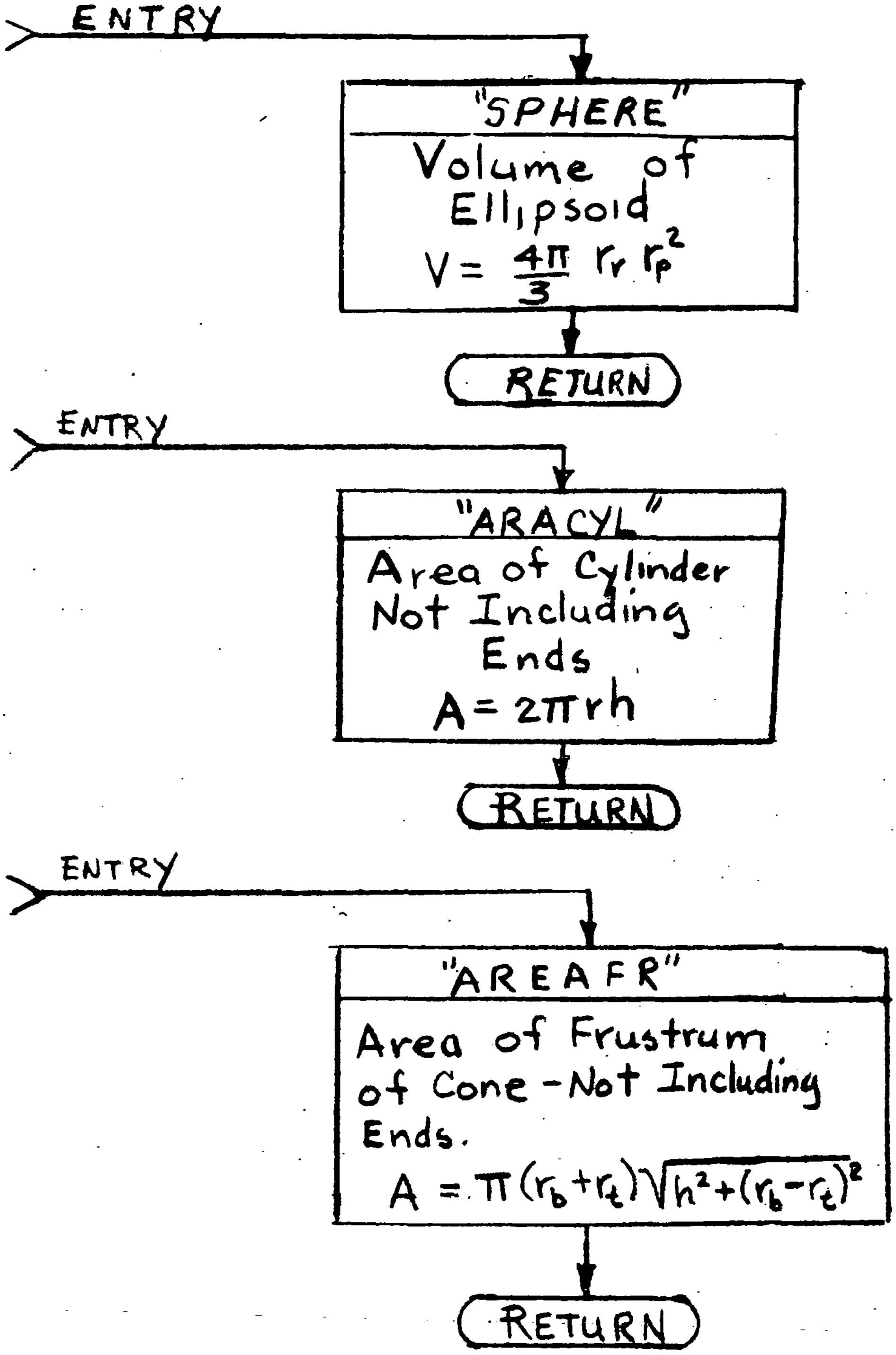


Fig. 1.9-8 Flowchart for GØMTRY (Continued)

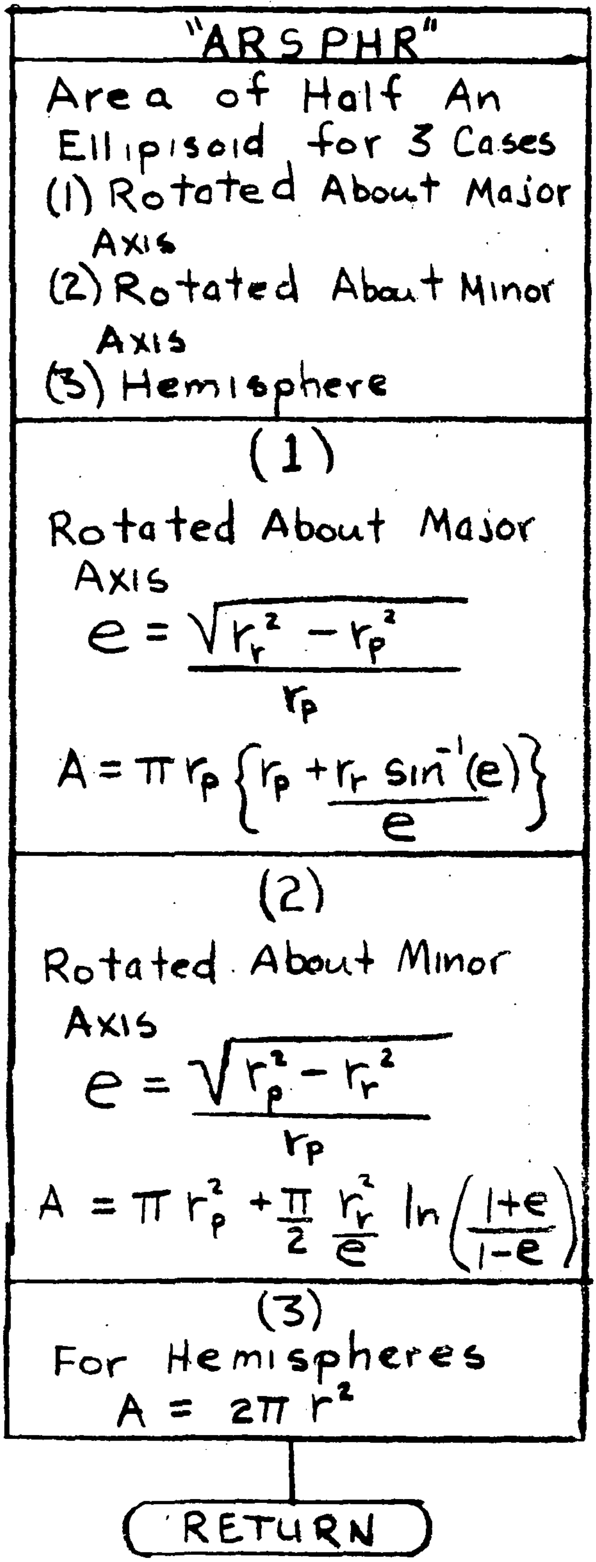


Fig. 1.9-8 Flowchart for GØMTRY (Continued)

SUBR0UTINE HEATEX

DESCRIPTION

This subroutine computes design parameters for sizing a heat exchanger, given the inlet and outlet temperatures and pressures for the hot and cold fluid sides, the flow rate for the cold fluid and the fluid type. However, in order to properly size the heat exchanger, it may be necessary to make changes to some of the input parameters. except that the cold fluid outlet temperature and pressure, which are set by previously calculate system parameters, cannot be changed.

The HEATEX subroutine calculates pressure and temperature drops from the input and checks that the pressure drops are within operating range and checks for condensation at the hot fluid outlet (so that freezing will not occur). Next, the heat exchanger is subdivided into subunits according to the heat transfer range designated by the input parameters. The subunit types are: (1) boiling subunit; (2) supercritical subunit; (3) parallel flow subunit and (4) counterflow subunit. After the proper subunit types have been determined the routine proceeds to design each one by calculating the number of transfer units (N_{tu}) necessary, the thermal conductance ratios (TCR), the UA and (W/UA) for each subunit. The weight of each subunit is then computed from these values and the total heat exchanger weight is the sum of the subunit weights or five pounds whichever is greater. The outputs from HEATEX are the weight and those input parameters which have been changed in the design process.

Labeled Common Used

C0MM0N/CHEX/
C0MM0N/CIQUNT/
C0MM0N/TABL0K/

Mathematical Model for HEATEX

The equations used by HEATEX may be found in Appendix C.

Calling Sequence

HEATEX is called by three subroutines and it has fourteen variables in its calling sequence, thirteen are input and one is output, however, some of the input variables may be changed by the design process.

Significant Variables

Name	Type	I/Ø	Dimension	Description
CMAX	R	I	1	Maximum capacity rate
CMIN	R	I	1	Minimum capacity rate
CR	R	I	1	Capacity rate ratio
DIC	R	I	1	Change in enthalpy cold side
DIH	R	I	1	Change in enthalpy hot side
DPC	R	I	1	Pressure drop cold side
DPH	R	I	1	Pressure drop hot side
DTC	R	I	1	Temperature change cold side
DTH	R	I	1	Temperature change hot side
EFFC	R	I	1	Cold side effectiveness
EFFH	R	I	1	Hot side effectiveness
EFSUM	R	I	1	Sum of effectiveness (EFFC + EFFH)
FDIC	R	I	1	Subunit change in enthalpy cold side
FDIH	R	I	1	Subunit change in enthalpy hot side
FDPC	R	I	1	Subunit pressure drop cold side
FDTC	R	I	1	Subunit temperature change cold side
FEMX	R	I	1	Subunit effectiveness
FIIN	R	I	1	Subunit enthalpy at inlet cold side
FIØT	R	I	1	Subunit enthalpy at outlet cold side
ICIN	R	I	1	Enthalpy at inlet cold side
ICØUT	R	I	1	Enthalpy at outlet cold side
IGAS	I	I	1	Fluid type 1 = 0_2, 2 = H_2
ISU	I	I	1	Index of DO-LOOP for subunit design
JHEX	I	I	1	Heat exchanger ID number
NCVG	I	I	1	Convergence flag = 0 converged ±0 not converged
NTU	R	I	1	Number of transfer units
ØF	R	I	1	Oxidizer to fuel ratio. Set = 1
OFR	R	I	1	Oxidizer to fuel ratio input but not used

Name	Type	I/Ø	Dimension	Description
PCIN	R	I	1	Inlet pressure cold side
PCØUT	R	I	1	Outlet pressure cold side
PHIN	R	I	1	Inlet pressure hot side
PHØUT	R	I	1	Outlet pressure hot side
PSAT	R	I	1	Saturation pressure at hot fluid outlet
SDPC	R	I	1	Sum of subunit pressure drops
TCIN	R	I	1	Inlet temperature cold side
TCØUT	R	I	1	Outlet temperature cold side
TCSAT	R	I	1	Saturation temperature at cold outlet pressure PCØUT
THIN	R	I	1	Inlet temperature hot side
THØUT	R	I	1	Outlet temperature hot side
THSAT	R	I	1	Saturation temperature at a pressure PSA'
TØTWHX	R	Ø	1	Total heat exchanger weight (pounds)
TCSAT	R	I	1	Saturation temperature at cold outlet pressure PCØUT
UA	R	I	1	UA
WDØTC	R	I	1	Flow rate of cold fluid
WDØTCI	R	I	1	Same as WDØTC
WDØTH	R	I	1	Flow rate of hot fluid
WDØTHI	R	I	1	Same as WDØTH
WØUA	R	I	1	Weight factor
WTHX	R	I	1	Weight of a particular subunit

Subprograms Referenced By HEATEX

Name	Type	Purpose	Reference
ALØG	F	Calculates natural log	UNIVAC 1108 System
ENTHØH	S	Calculates enthalpy of O_2 or H_2	Page B-218
FINTAB	S	Locate a designated table	Page B-147
MIPE	F	Performs interpolation of a given table	Page B-221
TCRCAL	S	Calculate maximum and minimum TCR	Page B-218
TCRCLC	S	Calculates thermal conductance ratio	Page B-218
TCRLØW	S	Lowers calculated TCR value	Page B-218
TCRRAZ	S	Raises calculated TCR value	Page B-218
TSAT	F	Calculates saturation temperature	Page B-308
WØUACL	S	Calculate (W/UA)	Page B-218

Subprograms Referencing HEATEX

Name	Type	Purpose	Reference
APUSUP	S	Performs APU supercritical calculations	Page B-8
CMPCAL	S	Performs component configuration calculations	Page B-50
TANK	S	Tank pressure, weight duty cycle history	Page B-277

Listing Reference

A listing of HEATEX may be found in Appendix B, Page 177.

Flow Chart

Flow charts for HEATEX are presented in Fig.1.9-9 and Fig. 1.9-10.

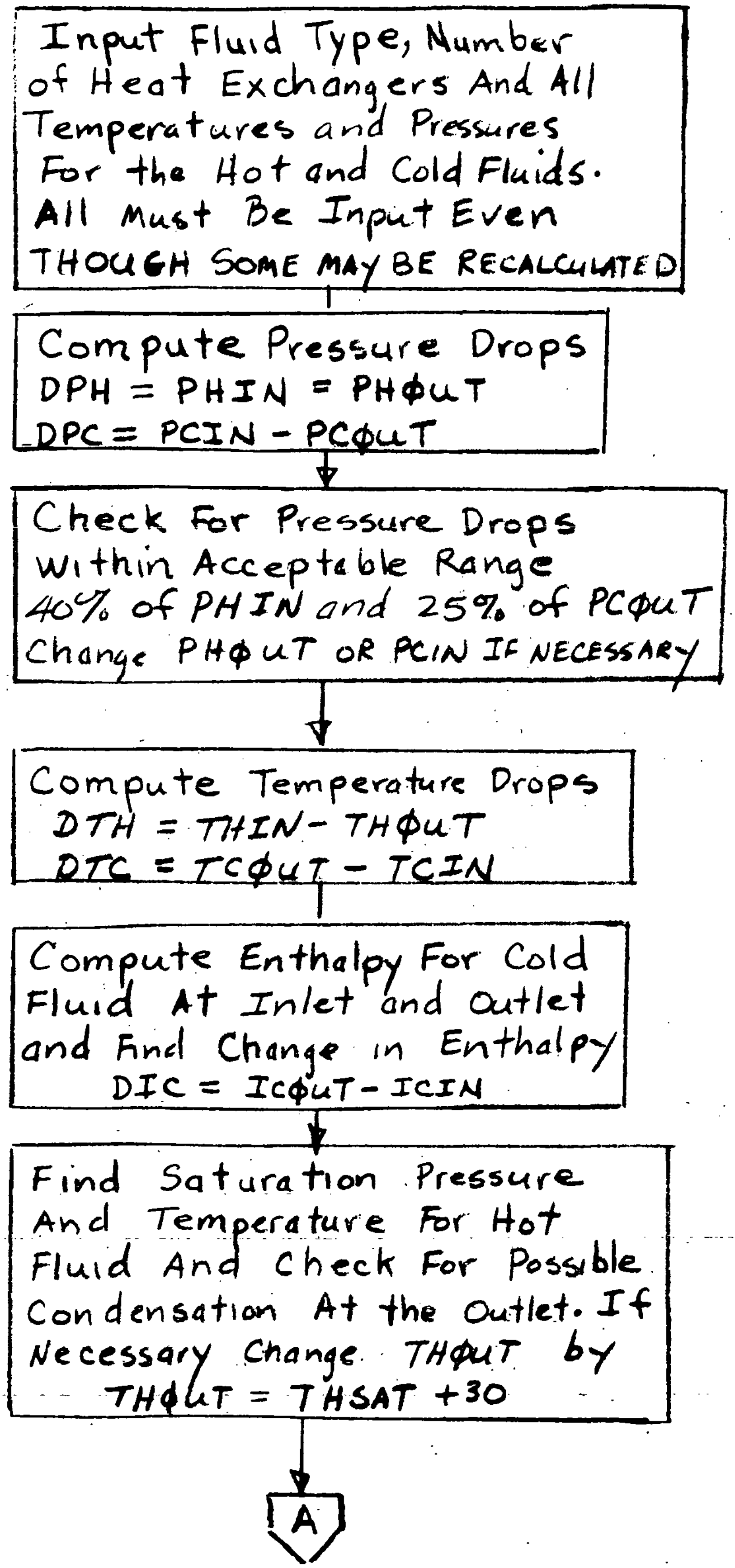


Fig. 1.9-9 Flowchart for HEATEX

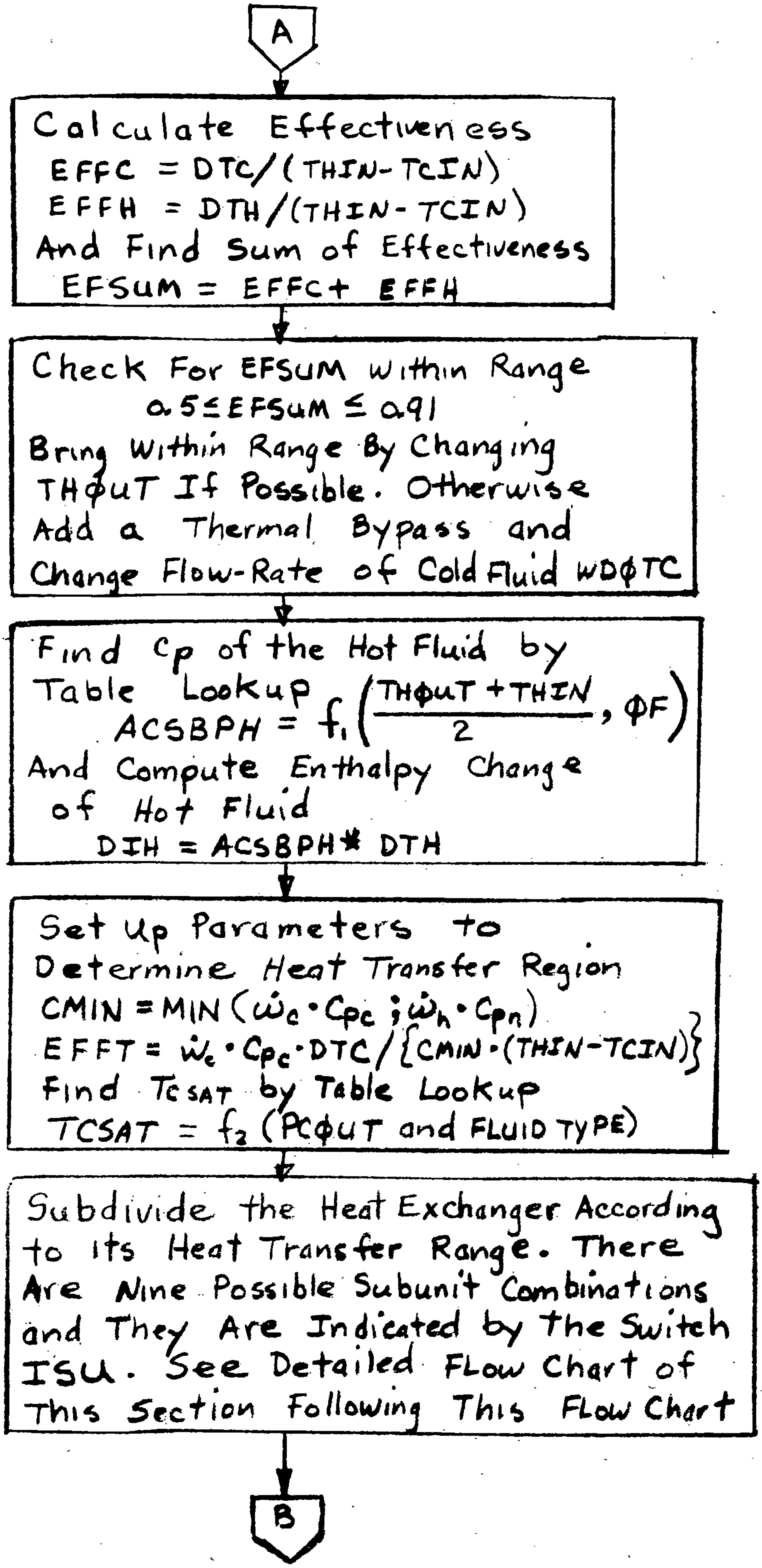


Fig. 1.9-9 Flowchart for HEATEX (Continued)

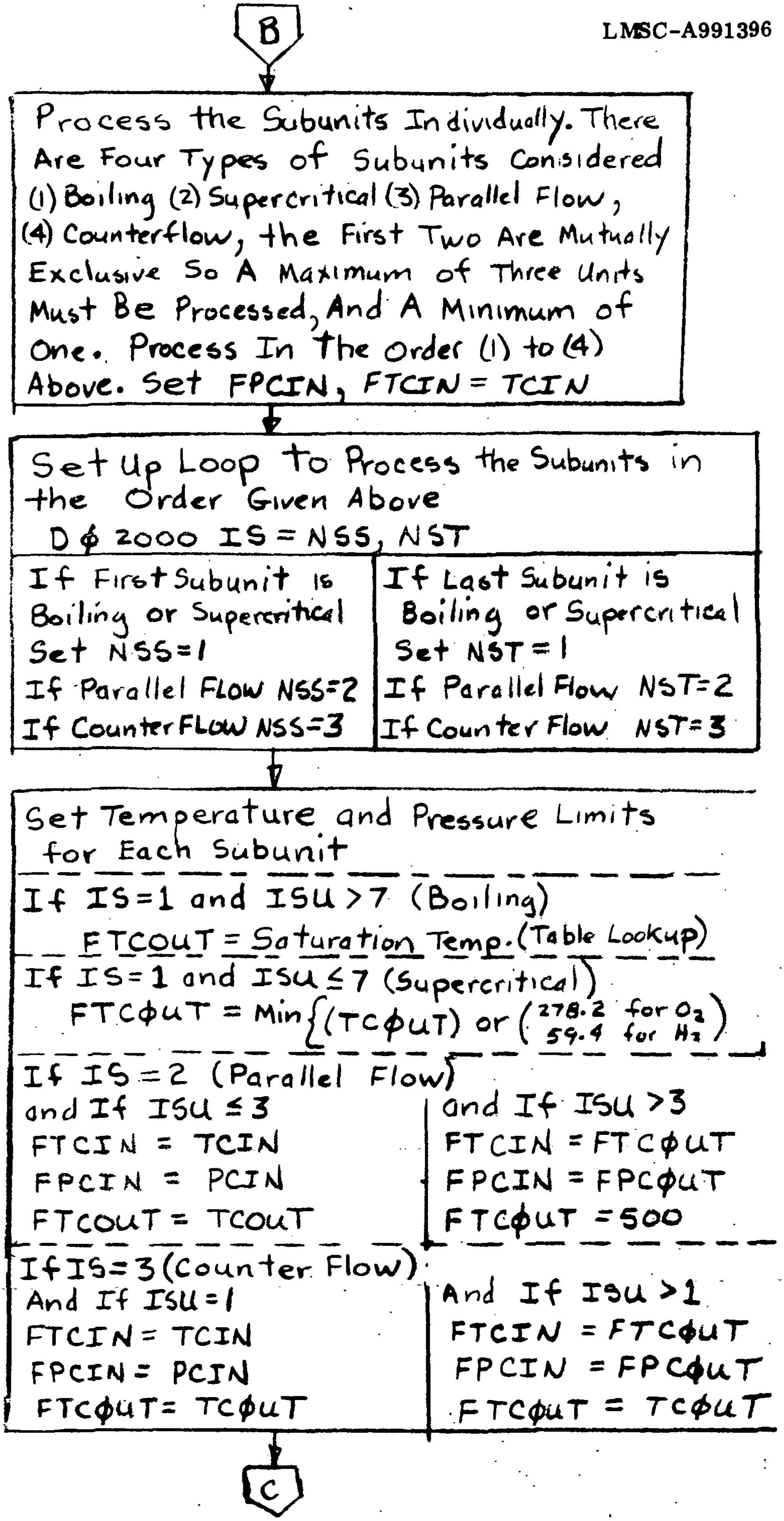


Fig. 1.9-9 Flowchart for HEATEX (Continued)

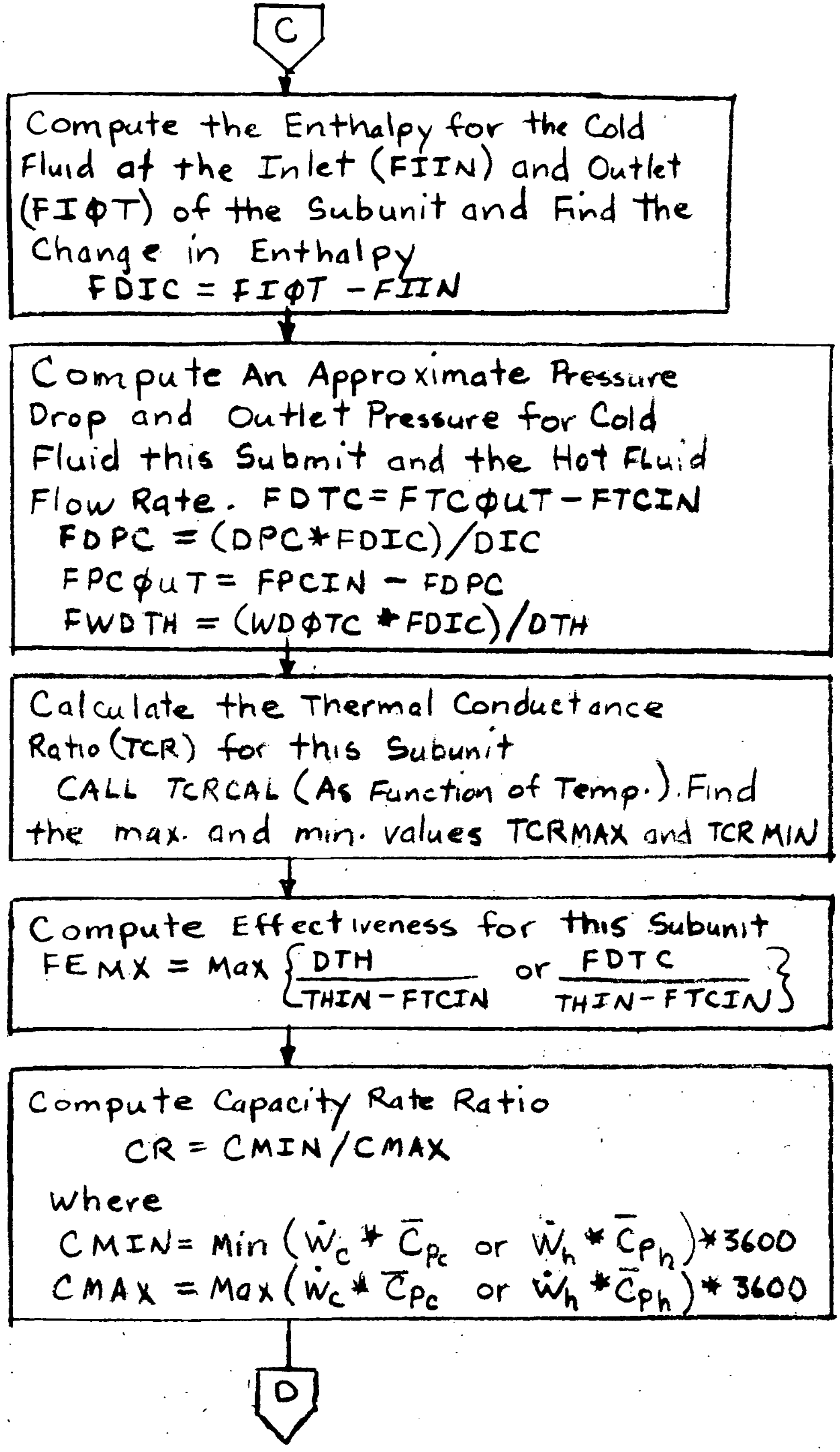
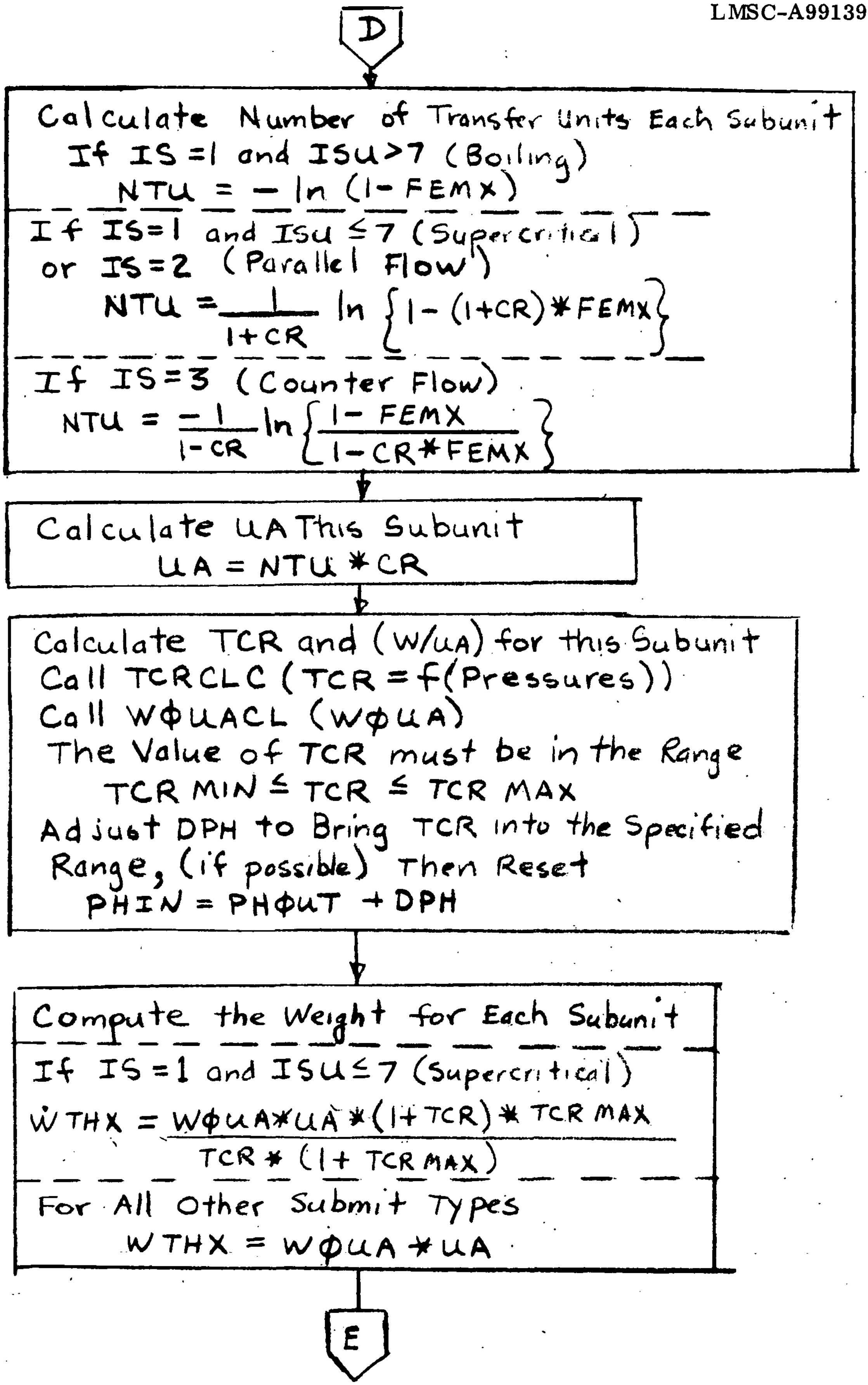


Fig. 1.9-9 Flowchart for HEATEX (Continued)



Calculate Number of Transfer Units Each Subunit

If IS = 1 and ISU > 7 (Boiling)

$$NTU = -\ln(1 - FEMX)$$

If IS = 1 and ISU ≤ 7 (Supercritical) or IS = 2 (Parallel Flow)

$$NTU = \frac{1}{1+CR} \ln \left\{ 1 - (1+CR) * FEMX \right\}$$

If IS = 3 (Counter Flow)

$$NTU = \frac{-1}{1-CR} \ln \left\{ \frac{1 - FEMX}{1 - CR * FEMX} \right\}$$

Calculate UA This Subunit

$$UA = NTU * CR$$

Calculate TCR and (W/UA) for this Subunit

Call TCRCLC (TCR = f(Pressures))

Call WØUACL (WØUA)

The Value of TCR must be in the Range

$$TCR\ MIN \le TCR \le TCR\ MAX$$

Adjust DPH to Bring TCR into the Specified Range, (if possible) Then Reset

$$PHIN = PHØUT + DPH$$

Compute the Weight for Each Subunit

If IS = 1 and ISU ≤ 7 (Supercritical)

$$\dot{W}THX = \frac{WØUA * UA * (1 + TCR) * TCR\ MAX}{TCR * (1 + TCR\ MAX)}$$

For All Other Submit Types

$$WTHX = WØUA * UA$$

Fig. 1.9-9 Flowchart for HEATEX (Continued)

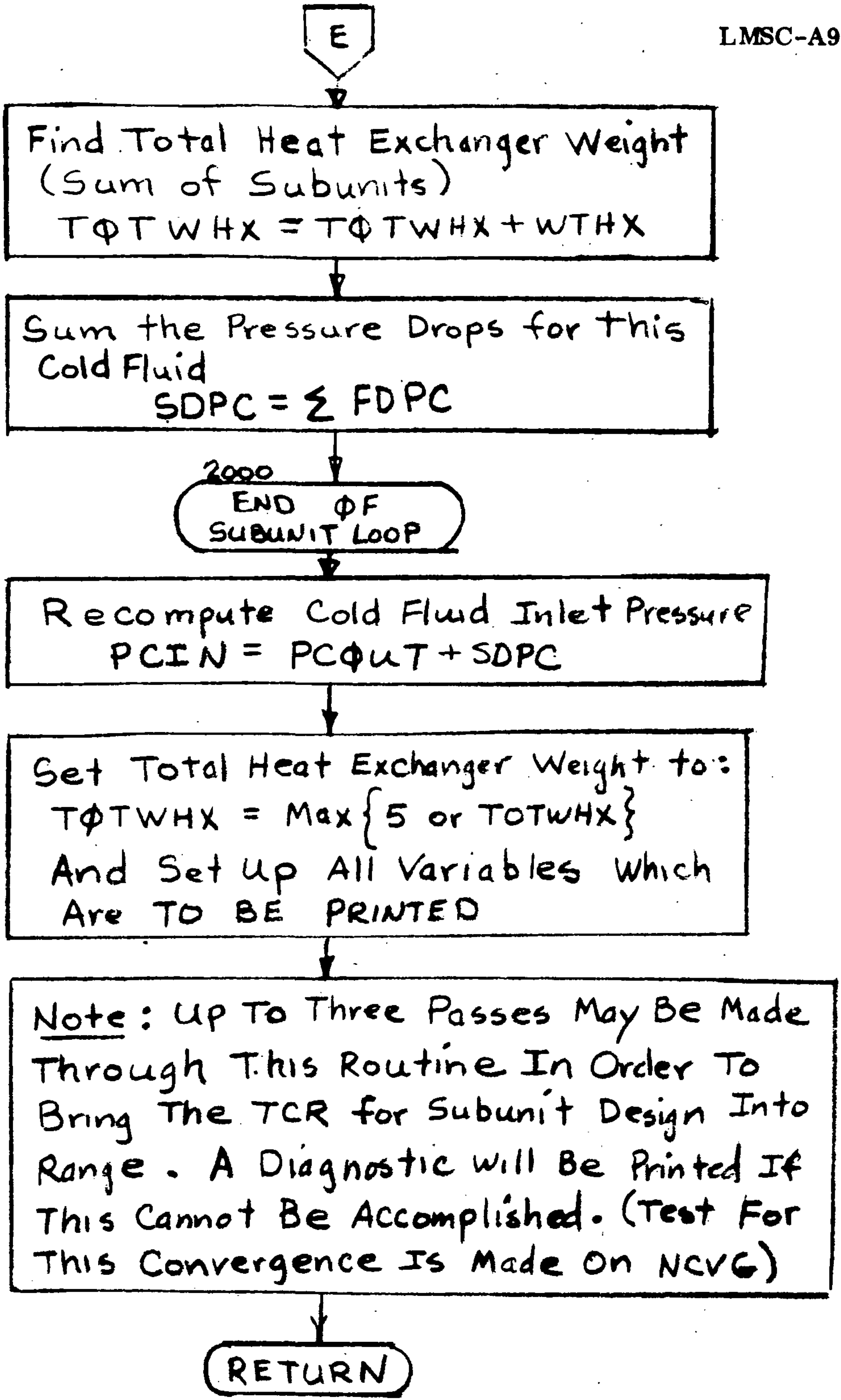


Fig. 1.9-9 Flowchart for HEATEX (Continued)

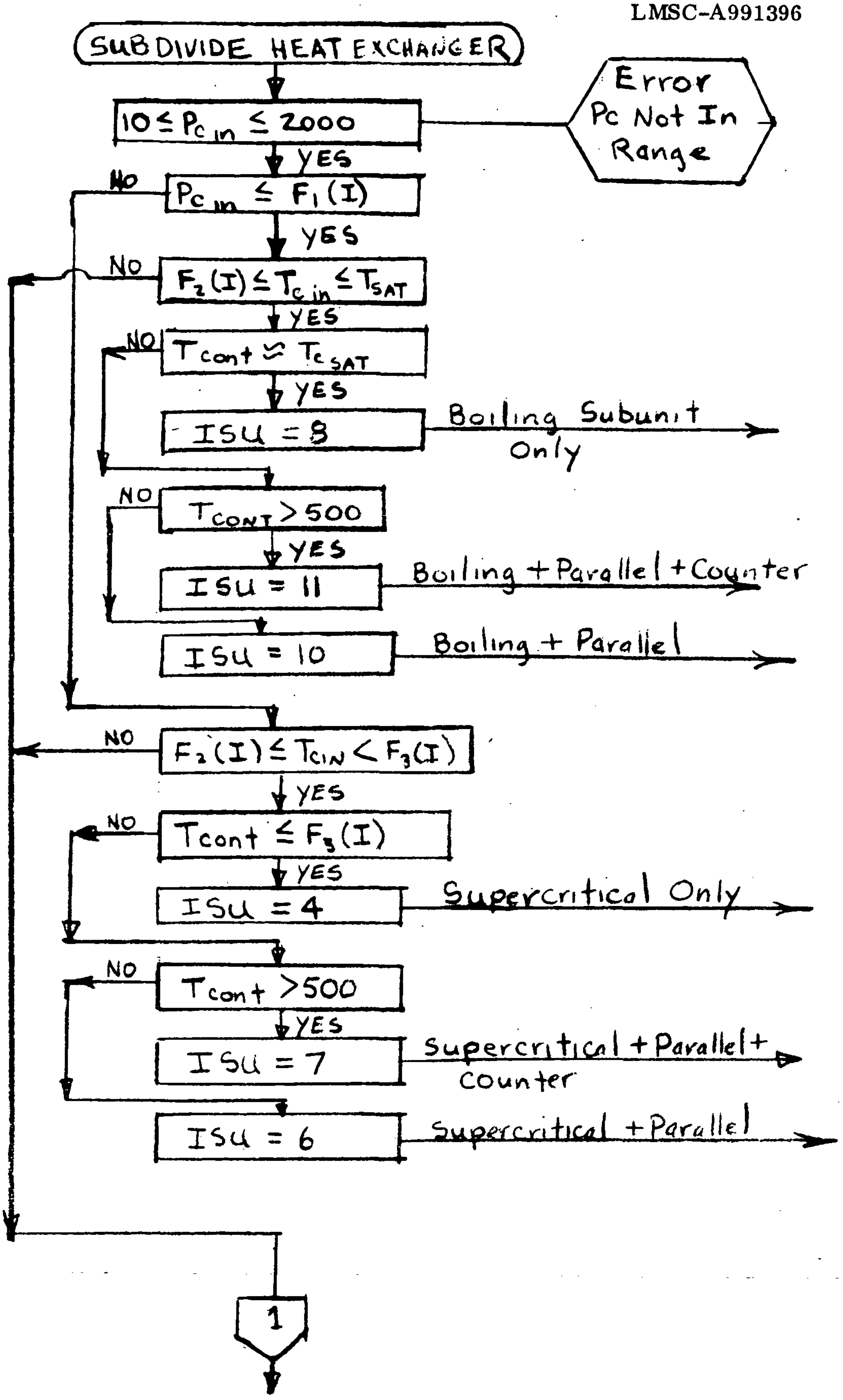
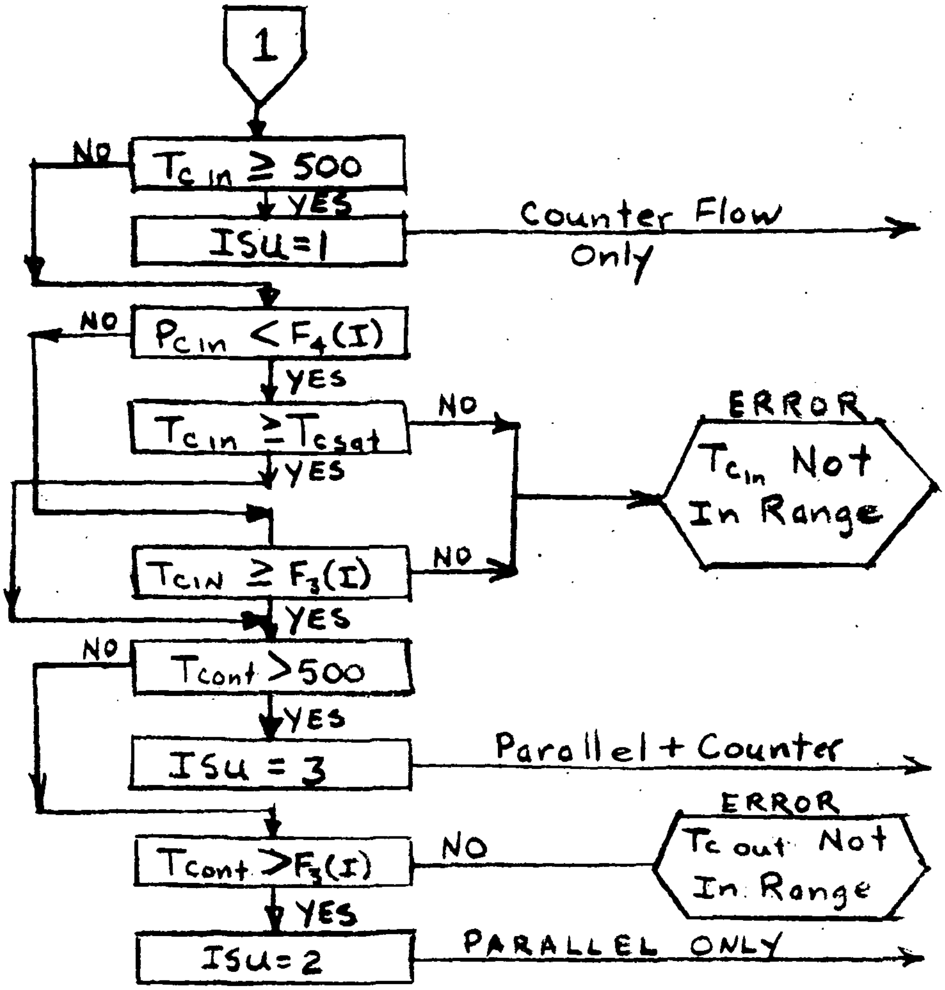


Fig. 1.9-10 Flowchart for HEATEX



	ϕ_2 (I=1)	H_2 (I=2)
F_1	700	180
F_2	160	35
F_3	320	90
F_4	731	188.1

Fig. 1.9-10 Flowchart for HEATEX (Continued)

SUBROUTINE HEXELC

DESCRIPTION

This subroutine essentially designs an electrically heated heat exchanger based upon two preset design configurations incorporated in the calculational technique. The concepts employed for the heat exchangers are based upon a NASA funded study conducted by the AiResearch Mfg Company (Ref. 1.9-7). The applicable portions of the study are discussed in the HEXELC math model. The subroutine incorporates equations and supporting table data permitting the application of the heat exchanger concepts to the use of three cryogen fluids; oxygen, hydrogen and nitrogen. Input variable values which must be supplied to the subroutine are:

Fluid type; O_2, H_2 and N_2
Inlet Gas Temperature
Outlet Gas Temperature
Inlet Gas Pressure
Thermal Output Rating of Heater
Inlet Line Diameter
Gaseous Fluid Flowrate
Gaseous Fluid Density
Fin Requirement Index

Upon completion of the calculations the subroutine returns as output the following variable values:

Heat Exchanger Weight
Heat Exchanger Pressure Drop
Overall Heat Transfer Coefficient
Heat Exchanger Diameter
Heat Exchanger Length

The input data for HEXELC is provided through the calling arguments. Access to common storage is required only for input-output control and table access control variables. The labeled CØMMØN blocks used by HEXELC ARE:

CØMMØN/CIØUNT/
CØMMØN/TABLØK/

HEXELC MATHEMATICAL MODEL

The heat exchanger concepts, mathematical procedures, equations and necessary table data and constants required are presented in Appendix C.

CALLING SEQUENCE

Subroutine HEXELC is initiated by a call from subroutine ECLSS with fourteen (14) calling arguments. These arguments are defined below. Data transfer to subroutine HEXELC is accomplished via nine of the calling arguments and the two INCLUDE statements as shown in the subroutine listing. Upon completion of the required computations, program control is returned to subroutine ECLSS.

SIGNIFICANT VARIABLES

Significant variables processed by subroutine HEXELC are as follows:

Name	Type	I/Ø	Dimension	Description
NGAS	I	I	1	Fluid I.D.; 1 = O_2; 2 = H_2; 18 = N_2
TIN	R	I	1	Fluid inlet temperature
TØUT	R	I	1	Fluid outlet temperature
PIN	R	I	1	Fluid inlet pressure
HF	R	I	1	Thermal output rating of heater
LDIA	R	I	1	Inlet line diameter
WDØT	R	I	1	Fluid flowrate
RHØGAS	R	I	1	Fluid inlet density
IFIN	I	I	1	Anti-Burnout fin index; O = no fins; 1 = with fins.
HEXWGT	R	Ø	1	Heat exchanger weight
DELTAP	R	Ø	1	Heat exchanger pressure drop
UØA	R	Ø	1	Overall thermal conductance of heat exchanger surface
DH	R	Ø	1	Diameter of heat exchanger
HLNGH	R	Ø	1	Heat exchanger length
PI	R	D	1	3.141593
TREF	R	D	1	Reference temperature of heater thermal output rating
PC1	R	D	1	Oxygen critical pressure
PC2	R	D	1	Hydrogen critical pressure
PC3	R	D	1	Nitrogen critical pressure

Name	Type	I/O	Dimension	Description
MASVEL	R	C	1	Fluid mass velocity
NTBID	I	D	50	Table data index
XTAB	R	D	7	Table lookup index
TMEAN	R	C	1	Mean temperature of fluid
CPBAR	R	C	1	Mean specific heat of fluid
BØNE	R	C	1	Heater thermal power per unit area
BPID	R	C	1	(2.0 * BØNE/PI*DH)
PHIØNE	R	C	1	$(T^2{}_2 - T^2{}_1)$/BPID
PHITWØ	R	C	1	(ln $\frac{T2}{T_1}$ /UØA)
PØPC	R	C	1	Ratio of pressure to critical pressure for fluid
BETA	R	C	1	Correction factor for PHITWØ
FINWGT	R	C	1	Weight of anti-burnout fins — if required
SIGDLP	R	C	1	Normalized pressure loss due only to skin friction and volume expansion in annular heat exchanger passages
DELTAP	R	Ø	1	Normalized pressure loss corrected for fluid density — to give pressure drop through exchanger

SUBPROGRAMS REFERENCED IN HEXELC

Name	Type	Purpose	Reference
FINTAB	S	Finds designated table of data	Page B-147
MIPE	F	Table data extraction	Page B-221
CSUBP	S	Computes specific heat of designated fluid at specified temperature and pressure	Page B-88

SUBPROGRAMS REFERENCING HEXELC

Name	Type	Purpose	Reference
ECLSS	S	Life Support System Analysis	Page B-122

LISTING REFERENCE PAGE

A listing of subroutine HEXELC will be found in Appendix B, page 184.

FLOW CHART

A flow chart for subroutine HEXELC is presented in Fig. 1.9-11.

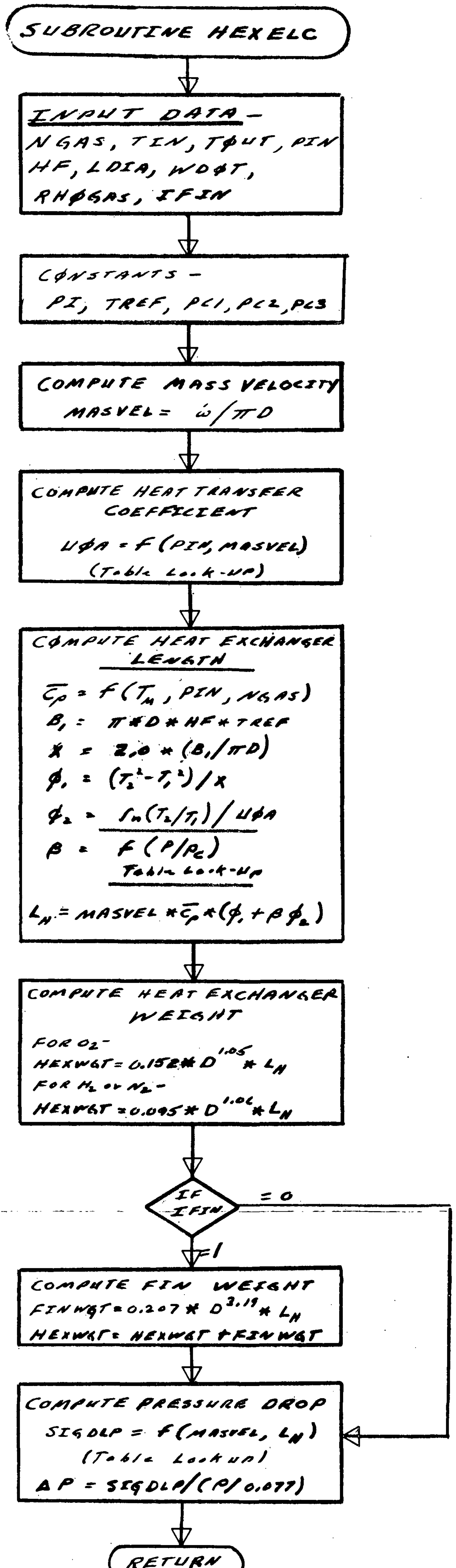


Fig. 1.9-11 Flowchart for HEXELC

SUBROUTINE HEXF21

DESCRIPTION

This subroutine is based upon a study of FREON-21 cryogenic heat exchanger parameters performed by the AIRESEARCH Mfg. Co. (Ref. 1.9-8). The study performed a matrix of heat exchanger parametric data which was reduced to a set of tables presenting the heat transferred for a set of fixed hot side conditions with variable cold side conditions, for both hydrogen and oxygen fluids. The tables were further regrouped by fluid type to reduce the data search variables to three key variables; fluid type, quantity of heat transferred, and cold fluid inlet pressure. The regrouped data readily covered the ranges of interest and yielded an orderly progression of heat exchanger weight as a function of quantity of heat to be transferred and cold fluid pressure.

The subroutine thus became a data sorting routine, using a series of IF statement checks to arrive at a heat exchanger weight for a given pressure range and heat transfer requirement range, for the specified cold fluid.

FREON Heat Exchanger Concept Considerations

The heat exchanger concepts considered in the referenced study (Ref. 1.9-8), utilized stainless steel, shell-over-tube matrices of brazed and welded construction. In all cases, the FREON-21 was multipassed outside of the tubes in an overall counterflow arrangement. Figure 1.9-12 illustrates the construction of a typical concept exchanger. Because of the requirement for pressure containment considerations of cryogen fluids above 450 psia, (and zero leakage requirement), tubular construction was selected over plate-fin construction. Another contributing influence was the typically small size of the units. Stainless steel was selected over aluminum for increased reliability

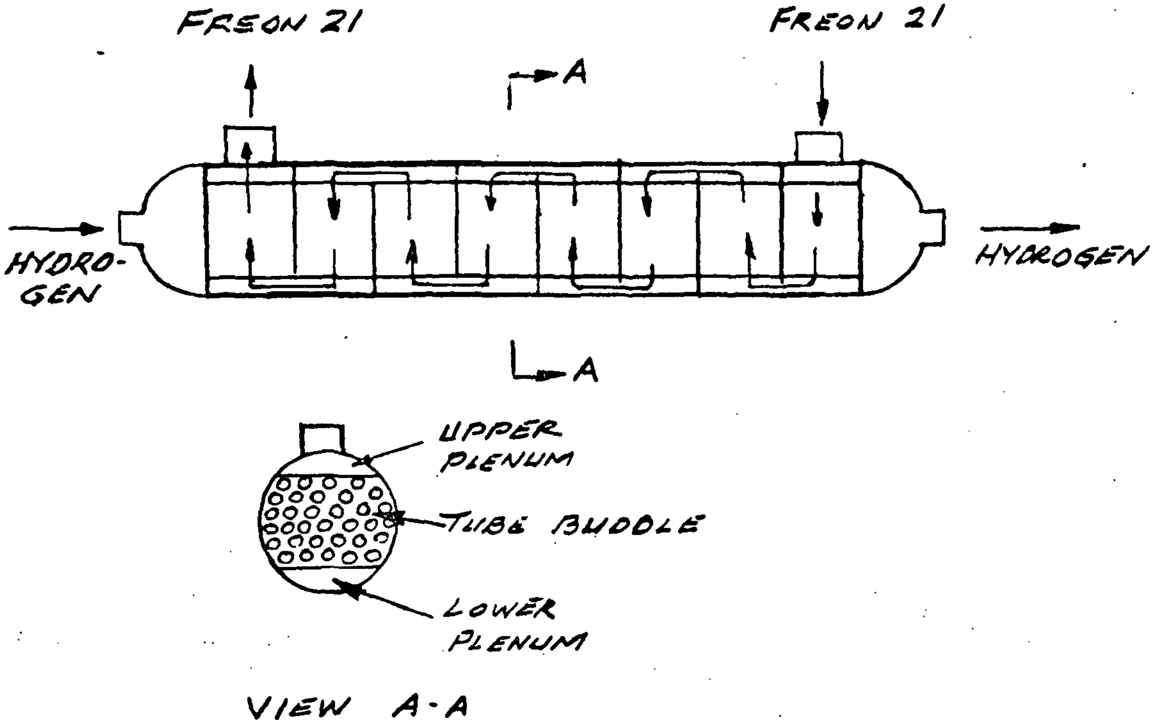


FIGURE 1.9-12 TYPICAL FREON-21 CRYOGENIC HEAT EXCHANGER DESIGN

and greater ease of manufacturing small-diameter, closely-packed matrixes. Aluminum has better strength-to-weight characteristics than nickels or stainless steels and has a definite weight advantage for all structure above minimum gauge. For these units, however, all items such as tube wall thickness and tube spacing are all at the minimum gauge. Because of considerations ;such as braze penetration, the minimum stainless steel tube wall thickness is 0.006-in. compared to 0.016-in. for aluminum in a typical 0.100-in. outside diameter tube. This alone overshadows the 2.86 weight advantage of aluminum. In addition, the selection of aluminum would require the use of more tubes for the same pressure drop, since the tube inside diameter for stainless stell tubes is 0.088 inches as against 0.068 inches for the aluminum tube, and the free flow area varies with the square of the inside diameter. The requirement for counterflow designs were generally dictated by heat transfer requirements.

THERMODYNAMIC CONSIDERATIONS

The most important limiting side condition for all Freon 21-to-cryogenic fluid heat exchangers was the maximum thermal conductance ratio (TCR) permissible to preclude freezing of Freon 21. Assuming a Freon 21 freezing point of $249^{\circ}R$, a minimum wall temperature of $275^{\circ}R$ was deemed permissible. Therefore, for counterflow units with a Freon 21 outlet temperature of $500^{\circ}R$ and a cryogen inlet temperature of $39^{\circ}R$ one finds the maximum TCR as follows:

$$hA_I (T_w - T_c) = hA_o (T_h - T_w) \text{ (cold fluid inside-the-tubes)}$$

$$\therefore \text{TCR} = \frac{hA_I}{hA_o} = \frac{T_h - T_w}{T_w - T_c}$$

$$\text{TCR} = \frac{500 - 275}{275 - 39}$$

$$\text{TCR} = 0.954$$

For a $300^{O}R$ Freon 21 outlet temperature and a $39^{O}R$ cryogen inlet temperature the maximum permissible TCR is 0.106 (or, in other words, the cryogen must have a controlling thermal resistance).

For very low velocity, laminar flow, the cryogen heat transfer co-efficient is sensitive to the local acceleration field. Therefore, in order to ensure acceptable operation during periods of sustained acceleration and deceleration, all designs were limited to turbulent flow inside the tubes.

GEOMETRY CONSIDERATION

Although there are numerous varieties and type of heat transfer matrixes, the most common for general "compact" type application are the plate-fin type matrix offers the following:

(a) High heat transfer area density per unit following
(b) High performance surfaces via boundary-layer interrupting, off-set fins
(c) Ease in balancing thermal conductance and overall geometry by varying the surface combinations

Small diameter tubular matricies are generally not as good as the plate-fin type in the above categories, but they do offer other advantages:

(a) Excellent pressure containment characteristics particularly in the classic shell-and-tube version.
(b) Usually a reduced total length of brazed-joint, fluid interface, and therefore a reduced liklihood of inter-fluid leakage.
(c) By proper design, good control of freezing or congealing may be achieved.

The advantages of shell-and-tube matrixes for the Freon 21-to-cryogenic fluid application outweighed those of the plate-fin type. By flowing hot fluid outside of the tubes, total tube blockage was eliminated. If a tube were fully blocked, high tube-to-tube thermal stresses could arise.

SUBROUTINE INPUT DATA REQUIREMENTS

Input data for use in subroutine HEXF21 are supplied through the calling arguments. The three input variables and the single output variable are as follows:

Fluid identity - 1 = O_2, 2 = H_2
Heat transfer required (Btu/H_2)
Cold Fluid Inlet Pressure (Psia)
Heat Exchanger Weight (lbs)

There are no common data block requirements in this subroutine.

HEXF21 MATHEMATICAL MODEL

There is no math model presented for HEXF21. The reader is referred to Reference 1.9-8 for further information.

CALLING SEQUENCE

Subroutine HEXF21 is initiated by a call from subroutine FUELCL with four (4) calling arguments. The first three arguments are input data and the fourth is for returning the single subroutine output value. The argument variables are defined below. Completion of the data search returns program control to subroutine FUELCL.

SIGNIFICANT VARIABLES

The significant variables processed by subroutine HEXF21 are defined in the following list:

NAME	TYPE	I/O	DIMENSION	DESCRIPTION
IGAS	I	I	1	Fluid Identification 1 = O_2; 2 = H_2

QREQ	R	I	1	Heat Transfer Required (BTU/Hr.)
PCIN	R	I	1	Cold Fluid Pressure (PSIA)
HXWT	R	0	1	Heat Exchanger Weight (lbs)

SUBPROGRAMS REFERENCED IN HEXF21

None

SUBPROGRAMS REFERENCING HEXF21

NAME	TYPE	PURPOSE	REFERENCE
FUELCL	S	Fuel Cell System Analysis	Page B-152.

LISTING REFERENCE PAGE

A listing of Subroutine HEXF21 will be found in Appendix-B, page 186.

FLOW CHART

There is no flow chart for subroutine HEXF21.

FUNCTI0N HFUNC

For a description of HFUNC see the writeup for "TKGE0M." Page B-299

FUNCTI0N HSPHER

For a description of HSPHER see the writeup for "G0MTRY." Page 175

Subroutine INTAB

DESCRIPTION

Subroutine INTAB reads and stores all table input data. The tables are stored in labeled common array (TABLE) which is dimensioned 7000. Tables are stored dynamically in the TABLE array and the location of each first word of a table is stored in a table location array (TLA) dimensioned 50.

Each table that is input is designated by a table ID number which must be between 1 and 50 and, therefore, as many as 50 tables may be stored as long as the total table storage, of 7000, is not exceeded. There are two types of table data which may be input. The first is coefficient data – this input is used as coefficient for an Nth degree polynomial, the first being the coefficient for the highest (Nth) order term and the last is the coefficient of the lowest (0th) order term. The second type table input is discrete table data which is used in the normal table interpolation manner. Either type table may have as many as six dimensions, five "independent" and one dependent variable, and the dependent variable may be interpolated linearly, parabolically, etc., or by an Nth degree polynomial.

Each table which has more than two dimensions is divided into subtables, and these subtables are composed of the normal (x, y) pair – one pair for each point on the table, or an Nth degree polynomial.

A table ID number of zero terminates the input.

An example of a table stored in the array TABLE follows.

EXAMPLE OF A TABLE STORED IN THE ARRAY TABLE (ITABLE)

(Location is for the 1st table stored)

Location		
(1)	ND_1 (number of dimensions of this table) (NOTE: this location count is stored in TLA (NT))	
	1 ND 6	
(2)	NP_1 (count of number of values for this "independent" variable (V_i) which follows)	
(3)	$V_1(1)$	NP_1 variables for first independent variable
(4)	$V_1(2)$	
	⋮	
($2+NP_1$)	$V_1(NP_1)$	
($3+NP_1$)	NP_2 (count of number of values for this "independent" variable)	
	$V_2(1)$	
	$V_2(2)$	NP_2 variables for 2nd independent variable
	⋮	
($3+NP_1+NP_2$)	$V_2(NP_2)$	
	⋮	
	NP_k (count of number of values for this "independent" variable	
	$V_k(1)$	
	$V_k(2)$	NP_k variables for the kth independent variable
	⋮	
$I = 1+\overset{k}{\underset{I=1}{}}(NP_i+1)$	$V_k(NP_k)$	k = ND-2
(I+1)	NV_1	*For Discrete Table input (TYPE = 1)
(I+2)	$TYPE_1$	
(I+3)	NIP_1	
(I+4)	$X_1(1)$ indep var. of (X_1Y) table	
	$X_1(+)$	
($I+3+NV_1$)	$X_1(NV)$	
	$Y_1(1)$ dependent var. of (X_1Y) table	
	$Y_1(+)$	
($I+3+2NV_1$)	$Y_1(NV_1)$	

$*NP_1 \times NP_2 \times \cdots \times NP_k$ of these subtables

EXAMPLE OF A TABLE STORED IN THE ARRAY TABLE (ITABLE) (Continued)

(Location is for the 1st table stored)

NV TYPE NIP COEF(1) COEF(2) ⋮ COEF (NV)	*For Coefficient Table Input (TYPE = 0)

*$NP_1 \times NP_2 \times \cdots \times NP_k$ of these subtables

Labeled Common Used

CØMMØN/CIØUNT/
CØMMØN/CTAB/
CØMMØN/CTABA/

INTAB Mathematical Model

This is an input routine and has no math model.

Calling Sequence

INTAB is called from CØNTROL and has no calling variables. All data is transferred by labeled CØMMØN CTAB and CTABA. When all table input has been read control returns to CØNTROL.

Significant Variables

Name	Type	I/Ø	Dimension	Description
IFT	I	I	1	Controls input from cards or other device
ITABLE	I	Ø	7000	Main storage array for table data
KMURD1	I	Ø	1	Location where next variable will be stored in TABLE
KWRD	I	Ø	1	Count of number of words in a table
LABX	I	Ø	3	Label for X-axis of table plot
LABY	I	Ø	3	Label for Y-axis of table plot
NC	I	I	1	Number of comment cards for table input
ND	I	I	1	Number of dimensions of the table
NIP	I	I	1	Number of points to be used in interpolation
NP	I	I	1	Number of points input for an independent variable
NPRT	I	I	1	Table output print control flag
NPRT2	I	I	1	Table output summary flag
NT	I	I	1	Table ID number-input

Name	Type	I/Ø	Dimension	Description
NV	I	I	1	Number of variables input to a subtable
NXYT	I	I	1	Number of subtables for a given table
ØFT	I	I	1	Controls output to a device if TABLE is to be saved
TABLE	R	I	7000	Equivalent to ITABLE (see ITABLE)
TLA	I	I	50	Contains location in TABLE of 1st word for each table
TYPE	I	I	1	Type of table flag. 0 = coefficient, = 1 discrete
XTAB	R	I	40	Temporary storage for independent variable or coefficient
YTAB	R	I	40	Temporary storage for dependent variable

Subprograms Referenced by INTAB

Name	Type	Purpose	Reference
PAGE	F	Controls Labeling of Output	Page B-239

Programs Reference INTAB

Name	Type	Purpose	Reference
CONTROL	Main Program	Control of Program Logic	Page B-75

Listing Reference

A listing of INTAB can be found in Appendix B, Page 198.

Flow Chart

For flow chart of INTAB see Figure 1.9-B.

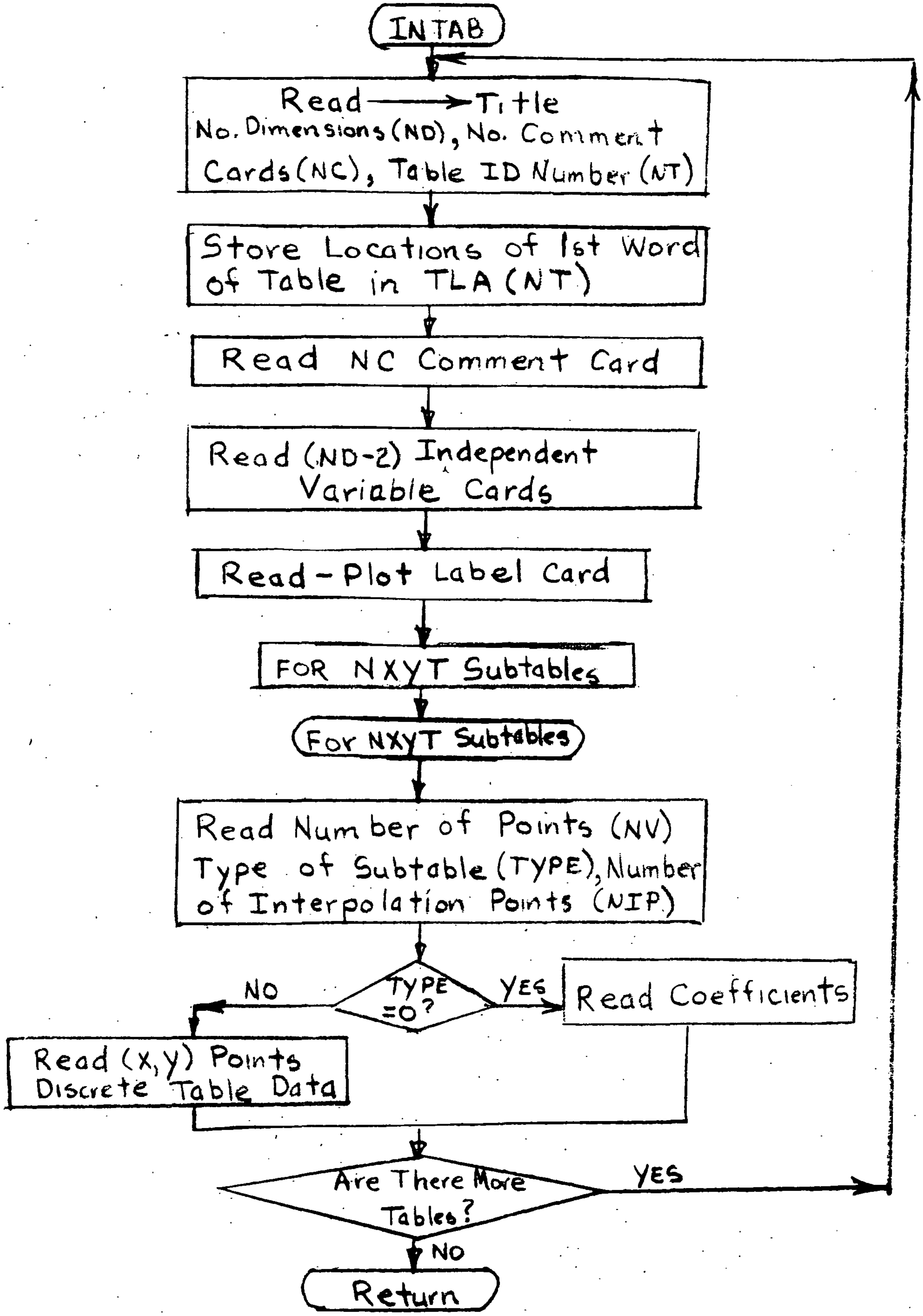


Fig. 1.9-13 Flowchart for INTAB

Subroutine LØCAT

DESCRIPTION

Subroutine LØCAT locates a specified subtable within the major table and stores its X and Y values or its coefficients into small arrays for later interpolation by function YLGINT.

The suitable number is passed via calling sequence to LØCAT from function MIPE, where it is calculated, and LØCAT uses this number together with a pointer (IDX1) calculated in subroutine FINTAB to calculate the location in TABLE of the first X (or coefficient) value for the designated subtable. After this location is found the subtable X (or coefficient) and Y values are loaded into two small arrays. The X (or coefficient) values are transferred to the array XTAB and the Y-values are transferred to YTAB, if the subtable is a coefficient type no Y values are transferred. The number of values to be transferred is determined by the variable NV which is the first word of the subtable. After NV, TYPE, NIP, XTAB and YTAB have been determined and loaded for this subtable, control returns to the calling routine MIPE.

Labeled Common Used

CØMMØN/CIØUNT/
CØMMØN/CTAB/
CØMMØN/CTABA/

Mathematical Model for LØCAT

None

Calling Sequence

LØCAT is called by function MIPE and it has one variable in its calling sequence. The variable is the subtable number which has been calculated in MIPE. All other data is transferred by the use of labeled common CTAB and CTABA.

Significant Variables

Name	Type	I/Ø	Dimension	Description
IDX1	I	I	1	Pointers to first word of first subtable
ITABLE	I	I	7000	Main storage array for table data
MNT	I	I	1	Number of the designated subtable from MIPE
NIP	I	Ø	1	Number of interpolation points for this subtable
NT	I	I	1	The absolute value of MNT
NV	I	Ø	1	Number of X-Y pairs or coefficient this subtable
TABLE	R	I	7000	Equivalent to ITABLE (see ITABLE)
TYPE	I	Ø	1	Type of subtable-discrete or coefficient for this subtable
XTAB	R	Ø	40	Array where independent (or coefficient) values are stored
YTAB	R	Ø	40	Array where dependent values are stored

Subprograms Referenced by LØCAT

Name	Type	Purpose	Reference
DIAG	F	Prints diagnostic trace	Page B-111

Subprograms Referencing LØCAT

Name	Type	Purpose	Reference
MIPE	F	Multilevel table interpolation	Page B-221

Listing Reference

A listing of L0CAT can be found in Appendix B, Page 205.

Flow Chart

For flow chart of L0CAT see Figure 1.9-14.

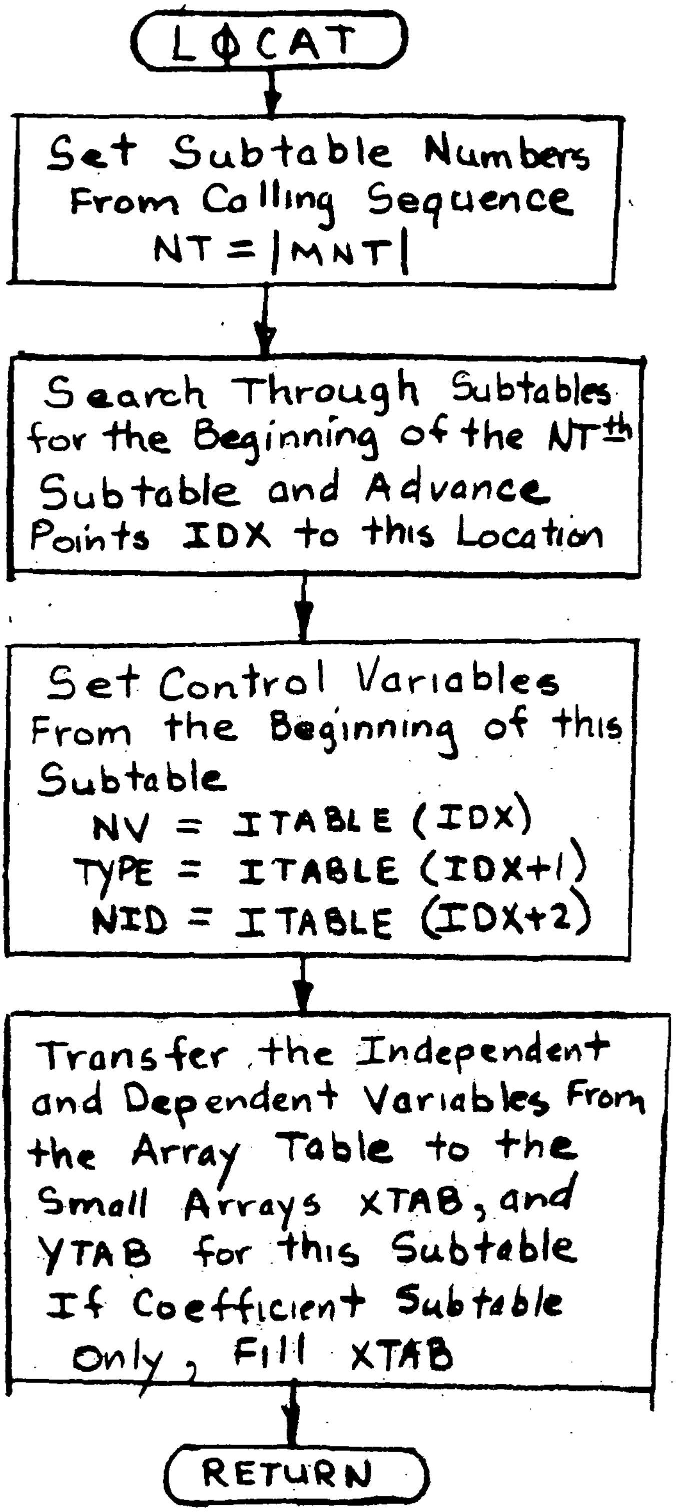


Fig. 1.9-14 Flowchart for LØCAT

SUBROUTINE LSSCMP

DESCRIPTION

The subroutine is a shortened and modified version of subroutine CMPCAL, arranged specifically to process a system employing the cryogen's oxygen and nitrogen. The subroutine provides configuration analysis for component sizing and pressure drop calculations for the ECLSS or similar systems. The logic employed is essentially the same as that used in subroutine CMPCAL and the same variables and common storage are utilized. The analytical procedure uses the configuration table readin by subroutine CØMPIL. (Note that the configuration table in the computer image of main stream flow schematic), where the subroutine considers the oxygen side of the system first and then considers the nitrogen side. Based upon the input configuration table data, the subroutine accomplishes the computation of the individual component sizing, weight, pressure drop and flow constraint data and presents the calculated values in tabular formatted output as a "Summary of Computed System Configuration Parameters."

The principal computations accomplished in subroutine LSSCMP are given briefly as follows:

(a) Initializes the routine and starts the configuration processing loop by calling for the decoding of the branching variables contained in the first configuration data card. The primary control branching variables are CFUNCT and CFTYPE as defined in subroutine CØMPIL and the PDP-CCNFIG. The branching variable CFUNCT successfully contains the coding for, the fluid identification, the consumer identification and, in turn, each component sequentially considered in the system. The branching variable CFTYPE successively contains the coding for the fluid state, the consumer characteristic type, and, in turn, the controlling characteristics of each component sequentially considered on the system. Subroutine branching to the specified component analysis is accomplished via a computed GØTØ statement, controlled by the variable CFUNCT.

(b) Identifies the fluid to be considered and specifies its state condition. Initializes the sequential indices.

(c) Identifies the consumer and sets up the consumer fluid flow rate, fluid pressure and fluid temperature with sequential indices.

(d) Processes a line segment (whenever called for by CFUNCT) through the sequence of the line analysis to compute flow conditions, pressure drop and line weight. Fano flow, compressible flow, velocity effects and minimum wall thickness are all considered in the analysis.

(e) Processes a control unit through the sequence of the control analysis to compute flow conditions, pressure drop and valve weight. Valve mass characteristics are based upon pressure requirements as specified by CFTYPE. Control unit may be a valve, check valve, regulator, orifice or flowmeter. Selection is made via the second index imbedded in CFTYPE. (As defined in PDP-CCNFIG).

(f) Processes a fitting or tap in much the same fashion as the line analysis is conducted, taking into account flow geometry effects. Computes flow condition pressure drop and fitting or tap weight.

(g) Processes a heat exchanger. Fits the previously calculated heat exchanger data into its nominal configuration sequence permitting the addition of the heat exchanger pressure drops to the system pressure drop sequence.

(h) Processes the fluid supply tank. Fits the previously calculated tank data into its nominal configuration sequence position. Tests to see if tank pressure is adequate for the system computed pressure drop.

(i) Outputs the computed configuration component data in a tabular formatted output wherein each component is identified by the same code name and sequence position as it appeared on the oriignal system schematic.

Input data for use in LSSCMP is read-in at program initiation time via subroutine COMPIL from the configuration data cards. Data from each card is stored in a packed array by subroutine STOCON using equivalenced array variables defined in

The Procedure Definition Processor CCNFIG. Retrieval of the data is accomplished in LSSCMP via repeated calls to subroutine GETC0N which unpacks the data as needed. The input data and computed values are stored in various regions of the labeled C0MM0N storage defined by PDP elements. The labeled C0MM0N areas employed by subroutine LSSCMP are as follows:

C0MM0N/CACCUM/
C0MM0N/CCNFIG/
C0MM0N/CCNTRL/
C0MM0N/CILSS/
C0MM0N/CVLSS/
C0MM0N/CENG/
C0MM0N/CHEX/
C0MM0N/CHS0RC/
C0MM0N/CNAMES/
C0MM0N/C0NST/
C0MM0N/CTANK/
C0MM0N/CI0UNT/

LSS CMP MATHEMATICAL MODEL

The LSSCMP is a modified version of subroutine CMPCAL retaining the major features of the CMPCAL math model. The reader is therefore referred to the subroute CMPCAL math model for details concerning the mathematical procedures and equations employed in subroutine LSSCMP. Reference Appendix C.

CALLING SEQUENCE

Subroutine LSSCMP is initiated via the statement CALL LSSCMP in subroutine ECLSS. No calling variables are required. Data transfer to and from subroutine LSSCMP is effected through the use of INCLUDE statements which bring in the appropriate PDP elements defining the required labeled C0MM0N storage areas. Upon completion of the LSSCMP computation program control returns to subroutine ECLSS.

SIGNIFICANT VARIABLES

Significant variables considered in, and processed by, subroutine LSSCMP are defined in the list given below:

NAME	TYPE	I/0	DIMENSION	DESCRIPTION
ICNF	I	I	1	Number of Configuration Data Cards Input
IDX	I	0	1	Configuration Item Index
ISIGN	I	0	1	Analysis directional index
CFUNCT	I	I	1	Integer Corresponding to Configuration Item Fun
CFTYPE	I	I	1	Integer Corresponding to Function Type
CMTYPE	I	I	1	Integer Corresponding to Material Type
CITYPE	I	I	1	Integer Corresponding to Insulation Type
CNOPER	I	I	1	Number of Units Operating
CNSTBY	I	I	1	Number of Units on Standby
FRCOEF	R	I	100	Characteristic Friction Factor for Flow Region
L0D	R	I	100	Length over Diameter, or, Length
DIAM	R	I	100	Diameter
ITHIK	R	I	100	Insulation Thickness
NBAR	R	I	100	Number of Layers of Insulation per Inch
C0DE	R	I	100	Identification Code for Configuration Unit
IGAS	I	I	1	Integer Corresponding to Fluid Kind.
GSTATE	I	I	1	Integer Corresponding to Fluid State
PRESS	R	0	100	Fluid Pressure at each Point in System
TEMP	R	0	100	Fluid Temperature at Each Point in System
WD0TN	R	0	100	Fluid Flowrate at each Point in System
WD0TI	R	I	2	Input Fluid Max. Flowrate at Consumer
PLSN0M	R	I	2	Input Fluid Pressure at Consumer
TLSN0M	R	I	2	Input Fluid Temperature at Consumer
FLD	R	0	1	$\frac{fL}{D}$ for Configuration Unit Considered
IDV	I	I	1	Integer Pointer for Control Mass Characteristic
LDV	I	I	1	Integer Pointer for Fitting and Tap Configurati
RH0	R	0	1	Fluid Density when a Gas
DELP	R	0	1	Fluid Pressure Drop Across Component
A	R	0	1	Cross-sectional Area of Flow Region
WEIGHT	R	0	1	Weight of Configuration Component Considered

NAME	TYPE	I/O	DIMENSION	DESCRIPTION
APRES	R	I	2	Accumulator Pressure(if used)
INDXAC	I	O	2	Accumulator Index (if used)
INDXTK	I	O	2	Fluid Tank Index - set to IDX
SIPRES	R	I	2, 1	Fluid Tank Initial Pressure
SITEMP	R	I	2, 1	Fluid Tank Initial Temperature
WTTOT	R	I	2	Fluid Tank Weight
WDOTCF	R	I	10, 2	Fluid Heat Exchanger Flow Rate
UCODE	R	I	10, 2	Fluid Heat Exchanger I.D. Code
HEXCIT	R	I	10, 2	Fluid Heat Exchanger Cold Inlet Temp
HXCDLP	R	I	10, 2	Fluid Heat Exchanger Delta-P
WHXTOT	R	I	10, 2	Fluid Heat Exchanger Weight
MACH	R	O	100	Fluid Mach No.
MFLG	I	O	100	Fluid Mach No. Flag

SUBPROGRAMS REFERENCED IN LSSCMP

Name	Type	Purpose	Reference
PAGE	F	Controls Pagination and Line Count	Page B-239
GETCON	S	Unpacks Configuration Data Records	Page B-174
DENSON	S	Computes Desired Fluid Density at Stated Conditions	Page B-108
COMFLO	S	Computes Pressure Drop and Mach Number for Desired Fluid at Stated Conditions Using Compressible Flow Equations	Page B-62
VGVS	S	Computes Mach Number for Desired Fluid Density Using Velocity of Sound Equations	Page B-322
LWEGHT	S	Computes Weight of a Line Segment	Page B-215
CFTW	F	Computes the Weight of a Control Unit, Fitting or Tap as specified	Page B-39

TABLES REFERENCED IN LSSCMP

TABLE NO.	TITLE

No tables are called in LSSCMP

SUBPROGRAMS REFERENCING LSSCMP

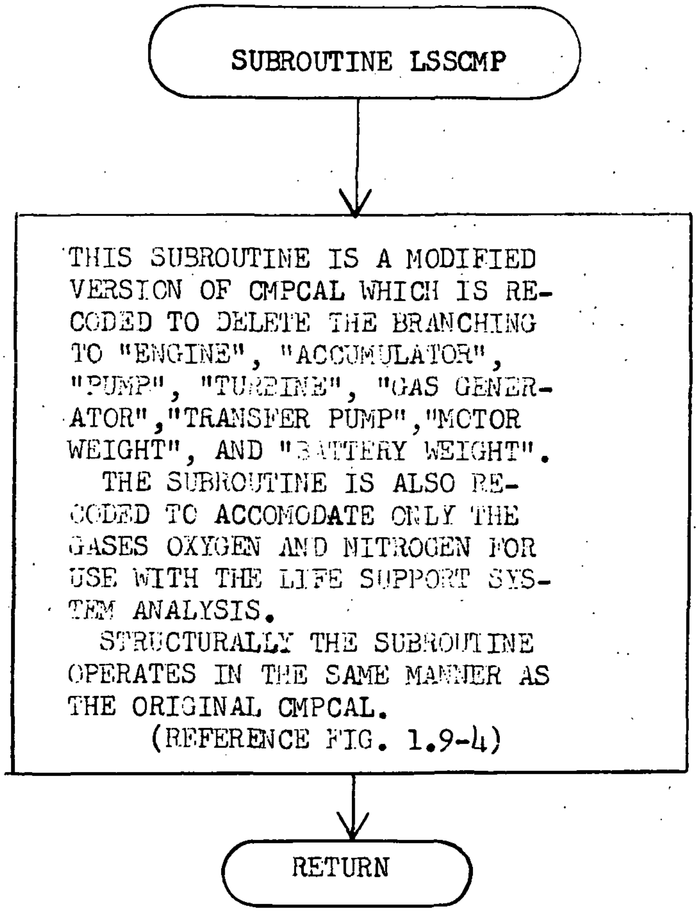
NAME	TYPE	PURPOSE	REFERENCE
ECLSS	S	Perform Analysis of Life Support System	Page B-122

LISTING REFERENCE PAGE

A listing for subroutine LSSCMP will be found in Appendix B, Page 208.

FLOW CHART

A flow chart for subroutein LSSCMP is presented in Figure 1.9-15.



THIS SUBROUTINE IS A MODIFIED VERSION OF CMPCAL WHICH IS RECODED TO DELETE THE BRANCHING TO "ENGINE", "ACCUMULATOR", "PUMP", "TURBINE", "GAS GENERATOR","TRANSFER PUMP","MOTOR WEIGHT", AND "BATTERY WEIGHT".

THE SUBROUTINE IS ALSO RECODED TO ACCOMODATE ONLY THE GASES OXYGEN AND NITROGEN FOR USE WITH THE LIFE SUPPORT SYSTEM ANALYSIS.

STRUCTURALLY THE SUBROUTINE OPERATES IN THE SAME MANNER AS THE ORIGINAL CMPCAL.

(REFERENCE FIG. 1.9-4)

FIGURE 1.9-15 FLOW CHART FOR SUBROUTINE LSSCMP

SUBROUTINE LWEGHT

DESCRIPTION

The subroutine LWEGHT contains the equations and computational procedures for determining the weight of fluid plumbing lines, fittings, line insulation and the weight of vacuum jacketed lines. The equations employ the basic properties and dimensions of the materials of construction and insulation specified for the lines and fittings, for the weight calculations. The calculations are constrained to practical cases through the use of minimum gage thickness values preset in the program. The basic materials properties and minimum gage thicknesses employed are defined in PDP-CMATRL and stored in subroutine ST0DTA. Ultimate stress values as a function of material temperature are obtained by table lookup.

Input data for use in subroutine LWEGHT is obtained from labeled C0MM0N storage accessed through INCLUDE statements. The labeled common storage required for use in subroutine LWEGHT is as follows:

```
C0MM0N/CCNFIG/
C0MM0N/CMATRL/
C0MM0N/C0NST/
C0MM0N/TABL0K/
```

LWEGHT MATHMATICAL MODEL

No mathematical model is presented since the equations are largely of type to be found in standard engineering handbooks and industrial manuals which may be found in any library. The subroutine listing is felt to be mathematically explicit. Materials stress data employed in the Data Tables was obtained from MIL-HDBK-5. Vacuum-jacketed line data was taken from Reference 1.9-2. Parametric line weight data curves will be found in the same reference.

CALLING SEQUENCE

Subroutine LWEGHT is called with two arguments, IDX and LDV. Argument IDX is a configuration data array ordering index which simply assures that the computed weight will be stored in the proper array position for later use. Argument LDV defines whether the component item being weighed is a line, or, a fitting and what kind of a fitting is being considered. Input data transfer as stated above is effected through the CØMMØN storage areas. Upon completion of the required calculations, program control is returned to the calling program.

SIGNIFICANT VARIABLES

Significant variables employed in subroutine LWEGHT are:

Name	Type	I/Ø	Dimension	Description
IDX	I	I	1	Configuration data ordering index
LDV	I	I	1	Configuration data type index
TEMP	R	I	1	Fluid temperature
PRES	R	I	1	Fluid pressure
THKL	R	C	1	Material calculated thickness
SI	R	C	1	Material F_{tu} at temperature TEMP
DIAM	R	I	100	Line or port diameter
MINTHK	R	I	15	Minimum gage limits for material
WGTFT	R	C	1	Weight per foot of line
FLØD	R	C	1	Equivalent length of fitting
LØD	R	I	100	Length of line
LWEGHT	R	Ø	100	Weight of line or fitting
ITHICK	R	I	100	Insulation thickness
RHØI	R	I	10	Insulation density
WI	R	Ø	100	Insulation weight

SUBPROGRAMS REFERENCED IN LWEGHT

Name	Type	Purpose	Reference
DIAG	F	Diagnostics Print	Page B-111
FINTAB	S	Table Lookup	Page B-147

SUBPROGRAMS REFERENCING LWEGHT

Name	Type	Purpose	Reference
CMPCAL	S	Configuration Analysis	Page B-50
LSSCMP	S	Configuration Analysis	Page B-208

LISTING REFERENCE PAGE

A listing of subroutine LWEGHT will be found in Appendix B, page 215.

FLOW CHART

None is presented

Function MIPE

DESCRIPTION

The real function MIPE is a multilevel interpolation and polynomial evaluation routine. The routine receives through its calling sequence the ND-1 "independent" variables along with a count (NV = ND-1). The "independent" variables are picked from an array labeled XVAC and the first NV-1 of these input variables are checked against the table stored independent variables to determine if they are within the range of the table. The routine then checks each input variable to determine where in the range of table values it falls, this is noted and stored as an index in the array KNT for later use in interpolation. The routine next determines which subtables, by number, must be interpolated (see following sheets for a detailed explanation) and the routines LØCAT and TEL are called upon to do this interpolation. The results of each of these $2^{(NL-1)}$ subtable interpolations are stored in an array YVAL, and are then linearly interpolated by pairs until a single Y value is obtained. This value is then returned to the calling routine. Polynomial evaluation is performed in the same manner and if fast the routine MIPE does not differentiate between the two type of evaluation.

The following is a detailed explanation of the routine's logic to determine the subtable numbers to be used for interpolation (coefficient evaluation). The independent variable table TAB (or ITAB) is supplied by FINTAB which is always called directly before MIPE. For purposes of explanation numeric table values have been assumed. A diagram of the subtable setup has also been included.

ITAB (6,5), TAB (6,5)

	1	2	3	4	5
1	3	3	3	0	0
2	1500.	75.	26.		
3	1750.	120.	32.		
4	2000.	155.	40.		
5					
6					
KNT(5)	3-1 = 2	3-1 = 2	2-1 = 1		
NTD(6)	8/1 = 8	8/2 = 4	8/4 = 2	8/8 = 1	
L(5)	3x3 = 9	1x3 = 3	1		

For an input to MIPE such as:

MIPE (NL, XVAL) with NL = 4
and XVAL (1) = 1802.
XVAL (2) = 137.
XVAL (3) = 27.
XVAL (4) = 123.

and the array TAB, (ITAB) filled as above, the variable arrays KNT, NID and L would be calculated and stored as shown above. The number of subtables which must be interpolated to find the Y is calculated as $NT = 2^{(NL-1)} = 2^3 = 8$. To find the subtable identifying numbers the variable KTB must be calculated for each of the eight subtables which are to be interpolated.

The first subtable number KTB, can be calculated as follows:

$$\begin{aligned} KTB_1 = {} & 1+L(1)*\left(KNT(1)-1+\text{mod}\left[0,NTD(1)\right]/NTD(2)\right) \\ & +L(2)*\left(KNT(2)-1+\text{mod}\left[0,NTD(2)\right]/NTD(3)\right) \\ & +L(3)*\left(KNT(3)-1+\text{mod}\left[0,NTD(3)\right]/NTD(4)\right) \end{aligned}$$

and this expression is evaluated as

$$\begin{aligned} KTB_1 &= 1+(9)*[2-1+0/4]+(3)[2-1+0/2]+(1)[1-1+0/1] \\ &= 1+9 \qquad\qquad\quad +3 \qquad\qquad\quad +0 \\ &= \underline{\underline{13}} \end{aligned}$$

so therefore the first subtable to be interpolated would be the 13th one.

The last (8th) subtable number KTB_8 can be calculated as

$$\begin{aligned} KTB_8 = {} & 1+L(1)*\{KNT(1)-1+mod[7,NTD(1)]/NTD(2)\} \\ & +L(2)*\{KNT(2)-1+mod[7,NTD(2)]/NTD(3)\} \\ & +L(3)*\{KNT(3)-1+mod[7,NTD(3)]/NTD(4)\} \end{aligned}$$

which can be evaluated as, (where X is the integer part of X)

$$\begin{aligned} KTB_8 &= 1+(9)*\{2-1+[7/4]\}+(3)\{2-1+[3/2]\}+(1)\{1-1+[1/1]\} \\ &= 1+9\ (2) \qquad\qquad\quad +3\ (2) \qquad\qquad\quad +1\ (1) \\ &= 1+18+6+1 = \underline{\underline{26}} \end{aligned}$$

so that the last subtable to be interpolated would be the 26th one. The other six would be between subtables 12 and 26 and in fact they are always taken in pairs and the complete set of eight subtables would be 13, 14; 16, 17; 22, 23; and 25,26.

The integer number KTB is used to call LØCAT which sets up the proper X-Y subtable for later interpolation by subroutine TEL and function YLGINT or for polynomial evaluation by subroutine TEL.

Note that, as the array ITAB (1,I) indicates, there are three "independent" variables each with values so that there is 3x3x3 = 37 total subtables which may be used to interpolate, however, only eight subtables are used for any given set of input data.

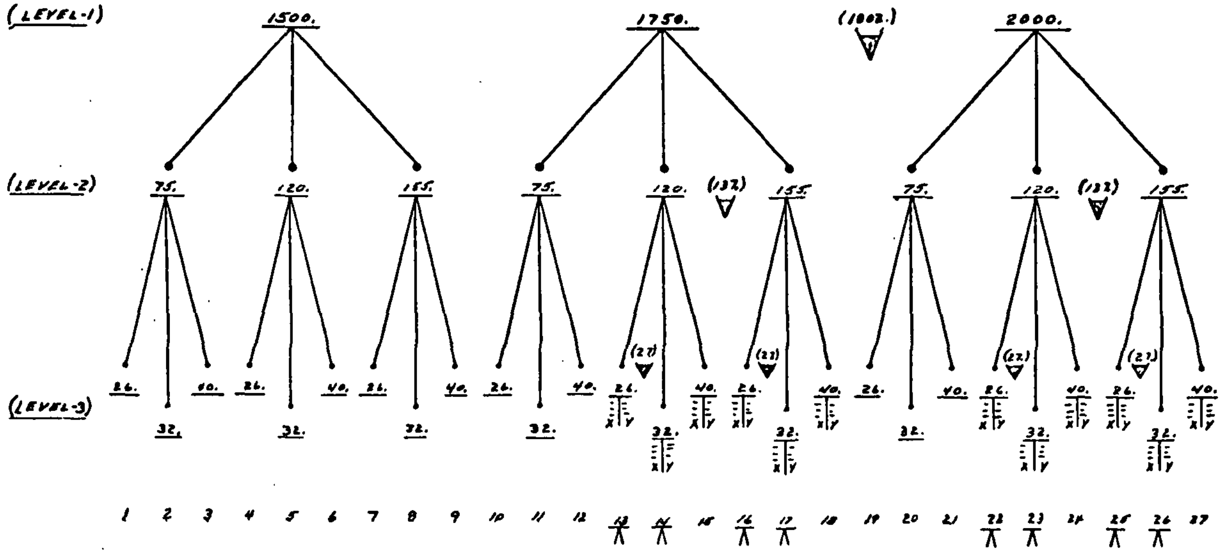


FIGURE 1.9-16 DIAGRAM OF SUBTABLE SETUP

Labeled Common Used

CØMMØN/CIØUNT/
CØMMØN/CKEYS/
CØMMØN/CTAB/

Mathematical Model of MIPE

None

Calling Sequence

MIPE is called from any routine which uses table interpolation (or polynomial evaluation). It has two input variables in its calling sequence: (1) the ND-1 "independent" variables and (2) the count of the number of these variables which is NV(=ND-1). All other data is passed by labeled common CTAB.

Significant Variables

Name	Type	I/O	Dimension	Description
FAC	R	Ø	1	Multiplying factor of linear interpolation $(X-X_1)/X_2-X_1)$
ITAB1	I	I	(6,5)	Counts of the number of the ND-2 independent variables
KNT	I	Ø	5	Index used in the linear interpolation of Y
KTB	I	Ø	1	Contains subtable number-given to LØCAT
L	I	Ø	5	Multiplying factor used to determine KTB
NL	I	I	1	Number of levels interpolation = ND-1
NT	I	Ø	1	The number of subtable interpolations to be performed
NTD	I	Ø	6	Multiplying factor used to determine KTB
TAB	R	I	6,5	Contains the ND-2 independent variables
TAB1	R	I	6,5	Equivalenced to XTAB (see XTAB)
XVAL	R	I	6	Input independent values used to calculate a Y
YVAL	R	Ø	32	Array used to store results of the NT subtable interpolations. The first location of which is = Y

Subprograms Referenced by MIPE

Name	Type	Purpose	Reference
DIAG	F	Prints diagnostic trace	Page B-111
L0CAT	S	Locates and loads subtable	Page B-205
TEL	S	Evaluates polynomial or controls interpolation by YLGINT	Page B-292

Subprograms Referencing MIPE

Name	Type	Purpose	Reference
APUSUP	S	Calculates parameters for APU-supercritical system	Page B-8
APUFL0	S	Calculates flow rates for APU system	Page B-5
CMPCAL	S	Computes weight, pressure, etc., for given components	Page B-50
ECLSS	S	Environment control and life support system	Page B-122
ENGINE	S	Calculates weight of engine and impulse propellants	Page B-138
FUELCL	S	Calculates fuel cell parameters	Page B-152
HEATEX	S	Calculates weight and flow rates for heat exchangers	Page B-177
HEXELC	S	Calculates weight P for electric heat exchanger	Page B-184
LWEGHT	S	Calculates line weights	Page B-215
MATHAX	S	Computes pump charact. and other math. relations	Page B-218
PARPMP	S	Computes pump design characteristics	Page B-242
TANK	S	Tank pressure, weight and duty cycle history	Page B-277
THKWTG	S	Calculates tank weight and wall thickness	Page B-297
VENT	S	Environment control and life support system	Page B-318

Listing Reference

A listing of MIPE can be found in Appendix B, Page 221.

Flow Chart

For flow chart of MIPE see Figure 1.9-17.

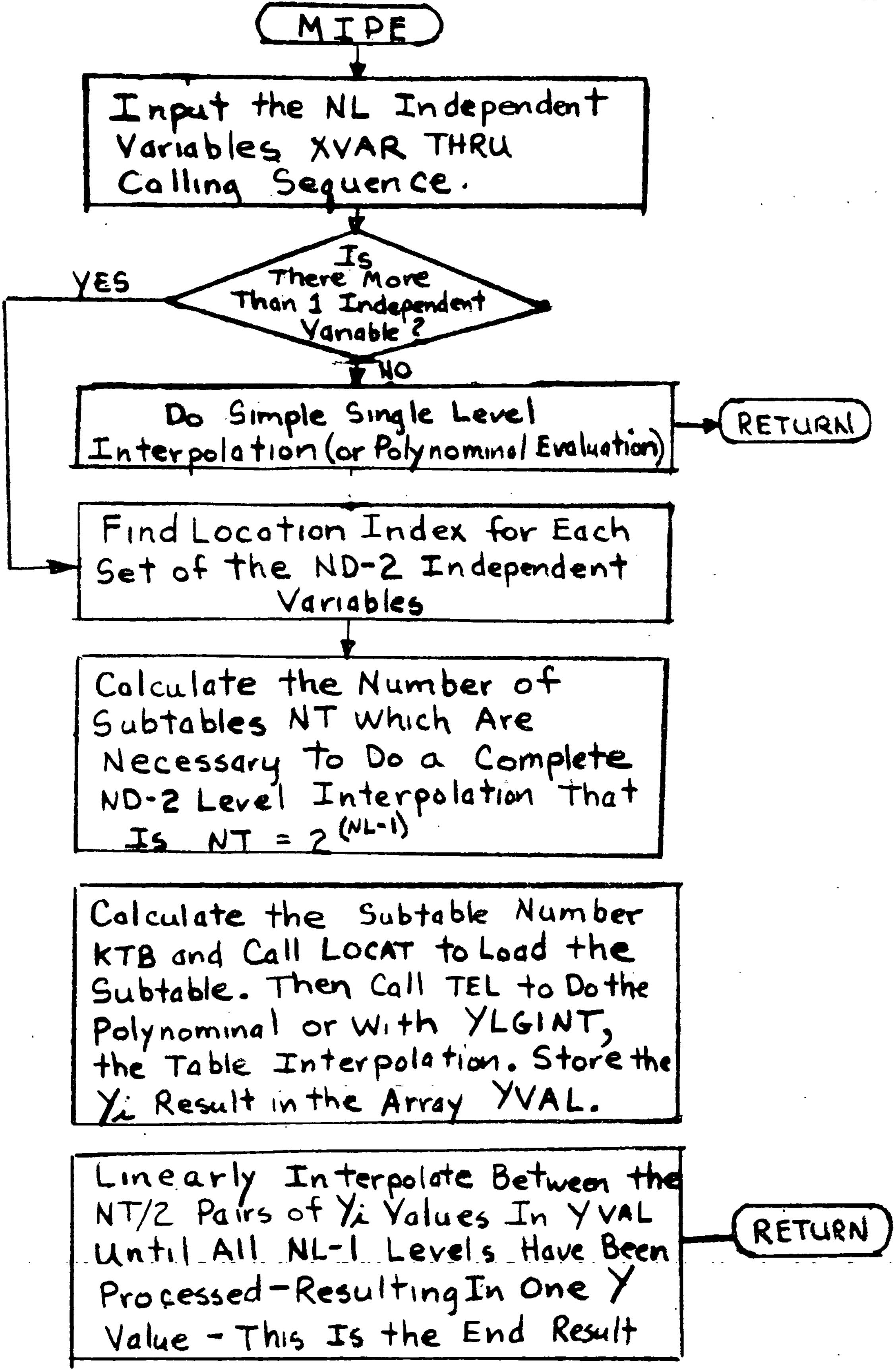


Fig. 1.9-17 Flowchart for MIPE

FUNCTION SPHERE

For a description of SPHERE see the writeup for "G0MTRY." Page B-175

SUBROUTINE PARPMP

DESCRIPTION

Subroutine PARPMP is essentially a pump design type of subprogram, in that, for specific input arguments, the routine will in effect design an oxygen or hydrogen pump to fit the stated requirements. The input variable values which must be supplied to the subroutine are:

Fluid Type:	O_2 or H_2
Design Constraints:	Minimum power, or minimum weight

Required Pump Pressure Rise
Delivered Flowrate Required
Net Positive Suction Pressure Available
Fluid Liquid Density

Upon completion of the calculations the subroutine returns the following variable values:

Pump Efficiency
Pump Volume
Pump Power Required
Pump Weight
Pump Rotational Speed
Required Number of Pump Stages
Revised NPSP Required by the Pump

The subroutine is based upon a pump parametric data study conducted by the AiResearch Mfg Company (Ref. 1.9-6). Data from the study was converted to a math model suitable for evaluating liquid oxygen and liquid hydrogen pump characteristics and performance for a larger variety of fluid inlet conditions, flowrates and pressure rise requirements. The math model in turn, was then coded as a subroutine. Performance characteristics provided by AiResearch as graphic parametric data, were converted either into equations or table data for lookup and incorporated into the subprogram. For both oxygen and hydrogen pumps, compressed liquid data is utilized since there is no requirement for zero-psi NPSP conditions in any of the cryogen systems contemplated The parametric data employed for the liquid hydrogen pumps covers roughly the range of 50 to 5000 psi for pressure rise, and 0.05 to approximately 10.0 lb/sec for flowrate. For liquid oxygen pumps the parametric data employed covers the range of pressure rise from 50 to 5000 psi, and flowrates of 0.1 through approximately 50.0 lb/sec.

The basic physical configuration for all pumps considered is assumed to be as follows:

(1) All are single modules utilizing 1 to 5 stages.

(2) The modules all have a fluid inlet at one end and an interface with a driving unit at the other.

(3) The modules are considered to contain sufficient bearings and seals for operation with any suitable type driving unit.

(4) All pumps use a basic radial flow configuration.

(5) Barske partial emission configurations are employed for high pressure rise with low flowrates.

(6) Full admission, axial-radial mixed flow configurations are employed for low pressure rise with high flowrates.

(7) Mid-range pumps employed a full admission centrifugal configuration.

(8) The first stage of all pumps was considered to be equipped with an inducer rotating at the same speed on the impeller.

(9) All impellers in a given multistage pump are the same diameter and driven by a single shaft.

(10) Pump housings are uninsulated and only the final stage of a multistage pump is considered to be equipped with a scroll.

(11) All pumps are considered to be lightweight designs constructed of lightweight materials.

(12) Driving devices for the pumps are not included in the best rotational speed determination, nor in the weight and volume determinations.

The following are the principal computations accomplished in the subroutine:

(a) Computes number of pump stages by iteration through computed pump parameters.

(b) Computes head rise per stage

(c) Computes multiplication factor for specific speed

(d) Computes maximum pump hydraulic efficiency

(e) Computes required net positive suction pressure

(f) Computes specific speed, head coefficient, adiabatic efficiency, impeller diameter, efficiency quotient and actual pump hydraulic efficiency for each iteration of pump stage evaluation loop.

(g) Computes diameter, length of pump, and pump weight for type of pump.

(h) Computes pump volume and pump power to chosen pump design constraint.

Input data for use in PARPMP is transmitted to the subroutine in the calling arguments. Data transfers such as constants and data tables are accomplished via labeled CØMMØN storage blocks defined by the PDP elements. The labeled CØMMØN areas employed by subroutine PARPMP are as follows:

CØMMØN/CIØUNT/
CØMMØN/CØNST/
CØMMØN/DUMMY/
CØMMØN/SPUMP/
CØMMØN/TABLØK/

PARPMP MATHEMATICAL MODEL

The PARPMP math model consisting of symbol definitions, equations, procedural logic and parameter data are presented in Appendix C.

CALLING SEQUENCE

Subroutine PARPMP is initiated by a call from subroutine CMPCAL with thirteen (13) calling arguments. Input and output variables make up the calling arguments as listed in the following subparagraph. Data transfer, other than the calling arguments, is accomplished through the use of INCLUDE statements as shown in the subroutine listing. Completion of PARPMP computations returns program control to subroutine CMPCAL.

SIGNIFICANT VARIABLES

Significant variables processed by subroutine PARPMP are defined as follows:

Name	Type	I/O	Dimension	Description
IGS	I	I	1	Fluid type; 1 = O_2; 2 = H_2
JKM	I	I	1	Design constraint; 1 = Minimum power 2 = Minimum weight
DLP	R	I	1	Pump rise — Delta-P
WDP	R	I	1	Flowrate required (lb/sec)
RNPS	R	I	1	NPSP available (psi)
RHW	R	I	1	Fluid density (lb/cu ft)
T0TNU	R	0	1	Pump efficiency
V	R	0	1	Pump volume (cu in.)
E	R	0	1	Pump power (Hp)
WT	R	0	1	Pump weight (lb)
PNSG	R	0	1	Pump speed (rpm)
NSTG	R	0	1	Number of Pump Stages
NPSPR	R	0	1	Computed NPSP required for pump (psi)
DELP	R	I	2	DLP
RH0	R	I	2	RHW
S	R		2	Suction specific speed
WD0TP	R	I	2	WDP
NPSPA	R	I	2	RNPS
NUMX	R	C	5	Maximum hydraulic efficiency
XM	R	D	12	Pump length constants
NMAX	R	C	1	Maximum rotational speed
AE	R	C	5	Value of E — each iteration
AV	R	C	5	Value of V-each iteration
AW	R	C	5	Value of WT-each iteration
SWB	R	D	2	Baseline flowrate constants for oxygen or hydrogen pumps
PB	R	D	1	Baseline scroll pressure (psi)
NSSI	R	C	1	Rotational speed at maximum hydraulic efficiency
NSS	R	C	1	Specific speed
SQTQ	R	C	1	Square root of volumetric flowrate
PDI	R	C	1	Pump diameter for volume calculation
PLGT	R	C	1	Pump length for volume calculation
NSG	R	C	1	Pump rotational speed (rpm)
WI	R	C	1	Weight of impeller
WH	R	C	1	Weight of housing
WS	R	C	1	Weight of scroll
WB	R	C	1	Baseline weight of pump stage
P	R	C	1	Pump rise plus NPSPA
NUZ	R	C		Adiabatic efficiency

Name	Type	I/O	Dimension	Description
NU	R	C	2	Hydraulic efficiency
EFFQ	R	C	1	Efficiency quotient
U	R	C	1	Impeller tip speed
PSI	R	C	1	Head coefficient
DI	R	C	1	Impeller diameter

SUBPROGRAMS REFERENCED IN PARPMP

Name	Type	Purpose	Reference
SQRT	F	Takes square root of named variable	System Library
PUMPEF	S	Auxiliary calculations for PARPMP. Entry point into subroutine MATHAX.	Page B-218
FINTAB	S	Table location and lookup	Page B-147
MIPE	F	Table data extraction	Page B-221
SIGN	F	Replace sign of first argument with sign of second argument.	System Library
DBLE	F	Convert to double precision	System Library

TABLES REFERENCED IN PARPMP

Table No.	Title
27	Head Coefficient vs Specific Speed
28	Adiabatic Efficiency vs Specific Speed
29	Efficiency Quotient vs Impeller Diameter
30	Baseline Stage Weight vs Impeller Diameter

SUBPROGRAMS REFERENCING PARPMP

Name	Type	Purpose	Reference
CMPCAL	S	Configuration Analysis, Component Weights, Pressure Drops, Flow Conditions	Page B-50

LISTING REFERENCE PAGE

The subroutine PARPMP listing will be found in Appendix B, page 242.

FLOW CHART

A flow chart for subroutine PARPMP is presented in Fig. 1.9-18.

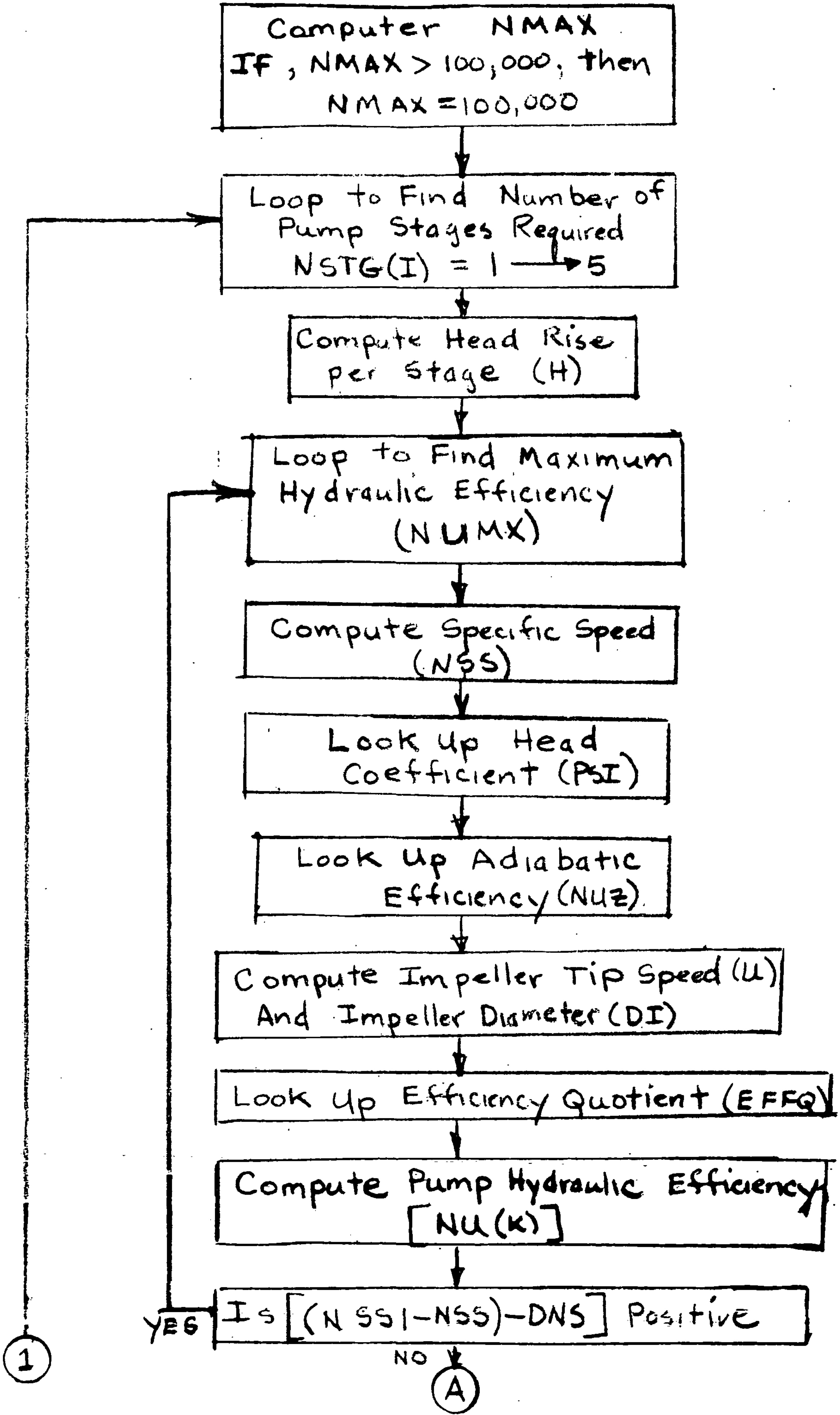


Fig. 1.9-18 Flowchart for PARPUMP

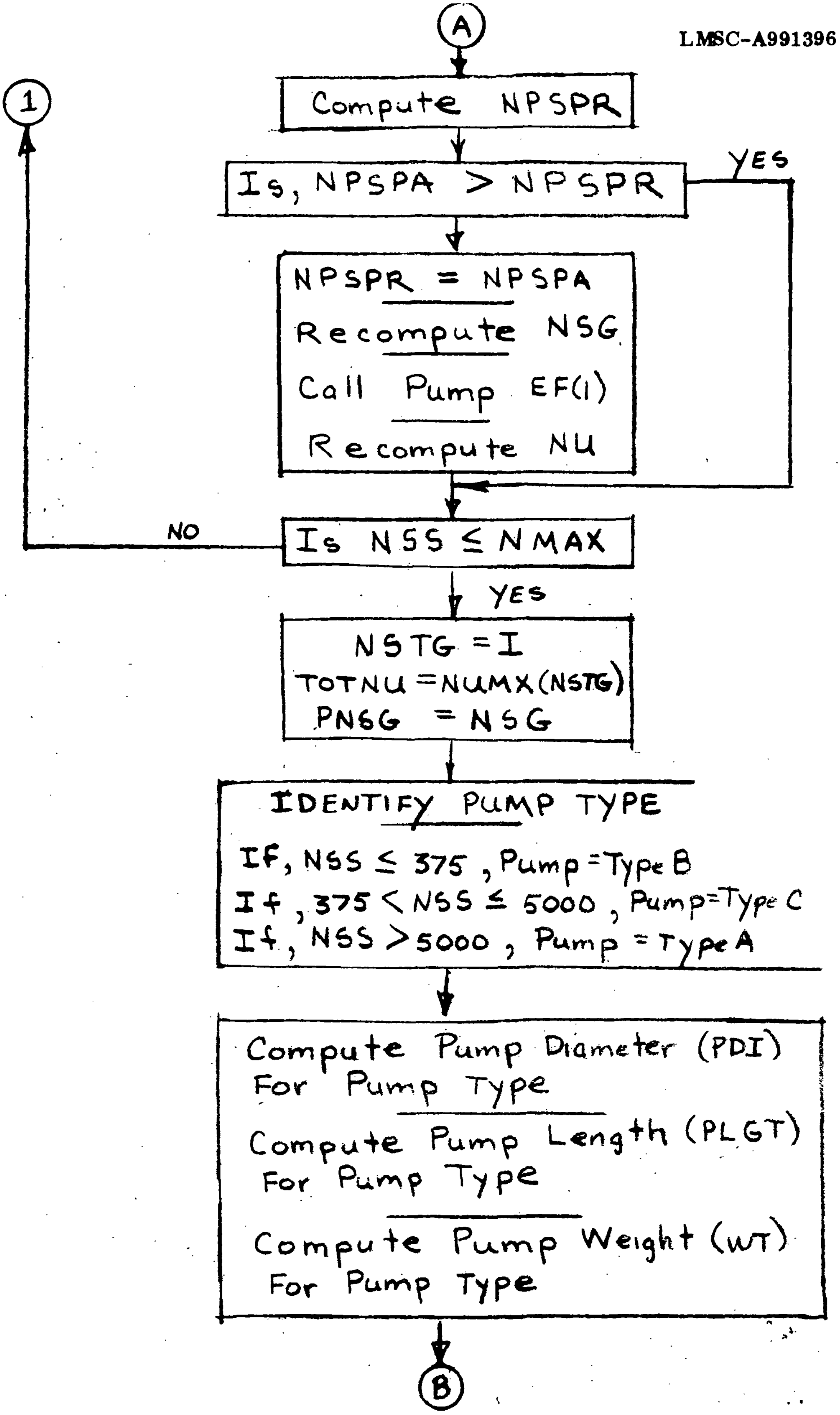


Fig. 1.9-18 Flowchart for PARPUMP (Continued)

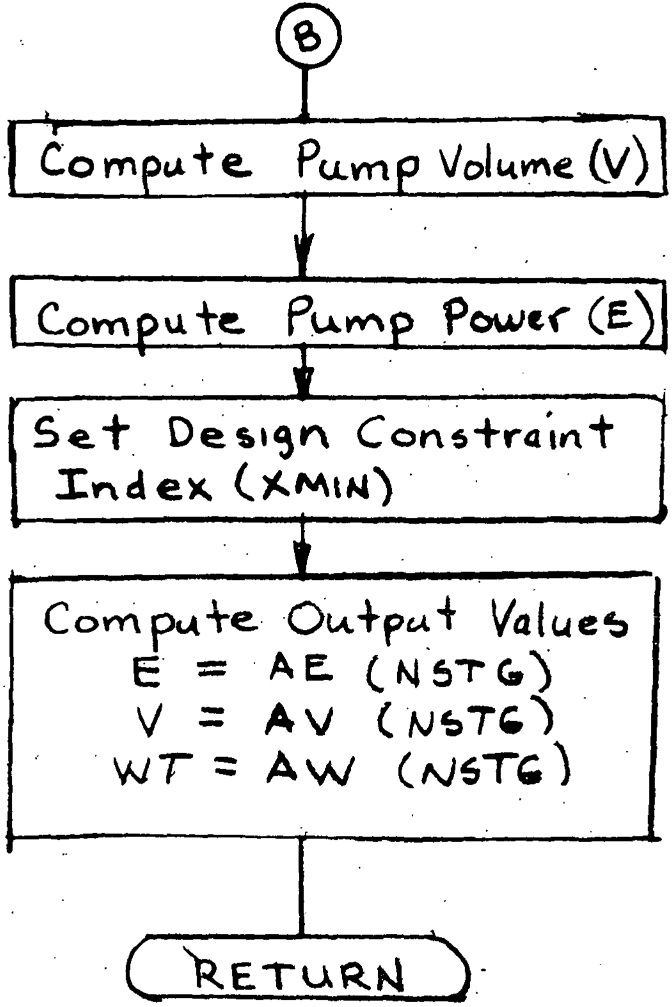


Fig. 1.9-18 Flowchart for PARPUMP (Continued)

SUBROUTINE SPHSEG

DESCRIPTION

Subroutine "SPHSEG" is actually a set of five subroutines using entry points under headi subroutine SPHSEG.

The entry point names and a description of their use follows:

SPHSEG calculates the fluid head in a hemisphere, given the radius and the volume of fluid which it contains.

ELIPSG calculates the fluid head in half a ellipsoid, given the lengths of the radius along the axis of rotation and the radius perpendicular to it and also the volume of fluid which it contains.

CYLHED calculates the fluid head in a right circular cylinder, given the radius of the cylinder and the volume of fluid which it contains.

FRHEAD calculates the fluid head in a frustrum of a right circular cone, given the radius of the top, the radius of the bottom, the height and the volume of fluid which it contains.

CYMSPH calculates the fluid head in the volume enclosed by a cylinder with an ellipsoid inserted into the top end. The necessary inputs to the routine are: (1) the radius along the axis of rotation of the ellipsoid which is equal to the height of the cylindrical section; (2) the radius perpendicular to the axis of rotation which is equal to the radius of the cylinder, and (3) the volume enclosed by this shape.

Labeled Common Used

```
CØMMØN/CØNST/
```

Mathematical Model of "SPHSEG"

For equations used see Appendix C.

Calling Sequence

Each subroutine entry point has a calling sequence as follows:

SPHSEG (Volume of fluid enclosed, radius, head calculated)

ELIPSG (Volume of fluid enclosed, radius along axis of rotation, radius perpendicular of axis of rotation, head calculated)

CYLHED (Volume of fluid enclosed, radius of cylinder, head calculated)

FRHEAD (Volume of fluid enclosed, radius of top, radius of bottom, height of frustrum, head calculated)

CYMSPH (Volume of fluid enclosed, radius along axis of rotation, radius of cylinder, head calculated)

Significant Variables

Name	Type	I/0	Dimension	Description
H	R	0	1	The fluid head calculated by a routine
HGT	R	I	1	Height of frustrum of cone
PV0L	R	I	1	Volume of fluid enclosed by the shape
RAD	R	I	1	Radius along axis of rotation
RB0T	R	I	1	Radius of bottom (or large) end of frustrum
RPD	R	I	1	Radius perpendicular to axis of rotation
RT0P	R	I	1	Radius of top (or small) end of frustrum
TV0L	R	I	1	The calculated total volume of half of an ellipsoid or a hemisphere

Subprograms Referenced By "SPHSEG"

Name	Type	Purpose	Reference
AC0S	F	Calculates arc cosine	Univac 1108 system
C0S	F	Calculates cosine	Univac 1108 system

Subprograms Referencing "SPHSEG"

Name	Type	Purpose	Reference
HFUNC	F	Controls calculation of fluid heads	Page B-175
TNKWTA	S	Control calculation of tank geometry	Page B-303

Listing Reference

A listing of "SPHSEG" can be found in Appendix B, Page 263.

Flow Chart

A flow chart of "SPHSEG" is presented in Fig. 1.9-19.

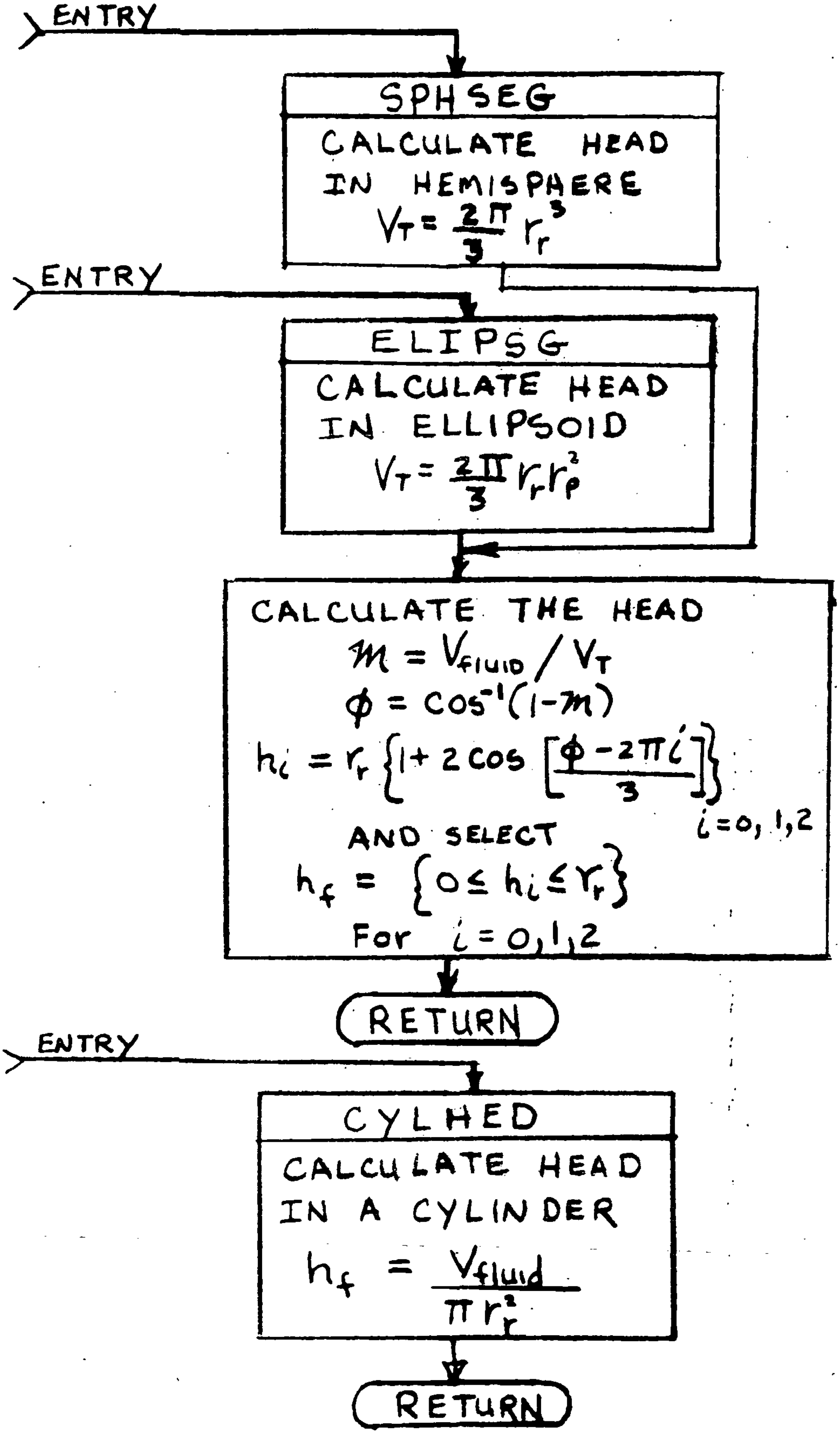


Fig. 1.9-19 Flowchart for SPHSEG

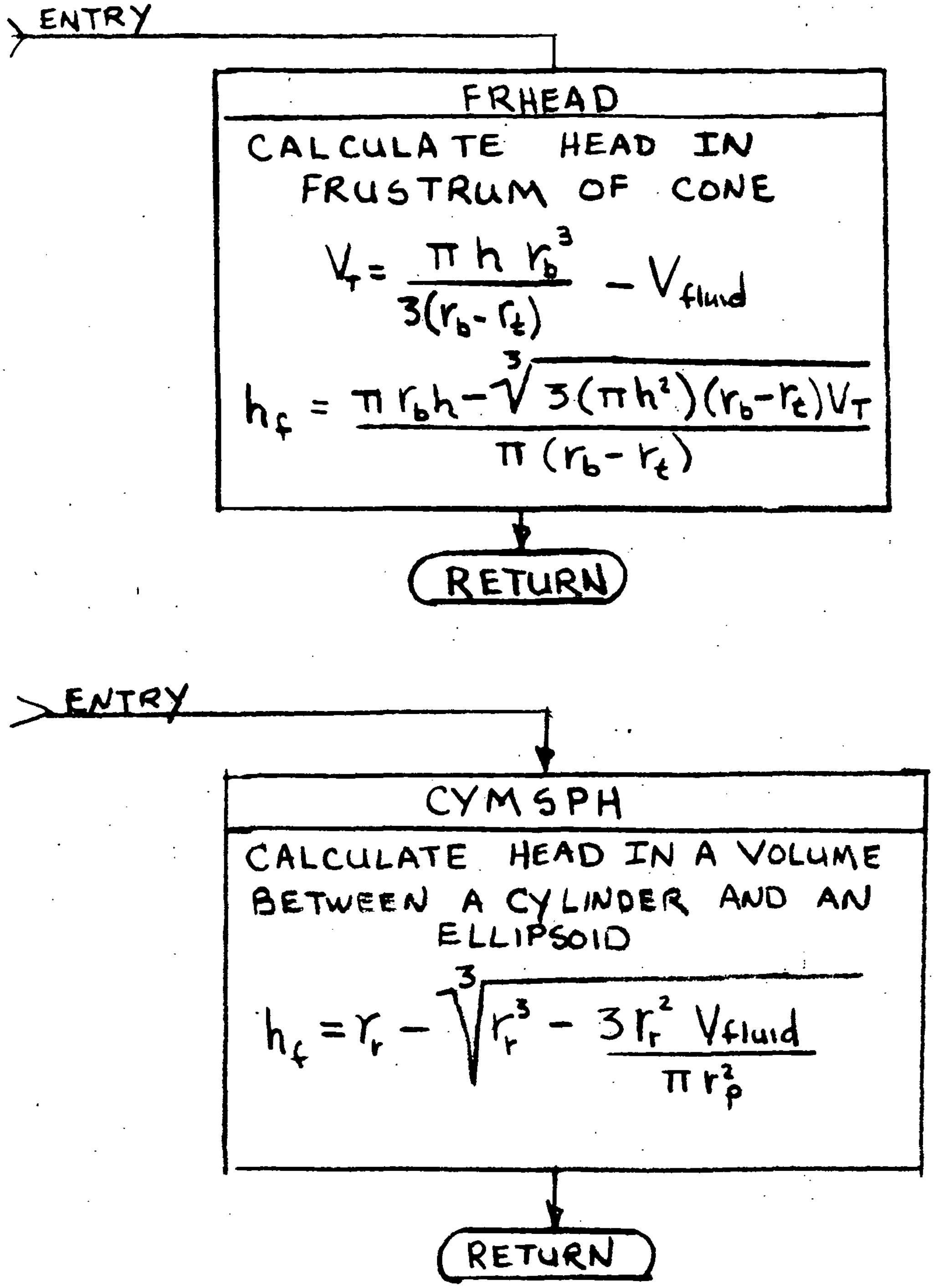


Fig. 1.9-19 Flowchart for SPHSEG (Continued)

Subroutine ST0C0N

DESCRIPTION

Subroutine ST0C0N packs six words of input data (integer) into one word. The six words of input data are as follows. (1) Function code (FUNCT) (2) Function type (CFTYPE), (3) Material type (CMTYPE), (4) Insulation type (CITYPE), (5) Number operating (CN0PER) and (6) Number of standby (CNSTBY), all of these six types or codes refer to the various components being input. The above named variable are equivalenced to the word ICNFIG(6) and this is the word referenced in this subroutine. The six words are packed by a standard (LMSC) system byte manipulation routine GPBYTE and are stored in the word CONFIG (IDX, 1) where IDX is defined via the calling sequence. The words of data are stored into the word CONFIG by bytes from left to right in the order stated above. C0NFIG is unpacked for use by the routine GETC0N.

Labeled Common Word

C0MM0N/CCNFIG/

ST0C0N Mathematical Model

None

Calling Sequence

ST0C0N is called by C0MPIL and it has one variable in its calling sequence. The variable is the location index for the component storage array. All other data is transferred through labeled common CCNFIG.

Significant Variables

Name	Type	I/0	Dimension	Description
CONFIG	I	0	100,7	Packed data stored in first column of this array
ICNFIG	I	I	6	Input array of data to be packed
IDX	I	I	1	Location index in the array C0NFIG

Subprograms Referenced by ST0C0N

Name	Type	Purpose	Reference
GPBYTE	F	Byte Manipulation Routine	LMSC System Routine

Subprograms Referencing ST0C0N

Name	Type	Purpose	Reference
COMPIL	S	Input of system components	Page B-64

Listing Reference

A listing of STOCON can be found in Appendix B, Page 269.

Flow Chart

None

SUBROUTINE TANK

DESCRIPTION

After the preliminary tank sizing calculations have been completed, Subroutine TANK is utilized to develop the propellant tank pressure histories as a function of; duty cycle, tank heat rates, pressurization system, and propellant withdrawal. From the resulting pressure history data; the gas and liquid residuals, pressurization fluid quantities, venting requirements and final tank sizes can be determined.

Subroutine TANK is configured to accumulate three pressurization options as follows:

1. Self Pressurization
2. Cold Helium Pressurization
3. Vaporized Propellant Pressurization

For whichever pressurization system is selected, the subroutine is programmed to evaluate each coast and burn period, as defined by the input duty cycle, and perform the following principal computations:

(a) Establish the Initial Tank Conditions:

Fluid being considered
Fluid temperature
Tank initial pressure
Tank initial temperature
Weight of liquid fluid in tank
Weight of fluid vapor in tank
Weight of pressurant gas in tank
Tank volume
Volume of liquid in tanks
Partial pressure of propellant vapor
Partial pressure of pressurant gas
Ullage volume in tank
Effective tank density
Effective internal energy

(b) For each coast period, compute:

Pre- or Non-Vent Conditions —

- Coast duration
- Fluid temperature in tank
- Weight of liquid fluid in tank
- Weight of fluid vapor in tank
- Weight of pressurant gas in vapor
- Partial pressure of fluid vapor
- Partial pressure of pressurant gas in vapor
- Current tank pressure
- Effective internal energy

Post-Vent Conditions —

- Tank vent pressure
- Weight of vented fluid and gas
- Weight of liquid in tank
- Weight of vapor in tank
- Weight of pressurant gas in vapor
- Total fluids in tank
- Partial pressure of fluid vapor
- Partial pressure of pressurant gas in vapor
- Vented tank pressure
- Effective internal energy

(c) For Each Burn Period, compute:

Energy Balance For Burn —

- Fluid considered
- Burn duration
- Flowrate for thrust
- Thrust propellant remaining
- Weight fluid in tank

Effective internal energy
Effective tank energy
Total flowrate from tank

The Resulting Tank Condition After Burn —

Propellant withdrawn
Total fluids in tank
Propellant (Liquid and Vapor) in tank
Thrust propellant remaining
New effective tank density
Partial pressure of propellant vapor
New effective internal energy

The Pressurant Needed for this Burn —

Tank liquid temperature
Stored pressurant gas temperature
New tank ullage volume
New propellant liquid volume
Liquid propellant remaining
Weight of propellant vapor in tank
Partial pressure of pressurant gas
Total pressure in tank
Nominal operating pressure of tank
Pressurant gas flowrate required
Weight of pressurant gas consumed
New tank pressure
Total pressurant consumed to this point in mission

(d) Final Engine Shutdown Tank Conditions:

The Final Tank Conditions —

Fluid considered
Fluid temperature
Time since shutdown

Weight of liquid residuals
Weight of propellant vapor
Weight pressurant gas in vapor
Partial pressure propellant vapor
Partial pressure pressurant gas
Current tank pressure
Effective internal energy
Final tank temperature
Total vented gas weight
Weight of gas residuals
Weight of liquid residuals

Pressurization System Weight —

Total pressurant gas required
Weight pressurant system

An example of typical output from subroutine TANK is presented in Fig. 1.9-20.

Input data for TANK has previously been read into the storage common blocks by subroutine CØMPIL. Specific labeled CØMMØN areas used by TANK for data storage and transfer are:

CØMMØN/CACCUM/
CØMMØN/CDCYCL/
CØMMØN/CENG/
CØMMØN/CHEX/
CØMMØN/CIØUNT/
CØMMØN/CMATRL/
CØMMØN/CMØYØR/
CØMMØN/CNAMES/
CØMMØN/CTANK/
CØMMØN/TABLØK/

```
                    NAME  USERS NAME  * * * * * * * * * * * * * * * * * * * * * PAGE     20
                    DEPT 6213         *        THE INTEGRATED MATH MODEL        * DATE 17 APR 73
                    EXT. 30235        *                                         * TIME 15:02:03
                    BLD. 104          *                 AT4307                  * CASE     1
                    * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
                                            ACPS - TEST DEMONSTRATION PROBLEM

                                  *** TANK AND VENT PARAMETER CALCULATIONS ***

               *** INITIAL TANK CONDITIONS ***

FLUID CONSIDERED -     OXYGEN            FLUID TEMPERATURE      =   163.91       TANK INITIAL PRESSURE =    16.00
WGT.OF LIQ. PROP.     =  5101.13         WGT. PROP. VAPOR       =     .741       WGT. LIQ. + VAPOR     =  5101.87
WGT. HELIUM IN VAPOR =       .00         TOTAL FLUIDS IN TANK   =  5101.87       VOL. OF LIQUID FLUID  =    71.80
PART.PRES.PROP.VAPOR  =  16.000          PART.PRES.HELIUM GAS   =     .000       ULLAGE VOLUME IN TANK =     2.46
TANK VOLUME           =     74.26        EFF. TANK DENSITY      =   68.702       EFF. INTERNAL ENERGY  =  -.56810388+02

                ******************** COAST NUMBER =   1      PRESS.SYS.NO. =   0 ********************

               *** PRE- OR NON-VENT CONDITIONS ***

FLUID CONSIDERED -     OXYGEN            FLUID TEMPERATURE      =   163.99       COAST DURATION - SEC. =     540.
WGT.OF LIQ. PROP.     = 5101.125         WGT. PROP. VAPOR       =     .744       WGT.HELIUM IN VAPOR  =     .000
PART.PRES.PROP.VAPOR  =    16.074        PART.PRES.HELIUM GAS   =     .000       CURRENT TANK PRESSURE =   16.074
EFF.INTERNAL ENERGY   =   -.56809886+02

                ******************** BURN NUMBER =   1      PRESS.SYS.NO. =   2 ********************

               *** COMPUTE ENERGY BALANCE FOR BURN ***

FLUID CONSIDERED -     OXYGEN            BURN DURATION - SEC.   =       5.       FLOWRATE FOR THRUST   =    9.990
THRUST PROP.REMAINING =  4235.05         PROPELLANT IN TANK     =  5101.13       EFF. INTERNAL ENERGY  =  -.56809886+02
EFF. TANK ENERGY      =   -.28672176+06                                          TOTAL FLOWRATE        =   12.033

               *** COMPUTE RESULTING TANK CONDITIONS ***

PROPELLANT WITHDRAWN  =    55.113        TOTAL FLUIDS IN TANK   =  5046.76       PROPELLANT LIQ.+VAP.  =  5046.76
THRUST PROP.REMAINING =  4189.29         NEW EFF. TANK DENSITY  =  67.9596       PART.PRES.PROP.VAPOR  =   16.056
NEW INTERNAL ENERGY   =   -.56813077+02

               *** COMPUTE PRESSURANT NEEDED FOR THIS BURN ***

TANK LIQ. TEMPERATURE =   163.97         STORED HELIUM TEMP.    =   170.00       NEW TANK ULLAGE VOL.  =    3.230
NEW PROP. LIQ. VOLUME =    71.03         PROP. LIQ. REMAINING   =  5045.78       WGT. OF PROP. VAPOR   =    .9742
HELIUM PART.PRESSURE  =   10.644         TOTAL PRES. *PPV+PHE*  =   16.056       NOM. OPERATING PRES.  =   26.700
HELIUM FLOW  RATE     =   .1644-01       WEIGHT OF HELIUM USED  =   .7528-01     NEW TANK PRESSURE     =   26.700
TOTAL HELIUM CONSUMED =     .075
```

Fig. 1.9-20 Typical Subroutine TANK Output

TANK MATHEMATICAL MODEL

The equations, mathematical logic, and procedures, necessary tables and constants required are presented in Appendix C.

CALLING SEQUENCE

Subroutine TANK is initiated by a simple call from subroutine CRYCØN, with no calling arguments. Data transfer to TANK is accomplished through INCLUDE statements as shown in the subroutine listing. Upon completion of the TANK computations, sequential control is returned to subroutine CRYCØN.

SIGNIFICANT VARIABLES

Significant variables employed in subroutine TANK are given as follows:

Name	Type	I/Ø	Dimension	Description
NØP	I	I	2,1	Number of tanks operating
SATYPE	I	I	2	Type acquisition device
SITYPE	I	I	2,1	Tank insulation type
SMTYPE	I	I	2,1	Tank material type
SPTYPE	I	I	2,1	Pressurization system type
SITEMP	R	I	2,1	Tank initial temperature
SIPRES	R	I	2,1	Tank initial pressure
SPGTEM	R	I	2,1	Pressurant gas temperature
SØPRES	R	I	2,1	Tank operating pressure
SVPRES	R	I	2,1	Tank vent pressure
SHFLUX	R	I	2,1	Heat flux into tank
SITHIK	R	I	2,1	Insulation thickness
FLDLØD	R	I	2	Fluid loaded into tank
SULGPC	R	I	2	Tank ullage volume (%)
SMDIAM	R	I	2,1	Tank maximum diameter
SHØTEM	R	I	2,1	Tank heat exchanger outlet temperature
SHDELP	R	I	2,1	Tank heat exchanger delta-P
SPDELP	R	I	2,1	Tank circulating pump delta-P
SGØTEM	R	I	2,1	Gas generatore outlet temperature
SGGPC	R	I	2,1	Gas generatore champer pressure
SGMRAT	R	I	2,1	Gas generatore mixture ratio
SNBAR	R	I	2	Insulation — layers per inch
IG	I	C	1	Fluid index: 1 = Ø2 , 2 = H2
IP	I	C	1	Duty cycle index

Name	Type	I/0	Dimension	Description
IW	I	C	1	Coast period index
IF	I	C	1	Burn period index
IBURN	I	C	1	Burn counting index
ISW	I	C	1	Current pressurant system type
WLRT	R	C	2,1	Total liquid residuals in tank
WHESUM	R	C	1	Sum of helium consumed to point
T	R	C	1	Temperature at any point
PWT0T	R	C	2	Propellant remaining in tank
WPT0T	R	I	2	Total propellant required for system
VLIQ	R	C	1	Volume of liquid in tank
PV0L	R	C	1	Ullage volume at any point
WPV	R	C	1	Weight of propellant vapor
PHe	R	C	1	Helium pressure
WHe	R	C	1	Weight of helium
WP	R	C	1	Weight of liquid propellant
WPT	R	C	1	WP + WPV
ENERGY	R	C	1	Effective internal energy
PPV	R	C	1	Partial pressure propellant vapor
SV0L	R	I	2	Volume of propellant tank
RH0P	R	C	1	Density of liquid fluid
RH0G	R	C	1	Density of gaseous fluid
PRES	R	C	60,2,1	Tank pressure at any point
RATI0	R	C	1	Weight ratio for energy change
ZHE	R	C	1	Helium compressibility
DCYCLE	R	I	60	Duty cycle time valve array
SVWT	R	C	30,2,1	Tank vented weight
WT0T	R	C	1	Current total fluids in tank
NDCYCL	I	I	1	Index of total values in DCYCLE array
WD0TJ	R	I	2,2	Flowrate for all gas generators in system
E	R	C	1	System effective energy
WVSUM	R	C	1	Summed vented weight at end of each coast period
SWVT0T	R	C	30,2	Summed total vent weight
WGR	R	C	2,1	Weight gas residual
TFINAL	R	C	1	Final temperature
RHE	R	C	1	Helium density at point of calculation
WD0THE	R	C	30,2,1	Helium flowrate
PRESHE	R	C	2,1	Helium pressure
WHET0T	R	C	2,1	Total helium consumed
WPGT0T	R	C	2,1	Total pressurant system weight
WD0TGG	R	C	30,2,1	Flowrate pressurant gas
WPVG	R	C	1	Weight propellant vent gas
WDPSMX	R	C	1	Pressurant gas flowrate
WGGPPG	R	C	2,1	Weight gas generator propellant gas required for tank heat exchanger
WGGAPG	R	C	2,1	Gas generatore systm weight
HPMXPG	R	C	1	Motor horsepower for propellant circulating pump

Name	Type	I/O	Dimension	Description
WMPG	R	C	2,1	Motor weight for circulating pump
WBPG	R	C	2,1	Battery weight for circulating pump motor
WCPPG	R	C	2,1	Weight circulating pump
WTSYPG	R	C	2,1	Pressurization system weight

SUBPROGRAMS REFERENCED IN TANK

Name	Type	Purpose	Reference
DIAG	F	Diagnostic print	Page B-111
RHØLIQ	S	Computes liquid density	Page B-262
GSDNST	S	Computes gas density	Page B-219
FINTAB	S	Finds designated table of data	Page B-147
MIPE	F	Table data extraction	Page B-221
PAGE	F	Controls page and line circuit	Page B-239
CSUBV	F	Computes C_V for fluid	Page B-93
TSAT	F	Computes saturation temperature for specified fluid	Page B-308
ZFIND	S	Finds compressibility of fluid at specified T&P	Page B-335
FINDR	F	Finds gas constant for specified fluid	Page B-140
VENT	S	Computes quantity of gaseous fluid vented	Page B-318
GSZDNS	S	Computes compressibility and density for specified fluid at specified T&P	Page B-219
AMAXI	F	Finds maximum of two values	System Routine
HEATEX	S	Computes heat exchanger parameters	Page B-177

SUBPROGRAMS REFERENCING TANK

Name	Type	Purpose	Reference
CRYCØN	S	Program sequential control	Page B-85

LISTING REFERENCE PAGE

A listing of subroutine TANK will be found in Appendix B, page 277.

FLOW CHART

A flow chart for subroutine TANK is presented in Fig. 1.9-21.

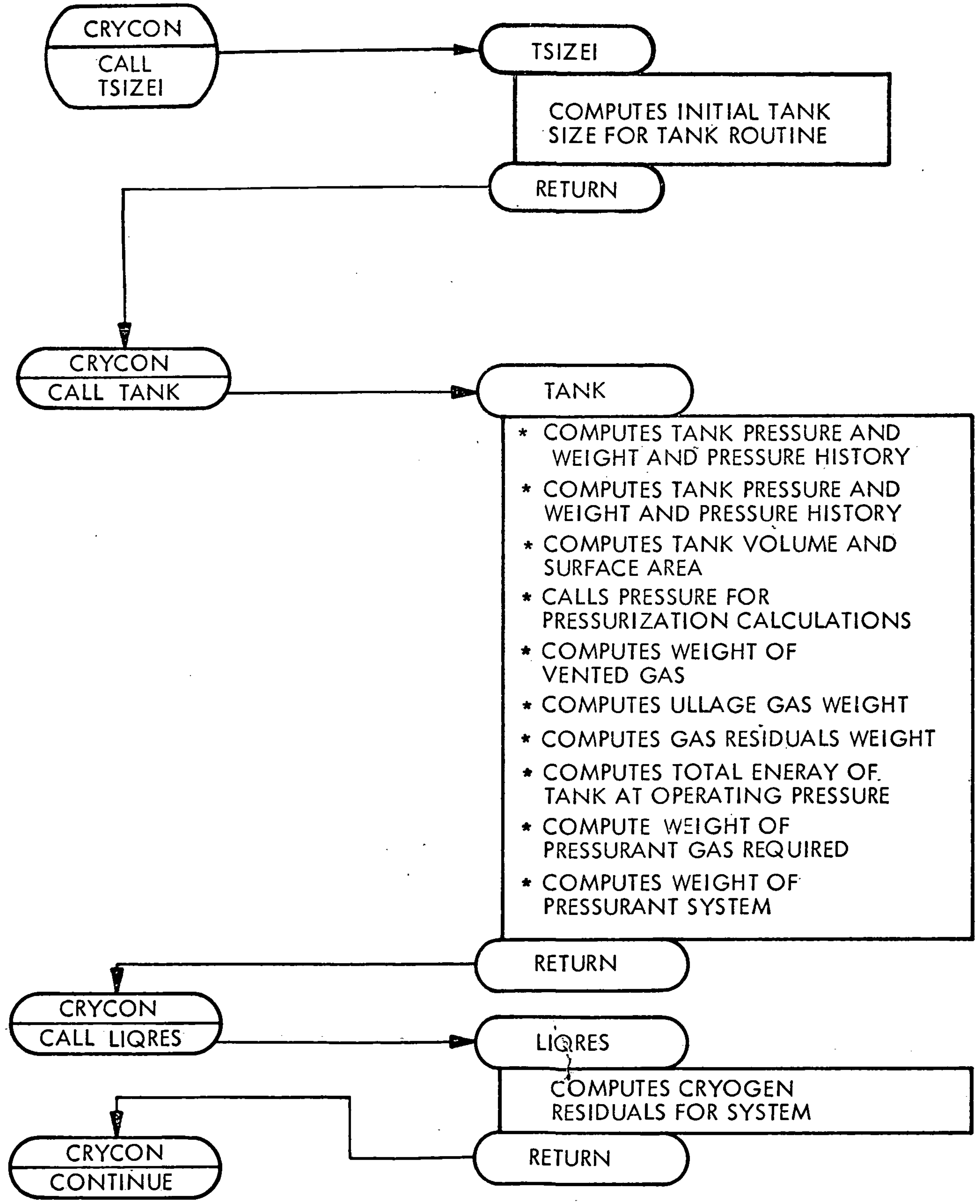


Fig. 1.9-21 Flowchart for Tank and TSIZEI

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SUBROUTINE TC0ND

DESCRIPTION

The subroutine provides an integrated subprogram package for the computation of the heat leak flux (per unit area) for nine different insulation materials including both monolayer and multilayer types. The data employed in the subroutine originated largely from LMSC study efforts described in References 1.9-9, -10, -11 and -12. The equations employed may be found in the subroutine math model and in coded form in the subroutine listing.

Specifically, the subroutine is programmed for the following insulation materials:

DOUBLE ALUMINIZED MYLAR - SILK NET
DOUBLE GOLDIZED MYLAR - SILK NET
DOUBLE ALUMINIZED MYLAR - TISSUE GLASS
CRINKLED DOUBLE ALUMINIZED MYLAR - TISSUE GLASS
NRC-2, CRINKLED SINGLE ALUMINIZED MYLAR
SUPERFLOC
MICROSPHERES
POLYURETHANE FOAM
FIBERGLASS BATTING - HELIUM PURGED

Input data for subroutine TC0ND is supplied through the calling arguments. The subroutine contains its own constants and does not require access to C0MM0N STORAGE BLOCKS.

TC0ND Mathematical Model

The TC0ND MATH MODEL consisting of the equations, constants and procedural steps required are presented in Appendix C.

Name	Type	I/0	Dimension	Description
SC0NST	R	D	1	Numerical constant in each equation for K_E
EMIT1	R	C	1	Value of ϵ
EMIT2	R	C	1	Value of ϵ
DEMIT	R	C	1	Value of $(\frac{2}{\epsilon} - 1)$
SC0ND	R	C	1	Value of first three
	R	C	1	terms of K_E equation
RNUM	R	C	1	Value of numerator of fractional term in K_E equation
RDEN	R	C	1	Value of denominator of tractional term in K_E equation
RC0ND	R	C	1	Value of fractional term in K_E equation or, value of K_E equation for microspheres
EMITA	R	C	1	Value of ϵa
EMITB	R	C	1	Value of ϵb
PKSUBE	R	C	1	Value of K_E equation for polyurethane foam
FKSUBE	R	C	1	Value of K_E equation for fiberglass buttin

SUBPROGRAMS REFERENCED IN TC0ND

Name	Type	Purpose	Reference

None referenced.

SUBPROGRAMS REFERENCING TC0ND

Name	Type	Purpose	Reference
APUSUB	S	Subcritical APU Analysis	Page B-8
APUSUP	S	Super Critical APU Analysis	Page B-12
ECLSS	S	Life Support System Analysis	Page B-122
FUELCL	S	Fuel Cell System Analysis	Page B-152

CALLING SEQUENCE

Subroutine TC0ND is initiated by the calling routines with six calling arguments. The first fivd arguments supply the required input data, while the sixth argument returns the computed value for the heat leak per unit area. The calling arguments are defined below.

SIGNIFICANT VARIABLES

The significant variables processed by subroutine TC0ND are defined in the following list:

Name	Type	I/0	Dimension	Description
TH	R	I	1	Hot boundary condition (T_H-°R)
TC	R	I	1	Cold boundary condition (T_c-°R)
NBAR	R	I	1	Number of radiation shields per inch thickness of insulation ($\overline{N}$)
THIKIN	R	I	1	Insulation thickness (inches)
INTYPE	I	I	1	Insulation type (see PDP-(MATRL))
QC0ND	R	0	1	Heat leak flux per unit area (BTu/Hr-ft^2)
DELT	R	C	1	(T_H-T_C)
TMEAN	R	C	1	$(T_H+T_C)/2.0$
SUMT	R	C	1	(TH+TC)
SUMSQT	R	C	1	$(T^2_H+T^2{}_C)$
TMPR1	R	C	1	T_C/T_H
TMPR2	R	C	1	$(\mathrm{TMPR1})^2$
TH3	R	C	1	$(T_H)^3$
NSHLD	R	C	1	THKIN* NBAR
THKFT	R	C	1	THKIN/12.0
THETH1	R	C	1	(1.0 + TMPR1)
THETA2	R	C	1	(1.0 + TMPR2)
SIGMA	R	C	1	$= 0.1713\mathrm{X}10^{-8}$ Steten-Boltzman constant

LISTING REFERENCE PAGE

A list of subroutine TC0ND will be found in Appendix B, page 290.

FLOW CHART

No flow chart is presented for subroutine TC0ND since the listing clearly presents the order of the computations.

Subroutine TEL

DESCRIPTION

Subroutine TEL evaluates a polynomial or performs a table interpolation, using YLGINT, according to the specification of TYPE for the particular subtable which was designated.

The dependent variable (X) is passed via the calling sequence and the table of values to be used in the operation is passed (from LOCAT) be use of labeled common arrays XTAB and YTAB. If TYPE is 0 TEL performs a polynomial evaluation using the NV values of coefficients stored in XTAB (if C_1 = XTAB(1), $\cdots$, C_n = XTAB(NV)) and the polynomial is calculated as $Y = C_n + C_{n-1}X + C_{n-2}X^2 + \cdots + C_1X^{n-1}$. The value of Y is transferred back to MIPE through the calling sequence.

If TYPE is 1 TEL performs are interpolation using X and the independent table variables stored in XTAB to calculate a Y value from the dependent table values stored in YTAB. The actual interpolation is performed by function YLGINT which is a standard UNIVAC-1108 routine.

Labeled Common Word

```
COMMON/CIOUNT/
COMMON/CKEYS
COMMON/CTAB
```

Mathematical Model for TEL

None

Calling Sequence

TEL is called from function MIPE and it has two variables in its calling sequence. The variables are – (1) the X or independent variable used to calculate the dependent variable and its input, (2) the output dependent variable Y which is calculated and depends on the value of X which was input. All other data is transferred by use of labeled common CTAB.

Significant Variables

Name	Type	I/0	Dimension	Description
NIP	I	I	1	Number of interpolation points for this subtable
NV	I	I	1	Number of X-Y pairs or coefficients for this subtable
TYPE	I	I	1	Type of subtable – discrete or coefficient for this subtable
X	R	I	1	Value of independent variable used to calculate Y
XTAB	R	I	40	Subtable values of the independent variables
Y	R	0	1	Value of the dependent variable calculated
YTAB	R	I	40	Subtable values of the dependent variable

Subprograms Referenced by TEL

Name	Type	Purpose	Reference
YLGINT	F	Interpolates from table	REF. 1.9-17

Subprograms Referencing TEL

Name	Type	Purpose	Reference
MIPE	F	Multilevel table interpolation	Page B-221

Listing Reference

A listing of TEL can be found in Appendix B, Page 292.

Flow Chart

For flow chart of TEL see Figure 1.9-22.

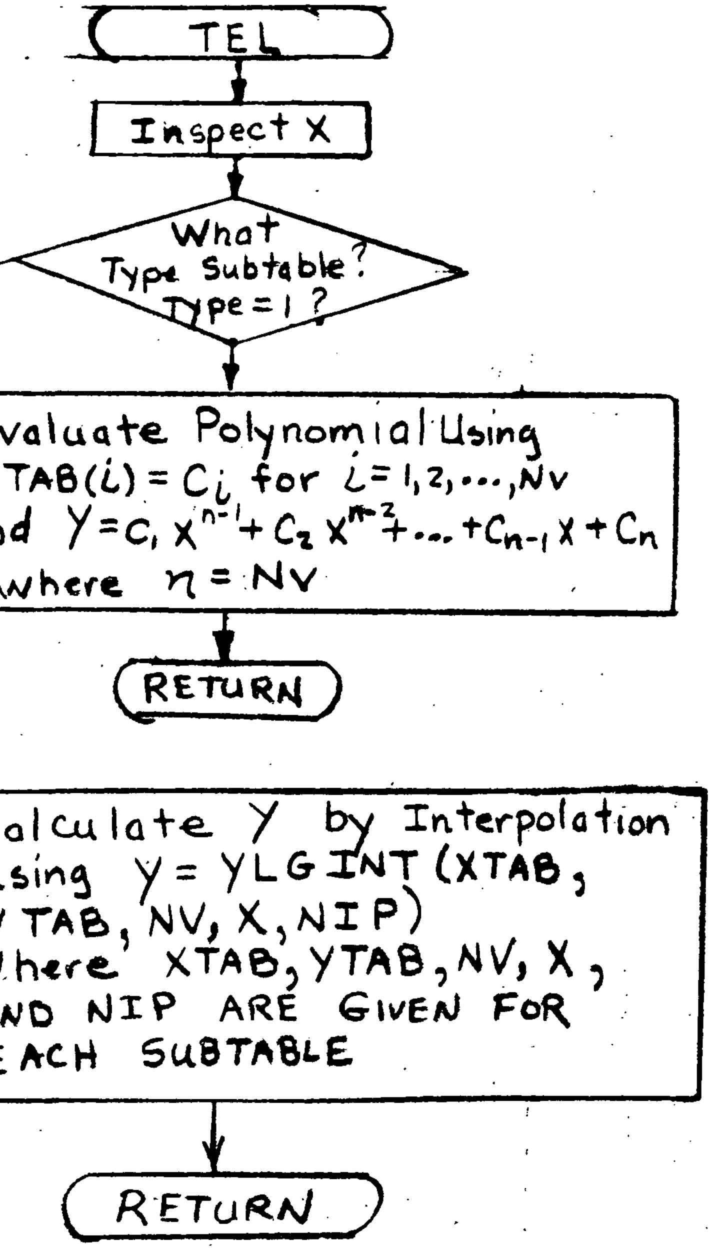

Fig. 1.9-22 Flowchart for Subroutine TEL

SUBR0UTINE THKWTG

DESCRIPTION

This subroutine calculates the weight of a tank as a function of tank temperature, pressure, head of fluid and the geometry of the tank. The tank material type may be specified as input and calculations will be performed using this type of material, however, if the material type is not designated then the subroutine will make three calculations, for each tank shape, where each calculation uses a different material type. The three materials which are used are: (1) 2219-T87 Aluminum Alloy, (2) 321/347 Stainless Steel, and (3) Titanium Ti-6Al-4V alloy. The routine will then select that material type which gives the lightest weight for the given shape. Weights are determined by first calculating wall thickness and then with a given area and material density the weight can be calculated.

Labeled Common Used

C0MM0N/CMATRL/
C0MM0N/TABL0K/

Mathematical Model of THKWTG

For equations used see Appendix C.

Calling Sequence

The calling sequence for THKWTG consists of thirteen variables of which eleven are inputs to the subroutine and two are outputs of the subroutine. See Significant variables, below, for a description of each.

Significant Variables

Name	Type	I/O	Dimension	Description
AREA	R	I	1	Area of the tank shape being processed
FTU	R	I	1	FTU for the designated material
HD	R	I	1	Fluid head
HT	R	I	1	Height of frustrum or a length of an ellipse axis
IGAS	I	I	1	Fluid type 1 = Ø_2, 2 = H_2
ITYPE	I	I	1	Tank shape type (1 to 4 see Listing)
KFLG	I	I	1	= 1 for full ellipsoid, =2 for ellipsoid connected to other shape
KMT	I	Ø	1	Type of material selected (if material type not input)
MINTHK	R	I	15	Minimum allowable wall thickness.
MTYPE	I	I	1	Material type input, if = 0 program will select.
P	R	I	1	Calculated tank pressure
PU	R	I	1	Ullage pressure input
RAD	R	I	1	Radius of cylinder, radius of top of frustrum, or semi-axis of an ellipsoid
RADI	R	I	1	Radius of bottom of frustrum
RHØF	R	I	1	Calculated fluid density
RHØL	R	I	10	Density of tank metal for specified type
TEMP	R	I	1	Temperature of fluid in tank
THK	R	I	1	Calculated tank wall thickness
TWEIGHT	R	Ø	1	Calculated total tank weight

Subprograms Referenced By THKWTG

Name	Type	Purpose	Reference
FDNSTY	S	Calculates fluid density	Page B-219
FINTAB	S	Locates a given table	Page B-147
MIPE	F	Interpolates a given table	Page B-221
SQRT	F	Calculate a square root	Univac 1108 System

Subprograms Referencing THKWTG

Name	Type	Purpose	Reference
TNKWTA	S	Controls calculation of tank geometry and weight	Page B-303

Listing Reference

A listing of THKWTG can be found in Appendix B, Page 297.

Flow Chart

A flow chart of THKWTG is presented in Fig. 1.9-23.

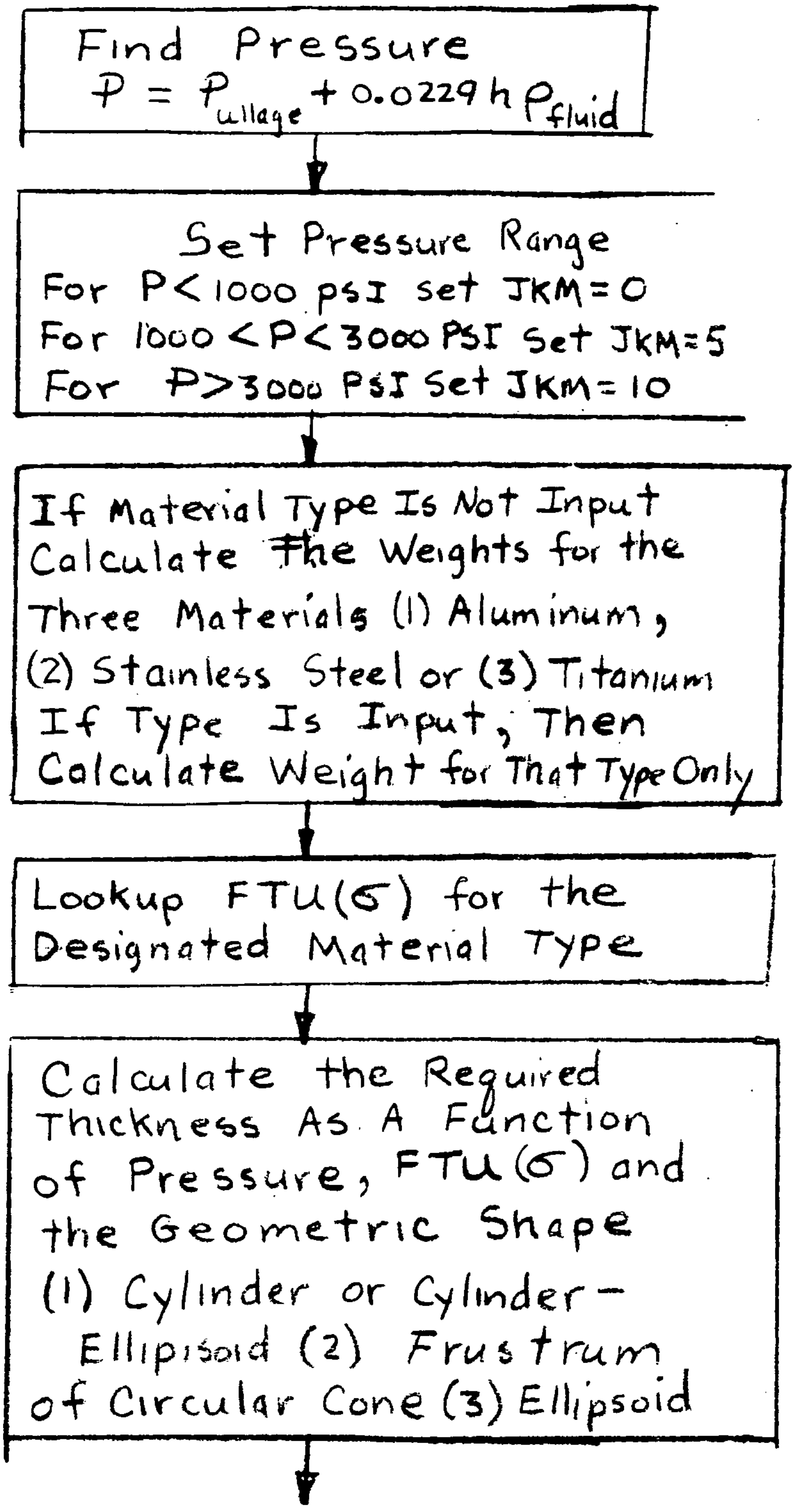

Fig. 1.9-23 Flowchart for TNKWTG

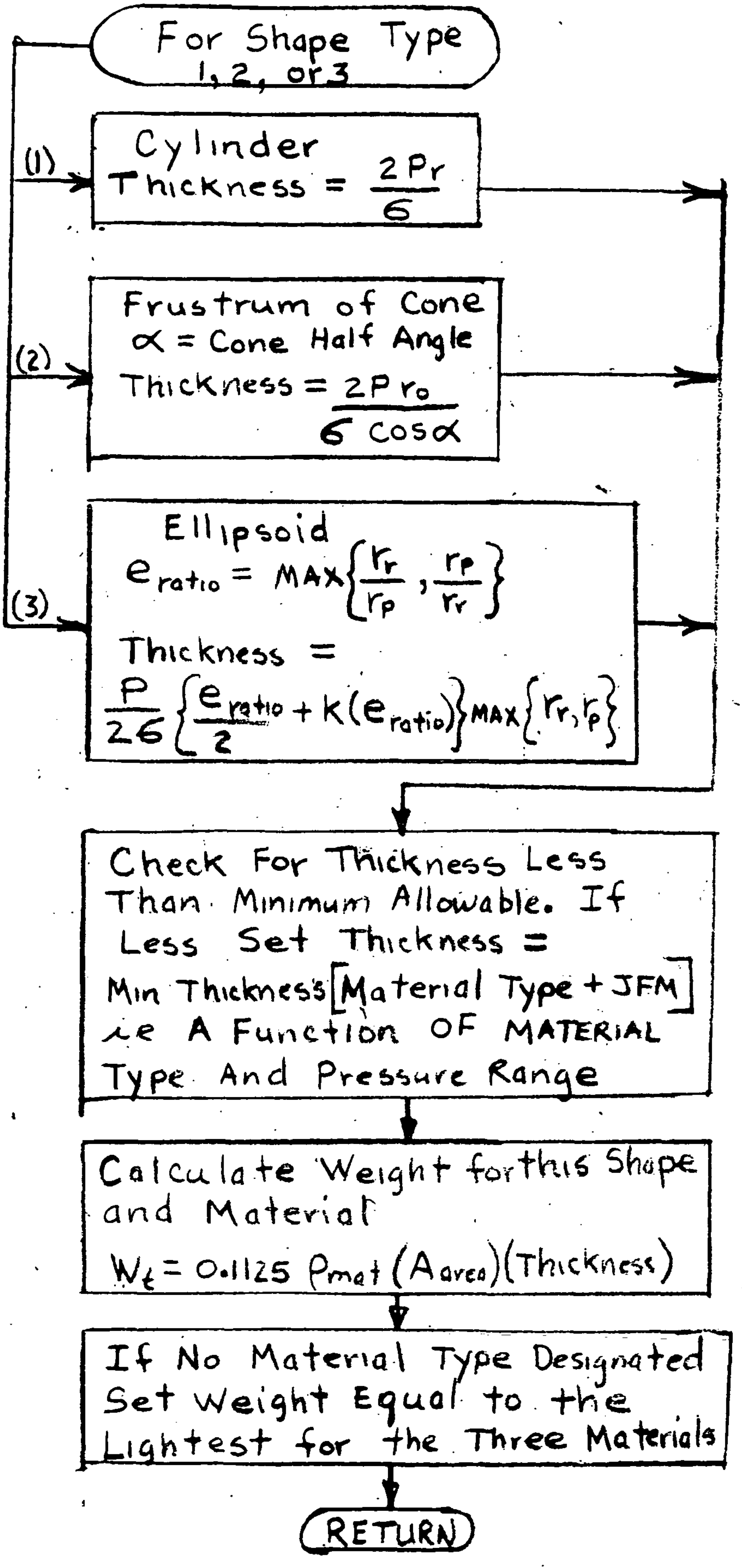

Fig. 1.9-23 Flowchart for TNKWTG (Continued)

FUNCTI0N TKGE0M

DESCRIPTION

The subprogram labeled TKGE0M on its control card is actually a set of three function subprograms, using entry points under the heading function "VFUNC." The entry point names and a description of the function follows.

AFUNC for an input pointer to the array JTKTYP a tank shape type is located and this controls the function to be called to calculate an area.

HFUNC for a given input point to the array JTKTYP a tank shape type is located and this controls the function to be called to calculate a fluid head.

VFUNC for a given input pointer to the array JTKTYP a tank shape type is located and this controls the function to be called to calculate the volume of the designated shape.

This set of routines is used by TNKWTA in processing the general tank configuration where there is no specific order in which the tank shapes must be input (IW0P = 2 or 3) In general, it acts as a control routine for the calculation of geometric parameters of geometric shapes which have been input in any order.

Labeled Common Used

C0MM0N/TANKWT/

Mathematical Model of TKGE0M

None

Calling Sequence

Each function entry point has an array pointer in its calling sequence, and each function is called only by the routine TNKWTA. In addition, HFUNC also has the fluid volume for the given shape as a calling sequence variable.

Significant Variables

Name	Type	I/O	Dimension	Description
HD	R	I	1	Fluid head in the designated tank shape
I	I	I	1	Pointer to the arrays JTKTYP, XD, YD and ZD
JTKTYP	I	I	10	Contains tank shape type information
PV0L	R	I	1	Volume of the fluid in the designated shape
VFUNC	R	0	1	Output of the calculated volume, area or fluid head
XD	R	I	10	Height or radius of a shape – see input writeup
YD	R	I	10	Radius of the shape – see input writeup
ZD	R	I	10	Radius of the bottom of a frustrum of cone.

Subprograms Referenced by TKGE0M

Name	Type	Purpose	Reference
ARACYL	F	Calculates area of cylinder	Page B-175
AREAFR	F	Calculates area of a frustrum of a cone	Page B-175
ARSPHR	F	Calculates area of half an ellipsoid	Page B-175
CYLHED	S	Calculates fluid head in a cylinder	Page B-263
CYLNDR	F	Calculates volume in a cylinder	Page B-175
CYLSPH	F	Calculates volume between cylinder and ellipsoid	Page B-175
CYMSPH	S	Calculates head between a cylinder and ellipsoid	Page B-263
ELIPSG	S	Calculates head in an ellipsoid	Page B-263
FRC0NE	F	Calculates volume of a frustrum of a cone	Page B-175
FRHEAD	S	Calculates head in a frustrum of a cone	Page B-263
HSPHER	F	Calculates volume of an ellipsoid	Page B-175

Subprograms Referencing TKGE0M

Name	Type	Purpose	Reference
TNKWTA	S	Controls calculation of tank geometry and weight	Page B-303

Listing Reference

A listing of "TKGE0M" can be found in Appendix B, Page 299.

Flow Chart

A flow chart of "TKGE0M" is presented in Fig.1.9-24.

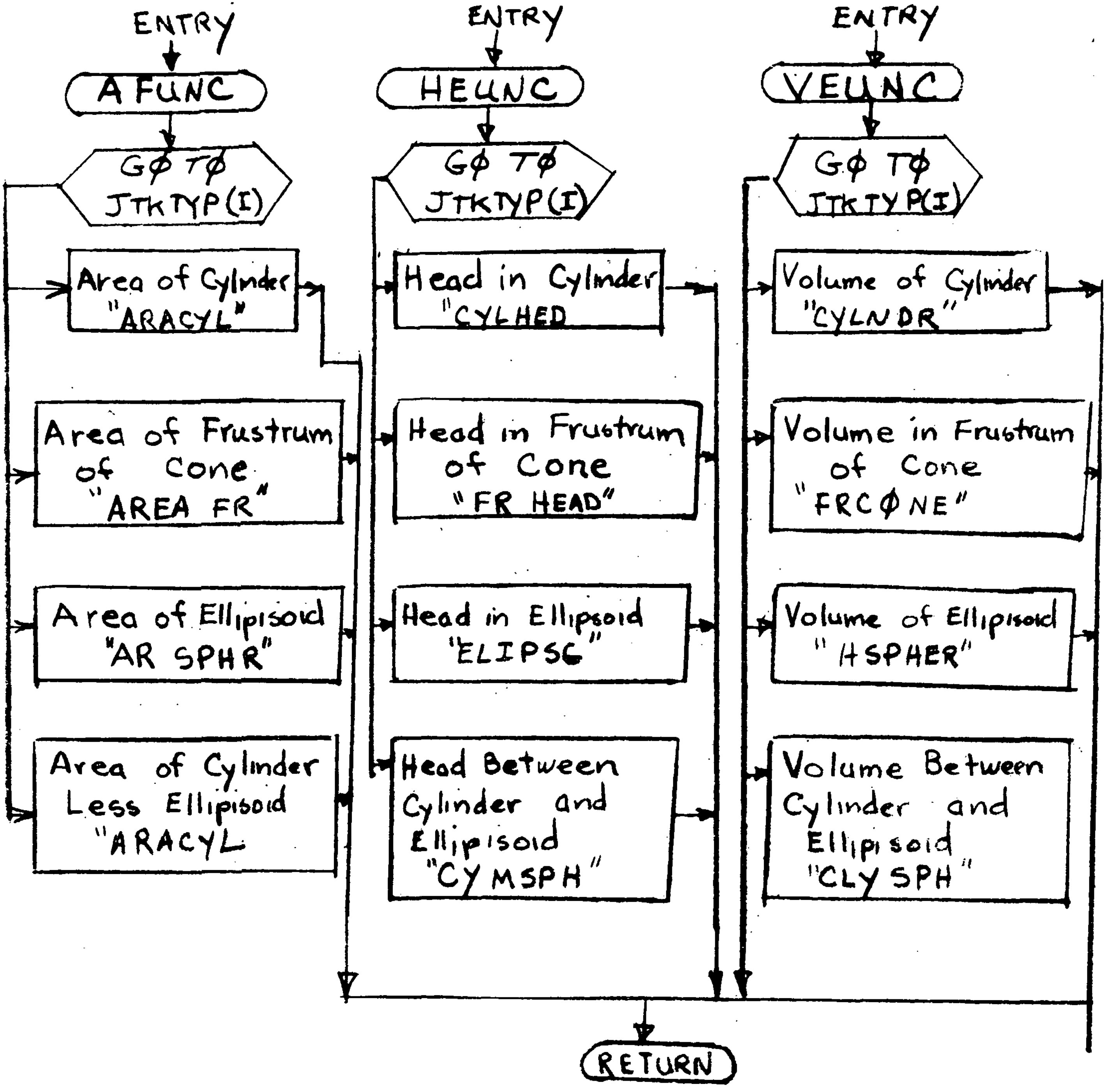

Fig. 1.9-24 Flowchart for TKGEØM

SUBRØUTINE TNKWTA

DESCRIPTION

TNKWTA is the main control routine for the calculation of tank weights. The routine accepts three input options which are determined by the input variable (flag) IWØP. With IWØP = 1 the subroutine processes a simple spherical tank shape which may have a cylindrical section added between two hemispherical sections. With IWØP = 2 or 3 a general shape tank can be constructed by inputting a string of tank shapes, in order, from "bottom" to "top" of the tank. IWØP = 2 allows the user to input all dimensions thereby setting the tank volume to a predetermined size. With IWØP = 3, the general tank configuration is fitted to the volume of fluid plus percent ullage volume which is input to this routine. This allows the fluid volume to be calculated by other system parameters.

Procedure for calculating tank weights is as follows.

IWØP = 1 For this option a maximum spherical tank volume is calculated from the input maximum tank diameter. If the specified fluid volume is greater than this maxim spherical volume, then a cylindrical section is fitted between two hemispheres of maximum diameter. If the fluid volume is less than the maximum spherical volume, then the given tank diameter is decreased to fit the fluid volume. After these geometri considerations have been satisfied the tank weight is calculated from tank area, wall thickness and material density.

IWØP = 2 For IWØP = 2, the total tank volume, area and weight is calculated based on the dimensions which have been input. The percent ullage volume is re-calculated using the total volume and the volume of fluid input and the required tank volume is set equal to the total tank volume which has been calculated.

IWØP = 3 For IWØP = 3, the total tank volume required is calculated from the fluid volume plus ullage volume which have been input to the routine. To use option IWØP = 3, a cylindrical shape must be input somewhere in the tank configuration and its height must be zero. The routine then goes through the tank configuration and calculates all volumes except that for the cylindrical section. When this is completed the volumes are summed and subtracted from the required volume, the difference thus obtained is then set as the volume of the cylindrical section. The height of the cylindrical section is then calculated to fit the volume calculated above. Now all dimensions are set and the areas can be calculated and along with the material density a weight can be computed.

The outputs from this routine are (1) the required volume used in the calculation of weight, (2) the total tank weight, (3) total surface area and (4) the height of the cylindrical section, if any.

Note: A diagram of the tank geometry routine linkage is supplied along with the flow chart of this subroutine. Note also that all calculations are performed for both the oxidizer and fuel tanks, if both are present.

Labeled Common Used

```
COMMON/CONST/
COMMON/TANKWT/
```

Mathematical Model of TNKWTA

For equations used, see Appendix C.

Calling Sequence

The calling sequence for TNKWTA consists of eleven variables of which seven are inputs to the subroutine and four are outputs of the subroutine, however, two of the input variables may be modified by the routine. See Significant Variables, below, for a description of each.

Significant Variables

Name	Type	I/Ø	Dimension	Description
A1	R	I	2	Aea of lower hemisphere for IWØP = 1
A2	R	I	2	Area of cylindrical section for IWØP = 1
A3	R	I	2	Area of upper hemisphere for IWØP = 1
DIAM	R	I	2	Maximum tank diameter for IWØP = 1
FLDVØL	R	I	2	Volume of fluid contained in tank (oxidizer and fuel)
HC	R	Ø	2	Height of cylindrical section for IWØP = 1
ISW	I	I	1	= 1 for storage tanks, = 2 for accumulato tanks
IWØP	I	I	1	Tank option flag – see description above
JFLTP	I	I	10	Fluid type contained in each tank shape IWØP = 2 or 3
JTKTYP	I	I	10	Tank shape type for general configuration IWØP = 2 or 3
KFLG	I	I	1	= 1 ellipsoid connected to ellipsoid, = 2 ellipsoid connected to other shape
MFLG1	I	I	1	Material type if material is not designated
MTYPE	I	I	2	Designated material type (if = 0 program will select one)
NØSHAP	I	I	1	Number of geometric shapes input
PCULLG	R	I	2	The percentage ullage volume for the tank
PVØL	R	I	1	"Partial" volume used when calculating fluid head
RMAX	R	I	2	Maximum tank diameter = DIAM/2.
TAR	R	I	10	Surface area for a designated shape IWØP = 2 or 3
TKPRES	R	I	2	Operating pressure of the tank.
TKTEMP	R	I	2	Operating temperature of the tank.
TNKVL	R	Ø	2	Required tank volume calculated by this routine
TØTARA	R	Ø	2	Total tank surface area = sum of areas of the shapes.
TVL	R	I	10	Volume of a designated shape IWØP = 2 or

Name	Type	I/O	Dimension	Description
VMX	R	I	2	Volume of maximum sphere for IW0P = 1
VI	R	I	2	Volume of lower hemisphere for IW0P = 1
V2	R	I	2	Volume of cylindrical section for IW0P = 1
V3	R	I	2	Volume of upper hemisphere for IW0P = 1
WT0FTK	R	0	2	Total tank weight, oxidizer and fuel tanks
XD	R	I	10	Height or radius of a shape – See input writeup IW0P = 2 or 3
YD	R	I	10	Radius of a shape – See input writeup IW0P = 2 or 3
ZD	R	I	10	Radius of the bottom of a frustrum of a cone IW0P = 2 or 3

Subprograms Referenced By TNKWTA

Name	Type	Purpose	Reference
AFUNC	F	Controls calculation of an area for a designated shape.	Page B-299
ARACYL	F	Calculates area of a cylinder	Page B-175
ARSPHR	F	Calculates area of half an ellipsoid	Page B-175
CYLHED	S	Calculates fluid head in a cylinder	Page B-263
HFUNC	F	Controls calculation of fluid head for a designated shape	Page B-299
SPHERE	F	Calculates volume of a sphere	Page B-175
SPHSEG	S	Calculates fluid head in a hemisphere	Page B-263
THKWTG	S	Calculates weight of a given tank shape	Page B-297
VFUNC	F	Controls calculation of a volume for a designated shape	Page B-299

Subprograms Referencing TNKWTA

Name	Type	Purpose	Reference
TSIZEI	S	Sizes tank to the calculated oxidizer and fuel requirements of the total system	Page B-310
WTACC	S	Sizes accumulator tanks and computes required insulation weights	Page B-330

Listing Reference

A listing of TNKWTA can be found in Appendix B, Page 303.

Flow Chart

A flow chart of TNKWTA is presented in Fig. 1.9-25.

Diagram of Subprograms Linkage

A diagram of called subprograms is presented in Fig. 1.9-26.

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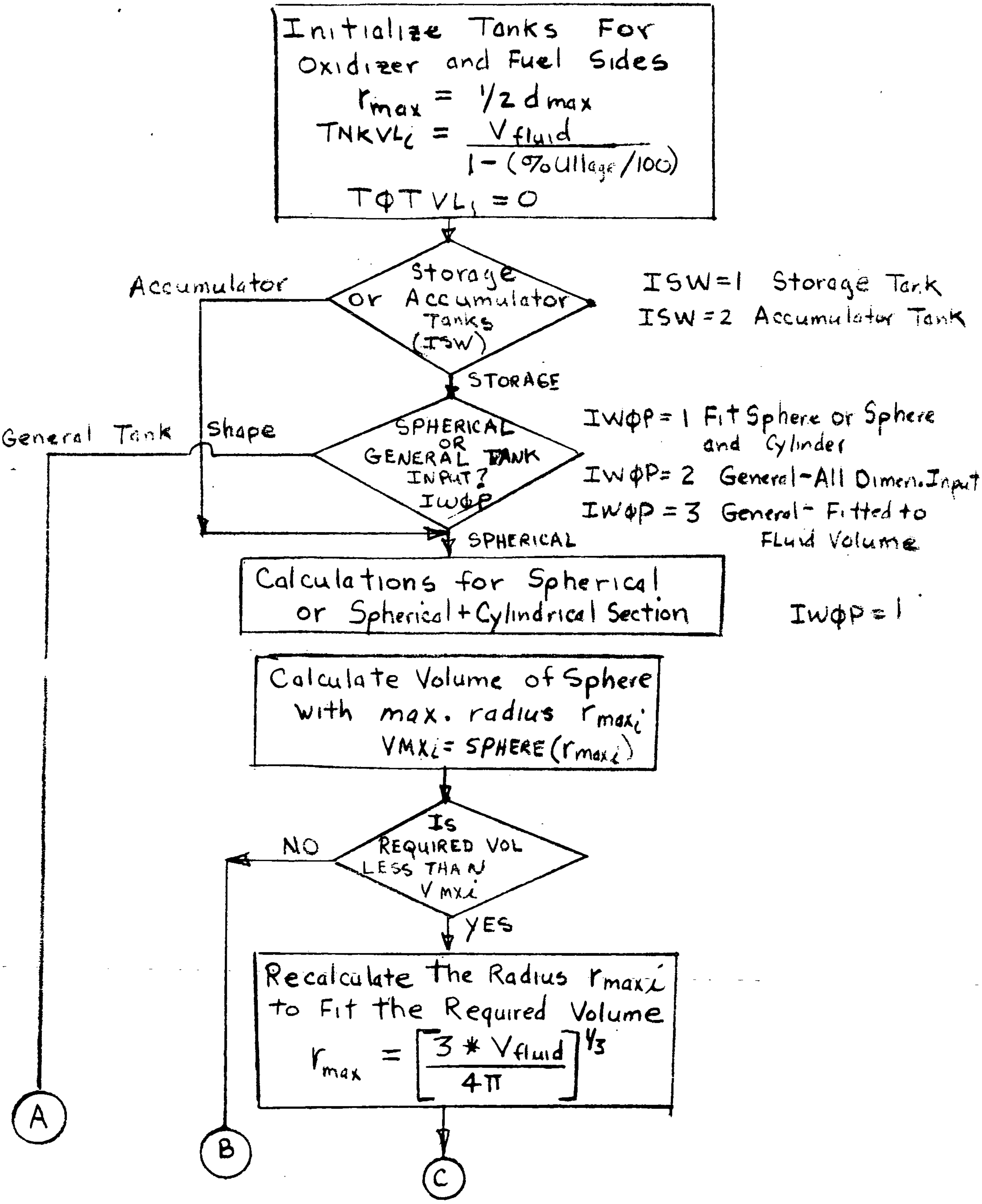
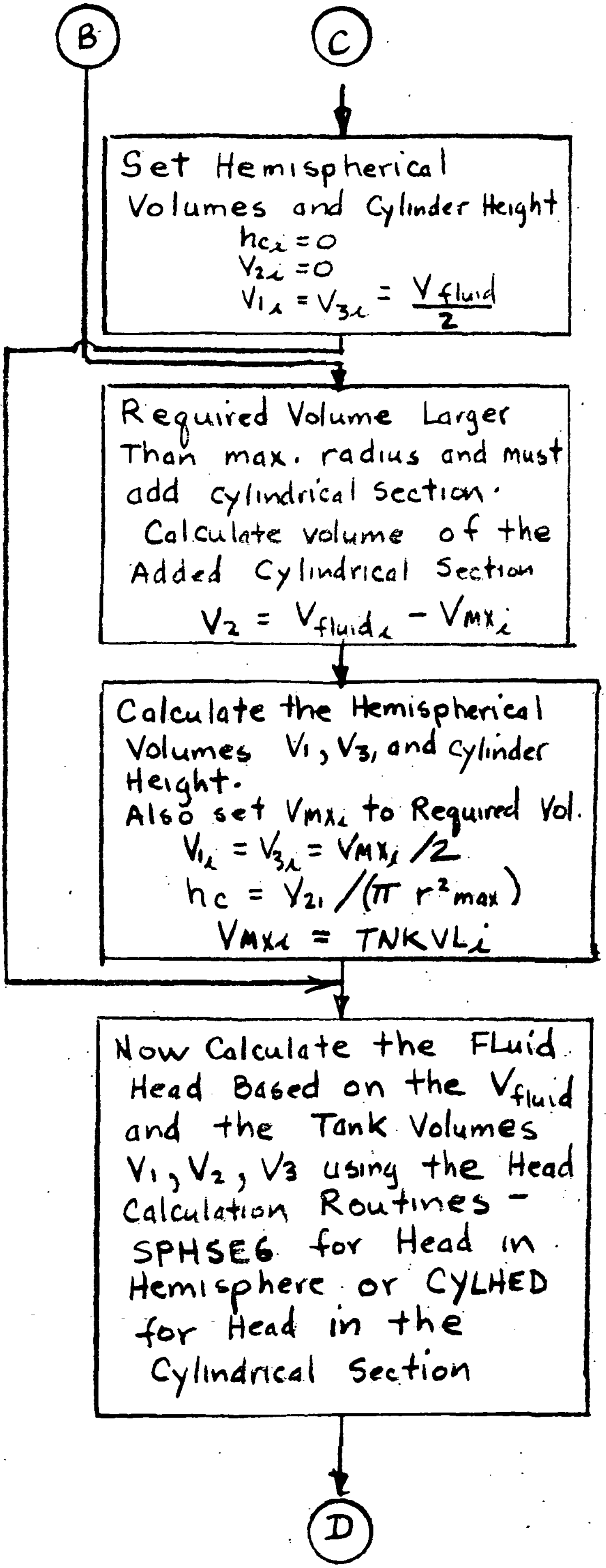


Fig. 1.9-25 Flowchart for TNKWTA



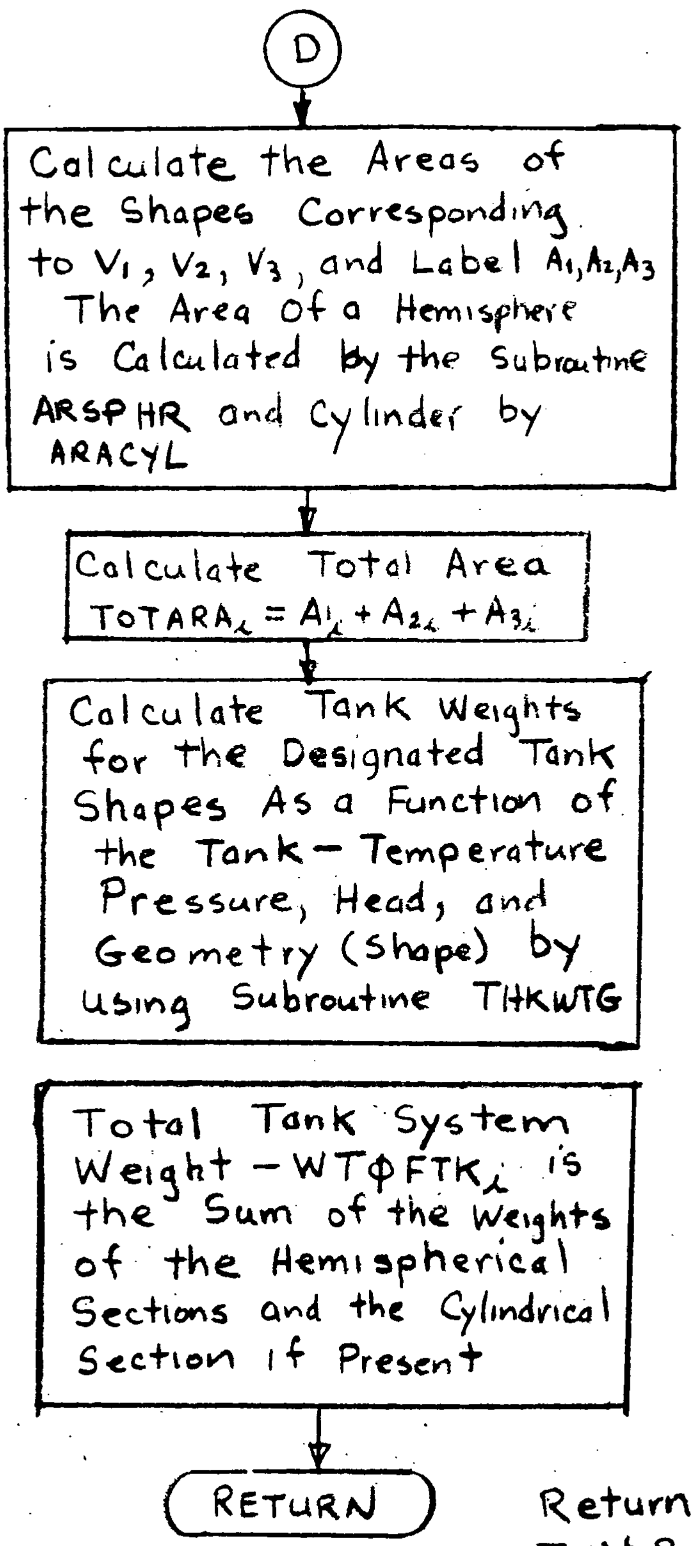
h_c = Height of Cylindrical Section

V_1 = Vol. of Upper Hemisphere

V_2 = Vol. of Cylindrical Section

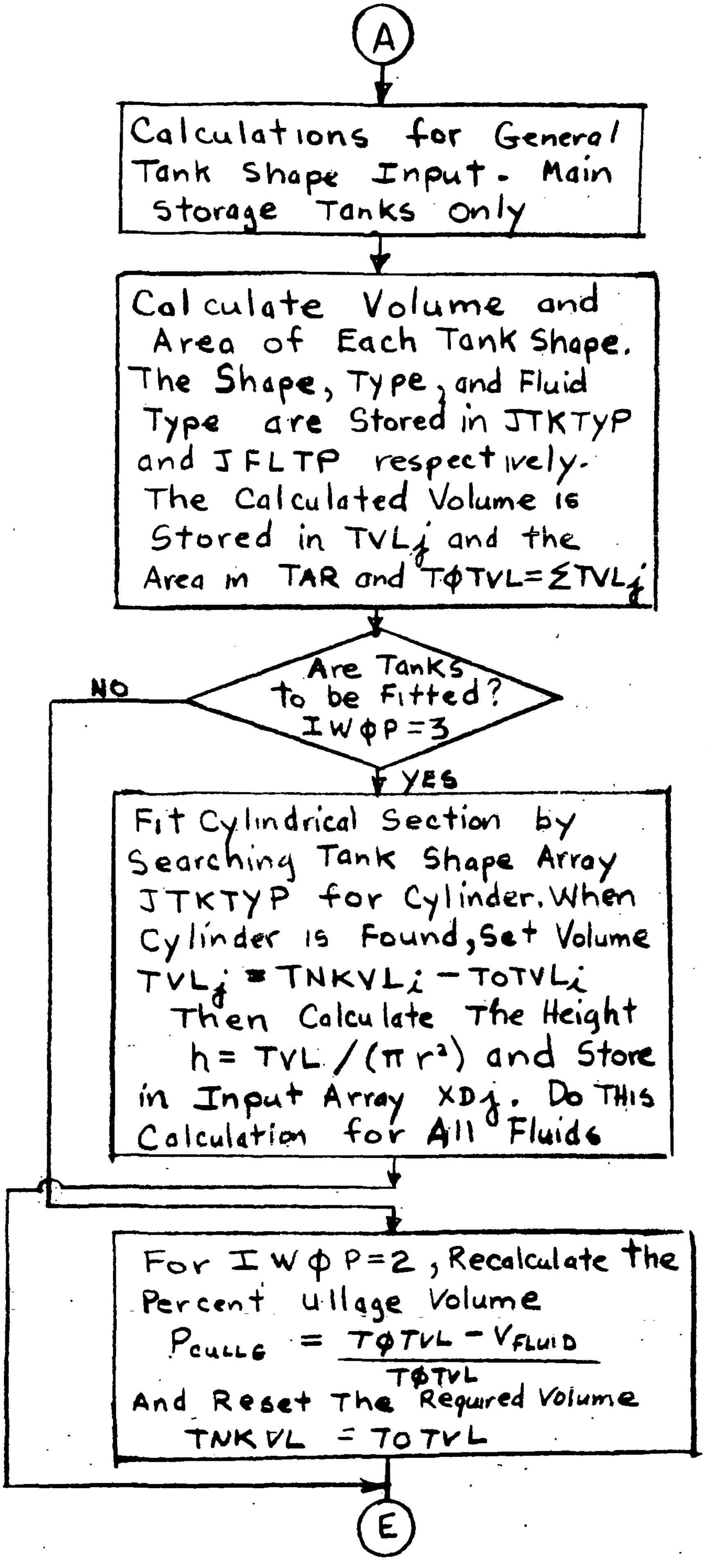
V_3 = Vol. of Lower Hemisphere

Fig. 1.9-25 Flowchart for TNKWTA (Continued)



Return for Option
IWØP=1 or for
Accumulator Tanks

Fig. 1.9-25 Flowchart for TNKWTA (Continued)



IWØP = 2 or 3

Fig. 1.9-25 Flowchart for TNKWTA (Continued)

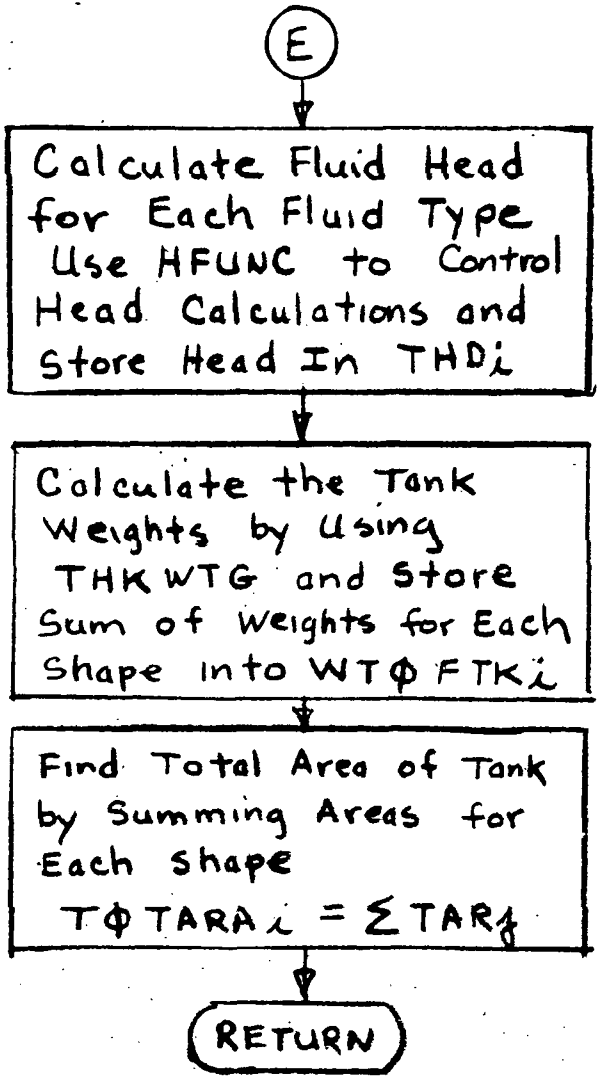


Fig. 1.9-25 Flowchart for TNKWTA (Continued)

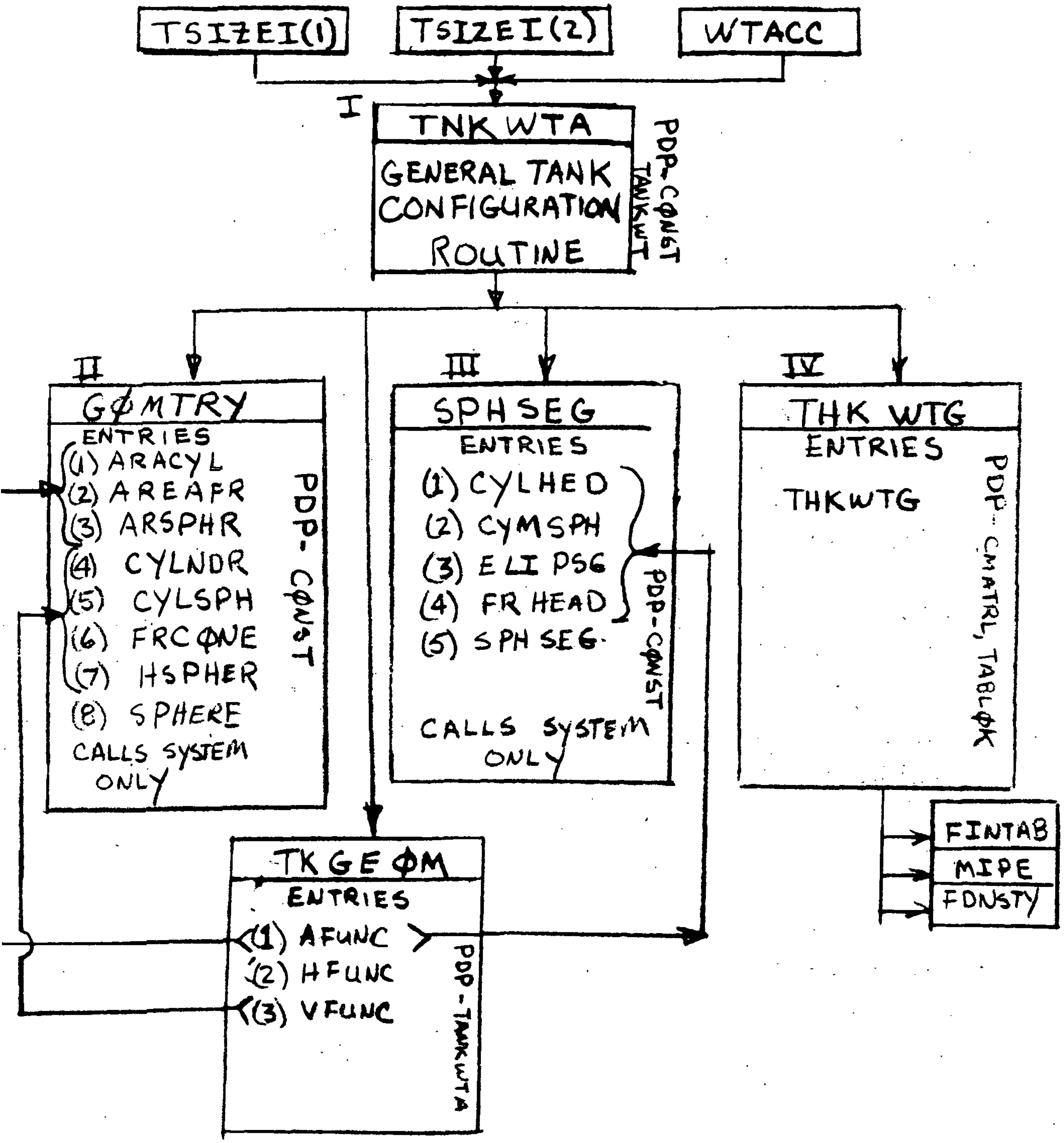


Fig. 1.9-26 Diagram of Tank Geometry Routine Linkage

SUBROUTINE TURBN

DESCRIPTION

The subroutine provides for the sizing and weighing of a turbine drive unit for the subcritical cryogenic pumps. The subroutine is based upon data derived from Ref. 1.9-14. Principal computation is performed in the subroutine are:

(a) Computes turbine rotor mean diameter.
(b) Computes weight of power transmission element.
(c) Computes weight of turbine rotor.
(d) Computes weight of inlet manifold and nozzle.
(e) Computes weight of inducer.
(f) Computes weight of turbine and power transmission element.

Input data for use in subroutine TURBN is transferred through labeled CØMMØN storage blocks. The CØMMØN storage blocks employed by TURBN for data transfer and output storage are:

CØMMØN/CHSØRC/
CØMMØN/CPUMP/
CØMMØN/CTURBN/

TURBN MATHEMATICAL MODEL

The TURBN Math Model consisting of symbols, constants and the equations required are presented in Appendix C.

CALLING SEQUENCE

Subroutine TURBN is initiated by a call from subroutine CMPCAL with two calling arguments. Data transfer to TURBN is accomplished through the use of INCLUDE statements as shown in the subroutine listing.

SIGNIFICANT VARIABLES

The significant variables processed by subroutine TURBN are defined in the following listing:

Name	Type	I/Ø	Dimension	Description
IGAS	I	I	1	Fluid identity; 1 = O_2; 2 = H_2
TRBWGT	R	Ø	1	Turbine assembly weight
PSPD	R	I	1	Pump speed (rpm)
PMPØW	R	I	1	Pump power (Hp)
TGGPC	R	I	1	Turbine inlet gas pressure (psia)
PSTAGE	R	I	1	Number of pump stages
TMBS	R	D	2	Turbine mean blade speed
TRMD	R	C	1	Turbine mean rotor diameter
FCTR	R	D	2	Turbine trans El Weight Factor
WPTEL	R	C	1	Power transmission element weight
WGTTR	R	C	1	Turbine rotor weight
WMFNZ	R	C	1	Inlet manifold and nozzle weight
WINDCR	R	C	1	Inducer weight

SUBPROGRAMS REFERENCED IN TURBN

None referenced

SUBPROGRAMS REFERENCING TURBN

Name	Type	Purpose	Reference
CMPCAL	S	Performs configuration analysis	Page B-50

LISTING REFERENCE PAGE

A listing of subroutine CMPCAL will be found in Appendix B, page 314.

FLOW CHART

No flow chart is presented since the listing clearly indicates the order of computations.

SUBROUTINE VENT

DESCRIPTION

This subroutine computes the total vent mass expelled during a vehicle coast period and computes revised values of liquid and ullage masses and the revised temperature for a mixed fluid system. The calculated values are returned to the calling subroutine. The principal computations accomplished in the subroutine are as follows:

(a) Computes the total mass of gas vented by iteration of pressure and vent mass increments.

(b) For a given pressure drop incrementation, a test is made for vent mass iteration convergence. If the vent mass iteration converges, the masses are recomputed and a test for the pressure iteration convergence is made. If the above vent mass iteration does not converge then a new and smaller pressure increment is used and the process is repeated. The basis for the iterative process in each instance is the internal energy for an assumed vent mass and the internal energy computed for the new saturation conditions resulting from the vent mass being vented.

(c) Computes revised values for liquid and ullages masses and vapor partial pressures.

The subroutine prints warning messages and current data values if vent mass convergence fails after twenty attempts.

Input data transfer to subroutine VENT is through the calling arguments. Access to labeled CØMMØN storage is required only for table lookup. The only labeled common block used by VENT is:

CØMMØN/TABLØK/

VENT MATHEMATICAL MODEL

The mathematical procedures, equations and necessary tables required in subroutine VENT are well defined in the subroutine listing. It does not appear that any advantage can be gained by repeating the entire listing as a separate model.

CALLING SEQUENCE

VENT is called from subroutine TANK with eleven calling arguments. The arguments in order of input are:

Argument	Description
Q	Total amount of heat added to tank (Btu)
MH	Mass of helium in ullage (lb)
MPV	Mass of propellant vapor on ullage (lb)
ML	Mass of liquid in tank (lb)
T	Temperature of fluid (liquid + vapor) in tank (^{o}R)
PV	Vent pressure (psia)
PI	Initial tank pressure (psia)
V	Total tank volume (cu ft)
IG	Fluid I.D. index (1 = 02, 2 = H2)
PPVF	Partial pressure of vapor in tank after venting (psia)
RHØP	Effective density of fluid (liquid + vapor) in tank (lb/cu ft)

SIGNIFICANT VARIABLES

Significant variables processed in subroutine VENT are as follows:

Name	Type	I/Ø	Dimension	Description
Q	R	I	1	Heat input to tank
MH	R	I&Ø	1	Mass helium in ullage
MPV	R	I&Ø	1	Mass propellant vapor in tank
ML	R	I	1	Mass liquid in tank
T	R	I	1	Tank temperature
PV	R	I	1	Vent pressure
PI	R	I&Ø	1	Initial tank pressure
V	R	I	1	Total tank volume
IG	I	I	1	Fluid I.D. index
PPVF	R	I&Ø	1	Fluid vapor partial pressure
RHØP	R	I&Ø	1	Tank fluid + vapor effective density
UF	R	C	1	Internal energy of fluid at new saturation condition
UFASS	R	C	1	Internal energy of assumed vent mass increment

Name	Type	I/Ø	Dimension	Description
HHV	R	C	1	Enthalpy of vent vapor
GC	R	I	1	Fluid gas constant
CMWR	R	I	1	Mass weight ratio constant
PH	R	C	1	Pressure of helium
RHØG	R	C	1	Density of gas
RL	R	C	1	Density of liquid
UI	R	C	1	Initial internal energy
UHI	R	C	1	Initial helium internal energy
RH	R	C	1	Density of helium
DP	R	C	1	Delta-Pressure
DEP	R	C	1	Initial pressure minus vent pressure
TF	R	C	1	Saturation temperature of propellant vapor
DIF	R	C	1	Delta-Internal energy

SUBPROGRAMS REFERENCED IN VENT

Name	Type	Purpose	Reference
DIAG	F	Diagnostic print	Page B-111
AMINI	F	Find minimum of two values	System Library
GSDNST	S	Computes density of gases	Page B-219
RHØLIQ	S	Computes density of liquids	Page B-262
ABS	F	Takes absolute value	System Library
FINTAB	S	Table lookup routine	Page B-147
MIPE	F	Interpolation of tables	Page B-221
GSZDNS	S	Computes density and Z for O_2 and H_2 gases	Page B-219
ZFIND	S	Finds Z for variety of fluids	Page B-335
TSAT	F	Computes saturation temperature of fluids	Page B-308
FINDR	F	Finds gas constant for variety of fluids	Page B-140

SUBPROGRAMS REFERENCING VENT

Name	Type	Purpose	Reference
TANK	S	Computes tank history and fluid conditions	Page B-277

LISTING REFERENCE PAGE

The VENT listing will be found in Appendix B, page 318.

FLOW CHART

A flow chart for subroutine VENT is presented in Fig. 1.9-27.

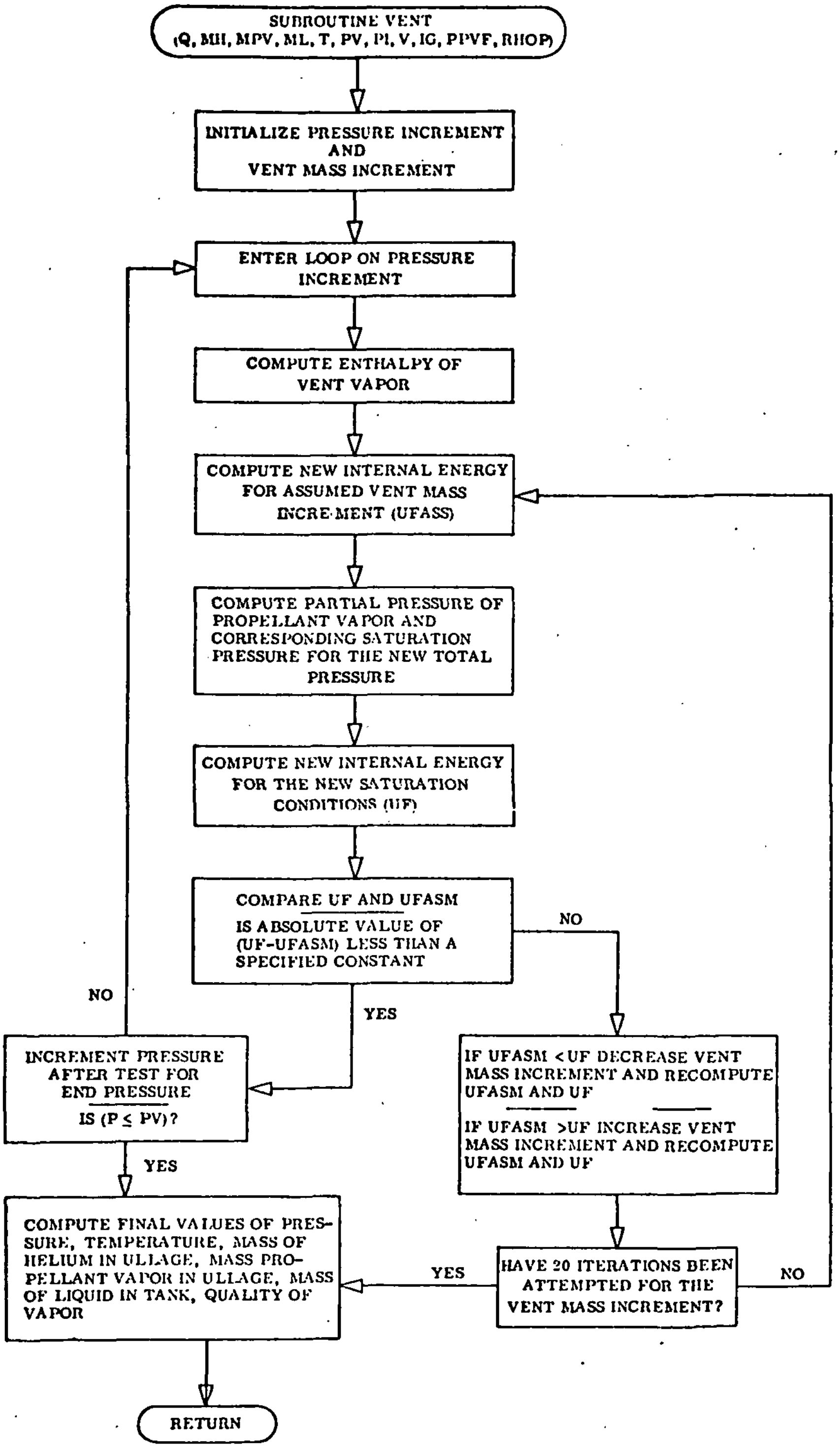


Figure 1.9-27 Flow Chart for Subroutine Vent

FUNCTIØN VFUNC

For a description of VFUNC see the writeup for "TKGEØM." Page B-299

Section 2
MATH MODEL SAMPLE PROBLEM

In order to illustrate the application of the Math Model Program, a sample problem for an Attitude Control Propulsion System was assembled and run. The ACPS problem was chosen because it exercises more of the major subprograms than the other systems. The sample problem graphically illustrates the conversion of the system concept schematic and supporting data into a problem data input deck and the analytical output obtained in the program run.

2.1 THE PROBLEM STATEMENT

The ACPS concept considered was chosen from among similar concepts previously studied under this contract (Ref. 2.1-1). The concept is illustrated in the schematic presented in Fig. 2.1-1. The concept is a cold helium pressurized, subcritical cryogen fluid supplied, bi-propellant gas fed propulsion system. The cryogens are stored as fluids under low pressure and converted to gasses at high pressure through the use of high pressure liquid pumps. The high pressure liquids are vaporized in gas generator fired heat exchangers. The resulting gaseous propellants are then fed to high pressure accumulators for storage until needed for the engines. Propellant feed to the engines is through pressure regulations which drop the feed pressure to the value required for the engines. Oxygen and hydrogen gas at engine feed pressure and temperature are available to other systems via taps in the engine feed line.

The initial run of the system sample problem will establish the nominal case values for the ACPS concept and provide the base-line temperatures, pressures, pressure drops, flow rates, and component and system weights for the specified duty cycle and performance constraints. Subsequent runs of the sample case would consider the effects of perturbing the base-line input data in whatever manner is of interest to the analyst. The collected series of runs would then provide the basis for wide range performance and trade-off analysis conclusions and recommendations.

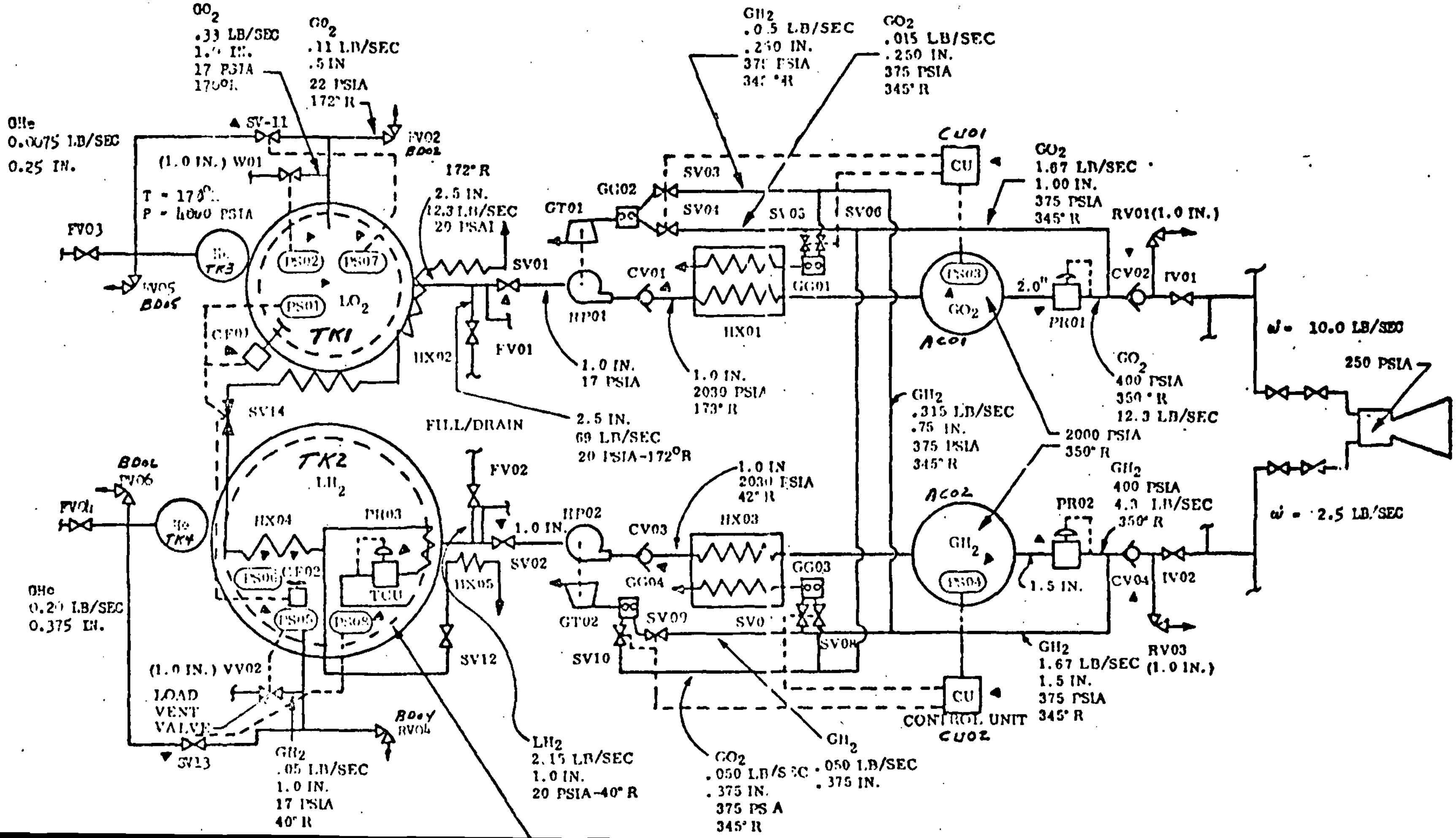
FIGURE 2.1-1

ATTITUDE CONTROL PROPULSION SYSTEM

HIGH PRESSURE - SUBCRITICAL STORAGE

CONCEPT 1A

STORED HELIUM PRESSURIZATION



The sample case run herein presented is the starting point, or, base-line concept analysis.

2.2 PROBLEM OUTLINE – DATA ACQUISITION

The problem outline will be provided to the analyst in the form of a preliminary study of some sort which will probably need elaboration. Specifically, the analyst will need to assure himself that the following data sources are in fact available:

Mission Duty Cycle
Concept Schematic
Engine Concept Details
Tankage Concept Details
Heat Exchanger Requirements
Pump and Turbine Requirements
Gas Generator Requirements
Subsystem Constraints
Plumbing Layout and Approximate (at least) Line Lengths

It should not be considered unusual if the analyst finds that the data supplied is not adequate to build an input data deck and that further source interrogation is required. Assuming the required sources are available, then the task of assembling the information into the input data deck format can be accomplished. The following subparagraphs elaborate on the data reduction aspects of this task.

2.2.1 Sample System Performance and Component Data

2.2.1.1 Duty Cycle. For the ACPS sample problem a twelve burn duty cycle representative of the total burn and coast times for a typical orbiter seven day mission was selected. The duty cycle events and pertinent propellant consumption data obtained from the referenced study are presented in Table 2.2-1.

TABLE 2.2-1

ACPS DUTY CYCLE

Event	Activity	Duration (sec)	Mission Time (min.)	O_2-Used (lbs)	H_2-Used (lbs)
1	Coast-1	540 sec	0-9.0	-	-
2	Burn-1	4.58 sec	9.0-9.07	50	14
3	Coast-2	7975 sec	9.07-142.	-	-
4	Burn-2	6.15 sec	142.0-142.1	67	19
5	Coast-3	2094 sec	142.1-177	-	-
6	Burn-3	3.58	177.0-177.06	39	11
7	Coast-4	536 sec	177.06-186	-	-
8	Burn-4	38.8 sec	186.0-186.65	423	120
9	Coast-5	2061 sec	186.65-221	-	-
10	Burn-5	7.43 sec	221.0-221.12	81	23
11	Coast-6	593 sec	221.12-231	-	-
12	Burn-6	3.58 sec	231.0-231.06	39	11
13	Coast-7	536 sec	231.06-240.	-	-
14	Burn-7	66.1 sec	240.0-241.1	720	204
15	Coast-8	714 sec	241.1-253.	-	-
16	Burn-8	32.3 sec	253.0-253.54	352	100
17	Coast-9	568 sec	253.54-263.	-	-
18	Burn-9	104.1 sec.	263.0-264.74	1135	320
19	Coast-10	1876 sec.	264.74-296	-	-
20	Burn-10	31.9 sec	296.0-296.53	348	96
21	Coast-11	571,048 sec	296.53-9814.	-	-
22	Burn-11	16.16 sec	9814.0-9814.27	176	50
23	Coast-12	9584 sec	9814.27-9974	-	-
24	Burn-12	100 sec	9974.0-9975.67	1090	310
Total Deliverable				4520	1278
Total Propellant:				5798	

M.I.B. degradation: = 0.90

2.2.1.2 Engine Data. The rocket engine characteristics employed in the problem are given as follows:

Number of Engines	3
Engine I_{sp}	420 sec
Engine Thrust	1750 lb
Expansion Ratio	40:1
Ø/F Mixture Ratio	4:1
Propellant Inlet Temp	350°R
Propellant Inlet Pressure	400 psia
Chamber Pressure	250 psia

2.2.1.3 Accumulator Data. The system requires two high pressure accumulators, one for each of the propellant gases. The accumulator characteristics employed in the sample problem are as follows:

Characteristic	02-Accum.	H2-Accum.
Accumulator Code	AC01	AC02
Maximum Diameter (ft)	2.05	5.2
Volume (ft^3)	2.5	72.5
Nominal Temp (°R)	350.	350.
Nominal Press. (psia)	2000.	2000.
Material Type	5.5.	5.5.
Insulation Type	CDAM/T.G.	CDAM/T.G.
Insulation Thickness (in.)	2.0	2.0
Est. Heal Leak Rate (Btu/hr)	0.1	0.2
Allowed Pressure Swing (psi)	500.	500.

2.2.1.4 Heat Exchanger Data. The concept requires two heat exchanger-gas generator sets for vaporization of the cryogen fluids. The heat exchanger and heat source characteristics employed in the problem are given as follows:

Characteristic	Oxygen Side	Hydrogen Side
Heat Exchangers:		
Heat Exchanger Code	HX01	HX03
Hot Fluid Inlet Temp ($^{\circ}$R)	2000.	2000.
Hot Fluid Outlet Temp ($^{\circ}$R)	1100.	1028.
Cold Fluid Inlet Temp ($^{\circ}$R)	173.	42.
Cold Fluid Outlet Temp ($^{\circ}$R)	350.	350.
Hot Fluid Nominal Pressure (psia)	245.	500.
Cold Fluid Nominal Pressure (psia)	2000.	2000.
Hot Side Delta-P (psi)	30.	30.
Cold Side Delta-P (psi)	30.	10.
Hot Side Nominal Flow Rate (lb/sec)	0.6	2.6
Cold Side Nominal Flow Rate (lb/sec)	12.3	4.3
Heat Source:		
Type	Gas Gen	Gas Gen
Ø/F Mixture Ratio	1:1	1:1
Outlet Temperature ($^{\circ}$R)	2060.	2060.
Chamber Pressure (psia)	245.	500.
External Available Energy (Btu)	0.	0.

2.2.1.5 Pump and Turbine Data. Two pump and drive turbine sets are required for the concept being considered. The pump and turbine characteristics employed f the sample problem are presented as follows:

Characteristic	Oxygen Side	Hydrogen Side
Pump:		
Pump Code	HP01	HP02
Type	Turbo-Pump	Turbo-Pump
Pump Efficiency (%)	52.	54.

Characteristic	Oxygen Side	Hydrogen Side
Pump: (Cont)		
Pump NPSP (psia)	8.7	1.1
Pump Shaft Speed (rpm)	20,000	70,000
Pump Outlet Pressure (psia)	2023.	2023.
Pump Inlet Pressure (psia)	17.	17.
Pump Inlet Temperature (°R)	165.	37.
Pump Drive: – Gas Turbine		
Turbine Code	GT01	GT02
Turbine Mixture Ratio	0.891	0.891
Turbine Inlet Temperature (°R)	2000.	2000.
Turbine Delta-P (psi)	230.	480.
Turbine Delta-T (°R)	840.	840.
Turbine Efficiency (%)	55.	36.
Turbine Inlet Pressure (psia)	250.	500.

2.2.1.6 Cryogen Supply Tankage Data. One tank is required for each cryogen fluid. Initially, it is assumed that the tanks are spherical since the program will add cylindrical sections to the tanks if the fluid volume exceeds that of a sphere having an input maximum diameter.

The tankage characteristics employed in this problem are as follows:

Characteristic	LO_2 Tank	LH_2 Tank
Tank Material	2219-Al	2219-Al
Number of Tanks	1.	1.
Tank Code	TK01	TK02
Acquisition Device	Surf Tension	Surf Tension
Insulation Type	DGM/SN	DGM/SN
Pressurization Type	Cold He	Cold He
Fluid Initial Temp (°R)	165.	37.

Characteristic	LO_2 Tank	LH_2 Tank
Tank Initial Pressure (psia)	16.	16.
Pressurant Gas Temp (^oR)	170.	40.
Tank Operating Pressure (psia)	26.7	19.1
Tank Vent Pressure (psia)	31.7	24.1
Estimated Heat Leak (Btu/hr-ft^2)	0.1	0.2
Insulation Thickness (in.)	2.0	2.0
Optional Input – Fluid Loaded (lb)	(Omit)	(Omit)
Initial Percent Ullage	3.0	3.0
Tank Maximum Diameter (ft)	5.07	5.0
Tank Heat Exchanger Outlet Temp (^oR)	NA	NA
Tank Heat Exchanger Delta-P (psi)	NA	NA
Tank Circular Pump Delta-P (psi)	NA	NA
Tank Heat Exchanger –		
Gas Gen Outlet Temp (^oR)	NA	NA
Gas Gen Chamber Pressure (psia)	NA	NA
Gas Gen Mixture Ratio (Ø/F)	NA	NA
Tank Insulation – Layers/Inch (Optional)	(Omit)	(Omit)

2.2.1.7 Lines, Controls, and Fittings Data. For the sample problem, all lines, valves and fittings are stainless steel, and are insulated where necessary with one-half inch of CDAM/TG insulation having a layer density of thirty layers per inch.

2.2.1.8 System Configuration Data. The remaining data to be assembled quite often proves to be somewhat time consuming, primarily, because in the concept stage (or, even in the early design stages) no one seems to know how long the pipes are. Ther fore, one obtains a large set of vehicle drawings and proceeds to obtain approximate lengths even though they are subject to changes. The task, at hand, is to convert the system process schematic into a configuration table with a close resemblance to wha the actual system will look like. This is best accomplished by detailing the data for oxidizer side of the system first, followed by the data for the fuel side. The data collected should be listed in the order required for data deck input. Considerable time may be saved by using 80 column keypunch worksheets with appropriately ruled and labeled columns for data collecting sheets and data card production. The basic information required for the configuration data table as derived from Fig. 2.2-1 and supporting data is presented in Tables 2.2-2 and 2.2-3. The data table will also require the use of some of the information developed for the larger components discussed in previous subsections.

2.3 PROBLEM DATA DECK

The sample problem data previously collected (subsection 2.2) can now be readied for the creation of an input data deck. Formatting information for the necessary data cards will be found in subsection 1.5.2 in the card format illustration sheets (1.5.2.1 through 1.5.2.17). The ACPS sample problem data input deck produced from the foregoing procedure is listed in Table 1.5.5-1.

Input Data Decks for other systems are created in the same general fashion as employed for the sample problem.

2.4 PROBLEM TABLE DATA REQUIREMENTS

While the data tables currently included in the Math Model Program, are adequate for the sample and test problems used for program checkout, there is no assurance that this is so for more advanced systems. Therefore, it is incumbent upon the program user to examine his system carefully for new table data requirements and make the necessary table substitutions as needed. The following tables are most likely to need either updating or the substitution of a complete new table of data:

Table Number	Descriptive Title	Number of Dimensions
1	RCS – Thruster Weight	4
2	RCS – Vac Sp Impulse	3
9	ØMS – Engine Weight	3
10	ØMS – Vac Sp Impulse	3

Table 2.2-2

CONFIGURATION DATA FOR ACPS – OXYGEN SIDE

Item I.D.	Item Code	Number Oper	Number Stby	Diameter (in.)	Length (in.)	Friction Factor	f (L/D)	Fluid State
Gas	02-VAP							G
Engine	ENG1	3	0					G
Line	LN01	3	0	2.0	110.0	0.0095	—	G
Tee	FT01	1	0			0.0095	126.3	G
Line	LN02	1	0	2.0	150.0	0.0095		G
Tap	FT02	1	0			0.0095	10.5	G
Line	LN03	1	0	2.0	24.0	0.0095		G
Valve	IV01	1	0			0.0095	10.5	G
Line	LN04	1	0	2.0	12.0	0.0095		G
Valve	CV02	1	0			0.0095	135.0	G
Line	LN05	1	0	2.0	40.0	0.0095		G
Tap	FT03	1	0			0.0095	10.5	G
Line	LN06	1	0	2.0	20.0	0.0095		G
Reg	PR01	1	0			0.0095	336.8	G
Line	LN07	1	0	2.0	30.0	0.0095		G
Accum	AC01	1	0			NA		G
Line	LN08	1	0	2.0	24.0	0.0095		G
HEX	HX01	1	0			NA		G/L
Gas	02-LIQ					NA		L
Line	LN09	1	0	1.0	12.0	0.0180		L
Valve	CV01	1	0			0.0180	65.5	L
Line	LN10	1	0	1.0	12.0	0.0180		L
Pump	HP01	1	0			NA		L
Line	LN11	1	0	1.5	160.0	0.0180		L
Valve	SV01	1	0			0.0180	6.7	L
Line	LN12	1	0	2.5	12.0	0.0180		L
Tap	FT04	1	0			0.0180	6.7	L
Line	LN13	1	0	2.5	24.0	0.0180		L
Tank	TK01	1	0			NA		L

Table 2.2-3

CONFIGURATION DATA FOR ACPS – HYDROGEN SIDE

Item I.D.	Item Code	Number Oper	Number Stby	Diameter (in.)	Length (in.)	Friction Factor	f (L/D)	Fluid State
Gas	H2-VAP							G
Engine	ENG1	3	0					G
Line	LN21	3	0	1.75	110.0	0.011		G
Tee	FT21	1	0			0.011	109.0	G
Line	LN22	1	0	1.75	150.0	0.011		G
Tap	FT22	1	0			0.011	9.0	G
Line	LN23	1	0	1.75	24.0	0.011		G
Valve	IV02	1	0			0.011	9.0	G
Line	LN24	1	0	1.75	12.0	0.011		G
Valve	CV04	1	0			0.011	86.0	G
Line	LN25	1	0	1.75	40.0	0.011		G
Tap	FT23	1	0			0.011	9.0	G
Line	LN26	1	0	1.75	20.0	0.011		G
Reg	PR02	1	0			0.011	336.4	G
Line	LN27	1	0	1.75	30.0	0.011		G
Accum	AC02	1	0					G
Line	LN28	1	0	1.50	24.0	0.011		G
HEX	HX03	1	0					G
Gas	H2-LIQ							G/L
Line	LN29	1	0	1.50	12.0	0.011		L
Valve	CV03	1	0			0.011	9.0	L
Line	LN30	1	0	1.50	12.0	0.011		L
Pump	HP02	1	0					L
Line	LN31	1	0	2.0	120.0	0.018		L
Valve	SV02	1	0			0.018	5.6	L
Line	LN32	1	0	2.0	12.0	0.018		L
Tap	FT24	1	0			0.018	5.6	L
Line	LN33	1	0	2.0	24.0	0.018		L
Tank	TK02	1	0					L
End								

Table Number	Descriptive Title	Number of Dimensions
11	HEX Hot Gas Flow – LO_2	5
12	HEX Hot Gas Flow – LH_2	5
13	Gas Generator Weight	4
14	LO_2 – Transfer Pump Weight	5
15	LH_2 – Transfer Pump Weight	5
16	Motor Weight (Elec)	3
17	Vac Jacket Diameter vs Weight	2

Care should be exercised in constructing the new table to insure using the same num of dimensions (variables) as in the original table, otherwise, the coding in the subprogram table-calling sequence will have to be changed for each place the table is called upon.

2.5 PROBLEM DATA OUTPUT

This subsection presents the entire output for the ACPS sample problem. The output, which follows, is indexed by page number in the header-box top left corner. This index will be used in describing the several output sections produced in the run.

2.5.1 Output Description

Page 1	Table Data Input Summary – Lists the tables loaded for the program run.
Page 2	System Input Verification – Verifies the system name called for on System Definition Card.
Pages 3,5	System Configuration and Duty Cycle Data – Echo of data in Input Data Deck.
Pages 6, 11	Echo of Major System Component Data – From Input Data Deck.
Page 12	Start of Program Calculations: Computed Engine Parameters – Characterizes engine weight, propellant consumption and I_{sp}.
Page 13	Computed Flowrate Data – Presents flowrate required for subsystem cryogen consumers and total flowrate from fluid tanks.
Pages 14,15	Computed System Configuration Parameters – Presents computed temperature, pressure, flowrate, flow condition and weight for each component item in system configuration.
Pages 16, 17	Computed Heat Exchanger and Gas Generator Characteristic Parameters – Presents summary characteristics and weight data for heat exchangers and associated gas generators.
Page 18	Computed Pump and Turbine Characteristics – Presents summary characteristics and weight data for pumps, turbines and turbine gas generators.
Page 19	Initial Tank Sizing Calculations – Presents initial tank size and weight data computed on first estimate basis.

Pages 20, 32	Tank and Vent Parameter Calculations – Characterizes oxygen tank history conditions for each Coast and Burn period of mission duty cycle.
Pages 33, 45	Tank and Vent Parameter Calculations – Characterizes hydrogen tank history conditions for each Coast and Burn period of mission duty cycle.
Page 46	Final Tank Sizing Calculations – Presents final tank size and weight data based upon detailed calculation of fluid requirements over integrated mission duty cycle span.
Page 47	Accumulator Sizing Calculations – Presents accumulator sizing and weight data computed in program.
Page 48	Tank Propellant Acquisition – Device Computation – Presents acquisition device computed weight, trapped propellant weight, and tank residual-propellant weight.
Page 49	Component Weight Summary and System Weight Summary – Presents a summary of individual component weights and corresponding insulation weights. Presents subsystem and systems weight totals.

The following pages present the detailed sample problem output.

```
DEPT 6213          *        THE INTEGRATED MATH MODEL          * DATE 17 APR 73
EXT. 30235         *                                           * TIME 15:01:40
BLD. 104           *                 AT4307                    * CASE      1
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
                         ACPS - TEST DEMONSTRATION PROBLEM

                              TABLE INPUT SUMMARY

 TABLE       TITLE OF TABLE               NUMBER OF      NUMBER OF      NUMBER OF
NUMBER                                    DIMENSIONS     SUBTABLES          WORDS

     1  RCS-THRUSTER WEIGHT                   4              6              122
     2  RCS-VAC. SP. IMPULSE                  3              3               68
     3  SPEC.HT/LB OF O2 REMOVED              3              5              206
     4  SPEC.HT/LB OF H2 REMOVED              3              5              184
     5  TEMP. /LB. OF O2 REMOVED              3              5              184
     6  TEMP. /LB. OF H2 REMOVED              3              5              192
     7  RR/ VS PGG,M/R,PAMB,PCHP              5             12               95
     8  KK VS PGG,M/R,PAMB,PCHP               5             12               95
     9  OMS ENGINE WEIGHT                     3              3               50
    10  OMS VAC. SP. IMPULSE                  3              3               68
    11  HEX HOT GAS FLOW - LO2                5             24              133
    12  HEX HOT GAS FLOW - LH2                5             12               71
    13  GAS GENERATOR WEIGHT                  4             10              220
    14  LO2 TRANSFER PUMP WEIGHT              5              8              130
    15  LH2 TRANSFER PUMP WEIGHT              5              8              138
    16  MOTOR WEIGHT                          3              5              120
    17  VAC,JAC.DIA.VS.WEIGHT                 2              1               34
    18  PHI - HYDROGEN                        3              5              172
    19  TEMP. OF N2 VS RHO F(P)               3              5              180
    20  HT.XFER.COEF.-H2                      3              4              106
    21  HT.XFER.COEF.-O2-N2                   3              4              138
    22  FTU OF 321/347 ST.STEEL               2              1               32
    23  FTU OF 2219-T87 ALUM.                 2              1               36
    24  FTU OF 6061-T6 ALUMINUM               2              1               30
    25  FTU OF INCONEL-718                    2              1               30
    26  FTU OF TI-6AL-4V                      2              1               30
    27  HEAD COEFFICIENT VS NS                2              1               34
    28  ADIABATIC EFF. VS NS                  2              1               44
    29  EFFIC. QUOT.VS IMP. DIAM              2              1               46
    30  BASE LINE STAGE WT VS DI              2              1               28
    31  SATURATED STEAM, T.VS P.              2              1               46
    32  SP.HT. OF O-H COMB.PROD.              3              4              114
    33  OXYGEN INTERNAL ENERGY                3              5              166
    34  HYDROGEN INTERNAL ENERGY              3              5              216
    35  OXYGEN INTERNAL ENERGY                3              5              142
    36  OXYGEN VAPOR PRESSURE                 3              5              166
    37  HYDROGEN VAPOR PRESSURE               3              5              216
    38  OXYGEN VAPOR PRESSURE                 3              5              142
    39  ENTHALPY OF LO2                       2              1               46
    40  ENTHALPY OF LH2                       2              1               24
    41  ENTHALPY OF HELIUM                    3              5              142
    42  OXYGEN ENTHALPY (GAS)                 3              5               98
    43  HYDROGEN ENTHALPY (GAS)               3              5              122
    44  BETA FACTOR                           2              1               28
    45  SIGMA-DELTAP FOR HEXELC               3              5              172
    46  BETA VALUES FOR H2                    3              5              168
                                              TOTAL TABLE STORAGE =        5024
```

```
NAME  USERS NAME  * * * * * * * * * * * * * * * * * * * * * * * PAGE      2
DEPT 6213         *       THE INTEGRATED MATH MODEL       * DATE 17 APR 73
EXT. 30235        *                                       * TIME 15:01:49
BLD. 104          *                 AT4307                * CASE      1
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
                           ACPS - TEST DEMONSTRATION PROBLEM


                   ***  YOU HAVE CALLED FOR THE SYSTEM ACPS      ***
```

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NAME   USERS NAME   * * * * * * * * * * * * * * * * * * * * * * * * * * PAGE
DEPT 6213           *            THE INTEGRATED MATH MODEL            * DATE 17 APR 73
EXT. 30235          *                                                 * TIME 15:01:49
BLD. 104            *                      AT430T                     * CASE     1
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
                                     ACPS - TEST DEMONSTRATION PROBLEM

                        ***** S Y S T E M   C O N F I G U R A T I O N *****

  COMP     COMP     FUNC.  NUMB.  NUMB.  MATRL.  FLOW FRICTION   LINE LENGTH      LINE     INSULATION   INSULATION   NO. LAYERS
  NAME     CODE     TYPE   OPER.  STBY.  TYPE     COEFICIENT     OR L-OVER-D    DIAMETER      TYPE       THICKNESS   INSULATION

 GAS      O2-VAP      1      1      0      0    .00000000              .00       .00         0          .00          .0
 ENGINE   ENG1        0      3      0      0    .00000000              .00       .00         0          .00          .0
 LINE     LN01       10      3      0      1    .95000000-02        110.00      2.00         4          .50        30.0
 TEE      FT01       21      1      0      1    .95000000-02        126.30       .00         0          .00          .0
 LINE     LN02       10      1      0      1    .95000000-02        150.00      2.00         4          .50        30.0
 TAP      FT02       31      1      0      1    .95000000-02         10.50       .00         0          .00          .0
 LINE     LN03       10      1      0      1    .95000000-02         24.00      2.00         4          .50        30.0
 VALVE    IV01       31      1      0      1    .95000000-02         10.50       .00         0          .00          .0
 LINE     LN04       10      1      0      1    .95000000-02         12.00      2.00         4          .50        30.0
 VALVE    CV02       21      1      0      1    .95000000-02        135.00       .00         0          .00          .0
 LINE     LN05       10      1      0      1    .95000000-02         40.00      2.00         4          .50        30.0
 TAP      FT03       31      1      0      1    .95000000-02         10.50       .00         0          .00          .0
 LINE     LN06       10      1      0      1    .95000000-02         20.00      2.00         4          .50        30.0
 REG      PR01       32      1      0      1    .95000000-02        336.80       .00         0          .00          .0
 LINE     LN07       10      1      0      1    .95000000-02         30.00      2.00         4          .50        30.0
 ACCUM    AC01        0      1      0      1    .00000000              .00       .00         4         2.00        30.0
 LINE     LN08       10      1      0      1    .95000000-02         24.00      2.00         4          .50        30.0
 HEX      HX01        1      1      0      1    .00000000              .00       .00         0          .00          .0
 GAS      O2-LIQ      1      2      0      0    .00000000              .00       .00         0          .00          .0
 LINE     LN09       10      1      0      1    .18000000-01         12.00      1.00         4          .50        30.0
 VALVE    CV01       31      1      0      1    .18000000-01           .00       .00         0          .00          .0
 LINE     LN10       10      1      0      1    .18000000-01         12.00      1.00         4          .50        30.0
 PUMP     HP01       21      1      0      1    .00000000              .00       .00         0          .00          .0
 LINE     LN11       10      1      0      1    .18000000-01        160.00      1.50         4          .50        30.0
 VALVE    SV01       21      1      0      1    .15000000-01          6.67       .00         0          .00          .0
 LINE     LN12       10      1      0      1    .15000000-01         12.00      2.50         4          .50        30.0
 TAP      FT04       31      1      0      1    .15000000-01          6.67       .00         0          .00          .0
 LINE     LN13       10      1      0      1    .15000000-01         24.00      2.50         4          .50        30.0
 TANK     TK01        0      1      0      2    .00000000              .00       .00         4         2.00        30.0
 GAS      H2-VAP      2      1      0      0    .00000000              .00       .00         0          .00          .0
 ENGINE   ENG1        0      3      0      0    .00000000              .00       .00         0          .00          .0
 LINE     LN21       10      3      0      1    .11000000-01        110.00      1.75         4         2.00        30.0
 TEE      FT21       21      1      0      1    .11000000-01        109.00       .00         0          .00          .0
 LINE     LN22       10      1      0      1    .11000000-01        150.00      1.75         4         2.00        30.0
 TAP      FT22       31      1      0      1    .11000000-01          9.00       .00         0          .00          .0
 LINE     LN23       10      1      0      1    .11000000-01         24.00      1.75         4         2.00        30.0
 VALVE    IV02       31      1      0      1    .11000000-01          9.00       .00         0          .00          .0
 LINE     LN24       10      1      0      1    .11000000-01         12.00      1.75         4         2.00        30.0
 VALVE    CV04       21      1      0      1    .11000000-01         86.00       .00         0          .00          .0
 LINE     LN25       10      1      0      1    .11000000-01         40.00      1.75         4         2.00        30.0
 TAP      FT23       31      1      0      1    .11000000-01          9.00       .00         0          .00          .0
 LINE     LN26       10      1      0      1    .11000000-01         20.00      1.75         4         2.00        30.0
 REG      PR02       32      1      0      1    .11000000-01        336.40       .00         0          .00          .0
 LINE     LN27       10      1      0      1    .11000000-01         30.00      1.75         4         2.00        30.0
 ACCUM    AC02        0      1      0      1    .00000000              .00       .00         4         2.00        30.0
```

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NAME  USERS NAME  * * * * * * * * * * * * * * * * * * * * * * PAGE      4
DEPT 6213         *       THE INTEGRATED MATH MODEL          * DATE 17 APR 73
EXT. 30235        *                                          * TIME 15:01:50
BLD. 104          *                   AT4307                 * CASE      1
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
                          ACPS - TEST DEMONSTRATION PROBLEM

                      ***** S Y S T E M   C O N F I G U R A T I O N *****

 COMP     COMP     FUNC.  NUMB.  NUMB.  MATRL.  FLOW FRICTION   LINE LENGTH     LINE     INSULATION   INSULATION   NO. LAYERS
 NAME     CODE     TYPE   OPER.  STBY.  TYPE     COEFICIENT    OR L-OVER-D   DIAMETER      TYPE       THICKNESS    INSULATION

LINE     LN28       10      1      0      1     .11000000-01       24.00        1.50         4            2.00         30.0
HEX      HX03        1      1      0      1     .00000000            .00         .00         0             .00           .0
GAS      H2-LIQ      2      2      0      0     .00000000            .00         .00         0             .00           .0
LINE     LN29       10      1      0      1     .11000000-01       12.00        1.50         4            2.00         30.0
VALVE    CV03       31      1      0      1     .11000000-01        9.00         .00         0             .00           .0
LINE     LN30       10      1      0      1     .11000000-01       12.00        1.50         4            2.00         30.0
PUMP     HP02       21      1      0      1     .00000000            .00         .00         0             .00           .0
LINE     LN31       10      1      0      1     .18000000-01      120.00        2.00         4            2.00         30.0
VALVE    SV02       21      1      0      1     .18000000-01        5.60         .00         0             .00           .0
LINE     LN32       10      1      0      1     .18000000-01       12.00        2.00         4            2.00         30.0
TAP      FT24       31      1      0      1     .18000000-01        5.60         .00         0             .00           .0
LINE     LN33       10      1      0      1     .18000000-01       24.00        2.00         4            2.00         30.0
TANK     TK02        0      1      0      2     .00000000            .00         .00         4            2.00         30.0
END                  0      0      0      0     .00000000            .00         .00         0             .00           .0
```

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                                           NAME  USERS NAME  * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
                                           DEPT 6213          *         THE INTEGRATED MATH MODEL         * DATE 17 APR 73
                                           EXT. 30235         *                                           * TIME 15:01:51
                                           BLD. 104           *                         AT4307            * CASE      1
                                           * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
                                                                  ACPS - TEST DEMONSTRATION PROBLEM

                                                             ***** D U T Y   C Y C L E   D A T A *****


OPER.TIME       NON-OPERATING    MIB-DEGRAD.    UNITS OPER.   HORSEPOWER    AMB.PRESSURE     POWER-KW     REPRES.TIME

.45800000+01    .54000000+03    .90000000+00         3         .00000000      .00000000      .00000000      .00000000
.61500000+01    .79750000+04    .90000000+00         3         .00000000      .00000000      .00000000      .00000000
.35800000+01    .20340000+04    .90000000+00         3         .00000000      .00000000      .00000000      .00000000
.38800000+02    .53600000+03    .90000000+00         3         .00000000      .00000000      .00000000      .00000000
.74300000+01    .20610000+04    .90000000+00         3         .00000000      .00000000      .00000000      .00000000
.35800000+01    .59300000+03    .90000000+00         3         .00000000      .00000000      .00000000      .00000000
.66100000+02    .53600000+03    .90000000+00         3         .00000000      .00000000      .00000000      .00000000
.32300000+02    .71400000+03    .90000000+00         3         .00000000      .00000000      .00000000      .00000000
.10410000+03    .56800000+03    .90000000+00         3         .00000000      .00000000      .00000000      .00000000
.31900000+02    .18760000+04    .90000000+00         3         .00000000      .00000000      .00000000      .00000000
.16160000+02    .57104800+06    .90000000+00         3         .00000000      .00000000      .00000000      .00000000
.10000000+03    .95840000+04    .90000000+00         3         .00000000      .00000000      .00000000      .00000000
.00000000      -.10000000+01    .00000000            0         .00000000      .00000000      .00000000      .00000000
```

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NAME  USERS NAME  * * * * * * * * * * * * * * * * * * * * * * * PAGE      6
DEPT 6213         *      THE INTEGRATED MATH MODEL      * DATE 17 APR 73
EXT. 30235        *                                     * TIME 15:01:51
BLD. 104          *              AT4307                 * CASE      1
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
                        ACPS - TEST DEMONSTRATION PROBLEM

                     ***** E N G I N E   D A T A *****

                              3  NUMBER OF ENGINES
                   .35000000+03  GAS INLET TEMP.
                   .40000000+03  GAS INLET PRES.
                   .17500000+04  ENGINE THRUST
                   .25000000+03  CHAMBER PRES.
                   .40000000+02  EXPANSION RATIO
                   .40000000+01  MIXTURE RATIO
```

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DEPT 6213          *        THE INTEGRATED MATH MODEL        * DATE 17 APR 73
EXT. 30235         *                                         * TIME 15:01:51
BLD. 104           *                 AT4307                  * CASE     1
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
                          ACPS - TEST DEMONSTRATION PROBLEM

                           ***** T A N K   D A T A *****


                  1               1          NUMBER OPERATING (NOP)
                  1               1          ACQUISITION TYPE
                  2               2          INSULATION TYPE
                  2               2          MATERIAL TYPE
                  2               2          PRESSURIZATION TYPE
           .16500000+03    .37000000+02  INITIAL TEMPERATURE (R)
           .16000000+02    .16000000+02  INITIAL PRESSURE
           .17000000+03    .40000000+02  PRESSURANT GAS TEMP. (R)
           .26700000+02    .19100000+02  OPERATING PRESS. (PSIA)
           .31700000+02    .24100000+02  VENTING PRESSURE
           .20000000+00    .30000000+00  HEAT FLUX (BTU/HR-FT**2)
           .20000000+01    .20000000+01  INSULATION THICKNESS
           .00000000       .00000000     INITIAL FLUID LOAD (OPT)
           .30000000+01    .30000000+01  PERCENT ULLAGE VOLUME
           .50660000+01    .50000000+01  MAXIMUM DIAMETER (FT)
           .00000000       .00000000     HEX OUTLET TEMP. (R)
           .00000000       .00000000     HEX DELTA PRESS. (PSIA)
           .00000000       .00000000     PUMP DELTA PRESS. (PSIA)
           .00000000       .00000000     GAS GEN OUTLET TEMP (R)
           .00000000       .00000000     P SUB C OF GAS GEN (PSIA
           .00000000       .00000000     GAS GEN MIXTURE RATIO
           .00000000       .00000000     NUMBER INSULATION LAYERS

                     1                   TANK WEIGHT-CONFIGURATION OPTION CONSIDERED
                     0                   NUMBER OF TANK SHAPES IN CONFIGURATION
```

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NAME  USERS NAME  * * * * * * * * * * * * * * * * * * * * * * PAGE      8
DEPT 6213         *       THE INTEGRATED MATH MODEL         * DATE 17 APR 73
EXT. 30235        *                                         * TIME 15:01:51
BLD. 104          *                 AT4307                  * CASE      1
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
                          ACPS - TEST DEMONSTRATION PROBLEM

                    ***** A C C U M U L A T O R   D A T A *****


                 1                1          NUMBER OPERATING (NOP)
                 4                4          INSULATION TYPE
                 1                1          MATERIAL TYPE
           .35000000+03     .35000000+03     OPERATING TEMP. (DEG R)
           .20000000+04     .20000000+04     OPERATING PRESS. (PSIA)
           .10000000+00     .20000000+00     HEAT FLUX (BTU/HR-FT**2)
           .20000000+01     .20000000+01     INSULATION THICKNESS
           .25000000+01     .72500000+02     TANK VOLUME (CU. FT.)
           .20500000+01     .52000000+01     MAXIMUM DIAMETER (FT)
           .50000000+03     .50000000+03     NOMINAL OPER. DELTA PRES
           .00000000        .00000000        NUMBER INSULATION LAYERS
```

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       USERS NAME  * * * * * * * * * * * * * * * * * * * * * * * PAGE
DEPT 6213          *         THE INTEGRATED MATH MODEL          * DATE 17 APR 73
EXT. 30235         *                                            * TIME 15:01:51
BLD. 104           *                     AT4307                 * CASE    1
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
                              ACPS - TEST DEMONSTRATION PROBLEM

                         ***** H E A T   E X C H A N G E R   D A T A *****


                              NUMBER OF HEAT EXCHANGERS INPUT =     1


      - 1 -                 - 2 -                 - 3 -                 - 4 -                 - 5 -          HEAT EXCHANGER NUMBER
OXYGEN  HYDROGEN    OXYGEN  HYDROGEN    OXYGEN  HYDROGEN    OXYGEN  HYDROGEN    OXYGEN  HYDROGEN

2000.0    2000.0        .0        .0        .0        .0        .0        .0        .0        .0      HEX HOT INLET TEMP.
1100.0    1028.0        .0        .0        .0        .0        .0        .0        .0        .0      HEX HOT OUTLET TEMP.
 173.0      42.0        .0        .0        .0        .0        .0        .0        .0        .0      HEX COLD INLET TEMP.
 350.0     350.0        .0        .0        .0        .0        .0        .0        .0        .0      HEX COLD OUTLET TEMP.
 245.0     500.0        .0        .0        .0        .0        .0        .0        .0        .0      HEX HOT INLET PRES.
 215.0     470.0        .0        .0        .0        .0        .0        .0        .0        .0      HEX HOT OUTLET PRES.
2030.0    2010.0        .0        .0        .0        .0        .0        .0        .0        .0      HEX COLD INLET PRES.
2000.0    2000.0        .0        .0        .0        .0        .0        .0        .0        .0      HEX COLD OUTLET PRES.
  30.0      30.0        .0        .0        .0        .0        .0        .0        .0        .0      HEX HOT SIDE DELTA-P
  30.0      10.0        .0        .0        .0        .0        .0        .0        .0        .0      HEX COLD SIDE DELTA-P
   1.0       1.0        .0        .0        .0        .0        .0        .0        .0        .0      HEX GAS GEN. O/F RATIO
```

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NAME  USERS NAME  * * * * * * * * * * * * * * * * * * * * * PAGE     10
DEPT 6213         *       THE INTEGRATED MATH MODEL         * DATE 17 APR 73
EXT. 39235        *                                         * TIME 15:01:51
BLD. 104          *                 AT4307                  * CASE     1
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
                           ACPS - TEST DEMONSTRATION PROBLEM

                     ***** H I G H   P R E S   P U M P   D A T A *****


                   2               2         TYPE
            .52000000+00    .54000000+00  EFFICIENCY
            .87000000+01    .11000000+01  NET + SUCTION HEAD
            .20000000+05    .70000000+05  SHAFT SPEED
            .20230000+04    .20230000+04  ESTIMATED DELTA PRES.

                      ***** L O W   P R E S   P U M P   D A T A *****


            .00000000       .00000000     PUMP EFFICIENCY
            .00000000       .00000000     NET POS. SUCTION HEAD
            .00000000       .00000000     PUMP PRESSURE RISE
            .00000000       .00000000     PUMP FLOW RATE

                         ***** T U R B I N E   D A T A *****


            .55000000+00    .36000000+00  TURBINE EFFICIENCY
            .20000000+04    .20000000+04  TURBINE INLET TEMP.
            .11600000+04    .11600000+04  TURBINE OUTLET TEMP.
            .89100000+00    .89100000+00  TURBINE MIXTURE RATIO
            .25000000+03    .50000000+03  TURBINE GAS GEN. PSUBC
```

```
DEPT 6213          *        THE INTEGRATED MATH MODEL        * DATE 17 APR 73
EXT. 30235         *                                         * TIME 15:01:52
BLD. 104           *                 AT4307                  * CASE    1
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
                             ACPS - TEST DEMONSTRATION PROBLEM

                           ***** H E A T   S O U R C E   D A T A *****

                             NUMBER OF HEAT SOURCES INPUT =     1

      - 1 -                - 2 -                - 3 -                - 4 -                - 5 -           HEAT SOURCE NUMBER
OXYGEN  HYDROGEN    OXYGEN  HYDROGEN    OXYGEN  HYDROGEN    OXYGEN  HYDROGEN    OXYGEN  HYDROGEN

     1         1         0         0         0         0         0         0         0         0   HEAT SOURCE TYPE
   1.0       1.0        .0        .0        .0        .0        .0        .0        .0        .0   HEAT SOURCE MIX. RATIO
2060.0    2060.0        .0        .0        .0        .0        .0        .0        .0        .0   HEAT SOURCE OUTLET TEMP.
    .0        .0        .0        .0        .0        .0        .0        .0        .0        .0   HEAT SOURCE AVAIL.ENERGY
 245.0     500.0        .0        .0        .0        .0        .0        .0        .0        .0   HEAT SOURCE PRESSURE
```

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NAME  USERS NAME  * * * * * * * * * * * * * * * * * * * * * * PAGE     12
DEPT 6213         *       THE INTEGRATED MATH MODEL         * DATE 17 APR 73
EXT. 30235        *                                         * TIME 15:01:53
BLD. 104          *                AT4307                   * CASE      1
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
                           ACPS - TEST DEMONSTRATION PROBLEM


                  *** INITIATE PROGRAM AND CHARACTERIZE CONSUMER PARAMETERS ***


                                       * COMPUTED ENGINE PARAMETERS *

                         ENGINE ISP                                .46712069+03
                         ENGINE WEIGHT - (LBS)                     .15937500+03
                         TOTAL ENGINE FLOW - (LB/SEC)              .12487850+02
                         ONE ENGINE OXID.FLOW RATE-(LB/SEC)        .99902804+01
                         ONE ENGINE FUEL FLOW RATE-(LB/SEC)        .24975701+01
                         THRUST IMPULSE PROPELLANT WGT.            .51784617+04
```

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NAME  USERS NAME    *                                             * DATE 17 APR
DEPT 6213           *        THE INTEGRATED MATH MODEL            * TIME 15:01:53
EXT. 30235          *                                             * CASE     1
BLD. 104            *                 AT4307
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
                           ACPS - TEST DEMONSTRATION PROBLEM

                            *** COMPUTED FLOWRATE DATA ***

                                                    OXIDYZER          FUEL

 WDOT OX-TURB.-G.G.                                .551258-01       .618696-01
 WDOT HY-TURB.-G.G.                                .370016+00       .415281+00
 WDOT BOTH TURB.-GG                                .425141+00       .477151+00


 WDOT OXY HEX.-G.G.                                .300310+00       .300310+00
 WDOT HYD HEX.-G.G.                                .132594+01       .132594+01
 WDOT BOTH HEX.-G.G                                .162626+01       .162626+01

 TOTAL FLOWRATE  **                                .120417+02       .460098+01
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                 NAME  USERS NAME  * * * * * * * * * * * * * * * * * * * * * PAGE    14
                 DEPT 6213         *       THE INTEGRATED MATH MODEL       * DATE 17 APR 73
                 EXT. 30235        *                                       * TIME 15:01:53
                 BLD. 104          *                AT4307                 * CASE     1
                 * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
                                             ACPS - TEST DEMONSTRATION PROBLEM

                               *** SUMMARY OF COMPUTED SYSTEM CONFIGURATION PARAMETERS ***

  F    CODE    FT  NO  NS  IS IDX   G  GS   FCOEF         L/D       DIAM   ITHICK     PRES     TEMP    WDOT  WEIGHT     MACH     MFLAG

 GAS  02-VAP   1   1   0   1   1    1   1  .000000       .0000     .0000    .0000      .00      .00     .00    .000  .0000000
 ENG  ENG1     0   3   0   1   2    1   1  .000000       .0000     .0000    .0000   400.00   350.00    9.99 159.375  .0000000
 LIN  LN01     0   3   0   1   3    1   1  .009500    110.0000    2.0000    .5000   400.35   350.00    9.99   4.009  .1307953
 TEE  FT01     1   1   0   1   4    1   1  .009500    126.3000    2.0000    .0000   407.49   350.00    9.99    .433  .1280855
 LIN  LN02     0   1   0   1   5    1   1  .009500    150.0000    2.0000    .5000   411.66   350.00    9.99   5.466  .1265442
 TAP  FT02     1   1   0   1   6    1   1  .009500     10.5000    2.0000    .0000   412.25   350.00   12.04    .342  .1522731
 LIN  LN03     0   1   0   1   7    1   1  .009500     24.0000    2.0000    .5000   413.21   350.00   12.04    .875  .1518509
 VAL  IV01     1   1   0   1   8    1   1  .009500     10.5000    2.0000    .0000   414.05   350.00   12.04   6.314  .1514840
 LIN  LN04     0   1   0   1   9    1   1  .009500     12.0000    2.0000    .5000   414.53   350.00   12.04    .437  .1512755
 VAL  CV02     1   1   0   1  10    1   1  .009500    135.0000    2.0000    .0000   425.15   350.00   12.04   4.406  .1467768
 LIN  LN05     0   1   0   1  11    1   1  .009500     40.0000    2.0000    .5000   426.70   350.00   12.04   1.458  .1461381
 TAP  FT03     1   1   0   1  12    1   1  .009500     10.5000    2.0000    .0000   427.51   350.00   12.04    .342  .1458060
 LIN  LN06     0   1   0   1  13    1   1  .009500     20.0000    2.0000    .5000   428.29   350.00   12.04    .729  .1454915
 REG  PR01     2   1   0   1  14    1   1  .009500    336.8000    2.0000    .0000  1750.00   350.00   12.04   9.630  .0000000
 LIN  LN07     0   1   0   1  15    1   1  .009500     30.0000    2.0000    .5000  1750.20   350.00   12.04   1.913  .0180427
 ACC  AC01     0   1   0   1  16    1   1  .000000       .0000     .0000   2.0000  2000.00   350.00   12.04    .000  .0000000
 LIN  LN08     0   1   0   1  17    1   1  .009500     24.0000    2.0000    .5000  2000.14   350.00   12.04   1.531  .0155240
 HEX  HX01     1   1   0   1  18    1   1  .000000       .0000     .0000    .0000  2022.29   173.00   12.04  22.655  .0000000
 GAS  02-LIQ   1   2   0   1  19    1   2  .000000       .0000     .0000    .0000  2022.29   173.00   12.04    .000  .0000000
 LIN  LN09     0   1   0   1  20    1   2  .018000     12.0000    1.0000    .5000  2023.94   173.00   12.04    .383  .0000000
 VAL  CV01     1   1   0   1  21    1   2  .018000       .0000    1.0000    .0000  2023.94   173.00   12.04   9.000  .0000000
 LIN  LN10     0   1   0   1  22    1   2  .018000     12.0000    1.0000    .5000  2025.58   173.00   12.04    .383  .0000000
 LIN  LN13     0   1   0  -1  28    1   2  .015000     24.0000    2.5000    .5000    15.97   165.00   12.04   1.093  .0000000
 TAP  FT04     1   1   0  -1  27    1   2  .015000      6.6700    2.5000    .0000    15.95   165.00   12.04    .534  .0000000
 LIN  LN12     0   1   0  -1  26    1   2  .015000     12.0000    2.5000    .5000    15.94   165.00   12.04    .547  .0000000
 VAL  SV01     1   1   0  -1  25    1   2  .015000      6.6700    1.5000    .0000    15.79   165.00   12.04   4.142  .0000000
 LIN  LN11     0   1   0  -1  24    1   2  .018000    160.0000    1.5000    .5000    12.98   165.00   12.04   4.373  .0000000
 PUM  HP01     1   1   0   1  23    1   2  .000000       .0000     .0000    .0000    12.98   165.00   12.04  73.362  .0000000
 TAN  TK01     0   1   0   1  29    1   2  .000000       .0000     .0000   2.0000    16.00   165.00   12.04    .000  .0000000
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DEPT 6213          *         THE INTEGRATED MATH MODEL           * DATE 17 APR 73
EXT. 30235         *                                             * TIME 15:02:00
BLD. 104           *                  AT4307                     * CASE      1
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
                           ACPS - TEST DEMONSTRATION PROBLEM

         *** SUMMARY OF COMPUTED SYSTEM CONFIGURATION PARAMETERS - CONTD. ***

 F    CODE    FT  NO  NS  IS IDX   G  GS    FCOEF       L/D        DIAM  ITHICK      PRES      TEMP     WDOT  WEIGHT      MACH     MFLAG

GAS  H2-VAP   2   1   0   1   30   2   1  .000000      .0000     .0000   .0000       .00       .00      .00    .000  .0000000
ENG  ENG1     0   3   0   1   31   2   1  .000000      .0000     .0000   .0000    400.00    350.00     2.50 159.375  .0000000
LIN  LN21     0   3   0   1   32   2   1  .011000   110.0000    1.7500  2.0000    400.12    350.00     2.50   3.508  .2095926
TEE  FT21     1   1   0   1   33   2   1  .011000   109.0000    1.7500   .0000    401.92    350.00     2.50    .331  .2086492
LIN  LN22     0   1   0   1   34   2   1  .011000   150.0000    1.7500  2.0000    403.33    350.00     2.50   4.783  .2079167
TAP  FT22     1   1   0   1   35   2   1  .011000     9.0000    1.7500   .0000    403.48    350.00     4.60    .262  .3828795     *
LIN  LN23     0   1   0   1   36   2   1  .011000    24.0000    1.7500  2.0000    404.24    350.00     4.60    .765  .3821540     *
VAL  IV02     1   1   0   1   37   2   1  .011000     9.0000    1.7500   .0000    404.74    350.00     4.60   6.121  .3816802     *
LIN  LN24     0   1   0   1   38   2   1  .011000    12.0000    1.7500  2.0000    405.12    350.00     4.60    .383  .3813205     *
VAL  CV04     1   1   0   1   39   2   1  .011000    86.0000    1.7500   .0000    409.86    350.00     4.60   4.255  .3768958     *
LIN  LN25     0   1   0   1   40   2   1  .011000    40.0000    1.7500  2.0000    411.11    350.00     4.60   1.275  .3757436     *
TAP  FT23     1   1   0   1   41   2   1  .011000     9.0000    1.7500   .0000    411.60    350.00     4.60    .262  .3752932     *
LIN  LN26     0   1   0   1   42   2   1  .011000    20.0000    1.7500  2.0000    412.22    350.00     4.60    .638  .3747235     *
REG  PRU2     2   1   0   1   43   2   1  .011000   336.4000    1.7500   .0000   1750.00    350.00     4.60   9.392  .0000000
LIN  LN27     0   1   0   1   44   2   1  .011000    30.0000    1.7500  2.0000   1750.24    350.00     4.60   1.674  .0938032
ACC  AC02     0   1   0   1   45   2   1  .000000      .0000     .0000  2.0000   2000.00    350.00     4.60    .000  .0000000
LIN  LN28     0   1   0   1   46   2   1  .011000    24.0000    1.5000  2.0000   2000.36    350.00     4.60   1.148  .1132123
HEX  HX03     1   1   0   1   47   2   1  .000000      .0000     .0000   .0000   2010.19     42.00     4.60  61.123  .0000000
GAS  H2-LIQ   2   2   0   1   48   2   2  .000000      .0000     .0000   .0000   2010.19     42.00     4.60    .000  .0000000
LIN  LN29     0   1   0   1   49   2   2  .011000    12.0000    1.5000  2.0000   2010.23     42.00     4.60    .574  .0000000
VAL  CV03     1   1   0   1   50   2   2  .011000     9.0000    1.5000   .0000   2010.28     42.00     4.60   9.214  .0000000
LIN  LN30     0   1   0   1   51   2   2  .011000    12.0000    1.5000  2.0000   2010.32     42.00     4.60    .574  .0000000
LIN  LN33     0   1   0  -1   57   2   2  .018000    24.0000    2.0000  2.0000     15.97     37.00     4.60    .875  .0000000
TAP  FT24     1   1   0  -1   56   2   2  .018000     5.6000    2.0000   .0000     15.96     37.00     4.60    .342  .0000000
LIN  LN32     0   1   0  -1   55   2   2  .018000    12.0000    2.0000  2.0000     15.94     37.00     4.60    .437  .0000000
VAL  SV02     1   1   0  -1   54   2   2  .018000     5.6000    2.0000   .0000     15.93     37.00     4.60   4.406  .0000000
LIN  LN31     0   1   0  -1   53   2   2  .018000   120.0000    2.0000  2.0000     15.77     37.00     4.60   4.373  .0000000
PUM  HP02     1   1   0   1   52   2   2  .000000      .0000     .0000   .0000     15.77     37.00     4.60  34.569  .0000000
TAN  TK02     0   1   0   1   58   2   2  .000000      .0000     .0000  2.0000     16.00     37.00     4.60    .000  .0000000
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NAME  USERS NAME  * * * * * * * * * * * * * * * * * * * * *  PAGE     16
DEPT 6213         *        THE INTEGRATED MATH MODEL         *  DATE 17 APR 73
EXT. 30235        *                                          *  TIME 15:02:01
BLD. 104          *                   AT4307                 *  CASE      1
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
                         ACPS - TEST DEMONSTRATION PROBLEM

          *** SUMMARY OF COMPUTED HEAT EXCHANGER CHARACTERISTICS ***

                              FOR UNITS     HX01              HX03

 HEAT EXCHANGER CHARACTERISTICS             OXYGEN            HYDROGEN

 COLD FLUID INLET TEMP                     .173000+03        .420000+02
 COLD FLUID OUTLET TEMP                    .350000+03        .350000+03
 COLD FLUID SPECIFIC HEAT                  .485697+00        .373836+01
 COLD FLUID FLOW RATE                      .120417+02        .460098+01
 HOT FLUID INLET TEMP                      .200000+04        .200000+04
 HOT FLUID OUTLET TEMP                     .110000+04        .102800+04
 HOT FLUID SPECIFIC HEAT                   .185245+01        .184709+01
 HOT FLUID FLOW RATE                       .620922+00        .295072+01
 COLD SIDE EFFECTIVENESS                   .968801-01        .157303+00
 HOT SIDE EFFECTIVENESS                    .492611+00        .496425+00
 TOTAL EFFECTIVENESS                       .589491+00        .653728+00

 HEX SUBUNIT TYPE  ***                    SUP-CRITICAL      SUP-CRITICAL

 THERML CONDUCTANCE RATIO                  .784822+00        .551711+00
 HOT FLUID FLOW RATE                       .323065+00        .101027+00
 COLD FLUID DELTA - P                      .780449+01        .171191+00
 CAPACITY RATIO                            .116889+00        .179012-01
 NUMBER OF TRANSFER UNITS                  .715320+00        .691449+00
 COMPUTED VALUE OF UA                      .154113+04        .464504+03
 COMPUTED VALUE OF W/UA                    .587501-02        .649877-02
 WEIGHT OF SUBUNIT                         .137806+02        .418989+01

 HEX SUBUNIT TYPE  ***                    PARALLEL-FLO      PARALLEL-FLO

 THERML CONDUCTANCE RATIO                  .790265+00        .140564+01
 HOT FLUID FLOW RATE                       .297075+00        .284969+01
 COLD FLUID DELTA - P                      .143533+02        .965759+01
 CAPACITY RATIO                            .797778-01        .298971+00
 NUMBER OF TRANSFER UNITS                  .769651+00        .809568+00
 COMPUTED VALUE OF UA                      .152479+04        .153405+05
 COMPUTED VALUE OF W/UA                    .582023-02        .371129-02
 WEIGHT OF SUBUNIT                         .887461+01        .569331+02

 WEIGHT OF HEAT EXCHANGER                  .226552+02        .611230+02
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NAME  USERS NAME  * * * * * * * * * * * * * * * * * * * * * PAGE     17
DEPT 6213         *       THE INTEGRATED MATH MODEL        * DATE 17 APR 73
EXT. 30235        *                                        * TIME 15:02:01
BLD. 104          *               AT4307                   * CASE     1
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
                          ACPS - TEST DEMONSTRATION PROBLEM

 *** SUMMARY OF COMPUTED HEAT EXCHANGER-GAS GENERATOR CHARACTERISTICS ***

  GAS GENERATOR CHARACTERISTICS                 OXYGEN          HYDROGEN

  GAS GEN. FLOW RATE - (LB/SEC)               .620922+00      .295072+01
  GAS GEN. PROPELLANT WGT.-(LBS)              .257484+03      .122361+04
  GAS GENERATOR WEIGHT - (LBS)                .136186+02      .161016+02

  WEIGHT OF HEX-GAS GEN. ASSY.                .362738+02      .772246+02

  CUMULATIVE GAS GEN. PROP. WTG.              .257484+03      .122361+04

  CUMULATIVE HEAT REQD. - (BTU)               .000000         .000000
  CUMULATIVE HOT FLUID - (LBS)                .000000         .000000
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NAME  USERS NAME  * * * * * * * * * * * * * * * * * * * * * PAGE    18
DEPT 6213         *       THE INTEGRATED MATH MODEL       * DATE 17 APR 73
EXT. 30235        *                                       * TIME 15:02:02
BLDG. 104         *                 AT4307                * CASE     1
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
                         ACPS - TEST DEMONSTRATION PROBLEM

         *** SUMMARY OF COMPUTED PUMP CHARACTERISTICS FOR THE SYSTEM ***

  PUMP CHARACTERISTICS                         OXYGEN          HYDROGEN

  TEMPERATURE                                 .165000+03      .370000+02
  PRESSURE                                    .129757+02      .157742+02
  FLOW RATE                                   .120417+02      .460098+01
  DELTA-PRESSURE                              .201261+04      .199454+04
  NPSH AVIALABLE                              .870000+01      .110000+01
  DENSITY OF FLUID                            .708162+02      .443309+01

  NUMBER OF STAGES REQD.                          1               5
  COMPUTED NPSP REQD                          .218270+01      .336251+00
  COMPUTED PUMP EFF.                          .725520+00      .766746+00
  COMPUTED PUMP VOL.                          .490617+02      .133186+03
  COMPUTED PUMP WGT.                          .146742+01      .359000+01
  COMPUTED PUMP PWR.                          .123499+03      .706864+03
  COMPUTED PUMP SPD.                          .174980+05      .834961+05

  SELECTED PUMP OPTION                            2               2

       *** SUMMARY OF COMPUTED TURBINE CHARACTERISTICS FOR THE SYSTEM ***

  TURBINE CHARACTERISTICS                      OXYGEN          HYDROGEN

  TURBINE ROTOR MEAN DIAMETER                 .850669+01      .274264+01
  WGT. OF PWR. TRANSMISSION ASSY              .137516+02      .103401+02
  WGT. OF TURBINE ROTOR                       .696344+01      .233372+00
  WGT. OF MANIFOLD AND NOZZLE                 .339364+02      .140023+01
  WEIGHT OF INDUCER                           .500000+01      .500000+01
  WEIGHT OF TURBINE ASSY.                     .596515+02      .186073+02

       *** SUMMARY OF COMPUTED TURBINE GAS GENERATOR CHARACTERISTICS ***

  GAS GENERATOR CHARACTERISTICS                OXYGEN          HYDROGEN

  GAS GEN. FLOW RATE - (LB/SEC)               .879073-01      .554576+00
  GAS GEN. PROPELLANT WGT.-(LBS)              .364534+02      .229972+03
  GAS GENERATOR WEIGHT - (LBS)                .122426+02      .123712+02
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DEPT 6213            *        THE INTEGRATED MATH MODEL                   * DATE
EXT. 30235           *                                                    * TIME 15:02:03
BLD. 104             *                  AT4307                            * CASE     1
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
                            ACPS - TEST DEMONSTRATION PROBLEM

                         *** INITIAL TANK SIZING CALCULATIONS ***

                                                 OXYGEN             HYDROGEN

 NUMBER OF TANKS                                    1                   1
 MATERIAL TYPE                                      2                   2
 FLUID WGT. (TOTAL)                           .510113+04          .194820+04
 FLUID VOLUME /TANK                           .720333+02          .439468+03
 WGT ADDED CYL SECT                           .306852+00          .197408+02
 DIAMETER (FT)/TANK                           .506600+01          .500000+01
 SURFACE AREA /TANK                           .855106+02          .388627+03
 TANK VOLUME / TANK                           .742612+02          .453059+03
 TANK WGT. (LB) TOT                           .426906+02          .192650+03
 HEAT LEAK BTU/H/FT                           .475059-02          .323856-01
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                    NAME  USERS NAME  * * * * * * * * * * * * * * * * * * * * * * PAGE     20
                    DEPT 6213          *        THE INTEGRATED MATH MODEL        * DATE 17 APR 73
                    EXT. 30235         *                                         * TIME 15:02:03
                    BLD. 104           *                  AT4307                 * CASE     1
                    * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
                                                 ACPS - TEST DEMONSTRATION PROBLEM

                                  *** TANK AND VENT PARAMETER CALCULATIONS ***

           *** INITIAL TANK CONDITIONS ***

FLUID CONSIDERED -     OXYGEN           FLUID TEMPERATURE        =   163.91      TANK INITIAL PRESSURE =     16.00
WGT.OF LIQ. PROP.    =  5101.13         WGT. PROP. VAPOR         =     .741      WGT. LIQ. + VAPOR     =  5101.87
WGT. HELIUM IN VAPOR =      .00         TOTAL FLUIDS IN TANK     =  5101.87      VOL. OF LIQUID FLUID  =     71.80
PART.PRES.PROP.VAPOR  =  16.000         PART.PRES.HELIUM GAS     =     .000      ULLAGE VOLUME IN TANK =      2.46
TANK VOLUME           =    74.26        EFF. TANK DENSITY        =   68.702      EFF. INTERNAL ENERGY  =  -.56810388+02

            ******************** COAST NUMBER =   1     PRESS.SYS.NO. =    0 ********************

           *** PRE- OR NON-VENT CONDITIONS ***

FLUID CONSIDERED -     OXYGEN           FLUID TEMPERATURE        =   163.99      COAST DURATION - SEC. =      540.
WGT.OF LIQ. PROP.     = 5101.125        WGT. PROP. VAPOR         =     .744      WGT.HELIUM IN VAPOR  =      .000
PART.PRES.PROP.VAPOR  =    16.074       PART.PRES.HELIUM GAS     =     .000      CURRENT TANK PRESSURE =    16.074
EFF.INTERNAL ENERGY   =    -.56809886+02

            ******************** BURN NUMBER =   1     PRESS.SYS.NO. =   2 ********************

           *** COMPUTE ENERGY BALANCE FOR BURN ***

FLUID CONSIDERED -     OXYGEN           BURN DURATION - SEC.     =       5.      FLOWRATE FOR THRUST   =     9.990
THRUST PROP.REMAINING =  4235.05        PROPELLANT IN TANK       =  5101.13      EFF. INTERNAL ENERGY  =  -.56809886+02
EFF. TANK ENERGY      =    -.28672176+06                                         TOTAL FLOWRATE        =    12.033

           *** COMPUTE RESULTING TANK CONDITIONS ***

PROPELLANT WITHDRAWN  =    55.113       TOTAL FLUIDS IN TANK     =  5046.76      PROPELLANT LIQ.+VAP.  =  5046.76
THRUST PROP.REMAINING =  4189.29        NEW EFF. TANK DENSITY    =  67.9596      PART.PRES.PROP.VAPOR  =    16.056
NEW INTERNAL ENERGY   =    -.56813077+02

           *** COMPUTE PRESSURANT NEEDED FOR THIS BURN ***

TANK LIQ. TEMPERATURE =    163.97       STORED HELIUM TEMP.      =   170.00      NEW TANK ULLAGE VOL.  =     3.230
NEW PROP. LIQ. VOLUME =     71.03       PROP. LIQ. REMAINING     =  5045.78      WGT. OF PROP. VAPOR   =     .9742
HELIUM PART.PRESSURE  =    10.644       TOTAL PRES. *PPV+PHE*    =   16.056      NOM. OPERATING PRES.  =    26.700
HELIUM FLOW RATE      =    .1644-01     WEIGHT OF HELIUM USED    =   .7528-01    NEW TANK PRESSURE     =    26.700
TOTAL HELIUM CONSUMED =      .075
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DEPT 6213          *          THE INTEGRATED MATH MODEL          *
EXT. 30235         *                                             * TIME 15:02:03
BLD. 104           *                  AT4307                     * CASE     1
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
                      ACPS - TEST DEMONSTRATION PROBLEM

              *** TANK AND VENT PARAMETER CALCULATIONS - CONTD. ***


       ******************** COAST NUMBER =   2     PRESS.SYS.NO. =   2 ********************

       *** PRE- OR NON-VENT CONDITIONS ***

FLUID CONSIDERED -     OXYGEN        FLUID TEMPERATURE       =   164.00      COAST DURATION - SEC. =    7975.
WGT.OF LIQ. PROP.      = 5045.781    WGT. PROP. VAPOR        =     .976      WGT.HELIUM IN VAPOR  =     .075
PART.PRES.PROP.VAPOR  =   16.084     PART.PRES.HELIUM GAS    =   10.269      CURRENT TANK PRESSURE =  26.353
EFF.INTERNAL ENERGY   =   -.56805571+02

       ******************** BURN NUMBER =   2     PRESS.SYS.NO. =   2 ********************

       *** COMPUTE ENERGY BALANCE FOR BURN ***

FLUID CONSIDERED -     OXYGEN        BURN DURATION - SEC.    =       6.      FLOWRATE FOR THRUST    =    9.990
THRUST PROP.REMAINING = 4189.29      PROPELLANT IN TANK      =  5046.76      EFF. INTERNAL ENERGY   =  -.56805571+02
EFF. TANK ENERGY      =   -.28250102+06                                      TOTAL FLOWRATE         =   12.035

       *** COMPUTE RESULTING TANK CONDITIONS ***

PROPELLANT WITHDRAWN  =   74.016     TOTAL FLUIDS IN TANK    =  4972.74      PROPELLANT LIQ.+VAP.   =  4972.74
THRUST PROP.REMAINING = 4127.85      NEW EFF. TANK DENSITY   =  66.9629      PART.PRES.PROP.VAPOR   =   16.061
NEW INTERNAL ENERGY   =   -.56809925+02

       *** COMPUTE PRESSURANT NEEDED FOR THIS BURN ***

TANK LIQ. TEMPERATURE =  163.97      STORED HELIUM TEMP.     =   170.00      NEW TANK ULLAGE VOL.   =    4.275
NEW PROP. LIQ. VOLUME =   69.99      PROP. LIQ. REMAINING    =  4971.45      WGT. OF PROP. VAPOR    =   1.2898
HELIUM PART.PRESSURE  =  10.639      TOTAL PRES. *PPV+PHE*   =   23.817      NOM. OPERATING PRES.   =   26.700
HELIUM FLOW  RATE     =  .3955-02    WEIGHT OF HELIUM USED   =  .2432-01     NEW TANK PRESSURE      =   26.700
TOTAL HELIUM CONSUMED =     .100
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                         NAME  USERS NAME  * * * * * * * * * * * * * * * * * * * * * * * * * * PAGE    22
                         DEPT 6213          *        THE INTEGRATED MATH MODEL       * DATE 17 APR 73
                         EXT. 30235         *                                        * TIME 15:02:03
                         BLD. 104           *                     AT4307             * CASE     1
                         * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
                                                 ACPS - TEST DEMONSTRATION PROBLEM

                                     *** TANK AND VENT PARAMETER CALCULATIONS - CONTD. ***


                    ******************** COAST NUMBER =   3     PRESS.SYS.NO. =   2 ********************

                   *** PRE- OR NON-VENT CONDITIONS ***

      FLUID CONSIDERED -     OXYGEN            FLUID TEMPERATURE       =    163.98      COAST DURATION - SEC. =    2094.
      WGT.OF LIQ. PROP.      = 4971.450        WGT. PROP. VAPOR        =     1.290      WGT.HELIUM IN VAPOR  =     .100
      PART.PRES.PROP.VAPOR  =   16.069         PART.PRES.HELIUM GAS    =    10.263      CURRENT TANK PRESSURE =   26.332
      EFF.INTERNAL ENERGY    =    -.56807924+02

                    ******************** BURN NUMBER =   3     PRESS.SYS.NO. =   2 ********************

                   *** COMPUTE ENERGY BALANCE FOR BURN ***

      FLUID CONSIDERED -     OXYGEN            BURN DURATION - SEC.    =        4.      FLOWRATE FOR THRUST     =    9.990
      THRUST PROP.REMAINING =  4127.85         PROPELLANT IN TANK      =   4972.74      EFF. INTERNAL ENERGY    =  -.56807924+02
      EFF. TANK ENERGY       =    -.28005587+06                                        TOTAL FLOWRATE          =   12.035

                   *** COMPUTE RESULTING TANK CONDITIONS ***

      PROPELLANT WITHDRAWN  =    43.086        TOTAL FLUIDS IN TANK   =   4929.65      PROPELLANT LIQ.+VAP.    =  4929.65
      THRUST PROP.REMAINING =  4092.09         NEW EFF. TANK DENSITY  =   66.3827      PART.PRES.PROP.VAPOR    =   16.055
      NEW INTERNAL ENERGY    =    -.56810441+02

                   *** COMPUTE PRESSURANT NEEDED FOR THIS BURN ***

      TANK LIQ. TEMPERATURE =    163.97        STORED HELIUM TEMP.    =    170.00      NEW TANK ULLAGE VOL.    =    4.886
      NEW PROP. LIQ. VOLUME =     69.38        PROP. LIQ. REMAINING   =   4928.18      WGT. OF PROP. VAPOR     =   1.4735
      HELIUM PART.PRESSURE  =    10.645        TOTAL PRES. *PPV+PHE*  =    25.035      NOM. OPERATING PRES.    =   26.700
      HELIUM FLOW  RATE     =    .3990-02      WEIGHT OF HELIUM USED  =    .1428-01     NEW TANK PRESSURE       =   26.700
      TOTAL HELIUM CONSUMED =      .114
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DEPT 6213          *         THE INTEGRATED MATH MODEL          * DATE
EXT. 30235         *                                            * TIME 15:02:04
BLD. 104           *                 AT4307                     * CASE    1
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
                             ACPS - TEST DEMONSTRATION PROBLEM

                      *** TANK AND VENT PARAMETER CALCULATIONS - CONTD. ***


          ******************** COAST NUMBER =   4     PRESS.SYS.NO. =   2 ********************

         *** PRE- OR NON-VENT CONDITIONS ***

FLUID CONSIDERED -     OXYGEN           FLUID TEMPERATURE       =    163.97      COAST DURATION - SEC. =      536.
WGT.OF LIQ. PROP.      = 4928.181       WGT. PROP. VAPOR        =     1.474      WGT.HELIUM IN VAPOR   =      .114
PART.PRES.PROP.VAPOR  =    16.058       PART.PRES.HELIUM GAS    =    10.268      CURRENT TANK PRESSURE =    26.326
EFF.INTERNAL ENERGY   =    -.56809925+02

          ******************** BURN NUMBER =   4     PRESS.SYS.NO. =   2 ********************

         *** COMPUTE ENERGY BALANCE FOR BURN ***

FLUID CONSIDERED -     OXYGEN           BURN DURATION - SEC.    =       39.      FLOWRATE FOR THRUST    =    9.990
THRUST PROP.REMAINING =  4092.09        PROPELLANT IN TANK      =  4929.65       EFF. INTERNAL ENERGY   =   -.56809925+02
EFF. TANK ENERGY      =    -.25365855+06                                         TOTAL FLOWRATE         =   12.035

         *** COMPUTE RESULTING TANK CONDITIONS ***

PROPELLANT WITHDRAWN  =   466.961       TOTAL FLUIDS IN TANK    =  4462.69       PROPELLANT LIQ.+VAP.   =  4462.69
THRUST PROP.REMAINING =  3704.47        NEW EFF. TANK DENSITY   =  60.0946       PART.PRES.PROP.VAPOR   =   15.918
NEW INTERNAL ENERGY   =    -.56839786+02

         *** COMPUTE PRESSURANT NEEDED FOR THIS BURN ***

TANK LIQ. TEMPERATURE =   163.82        STORED HELIUM TEMP.     =   170.00       NEW TANK ULLAGE VOL.   =   11.516
NEW PROP. LIQ. VOLUME =    62.75        PROP. LIQ. REMAINING    =  4459.25       WGT. OF PROP. VAPOR    =   3.4458
HELIUM PART.PRESSURE  =   10.782        TOTAL PRES. *PPV+PHE*   =   20.270       NOM. OPERATING PRES.   =   26.700
HELIUM FLOW  RATE     =   .4072-02      WEIGHT OF HELIUM USED   =   .1580+00     NEW TANK PRESSURE      =   26.700
TOTAL HELIUM CONSUMED =     .272
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                                   NAME  USERS NAME  * * * * * * * * * * * * * * * * * * * * * * * * * * * PAGE     24
                                   DEPT 6213         *         THE INTEGRATED MATH MODEL        * DATE 17 APR 73
                                   EXT. 30235        *                                          * TIME 15:02:04
                                   BLD. 104          *                    AT4307                * CASE      1
                                   * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
                                                             ACPS - TEST DEMONSTRATION PROBLEM

                                                   *** TANK AND VENT PARAMETER CALCULATIONS - CONTD. ***


                         ******************** COAST NUMBER =   5     PRESS.SYS.NO. =   2 ********************

                        *** PRE- OR NON-VENT CONDITIONS ***

FLUID CONSIDERED -      OXYGEN           FLUID TEMPERATURE        =    163.84       COAST DURATION - SEC. =    2061.
WGT.OF LIQ. PROP.       = 4459.244       WGT. PROP. VAPOR         =     3.450       WGT.HELIUM IN VAPOR  =     .272
PART.PRES.PROP.VAPOR  =   15.939         PART.PRES.HELIUM GAS     =    10.392       CURRENT TANK PRESSURE =   26.332
EFF.INTERNAL ENERGY   =   -.56837592+02

                         ******************** BURN NUMBER =   5     PRESS.SYS.NO. =   2 ********************

                        *** COMPUTE ENERGY BALANCE FOR BURN ***

FLUID CONSIDERED -      OXYGEN           BURN DURATION - SEC.     =        7.       FLOWRATE FOR THRUST    =     9.990
THRUST PROP.REMAINING =  3704.47         PROPELLANT IN TANK       =   4462.69       EFF. INTERNAL ENERGY   =   -.56837592+02
EFF. TANK ENERGY      =   -.24858964+06                                             TOTAL FLOWRATE         =    12.035

                        *** COMPUTE RESULTING TANK CONDITIONS ***

PROPELLANT WITHDRAWN  =    89.421        TOTAL FLUIDS IN TANK     =  4373.27        PROPELLANT LIQ.+VAP.   =  4373.27
THRUST PROP.REMAINING =  3630.24         NEW EFF. TANK DENSITY    =  58.8904        PART.PRES.PROP.VAPOR   =    15.912
NEW INTERNAL ENERGY   =   -.56842927+02

                        *** COMPUTE PRESSURANT NEEDED FOR THIS BURN ***

TANK LIQ. TEMPERATURE =   163.81         STORED HELIUM TEMP.      =    170.00       NEW TANK ULLAGE VOL.   =    12.780
NEW PROP. LIQ. VOLUME =    61.48         PROP. LIQ. REMAINING     =  4369.45        WGT. OF PROP. VAPOR    =    3.8229
HELIUM PART.PRESSURE  =   10.788         TOTAL PRES. *PPV+PHE*    =    25.273       NOM. OPERATING PRES.   =    26.700
HELIUM FLOW  RATE     =   .4042-02       WEIGHT OF HELIUM USED    =    .3003-01     NEW TANK PRESSURE      =    26.700
TOTAL HELIUM CONSUMED =     .302
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                        EXT. 30235           *                                         * TIME 15:02:04
                        BLD. 104             *                  AT4307                 * CASE    1
                        * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
                                                     ACPS - TEST DEMONSTRATION PROBLEM

                                             *** TANK AND VENT PARAMETER CALCULATIONS - CONTD. ***


                    ******************** COAST NUMBER =   6     PRESS.SYS.NO. =   2 ********************

                 *** PRE- OR NON-VENT CONDITIONS ***

FLUID CONSIDERED -     OXYGEN           FLUID TEMPERATURE      =    163.81      COAST DURATION - SEC. =     593.
WGT.OF LIQ. PROP.      = 4369.449       WGT. PROP. VAPOR       =     3.824      WGT.HELIUM IN VAPOR   =     .302
PART.PRES.PROP.VAPOR   =    15.916      PART.PRES.HELIUM GAS   =    10.396      CURRENT TANK PRESSURE =   26.313
EFF.INTERNAL ENERGY    =    -.56842283+02

                    ******************** BURN NUMBER =   6     PRESS.SYS.NO. =   2 ********************

                 *** COMPUTE ENERGY BALANCE FOR BURN ***

FLUID CONSIDERED -     OXYGEN           BURN DURATION - SEC.   =        4.      FLOWRATE FOR THRUST    =    9.990
THRUST PROP.REMAINING =  3630.24        PROPELLANT IN TANK     =   4373.27      EFF. INTERNAL ENERGY   =  -.56842283+02
EFF. TANK ENERGY       =    -.24614875+06                                       TOTAL FLOWRATE         =   12.035

                 *** COMPUTE RESULTING TANK CONDITIONS ***

PROPELLANT WITHDRAWN   =    43.086      TOTAL FLUIDS IN TANK   =   4330.19      PROPELLANT LIQ.+VAP.   = 4330.19
THRUST PROP.REMAINING =   3594.47       NEW EFF. TANK DENSITY  =   58.3103      PART.PRES.PROP.VAPOR   =   15.903
NEW INTERNAL ENERGY    =    -.56844824+02

                 *** COMPUTE PRESSURANT NEEDED FOR THIS BURN ***

TANK LIQ. TEMPERATURE =    163.80       STORED HELIUM TEMP.    =    170.00      NEW TANK ULLAGE VOL.   =   13.391
NEW PROP. LIQ. VOLUME =     60.87       PROP. LIQ. REMAINING   =   4326.18      WGT. OF PROP. VAPOR    =   4.0035
HELIUM PART.PRESSURE  =    10.797       TOTAL PRES. *PPV+PHE* =    25.824      NOM. OPERATING PRES.   =   26.700
HELIUM FLOW RATE      =    .4101-02     WEIGHT OF HELIUM USED =     .1468-01    NEW TANK PRESSURE      =   26.700
TOTAL HELIUM CONSUMED =      .317
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NAME  USERS NAME  * * * * * * * * * * * * * * * * * * * * * PAGE     26
DEPT 6213         *      THE INTEGRATED MATH MODEL        * DATE 17 APR 73
EXT. 30235        *                                       * TIME 15:02:04
BLD. 104          *                AT4307                 * CASE      1
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
                          ACPS - TEST DEMONSTRATION PROBLEM

                 *** TANK AND VENT PARAMETER CALCULATIONS - CONTD. ***


        ******************** COAST NUMBER =   7     PRESS.SYS.NO. =   2 ********************

        *** PRE- OR NON-VENT CONDITIONS ***

FLUID CONSIDERED -     OXYGEN         FLUID TEMPERATURE      =   163.80     COAST DURATION - SEC. =     536.
WGT.OF LIQ. PROP.      = 4326.183     WGT. PROP. VAPOR       =    4.004     WGT.HELIUM IN VAPOR  =     .317
PART.PRES.PROP.VAPOR  =    15.906     PART.PRES.HELIUM GAS   =   10.404     CURRENT TANK PRESSURE =   26.310
EFF.INTERNAL ENERGY   =    -.56844236+02

        ******************** BURN NUMBER =   7     PRESS.SYS.NO. =   2 ********************

        *** COMPUTE ENERGY BALANCE FOR BURN ***

FLUID CONSIDERED -     OXYGEN         BURN DURATION - SEC.   =      66.     FLOWRATE FOR THRUST    =     9.990
THRUST PROP.REMAINING =  3594.47      PROPELLANT IN TANK     =  4330.19     EFF. INTERNAL ENERGY   =  -.56844236+02
EFF. TANK ENERGY      =    -.20112651+06                                   TOTAL FLOWRATE         =    12.035

        *** COMPUTE RESULTING TANK CONDITIONS ***

PROPELLANT WITHDRAWN  =   795.519     TOTAL FLUIDS IN TANK   =  3534.67     PROPELLANT LIQ.+VAP.   =  3534.67
THRUST PROP.REMAINING =  2934.12      NEW EFF. TANK DENSITY  =  47.5978     PART.PRES.PROP.VAPOR   =    15.752
NEW INTERNAL ENERGY   =    -.56901096+02

        *** COMPUTE PRESSURANT NEEDED FOR THIS BURN ***

TANK LIQ. TEMPERATURE =    163.63     STORED HELIUM TEMP.    =   170.00     NEW TANK ULLAGE VOL.   =    24.656
NEW PROP. LIQ. VOLUME =     49.61     PROP. LIQ. REMAINING   =  3527.36     WGT. OF PROP. VAPOR    =    7.3072
HELIUM PART.PRESSURE  =    10.946     TOTAL PRES. *PPV+PHE*  =   21.396     NOM. OPERATING PRES.   =    26.700
HELIUM FLOW  RATE     =   .4152-02    WEIGHT OF HELIUM USED  =   .2744+00   NEW TANK PRESSURE      =    26.700
TOTAL HELIUM CONSUMED =      .591
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DEPT 8215           *          THE INTEGRATED DATA MODEL
EXT. 30235          *                                                  * TIME 15:02:05
BLD. 104            *                       AT4307                     * CASE     1
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
                                  ACPS - TEST DEMONSTRATION PROBLEM

                        *** TANK AND VENT PARAMETER CALCULATIONS - CONTD. ***


            ******************** COAST NUMBER =   8     PRESS.SYS.NO. =   2 ********************

            *** PRE- OR NON-VENT CONDITIONS ***

FLUID CONSIDERED -    OXYGEN          FLUID TEMPERATURE     =   163.68     COAST DURATION - SEC. =     714.
WGT.OF LIQ. PROP.     = 3527.344      WGT. PROP. VAPOR      =    7.325     WGT.HELIUM IN VAPOR  =     .591
PART.PRES.PROP.VAPOR  =   15.793      PART.PRES.HELIUM GAS  =   10.541     CURRENT TANK PRESSURE =   26.334
EFF.INTERNAL ENERGY   =    -.56900137+02

            ******************** BURN NUMBER =   8     PRESS.SYS.NO. =   2 ********************

            *** COMPUTE ENERGY BALANCE FOR BURN ***

FLUID CONSIDERED -    OXYGEN          BURN DURATION - SEC.  =      32.     FLOWRATE FOR THRUST    =    9.990
THRUST PROP.REMAINING = 2934.12       PROPELLANT IN TANK    =  3534.67     EFF. INTERNAL ENERGY   =   -.56900137+02
EFF. TANK ENERGY      =    -.17910453+06                                   TOTAL FLOWRATE         =   12.035

            *** COMPUTE RESULTING TANK CONDITIONS ***

PROPELLANT WITHDRAWN  =  388.733      TOTAL FLUIDS IN TANK  =  3145.94     PROPELLANT LIQ.+VAP.   =  3145.94
THRUST PROP.REMAINING = 2611.43       NEW EFF. TANK DENSITY =  42.3631     PART.PRES.PROP.VAPOR   =   15.902
NEW INTERNAL ENERGY   =    -.56932047+02

            *** COMPUTE PRESSURANT NEEDED FOR THIS BURN ***

TANK LIQ. TEMPERATURE =   163.80      STORED HELIUM TEMP.   =   170.00     NEW TANK ULLAGE VOL.   =   30.124
NEW PROP. LIQ. VOLUME =    44.14      PROP. LIQ. REMAINING  =  3136.93     WGT. OF PROP. VAPOR    =   9.0060
HELIUM PART.PRESSURE  =   10.798      TOTAL PRES. *PPV+PHE* =   24.536     NOM. OPERATING PRES.   =   26.700
HELIUM FLOW  RATE     =   .3752-02    WEIGHT OF HELIUM USED =   .1212+00   NEW TANK PRESSURE      =   26.700
TOTAL HELIUM CONSUMED =     .712
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                              NAME  USERS NAME  * * * * * * * * * * * * * * * * * * * * * * * * * * PAGE    28
                              DEPT 6213            *        THE INTEGRATED MATH MODEL        * DATE 17 APR 73
                              EXT. 30235           *                                         * TIME 15:02:05
                              BLD. 104             *                  AT4307                 * CASE     1
                              * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
                                                        ACPS - TEST DEMONSTRATION PROBLEM

                                              *** TANK AND VENT PARAMETER CALCULATIONS - CONTD. ***


                        ******************** COAST NUMBER =   9     PRESS.SYS.NO. =   2 ********************

                       *** PRE- OR NON-VENT CONDITIONS ***

FLUID CONSIDERED -     OXYGEN          FLUID TEMPERATURE      =   163.82      COAST DURATION - SEC. =     568.
WGT.OF LIQ. PROP.     = 3136.918       WGT. PROP. VAPOR       =    9.017      WGT.HELIUM IN VAPOR  =     .712
PART.PRES.PROP.VAPOR  =   15.924       PART.PRES.HELIUM GAS   =   10.406      CURRENT TANK PRESSURE =   26.330
EFF.INTERNAL ENERGY   =    -.56931190+02

                        ******************** BURN NUMBER =   9     PRESS.SYS.NO. =   2 ********************

                       *** COMPUTE ENERGY BALANCE FOR BURN ***

FLUID CONSIDERED -     OXYGEN          BURN DURATION - SEC.   =     104.      FLOWRATE FOR THRUST   =    9.990
THRUST PROP.REMAINING =  2611.43       PROPELLANT IN TANK     =  3145.94      EFF. INTERNAL ENERGY  =   -.56931190+02
EFF. TANK ENERGY      =    -.10821124+06                                      TOTAL FLOWRATE        =   12.035

                       *** COMPUTE RESULTING TANK CONDITIONS ***

PROPELLANT WITHDRAWN  = 1252.852       TOTAL FLUIDS IN TANK   =  1893.08      PROPELLANT LIQ.+VAP.  =  1893.08
THRUST PROP.REMAINING =  1571.44       NEW EFF. TANK DENSITY  =  25.4922      PART.PRES.PROP.VAPOR  =   14.508
NEW INTERNAL ENERGY   =    -.57161386+02

                       *** COMPUTE PRESSURANT NEEDED FOR THIS BURN ***

TANK LIQ. TEMPERATURE =   162.19       STORED HELIUM TEMP.    =   170.00      NEW TANK ULLAGE VOL.  =   47.937
NEW PROP. LIQ. VOLUME =    26.32       PROP. LIQ. REMAINING   =  1879.91      WGT. OF PROP. VAPOR   =  13.1757
HELIUM PART.PRESSURE  =   12.192       TOTAL PRES. *PPV+PHE*  =   20.982      NOM. OPERATING PRES.  =   26.700
HELIUM FLOW  RATE     =   .5949-02     WEIGHT OF HELIUM USED  =   .5673+00    NEW TANK PRESSURE     =   26.700
TOTAL HELIUM CONSUMED =    1.280
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DEPT 6213           *        THE INTEGRATED MATH MODEL          * DATE 17 APR 73
EXT. 30235          *                                           * TIME 15:02:05
BLD. 104            *                      AT4307               * CASE      1
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
                                 ACPS - TEST DEMONSTRATION PROBLEM

                      *** TANK AND VENT PARAMETER CALCULATIONS - CONTD. ***


            ******************** COAST NUMBER =  10     PRESS.SYS.NO. =   2 ********************

           *** PRE- OR NON-VENT CONDITIONS ***

FLUID CONSIDERED -     OXYGEN          FLUID TEMPERATURE       =   162.38     COAST DURATION - SEC. =     1876.
WGT.OF LIQ. PROP.     = 1879.780       WGT. PROP. VAPOR        =   13.302     WGT.HELIUM IN VAPOR  =     1.280
PART.PRES.PROP.VAPOR  =    14.660      PART.PRES.HELIUM GAS    =   11.646     CURRENT TANK PRESSURE =    26.306
EFF.INTERNAL ENERGY   =    -.57156679+02

            ******************** BURN NUMBER =  10     PRESS.SYS.NO. =   2 ********************

           *** COMPUTE ENERGY BALANCE FOR BURN ***

FLUID CONSIDERED -     OXYGEN          BURN DURATION - SEC.    =      32.     FLOWRATE FOR THRUST     =     9.990
THRUST PROP.REMAINING =  1571.44       PROPELLANT IN TANK      =  1893.08     EFF. INTERNAL ENERGY    =   -.57156679+02
EFF. TANK ENERGY      =    -.86250527+05                                      TOTAL FLOWRATE          =    12.035

           *** COMPUTE RESULTING TANK CONDITIONS ***

PROPELLANT WITHDRAWN  =  383.919       TOTAL FLUIDS IN TANK    =  1509.16     PROPELLANT LIQ.+VAP.    =  1509.16
THRUST PROP.REMAINING =  1252.75       NEW EFF. TANK DENSITY   =  20.3224     PART.PRES.PROP.VAPOR    =    14.350
NEW INTERNAL ENERGY   =    -.57151208+02

         - *** COMPUTE PRESSURANT NEEDED FOR THIS BURN ***

TANK LIQ. TEMPERATURE =   162.00       STORED HELIUM TEMP.     =   170.00     NEW TANK ULLAGE VOL.    =    53.344
NEW PROP. LIQ. VOLUME =    20.92       PROP. LIQ. REMAINING    =  1494.65     WGT. OF PROP. VAPOR     =   14.5152
HELIUM PART.PRESSURE  =   12.350       TOTAL PRES. *PPV+PHE*   =   24.791     NOM. OPERATING PRES.    =    26.700
HELIUM FLOW  RATE     =   .5102-02     WEIGHT OF HELIUM USED   =  .1628+00    NEW TANK PRESSURE       =    26.700
TOTAL HELIUM CONSUMED =    1.442
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            NAME  USERS NAME * * * * * * * * * * * * * * * * * * * * * * PAGE    30
            DEPT 6213        *     THE INTEGRATED MATH MODEL        * DATE 17 APR 73
            EXT. 30235       *                                      * TIME 15:02:06
            BLD. 104         *                 AT4307               * CASE    1
            * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
                                     ACPS - TEST DEMONSTRATION PROBLEM

                             *** TANK AND VENT PARAMETER CALCULATIONS - CONTD. ***


         ******************** COAST NUMBER =  11     PRESS.SYS.NO. =   2 ********************

        *** PRE- OR NON-VENT CONDITIONS ***

FLUID CONSIDERED -     OXYGEN            FLUID TEMPERATURE      =   165.93      COAST DURATION - SEC. =  571048.
WGT.OF LIQ. PROP.      = 1491.376        WGT. PROP. VAPOR       =   17.788      WGT.HELIUM IN VAPOR  =    1.442
PART.PRES.PROP.VAPOR  =    17.914        PART.PRES.HELIUM GAS   =   12.055      CURRENT TANK PRESSURE =   29.969
EFF.INTERNAL ENERGY   =     -.55353647+02

         ******************** BURN NUMBER =  11     PRESS.SYS.NO. =   2 ********************

        *** COMPUTE ENERGY BALANCE FOR BURN ***

FLUID CONSIDERED -     OXYGEN            BURN DURATION - SEC.   =      16.      FLOWRATE FOR THRUST     =     9.990
THRUST PROP.REMAINING =  1252.75         PROPELLANT IN TANK     =  1509.16      EFF. INTERNAL ENERGY    =    -.55353647+02
EFF. TANK ENERGY      =     -.72687199+05                                      TOTAL FLOWRATE          =    12.035

        *** COMPUTE RESULTING TANK CONDITIONS ***

PROPELLANT WITHDRAWN  =  194.487         TOTAL FLUIDS IN TANK   =  1314.68      PROPELLANT LIQ.+VAP.    =  1314.68
THRUST PROP.REMAINING =  1091.31         NEW EFF. TANK DENSITY  =  17.7034      PART.PRES.PROP.VAPOR    =   16.731
NEW INTERNAL ENERGY   =     -.55289029+02

        *** COMPUTE PRESSURANT NEEDED FOR THIS BURN ***

TANK LIQ. TEMPERATURE =   164.70         STORED HELIUM TEMP.    =   170.00      NEW TANK ULLAGE VOL.    =   55.961
NEW PROP. LIQ. VOLUME =    18.30         PROP. LIQ. REMAINING   =  1297.15      WGT. OF PROP. VAPOR     =  17.5271
HELIUM PART.PRESSURE  =   11.406         TOTAL PRES. *PPV+PHE*  =   28.137      NOM. OPERATING PRES.    =   26.700
HELIUM FLOW  RATE     =   .0000          WEIGHT OF HELIUM USED  =   .0000       NEW TANK PRESSURE       =   28.137
TOTAL HELIUM CONSUMED =    1.442
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                     EXT. 30235          *                                                      * TIME 15:02:06
                     BLD. 104            *                    AT4307                            * CASE      1
                     * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
                                                             ACPS - TEST DEMONSTRATION PROBLEM

                                               *** TANK AND VENT PARAMETER CALCULATIONS - CONTD. ***


                 ******************** COAST NUMBER =  12     PRESS.SYS.NO. =   2 ********************

                *** PRE- OR NON-VENT CONDITIONS ***

FLUID CONSIDERED -      OXYGEN            FLUID TEMPERATURE        =    164.77      COAST DURATION - SEC. =     9584.
WGT.OF LIQ. PROP.     = 1297.085          WGT. PROP. VAPOR         =    17.592      WGT.HELIUM IN VAPOR   =    1.442
PART.PRES.PROP.VAPOR  =    16.798         PART.PRES.HELIUM GAS     =    11.410      CURRENT TANK PRESSURE =   28.208
EFF.INTERNAL ENERGY   =    -.55254397+02

                 ******************** BURN NUMBER =  12     PRESS.SYS.NO. =   2 ********************

                *** COMPUTE ENERGY BALANCE FOR BURN ***

FLUID CONSIDERED -      OXYGEN            BURN DURATION - SEC.     =      100.      FLOWRATE FOR THRUST      =    9.990
THRUST PROP.REMAINING =  1091.31          PROPELLANT IN TANK       =   1314.68      EFF. INTERNAL ENERGY     =   -.55254397+02
EFF. TANK ENERGY      =    -.49881426+04                                            TOTAL FLOWRATE           =   12.035

                *** COMPUTE RESULTING TANK CONDITIONS ***

PROPELLANT WITHDRAWN  = 1203.508          TOTAL FLUIDS IN TANK     =    111.17      PROPELLANT LIQ.+VAP.     =   111.17
THRUST PROP.REMAINING =    92.28          NEW EFF. TANK DENSITY    =    1.4970      PART.PRES.PROP.VAPOR     =   14.580
NEW INTERNAL ENERGY   =    -.44870217+02

                *** COMPUTE PRESSURANT NEEDED FOR THIS BURN ***

TANK LIQ. TEMPERATURE =   162.28          STORED HELIUM TEMP.      =    170.00      NEW TANK ULLAGE VOL.     =   72.986
NEW PROP. LIQ. VOLUME =     1.27          PROP. LIQ. REMAINING     =     91.02      WGT. OF PROP. VAPOR      =  20.1522
HELIUM PART.PRESSURE  =   12.120          TOTAL PRES. *PPV+PHE*    =    23.197      NOM. OPERATING PRES.     =   26.700
HELIUM FLOW  RATE     =   .4943-02        WEIGHT OF HELIUM USED    =  .4943+00      NEW TANK PRESSURE        =   26.700
TOTAL HELIUM CONSUMED =    1.937
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NAME  USERS NAME  * * * * * * * * * * * * * * * * * * * * * * * * * * PAGE     32
DEPT 6213         *       THE INTEGRATED MATH MODEL        * DATE 17 APR 73
EXT. 30235        *                                        * TIME 15:02:06
BLD. 104          *                 AT4307                 * CASE      1
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
                               ACPS - TEST DEMONSTRATION PROBLEM

                     *** TANK AND VENT PARAMETER CALCULATIONS - CONTD. ***


          ********************  FINAL ENGINE SHUTDOWN PROPELLANT TANK CONDITIONS  ********************

          *** COMPUTE FINAL TANK CONDITIONS ***

FLUID CONSIDERED -    OXYGEN          FLUID TEMPERATURE      =   163.01     COAST DURATION - SEC. =     300.
WGT.OF LIQ. PROP.    =   90.226       WGT. PROP. VAPOR       =   20.942     WGT.HELIUM IN VAPOR  =    1.937
PART.PRES.PROP.VAPOR =   15.206       PART.PRES.HELIUM GAS   =   11.622     CURRENT TANK PRESSURE =   26.828
EFF.INTERNAL ENERGY  =   -.44857398+02

FINAL TANK TEMP.     =  163.012       TOTAL VENTED GAS WGT. =      .000     WGT. OF GAS RESIDUALS =   22.879
WGT. OF LIQ.RESIDUALS =   90.226

          *** COMPUTE PRESSURIZATION SYSTEM WEIGHT ***

TOTAL HELIUM GAS REQD =     1.937     WGT.PRESSURANT SYSTEM =   42.905
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EXT. 30235               *                                                    * TIME 15:02:06
BLD. 104                 *                      AT4307                        * CASE      1
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
                                        ACPS - TEST DEMONSTRATION PROBLEM

                                *** TANK AND VENT PARAMETER CALCULATIONS ***

                *** INITIAL TANK CONDITIONS ***

      FLUID CONSIDERED -   HYDROGEN         FLUID TEMPERATURE      =    37.05     TANK INITIAL PRESSURE =    16.00
      WGT.OF LIQ. PROP.    =  1948.20       WGT. PROP. VAPOR       =    1.204     WGT. LIQ. + VAPOR     =  1949.40
      WGT. HELIUM IN VAPOR =      .00       TOTAL FLUIDS IN TANK   =  1949.40     VOL. OF LIQUID FLUID  =   439.63
      PART.PRES.PROP.VAPOR  =  16.000       PART.PRES.HELIUM GAS   =     .000     ULLAGE VOLUME IN TANK =    13.43
      TANK VOLUME           =  453.06       EFF. TANK DENSITY      =    4.303     EFF. INTERNAL ENERGY  =  -.11041192+03

                ******************** COAST NUMBER =   1      PRESS.SYS.NO. =    0 ********************

                *** PRE- OR NON-VENT CONDITIONS ***

      FLUID CONSIDERED -   HYDROGEN         FLUID TEMPERATURE      =    37.95     COAST DURATION - SEC. =     540.
      WGT.OF LIQ. PROP.     = 1948.037      WGT. PROP. VAPOR       =    1.365     WGT.HELIUM IN VAPOR  =     .000
      PART.PRES.PROP.VAPOR  =   18.365      PART.PRES.HELIUM GAS   =     .000     CURRENT TANK PRESSURE =   18.365
      EFF.INTERNAL ENERGY   =   -.11040295+03

                ******************** BURN NUMBER =   1     PRESS.SYS.NO. =   2 ********************

                *** COMPUTE ENERGY BALANCE FOR BURN ***

      FLUID CONSIDERED -   HYDROGEN         BURN DURATION - SEC.   =       5.     FLOWRATE FOR THRUST   =    2.498
      THRUST PROP.REMAINING =  1066.76      PROPELLANT IN TANK     =  1948.20     EFF. INTERNAL ENERGY  =  -.11040295+03
      EFF. TANK ENERGY      =   -.21299417+06                                     TOTAL FLOWRATE        =    4.561

                *** COMPUTE RESULTING TANK CONDITIONS ***

      PROPELLANT WITHDRAWN  =   20.890      TOTAL FLUIDS IN TANK   =  1928.51     PROPELLANT LIQ.+VAP.  =  1928.51
      THRUST PROP.REMAINING =  1055.32      NEW EFF. TANK DENSITY  =   4.2566     PART.PRES.PROP.VAPOR  =   17.366
      NEW INTERNAL ENERGY   =   -.11044483+03

                *** COMPUTE PRESSURANT NEEDED FOR THIS BURN ***

      TANK LIQ. TEMPERATURE =    37.58      STORED HELIUM TEMP.    =    40.00     NEW TANK ULLAGE VOL.  =   16.385
      NEW PROP. LIQ. VOLUME =   436.67      PROP. LIQ. REMAINING   =  1926.93     WGT. OF PROP. VAPOR   =   1.5824
      HELIUM PART.PRESSURE  =    1.734      TOTAL PRES. *PPV+PHE*  =   17.366     NOM. OPERATING PRES.  =   19.100
      HELIUM FLOW  RATE     =  .5777-01     WEIGHT OF HELIUM USED  =  .2646+00     NEW TANK PRESSURE     =   19.100
      TOTAL HELIUM CONSUMED =     .265
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                         NAME  USERS NAME  * * * * * * * * * * * * * * * * * * * * * * PAGE      34
                         DEPT 6213         *         THE INTEGRATED MATH MODEL         * DATE 17 APR 73
                         EXT. 30235        *                                           * TIME 15:02:06
                         BLD. 104          *                  AT4307                   * CASE      1
                         * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
                                                   ACPS - TEST DEMONSTRATION PROBLEM

                                   *** TANK AND VENT PARAMETER CALCULATIONS - CONTD. ***


                   ******************** COAST NUMBER =   2     PRESS.SYS.NO. =   2 ********************

                  *** PRE- OR NON-VENT CONDITIONS ***

FLUID CONSIDERED -    HYDROGEN            FLUID TEMPERATURE        =     38.56      COAST DURATION - SEC. =    7975.
WGT.OF LIQ. PROP.     = 1926.778          WGT. PROP. VAPOR         =     1.734      WGT.HELIUM IN VAPOR  =     .265
PART.PRES.PROP.VAPOR  =    19.267         PART.PRES.HELIUM GAS     =     1.671      CURRENT TANK PRESSURE =   20.938
EFF.INTERNAL ENERGY   =    -.11031090+03

                   ******************** BURN NUMBER =   2     PRESS.SYS.NO. =   2 ********************

                  *** COMPUTE ENERGY BALANCE FOR BURN ***

FLUID CONSIDERED -    HYDROGEN            BURN DURATION - SEC.     =        6.      FLOWRATE FOR THRUST      =    2.498
THRUST PROP.REMAINING =  1055.32          PROPELLANT IN TANK       =   1928.51      EFF. INTERNAL ENERGY     =   -.11031090+03
EFF. TANK ENERGY      =    -.20976858+06                                            TOTAL FLOWRATE           =    4.564

                  *** COMPUTE RESULTING TANK CONDITIONS ***

PROPELLANT WITHDRAWN  =    28.069         TOTAL FLUIDS IN TANK     =   1900.44      PROPELLANT LIQ.+VAP.     =  1900.44
THRUST PROP.REMAINING =  1039.96          NEW EFF. TANK DENSITY    =    4.1947      PART.PRES.PROP.VAPOR     =   17.676
NEW INTERNAL ENERGY   =    -.11037879+03

                  *** COMPUTE PRESSURANT NEEDED FOR THIS BURN ***

TANK LIQ. TEMPERATURE =     37.69         STORED HELIUM TEMP.      =     40.00      NEW TANK ULLAGE VOL.     =   22.481
NEW PROP. LIQ. VOLUME =    430.58         PROP. LIQ. REMAINING     =   1898.24      WGT. OF PROP. VAPOR      =   2.2065
HELIUM PART.PRESSURE  =     1.424         TOTAL PRES. *FPV+PHE*    =    18.867      NOM. OPERATING PRES.     =   19.100
HELIUM FLOW  RATE     =     .5471-02      WEIGHT OF HELIUM USED    =    .3365-01     NEW TANK PRESSURE        =   19.100
TOTAL HELIUM CONSUMED =      .298
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DEPT 6213                 *        THE INTEGRATED MATH MODEL          * DATE 17 APR 73
EXT. 30235                *                                           * TIME 15:02:07
BLD. 104                  *                  AT4307                   * CASE      1
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                                      ACPS - TEST DEMONSTRATION PROBLEM

                        *** TANK AND VENT PARAMETER CALCULATIONS - CONTD. ***


          ******************** COAST NUMBER =    3     PRESS.SYS.NO. =    2 ********************

        *** PRE- OR NON-VENT CONDITIONS ***

FLUID CONSIDERED -    HYDROGEN         FLUID TEMPERATURE        =      37.84      COAST DURATION - SEC. =     2094.
WGT.OF LIQ. PROP.     = 1898.193       WGT. PROP. VAPOR         =      2.250      WGT.HELIUM IN VAPOR   =     .298
PART.PRES.PROP.VAPOR  =    18.059      PART.PRES.HELIUM GAS     =      1.347      CURRENT TANK PRESSURE =   19.406
EFF.INTERNAL ENERGY   =    -.11034311+03

          ******************** BURN NUMBER =    3     PRESS.SYS.NO. =    2 ********************

        *** COMPUTE ENERGY BALANCE FOR BURN ***

FLUID CONSIDERED -    HYDROGEN         BURN DURATION - SEC.     =         4.      FLOWRATE FOR THRUST      =    2.498
THRUST PROP.REMAINING =  1039.96       PROPELLANT IN TANK       =    1900.44      EFF. INTERNAL ENERGY     =  -.11034311+03
EFF. TANK ENERGY      =    -.20795540+06                                          TOTAL FLOWRATE           =    4.564

        *** COMPUTE RESULTING TANK CONDITIONS ***

PROPELLANT WITHDRAWN  =    16.339      TOTAL FLUIDS IN TANK     =    1884.10      PROPELLANT LIQ.+VAP.     =  1884.10
THRUST PROP.REMAINING =  1031.02       NEW EFF. TANK DENSITY    =     4.1586      PART.PRES.PROP.VAPOR     =   17.334
NEW INTERNAL ENERGY   =    -.11037366+03

        *** COMPUTE PRESSURANT NEEDED FOR THIS BURN ***

TANK LIQ. TEMPERATURE =    37.57       STORED HELIUM TEMP.      =      40.00      NEW TANK ULLAGE VOL.     =   26.715
NEW PROP. LIQ. VOLUME =   426.34       PROP. LIQ. REMAINING     =    1881.53      WGT. OF PROP. VAPOR      =   2.5757
HELIUM PART.PRESSURE  =    1.766       TOTAL PRES. *PPV+PHE*    =     18.460      NOM. OPERATING PRES.     =   19.100
HELIUM FLOW  RATE     =   .3943-01     WEIGHT OF HELIUM USED    =    .1412+00     NEW TANK PRESSURE        =   19.100
TOTAL HELIUM CONSUMED =     .439
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                     NAME  USERS NAME  * * * * * * * * * * * * * * * * * * * * * PAGE     36
                     DEPT 6213          *        THE INTEGRATED MATH MODEL       * DATE 17 APR 73
                     EXT. 30235         *                                        * TIME 15:02:07
                     BLD. 104           *                   AT4307               * CASE      1
                     * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
                                                ACPS - TEST DEMONSTRATION PROBLEM

                                  *** TANK AND VENT PARAMETER CALCULATIONS - CONTD. ***


               ******************** COAST NUMBER =   4     PRESS.SYS.NO. =   2 ********************

              *** PRE- OF NON-VENT CONDITIONS ***

 FLUID CONSIDERED -   HYDROGEN          FLUID TEMPERATURE      =     37.61    COAST DURATION - SEC. =    536.
 WGT.OF LIQ. PROP.    = 1881.512        WGT. PROP. VAPOR       =     2.591    WGT.HELIUM IN VAPOR  =     .439
 PART.PRES.PROP.VAPOR  =    17.449      PART.PRES.HELIUM GAS   =     1.660    CURRENT TANK PRESSURE =  19.110
 EFF.INTERNAL ENERGY   =    -.11036445+03

               ******************** BURN NUMBER =   4     PRESS.SYS.NO. =   2 ********************

              *** COMPUTE ENERGY BALANCE FOR BURN ***

 FLUID CONSIDERED -   HYDROGEN          BURN DURATION - SEC.   =       39.    FLOWRATE FOR THRUST   =    2.498
 THRUST PROP.REMAINING =  1031.02       PROPELLANT IN TANK     =   1884.10    EFF. INTERNAL ENERGY  =   -.11036445+03
 EFF. TANK ENERGY      =    -.18892080+06                                     TOTAL FLOWRATE        =    4.564

              *** COMPUTE RESULTING TANK CONDITIONS ***

 PROPELLANT WITHDRAWN  =  177,087       TOTAL FLUIDS IN TANK   =   1707,02    PROPELLANT LIQ.+VAP.  =  1707,02
 THRUST PROP.REMAINING =   934.12       NEW EFF. TANK DENSITY  =    3.7678    PART.PRES.PROP.VAPOR  =   14.841
 NEW INTERNAL ENERGY   =    -.11067308+03

              *** COMPUTE PRESSURANT NEEDED FOR THIS BURN ***

 TANK LIQ. TEMPERATURE =    36.57       STORED HELIUM TEMP.    =     40.00    NEW TANK ULLAGE VOL.  =   70.609
 NEW PROP. LIQ. VOLUME =   382.45       PROP. LIQ. REMAINING   =   1701.11    WGT. OF PROP. VAPOR   =   5.9096
 HELIUM PART.PRESSURE  =    4.259       TOTAL PRES. *PPV+PHE*  =    15.452    NOM. OPERATING PRES.  =   19.100
 HELIUM FLOW  RATE     =   .6082-01     WEIGHT OF HELIUM USED  =   .2360+01   NEW TANK PRESSURE     =   19.100
 TOTAL HELIUM CONSUMED =    2.799
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                                   ACPS - TEST DEMONSTRATION PROBLEM

                          *** TANK AND VENT PARAMETER CALCULATIONS - CONTD. ***


            ******************** COAST NUMBER =   5     PRESS.SYS.NO. =   2 ********************

           *** PRE- OR NON-VENT CONDITIONS ***

FLUID CONSIDERED -   HYDROGEN          FLUID TEMPERATURE      =    36.62      COAST DURATION - SEC. =    2061.
WGT.OF LIQ. PROP.     = 1701.064       WGT. PROP. VAPOR       =    5.953      WGT.HELIUM IN VAPOR  =    2.799
PART.PRES.PROP.VAPOR  =   14.962       PART.PRES.HELIUM GAS   =    3.899      CURRENT TANK PRESSURE =   18.860
EFF.INTERNAL ENERGY   =  -.11063398+03

            ******************** BURN NUMBER =   5     PRESS.SYS.NO. =   2 ********************

           *** COMPUTE ENERGY BALANCE FOR BURN ***

FLUID CONSIDERED -   HYDROGEN          BURN DURATION - SEC.   =       7.      FLOWRATE FOR THRUST    =    2.498
THRUST PROP.REMAINING =   934.12       PROPELLANT IN TANK     =  1707.02      EFF. INTERNAL ENERGY   =  -.11063398+03
EFF. TANK ENERGY      =  -.18513058+06                                        TOTAL FLOWRATE         =    4.564

           *** COMPUTE RESULTING TANK CONDITIONS ***

PROPELLANT WITHDRAWN  =   33.911       TOTAL FLUIDS IN TANK   =  1673.11      PROPELLANT LIQ.+VAP.   =  1673.11
THRUST PROP.REMAINING =   915.56       NEW EFF. TANK DENSITY  =   3.6929      PART.PRES.PROP.VAPOR   =   14.818
NEW INTERNAL ENERGY   =  -.11065086+03

           *** COMPUTE PRESSURANT NEEDED FOR THIS BURN ***

TANK LIQ. TEMPERATURE =    36.56       STORED HELIUM TEMP.    =    40.00      NEW TANK ULLAGE VOL.   =   78.406
NEW PROP. LIQ. VOLUME =   374.65       PROP. LIQ. REMAINING   =  1666.55      WGT. OF PROP. VAPOR    =   6.5528
HELIUM PART.PRESSURE  =    4.282       TOTAL PRES. *PPV+PHE*  =   16.323      NOM. OPERATING PRES.   =   19.100
HELIUM FLOW  RATE     =  .4390-01      WEIGHT OF HELIUM USED  =  .3262+00     NEW TANK PRESSURE      =   19.100
TOTAL HELIUM CONSUMED =    3.125
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NAME  USERS NAME  * * * * * * * * * * * * * * * * * * * * * * * PAGE    38
DEPT 6213         *        THE INTEGRATED MATH MODEL          * DATE 17 APR 73
EXT. 30235        *                                           * TIME 15:02:07
BLD. 104          *                 AT4307                    * CASE     1
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
                         ACPS - TEST DEMONSTRATION PROBLEM

                 *** TANK AND VENT PARAMETER CALCULATIONS - CONTD. ***


        ******************** COAST NUMBER =   6     PRESS.SYS.NO. =   2 ********************

        *** PRE- OR NON-VENT CONDITIONS ***

FLUID CONSIDERED -   HYDROGEN         FLUID TEMPERATURE      =     36.57     COAST DURATION - SEC. =    593.
WGT.OF LIQ. PROP.    = 1666.543       WGT. PROP. VAPOR       =     6.562     WGT.HELIUM IN VAPOR  =    3.125
PART.PRES.PROP.VAPOR =    14.841      PART.PRES.HELIUM GAS   =     3.915     CURRENT TANK PRESSURE =   18.756
EFF.INTERNAL ENERGY  =    -.11063939+03

        ******************** BURN NUMBER =   6     PRESS.SYS.NO. =   2 ********************

        *** COMPUTE ENERGY BALANCE FOR BURN ***

FLUID CONSIDERED -   HYDROGEN         BURN DURATION - SEC.   =        4.     FLOWRATE FOR THRUST   =    2,498
THRUST PROP.REMAINING =   915.56      PROPELLANT IN TANK     =  1673.11      EFF. INTERNAL ENERGY  =   -.11063939+03
EFF. TANK ENERGY      =   -.18331533+06                                      TOTAL FLOWRATE        =    4.564

        *** COMPUTE RESULTING TANK CONDITIONS ***

PROPELLANT WITHDRAWN  =   16.339      TOTAL FLUIDS IN TANK   =  1656.77      PROPELLANT LIQ.+VAP.  =  1656.77
THRUST PROP.REMAINING =   906.62      NEW EFF. TANK DENSITY  =   3.6568      PART.PRES.PROP.VAPOR  =   14.773
NEW INTERNAL ENERGY   =   -.11064647+03

        *** COMPUTE PRESSURANT NEEDED FOR THIS BURN ***

TANK LIQ. TEMPERATURE =    36.54      STORED HELIUM TEMP.    =    40.00      NEW TANK ULLAGE VOL.  =   82.200
NEW PROP. LIQ. VOLUME =   370.86      PROP. LIQ. REMAINING   =  1649.92      WGT. OF PROP. VAPOR   =   6.8510
HELIUM PART.PRESSURE  =    4.327      TOTAL PRES. *PPV+PHE*  =   18.504      NOM. OPERATING PRES.  =   19.100
HELIUM FLOW  RATE     =   .5178-01    WEIGHT OF HELIUM USED  =   .1854+00    NEW TANK PRESSURE     =   19.100
TOTAL HELIUM CONSUMED =    3.311
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                         EXT. 30235          *                                              * TIME 15:02:07
                         BLD. 104            *                AT4307                        * CASE      1
                         * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
                                                       ACPS - TEST DEMONSTRATION PROBLEM

                                         *** TANK AND VENT PARAMETER CALCULATIONS - CONTD. ***

                    ******************** COAST NUMBER =    7     PRESS.SYS.NO. =    2 ********************

                   *** PRE- OR NON-VENT CONDITIONS ***

FLUID CONSIDERED -    HYDROGEN         FLUID TEMPERATURE        =      36.55      COAST DURATION - SEC. =      536.
WGT.OF LIQ. PROP.     = 1649.908       WGT. PROP. VAPOR         =      6.858      WGT.HELIUM IN VAPOR  =     3.311
PART.PRES.PROP.VAPOR  =    14.791      PART.PRES.HELIUM GAS     =      3.953      CURRENT TANK PRESSURE =   18.744
EFF.INTERNAL ENERGY   =    -.11063599+03

                    ******************** BURN NUMBER =    7     PRESS.SYS.NO. =    2 ********************

                   *** COMPUTE ENERGY BALANCE FOR BURN ***

FLUID CONSIDERED -    HYDROGEN         BURN DURATION - SEC.     =        66.      FLOWRATE FOR THRUST     =    2.498
THRUST PROP.REMAINING =    906.62      PROPELLANT IN TANK       =    1656.77      EFF. INTERNAL ENERGY    =   -.11063599+03
EFF. TANK ENERGY      =    -.15012108+06                                          TOTAL FLOWRATE          =    4.564

                   *** COMPUTE RESULTING TANK CONDITIONS ***

PROPELLANT WITHDRAWN  =   301.686      TOTAL FLUIDS IN TANK     =    1355.08      PROPELLANT LIQ.+VAP.    =  1355.08
THRUST PROP.REMAINING =    741.53      NEW EFF. TANK DENSITY    =     2.9910      PART.PRES.PROP.VAPOR    =   13.513
NEW INTERNAL ENERGY   =    -.11078394+03

                   *** COMPUTE PRESSURANT NEEDED FOR THIS BURN ***

TANK LIQ. TEMPERATURE =     36.00      STORED HELIUM TEMP.      =      40.00      NEW TANK ULLAGE VOL.    =  152.365
NEW PROP. LIQ. VOLUME =    300.69      PROP. LIQ. REMAINING     =    1343.37      WGT. OF PROP. VAPOR     =  11.7113
HELIUM PART.PRESSURE  =     5.587      TOTAL PRES. *PPV+PHE*    =     15.613      NOM. OPERATING PRES.    =   19.100
HELIUM FLOW  RATE     =   .6976-01     WEIGHT OF HELIUM USED    =    .4611+01     NEW TANK PRESSURE       =   19.100
TOTAL HELIUM CONSUMED =     7.922
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                         NAME  USERS NAME  * * * * * * * * * * * * * * * * * * * * * * * * * PAGE     40
                         DEPT 6213           *        THE INTEGRATED MATH MODEL         * DATE 17 APR 73
                         EXT. 30235          *                                          * TIME 15:02:08
                         BLD. 104            *                   AT4307                 * CASE     1
                         * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
                                                        ACPS - TEST DEMONSTRATION PROBLEM

                                         *** TANK AND VENT PARAMETER CALCULATIONS - CONTD. ***


                   ******************** COAST NUMBER =   8     PRESS.SYS.NO. =   2 ********************

                   *** PRE- OR NON-VENT CONDITIONS ***

FLUID CONSIDERED -    HYDROGEN           FLUID TEMPERATURE        =       36.09      COAST DURATION - SEC. =      714.
WGT.OF LIQ. PROP.      = 1343.198        WGT. PROP. VAPOR         =      11.882      WGT.HELIUM IN VAPOR  =     7.922
PART.PRES.PROP.VAPOR   =    13.730       PART.PRES.HELIUM GAS     =       5.041      CURRENT TANK PRESSURE =     18.771
EFF.INTERNAL ENERGY    =    -.11076687+03

                   ******************** BURN NUMBER =   8     PRESS.SYS.NO. =   2 ********************

                   *** COMPUTE ENERGY BALANCE FOR BURN ***

FLUID CONSIDERED -    HYDROGEN           BURN DURATION - SEC.     =         32.      FLOWRATE FOR THRUST   =     2.498
THRUST PROP.REMAINING =   741.53         PROPELLANT IN TANK       =     1355.08      EFF. INTERNAL ENERGY  =    -.11076687+03
EFF. TANK ENERGY       =    -.13372769+06                                            TOTAL FLOWRATE        =     4.564

                   *** COMPUTE RESULTING TANK CONDITIONS ***

PROPELLANT WITHDRAWN   =  147.420        TOTAL FLUIDS IN TANK     =     1207.66      PROPELLANT LIQ.+VAP.  =   1207.66
THRUST PROP.REMAINING =   660.86         NEW EFF. TANK DENSITY    =      2.6656      PART.PRES.PROP.VAPOR  =    12.991
NEW INTERNAL ENERGY    =    -.11073291+03

                   *** COMPUTE PRESSURANT NEEDED FOR THIS BURN ***

TANK LIQ. TEMPERATURE =    35.76         STORED HELIUM TEMP.      =       40.00      NEW TANK ULLAGE VOL.  =   186.312
NEW PROP. LIQ. VOLUME =   266.75         PROP. LIQ. REMAINING     =     1193.84      WGT. OF PROP. VAPOR   =   13.8188
HELIUM PART.PRESSURE   =     6.109       TOTAL PRES. *PPV+PHE*    =      17.075      NOM. OPERATING PRES.  =    19.100
HELIUM FLOW  RATE      =   .8258-01      WEIGHT OF HELIUM USED    =    .2667+01      NEW TANK PRESSURE     =    19.100
TOTAL HELIUM CONSUMED =   10.589
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            NAME  USERS NAME  * * * * * * * * * * * * * * * * * * * * * * * * * PAGE
            DEPT 6213         *         THE INTEGRATED MATH MODEL          * DATE 17 APR 73
            EXT. 30235        *                                            * TIME 15:02:08
            BLD. 104          *                 AT4307                     * CASE     1
            * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
                                         ACPS - TEST DEMONSTRATION PROBLEM

                              *** TANK AND VENT PARAMETER CALCULATIONS - CONTD. ***


        ********************* COAST NUMBER =   9     PRESS.SYS.NO. =   2 *********************

        *** PRE- OR NON-VENT CONDITIONS ***

FLUID CONSIDERED -   HYDROGEN          FLUID TEMPERATURE      =    35.82     COAST DURATION - SEC. =     568.
WGT.OF LIQ. PROP.    = 1193.713        WGT. PROP. VAPOR       =   13.947     WGT.HELIUM IN VAPOR  =   10.589
PART.PRES.PROP.VAPOR =   13.124        PART.PRES.HELIUM GAS   =    5.469     CURRENT TANK PRESSURE =  18.593
EFF.INTERNAL ENERGY  =   -.11071768+03

        ********************* BURN NUMBER =   9     PRESS.SYS.NO. =   2 *********************

        *** COMPUTE ENERGY BALANCE FOR BURN ***

FLUID CONSIDERED -   HYDROGEN          BURN DURATION - SEC.   =     104.     FLOWRATE FOR THRUST    =    2.498
THRUST PROP.REMAINING =   660.86       PROPELLANT IN TANK     =  1207.66     EFF. INTERNAL ENERGY   =  -.11071768+03
EFF. TANK ENERGY     =   -.80652389+05                                       TOTAL FLOWRATE         =    4.564

        *** COMPUTE RESULTING TANK CONDITIONS ***

PROPELLANT WITHDRAWN  =  475.122       TOTAL FLUIDS IN TANK   =   732.54     PROPELLANT LIQ.+VAP.   =   732.54
THRUST PROP.REMAINING =   400.86       NEW EFF. TANK DENSITY  =   1.6169     PART.PRES.PROP.VAPOR   =   11.072
NEW INTERNAL.ENERGY  =   -.11009992+03

        *** COMPUTE PRESSURANT NEEDED FOR THIS BURN ***

TANK LIQ. TEMPERATURE =    34.83       STORED HELIUM TEMP.    =    40.00     NEW TANK ULLAGE VOL.   =  294.714
NEW PROP. LIQ. VOLUME =   158.35       PROP. LIQ. REMAINING   =   713.62     WGT. OF PROP. VAPOR    =  18.9178
HELIUM PART.PRESSURE =    8.028        TOTAL PRES. *PPV+PHE*  =   14.433     NOM. OPERATING PRES.   =   19.100
HELIUM FLOW  RATE    =   .1096+00      WEIGHT OF HELIUM USED  =  .1141+02    NEW TANK PRESSURE      =   19.100
TOTAL HELIUM CONSUMED =   22.001
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                    NAME  USERS NAME  * * * * * * * * * * * * * * * * * * * * * PAGE    42
                    DEPT 6213         *        THE INTEGRATED MATH MODEL        * DATE 17 APR 73
                    EXT. 30235        *                                         * TIME 15:02:09
                    BLD. 104          *                   AT4307                * CASE     1
                    * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
                                              ACPS - TEST DEMONSTRATION PROBLEM

                                *** TANK AND VENT PARAMETER CALCULATIONS - CONTD. ***


              ******************** COAST NUMBER =  10     PRESS.SYS.NO. =   2 ********************

             *** PRE- OR NON-VENT CONDITIONS ***

FLUID CONSIDERED -   HYDROGEN          FLUID TEMPERATURE      =    35.14      COAST DURATION - SEC. =    1876.
WGT.OF LIQ. PROP.      =  712.672      WGT. PROP. VAPOR       =   19.866      WGT.HELIUM IN VAPOR  =  22.001
PART.PRES.PROP.VAPOR   =   11.689      PART.PRES.HELIUM GAS   =    7.050      CURRENT TANK PRESSURE =  18.739
EFF.INTERNAL ENERGY    =   -.11001698+03

              ******************** BURN NUMBER =  10     PRESS.SYS.NO. =   2 ********************

             *** COMPUTE ENERGY BALANCE FOR BURN ***

FLUID CONSIDERED -   HYDROGEN          BURN DURATION - SEC.   =      32.      FLOWRATE FOR THRUST    =    2.498
THRUST PROP.REMAINING =   400.86       PROPELLANT IN TANK     =   732.54      EFF. INTERNAL ENERGY   =  -.11001698+03
EFF. TANK ENERGY       =   -.64112928+05                                      TOTAL FLOWRATE         =    4.564

             *** COMPUTE RESULTING TANK CONDITIONS ***

PROPELLANT WITHDRAWN   =  145.594      TOTAL FLUIDS IN TANK   =   586.94      PROPELLANT LIQ.+VAP.   =   586.94
THRUST PROP.REMAINING =   321.19       NEW EFF. TANK DENSITY  =   1.2955      PART.PRES.PROP.VAPOR   =   11.374
NEW INTERNAL ENERGY    =   -.10923182+03

             *** COMPUTE PRESSURANT NEEDED FOR THIS BURN ***

TANK LIQ. TEMPERATURE =    34.98       STORED HELIUM TEMP.    =    40.00      NEW TANK ULLAGE VOL.   =  327.458
NEW PROP. LIQ. VOLUME =   125.60       PROP. LIQ. REMAINING   =   565.41      WGT. OF PROP. VAPOR    =  21.5356
HELIUM PART.PRESSURE   =    7.726      TOTAL PRES. *PPV+PHE*  =   17.689      NOM. OPERATING PRES.   =   19.100
HELIUM FLOW  RATE      =   .4791-01    WEIGHT OF HELIUM USED  =  .1528+01     NEW TANK PRESSURE      =   19.100
TOTAL HELIUM CONSUMED =    23.529
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DEPT 6213            *         THE INTEGRATED MATH MODEL          * DATE 17 APR 73
EXT. 30235           *                                            * TIME 15:02:09
BLD. 104             *                    AT4307                  * CASE     1
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
                              ACPS - TEST DEMONSTRATION PROBLEM

                         *** TANK AND VENT PARAMETER CALCULATIONS - CONTD. ***


           ******************** COAST NUMBER =  11     PRESS.SYS.NO. =   2 ********************

          *** PRE- OR NON-VENT CONDITIONS ***

FLUID CONSIDERED -    HYDROGEN         FLUID TEMPERATURE        =      43.03     COAST DURATION - SEC. =  571048.
WGT.OF LIQ. PROP.      =  522.176      WGT. PROP. VAPOR         =     64.768     WGT.HELIUM IN VAPOR  =   23.529
PART.PRES.PROP.VAPOR   =   37.502      PART.PRES.HELIUM GAS     =      8.313     CURRENT TANK PRESSURE =   45.816
EFF.INTERNAL ENERGY    =  -.77723276+02

          *** POST VENT CONDITIONS ***

TANK VENT PRESSURE     =    24.10      WGT.VENTED FLUIDS        =      54.91     WGT.OF LIQ.IN TANK     =  495.18
WGT.VAPOR IN TANK      =   36.853      WGT.HELIUM IN VAPOR  =    13.105     TOTAL FLUIDS IN TANK   =   545.14
PART.PRES.PROP.VAPOR   =   19.762      PART.PRES.HELIUM GAS     =      4.338     VENTED TANK PRESSURE   =   24.100
EFF.INTERNAL ENERGY    =  -.94977942+02

           ******************** BURN NUMBER =  11     PRESS.SYS.NO. =   2 ********************

          *** COMPUTE ENERGY BALANCE FOR BURN ***

FLUID CONSIDERED -    HYDROGEN         BURN DURATION - SEC.     =        16.     FLOWRATE FOR THRUST    =    2.498
THRUST PROP.REMAINING =   321.19       PROPELLANT IN TANK       =     495.18     EFF. INTERNAL ENERGY   =   -.94977942+02
EFF. TANK ENERGY       =  -.45225773+05                                          TOTAL FLOWRATE         =    3.851

          *** COMPUTE RESULTING TANK CONDITIONS ***

PROPELLANT WITHDRAWN   =   62.225      TOTAL FLUIDS IN TANK     =     482.91     PROPELLANT LIQ.+VAP.   =   469.81
THRUST PROP.REMAINING =   280.83       NEW EFF. TANK DENSITY =       1.0370     PART.PRES.PROP.VAPOR   =   20.339
NEW INTERNAL ENERGY    =  -.93651651+02

          *** COMPUTE PRESSURANT NEEDED FOR THIS BURN ***

TANK LIQ. TEMPERATURE =     38.89      STORED HELIUM TEMP.      =      40.00     NEW TANK ULLAGE VOL.   =  354.452
NEW PROP. LIQ. VOLUME =     98.61      PROP. LIQ. REMAINING     =     430.36     WGT. OF PROP. VAPOR    =  39.4450
HELIUM PART.PRESSURE  =     3.862      TOTAL PRES. *PPV+PHE* =      24.201     NOM. OPERATING PRES.   =   19.100
HELIUM FLOW  RATE     =     .0000      WEIGHT OF HELIUM USED =       .0000     NEW TANK PRESSURE      =   24.201
TOTAL HELIUM CONSUMED =    23.529
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                NAME  USERS NAME  * * * * * * * * * * * * * * * * * * * * * * PAGE    44
                DEPT 6213         *         THE INTEGRATED MATH MODEL        * DATE 17 APR 73
                EXT. 30235        *                                          * TIME 15:02:09
                BLD. 104          *                  AT4307                  * CASE     1
                * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
                                         ACPS - TEST DEMONSTRATION PROBLEM

                               *** TANK AND VENT PARAMETER CALCULATIONS - CONTD. ***


           ******************** COAST NUMBER =  12     PRESS.SYS.NO. =   2 ********************

          *** PRE- OR NON-VENT CONDITIONS ***

FLUID CONSIDERED -   HYDROGEN          FLUID TEMPERATURE        =     39.03      COAST DURATION - SEC. =    9584.
WGT.OF LIQ. PROP.     =  429.512       WGT. PROP. VAPOR         =    40.298      WGT.HELIUM IN VAPOR  =   13.105
PART.PRES.PROP.VAPOR  =   20.813       PART.PRES.HELIUM GAS     =     3.875      CURRENT TANK PRESSURE =   24.688
EFF.INTERNAL ENERGY   =   -.92990993+02

          *** POST VENT CONDITIONS ***

TANK VENT PRESSURE    =    24.10       WGT.VENTED FLUIDS        =      1.40      WGT.OF LIQ.IN TANK    =  428.93
WGT.VAPOR IN TANK     =   39.484       WGT.HELIUM IN VAPOR  =   12.654          TOTAL FLUIDS IN TANK  =   481.07
PART.PRES.PROP.VAPOR  =   20.317       PART.PRES.HELIUM GAS     =     3.783      VENTED TANK PRESSURE  =   24.100
EFF.INTERNAL ENERGY   =   -.93436532+02

           ******************** BURN NUMBER =  12     PRESS.SYS.NO. =   2 ********************

          *** COMPUTE ENERGY BALANCE FOR BURN ***

FLUID CONSIDERED -   HYDROGEN          BURN DURATION - SEC.     =      100.      FLOWRATE FOR THRUST   =    2.498
THRUST PROP.REMAINING =   280.83       PROPELLANT IN TANK       =    428.93      EFF. INTERNAL ENERGY  =   -.93436532+02
EFF. TANK ENERGY      =   -.49783530+04                                          TOTAL FLOWRATE        =    3.815

          *** COMPUTE RESULTING TANK CONDITIONS ***

PROPELLANT WITHDRAWN  =  381.474       TOTAL FLUIDS IN TANK     =     99.59      PROPELLANT LIQ.+VAP.  =    86.94
THRUST PROP.REMAINING =    31.07       NEW EFF. TANK DENSITY    =     .1919      PART.PRES.PROP.VAPOR  =   17.623
NEW INTERNAL ENERGY   =   -.49986179+02

          *** COMPUTE PRESSURANT NEEDED FOR THIS BURN ***

TANK LIQ. TEMPERATURE =    37.67       STORED HELIUM TEMP.      =     40.00      NEW TANK ULLAGE VOL.  =  443.180
NEW PROP. LIQ. VOLUME =     9.88       PROP. LIQ. REMAINING     =     43.56      WGT. OF PROP. VAPOR   =  43.3789
HELIUM PART.PRESSURE  =    2.888       TOTAL PRES. *PPV+PHE*    =    20.512      NOM. OPERATING PRES.  =   19.100
HELIUM FLOW  RATE     =    .0000       WEIGHT OF HELIUM USED    =     .0000      NEW TANK PRESSURE     =   20.512
TOTAL HELIUM CONSUMED =   23.529
```

```
EXT. 30235          *                                           * TIME
FLD. 104            *                  AT4307                   * CASE     1
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
                                 ACPS - TEST DEMONSTRATION PROBLEM

                         *** TANK AND VENT PARAMETER CALCULATIONS - CONTD. ***


             ********************  FINAL ENGINE SHUTDOWN PROPELLANT TANK CONDITIONS  ********************

             *** COMPUTE FINAL TANK CONDITIONS ***

FLUID CONSIDERED -   HYDROGEN          FLUID TEMPERATURE      =     37.68      COAST DURATION - SEC. =      300.
WGT.OF LIQ. PROP.     =   43.505       WGT. PROP. VAPOR       =    43.436      WGT.HELIUM IN VAPOR   =   12.654
PART.PRES.PROP.VAPOR  =   17.649       PART.PRES.HELIUM GAS   =     2.689      CURRENT TANK PRESSURE =   20.537
EFF.INTERNAL ENERGY   =   -.49874429+02

FINAL TANK TEMP.      =   37.684       TOTAL VENTED GAS WGT. =    56.304      WGT. OF GAS RESIDUALS =   56.090
WGT. OF LIQ.RESIDUALS =   43.505

             *** COMPUTE PRESSURIZATION SYSTEM WEIGHT ***

TOTAL HELIUM GAS REQD =   23.529       WGT.PRESSURANT SYSTEM =    75.294
```

```
NAME  USERS NAME  * * * * * * * * * * * * * * * * * * * * *  PAGE    46
DEPT 6213         *       THE INTEGRATED MATH MODEL        *  DATE 17 APR 73
EXT. 30235        *                                        *  TIME 15:02:10
BLD. 104 .        *               AT4307                   *  CASE     1
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
                           ACPS - TEST DEMONSTRATION PROBLEM

                       *** FINAL TANK SIZING CALCULATIONS ***

                                                    OXYGEN          HYDROGEN

 NUMBER OF TANKS                                      1                 1
 MATERIAL TYPE                                        2                 2
 INSULATION TYPE                                      2                 2
 FLUID WGT. (TOTAL)                             .543008+04        .225820+04
 FLUID VOLUME /TANK                             .766785+02        .509397+03
 WGT ADDED CYL SECT                             .544434+00        .234124+02
 DIAMETER (FT)/TANK                             .506600+01        .500000+01
 SURFACE AREA /TANK                             .892918+02        .446301+03
 TANK VOLUME / TANK                             .790500+02        .525151+03
 TANK WGT. (LB) TOT                             .448476+02        .221240+03
 INSUL. THICKNESS                               .200000+01        .200000+01
 INSUL. WT (LB) TOT                             .364608+02        .182240+03
```

```
DEPT 6213          *
EXT. 30235         *                                           * TIME 15:02:10
BLD. 104           *                 AT4307                    * CASE      1
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
                        ACPS - TEST DEMONSTRATION PROBLEM

                   *** ACCUMULATOR SIZING CALCULATIONS ***

                                              OXYGEN           HYDROGEN

  NUMBER OF TANKS                               1                  1
  MATERIAL TYPE                                 1                  1
  INSULATION TYPE                               4                  4
  WGT ADDED CYL SECT                        .000000            .000000
  DIAMETER (FT)/TANK                        .168389+01         .517344+01
  SURFACE AREA /TANK                        .690794+01         .840832+02
  TANK VOLUME / TANK                        .250000+01         .725000+02
  TANK WGT. (LB) TOT                        .347921+02         .100850+04
  INSUL. THICKNESS                          .200000+01         .200000+01
  INSUL. WT (LB) TOT                        .124117+01         .117156+02
  GAS RESIDUALS WT.                         .683188+02         .695175+02
```

```
NAME  USERS NAME  * * * * * * * * * * * * * * * * * * * * * PAGE    48
DEPT 6213          *       THE INTEGRATED MATH MODEL       * DATE 17 APR 73
EXT. 30235         *                                       * TIME 15:02:10
BLD. 104           *                AT4307                 * CASE     1
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
                          ACPS - TEST DEMONSTRATION PROBLEM

             *** TANK PROPELLANT ACQUISITION DEVICE COMPUTATION***

                                                OXYGEN          HYDROGEN

  TYPE ACQ. DEVICE                          SURF TENSION      SURF TENSION
  DEVICE WT. (LBS)                           .190053+02        .751981+02
  TRAPPED BY DEVICE                          .112225+03        .435049+02
  RESID. PROPELLANT                          .902258+02        .435049+02
```

```
                  DEPT 6213        *       THE INTEGRATED MATH MODEL        * DATE 17 APR-73
                  EXT. 30235       *                                        * TIME 15:02:10
                  BLD. 104         *                 AT4307                 * CASE    1
                  * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
                                          ACPS - TEST DEMONSTRATION PROBLEM

                                        *** COMPONENT WEIGHT SUMMARY ***

                  ... OXIDYZER ...                                                  ... FUEL ...
                      --------                                                          ----
                                COMPONENT       INSULATION                                      COMPONENT      INSULATION
     COMPONENT        CODE      WT. (LBS)       WT. (LBS)          COMPONENT        CODE        WT. (LBS)      WT. (LBS)

       LINE           LN01          4.009            .188     .      LINE           LN21            3.508           .920
       TEE            FT01           .433            .000     .      TEE            FT21             .331           .000
       LINE           LN02          5.466            .256     .      LINE           LN22            4.783          1.254
       TAP            FT02           .342            .000     .      TAP            FT22             .262           .000
       LINE           LN03           .875            .041     .      LINE           LN23             .765           .201
       VALVE          IV01          6.314            .000     .      VALVE          IV02            6.121           .000
       LINE           LN04           .437            .021     .      LINE           LN24             .383           .100
       VALVE          CV02          4.406            .000     .      VALVE          CV04            4.255           .000
       LINE           LN05          1.458            .068     .      LINE           LN25            1.275           .334
       TAP            FT03           .342            .000     .      TAP            FT23             .262           .000
       LINE           LN06           .729            .034     .      LINE           LN26             .638           .167
       REG            PR01          9.630            .000     .      REG            PR02            9.392           .000
       LINE           LN07          1.913            .051     .      LINE           LN27            1.674           .251
       ACCUM          AC01         34.792           1.241     .      ACCUM          AC02         1008.496         11.716
       LINE           LN08          1.531            .041     .      LINE           LN28            1.148           .182
       HEX            HX01         22.655            .000     .      HEX            HX03           61.123           .000
       LINE           LN09           .383            .011     .      LINE           LN29             .574           .091
       VALVE          CV01          9.000            .000     .      VALVE          CV03            9.214           .000
       LINE           LN10           .383            .011     .      LINE           LN30             .574           .091
       PUMP           HP01         73.362            .000     .      PUMP           HP02           34.569           .000
       LINE           LN11          4.373            .213     .      LINE           LN31            4.373          1.094
       VALVE          SV01          4.142            .000     .      VALVE          SV02            4.406           .000
       LINE           LN12           .547            .025     .      LINE           LN32             .437           .109
       TAP            FT04           .534            .000     .      TAP            FT24             .342           .000
       LINE           LN13          1.093            .050     .      LINE           LN33             .875           .219
       TANK           TK01         63.853          36.461     .      TANK           TK02          296.438        182.240

                                     *** COMPONENT WEIGHT SUMMARY TOTALS ***

                    CONSUMER WEIGHT - LBS                            .159375+03
                    OXIDYZER SYSTEM WT. -LBS                         .253000+03
                    OXID INSULATION WT - LBS                         .387139+02
                    FUEL SYSTEM WT. - LBS                            .145622+04
                    FUEL INSULATION WT - LBS                         .198969+03
                    TOTAL SYSTEM WT. - LBS                           .210628+04

@ FIN
```

Section 3.0
LIBRARY ROUTINES AND SUBPROGRAMS FROM OTHER SOURCES

This section contains pertinent library routines and a brief resume of subprograms from other sources which are employed in Program TCIMM. The list includes Lockheed system routines, UNIVAC FORTRAN V math function routines, UNIVAC FORTRAN V math function routines, National Bureau of Standards TABCODE routines and modified versions of the University of Idaho, Thermodynamics Properties of Oxygen and Nitrogen Program.

3.1 LOCKHEED SYSTEM ROUTINES

This subsection contains descriptions for those system routines which are unique to Lockheed Missiles & Space Company (LMSC).

3.1.1 Subroutine DATE

Description

Subroutine DATE provides the current date through the following Fortran CALL statement:

```
CALL DATE(COL,IMAGE)
```

which stores nine characters of the form

ddΔxxxΔyy

where dd is the day of the month, xxx is the usual three-letter abbreviation for the month, yy is the last two digits of the year, and Δ is a blank.

The date will be stored with its right-most character in column COL of the array area beginning at image. The field COL may range from 1 to 120.

An example for the use of DATE is shown below:

```
DIMENSION B(2)
CALL DATE(9,B)
```

where a two-word array B (12 characters) is specified and the complete image would be $\mathrm{dd}_{\mathrm{b}}\mathrm{xxx}_{\mathrm{b}}\mathrm{yy}_{\mathrm{bbbb}}$.

This may then be written on the standard Fortran list output by:

```
      WRITE(6,3)B
    3 FORMAT(A6,A3)
```

Calling Sequence

```
CALL DATE(COL,IMAGE)
```

Name	Type	I/O	Dimension	Description
COL	I			The right-most character is in this column of array IMAGE.
IMAGE			2	Array in which date and time is stored.

Significant Variables

None

Subprograms Referenced by this Subprogram

None

Subprograms Referencing this Subprogram

Routine	Type	Reference
CØNTRL	P	Page B-75

Listing Reference Page

None

Flow Chart

None

3.1.2 Subroutine TOD

Description

The current time is available through the Fortran statement

```
CALL TOD(COL,IMAGE)
```

which will cause the eight characters

```
hh:mm:ss
```

representing the hours, minutes, and seconds of the current time (on the 24-hour clock) to be stored in Fieldata code with the right-most character in column COL of the array area beginning at IMAGE.

An example of use of TOD is shown below:

```
      DIMENSION A(2)
      CALL TOD(8,A)
```

where a two-word array A (12 characters) is specified and the complete image would be hh:mm:ss0000.

This may then be written on the standard Fortran list output by:

```
      WRITE(6,2)A
    2 FORMAT(A6,A2)
```

Calling Sequence

```
CALL TOD(COL,IMAGE)
```

Name	Type	I/O	Dimension	Description
COL	I			Right-most character of data stored in array IMAGE
IMAGE	I		2	Storage area for current time on the 24 hour clock

Significant Variables

None

Subprograms Referenced in this Subprogram

None

Subprograms Referencing this Subprogram

Routine	Type	Reference
PAGE	S	Page B-239

Listing Reference Page

None

Flow Chart

None

3.2 UNIVAC MATH ROUTINES

The LMSC 1108 library contains the UNIVAC FORTRAN V standard mathematical function routines, of which the following are used by TCIMM:

SQRT	Square Root
CBRT	Cuba Root
EXP	Exponential
DEXP	Double Precision Exponential
ALOG	Natural Logarithm (Sn x)
DLØG	Double Precision Natural Logarithm
ABS	Absolute Value
DABS	Double Precision Absolute Value
AMAXI	Sets Largest Value of Arguments
AMTNI	Sets Smallest Value of Arguments
DBLE	Converts REAL to Double Precision

3.3 NBS – TAB CØDE ROUTINES

3.3.1 Hydrogen Thermodynamic Properties Routines

In order to provide for the closed form calculation of the thermodynamic properties o hydrogen as needed in TCIMM, a set of subprograms from the NBS-TABCØDE were integrated into TCIMM.

The subprograms used are as follows:

Name	Use
Function HPTCP	Cp of Hydrogen
Function HPTCV	Cv of Hydrogen
Function HPTGAM	Ratio at Cp/Cv
Function HYENTH	Enthalpy of Hydrogen
Function PSATH	Saturation Temperatures
Function PTDENS	Density of Hydrogen
Function PTHEAT	Specific Heat Subprogram
Block Data SPHTDA	Thermodynamic Constants
Function TSATH	Saturation Pressure

A detailed description of the above subprograms will be found in References 3.3-1 and 3.3-2. Subprogram listings are also given in Appendix B of this report.

3.4 UNIVERSITY OF IDAHO – OXYGEN AND NITROGEN THERMODYNAMIC PROPERTIES PROGRAM

A unique set of thermodynamic properties computer programs have been developed under the guidance of R. B. Stuart of the University of Idaho. The programs provide in an integrated set of subprograms the desired thermodynamic properties for either oxygen or nitrogen. This set of programs has been modified by LMSC to work in essentially a single precision mode on the UNIVAC-1108, thus providing very rapid closed-form calculation of the desired oxygen and nitrogen properties. The subprograms employed in Program TCIMM are fully described in Reference 3.4-1. The salient features of the subprograms are presented below as abstracted from Ref. 3.4-1.

3.4.1 DESCRIPTION AND USE OF SUBPROGRAMS

The subprograms in this package may be classified into five general categories:

A. Subprograms which are used directly in a calling program

B. Subprograms that are called by other routines in this package

C. Subprograms that initialize data

D. Subprograms that convert units of input and output for calculatin properties in engineering units

E. Heat Transfer Parameter Calculation Subprograms.

3.4.1.1 Subprograms Used Directly In a Calling Program

The units employed for various quantities in the following routines a

Temperature--degrees Kelvin
Pressure--atmospheres
Density--moles/liter
Enthalpy--joules/mole
Internal Energy--joules/mole
Entropy--joules/mole-K
Specific Heat at Constant Pressure--joules/mole-K
Specific Heat at Constant Volume--joules/mole-K
Sonic Velocity--meters/second

For input and output arguments in other units, the user must modify t calling program to accommodate the desired units. One example of this is presented in Subsection 3.4.1.4.

1. NAME: SUBROUTINE PROP (T, P, D, K, H, S, U)

   PURPOSE:

   For (K = 1) - Calculates density, D, enthalpy, H, entropy, S, and internal energy, U for input temperature, T, and pressure, P.

   For (K = 2) - Calculates P, H, S, and U for input of T and D.

   For (K = 3) - Calculates P, D, H, S, and U of the saturated vapor at input temperature, T.

   For (K = 4) - Calculates P, D, H, S, and U of the saturated liqui at input temperature, T.

2. NAME: SUBROUTINE PFND (T, D, P)

   PURPOSE: Calculates pressure, P, at temperature, T, and density, D, from the equation of state.

   NOTE: If only pressure is required in the calling routine the use of PFND instead of PROP (with K = 1 or 2) will save computer time.

3. NAME: SUBROUTINE DFND (T, P, D, K)

   PURPOSE:

   For (K = 0) - Calculates density, D, given temperature, T, and pressure, P.

   For (K = 1) - Calculates D and P for the saturated liquid at temperature T.

   For (K = 2) - Calculates D and P for the saturated vapor at temperature T.

   NOTE: If only density is required the use of DFND instead of PROP (for K = 1 or 3) will save computer time.

4. NAME: FUNCTION VPN (T)

   PURPOSE: Calculates the vapor pressure, P, at temperature, T.

5. NAME: SUBROUTINE TVP (P, T)

   PURPOSE: Calculates the saturation temperature, T, for pressure, P.

6. NAME: SUBROUTINE CPVTD (T, D, CP, CV)

   PURPOSE: Calculates the specific heat at constant pressure CP, and the specific heat at constant volume, CV, at input temperature, T, and density, D.

7. NAME: SUBROUTINE VSND (T, P, D, K, W)

   PURPOSE:

   For (K = 1) - Calculates density, D, and the sonic velocity, W, at temperature, T, and pressure, P.

   For (K = 2) - Calculates W for input of T and D.

   For (K = 3) - Calculates D, P, and W for the saturated vapor at temperature, T.

   For (K = 4) - Calculates D, P, and W for the saturated liquid at temperature, T.

   NOTE: These calculations require modification if a set of units other than that discussed below in Section 3.4.1.3.

1.2 Subprograms Called Only By Other Subprograms In This Package

1. NAME: SUBROUTINE VPROP (T, P, D, K, H, S, U)

   PURPOSE: Calculates properties of the vapor phase.

2. NAME: SUBROUTINE LPROP (T, P, D, K, H, S, U)

   PURPOSE: Calculates properties of the liquid phase.

3. NAME: SUBROUTINE DCALC (D, T, P, DL, DH)

   PURPOSE: Performs iterative solution of the equation of state for density given temperature and pressure.

   NOTE: The solution density. D, must be bracketed by trial densities, DL, and DH.

4. NAME: FUNCTION DSATV (T)

   PURPOSE: Calculates an approximate value of the density of the saturated vapor at temperature, T.

5. NAME: FUNCTION DSATL (T)

   PURPOSE: Calculates an approximate value of the density of the saturated liquid at temperature, T.

6. NAME: SUBROUTINE DPDTVP (T, P, DPDT)

   PURPOSE: Calculates the derivative of the vapor pressure equation, dP/dT, given temperature, T, and pressure, P.

7. NAME: FUNCTION CPIG (T)

   PURPOSE: Calculates the specific heat at constant pressure of the ideal gas at temperature, T.

8. NAME: FUNCTION CPSI (T)

   PURPOSE: Calculates $\int (C_p^o/T)\ dT$

   NOTE: Must be called once for each limit of integration.

9. NAME: FUNCTION CPHI (T)

   PURPOSE: Calculates $\int C_p^o\ dT$

   NOTE: Must be called once for each limit of integration.

10. NAME: FUNCTION DPDD (T, D)

    PURPOSE: Calculates $(\partial P/\partial \rho)_T$

11. NAME: FUNCTION DPDT (T, D)

    PURPOSE: Calculates $(\partial P/\partial T)_\rho$ of the equation of state.

12. NAME: FUNCTION FING1 (T, D)

    PURPOSE: Calculates $\int \{(R/\rho) - (1/\rho^2)\ [(\partial P/\partial T)_\rho]\}\ d\rho$

    NOTE: Must be called once for each limit of integration.

13. NAME: FUNCTION FING2 (T, D)

    PURPOSE: Calculates $\int [(P/\rho^2) - (RT/\rho)]\ d\rho$

    NOTE: Must be called once for each limit of integration.

14. NAME: FUNCTION FING3 (T, D)
PURPOSE: Calculates $\int (T/\rho^2) [(\partial^2 P/\partial T^2)_\rho]\, d\rho$
NOTE: Must be called once for each limit of integration.

15. NAME: FUNCTION TMELT (P, K)
PURPOSE: Calculates melting curve temperature for input pressure, P.
For (K = 1) - Calculates melting temperature for oxygen,
For (K = 2) - Calculates melting temperature for nitrogen.

16. NAME: SUBROUTINE TEMP (T)
PURPOSE: Converts input temperatures on the NBS-55 or IPTS-48 scales to IPTS-68.

17. NAME: SUBROUTINE WFIND (T, W)
PURPOSE: Calculates reference functions for temperature conversions for return to SUBROUTINE TEMP.

1.3 Data Initialization Subprograms

Two data initialization subprograms are provided in this package, DATAO2 and DATAN2, for the calculation of the properties of oxygen and nitrogen, respectively. The data values in these subroutines are taken from [1] and [2]. A call statement to a data initialization routine must precede the call statement to any other routine in this package. A discussion of the data held in these routines is given in the comments for each subprogram.

The data initialization routines contain a common block, /METH/M. If (M = 1), integration along isotherms is carried out through the two-phase region into the liquid. If (M = 2), the Clapeyron equation across the two-phase region is used.

.1.4 Unit Conversion Subprograms

Engineering Units

The following subprograms are designed for use in programs where the input and output arguments are in engineering units. The following units are employed for input and output variables in these routines:

Temperature--degrees Rankine
Pressure--psia
Density--lbm/ft^3
Enthalpy--Btu/lbm
Internal Energy--Btu/lbm
Entropy--Btu/lbm - R
Specific Heat at Constant Pressure--Btu/lbm - R
Specific Heat at Constant Volume--Btu/lbm - R
Sonic Velocity--feet/second

These subprograms require access to all of the subprograms listed in 3.4.1.1 and are interposed between the calling program and the subprograms of 3.4.1.1 for the purpose of converting units of input and output arguments between the system lis above and the MKS system used by the subprograms in 3.4.1.1. Unit conversion fa tors used in these subprograms are taken from REF. 3.4-2.

1. NAME: SUBROUTINE PROPB (TB, PB, DB, K, HB, SB, UB)

   PURPOSE: Accepts input arguments in engineering units in the same order as SUBROUTINE PROP, converts to the MKS units accepted by SUBROUTINE PROP, calls PROP, and converts the output arguments to engineering units for return to the calling program.

2. NAME: SUBROUTINE LPROPB (TB, PB, DB, K, HB, SB, UB)

   PURPOSE: Accepts input arguments in engineering units in the same order as SUBROUTINE LPROP, converts to MKS units, calls LPROP, and converts the output arguments to engineering units for return to the calling program.

3. NAME: SUBROUTINE VPROPB (TB, PB, DB, K, HB, SB, UB)

   PURPOSE: Accepts input arguments in engineering units in the same order as SUBROUTINE VPROP, converts to MKS units, calls VPROP, and converts the output arguments to engineering units for return to the calling program.

4. NAME: SUBROUTINE CPVTDB (TB, DB, CPB, CVB)

   PURPOSE: Accepts input arguments in engineering units in the same order as SUBROUTINE CPVTD, converts to MKS units, calls CPVTD, and converts the output arguments to engineering units for return to the calling program.

5. NAME: SUBROUTINE VSNDB (TB, PB, DB, K, WB)

   PURPOSE: Accepts input arguments in engineering units in the same order as SUBROUTINE VSND, converts to MKS units, calls VSND, and converts the output arguments to engineering units for return to the calling program.

6. NAME: SUBROUTINE TVPB (PB, TB)

   PURPOSE: Accepts input arguments in engineering units in the same order as SUBROUTINE TVP, converts to MKS units, calls TVP, and converts the output arguments to engineering units for return to the calling program.

7. NAME: FUNCTION VPNB (TB)

   PURPOSE: Accepts input temperature in degrees R, converts to degrees K, calculates vapor pressure from FUNCTION VPN, and converts the output pressure to psia for return to the using program.

8. NAME: SUBROUTINE DFNDB (TB, PB, DB, K)

   PURPOSE: Accepts input arguments in engineering units in the same order as SUBROUTINE DFND, converts to MKS units, calls DFND, and converts the output arguments to engineering units for return to the calling program.

9. NAME: SUBROUTINE PFNDB (TB, DB, PB)

   PURPOSE: Accepts input arguments in engineering units in the same order as SUBROUTINE PFND, converts to MKS units, calls PFND, and converts the output arguments to engineering units for return to the calling program.

10. NAME: FUNCTION DPDDB (TB, DB)

    PURPOSE: Accepts input temperature and density in engineering units, converts to MKS units, calculates $(\partial P/\partial \rho)_T$ with FUNCTION DPDD, and converts the output value to engineering units for return to the using program.

11. NAME: FUNCTION DPDTB (TB, DB)

    PURPOSE: Accepts input temperature and density in engineering units, converts to MKS units, calculates $(\partial P/\partial T)_\rho$ with FUNCTION DPDT, and converts the output value to engineering units for return to the using program.

12. NAME: FUNCTION TMELTB (PB, K)

    PURPOSE: Accepts input pressure in psia and K as in FUNCTION TMELT, converts pressure to atmospheres, calculates the melting temperature using TMELT, and converts the output temperature from degrees K to degrees R for return to the using program.

.1.5 Heat Transfer Parameter Calculation Subprograms

The following subprograms are used to calculate thermodynamic quantities of particular interest in heat transfer calculations. Input and output arguments are in engineering units.

1. NAME: SUBROUTINE PHIB (DB, CVB, D2B, EDB)

   PURPOSE: Calculates the energy derivative, $V\ (dP/\partial U)_V$, from the equation of state in engineering units. Use must follow calls of PROPB, CPVTDB, and DPDTB to define input arguments.

2. NAME: SUBROUTINE THETAB (DB, CPB, D1B, D2B, SHI)

   PURPOSE: Calculates specific heat input, $V(\partial H/\partial V)_p$, from the equation of state in engineering units. Use must follow calls of PROPB, CPVTDB, DPDDB, and DPDTB to define input arguments.

3. **NAME:** SUBROUTINE ALPHAB (DB, D1B, TMODB)

PURPOSE: Calculates the negative of the isothermal bulk modulus, $V(\partial P/\partial V)_T$, from the equation of state in engineering units. Use must follow calls of PROPB and DPDDB to define input arguments.

4. **NAME:** SUBROUTINE BETAB (DB, D1B, D2B, VEXB)

PURPOSE: Calculates the volume expansivity, $(1/V)\ (\partial V/\partial T)_p$, from the equation of state in engineering units. Use must follow calls of PROPB, DPDDB, and DPDTB to define input arguments.

The subprograms described in this section are listed in Appendix B of this manu in alphabetical order. Further information on the University of Idaho Programs may be found in References 3.4-3 and 3.4-4.

Section 4.0
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