34902-H002-R0-00

NASA CR-160769

ADVANCED FLIGHT DESIGN SYSTEMS

SUBSYSTEM PERFORMANCE MODELS

JUNE 1980 CONTRACT NO. NAS9-15793

(NASA-CR-160769) ADVANCED FLIGHT DESIGN SYSTEMS SUBSYSTEM PERFORMANCE MODELS. USER GUIDE: ENVIRONMENTAL ANALYSIS ROUTINE LIBRARY (TRW Defense and Space Systems Group) 138 p HC A07/MF A01 CSCL 06K G3/54
N80-31045
Unclas
28522

USER GUIDE

ENVIRONMENTAL ANALYSIS ROUTINE LIBRARY

Prepared By

K. C. Parker

J. G. Torian

Systems Engineering and Analysis

Department

TRW

DEFENSE AND SPACE SYSTEMS GROUP

34902-H002-R0-00

ADVANCED FLIGHT DESIGN SYSTEMS

SUBSYSTEM PERFORMANCE MODELS

JUNE 1980 CONTRACT NO. NAS9-15793

USER GUIDE

ENVIRONMENTAL ANALYSIS ROUTINE LIBRARY

Prepared By

K. C. Parker

J. G. Torian

Systems Engineering and Analysis

Department

TRW

DEFENSE AND SPACE SYSTEMS GROUP

PREFACE

Subsystem performance analysis is required in Flight Design to assess the capability of the Environmental Control and Life Support System (ECLSS) to support the flight requirements and define operational procedures under contingency flight conditions. Current ECLSS modeling techniques are limited in the variety of configurations and they employ batch mode computer programs execution methods. Future spacecraft will require analysis of both a greater variety and a greater number of ECLSS than for previous spacecraft programs. Improvements in the variety of configurations that can be modeled and a reduction in effort required for modeling and analysis can be accomplished by developing a modular computer program which operates interactively.

An effort has been conducted to develop a modular interactive ECLSS performance analysis tool. The final reports on the effort are included in an Executive Summary and two Technical Reports. The Technical Reports include a User Guide and a sample model.

The Executive Summary presents an overview of the effort.

This Technical Reports presents a User Guide which, due to the modular nature of the Program Library, includes a greater degree of technical detail than one for a conventional program. A sample model report supplements the User Guide and illustrates a complete ECLSS model set up and execution.

CONTENTS

CONTENTS (Continued)

LIST OF FIGURES

LIST OF FIGURES (Continued)

LIST OF TABLES

LIST OF TABLES (Continued)

1. INTRODUCTION

This report presents a user guide for a library of interactive computer routines used to develop performance analysis models of specific Environmental Control and Life Support Subsystems (ECLSS). This volume is supplemented by a second volume in this series of reports which presents an example of a complete model set up and execution.

The Environmental Analysis Routine Library (EARL) is designed such that additional ECLSS component performance routines may be added as required. To facilitate report revisions associtated with such additions a page, Table, and Figure numbering system based on the sections numbers is used. In this system the last number identifies the page, Table, or Figure number for that section whose number preceeds. This system facilitates revisions and additions without requiring complete renumbering.

2. FORMULATION OF ENVIRONMENTAL CONTROL AND LIFE SUPPORT SYSTEM ANALYTICAL MODELS

Evaluation of various Environmental Control and Life Support Systems (ECLSS) performance may be conducted by the application of the subject interactive computer program with which the user accesses a library of routines simulating the performance of various components and functions common to ECLSS. These routines are assembled with a driver routine (MAIN) to simulate the particular ECLSS under consideration. The assembled program is then loaded and executed to produce the transient performance parameters of the ECLSS under prescribed boundary conditions. The contents of the MAIN are typified on Table 2.1.

The assembly procedures for a program are shown in Figure 2.1. The master library of routines is extracted from a secure file. The user has the option to enter a MAIN routine (as for initial development of an ECLSS model), or extract a particular MAIN from his individual library (as for update/edit and/or additional studies with a previously developed ECLSS model). The extracted MAIN may be altered as part of the update/edit process. The program is then MAP'ed and the MAIN may be stored in the user's file for future use. The particular ECLSS program is then ready for execution.

The execution procedure including a variety of input/output options is shown in Figure 2.2. The component characteristic data and initial conditions may be read in from restart data stored previously or entered directly. If the user desires, the system will output a schematic of the ECLSS modeled. The user has the option to select particular nodes (component locations) to be included in tabular output or the system will default to include output for all nodes defined in the model. If plots are desired, the user simply defines the particular parameters to be plotted. Restart data may be stored for future use. Up to this point the program is executed in an interactive mode. The program then transfers to a second stage of execution.

The second stage of execution is passive in the sense the data is processed with no interaction on the part of the user except to produce hard copy of the output. The processing accesses Electrical Power System (EPS) data and/or trajectory data automatically, if required. The data can be accessed from tape, secure files, or interface to other programs resident in the system. This stage of execution produces the tabular and plot data.

Table 2.1. Typical MAIN Contents

```
      CALL START                } PROGRAM CONTROL
333   CONTINUE
      CALL STEP(....   )        } CALL TO INPUT UTILITY ROUTINES
3133  CONTINUE
      CALL LOOP(....   )        } CONVERGENCE CONTROL
      CALL PLATE(....   )       )
      ....                      } CALL TO COMPONENT ROUTINES
      CALL MIX(....   )         )
      CALL CONVRG(....   )      } CONVERGENCE CONTROL
      CALL PRINT                } PROGRAM CONTROL AND TIMING UPDATE
      GO TO 333
      END
```

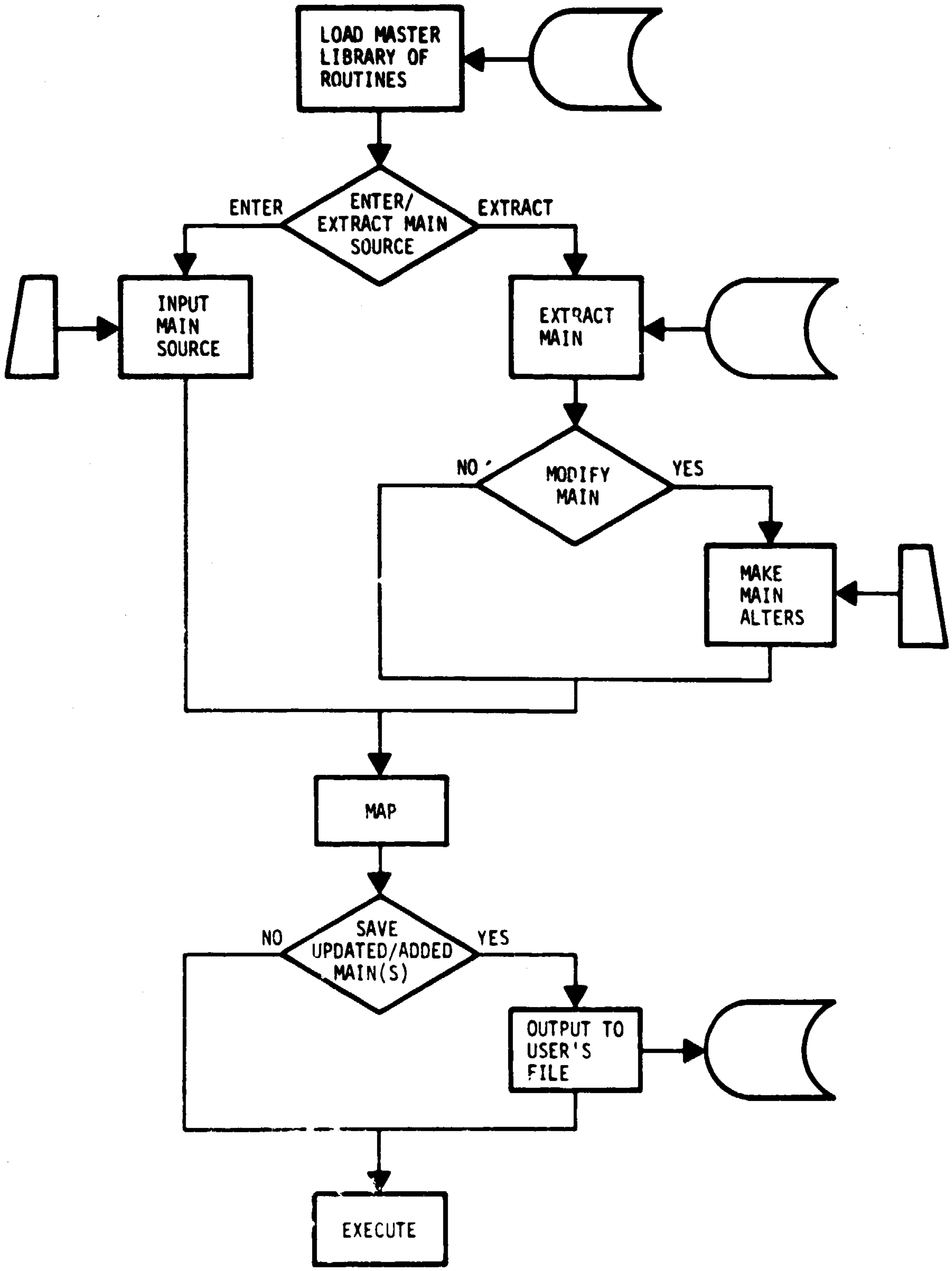


Figure 2.1. ECLSS Program Assembly Procedure

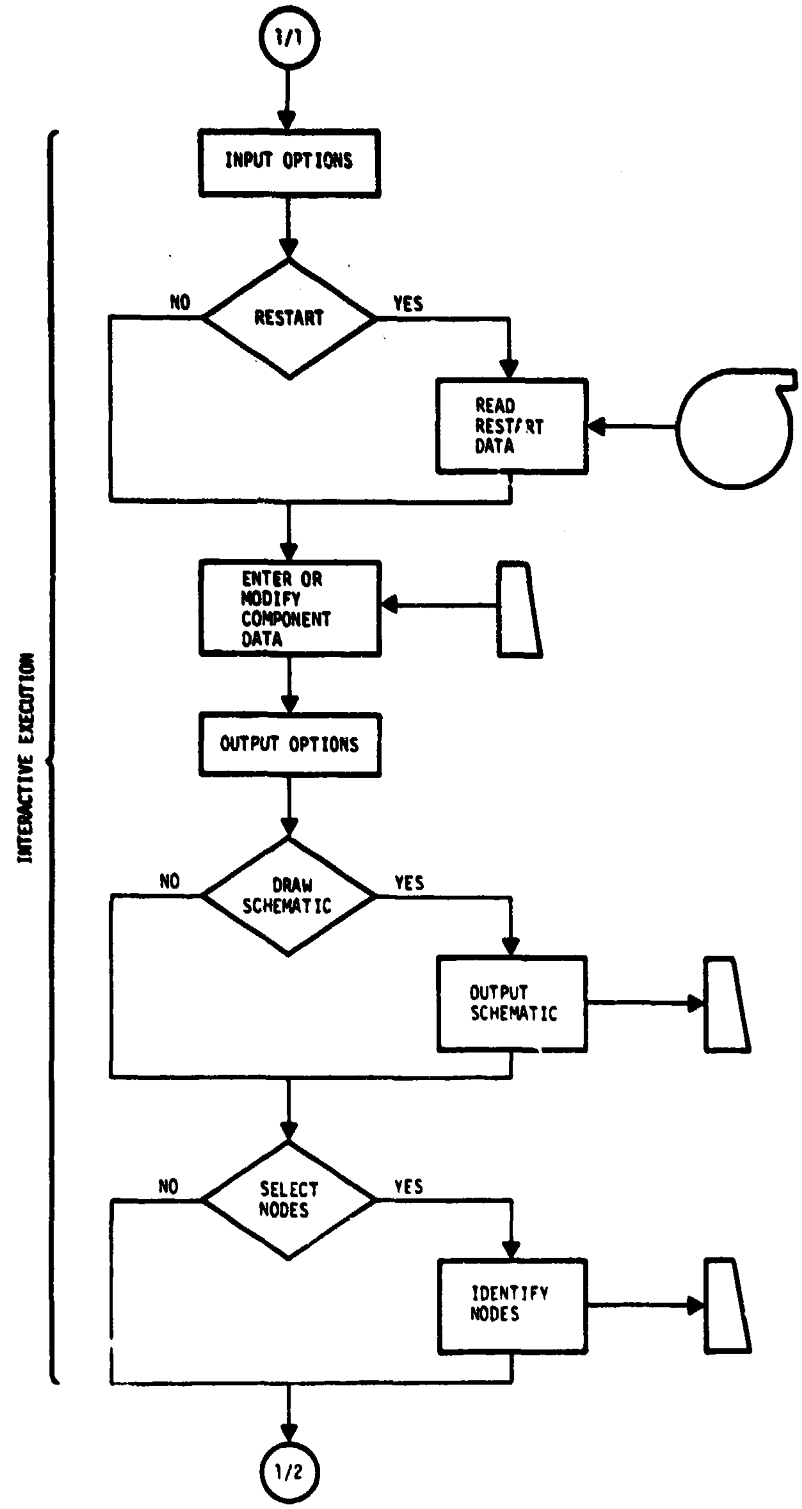


Figure 2.2. ECLSS Program Execution Procedure

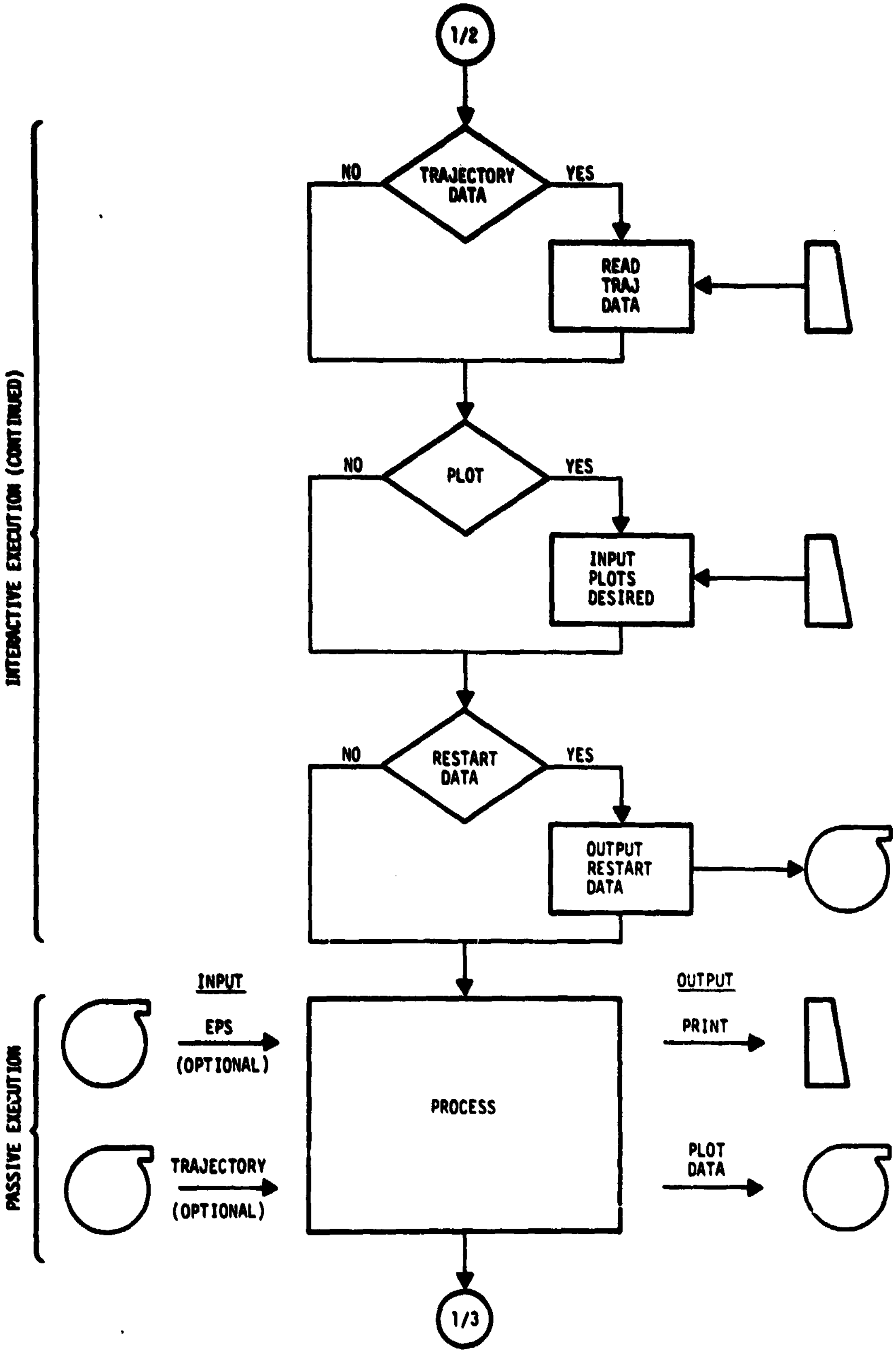


Figure 2.2. ECLSS Program Execution Procedure (Continued)

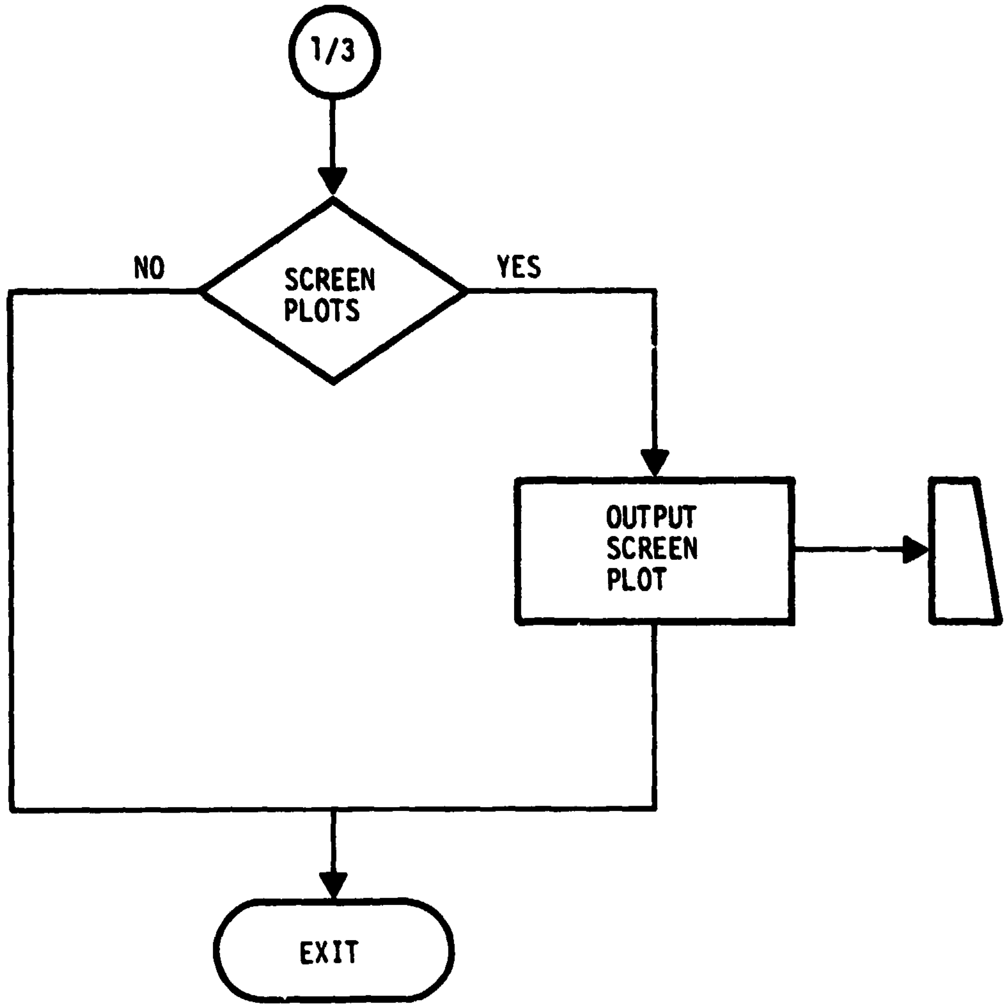


Figure 2.2. ECLSS Program Execution Procedure (Concluded)

3. LIBRARY OF ROUTINES

Two catagories of Routines make up the library. The first catagory is Referenced Routines, which are directly referenced in the user's MAIN. The second catagory includes the Unreferenced Routines which are automatically executed, but are not referenced directly by the user. All Referenced Routines are discussed in the following section. Those Unreferenced Routines with which the user may desire indirect communication are discussed in the subsequent section. Unreferenced Routines also include a variety of Control, Computational, and Support Routines.

3.1 REFERENCED ROUTINES

This section presents a description of the functions, application, and parameters associated with those Library Routines which are directly referenced in the user's MAIN. These include Program Control Routines, Component Performance Routines, and Input Utility Routines. The following discussion includes the reference procedure, interactive communication, and a cross reference to the various parameters for dynamic communication.

3.1.1 Program Control Routines

Four Routines are used for basic program control. These control Routines are summarized on Table 3.1.1.1. Routines START and PRINT are mandatory as they control initialization, communication with boundary condition routines, timing, and output. Routines LOOP and CONVRG are optional depending on the configuration of the ECLSS model.

Control and timing parameters are entered through interactive displays during active execution of START and PRINT. It may be desirable to dynamically communicate with the timing parameters during passive execution. This type of communication is affected by entries in the user's MAIN. The following Control Routine descriptions include information on the interactive displays as well as cross reference to the timing parameters. Examples of dynamic communication are included in the sample model text.

Table 3.1.1.1. Summary of Program Control Routines

START	Initialization control
PRINT	Boundary Condition Routine communication, timing control, and output control
LOOP	Timing control for first referenced ECLSS component in closed loop system
CONVRG	Convergence control in closed loop system

3.1.1.1 Routine START

A flow diagram of the functions of Routine START is given on Figure 3.1.1.1.1.

A reference procedure is

CALL START

for program execution initialization. The call to Routine START is the mandatory first executable statement in the MAIN.

Interactive communication with the initialization parameters is through console displays as shown on Figures 3.1.1.1.2 and 3.1.1.1.3.

The cross reference to initialization parameters is shown on Table 3.1.1.1.1.

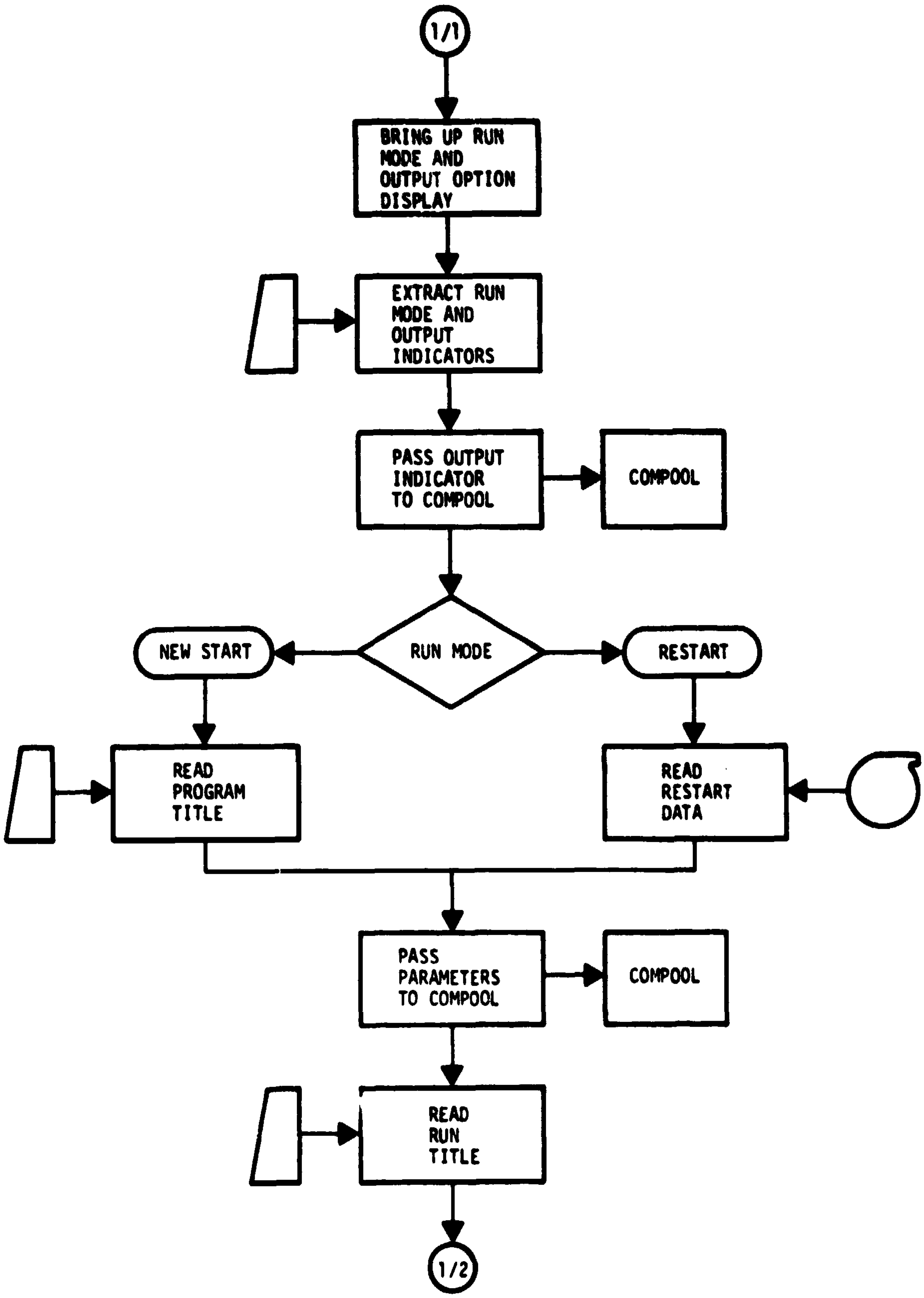


Figure 3.1.1.1.1. Routine START

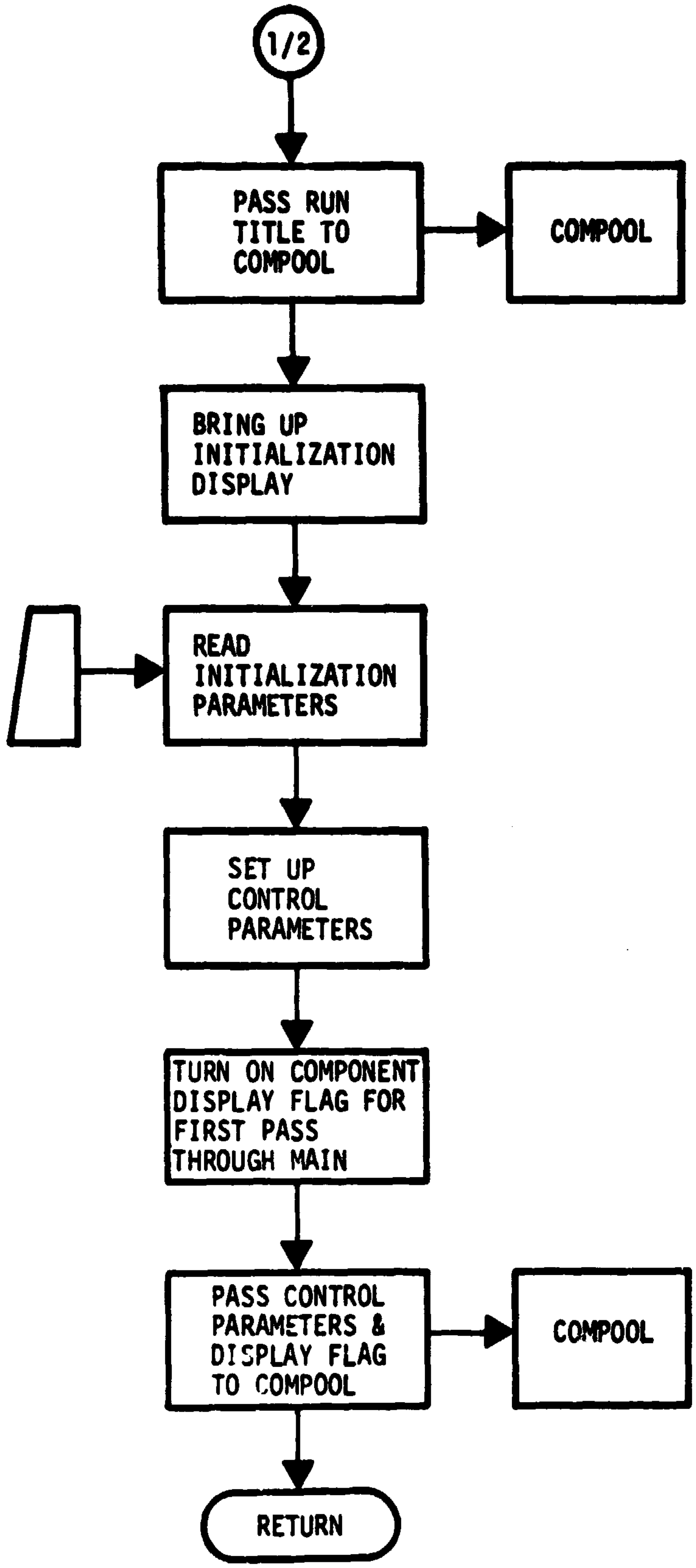


Figure 3.1.1.1.1. Routine START (Concluded)

```
****************************
 FORTRAN ENVIRONMENTAL
   ANALYSIS ROUTINES
    CONTROL DISPLAY
ENTER RUN MODE (INTEGER)
   NEW START = 0
   RESTART   = 1
ENTER OUTPUT OPTION
   NO RESTART TAPE       = 0
   WRITE BEGINNINTG RESTART TAPE = 1
   WRITE ENDING RESTART TAPE = 2
****************************
```


Figure 3.1.1.1.2. Typical Run Mode Option Display

```
******************************************
             INITIALIZATION CONTROL
         TFEAR
         TEST TFEAR
ITEM
 1    COMP. TIME INCREMENT          .010 HR
 2    START TIME                    .000 HR
 3    STOP TIME                     .050 HR
 4    PRINT INCREMENT               .010 HR
 6    INITIAL SYSTEM TEMP        521.100 DEG
******************************************
```

Figure 3.1.1.1.3. Typical Initialization Data Display

Table 3.1.1.1.1. Dynamic Communication Cross Reference for Program Control

VARIABLE	SYMBOL	UNITS	STORAGE	TYPE	COMMON
Compute time increment	ΔT	HRS	DELT*	R	TIMES
Start Time	t_o	HRS	TIME	R	TIMES
Stop Time	-	HRS	TSTOP	R	TIMES
Print increment	-	HRS	PRNT	R	TIMES
Initial System Temp.	-	DEG	TEMP†	R	TIMES
Simulated Time	t	HRS	TIME	R	TIMES
Present Time index	-	INTEGER	L	I	MEAT
Previous Time index	-	INTEGER	K	I	MEAT

*Δt is stored in DELTO2 also. DELT is set equal to zero for first pass through MAIN at t_o.

†Default value for component temperatures.

3.1.1.2 Routine PRINT

A flow diagram of the functions of Routine PRINT is given on Figure 3.1.1.2.1.

The reference procedure is

CALL PRINT

for program control. The call to PRINT is the last Routine call in the timing loop.

Basic interactive communication is through the console display shown on Figure 3.1.1.2.2. If the MAIN references component simulation routines which imply consumables usage and/or orbital heating data is required the display shown on Figure 3.1.1.2.2 will be preceded by initialization and control data displays for these boundary condition functions. The Boundary Condition Routines are discussed in Section 3.2.1. Selection of the various output options will bring the various Output Routines and their associated control displays into effect. The Output Routines are discussed in Section 3.2.2.

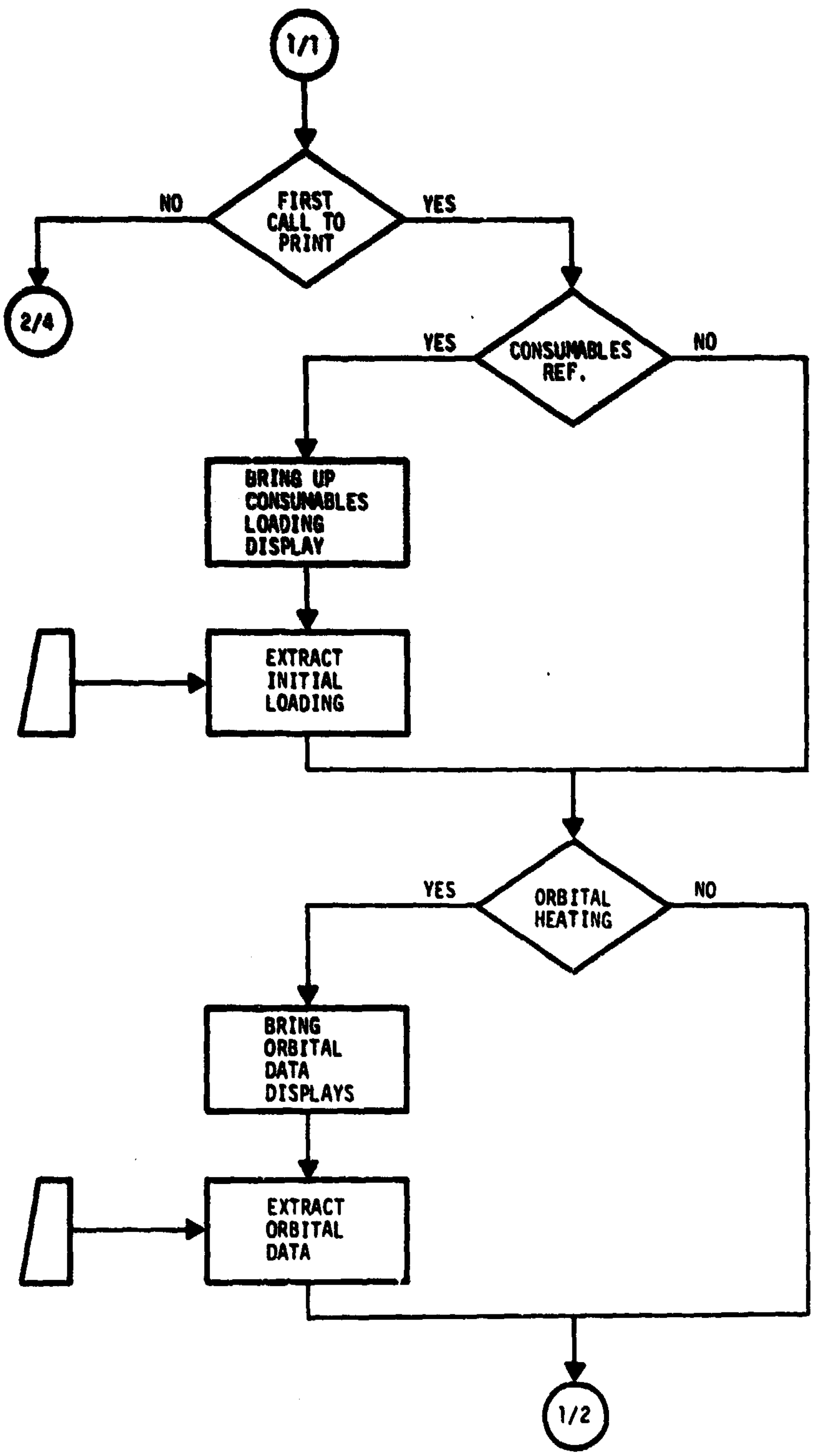


Figure 3.1.1.2.1. Routine PRINT

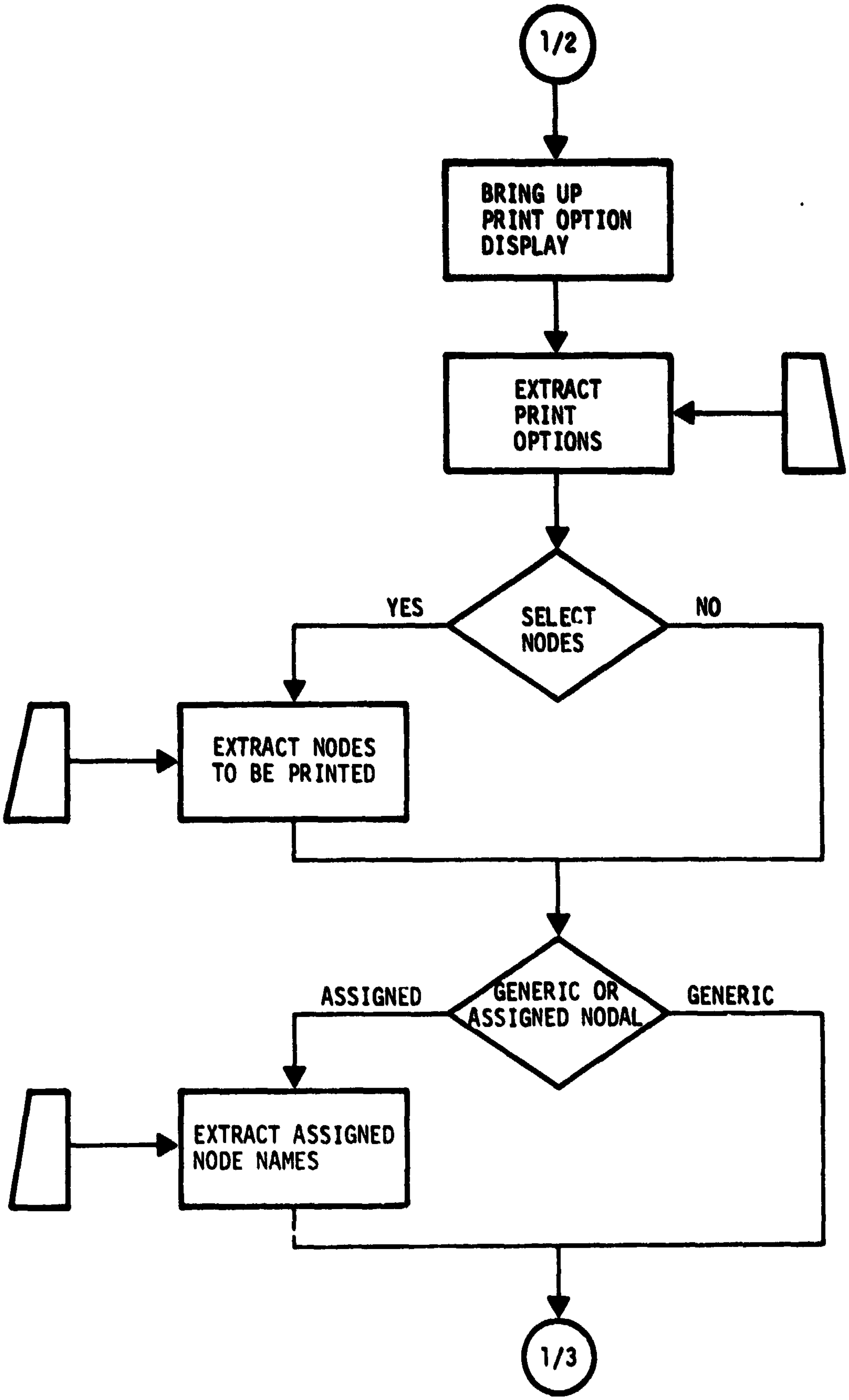


Figure 3.1.1.2.1. Routine PRINT (Continued)

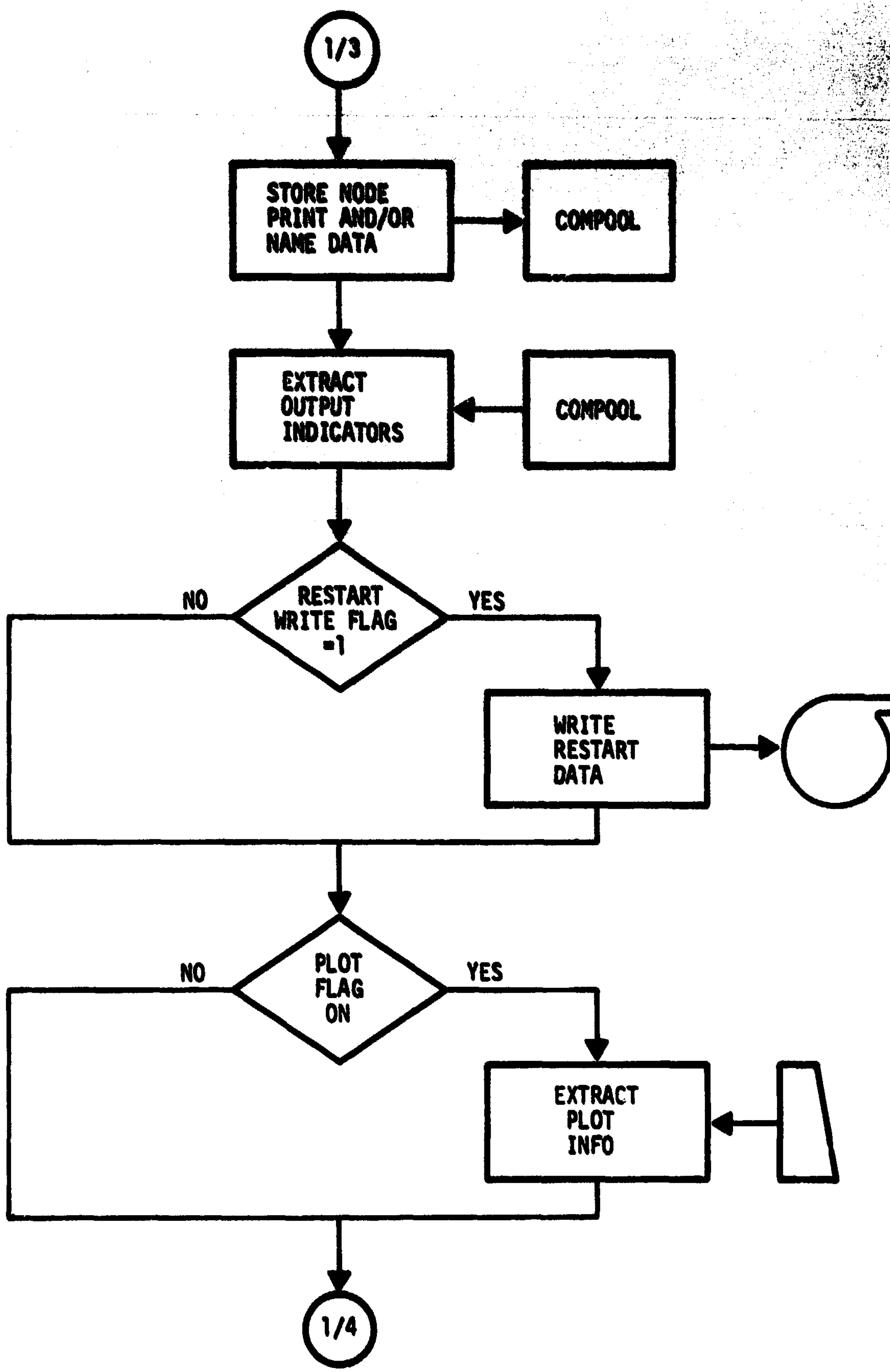


Figure 3.1.1.2.1. Routine PRINT (Continued)

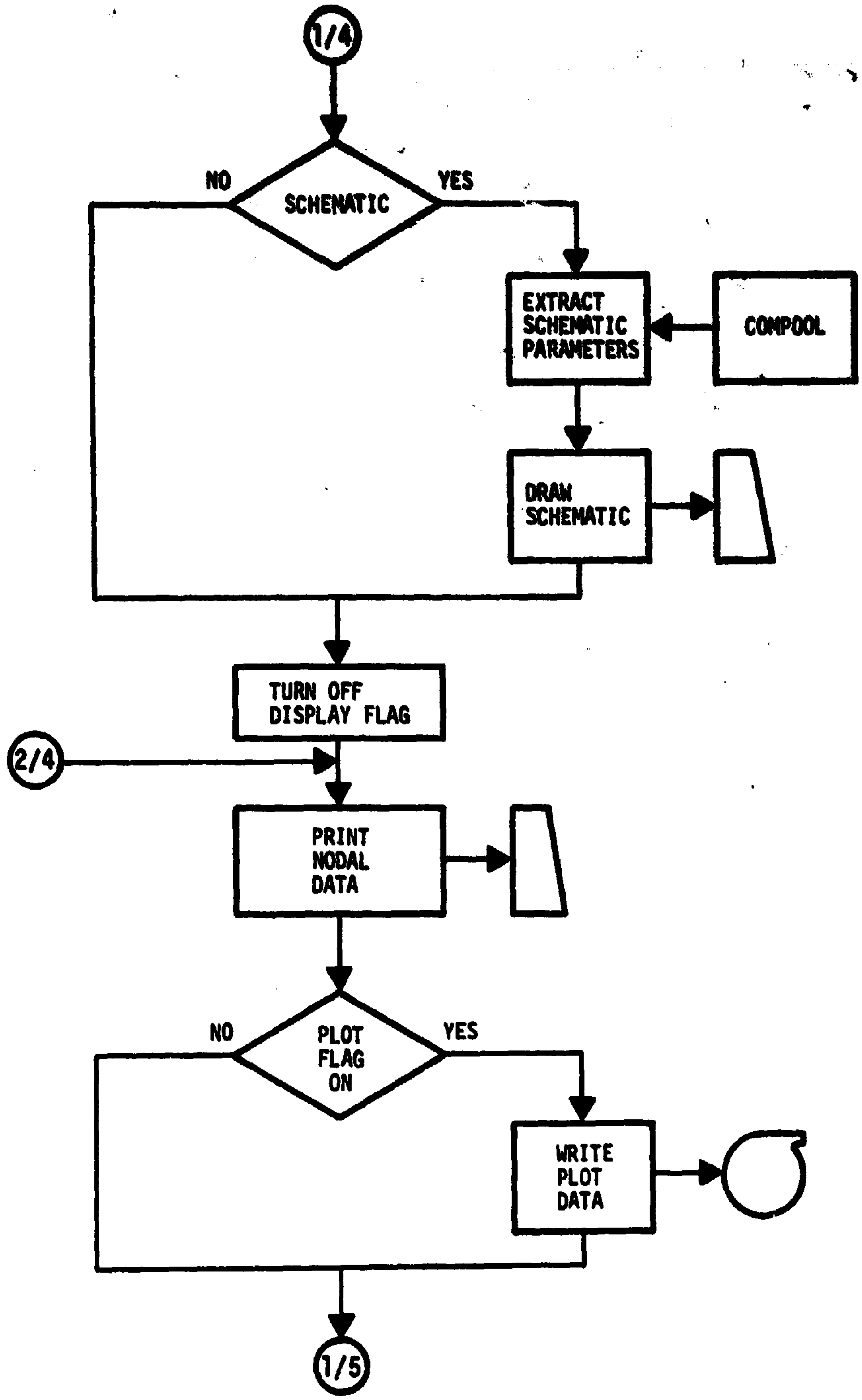


Figure 3.1.1.2.1. Routine PRINT (Continued)

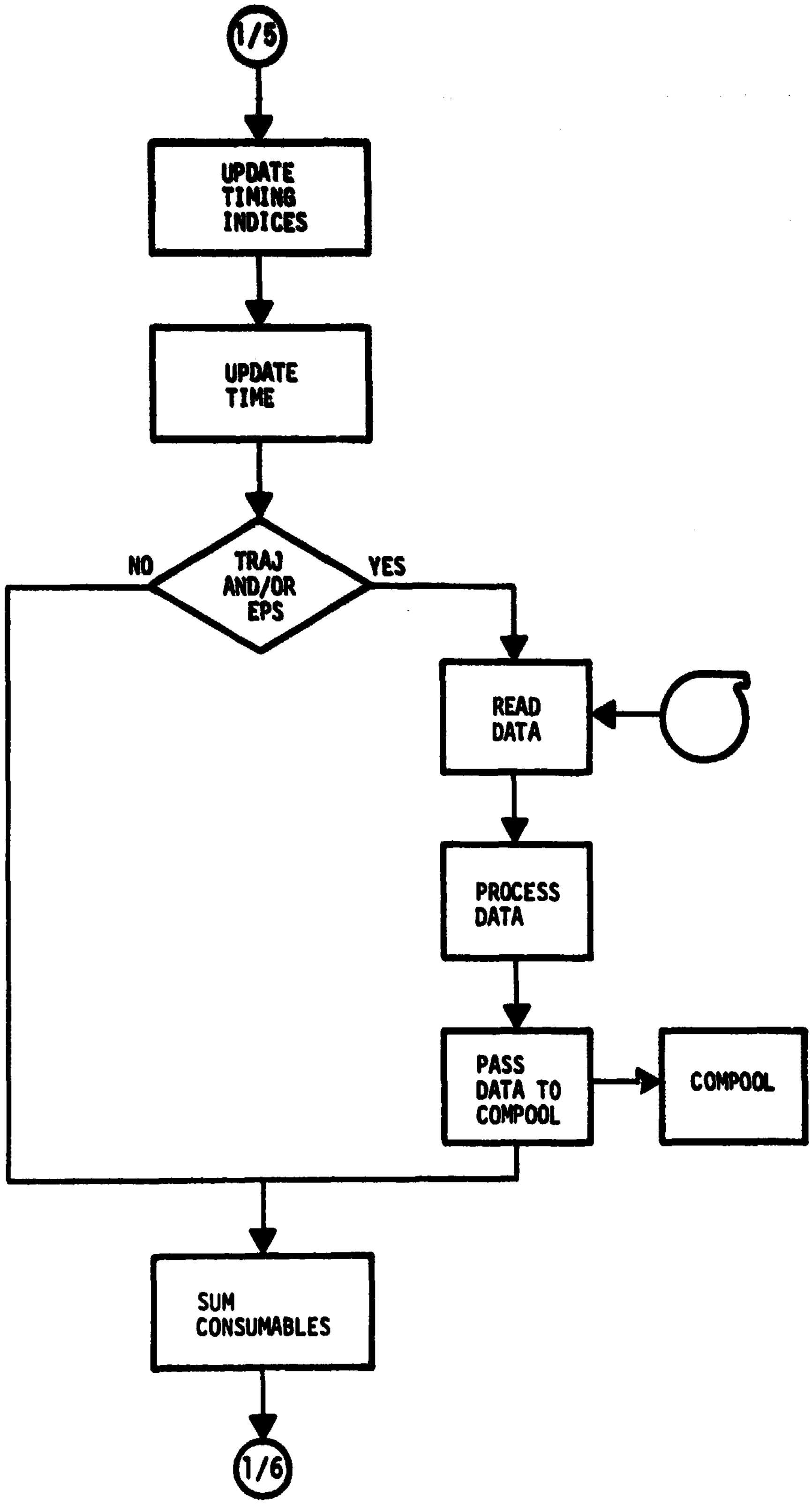


Figure 3.1.1.2.1. Routine PRINT (Continued)

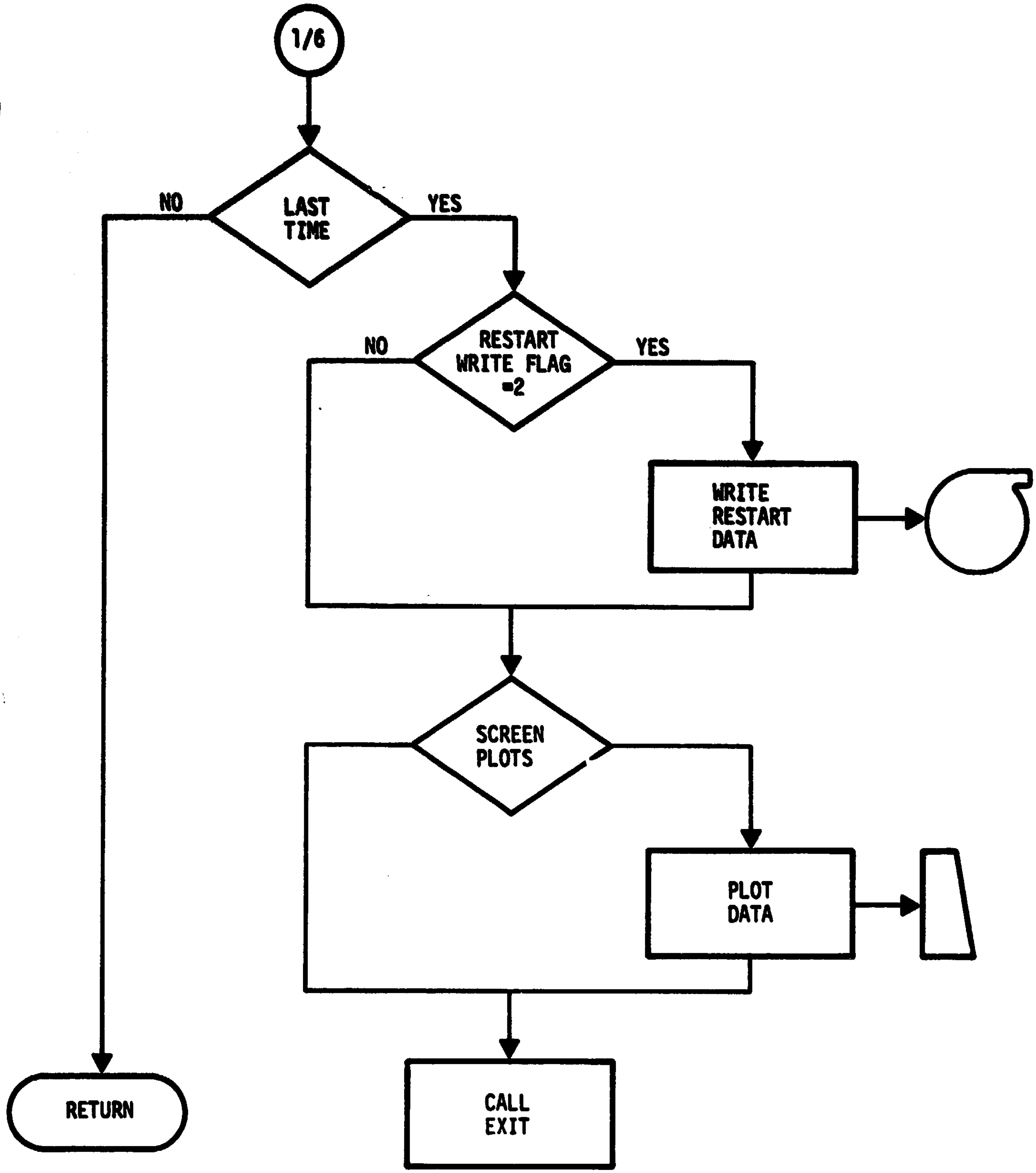


Figure 3.1.1.2.1. Routine PRINT (Concluded)

```
**************************************
          PRINT OPTION
            DISPLAY
                                FLAG
 ITEM    OPTION                STATUS
  1      SELECT NODES            0
  2      PLOTS                   1
  3      SCHEMATIC               0
**************************************
```


Figure 3.1.1.2.2. Typical Print Option Display

3.1.1.3 Routine LOOP

Special timing control is required for the nodal designation i associated with the first referenced ECLSS component in a closed loop system. Routine LOOP provides this control.

The reference procedure

```
CALL LOOP(I)
```

which precedes the call to a component simulation routine with the nodal designation I.

There is no further user communication with the functions or parameters of this Routine. The use of this routine is mandatory for closed loop systems.

3.1.1.4 Routine CONVRG

Routines LOOP and CONVRG are used in conjunction for a closed loop system to control iteration to a prescribed convergence tolerance. A typical application for iteration about the node i follows:

```
NN1  CONTINUE
     CALL LOOP(I)
     CALL PLATE(I,J)      \
          .                |
          .                |  Typical component
          .                |  simulation calls
     CALL EVAP(M,I)       /
     CALL CONVRG(I,TOL,MAX,$NN2,$NN1)
NN2  CONTINUE
```

The call to CONVRG compares the inlet fluid temperature at node I used in the first component call to the outlet fluid temperature at node I calculated by the last component call. If the two temperatures agree within the tolerance specified by the value of TOL, a return to statement number NN2 in the MAIN is made. Whereas, if the agreement is not in effect, the value of the temperature at node I for the first component call will be modified and the return will be to statement number NN1 in the MAIN. The parameter MAX is a user selected maximum number of non-converging iterations before CONVRG will terminate the execution.

There is no further user communication with the functions of Routine CONVRG. The use of Routine CONVRG is optional.

3.1.2 Component Performance Routine

This section provides information on the simulation of various ECLSS components through application of the Library of Component Routines. This Library and a brief description of their function is summarized on Table 3.1.2.1.

Initial characteristics of the various components are entered or updated through an interactive display during active execution. It is often desirable to dynamically update or access various characteristics and variables during the passive execution. This latter updating is accomplished by entries in the user's MAIN which communicate with the subject routine variables. The following component routine descriptions include information on the interactive display as well as cross reference data for dynamic communication. Several simple dynamic updating examples are included in the sample model.

Table 3.1.2.1. Summary of ECLSS Component Performance Routines

PLATE	Forced cooled internal heat generating equipment
EVAP	Evaporator
SPLIT	Branching of coolant flow
MIX	Mixing of coolant legs into a single junction
MOD	Controlled proportioning of flow between two branches
RAD	Radiator panel
EXCH	Counterflow and parallel flow heat exchanges
HEATER	Controlled fluid line heater
ATMO	Atmospheric compartment (Cabin)
LIOH	Carbon Dioxide removal with Expendable Lithium Hydroxide
CONXG	Condensing Heat Exchanger, condensing side
CONXI	Condensing Heat Exchanger, interface (sink) side

3.1.2.1 Routine PLATE

The transient performance of forced cooled internal heat generating equipment is simulated by Routine Plate. The routine is an adaptive transfer function for the fluid flow segment from node i to j which processes the following equations.

$$(mC)_i \frac{d\, T_{c_i}}{dt} = Q_{I_i} - Q_c - (UA)_i\, \Delta T_{\ell m} \;.$$

and

$$(WC_p)_i\, (T_j - T_i) = (UA)_i\, \Delta T_{\ell m} \;.$$

where

$$\Delta T_{\ell m} = \frac{(T_{c_i} - T_i) - (T_{c_i} - T_j)}{\ell n \left[\dfrac{T_{c_i} - T_i}{T_{c_i} - T_j} \right]} \;.$$

The net loss of heat due to thermal coupling to m nodes defined by $K(\ell)$ is given by

$$Q_c = \sum_{\ell=1}^{m} C_{iK(\ell)}\, (T^a_{c_i} - T^a_{cK(\ell)}) ,$$

where

$$C_{iK(\ell)} = (UA)_{iK(\ell)} \;,$$

and

$$a = 1$$

for conduction or convective coupling, and,

$$C_{iK(\ell)} = \sigma\epsilon A F_{iK(\ell)} ,$$

and

$$a = 4$$

for radiation coupling of node i to $K(\ell)$.

The reference procedure is

CALL PLATE(I,J)

to process the transfer function through node I to J.

Interactive communication with the parameters and functions of the simulated component is through a console display as illustrated on Figure 3.1.2.1.1. An integer value greater than zero assigned to item 6, 7, and/or 8 will extend the communication upon exit from this display as follows:

<u>ITEM 6 Atmospheric Coolant</u>. The atmospheric parameters shown on Figure 3.1.2.1.2 will be put through to node J. This feature is used for continuity and mass conservation when PLATE is used as a component simulation.

<u>ITEM 7 EPS Data Assignment</u>. The interactive display shown on Figure 3.1.2.1.3 is used to assign word numbers in the EPS data array to Q_{I_i}. (See Routine REPS.)

<u>ITEM 8 Thermal Coupling</u>. The interactive display shown on Figure 3.1.2.1.4 is used to thermally couple node I to m nodes defined by $K(\ell)$. The 100 series nodes are used for convective coupling. The 200 series nodes are used for radiation coupling. To thermally couple node I to node 8 by conduction or convection assign 108 as the coupling code. Assignment of a 208 as the coupling will result in node I being coupled

to node 8 by radiation. Note the respective units of the coupling values as displayed.

The cross reference to Routine PLATE parameters is shown on Table 3.1.2.1.1. Additional information related to communication with the Thermal Coupling parameters is given in the section on Routine COUPL.

```
**************************************************
                      NODE NUMBER  6
                        COLD PLATE
ITEM
1      THERMAL CAPACITY          150.000     BTU/DEG
2      OVERALL HEAT TRANSFER
          COEF.                 2500.000     BTU/HR DEG
3      COOLANT FLOW RATE        1490.484     BTU/HR DEG
4      INITIAL COMPONENT
          TEMP.                  521.000     DEG
5      INITIAL COOLANT
          INLET TEMP.            498.474     DEG
6      ATMOSPHERIC COOLANT             0     INTEGER
             0 = NO
             1 = YES
7      EPS DATA ASSIGNMENT             0     INTEGER
             0 = NO
             1 = YES
8      THERMAL COUPLING                0     INTEGER
             0 = NO
             1 = YES
       INLET NODE NUMBER          OUTLET NODE NUMBER
               6                           7
**************************************************
```

Figure 3.1.2.1.1. Typical Cold Plate Interactive Display

```
**********************************************
            ATMOSPHERIC COOLANT
             PROPERTIES FOR
             NODE NUMBER    3
            INFORMATION ONLY
              NOT EDITABLE
PARTIAL PRESSURE OF WATER            .154       PSIA
PARTIAL PRESSURE OF NITROGEN       11.600       PSIA
PARTIAL PRESSURE OF OXYGEN          3.100       PSIA
PARTIAL PRESSURE OF CARBON           .097       PSIA
  DIOXIDE
ATMOSPHERIC PRESSURE               14.700       PSIA
**********************************************
```

Figure 3.1.2.1.2. Typical Atmospheric Property Display

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

    EPS DATA ASSIGNMENT
            FOR
      NODE NUMBER    6
           WORD
 ITEM     NUMBER
   1          38      INTEGER
   2          39      INTEGER
   3          40      INTEGER
****************************
```


Figure 3.1.2.1.3. Typical EPS Data Assignment Interactive Display

```
****************************************
          THERMAL COUPLING DATA
            FOR NODE NO.   22
           COUPLED TO 1 NODES
        TYPE OF HEAT TRANSFER AND
 ITEM   COUPLING NODE NUMBER CODE    VALUE
  1               108                 .500
 VALUES ARE:
     BTU/HR FOR SERIES 100 COUPLING
     BTU/HR DEG**4 FOR SERIES 200 COUPLING
****************************************
```

Figure 3.1.2.1.4. Typical Thermal Coupling Interactive Display

Table 3.1.2.1.1. Dynamic Communication Cross Reference for Routine PLATE Parameters at Node I

VARIABLE	SYMBOL	UNITS	STORAGE	TYPE	COMMON
Component temperature	T_{c_i}	DEG	$P(I,X^{\dagger})$	R	MEAT
Fluid inlet temperature	T_i	DEG	$F(I,X^{\dagger})$	R	MEAT
Thermal capacitance	$(MC)_i$	BTU/DEG	C(I,1)	R	MEAT
Heat transfer coefficient	$(UA)_i$	BTU/HR DEG	C(I,2)	R	MEAT
Coolant flow rate	$(WC_p)_i$	BTU/HR DEG	C(I,3)	R	MEAT
Internal heat generation	Q_{I_i}	BTU/HR	C(I,4)	R	MEAT
Specific heat of gas mixture	-	BTU/LB DEG	C(I,5)	R	MEAT
Partial pressure of H_2O	-	PSI	C(I,6)	R	MEAT
N_2	-	PSI	C(I,7)	R	MEAT
O_2	-	PSI	C(I,8)	R	MEAT
CO_2	-	PSI	C(I,9)	R	MEAT
Pressure of gas mixture	-	PSI	C(I,10)	R	MEAT
Coupling values 1st ref. node	$C_{iK(1)}$	*	C(I,15)	R	MEAT
2nd ref. node	$C_{iK(2)}$	*	C(I,16)	R	MEAT
.	.	.	.	.	.
.	.	.	.	.	.
.	.	.	.	.	.
6th ref. node	$C_{iK(6)}$	*	C(I,20)	R	MEAT
Number of coupled nodes	m	INTEGER	IC(I,4)	R	MEAT
Coupling node number 1st ref.	K(1)	INTEGER	IC(I,5)	R	MEAT
2nd ref.	K(2)	INTEGER	IC(I,6)	R	MEAT
.	.	.	.	.	.
.	.	.	.	.	.
.	.	.	.	.	.
6th ref.	K(6)	INTEGER	IC(I,10)	R	MEAT

†X = L present value
X = K previous value

*BTU/HR DEG for convection and conduction coupling (series 100).
$BTU/HR\ DEG^4$ for radiation coupling (series 200).

3.1.2.2 Routine EVAP

The transient performance of an evaporator used as an ultimate heat sink is simulated by Routine EVAP, The routine is a transfer function for the fluid flow segment from node i to j which processes the following equations.

$$(WC_p)_i \; (T_j - T_i) = (UA)_i \; \Delta T_{\ell m} \; ,$$

where

$$\Delta T_{\ell m} = \frac{T_j - T_i}{\ell n \left[\dfrac{T_s - T_i}{T_s - T_j} \right]} \; .$$

The media evaporated over the time span a to b is calculated as

$$M = \frac{1}{h_{fg}} \int_a^b (WC_p)_i \; (T_j - T_i) \; dt$$

and is withdrawn from a source n as prescribed by the user.

The simulation assumes the media to be at the saturation temperature T_s and does not account for sensible heat requirements to achieve this temperature.

The reference procedure is

```
CALL EVAP(I,J)
```

to process the transfer function through node I to J.

Interactive communication with the parameters and functions of the simulated component is through a console display as illustrated on Figure 3.1.2.2.1. Reference to this Routine will automatically bring up the consumables source initial loading display as illustrated on Figure 3.1.2.2.2. This display is brought up immediately prior to passive execution and includes all referenced consumables sources as well as the source referenced through a particular call to EVAP.

The cross reference to Routine EVAP parameters is shown on Table 3.1.2.2.1. Additional information related to source assignment and initial loading quantity for the evaporating media is given in the section on Routine CONSUM.

```
*************************************************
                        NODE NUMBER  5
                          EVAPORATOR
ITEM
1      HEAT OF VAPORAZATION        1060.000  BTU/LB
2      OVERALL HEAT
        TRANSFER COEF.             3000.000  BTU/HR DEG
3      COOLANT FLOW RATE           1000.000  BTU/HR DEG
4      SATURATION TEMP              495.000  DEG
5      INITAL FLUID
        INLET TEMP                     .000  DEG
6      CONSUMABLE                        1  INTEGER .LE. 10
       1 = POTABLE WATER
       2 = WATER
       3 = AMMONIA
       4 = OTHER
7      TANK ASSIGNMENT                   6  INTEGER .LE. 20
  INLET NODE NUMBER       OUTLET NODE NUMBER
            5                       6
*************************************************
```


Figure 3.1.2.2.1. Typical Evaporator Interactive Display

****

CONSUMABLES
SOURCES

ITEM	SOURCE NO.	TYPE OF, CONSUMABLE	UNIT	INITIAL LOADING
1	1	NITROGEN	LBS	.000
2	2	OXYGEN	LBS	.000
3	3	LITHIUM HYDROXIDE	LBS	.000
4	4	WATER	LBS	.000
5	5	ELECTRIC POWER	WATT HRS	.000
6	6	POTABLE WATER	LBS	.000

****

Figure 3.1.2.2.2. Typical Consumables Source Display

Table 3.1.2.2.1. Dynamic Communication Cross Reference for the Routine EVAP Parameters at Node I

VARIABLE	SYMBOL	UNITS	STORAGE	TYPE	COMMON
Saturation temperature	T_s	DEG	$P(I,X^{\dagger})$	R	MEAT
Fluid inlet temperature	T_i	DEG	$F(I,X^{\dagger})$	R	MEAT
Heat of vaporation	h_{fg}	BTU/LB	C(I,1)	R	MEAT
Heat transfer coefficient	$(UA)_i$	BTU/HR DEG	C(I,2)	R	MEAT
Coolant flow rate	$(WC_p)_i$	BTU/HR DEG	C(I,3)	R	MEAT
Consumables type	-	INTEGER	IC(I,3)*	I	MEAT
Tank (source) number	n	INTEGER	IC(I,4)	I	MEAT
Media consumed	M	LBS	CONTOT(N)	R	CONS

†X = L present value
X = K previous value

*The consumables type is used only for print out heading control and is transferred to IAMCON(N) during initialization. IAMCON(N) is stored in the common CONS. (See Routine CONSUM.)

3.1.2.3 Routine SPLIT

The splitting of flow at node i in n branches with a fixed flow proportion $m_{j(K)}$ at each node j(K) is simulated by Routine SPLIT. The routine processes the equations

$$\left.\begin{aligned}(WC_p)_{j(K)} &= m_{j(K)}\,(WC_p)_i \\ T_{j(K)} &= T_i\end{aligned}\right\}\quad K = 1,n$$

The reference procedure is

CALL SPLIT(I,N)

to split node I onto N branches.

Interactive communication with the parameters and functions of the branching is through a console display as shown on Figure 3.1.2.3.1. An integer value of unity assigned to item 4 will bring up the Atmospheric Property display as shown on Figure 3.1.2.1.2. The atmospheric properties at node I will be put through to the branches j(K).

The cross reference to Routine SPLIT parameters is shown on Table 3.1.2.3.1.

```
********************************
         NODE NO.   12
            BRANCH
      SPLIT INTO    2 LEGS
        LEG NODE       FLOW
 ITEM     NUMBER     PROPORTION
   1        13           .500
   2        17           .500
 3  ATMOSPHERIC COOLANT   0 INTEGER
            0 = NO
            1 = YES
 4  COOLANT FLOW RATE    769.090  BTU/HR DEG
 5  COOLANT INLET TEMP   520.317  DEG
********************************
```

Figure 3.1.2.3.1. Typical Branching of Flow Interactive Display

Table 3.1.2.3.1. Dynamic Communication Cross Reference for the Routine SPLIT Parameters at Node I

VARIABLE	SYMBOL	UNITS	STORAGE	TYPE	COMMON
Fluid inlet temperature	T_i	DEG	F(I,X†)	R	MEAT
Coolant flow rate	$(WC_p)_i$	BTU/HR DEG	C(I,3)	R	MEAT
1st branch node number	j(1)	INTEGER	IC(I,2)	I	MEAT
2nd branch node number	j(2)	INTEGER	IC(I,3)	I	MEAT
.	.	.	.	.	.
.	.	.	.	.	.
.	.	.	.	.	.
9th branch node number	j(9)	INTEGER	IC(I,10)	I	MEAT
1st branch flow proportion	$M_{j(1)}$	FRACTION	C(I,12)	R	MEAT
2nd branch flow proportion	$M_{j(2)}$	FRACTION	C(I,13)	R	MEAT
.	.	.	.	.	.
.	.	.	.	.	.
.	.	.	.	.	.
9th branch flow proportion	$M_{j(9)}$	FRACTION	C(I,20)	R	MEAT
Specific heat of gas mixture	-	BTU/LB DEG	C(I,5)	R	MEAT
Partial pressure of H_2O	-	PSI	C(I,6)	R	MEAT
N_2	-	PSI	C(I,7)	R	MEAT
O_2	-	PSI	C(I,8)	R	MEAT
CO_2	-	PSI	C(I,9)	R	MEAT
Pressure of gas mixture	-	PSI	C(I,10)	R	MEAT

†X = L present
X = K previous

3.1.2.4 Routine MIX

The mixing of flow from n legs defined by the nodes j(K) into a single node i is simulated by Routine MIX. The routine processes the equations

$$(WC_p)_i = \sum_{K=1}^{n} (WC_p)_{j(K)}$$

$$T_i = \frac{\sum_{K=1}^{n} (WC_p)_{j(K)} \, T_{j(K)}}{(WC_p)_i}$$

The reference procedure is

CALL MIX(I,N)

to mix N legs into the junction I.

Interactive communication with the parameters and functions of the mixing is through a console display as shown on Figure 3.1.2.4.1. An integer value of unity assigned to item 4 will result in processing of the atmospheric properties at the N nodes into the node I.

The cross reference to Routine MIX parameters is shown on Table 3.1.2.4.1.

```
***************************************
              NODE NO.  5
               JUNCTION
            MIXING  3 NODES
              MIXED NODE
   ITEM          NUMBER          UNIT
    1              11           INTEGER
    2              16           INTEGER
    3              20           INTEGER
    4   ATMOSPHERIC COOLANT   0    INTEGER
         0 = NO
         1 = YES
***************************************
```

Figure 3.1.2.4.1. Typical Junction Interactive Display

Table 3.1.2.4.1. Dynamic Communication Cross Reference for Routine MIX at Node I

VARIABLE	SYMBOL	UNITS	STORAGE	TYPE	COMMON
Fluid temperature at junction	T_i	DEG	$F(I,X^{\dagger})$	R	MEAT
Coolant flow rate at junction	$(WC_p)_i$	BTU/HR DEG	C(I,3)	R	MEAT
1st mixing node number	J(1)	INTEGER	MIXUM(M)*	I	MIXUP
2nd mixing node number	J(2)	INTEGER	MINUM (M+1)	I	MIXUP
.	.	.	.	.	.
.	.	.	.	.	.
.	.	.	.	.	.
nth mixing node number	J(n)	INTEGER	MIXUM (M+N-1)	I	MIXUP
Specific heat of gas mixture	-	BTU/LB DEG	C(I,5)	R	MEAT
Partial pressure of H_2O	-	PSI	C(I,6)	R	MEAT
N_2	-	PSI	C(I,7)	R	MEAT
O_2	-	PSI	C(I,8)	R	MEAT
CO_2	-	PSI	C(I,9)	R	MEAT
Pressure of gas mixture	-	PSI	C(I,10)	R	MEAT

†X = L present
X = K previous

*The value of M is dynamically assigned during initialization and is one greater than the total number of mixed nodes referenced prior to a particular call to MIX. M can be determined as the location of the value I in the IMIX array. That is, IMIX(M) = I. IMIX is in the common MIXUP.

3.1.2.5 Routine MOD

The branching of flow at node i onto two legs defined by nodes j and n such that the flow proportioning f_j and f_n is modulated to maintain a fixed temperature T_c at a control node m is simulated by routine MOD. The routine processes equations similar to Routine SPLIT except that the flow proportioning is dynamic, such that

$$\Delta f_j = g(T_m - T_c)$$

where Δm_j is a change in the flow proportioning factor from the previous calculation, g is a proportional gains, and

$$f_n = 1 - f_j \ .$$

A maximum and minimum value for f_j is prescribed by the user. Note that a positive gains will favor node j if T_n is greater than T_c (i.e., node j in this case is assumed to be the cooling leg).

The reference procedure is

```
CALL MOD(I)
```

to modulate the branching of flow at node I.

Interactive communication with the parameters and functions of the modulation is through a console display as shown on Figure 3.1.2.5.1. An integer value of unity assigned to item 11 will bring up the atmospheric properties display for node I (see Figure 3.1.2.1.2) and put through the properties to the branches J and N.

The cross reference to Routine MOD parameters is shown on Table 3.1.2.5.1.

```
******************************************************************
                       NODE NUMBER 10
                      MODULATION VALUE
ITEM   DESCRIPTION                         VALUE     UNIT
 1*    LEG 1 NODE NUMBER                      12    INTEGER
 2*    LEG 2 NODE NUMBER                      11    INTEGER
 3*    CONTROL NODE NUMBER                     5    INTEGER
 4     CONTROL TEMP                      505.000    DEG
 5     INITIAL TEMP AT CONTROL NODE      521.000    DEG
 6     PROPORTIONAL GAINS                   .001    FRACTION/DEG
 7     MAX HARD OVER                       1.000    FRACTION
 8     MIN HARD OVER                        .000    FRACTION
 9     INITIAL TEMP AT MOD NODE          518.891    DEG
10     COOLANT FLOW AT MOD NODE         1490.484BTU/HR.DEG.
11     ATMOSPHERIC COOLANT                     0    INTEGER
           0 = NO
           1 = YES
  * MUST BE DEFINED BEFORE YOU EXIT DISPLAY
******************************************************************
```

Figure 3.1.2.5.1. Typical Modulation Value Interactive Display

Table 3.1.2.5.1. Dynamic Communication Cross Reference for Routine MOD at Node I

VARIABLE	SYMBOL	UNITS	STORAGE	TYPE	COMMON
Leg 1 node number	j	INTEGER	IC(I,4)	I	MEAT
Leg 2 node number	n	INTEGER	IC(I,5)	I	MEAT
Control node	m	INTEGER	IC(I,6)	I	MEAT
Control temperature	T_c	DEG	C(I,15)	R	MEAT
Temperature at control node	T_m	DEG	$F(M,X^{\dagger})$	R	MEAT
Proportional gains	g	FRACTION	C(I,16)	R	MEAT
Maximum hard over	MAX f_j	FRACTION	C(I,17)	R	MEAT
Minimum hard over	MIN f_j	FRACTION	C(I, 18)	R	MEAT
Coolant temperature at MOD node	T_i	DEG	$F(I,X^{\dagger})$	R	MEAT
Coolant flow at MOD node	$(WC_p)_i$	BTU/HR DEG	C(I,3)	R	MEAT
Specific hear of gas mixture	-	BTU/LB DEG	C(I,5)	R	MEAT
Partial pressure of H_2O	-	PSI	C(I,6)	R	MEAT
N_2	-	PSI	C(I,7)	R	MEAT
O_2	-	PSI	C(I,8)	R	MEAT
C_2	-	PSI	C(I,9)	R	MEAT
Pressure of gas mixture	-	PSI	C(I,10)	R	MEAT

† X = L present
X = K previous

3.1.2.6 Routine RAD

The transient performance of a radiator consisting of fluid flow paths attached to, or integral with, a panel is simulated by Routine RAD. Each fluid flow path is paralled by a right and left section of the panel. The panel is subject to incident heat resulting from on-orbit operation. The Routine is an adaptive transfer function for the fluid flow segment from node i to j which processes the following equations.

$$(MC)_i \frac{d T_{c_i}}{dt} = - (Q_{REJ} + Q_c) - (UA)_i \Delta T_{\ell m} ,$$

and

$$(WC_p)_i (T_j - T_i) = (UA)_i \Delta T_{\ell m} ,$$

where

$$\Delta T_{\ell m} = \frac{(T_{c_i} - T_i) - (T_{c_i} - T_j)}{\ell n \left[\frac{T_{c_i} - T_i}{T_{c_i} - T_j}\right]}$$

$$Q_{REJ} = \sigma \ \varepsilon \sum_{n=1}^{2} A_n T_{c_i}^4 \left[1 - \frac{Q_{ABS}}{\sigma \ \varepsilon \ T_{c_i}^4}\right] \eta_n ,$$

Q_{ABS} is the absorbed heat, and Q_c is the net flow of heat resulting from thermal coupling. (The thermal coupling calculations are the same as those used for a cold plate, Section 3.1.2.1.)

The reference procedure is

```
CALL RAD(I,J)
```

to process the transfer function through node I to J. Reference to this routine will automatically bring up an interactive display for definition of orbital information immediately prior to passive execution. (See Routine TRAJ.)

Interactive communication with the parameters and functions is through a console display as illustrated on Figure 3.1.2.6.1. Positioning of the panel with respect to the spacecraft axes is defined by the angle of incident and dihedral angle as shown on Figure 3.1.2.6.2. The normal vector is calculated internally. An integer value of unity assigned to item 14 will bring up the interactive node coupling display as for a cold plate. (See Section 3.1.2.1, Figure 3.1.2.1.4.) An integer value greater than zero for item 15 indicates shadowing by the node number indicated. The interactive display for communication with the shadowing parameters shown on Figure 3.1.2.6.3 is brought up in this case. This display is in communication with the shadowing routines. (See Routine SHAD.)

The cross reference to Routine RAD parameters is shown on Table 3.1.2.6.1.

```
*****************************************************
                    NODE NUMBER 13
                    RADIATOR PANEL
ITEM                                        VALUE    UNIT
.
 1     THERMAL CAPACITANCE                   25.000  BTU/DEG
 2     OVERALL HEAT TRANSFER   COEF.       1500.000  BTU/HR DEG
 3     COOLANT FLOW RATE                    384.645  BTU/HR DEG
 4     SOLAR ABSORBIVITY                       .100  FRACTION
 5     EMMISIVITY                              .900  FRACTION
 6     RIGHT FIN EFFECTIVENESS                 .800  FRACTION
 7     LEFT FIN EFFECTIVENESS                  .800  FRACTION
 8     RIGHT FIN AREA                        10.000  SQ FT
 9     LEFT FIN AREA                         10.000  SQ FT
10     ANGLE OF INCIDI NCE                     .000  RAD
11     DIHEDERIAL ANGLE                        .000  RAD
12     INITIAL FIN TEMP                     521.000  DEG
13     INITIAL COOLANT   INLET TEMP.        518.891  DEG
14     NODE COUPLING                            0  INTEGER
.
         NO = 0
         YES = 1
15     SHADOW NODE NUMBER                      26  INTEGER
  INLET NODE NUMBER     OUTLET NODE NUMBER
         13                     14
*****************************************************
```

Figure 3.1.2.6.1. Typical Radiator Panel Interactive Display

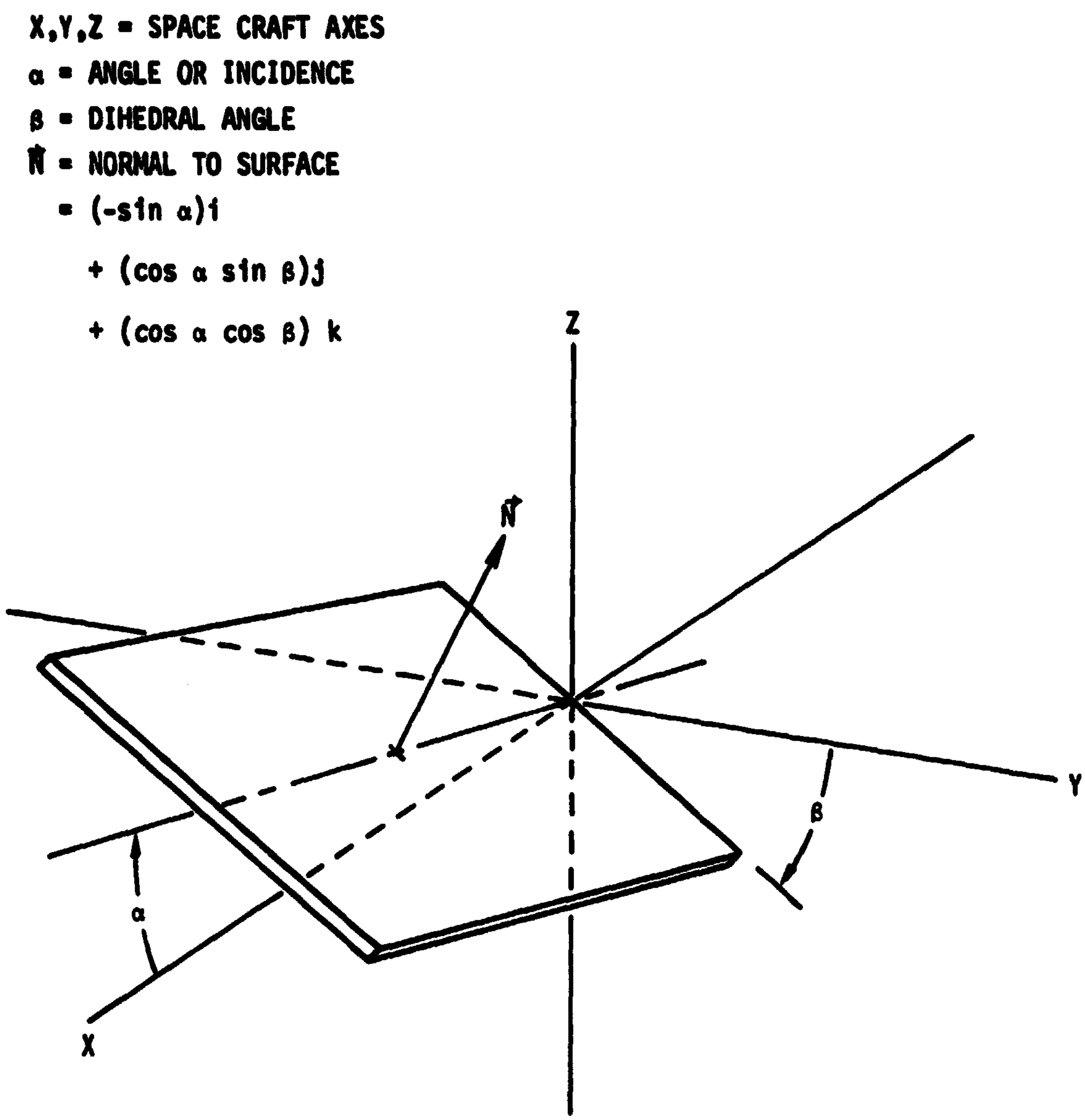


Figure 3.1.2.6.2. Panel Positioning with Respect to Spacecraft Axes

```
**********************************************
                    SHADOWING DATA
                    FOR NODE NO. 13
                    SHADOWED BY 26

ITEM
1     SHADOW NODE AREA                            1.000  SQ FT
2     ANGLE OF INCIDENCE                           .000  RAD
3     DIHEDRAL ANGLE                               .000  RAD
4     STAND-OFF VECTOR DATA                          26  INTEGER
5     STAND-OFF DISTANCE                          2.000  FT
6     EQUIV. STAND-OFF  ANGLE OF INCIDENCE         .000  RAD
7     EQUIV. STAND-OFF  DIHEDRAL ANGLE             .000  RAD
**********************************************
```

Figure 3.1.2.6.3. Typical Shadowing Parameter Interactive Display

Table 3.1.2.6.1. Dynamic Communication Cross Reference for Routine RAD Parameters at Node I

VARIABLE	SYMBOL	UNITS	STORAGE	TYPE	COMMON
Base temperature	T_{c_i}	DEG	P(I,X†)	R	MEAT
Fluid inlet temperature	T_i	DEG	F(I,X)	R	MEAT
Thermal capacitance	$(MC)_i$	BTU/DEG	C(I,1)	R	MEAT
Heat transfer coefficient	$(UA)_i$	BTU/HR DEG	C(I,2)	R	MEAT
Coolant flow rate	$(WC_p)_i$	BTU/HR DEG	C(I,3)	R	MEAT
Incident heat	Q_{ABS}	BTU/HR FT^2	C(I,4)	R	MEAT
Solar absorbability	α	FRACTION	C(I,5)	R	MEAT
Thermal emissivity	β	FRACTION	C(I,6)	R	MEAT
Right fin effectivity	r_1	FRACTION	C(I,7)	R	MEAT
Left fin effectivity	r_2	FRACTION	C(I,8)	R	MEAT
Right fin surface area	A_1	FT^2	C(I,9)	R	MEAT
Left fin surface area	A_2	FT^2	C(I,10)	R	MEAT
Angle of incidence	α	RAD	C(I,11)	R	MEAT
Dihedral angle	β	RAD	C(I,12)	R	MEAT
Coupling value 1st ref node	$C_{iK(1)}$	*	C(I,15)	R	MEAT
2nd ref node	$C_{iK(2)}$	*	C(I,16)	R	MEAT
. . .	. . .	. . .	. . .	. . .	. . .
6th ref node	$C_{iK(6)}$	*	C(I,20)	R	MEAT
Number of coupled nodes	M	INTEGER	IC(I,4)	I	MEAT
Coupling node number 1st ref	K(1)	INTEGER	IC(I,5)	I	MEAT
2nd ref	K(2)	INTEGER	IC(I,6)	I	MEAT
. . .	. . .	. . .	. . .	. . .	. . .
6th ref	K(6)	INTEGER	IC(I,10)	I	MEAT
Shadowing node number	-	INTEGER	IC(I,2)	I	MEAT

†X = L present value
X = K previous value

*BTU/HR DEG for convection and conduction coupling (series 100).
BTU/HR DEG^4 for radiation coupling (series 200).

3.1.2.7 Routine EXCH

The exchange of heat in counter flow and parallel flow heat exchangers is simulated by Routine EXCH. The routine is a transfer function for the fluid flow segment from node i to j where the interfacing fluid flow from m to n. The routine processes the equation for counter and parallel flow heat exchangers based of the methods of Reference 1.

The reference procedure is

```
CALL EXCH(I,J,M,N)
```

to process the transfer function through node I to J based on the interfacing condition at nodes M and N. A second call is normally referenced in the interfacing coolant loop part of the model as

```
CALL EXCH(M,N,I,J)
```

which processes the transfer function through node M to N based on conditions at nodes I and J. The second call is not mandatory. It is used only as the model requires updating of the conditions at node N in the interfacing loop.

Interactive communication is through a console display as illustrated on Figure 3.1.2.7.1. Note that information pertaining to the interfacing side is also included.

An integer value of unity for item 5 will cause the routine to put through the atmospheric properties from node I to J. This routine should not be used when the conditions at the interface could result in condensation. (See Routines CONXG and CONXI.)

The cross reference to Routine EXCH parameters is shown on Table 3.1.2.7.1.

```
*****************************************************************************
                               NODE NO.  21
.
                              HEAT EXCHANGER
ITEM                                                    VALUE      UNIT
.
                           *** CALLING SIDE ***
.
   1     HEAT TRANSFER COEF.                           300.000    BTU/HR DEG
.
   2     COOLANT FLOW RATE                             100.000    BTU/HR DEG
.
   3     FLUID INLET TEMPERATURE                       521.000    DEG
.
   4     TYPE                                               0     INTEGER
.
              COUNTERFLOW   = 0
              PARALLEL FLOW = 1
   5     ATMOSPHERIC COOLANT                                0     INTEGER
.
              NO  = 0
              YES = 1
                          *** INTERFACE SIDE ***
.
   6     HEAT TRANSFER COEF.                          3000.000    BTU/HR DEG
.
   7     COOLANT FLOW RATE                            1490.484    BTU/HR DEG
.
   8     FLUID INLET TEMPERATURE                       518.751    DEG
.
*****************************************************************************
```

Figure 3.1.2.7.1. Typical Counter or Parallel Flow Heat Exchanger Interactive Display

Table 3.1.2.7.1. Dynamic Communication Cross Reference for Routine EXCH Parameters at Node I Interfaced to Node M

VARIABLE	SYMBOL	UNITS	STORAGE	TYPE	COMMON
Calling Side					
Fluid inlet temperature	T_i	DEG	$F(I,X^{\dagger})$	R	MEAT
Heat transfer coefficient	$(UA)_i^*$	BTU/HR DEG	C(I,2)	R	MEAT
Coolant flow rate	$(WC_p)_i$	BTU/HR DEG	C(I,3)	R	MEAT
Specific heat of mixture	-	BTU/LB DEG	C(I,5)	R	MEAT
Partial pressure of H_2O	-	PSI	C(I,6)	R	MEAT
N_2	-	PSI	C(I,7)	R	MEAT
O_2	-	PSI	C(I,8)	R	MEAT
CO_2	-	PSI	C(I,9)	R	MEAT
Pressure of mixture	-	PSI	C(I,10)	R	MEAT
Interface Side					
Fluid inlet temperature	T_m	DEG	$F(M,X^{\dagger})$	R	MEAT
Heat transfer ceofficient	$(UA)_m^*$	BTU/HR DEG	C(M,2)	R	MEAT
Coolant flow rate	$(WC_p)_m$	BTU/HR DEG	C(M,3)	R	MEAT

†X = L present value
X = K previous value

*The Routine processes an overall heat transfer coefficient

$$(UA)_o = \frac{1}{\frac{1}{(UA)_i} + \frac{1}{(UA)_m}}$$

3.1.2.8 Routine HEATER

The performance of an in-line fluid heater, whose power is Q_{PWR} switched in response to the fluid temperature at a control node n and a control temperature of T_c. The routine is an adaptive transfer function for the fluid flow segment i to j and processes equations as for Routine PLATE except that Q_{I_i}, is either Q_{PWR} or zero depending on the on/off configuration, respectively.

The on/off configuration is control to a dead-band ΔT about the control temperature T_c. The heater is switched on when T_n is less than $T_c - \Delta T$ and does not go off until T_n is greater than $T_c + \Delta T$. The energy in watt hours consumed over the time span a to b is calculated as

$$E = 3.4130 \int_a^b Q_{I_i} \, dt.$$

and is drawn from a source ix as prescribed by the user.

The reference procedure is

```
CALL HEATER(I,J)
```

to process the transfer function through node I to J.

Interactive communication with the parameters and functions of the in-line heater is through a console display as illustrated on Figure 3.1.2.8.1. Integer values of unity for items 10 and/or 11 will put through the atmospheric properties and/or set up for thermal coupling data entry, respectively. (See Routine PLATE). Reference to this Routine will automatically bring up the consumables source initial loading display as illustrated on Figure 3.1.2.2.2. This display is brought up immediately prior to passive execution and includes all referenced consumables sources as well as the source referenced through a particular call to HEATER.

The cross reference to Routine HEATER parameters is shown on Table 3.1.2.8.1. Additional information related to source assignment for the energy is given in the section on Routine CONSUM.

****

NODE NUMBER 4

HEATER

ITEM		VALUE	UNIT
1	THERMAL CAPACITY	200.000	BTU/DEG
2	OVEALL HEAT TRANSFER COEF.	1500.000	BTU/HR DEG
3	COOLANT FLOW RATE	501.000	BTU/HR DEG
4	INITIAL COMPONENT TEMPERATURE	521.000	DEG.
5	INITIAL INLET TEMPERATURE	500.830	DEG.
6	HEATER POWER	450.000	BTU/HR DEG.
7	CONTROL NODE NUMBER	2	INTEGER
8	CONTROL TEMPERATURE	532.000	DEG.
9	DEAD BAND	2.000	DEG.
10	INITIAL TEMP AT CONTROL NODE	510.165	DEG
11	ATMOSPHERIC COOLANT 0 = NO 1 = YES	1	INTEGER
12	THERMAL COUPLING 0 = NO 1 = YES	0	INTEGER
13	POWER SOURCE	5	INTEGER

INLET NODE NO.	OUTLET NODE NO.
4	1

****

Figure 3.1.2.8.1. Typical In-line Heater Interactive Display

Table 3.1.2.8.1. Dynamic Communication Cross Reference for Routine HEATER Parameters at Node I

VARIABLE	SYMBOL	UNITS	STORAGE	TYPE	COMMON
Component temperature	T_{c_i}	DEG	$P(I,X^\dagger)$	R	MEAT
Fluid inlet temperature	T_i	DEG	$F(I,X^\dagger)$	R	MEAT
Thermal Capacitance	$(MC)_i$	BTU/DEG	C(I,1)	R	MEAT
Heat transfer coefficient	$(UA)_i$	BTU/HR DEG	C(I,2)	R	MEAT
Coolant flow rate	$(WC_p)_i$	BTU/HR DEG	C(I,3)	R	MEAT
Power Applied	Q_{I_i}	BTU/HR	C(I,4)	R	MEAT
Control node number	n	INTEGER	IC(I,2)	I	MEAT
Control temperature	T_c	DEG	C(I,11)	R	MEAT
Deadband	ΔT	DEG	C(I,13)	R	MEAT
Temperature at control node	T_n	DEG	$F(N,X^\dagger)$	R	MEAT
Heater power (ON)	Q_{PWR}	BTU/HR	C(I,12)	R	MEAT
Energy source	ix	INTEGER	IC(I,3)	I	MEAT
Energy	E	WATT HRS	CONTOT(IX)	R	CONS
Specific heat of mixture	-	BTU/LB DEG	C(I,5)	R	MEAT
Partial pressure of H_2O	-	PSI	C(I,6)	R	MEAT
N_2	-	PSI	C(I,7)	R	MEAT
O_2	-	PSI	C(I,8)	R	MEAT
CO_2	-	PSI	C(I,9)	R	MEAT
Pressure of mixture	-	PSI	C(I,10)	R	MEAT
Coupling value 1st ref. node	$C_{iK(1)}$	*	C(I,15)	R	MEAT
2nd ref. node	$C_{iK(2)}$	*	C(I,16)	R	MEAT
. . .	. . .	. . .	. . .	. . .	. . .
6th ref. node	$C_{iK(6)}$	*	C(I,20)	R	MEAT
Number of coupled nodes	M	INTEGER	IC(I,4)	I	MEAT
Coupling node number 1st ref.	K(1)	INTEGER	IC(I,5)	I	MEAT
2nd ref.	K(2)	INTEGER	IC(I,6)	I	MEAT
. . .	. . .	. . .	. . .	. . .	. . .
6th ref.	K(6)	INTEGER	IC(I,10)	I	MEAT

† X = L present value
X = K previous value

*BTU/HR DEG for convection and conduction coupling (series 100).
BTU/HR DEG^4 for radiation coupling (series 200).

3.1.2.9 Routine ATMO

Processing of a gas stream through atmospheric compartment subject to heat addition, moisture generation, carbon dioxide generation, oxygen consumption, and external leakage is simulated by Routine ATMO. The heat addition results from equipment heat generation, Q_{I_i}, and the sensible metabolic heat of up to six crew members. Crew sensible heat, water addition, carbon dioxide addition, and oxygen consumption are proportional to the user specified metabolic load of the occupants. Oxygen and Nitrogen external leakage make up is supplied from sources n_1 and n_2 specified by the user. The routine is an adaptive transfer function for the gas flow segment from the inlet i to the exit j and performs a mass balance on the atmospheric constituents. The atmospheric conditions at node j represent the compartment conditions.

The reference procedure is

```
CALL ATMO(I,J)
```

to process the transfer function from node I to J. The first component simulation call in an atmospheric loop should reference this routine.

Interactive communication with the parameters and functions of the atmospheric compartment simulation is through console displays as shown on Figures 3.1.2.9.1 and 3.1.2.9.2. Reference to this routine will automatically bring up the consumables source initial loading display as illustrated on Figure 3.1.2.2.2. This display is brought up immediately prior to passive execution and includes all referenced consumables sources as well as the source referenced through a particular call to ATMO.

The cross reference to Routine ATMO parameters is shown on Table 3.1.2.9.1 Additional information related to source assignment for the oxygen and nitrogen is given in the section on Routine CONSUM.

```
*********************************************************************
                              NODE   1
                       ATMOSPHERIC COMPARTMENT
ITEM                                              VALUE      UNIT
  1     COMPARTMENT VOLUME                      1000.000     CUBIC FT
  2     LEAKAGE RATE                               2.000     LB/HR
  3     COOLANT FLOW RATE                        501.000     BTU/HR DEG
  4     HEAT LOAD                               2001.000     BTU/HR
  5     SPECIFIC HEAT OF GAS                        .210     BTU/LB DEG
  6     PARTIAL PRESSURE OF WATER                   .130     PSI
  7     PARTIAL PRESSURE OF NITROGEN              11.600     PSI
  8     PARTIAL PRESSURE OF OXYGEN                 3.100     PSI
  9     PARTIAL PRESSURE OF CARBON DIOXIDE          .093     PSI
 10     TOTAL PRESSURE                            14.700     PSI
 11     NITROGEN TANK                                  1     INTEGER
 12     OXYGEN TANK                                    2     INTEGER
 13     INLET GAS TEMPERATURE                    505.100     DEG
*********************************************************************
```

Figure 3.1.2.9.1. Typical Atmospheric Compartment Interactive Display

```
**************************************************************************
                         CREW MEMBER
                       METABOLIC RATES

                         NODE NO.    1

                ITEM          METABOLIC           UNIT
                                RATE

                   1               .000           BTU/HR
                   2               .000           BTU/HR
                   3               .000           BTU/HR
                   4            600.000           BTU/HR
                   5               .000           BTU/HR
                   6               .000           BTU/HR
**************************************************************************
```

Figure 3.1.2.9.2. Typical Crew Metabolic Data Interactive Display

Table 3.1.2.9.1 Dynamic Communication Cross Reference Parameters for ATMO Parameters at Node I

VARIABLE	SYMBOL	UNITS	STORAGE	TYPE	COMMON
Gas inlet temperature	T_i	DEG	F(I,X†)	R	MEAT
Compartment volume	V_i	FT^3	C(I,1)	R	MEAT
Leakage rate	W_{ei}	LB/HR	C(I,2)	R	MEAT
Gas flow rate	$(WC_p)_i$	LB/HR DEG	C(I,3)	R	MEAT
Equipment heat load	QI_i	BTU/HR	C(I,4)	R	MEAT
Specific heat of gas mixture	-	BTU/LB DEG	C(I,5)	R	MEAT
Partial pressure of H_2O	-	PSI	C(I,6)	R	MEAT
N_2	-	PSI	C(I,7)	R	MEAT
O_2	-	PSI	C(I,8)	R	MEAT
CO_2	-	PSI	C(I,9)	R	MEAT
Pressure of gas mixture	-	PSI	C(,10)	R	MEAT
Metabolic rate 1st member	-	BTU/HR	C(I,15)	R	MEAT
2nd member	-	BTU/HR	C(I,16)	R	MEAT
.	.	.	.	.	.
.	.	.	.	.	.
.	.	.	.	.	.
6th member	-	BTU/HR	C(I,20)	R	MEAT
Source of N_2	n_1	INTEGER	IC(I,5)	I	MEAT
Same for O_2	n_2	INTEGER	IC(I,6)	I	MEAT
N_2 consumed	M_{N2}	LBS	CONTOT(N1)	R	MEAT
O_2 consumed	M_{O2}	LBS	CONTOT(N2)	R	MEAT

†X = L present value
X = K previous value

3.1.2.10 Routine LIOH

The removal of Carbon Dioxide from a gas stream by a Lithium Hydroxide canister is simulated by Routine LIOH. The routine is an adaptive transfer function for the gas stream segment from node i to j which processes the following equations.

$$P_{CO_2 j} = P_{CO_2 i} (1 - \phi)$$

where ϕ, an efficiency factor is given by

$$\phi = \frac{1 - e^{-\alpha}}{1 - e^{-\alpha} + e^{\alpha\beta - \alpha}} \ .$$

here

$$\alpha = \frac{K \ M_i \ \rho_i}{W_i} \ ,$$

where K is an empirically determined reaction rate (Reference 1) given by

$$K = 1100. - 700. \ (1 - e^{10.\beta}) \qquad 0. \leq \beta \leq .8$$

$$K = 400. \qquad \beta > .8$$

and

$$\beta = \int_a^b \frac{C_{CO_2} \ W_i}{M_i} \ dt$$

where C_{CO_2} is the Carbon Dioxide concentration. Heat and moisture is added to the stream by the reaction.

The amount of Lithium Hydroxide consumed is equal to the number of canister changes time the mass of the canisters. A canister is automatically changed when

$$P_{CO_2 j} > (P_{CO_2 j})_{MAX}.$$

The Lithium Hydroxide is withdrawn from a source n specified by the user. The reference procedure is

```
CALL LIOH(I,J)
```

to process the transfer function through node I to J.

Interactive communication with the parameters and functions of the canister is through a console display as shown on Figure 3.1.2.10.1 Reference to this routine will automatically bring up the consumables source initial loading display as illustrated on Figure 3.1.2.2.2. This display is brought up immediately prior to passive execution and includes all referenced consumables sources as well as the source referenced through a particular call to LIOH. The routine automatically processes the remaining atomospheric properties.

The cross reference to Routine LIOH parameters is shown on Table 3.1.2.10.1. Additional information related to source assignment for the Lithium Hydroxide is given in the section on Routine CONSUM.

NODE NO. 2

LITHIUM HYDROXIDE

CANISTER

ITEM		VALUE	UNITS
1	CANISTER MASS	1.000	LBS
2	GAS FLOW RATE	501.000	BTU/HR DEG
3	CANISTER PRESSURE CHANGE	.150	PSI
4	SPECIFIC HEAT OF GAS	.210	BTU/LB DEG
5	PARTIAL PRESSURE OF WATER	.130	PSI
6	PARTIAL PRESSURE OF NITROGEN	11.600	PSI
7	OXYGEN	3.100	PSI
8	CARBON DIOXIDE	.093	PSI
9	TOTAL PRESSURE	14.700	PSI
10	INITIAL ABSORBED QUANTITY	.000	FRACTION
11	CANISTER SOURCE	3	INTEGER
12	INLET GAS TEMPERATURE	510.165	DEG

Figure 3.1.2.10.1. Typical Lithium Hydroxide Canister Interactive Display

Table 3.1.2.10.1. Dynamic Cross Reference to Routine LIOH Parameters at Node I

VARIABLE	SYMBOL	UNITS	STORAGE	TYPE	COMMON
Gas inlet temperature	T_i	DEG	$F(I,X^{\dagger})$	R	MEAT
Canister mass	M_i	DEG	C(I,1)	R	MEAT
Gas flow rate	$(WC_p)_i$	BTU/HR DEG	C(I,3)	R	MEAT
Canister change pressure	$(P_{CO_2})_{MAX}$	PSI	C(I,11)	R	MEAT
Heat added	-	BTU/HR	C(I,4)	R	MEAT
Specific heat of mixture	-	BTU/LB DEG	C(I,5)	R	MEAT
Partial pressure of H_2O	-	PSI	C(I,6)	R	MEAT
N_2	-	PSI	C(I,7)	R	MEAT
O_2	-	PSI	C(I,8)	R	MEAT
CO_2	P_{CO_2}	PSI	C(I,9)	R	MEAT
Pressure of gas mixture	-	PSI	C(I,10)	R	MEAT
Lithium Hydroxide source	n	INTEGER	IC(I,5)	I	MEAT
Consumed Lithium Hydroxide		LBS	CONTOT(N)	R	CONS

†X = L present value
X = K previous value

3.1.2.11 Routine CONXG

The performance of a counterflow condensing heat exchanger is simulated by Routines CONXG and CONXI. Routine CONXG, discussed in this section, processes the condensing side of the heat exchanger. Routine CONXI, discussed in the next section, processes the interface (or sink) side of the heat exchanger. The routine discussed in this section is a transfer function for the gas stream segment i to j interfacing with a counterflow segment m to n. Processing is as follows and is illustrated on Figure 3.1.2.11.1.

The gas and water vapor mixture enter at a temperature t_i and partial pressure P_{H_2Oi}. The mixture experiences only sensible cooling until the dew point is reached. The remaining portion of the heat exchanger dehumifies and cools the mixture to t_j and P_{H_2Oj} at the exit. The sensible cooling portion of the heat exchanger is referred to as the "dry" section with a heat transfer coefficient of UA_{D_i} if the entire heat exchanger were dry. The dehumidifying section is referred to as the "wet" section with a heat transfer coefficient of UA_{W_i} if the entire heat exchanger were wet. Internal calculation proportion the dry and wet sections and the applicable value of the heat transfer coefficients. The condensation is stored in a source (tank) n_1 as prescribed by the user.

The reference procedure is

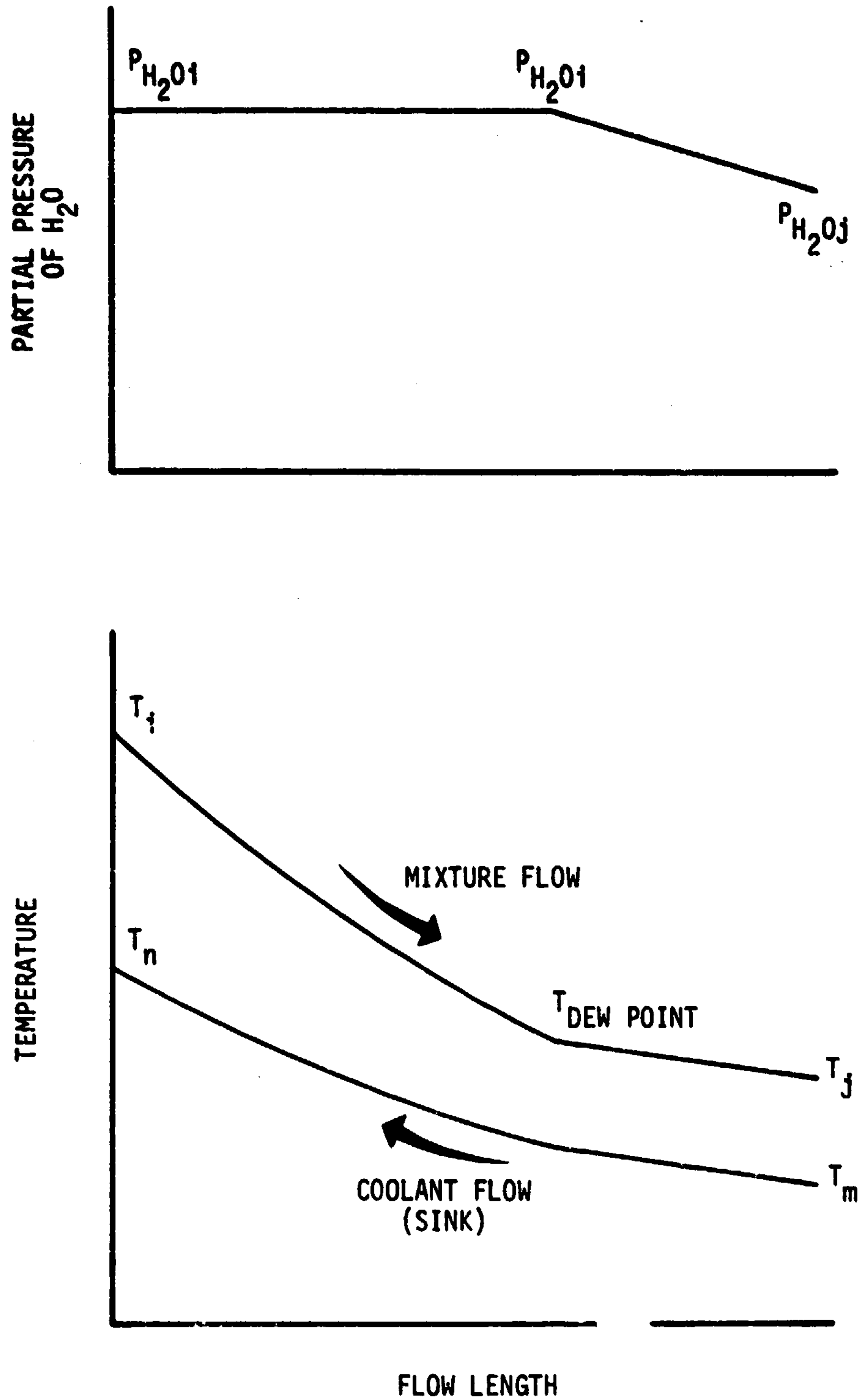
CALL CONXG(I,J M,N)

to process the condensing side from node I through node J with nodes M and N as the respective inlet and outlet of the interfacing sink fluid. A call to CONXI is mandatory in the interfacing coolant loop part of the model.

Interactive communication with the parameters and functions of the condensing side of the heat exchanger is through a console display as shown on Figure

3.1.2.11.2. Reference to this routine will automatically bring up the consumables source initial loading display as illustrated on Figure 3.1.2.2.2. This display is brought up immediately prior to passive execution and includes all reference consumables sources as well as the source referenced through a particular call to CONXG. The routine automatically processes the remaining atmospheric properties.

The cross reference to Routine CONXG parameters is shown on Table 3.1.2.11.1. Additional information related to storage assignment for the condensation is given in the section on Routine CONSUM.



..gure 3.1.2.11.1. Counterflow Condensing Heat Exchanger Performance

```
*******************************************************************************
                              NODE NO.    3
                         CONDENSING HEAT EXCHANGER
                             ATMOSPHERIC SIDE

ITEM                                                  VALUE       UNIT
                          *** CALLING SIDE ***

  1     CONDENSING HEAT TRANSFER COEF.              2000.000     BTU/HR DEG
  2     DRY HEAT TRANSFER COEF.                     1000.000     BTU/HR DEG
  3     COOLANT FLOW RATE                            501.000     BTU/HR DEG
  4     FLUID INLET TEMP                             512.278     DEG
  5     CONDENSATE TANK NO.                                4     INTEGER

                          *** INTERFACE SIDE ***

  6     COOLANT FLOW RATE                           1490.484     BTU/HR DEG
  7     FLUID INLET TEMP                             499.000     DEG

         CALLING SIDE NODES        IN    3          OUT    4
         INTERFACE SIDE NODES      IN    7          OUT    8

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

Figure 3.1.2.11.2. Typical Condensing Heat Exchanger (Condensing Side) Interactive Display

Table 3.1.2.11.1. Dynamic Cross Reference to Routine CONXG at Node I Interfaced to Node M

VARIABLE	SYMBOL	UNITS	STORAGE	TYPE	COMMON
Gas inlet temperature	T_i	DEG	F(I,X†)	R	MEAT
Heat transfer coefficient, wet	UA_{W_i}	BTU/HR DEG	C(I,1)	R	MEAT
Heat transfer coefficient, dry	UA_{D_i}	BTU/HR DEG	C(I,2)	R	MEAT
Gas flow rate	$(WC_p)_i$	BTU/HR DEG	C(I,3)	R	MEAT
Heat rejected	-	BTU/HR	C(M,4)	R	MEAT
Specific heat of mixture	-	BRU/LB DEG	C(I,5)	R	MEAT
Partial pressure of H_2O	P_{H_2Oi}	PSI	C(I,6)	R	MEAT
N_2	-	PSI	C(I,7)	R	MEAT
O_2	-	PSI	C(I,8)	R	MEAT
CO_2	-	PSI	C(I,9)	R	MEAT
Pressure of mixture	-	PSI	C(I,10)	R	MEAT
Condensate tank number	n_1	INTEGER	IC(I,3)	I	MEAT
Condensate stored	-	LBS	CONTOT(N1)	R	CONS

†X = L present value
X = K previous value

3.1.2.12 Routine CONXI

Routine CONXI is a mandatory companion routine to CONXG of the preceding section for simulation of a counterflow condensing heat exchanger. The routine discussed in this section is a transfer function for the interfacing side of a condensing heat exchanger fluid segment m to n with counterflow on the condensing segment from i to J. The routine processes the following equation

$$T_n = T_m + Q_m/(WC_p)_m$$

where Q_m has been assigned by the processing of Routine CONXG.

Interactive communication with the parameters and functions of the interface side of a condensing heat exchanger is through a console display as shown on Figure 3.1.2.12.1. Entry of an integer value of unity for item 3 will put through the atmospheric properties of node m to node n.

The cross reference to the parameters for interfacing side of a condensing heat exchanger are shown on Table 3.1.2.12.1.

```
*********************************************************************
                          NODE NO.    7
                   CONDENSING HEAT EXCHANGER
                         INTERFACE SIDE

ITEM                                                 VALUE      UNIT
                          *** CALLING SIDE ***

  1     COOLANT FLOW RATE                        14[illegible]0.484   BTU/HR DEG
  2     FLUID INLET TEMP.                         4[illegible]9.715   DEG
  3     ATMOSPERIC COOLANT                             0      INTEGER
             NO  = 0
             YES = 1

                        *** ATMOSPHERIC SIDE ***
  4     COOLANT FLOW RATE                         [illegible]01.000   BTU/HR DEG
  5     FLUID INLET TEMP                          [illegible]1[illegible].278   DEG
         CALLING SIDE NODES       IN    7         OUT    8
         ATMOSPHERIC SIDE NODES   IN    3         OUT    4
*********************************************************************
```

Figure 3.1.2.12.1. Typical Condensing Heat Exchanger (Interface Side) Interactive Display

Table 3.1.2.12.1. Dynamic Cross Reference to Routine CONXI at Node M

VARIABLE	SYMBOL	UNITS	STORAGE	TYPE	COMMON
Fluid inlet temperature	T_m	DEG	F(I,X[†])	R	MEAT
Coolant flow rate	$(WC_p)_m$	BTU/HR DEG	C(M,3)	R	MEAT
Heat absorbed	Q_m	BTU/HR	C(M,4)*	R	MEAT
Specific heat of mixture	-	BTU/LB DEG	C(M,5)	R	MEAT
Partial pressure of H_2O	-	PSI	C(M,6)	R	MEAT
N_2	-	PSI	C(M,7)	R	MEAT
O_2	-	PSI	C(M,8)	R	MEAT
CO_2	-	PSI	C(M,9)	R	MEAT
Pressure of mixture	-	PSI	C(M,10)	R	MEAT

[†]X = L present value
X = K previous value

*Value assigned by companion call to CONXG.

3.1.3 Input Utility Routine

Two routines are available for tabular data look-up and interpolation. The routines TABLE and STEP as summarized on Table 3.1.3.1 differ only in the manner of interpolation.

The Input Utility Routine descriptions which follow include reference procedure and interactive communication in the table data set up.

Table 3.1.3.1. Summary of Input Utility Routines

TABLE	Linear interpolation of dependent variable in tabular data.
STEP	Interpolates tabular data as step function.

3.1.3.1. Routine TABLE

Linear interpolation of input tabular data is performed by Routine TABLE. The reference procedure is

```
CALL TABLE(NTAB,XX1,YY1)
```

where NTAB is the table number. The Routine returns the linear interpolated value of YY1 for the prescribed independent variable XX1 from the tabular arrays XX and YY.

Interactive communication is through a console display as shown on Figure 3.1.3.1.1.

```
*************************
        TABLE 2
     XX         YY
  1    .000       200.000
  2   2.500       400.000
*************************
```

Figure 3.1.3.1.1. Typical Interactive Tabular Data Display

3.1.3.2 Routine STEP

Interpolation of input step function tabular data is performed by Routine STEP.

The reference procedure is

CALL STEP(NTAB,XX1,YY1).

The functions and interactive communication with the routine is the same as for Routine TABLE except for the method of interpolation.

3.2 UNREFERENCED ROUTINES

This section presents a description of the functions and parameters of those library routines which are automatically brought into execution as a result of use of and/or specific option selection with respect to the referenced routines of Section 3.1. Only those library routines with which the user has interactive communication and/or may desire dynamic communication are included. These types of routines include Boundary Condition Routines and Output Routines.

3.2.1 Boundary Condition Routines

Five routines are directly associated with development of Boundary Conditions. The function of these routines are summarized on Table 3.2.1.1.

Table 3.2.1.1. Summary of Boundary Condition Control Routines

COUPL	Provides for initial cross coupling of thermally connected nodes.
REPS	Provides data array for electrical power assignment.
CONSUM	Provides for integration of expended or generated media for various source assignments.
TRAJ	Performs incident (orbital) heating calculations.
SHAD	Assembles absorbed (orbital) heat for a panel.

3.2.1.1 Routine COUPL

All thermal coupling data is performed internal to the argumented component performance routines. Initial coupling data is loaded through the interactive displays associated with these routines. Routine COUPL performs the cross coupling during this initial loading. If the user specifies node I is coupled to node J, Routine COUPL automatically couples node J to I with the same coupling value. This function is performed only during initial loading. Accordingly, any dynamic communication with coupling values and/or type of coupling requires that the user search out the location and change the coupling data for both node I and J.

3.2.1.2 Routine REPS

Electric power data assignment is controlled through the initial interactive communication with the argument component performance routine reference. Routine REPS provides the interface of the data assignment to the electrical power data to be read from tape or assigned through an interface to another program. The communication is trhough the dimensioned variables NEPS(100) and DEPS(100) in the COMMON/EPS/. The resident value P_i of electrical power (BTU/HR) in DEPS(I) is assigned to node J by setting

$$NEPS(I) = J.$$

The argumented component performance routine at node J searches the NEPS array for the integer J and sums all corresponding values of DEPS into C(J,4). Dynamic reassignment is accomplisjed by control of the NEPS array.

The current version of Routine REPS assigns specific Shuttle Orbiter electrical power heating value to the NEPS array words shown on the menu illustrated on Figure 3.2.1.2.1. The routine reads a dictionary of active components from Unit 10 and the power timeline from Unit 11.

```
MPL3
>
 IF YOU WANT TO DISPLAY MENU ENTER 1, OTHERWISE BLANK
>1
                                    STS
                               HEAT LOAD MENU

 WORD NO.        DESCRIPTION

      1          AVIONICS AIR BAY 1
      2          AVIONICS AIR BAY 2
      3          AVIONICS AIR BAY 3
      4          AVIONICS FAN 1A/1B BAY =1
      5          AVIONICS FAN 2A/2B BAY =2
      6          AVIONICS FAN 3A/3B BAY =3
      7          CABIN AIR COOLED
      8          CABIN FAN
      9          COLDPLATE FREON DFI MID-BDY CONTAINER =1
     10          COLDPLATE FREON DFI MID-BDY CONTAINER =2
     11          COLDPLATE FREON DFI MID-BDY CONTAINER =3
     12          TBD
     13          COLDPLATE WATER DFI FWD CONTAINER
     14          COLDPLATE FREON BAY = 4
     15          COLDPLATE FREON BAY = 5
     16          COLDPLATE FREON BAY = 6
     17          COLDPLATE FREON OUTSIDE FREON BAYS
     18          TBD
     19          COLDPLATE FREON MIDSECTION
     20          FREON PUMP
     21          TBD
     22          CABIN AIR COOLED(DIRECT TO HEAT EXCHANGER)
     23          IMU
     24          IMU FAN
     25          NOT ACTIVELY COOLED
     26          PAYLOAD HEAT EXCHANGER
     27          COLDPLATE WATER BAY =1
     28          COLDPLATE WATER BAY =2
     29          COLDPLATE WATER BAY =3A
     30          COLDPLATE WATER BAY =3B
     31          CABIN COLDPLATE WATER
     32          WATER PUMP
     33          INVERTER =1
     34          INVERTER =2
     35          INVERTER =3
     36          INVERTER =4
     37          INVERTER =5
     38          FUEL CELL =1
     39          FUEL CELL =2
     40          FUEL CELL =3
     41          FOOD PREP
 PAUSE FOR HARDCOPY. ENTER ANY CHARACTER TO CONTINUE
>_
```


Figure 3.2.1.2.1 Electrical Power Assignment Menu

3.2.1.3 Routine CONSUM

The integration of expended or generated media for the various sources assignments is performed in Routine CONSUM. The control is through the COMMON/CONS/ which contains the dimensioned variables CONRAT(20), CONTOT(20), and IAMCON(20),

where

IAMCON(I) = Type of media for source I indexed as shown on Table 3.2.1.3.1,

CONRAT(I) = Media expended (+) or generated (-) for source I during most recent time step,

and

CONTOT(I) = Total (integrated) expended (+) or generated for source I at current time.

The source assignment I and the type of media is assigned through the cross reference data for the argumented component performance routine(s) during active execution. The arrays CONRAT and CONTOT reflect the algebraic sum of all transaction referencing that source.

In the latter stages of active execution the IAMCON array is searched for nonzero values. The existance of one or more such values brings up the initial loading interactive display shown on Figure 3.2.1.3.1. The COMMON/CMORE/ which contains the variable NCON, and the dimensioned variables ICON(20) and CONSTA(20) is loaded at this time,

where

NCON = Number of nonzero elements in IAMCON,

ICON = Contains the NCON referenced source numbers in the first NCON locations, and

CONSTA(I) = Initial quantity for source I.

It should be noted that the ICON array is used for initial loading and output (see Routine CONPR) control rather than a repeated search of IAMCON. The ICON array includes only those sources referenced immediately prior to initial loading. Accordingly, any dynamic communication must refer only to sources that have been referenced at this time. Additional source references may be enforced by setting

IAMCON(I) = J,

where I is the source number and J is the media index. Such an entry is best affected immediately after the call to START and outside the timing loop.

Quantity remaining for each of the sources is calculated in the output Routine CONPR.

Table 3.2.1.3.1. Consumables Media Index for Source I

IAMCON(I)		SYMBOL	UNITS
1	Potable water	H_2O	LSB
2	Water	H_2O	LBS
3	Carbon Dioxide	CO_2	LBS
4	Oxygen	O_2	LBS
5	Hydrogen	H_2	LBS
6	Nitrogen	N_2	LBS
7	Methane	CH_4	LBS
8	Hydrogen Peroxide	H_2O_2	LBS
9	Ammonia	NH_3	LBS
10	Other	-	LBS
11	Electrical Power	-	WATT HRS
12	Lithium Hydroxide	LIOH	LBS

```
*************************************************************
                      CONSUMABLES
                        SOURCES
     SOURCE          TYPE OF,                        INITIAL
ITEM   NO.          CONSUMABLE            UNIT       LOADING
 1      1      NITROGEN                    LBS           .000
 2      2      OXYGEN                      LBS           .000
 3      3      LITHIUM HYDROXIDE           LBS           .000
 4      4      WATER                       LBS           .000
 5      5      ELECTRIC POWER            WATT HRS        .000
 6      6      POTABLE WATER               LBS           .000
*************************************************************
```

Figure 3.2.1.3.1. Typical Interactive Source Initial Loading Quantity Display

3.2.1.4 Routine TRAJ

Reference to component simulation routines which imply incident (orbital) heating as a boundary condition automatically brings Routine TRAJ into execution. There are three components of incident heat resulting from orbital operation.

(1) Solar radiation directly from the Sun,

(2) Thermal radiation from the planet being orbited, and

(3) Albedo (reflected solar radiation) from the planet.

Routine TRAJ controls the calculations for these three heating components.

The items required to evaluate the incident heating are:

(1) Location of the panel with respect to the vehicle coordinate system,

(2) Attitude of the spacecraft with respect to a geocentric inertial or local vertical,

(3) Position of the Sun with respect to the geocentric system, and

(4) Position of the spacecraft with respect to the geocentric system.

The first item is characteristic of the subject panel. These parameters are entered through the subject component simulation routine. Two options are available to establish the latter items. The data may be read in from a previously generated trajectory tape or calculated with respect to a prescribed set of orbital parameters. Both options use the following coordinate systems.

(1) The Geocentric Inertial System (GCI). The coordinate system origin is at the center of the Earth. The X-axis lies in the equatorial plane and points toward the vernal equinox. The Z-axis passes through the North Pole. The Y-axis lies in the equatorial plane and forms a right-handed system.

(2) The Vehicle System (VS). This is the principal system in which the flat plate vehicle geometry is defined. It differs from the geocentric inertial (GCI) system by the amount of pitch, yaw, and roll.

The interactive communication is initially through a console display requesting the selection of these options as shown on Figure 3.2.1.4.1. Item 2 on this display is a control parameter related to the dimensional units on the tape and is active only for the tape read option.

The format of the trajectory tape is shown on Table 3.2.1.4.1. With this option in effect dynamic communication should be limited to the characteristic of the subject panel.

Interactive communication is further extended through the console display shown on Figure 3.2.1.4.2 for the calculated trajectory option. The orbited parameters are initially loaded with a default inertial hold circular equatorial orbit with the Sun located out the X-axis.

The attitude hold key establishes whether the spacecraft defined pitch, yaw, and roll are referenced to the inertial (GCI) or the orbital plane (Local Vertical System). In the Local Vertical System the X-axis is along the planet to spacecraft vector, the Z-axis is perpendicular to the orbital plane, and the Y-axis completes a right-handed system.

The Euler angles which are defined as:

ψ Rotation about the Z-axis

θ Rotation about the Y-axis

ϕ Rotation about the Z-axis

and are illustrated on Figure 3.2.1.4.3.

The orbital parameters, which are used to calculate the time dependent coordinate location of the spacecraft are illustrated on Table 3.2.4.1.2. Dynamic cross reference to these parameters is shown on Table 3.2.4.1.3.

Absorbed heat is processed and assembled for the panels through a call to Routine SHAD directly from the component performance routine. (See Routine SHAD.)

Having established the basic parameters the vector manipulation is performed to obtain the required angles and the components of incident heating are evaluated as follows:

Solar Radiation to a Flat Plate

The direct solar radiation to a flat plate is given by

$$q_s = S \cos \theta_3$$

where

q_s = Incident energy from the Sun (BTU/HR FT^2)

S = Solar constant (BTU/HR FT^2)

θ_3 = The angle between the vehicle-Sun vector and a normal to a flat plate element (DEG)

Planetary Thermal Radiation to a Flat Plate

The planetary thermal radiation from an isothermal body to a flat plate is given by:

$$q_t = F_t I_t$$

where

q_t = Incident planetary thermal radiation (BTU/HR FT^2)

F_t = View factor for a flat plate (nd)

I_t = Total energy emitted from planet unit area (BTU/HR FT^2)

and

$$I_t = (1 - a) S \frac{A_p}{A_t} = (1 - a) S/4$$

where S is the solar constant, a is the planetary albedo constant, A_p is the projected area of the planet, and A_t is the total surface area of the planet. For a sphere, $A_p/A_t = 1/4$.

The view factor F_t for a flat plate is defined by the following:

$$F_t = \frac{1}{2\pi}\left[\pi - 2 \sin^{-1} \frac{\sqrt{H^2 - R^2}}{H \sin \theta_2}\right] - \frac{1}{2\pi} \sin \left[2 \sin^{-1} \frac{\sqrt{H^2 - R^2}}{H \sin \theta_2}\right] +$$

$$\frac{1}{2} \frac{R^2}{H^2} \left\{-1 + \frac{2}{\pi} \sin^{-1} \frac{\sqrt{H^2 - R^2}}{R \tan \theta_2} + \frac{1}{\pi} \sin \left[2 \sin^{-1} \frac{\sqrt{H^2 - R^2}}{R \tan \theta_2}\right]\right\} \cos \theta_2$$

or if

$$\theta_2 < \tan^{-1} \frac{\sqrt{H^2 - R^2}}{R}$$

the expression for F_t is

$$F_t = \frac{-R^2}{H^2} \cos \theta_2$$

where

$H = R + h$

R = The radius of the planet (n mi)

h = Vehicle altitude (n mi)

θ_2 = The angle between a normal to the flat plate and the radius vector from the planet to the vehicle

Figure 3.2.1.4.4 shows the geometric relationships for planetary thermal radiation from an isothermal body to a flat plate.

Planetary Albedo to a Flat Plate

The planetary albedo radiation to a flat plate is given by

$$q_a = aF_a$$

where

q_a = Incident planetary albedo (BTU/HR FT^2)

F_a = View factor for a flat plate (nd)

S = Solar constant (BTU/HR FT^2)

a = Albedo constant

The view factor F_a for a flat plate was obtained from Reference 2. This expression is a modified solution for planetary thermal radiation multiplied with a correction term, which, since planetary albedo obeys Lambert's Law, accounts for the cosine distribution not only with respect to the angular radiation from a given area but over the sunlit surface of the planet as well.

The view factor for planetary albedo is expressed as

$$F_a = F_t\,(\theta_2, h)\left(0.86 + 0.14e^{-0.757\ h/R}\right)$$

$$\cos\left\{\theta_1 - \left[0.1369\ (\pi - \theta_2)^3 \cos\ (\theta_c)\left(1 - e^{-5.66\ h/R\ (\pi - \theta_2)^2}\right)\right]\right\}$$

where

h = Vehicle altitude (n mi)

θ_2 = Angle between a normal to the flat plate and the radius vector

θ_1 = The angle between the planet-Sun vector and the radius vector from the planet to the vehicle

θ_c = The angle of rotation of a normal to a flat plate element, measured from a plane containing the planet-Sun vector and the radius vector from the planet to the vehicle

Figure 3.2.1.4.5 shows the geometric relationships between the parameters.

When the spacecraft is shadowed by the planet it is orbiting, the solar heating rate to each flat element is set to zero. The position of the spacecraft relative to the Sun and the planet is checked in this subroutine to see if occulation has occurred.

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

                         ORBITAL HEATING
                       CONTROL PARAMETERS

ITEM                                         VALUE            UNIT

 1    CONTROL INDICATOR                        2              INTEGER
      1 = READ TAPE
      2 = CALCULATE TRAJECTORY

 2    UNIT CONVERSION FOR TAPE                 1              INTEGER
      1 = EARTH RADII(ER.)
      2 = KILOMETERS (KM.)

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

Figure 3.2.1.4.1. Typical Interactive Orbital Heating Control Display

Table 3.2.1.4.1. Edited Trajectory Tape Format

FORTRAN Tape Number 13

Identification: Edited Trajectory Information Tape
Type: Binary
Density: 800
1108 File Letter: K

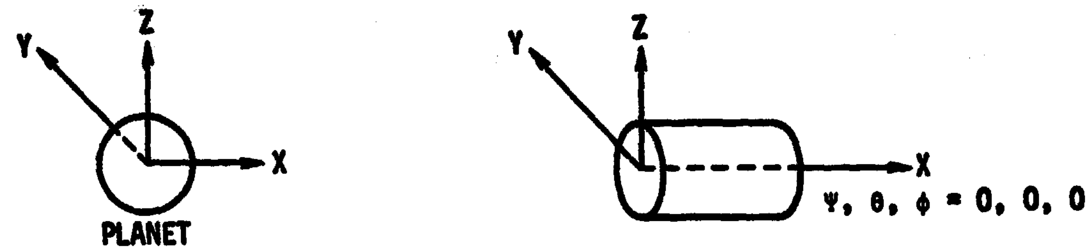
Record Description

Word Number	Type	Description		Units
1	R	Ground Elapsed Time (GET) in decimal hours		HR
2	I	Year	Calendar date	
3	I	Month		
4	I	Day		
5	I	Hour		
6	I	Minute		
7	I	Second		
8	I	Revolution Counter		
9	I	Physical Eclipse indicator (0 Sun, 1 shadow)		
10	I	Noon indicator (1 noon, 0 other)		
11	I	Not Used		
12	I	Not Used		
13	R	Vehicle vector	X	ER or KM
14	R	Vehicle vector	Y	ER or KM
15	R	Vehicle vector	Z	ER or KM
16	R	Vehicle vector	X (x dot)	ER/HR or KM/HR
17	R	Vehicle vector	Y (y dot)	ER/HR or KM/HR
18	R	Vehicle vector	Z (z dot)	ER/HR or KM/HR
19	R	Vehicle vector	R (radius vector to spacecraft)	ER or KM
20	R	Direction Cosines	XTX	
21	R	Direction Cosines	XTY	
22	R	Direction Cosines	XTZ	
23	R	Direction Cosines	YTX	
24	R	Direction Cosines	YTY	
25	R	Direction Cosines	YTZ	
26	R	Direction Cosines	ZTX	
27	R	Direction Cosines	ZTY	
28	R	Direction Cosines	ZTZ	
29	R	Sun vectors	X SUN	ER or KM
30	R	Sun vectors	Y SUN	ER or KM
31	R	Sun vectors	Z SUN	ER or KM
32	R	Solar Incidence Angle	Beta	DEG
33	R	Orbital period		HR

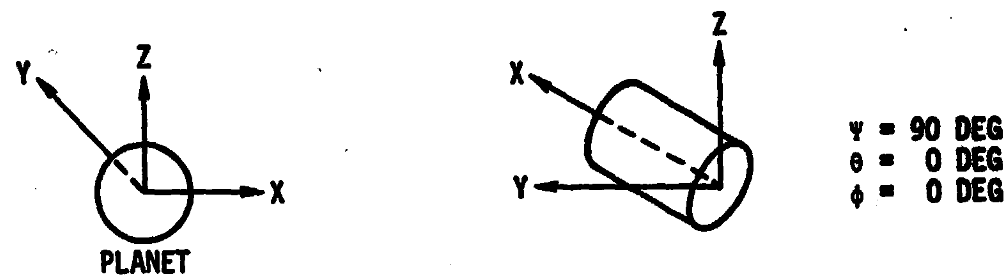
```
**************************************************************
                    ORBITAL PARAMETERS
ITEM                                    VALUE          UNIT
 1   COMP FREQUENCY                         1          INTEGER
 2   ATTITUDE HOLD KEY                      1          INTEGER
     1 = INERTIAL
     2 = LOCAL VERTICAL
 3   SUN COORDINATE       X      2.3466000+04          ER.
 4                        Y      0.0000000             ER.
 5                        Z      0.0000000             ER.
 6   EULER ANGLE ABOUT    Z          .000              RAD.
 7                        Y          .000              RAD.
 8                        X          .000              RAD.
 9   ORBIT SEMIMAJOR AXIS           1.029              ER.
10   ORBIT ECCENTRICITY              .000              N/D
11   ORBIT INCLINATION               .000              RAD.
12   RIGHT ASCENSION                 .000              RAD.
13   ARGUMENT OF PERIGEE             .000              RAD.
14   TIME OF PERIGEE PASSAGE         .000              ER.
**************************************************************
```

Figure 3.2.1.4.2. Typical Interactive Orbital Parameter Display

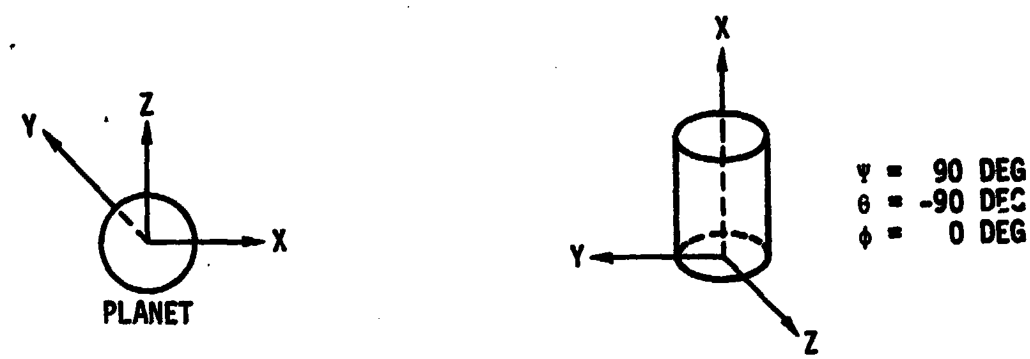
1. SC axis initially aligned with GCI axis



2. Rotate 90 degrees about Z-axis (Positive rotation is X-axis towards Y-axis)



3. Rotate 90 degrees about Y-axis (Positive rotation is Z-axis towards X-axis)



4. Rotate 90 degrees about X-axis (Positive rotation is Y-axis towards Z-axis)

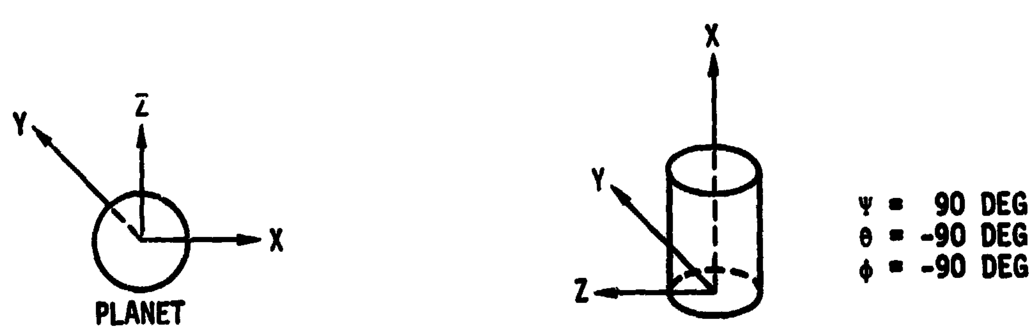
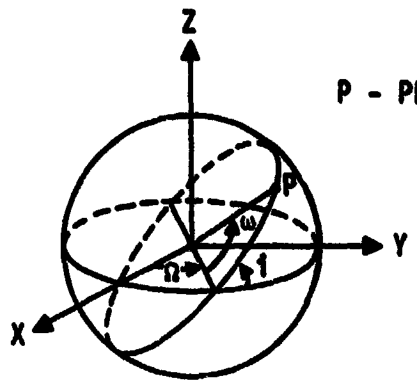


Figure 3.2.1.4.3. Illustration of Euler Angle Sequence Showing Spacecraft Position

Table 3.2.1.4.2. Classical Elements of an Orbit



The elements which define an orbit are:

a - Semimajor axis of the orbit

e - Eccentricity of the orbit

i - Inclination of the orbit, angle between the orbital plane and the equator $0° \leq i \leq 180°$

Ω - Right ascension of the ascending node $0° \leq \Omega \leq 360°$

ω - Argument of perigee

τ - Time of perigee passage

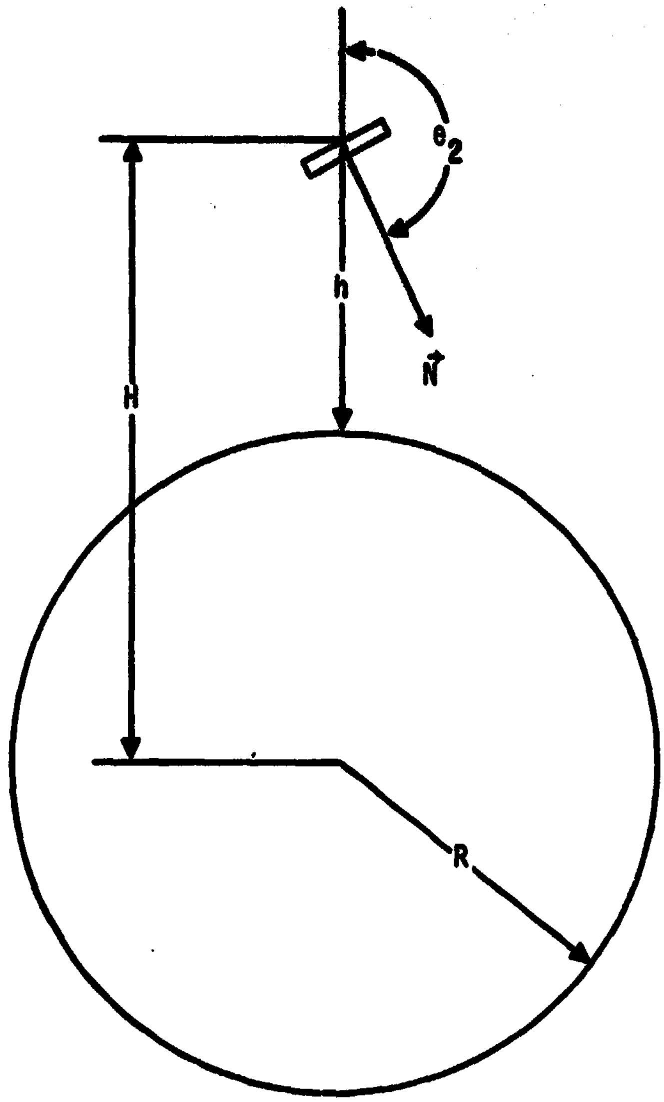


Figure 3.2.1.4.4. Planetary Thermal Radiation to a Flat Plate

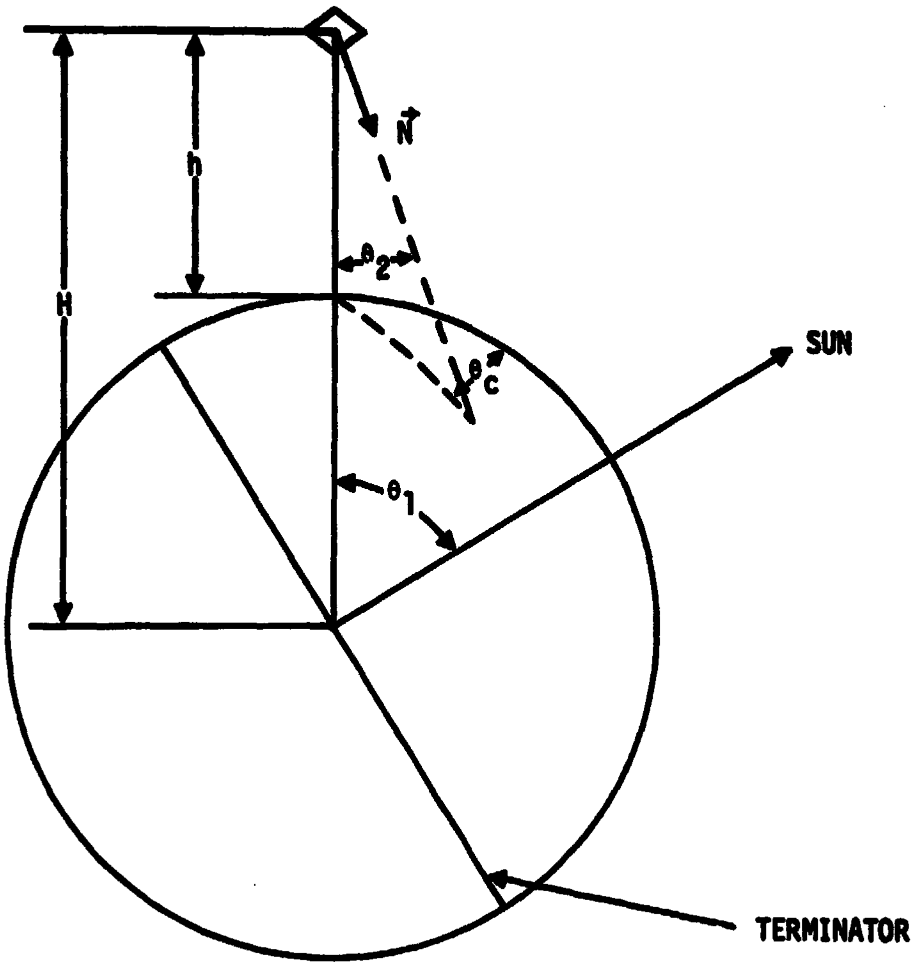


Figure 3.2.1.4.5. Planetary Albedo to a Flat Plate

Table 3.2.4.1.3. Dynamic Cross Reference to Orbital Parameters

VARIABLE	SYMBOL	UNITS	STORAGE	TYPE	COMMON
Compute frequency	-	INTEGER	IFREQ	I	HCONT
Attitude hold key	-	INTEGER	IHOLD	I	HEAT
Sun coordinate X	X_S	ER	SUN(1)	R	HEAT
Y	Y_S	ER	SUN(2)	R	HEAT
Z	Z_S	ER	SUN(3)	R	HEAT
Euler angle about Z	ψ	RAD	EULAN(1)	R	HEAT
Y	θ	RAD	EULAN(2)	R	HEAT
X	ϕ	RAD	EULAN(3)	R	HEAT
Orbit semimajor axis	a	ER	A	R	HEAT
Orbit eccentricity	e	FRACTION	E	R	HEAT
Right ascention	r	RAD	BO	R	HEAT
Argument of perigee	w	RAD	Sϕ	R	HEAT
Time of perigee passage	τ	HRS	TAU	R	HEAT
Inclination	i	RAD	E	R	HEAT

3.2.1.5 Routine SHAD

The absorbed heat for a panel i is assembled in Routine SHAD in response to a direct call from the component routine processing node i.

If the component routine processing node i does not reference shadowing the assembly is simply

$$q_{ABS} = \alpha(q_s + q_a) + \varepsilon\, q_t$$

from the three incident heat components calculated by control through Routine TRAJ and the panel solar absorbtivity and thermal emissivity prescribed for node i.

If the component routine processing node i references a shadowing node j and a stand-off vector storage location n the shadowing effect is taken into account before the absorbed heat is calculated.

The shadowing calculations set up two concentric solid angles defined by the angles of lune α_1 and α_2, which define the total and partial shadowing bounds for solar radiation as shown for a simple configuration on Figure 3.2.1.5.1. For simplicity the configuration is representative of a system in which the normal to i and j and the stand-off vector coincide. The panels may have any relative position on the spacecraft defined by their dihedral angle (β) and angle of incidence (α). Simularly for the stand-off vector parameters β_m and α_m. The parameters α_m and β_m are the angle of incidence and dihedral angles of a panel that result in a normal that is in the direction of a vector drawn from the center of panel i to the center of panel j. Panels i and j are separated by the distance m along this vector. Albedo and thermal shadowing effects are evaluated as:

$$0 \leq q_a = q_{ai} - q_{aj}$$

and

$$0 \leq q_t = q_{ti} - q_{tj}$$

for node i.

Interactive communication with the shadowing node and stand-off vector parameters is through the console display shown on Figure 3.1.2.6.3.

The cross reference to shadowed node, shadowing node and stand-off vector parameters are shown on Table 3.2.1.5.1.

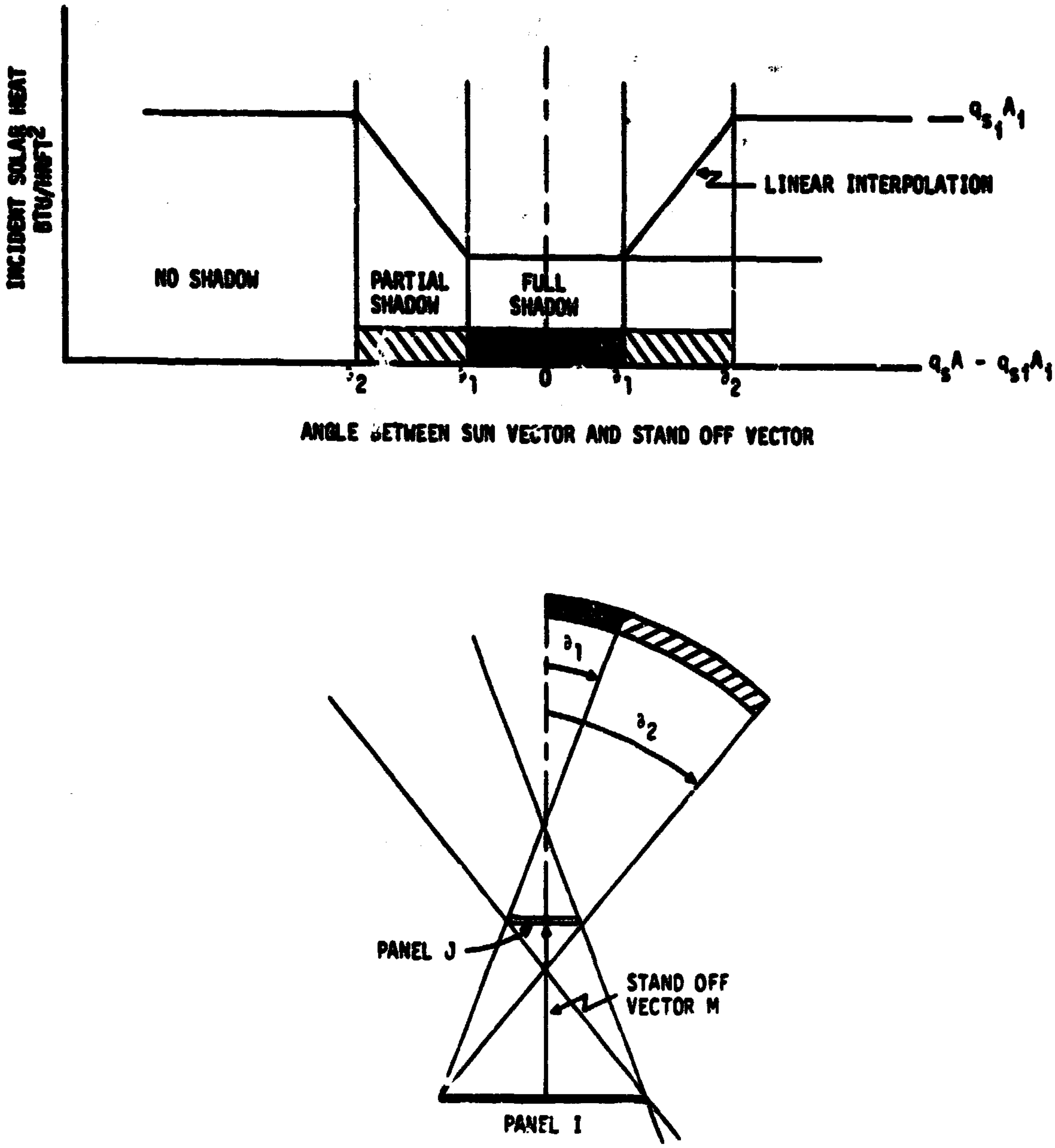


Figure 3.2 1.5.1. Typical Solar Shadowing Illustration

Table 3.2.1.5.1. Dynamic Cross Reference Parameters for Node I Shadowed by Node J With Stand-Off Vector Storage in M

VARIABLE	SYMBOL	UNITS	STORAGE	TYPE	COMMON
Shadowed node area	A_i	FT^2	C(I,9) + C(I,10)	R	MEAT
Shadowing node area	A_j	FT^2	C(J,10)	R	MEAT
Angle of incidence shadowed node	α_i	RAD	C(I,11)	R	MEAT
Angle of incidence shadowing node	α_j	RAD	C(J,11)	R	MEAT
Angle of incidence stand-off vector (equivalent)	α_m	RAD	C(M,11)	R	MEAT
Dihedral angle shadowed node	β_i	RAD	C(I,12)	R	MEAT
Dihedral angle shadowing node	β_j	RAD	C(J,12)	R	MEAT
Dihedral angle stand-off vector (equivalent)	δ_m	RAD	C(M,12)	R	MEAT
Stand-off distance	$_m$	FT	C(M,10)	R	MEAT

3.2.2 Output Routines

The basic control of output data is through the control Routine PRINT via initial Interactive Print Option Display shown on Figure 3.1.1.2.2. This section discusses the subsequent interactive, and possible dynamic, communication resulting from the selection of various print options, as well as various output functions which are automatically executed in response to the particular model component performance routines characteristics. A summary of the output routines is shown on Table 3.2.2.1.

Table 3.2.2.1. Summary of Output Routines

NODPRT	Displays fluid property data with generic names at selected print frequency.
NASPRT	Displays fluid property data with assigned node names at selected print frequency.
GASPR	Displays atmospheric property data at selected print frequency.
CONPRT	Displays consumables data for referenced sources at selected print frequency.
PLOOT	Stores data for plotting.
SCHEM	Displays modelled system schematic.

3.2.2.1. Routine NODPRT

The basic output of fluid property data is written from Routine NODPRT. The routine automatically outputs data during passive execution for all referenced node numbers in the order of reference as shown on Figure 3.2.2.1.1 unless the user specifies the select node option. The output at the print frequency specified at the time of initialization control (Figure 3.1.1.1.3). The generic name of the referenced nodes is included.

TFEAR

TEST TFEAR PLOT OPTION

FLUID PROPERTIES

TIME = 1.500

NODE. NO			COMP TEMP DEG	FLUID TEMP DEG	WCP BTU/HR DEG	HEAT LOAD BTU/HR
1	CABIN IN	/HEATER OUT		498.364	501.000	2001.000
2	CABIN OUT	/LIOH IN		503.450	501.000	
3	LIOH OUT	/COND. IN		503.870	501.000	
4	COND. OUT	/HEATER IN	498.448	496.573	501.000	450.000
5	EVAP IN	/JUNCTION	495.000	500.630	1490.483	
6	EVAP OUT	/PLATE IN	495.601	495.755	1490.483	
7	PLATE OUT	/INTF IN		495.625	1490.483	3793.755
8	INTF OUT	/PLATE IN	499.816	498.170	1490.483	150.000
9	PLATE OUT	/EXCH IN		499.598	1490.483	
10	EXCH OUT	/DIVERT		501.023	1490.483	
12	LEG	/BRANCH		501.023	7.452	
11	LEG	/MIXER		501.023	1483.031	
13	LEG	/RADIN	482.899	501.023	3.726	
17	LEG	/RADIN	482.899	501.023	3.726	
14	RADOUT	/RADIN	475.798	483.158	3.726	
15	RADOUT	/RADIN	470.936	476.049	3.726	
16	RADOUT	/MIXER		471.178	3.726	
18	RADOUT	/RADIN	475.798	483.158	3.726	
19	RADOUT	/RADIN	371.416	476.049	3.726	
20	RADOUT	/MIXER		373.764	3.726	
21	EXCH IN	/PLATE OUT		522.508	100.000	
22	EXCH OUT	/PLATE IN	523.615	501.291	100.090	200.000

Figure 3.2.2.1.1. Typical Fluid Property Output Data - Generic Names

3.2.2.2 Routine NASPRT

If the option to select nodes in is effect, output interactive communication is extended through a display requesting the node numbers to be output and whether or not to use assigned or generic node names. If the generic name option is in effect, the output is through Routine NODPRT, except that the selected set of node numbers (in the order they were input), rather than all referenced model nodes are printed. Selection of the option of assigning node names extends the interactive communication through a display requesting the nodal names in the same order as the node number selection. Subsequent output is through Routine NASPRT reflecting the selected node numbers and the assigned names as shown on Figure 3.2.2.2.1.

```
********************************************************************************
        TFEAR
        TEST TAPE READ CAPABILITY
                             FLUID PROPERTIES
TIME =     .000
                                          COMP      FLUID      WCP        HEAT
NODE                                      TEMP      TEMP       BTU/HR     LOAD
 NO                                       DEG       DEG        DEG        BTU/HR
  2   CABIN                                         510.165    501.000
  6   FUEL CELL                          521.000    498.474   1490.484
  8   EQUIPMENT                          521.000    515.559   1490.484
 22   PAYLOAD                            521.000    520.339    100.000
********************************************************************************
```

Figure 3.2.2.2.1. Typical Fluid Property Output Data - Assigned Names

3.2.2.3 Routine GASPR

Reference to atmospheric properties for one or more component performance routines will automatically execute the atmospheric data output Routine GASPR. The data as shown on Figure 3.2.2.3.1 is at the selected print frequency and includes all node numbers referencing atmospheric processing.

GAS PROPERTIES

TIME = 1.500

NODE NO	SPECIFIC HEAT	WATER PSI	NITROGEN PSI	OXYGEN PSI	CO2 PSI	TOTAL PSI
1	.210	.106	11.600	3.100	.073	14.700
2	.210	.107	11.600	3.100	.073	14.700
3	.210	.107	11.600	3.100	.073	14.700
4	.210	.106	11.600	3.100	.073	14.700

Figure 3.2.2.3.1. Typical Atmospheric Data Output

3.2.2.4 Routine CONPRT

Reference to one or more storage sources will automatically execute Routine CONPRT to output the summary of the status of the various sources. The output is at the selected print frequency and reflects the remaining quantity at the given time as shown on Figure 3.2.2.4.1. The remaining quantity for a source i is calculated internally as

CONSTA(I) - CONTOT(I)

referenced in the discussion of Routine CONSUM. Dynamic communication with the remaining quantity should reference these variables.

```
****************************************************************
                        CONSUMABLES
                           USAGE
TIME =      1.500
             INITIAL              QUANTITY            QUANTITY
SOURCE      AVAILABLE               USED              REMAINING
   1            .000               2.298              -2.298
   2            .000                .848               -.848
   3            .000                .000                .000
   4            .000               -.324                .324
   5            .000             197.947            -197.947
   6            .000              11.900             -11.900
```

ORIGINAL PAGE IS
OF POOR QUALITY

Figure 3.2.2.4.1. Typical Consumables Data Output

3.2.2.5 Routine PLOOT

Selection of the Plot Option will extend the interactive communication through a display requesting the node numbers and type of information to be plotted. A completed display of this type is shown on Figure 3.2.2.5.

The Plot Option automatically executes Routine PLOOT which stores the data to be plotted at each calculated time point. Near run termination the data stored is prepared in screen plots by Routine DRAW.

```
**************************************
             FUNCTION MENU
YPE             DESCRIPTION
 1     FLUID TEMP          (DEG/R)
 2     COMP TEMP           (DEG/R)
 3     FLOW RATE          (LBS/HR)
 4     HEAT               (BTU/HR)
 5     ACC CONSUM            (LBS)
 6     HEATER PWR         (BTU/HR)
 7     PRT PRES H2O          (PSI)
 8     PRT PRES N2           (PSI)
 9     PRT PRES O2           (PSI)
10     PRT PRES CO2         (MMHG)
11     HTR ENERGY            (BTU)
**************************************
```

```
**************************************************************
                    PLOT CONTROL
TEM        NODE NO         TYPE              MAX         MIN
 1               2       FLUID TEMP          .000        .000
 2              12       FLOW RATE           .000        .000
 3              22       HEAT                .000        .000
**************************************************************
```

Figure 3.2.2.5. Typical Plot Control Data Display

3.2.2.6 Routine SCHEM

Request for a schematic of the modelled system will automatically execute Routine SCHEM immediately prior to passive execution. Routine SCHEM processes the referenced node numbers and their generic names to assign a node number and type to each subplot in a composite display of the system schematic. Routine SCHEM prepares the control parameters for a single page of the schematics and then processes a call to Routine PICT to display that page. The paging process continues until the schematic is complete. A typical single page schematic is shown on Figure 3.2.2.6.1.

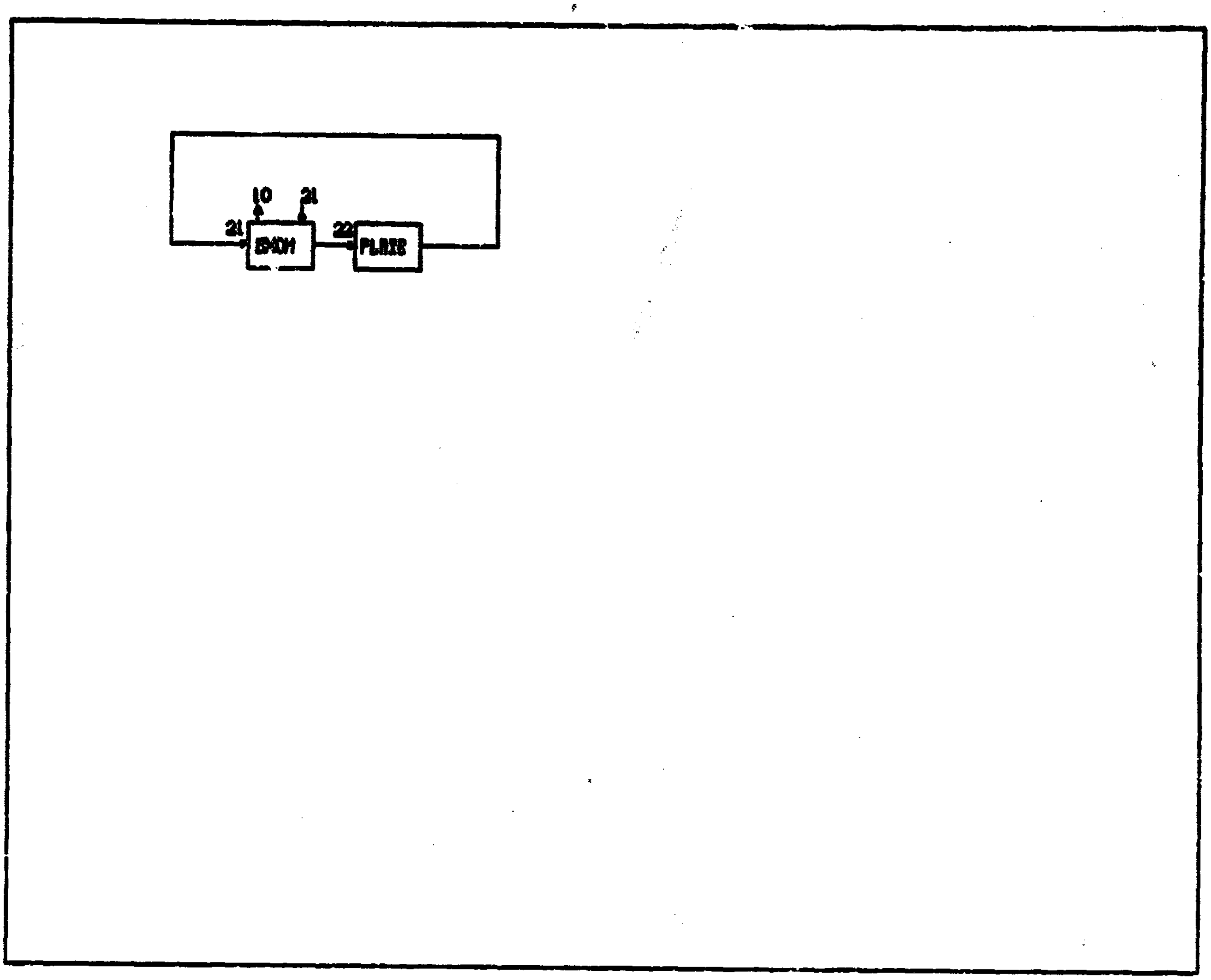


Figure 3.2.2.6.1. Typical Schematic Output

REFERENCES

1. Paul D. Aaron and M. R. Reumont, "Correlation of Carbon Dioxide System Performance with Qualification Test Data and Apollo 11 through 15 Flights," TRW 72.4910.1-3, 29 March 1972.

2. R. R. McMurchy and A. J. Kessler, "ASIS Incident Heating Model Computer Program," TRW 3141-23.111, 3 March 1967.