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SINDA/SINFLO COMPUTER ROUTINE

Report No. 2-53002/4R-3167

Revision A

VOLUME I

15 February 1975

Submitted By

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To

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VOUGHT SYSTEMS DIVISION
LTV AEROSPACE CORPORATION

PERFORMED UNDER
TRW SUBCONTRACT 183LK3E
NASA CONTRACT NAS9-10435

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1.0 INTRODUCTION AND SUMMARY

This report describes the SINFLO modification package for SINDA,[7*] which was developed by the Vought Systems Division (VSD) of LTV Aerospace Corporation under subcontract to TRW Systems Group during the period of August 1973 to February 1975. Also included in this report is a description of the capabilities added during the development of SINDA-VERSION 9[5]. The SINFLO package was developed to modify the SINDA preprocessor to accept and store the input data for fluid flow systems analysis and adding the FLOSOL user subroutine to perform the flow solution. This greatly reduced and simplified the user input required for analysis of flow problems. Also, a temperature calculation method, the Flow-Hybrid method which was developed in previous VSD thermal simulator routines[3], was incorporated for calculating fluid temperatures. The calculation method accuracy was improved by using fluid enthalpy rather than specific heat for the convective term of the fluid temperature equation.

The effort described herein was performed under Task Order LT-1 and Task Order LT-2 of Subcontract 183LK3E of NASA Contract NAS9-10435. Task Order LT-1 calls for the completion of the following tasks:

A. Optimize the SINDA Routine flow input data which includes the following effort:
   1. Establish the best input format for the flow systems data block to be added.
   2. Establish the format for storing the flow systems data by the preprocessor.
   3. Submit the user input and preprocessor output formats for mutual agreement between NASA-JSC, TRW, Inc. and VSD.
   4. Modify the preprocessor to accept the input from the new flow data block and store for use with processor routines.

B. Write routine to perform fluid flow analysis using data stored by proprocessor.

C. Develop Fluid Hybrid Routine for SINDA which will take advantage of the temperature calculation equation form for the fluid lumps to calculate the fluid and the tube lumps temperatures using an implicit method while the remaining structure lumps will be calculated utilizing the method specified by the user.

*Superscripts indicate reference numbers in Section 7.0

Task Order LT-2 required the completion of the following tasks:

A. Modify the following SINDA execution routines to interface with subroutine FLUID so that thermal analysis of fluid flow systems may be performed: (1) SNFRDL, (2) SNFRWD, (3) CINDSL, (4) FWDBCK, (5) SNDSNR, (6) STDSTL.

B. Add the capability to analyze valves which will split incoming flow between the two outlet sides of the valve in proportion to the valve position regardless of the pressure balance.

These tasks were completed and the resulting routines added to and substituted into the SINDA general thermal analyzer routine expanded the capabilities of the SINDA to include analysis of systems containing flowing fluids, fluid system controls and heat exchangers. A pressure-flow analysis of a system containing an arbitrary tube network is performed simultaneously with the thermal analysis during transient or steady state solutions. This permits the mutual influences of thermal and fluid problems to be included in the analysis.

The general flow solution capabilities include extensive valve characterizations and ability to match pump curves and system pressure-flow characteristics. The valves have been formulated so that either cooling (space radiator) or heating (solar absorber) situations may be controlled with any of the valve types. Pump options included are pressure rise as a tabulated function of system flow rate and pressure rise as a polynomial function of flow rate.

The formulation of the capabilities added during this effort are described in Section 2.0, modifications to the SINDA subroutines are described in Section 3.0, and the data input requirements for the new data block are described in Section 4.0. Section 5.0 describes user subroutines which have been added or modified by VSD including those developed for SINDA-VERSION9.

Appendix A contains a description of the capabilities incorporated into subroutines during the development of SINDA-VERSION 9 to facilitate analysis of radiation heat transfer in an enclosure. A description of the usage of the plot program is presented in Appendix C.

A discussion of the flow data storage is presented in Appendix B. Listings of the new and modified subroutines are given in Appendix D. Appendix D is contained in Volume II.

2.0 DISCUSSION OF METHODS

The analytical methods utilized in the subroutines which were added to the SINDA routine are described in this Section. Section 2.1 describes the methods used for calculating temperatures of flowing fluids and Section 2.2 describes methods used in the pressure/flow analysis of flow networks.

2.1 Thermal Analysis Methods

The Flow-Hybrid method for obtaining temperature solutions was formulated for use with several SINDA temperature solution routines including CNFRWD, CNFAST, CNBACK, CNFWBK, CINDSS, HYBRID, SNFRDL, SNFRWD, CINDSL, FWDBCK, SNDSNR and STDSTL. The formulation included utilization of the fluid flow analysis data for the thermal analysis thus minimizing input and data storage requirements. The Flow-Hybrid method is described separately below for explicit methods (CNFRWD, SNFRDL, SNFRWD, and CNFAST), implicit methods (CNBACK, FWDBCK and CNFWBK), general hybrid methods (HYBRID) and steady state (CINDSS, SNDSNR, STDSTL and CINDSL).

2.1.1 Flow-Hybrid Solution for Explicit Problems

The fluid nodes temperatures are solved using the "Flow-Hybrid" solution method in the explicit SINDA user subroutines, CNFRWD, SNFRDL, SNFRWD and CNFAST. This method requires that the finite difference equations be written in the implicit form for the fluid lumps, while remainder of the lumps in the problem are solved using the explicit methods.

The finite difference equations for the Flow-Hybrid method are as follows:

For the fluid lump

$$T_f{}' = T_f + \frac{\Delta\tau}{w_f c_f}\left[\dot{w}\,\bar{C}p\,(T_u{}' - T_f{}') + HA(T_t{}' - T_f{}') + Q_f\right] \tag{1}$$

For the tube lump

$$T_t{}' = T_t + \frac{\Delta\tau}{w_t c_t}\left[\sum_j G_{tj}(T_j - T_t) + HA(T_f{}' - T_t{}') + Q_t\right] \tag{2}$$

where:

T_f = the fluid lump temperature

T_t = the tube lump temperature

$\Delta\tau$ = time increment

w_f = weight of fluid lump

C_f = capacitance of the fluid

$\dot{w}$ = flowrate in the tube which contains the fluid lump

$\bar{C}p$ = mean specific heat for the flowing fluid between the upstream lump and the fluid lump

$$= \frac{h_f - h_u}{T_f - T_u}$$

h_f = the enthalpy of the fluid lump at temperature T_f

h_u = the enthalpy of the fluid lump at temperature T_u

T_u = the temperature of upstream lump

HA = the convection coefficient times area

G_{tj} = the conductance value from tube lump t to lump j

w_t = weight of tube lump t

c_t = specific heat of tube lump t
Q_f = the heat absorbed by fluid lump f
Q_t = the heat absorbed by tube lump t

If the fluid lump is the first in the tube, h_u is determined as follows:

$$h_u = \frac{\sum_k \dot{w}_k h_{ok}}{\sum_k \dot{w}_k}$$

where h_{ok} = is the enthalpy of the fluid leaving tube k and entering fluid lump f

$\dot{w}_k$ = is the flow rate of tube k

The value for T_u for the first fluid lump in a tube is obtained by reve··e interpolation of the enthalpy curve at h_u. The primed temperatures in equations (1) and (2) represent temperatures at the end of the iteration; the unprimed temperature represent these at the iteration start.

The fluid hybr~~i~~d solution methods are derived as follows:

Solve equation (2) for $T_t{}'$

$$T_t{}' = \frac{T_t + \frac{\Delta\tau}{W_t C_t}\left[\sum_j G_{tj}\,(T_j - T_t) + Q_t\right] + \frac{\Delta\tau HA}{W_t C_t}\,T_f{}'}{1 + \frac{\Delta\tau HA}{W_t C_t}}$$

$$= \frac{T_{ti}{}' + \frac{\Delta\tau HA}{W_t C_t}\,T_f{}'}{1 + \frac{\Delta\tau HA}{W_t C_t}} \qquad (3)$$

where $T_{ti}{}'$ is the intermediate tube temperature that would be obtained with no connection to the fluid lump.

If equation (3) is substituted into equation (1) and simplified we get:

$$T_f{}' = \frac{T_f + \frac{\Delta\tau}{W_f C_f}\left[\dot{w}\,\bar{C}p T_u{}' + \left(\frac{HA}{1 + \frac{HA\Delta\tau}{W_t C_t}}\right)T'_{ti} + Q_f\right]}{1 + \frac{\Delta\tau}{W_f C_f}\left[\dot{w}\,\bar{C}p + \frac{HA}{1 + \frac{HA\Delta\tau}{W_t C_t}}\right]} \qquad (4)$$

The value of $T_{ti}{}'$ in equation (3) is given by

$$T'_{ti} = T_t + \frac{\Delta\tau}{W_t C_t}\left[\sum_j G_{tj}\,(T_j - T_t) + Q_t\right] \qquad (5)$$

Examination of equation (4) reveals two primed temperatures: T_u' and T_{ti}'. Thus, we must calculate these values prior to evaluation of equation (4). The value of T_u' can be obtained if the order of calculations start with the first lump in the system and progresses around the system in order, one lump at a time. Since the value of T_{ti}' given by equation (5) contains no primed values, its value may be evaluated first. Thus, the order of calculations are:

(1) Calculate the value of all T_{ti}' using the normal explicit temperature calculations assuming no fluid lump convection exist. This is given by Equation (5).

(2) Calculate the value of all T_f' in order of their position in the tubes starting with the first lump in the first tube and progressing around the system.

(3) Update the tube temperature using equation (3) to obtain T_t'.

Of course the coefficients in equations (3), (4) and (5) are evaluated prior to evaluation of the equations. Methods used in determining coefficient values are discussed in Section 2.1.5.

2.1.2 Fluid Temperature Solution for Implicit Problems

The implicit user subroutines, CNBACK, FWDBCK and CNFWBK, were modified so that the fluid temperatures are calculated simultaneously with the other temperatures of the problem. For CNBACK, FWDBCK and CNFWBK, the fluid lump temperatures are calculated using the relation

$$T_f' = \frac{T_f + \frac{\Delta\tau}{w_f c_p}\left[\dot{w}\ \bar{C}_p T_u' + HAT_t' + Q_f\right]}{1 + \frac{\Delta\tau}{w_f c_p}\left[\dot{w}\ \bar{C}_p + HA\right]} \qquad (6)$$

Where all the variables are as defined for equations (1) and (2) and T_t' is the last calculated value of the tube lump temperature.

The tube temperatures are calculated using the normal equations but are modified to use the HAT_f' and HA terms as follows: For CNBACK:

$$T_t' = \frac{T_t + \frac{\Delta\tau}{w_t c_t}\left[\sum_j G_{tj}T_j' + Q_t' + HAT_f'\right]}{1 + \frac{\Delta\tau}{w_t c_t}\left[\sum_j G_{tj} + HA\right]} \tag{7}$$

For CNFWBK

$$T_t' = \frac{T_t + \frac{\Delta\tau}{2w_t c_t}\left[\sum_j G_{tj}T_j' + Q_t' + HAT_f' + \Sigma\, G_{tj}(T_j - T_t) + Q_t + HA(T_f - T_t)\right]}{1 + \frac{\Delta\tau}{2w_t c_t}\left[\sum_j G_{tj} + HA\right]} \tag{8}$$

The order of calculations for the implicit routines are:

(1) Calculate the value of all T_f using equation (6). Fluid flow data is utilized to obtain coefficients in the equation.

(2) During the calculation in (1) the HA values and the fluid lump number for each tube lump are stored in the X array. (captured dynamic storage)

(3) The temperatures for the remaining lumps are calculated using the normal calculations, except tube lump temperatures equations are modified to include the HA and HAT terms as shown in equations (7) and (8).

2.1.3 Fluid Temperature Solution for General Hybrid Problems

The HYBRID user subroutine was modified to permit calculation of fluid lump temperatures during the normal temperature calculations. Explicit and implicit lumps are determined by calculating the CSG value for each lump and comparing it with the input time increment. Those lumps with CSG values larger than the input time increment are explicit and the remaining lumps are implicit. If the tube lumps are all explicit, the fluid and tube lump temperatures are calculated using equations (3) and (4). If any of the tube lumps are implicit, the fluid lumps are calculated using equation (6) and tube lumps are calculated using the following equation:

$$T_t' = \frac{T_t + \frac{\Delta\tau}{w_t c_t}\left[\alpha \sum_{ji=1}^{ni} G_{ji} T_{ji}' + HAT_f' + (1-\alpha)\sum_{ji=1}^{ni} G_{ji}(T_{ji} - T_t) + Q_t'' + \sum_{je=1}^{ne} G_{je}(T_{je} - T_t)\right]}{1 + \frac{\Delta\tau}{w_t c_t}\left[\alpha \sum_{ji=1}^{ni} G_{ji} + HA\right]} \tag{9}$$

Where α = the point in the iteration for evaluating heat flux

G_{ji} = the conductance value from tube lump t to lump ji, where lump ji is implicit

G_{je} = the conductance value from tube lump t to lump je, where lump je is explicit

Q_t'' = the heat absorbed by tube lump t evaluated at $\tau + \alpha\Delta\tau$

The following calculation procedure is used:

(1) Determine the explicit and implicit lumps by comparing the CSG value for each lump with the input computation interval.

(2) Determine which of the explicit lumps determined in step (1) are interface lumps. Interface lumps are subsequently treated as implicit lumps. Interface lumps are any explicit lumps which are connected to an implicit lump. If any tube lump is treated as an implicit lump, all tube lumps are treated as implicit lumps.

(3) Calculate explicit lump temperatures using the same $\Sigma\, G_{je}(T_j - T_i)$ for all interface nodes and for adjacent lumps if the adjacent lumps are implicit.

(4) Calculate fluid and tube lump temperatures for tube lumps which are explicit.

(5) Calculate implicit lump temperatures.

2.1.4 Fluid Temperature Solution for Steady State Problems

The steady state solution subroutines, CINDSS, CINDSL, STDSTL were modified to include a calculation of fluid lump temperatures. The following relations are used for calculating the fluid and tube lump temperatures:

For the tube lump:

$$T_t' = \frac{\Sigma G_{ij} T_j + Q_t + HAT_t}{\Sigma G_{ij} + HA} \tag{10}$$

For the fluid lump:

$$T_f' = \frac{\dot{w}\,\bar{C}p\,T_u' + HAT_t' + Q_f}{\dot{w}\,\bar{C}p + HA} \tag{11}$$

The following order of calculation is used:

(1) Calculate the fluid lump temperatures.

(2) Calculate temperatures for all other lumps using the normal SINDA temperature equation, except tube lump temperature equations are modified to include the HA and HAT terms.

2.1.5 Coefficient To Temperature Equations

A brief description of the methods used to obtain the convection heat transfer coefficient, H, and the mean specific heat for a flowing fluid $\bar{C}p$ (Equation 1) is considered to be of value. They are discussed separately below.

Convection Coefficient Determination

Several methods are available to the SINFLO user for determine the heat transfer coefficient, H. The different options are available for each fluid lump and are specified by supplying values for F1, the eighth value of the type array (see Section 4.2). When F1 is real, the programmed equations for flow in a tube are used to obtain H. Using this method, the flow regime is assumed to be laminar when the Reynolds number is 2000 or less. For this regime the convection heat transfer coefficient is calculated by:

$$h = \frac{k}{D}\left[3.66 \cdot F1 + \frac{.0155 \cdot F2}{\frac{1}{R_e P_r}\frac{X}{D} + .015\left[\frac{1}{R_e P_r}\frac{X}{D}\right]^{1/3}}\right] \tag{12}$$

where: k = thermal conductivity

D = hydraulic diameter to flow

X = distance from tube entrance

Re = Reynolds number

$= \frac{4\,\dot{m}}{\mu P}$

$\dot{m}$ = flow rate of fluid

μ = viscosity of fluid

P = wetted perimeter of fluid flow passage

F1 = An input factor for modifying fully developed flow

F2 = An input factor for modifying developing flow

Equation (12) is a curve fit obtained by VSD to approximate the Graetz solution to flow in a tube for values of $\frac{X}{D}\,\frac{1}{RePr}$ greater than 0.001. The convection heat transfer coefficient for flow in a tube in the transition flow regime ($2000 < Re < 6400$) is approximated by the following relation:

$$h = \frac{K}{D}\left[0.116\,(Re^{2/3} - 125)\,(Pr)^{1/3}\right] \tag{13}$$

This relation was derived by Hausen and holds only for fully developed flow. The relation used to determine h for turbulent flow ($Re \geq 6400$) is the following

$$h = .023\,\frac{K}{D}\,(Re)^{.8}(Pr)^{1/3} \tag{14}$$

If F1 is the integer 1, a more general option is used for determining the convection heat transfer coefficient. A curve of $St(Pr)^{2/3}$ vs Reynolds No. is interpolated to obtain the value of $St(Pr)^{2/3}$. That is,

$$St(PR)^{2/3} = F(Re) \tag{15}$$

where: St = Stanton number

$= \frac{Nu}{Re\,Pr}$

$= \frac{h}{CpV}$

V = Average fluid velocity

$F(Re)$ = An arbitrary function of Reynolds number which the user inputs as a table (identified by F2)

The heat transfer coefficient is calculated by

$$h = \frac{K}{D} F(Re)\, Re(Pr)^{1/3} \tag{16}$$

If F1 is input as the integer 2 the convection heat transfer coefficient is obtained by direct interpolation of a curve of heat transfer coefficient vs flowrate which is identified by F2.

<u>Mean Specific Heat</u>

The method for obtaining the convective term ($\dot{w}Cp$) in equation (1) was modified with SINFLO to get better accuracy. Rather than just using the lump specific heat, a mean value of specific heat was obtained as follows.

The mean specific heat for a fluid going from upstream temperature T_u to fluid lump temperature T_f may be obtained by integrating:

$$\bar{C}p = \frac{\int_{T_u}^{T_f} Cp(T) \cdot dT}{\int_{T_u}^{T_f} dT}$$

$$= \frac{\int_{T_o}^{T_f} Cp(T)\, dT - \int_{T_o}^{T_u} Cp(T)\, dT}{T_f - T_u}$$

$$= \frac{h_f - h_u}{T_f - T_u} \tag{17}$$

Where h is the fluid enthalpy

Equation (17) is used to obtain the mean specific heat for equation (1). The enthalpy curve is required as input.

For temperature lumps that have multiple upstream lumps, such as mixing junctions, the value of h_u is determined as follows:

$$h_u = \frac{\sum_i w_i hu_i}{\sum_i w_i} \tag{18}$$

and the upstream temperature, T_u, obtained by reverse interpolation of the enthalpy curve. Equation (17) is then applied using the values of h_u and T_f thus obtained.

2.1.6 Heat Exchanger Analysis

Five subroutines have been written to facilitate the thermal analysis of systems containing heat exchangers. These are HXCNT for analysis of counter flow heat exchangers, HXPAR for parallel flow heat exchangers, HXCROS for cross flow heat exchangers, HXEFF for any heat exchanger with an input effectiveness, and HXCOND for condensing heat exchangers. These subroutines calculate the outlet temperatures of two sides based upon the inlet temperatures and heat exchanger effectiveness. The relations used for calculating effectiveness are described below.

2.1.6.1 Counterflow Heat Exchanger

Subroutine HXCNT calculates the heat exchanger effectiveness using the relation from Reference 1 for counterflow heat exchangers. That is,

$$\epsilon = \frac{1-e^{-\left[\frac{UA}{(MC)_s}\left\{1-\frac{(MC)_s}{(MC)_l}\right\}\right]}}{1-\frac{(MC)_s}{(MC)_l}\, e^{-\left[\frac{UA}{(MC)_s}\left\{1-\frac{(MC)_s}{(MC)_l}\right\}\right]}} \tag{19}$$

Where ϵ = effectiveness

UA = overall effectiveness

$(MC)_s$ = mass, specific heat product for the side with the smallest MC

$(MC)_l$ = mass, specific heat product for the side with the largest MC

The limiting cases for this relation are:

(1) When $(MC)_s/(MC)_l = 0$,

$$\varepsilon = 1-e^{-UA/(MC)_s}$$

(2) When $(MC)_s/(MC)_l = 1$

$$\varepsilon = \frac{\frac{UA}{(MC)_s}}{1 + \frac{UA}{(MC)_s}} = \frac{UA}{(MC)_s + UA}$$

Using the effectiveness as calculated by the above method, the outlet temperatures are calculated as follows:

1. For the side with the smallest MC, $(MC)_s$:

$$Tout_s = Tin_s - \varepsilon\,(Tin_s - Tin_l) \quad (20)$$

2. The enthalpy of outlet for the side with the large MC is then calculated by

$$hout_\ell = hin_\ell + (hin_s - hout_s)\,\frac{\dot{w}_s}{\dot{w}_\ell} \quad (21)$$

where:

$hout_\ell$	=	enthalpy of the outlet for the side with the large MC
hin_ℓ	=	enthalpy of the inlet for the side with the large MC
hin_s	=	enthalpy of the inlet for the side with the small MC
$hout_s$	=	enthalpy of the outlet for the side with the small MC
$\dot{w}_s$	=	flow rate of the side with the small MC
$\dot{w}_\ell$	=	flow rate of the side with the large MC

3. $Tout_\ell$ is obtained by reverse interpolation of the enthalpy curve at $hout_\ell$.

2.1.6.2 Parallel Flow Heat Exchanger

Subroutine HXPAR calculates the heat exchanger effectiveness using the relation for parallel flow heat exchangers[1] which is:

$$\epsilon = \frac{1 - e^{-\frac{UA}{(MC)_s}\left[\frac{1+(MC)_s}{(MC)_l}\right]}}{1 + \frac{(MC)_s}{(MC)_l}} \tag{22}$$

The limiting cases are

(1) When $(MC)_s/(MC)_l = 0$,

$$\epsilon = 1 - e^{-UA/(MC)_s}$$

(2) When $(MC)_s/(MC)_l = 1.$,

$$\epsilon = \frac{1 - e^{-2\frac{UA}{(MC)_s}}}{2.0}$$

The heat exchanger outlet temperatures are then calculated using the method described for HXCNT.

2.1.6.3 Cross Flow Heat Exchanger

Subroutine HXCROS calculates the effectiveness for cross flow heat exchangers using one of the four relations below depending upon mixing of the streams.

Both Streams Unmixed

$$\epsilon = 1 - e^{\left[\left(e^{\left[-\frac{UA}{(MC)_s}\frac{(MC)_s}{(MC)_l}\eta\right]}-1\right)\frac{(MC)_l}{(MC)_s}\frac{1}{\eta}\right]} \tag{23}$$

Where $\eta = \left[\frac{(MC)_s}{UA}\right]^{0.22}$

Both Streams Mixed

$$\epsilon = \frac{\frac{UA}{(MC)_s}}{\frac{\frac{UA}{MC_s}}{1-e^{-\frac{UA}{(MC)_s}}} + \frac{\frac{UA}{(MC)_l}}{1-e^{-\frac{UA}{(MC)_l}}}} \tag{24}$$

Stream $(MC)_s$ Unmixed

$$\epsilon = \frac{1 - e^{-\frac{(MC)_s}{(MC)_l}\left[1 - e^{-\frac{UA}{(MC)_s}}\right]}}{\frac{(MC)_s}{(MC)_l}} \tag{25}$$

Stream $(MC)_l$ Unmixed

$$\epsilon = 1 - e^{-\frac{(MC)_l}{(MC)_s}\left[1 - e^{-\frac{UA}{(MC)_l}}\right]} \tag{26}$$

The heat exchanger outlet temperatures are calculated using the method described for HXCNT.

2.1.6.4 User Supplied Effectiveness

Subroutine HXEFF was written to perform heat exchanger thermal analysis with a user supplied effectiveness. The effectiveness may either be supplied as a constant or as an array number which gives the effectiveness as a bivariant function of the flowrates on the two sides. The outlet temperatures are then calculated using the method described for HXCNT.

2.1.6.5 Condensing Heat Exchanger

Subroutine HXCOND was written to analyze a condensing heat exchanger. The effectiveness may either be supplied as a constant or as a trivariant function of humidity, flow rate of the gas, and flow rate of the coolant. The outlet temperatures are calculated as follows:

$$TG_{out} = TG_{in} - \varepsilon\,(TG_{in} - TC_{in})$$

where: TG_{out} = temperature of the gas out of the heat exchanger

ε = effectiveness

TG_{in} = temperature of the gas into the heat exchanger

TC_{in} = temperature of the coolant into the heat exchanger

The saturation pressure is given by

$$PB_{out} = .1217\, e^{\left(19.3 \frac{TG_{out}-500}{TG_{out}}\right)}$$

where: PB_{out} = saturation pressure of the gas

And the outlet humidity is

$$\psi = \frac{XMIMO \cdot PBOUT}{P - PBOUT}$$

Where ψ = humidity ($\psi_{in} > \psi_{out} > 0$)

XMIMO = molecular weight ratio

P = total gas pressure

The flow rate of the liquid is

$$\dot{w}_{\ell} = \dot{w}_g\, (\psi_{in} - \psi_{out})$$

where: $\dot{w}_{\ell}$ = flow rate of the liquid

$\dot{w}_g$ = flow rate of the gas

The enthalpy of the coolant out of the heat exchanger is

$$hc_{out} = hc_{in} + \frac{[\ \{(hg_{in} + hg_{out})\ \dot{w}_g\ \} + \dot{w}_{\ell} \cdot XLAM\ ]}{\dot{w}_c}$$

where: XLAM = latent heat of vaporization

The outlet temperature of the coolant is obtained by reverse interpolation of the enthalpy curve at hc_{out}.

2.1.7 Cabin Analysis

A subroutine has been written for use with SINDA which will give the user the ability to perform thermal analyses on cabin air systems including condensation on the walls and a vapor mass balance. The cabin heat transfer and condensation analysis involves the two-component flow of a condensible vapor and a non-condensable gas, with condensation of the vapor occurring on surfaces in contact with the fluid. Two problems of this nature have been studied extensively.

1. Condensation on, or evaporation from, a surface over which a free stream of fluid is passing. In this case, for relatively low mass transfer rates, the fluid properties can be assumed to be constant.
2. Dehumidification of a confined fluid stream by a bank of tubes. In this case there is a marked change in the temperature and vapor content of the fluid, and the detailed deposition of the condensate is not of primary interest. This type of analysis is usually handled on an overall basis similar to heat exchanges effectiveness calculations.

The following additional assumptions have been made with respect to the cabin atmospheric conditions.

1. The heat of circulation in the cabin is sufficiently high that the temperature and humidity are effectively the same throughout the cabin.
2. The velocity at all points where heat transfer and/or condensation can occur is known, and is proportional to the total mass flow rate in the cabin.

These assumptions make it possible to calculate the heat and vapor balance in the cabin for the entire volume as a unit, and to solve the heat transfer and condensation equations at each node independently of the other nodes.

Cabin humidity can be determined from an overall vapor balance in the cabin. The total vapor in the cabin at the end of an iteration is:

$$W_V = W_V^{\,i-1} + W_V \text{ in} - W_V \text{ out} - \Sigma W_L$$

Where
W_V = mass of vapor in cabin at end of iteration i
$W_V^{\,i-1}$ = mass of vapor in cabin at start of iteration i-1
$W_{V\,in}$ = mass of vapor flowing into cabin during iteration i
$W_{V\,out}$ = mass of vapor flowing out of cabin during iteration i
ΣW_L = mass of vapor condensed during iteration ·1

$W_{V\,in}$ is determined from the known conditions of the gas flowing into the cabin.

$$W_{V\,in} = \dot{m} \text{ in} \left[\frac{\psi in}{1. + \psi in} \right]$$

Where
$\dot{m}$ in = mass flow rate into cabin
ψ in = specific humidity of gas flowing into cabin
= time increment

It is assumed that an equal volume of gas is flowing out of the cabin. Then,

$$W_{V\,out} = \dot{m} \text{ out} \left[\frac{\psi_c}{1 + \psi_c} \right]$$

Where ψ_c = specific humidity in the cabin (at the end of the previous iteration)

and $\dot{m}$ out = $\dot{m}$ in $[\rho_c / \rho in]$

Where
ρ_c = cabin density
ρin = density of gas flowing into cabin

The condensation term ΣW_L is determined from the calculations for the individual nodes as described below. The properties of the cabin atmosphere are determined from the calculated value of W_V. The vapor pressure in the cabin is

$$P_v = \frac{W_v}{V_c} R_v T_c$$

Where V_c = cabin volume

R_v = gas constant

T_c = temperature of cabin gas

P_v = vapor pressure

Assuming that the cabin pressure P_c is a constant, the gas partial pressure P_a is:

$$P_a = P_c - P_v$$

and $$W_a = \frac{P_a}{R_a T_c}$$

Where W_a = mass of non-condensible gas in the cabin.

Now the new value of specific humidity in the cabin can be determined by

$$\psi_c = \frac{W_v}{W_a}$$

The properties of the atmosphere can now be determined by

$$\mu c = \frac{X\mu g + \psi c \mu v}{X + \psi c}$$

$$Cpc = \frac{Cpg + \psi cCpv}{1 + \psi c}$$

$$k_c = \frac{Xkg + \psi ckv}{X + \psi c}$$

$$\rho c = \frac{W_v + W_s}{V_c}$$

Where μ = viscosity

C_p = specific heat

k = thermal conductivity

X = molecular weight ratio, $\frac{M_v}{M_g}$

and all values are evaluated at T_c^{i-1}. Cabin temperature T_c can be determined by a heat balance on the cabin atmosphere.

$$T_c = T_c^{i-1} + \frac{\dot{m}\ \text{in}\ C_{pc}\,(T_{in} - T_c^{i-1}) - \Sigma Q_L}{(W_V + W_A)\ \ C_{pc}}$$

Where T_c^{i-1} = T_c after previous iteration

T_{in} = temperature of gas flowing into cabin

ΣQ_L = net heat loss to cabin lumps

The heat transfer between the cabin atmosphere and the tube and structure lumps in the cabin is defined by:

$$Q_{Li} = hA_{Li}\ \left[\ Tc - T_{Li}\ \right]\Delta\tau$$

Where h = heat transfer coefficient
A_{Li} = heat transfer area of lump
T_{Li} = temperature of tube lump
$\Delta\tau$ = time increment

Using the Colburn-Chilton heat transfer-mass transfer analogy, the condensation (or evaporation) at the tube lump is determined by:

$$\Delta W_{Li} = K_m\ A_{Li}\left[P_V - P_{wi}\right]\Delta\tau$$

Where W_{Li} = condensation on wall, lb.

K_m = mass transfer coefficient

P_{wi} = vapor pressure at T_{Li}

The latent heat addition to the lump due to this condensation is

$$\Delta Q_\lambda = \Delta W_{Li}\lambda$$

Where λ = latent heat of vaporization

The vapor pressure P_{wi} can be determined by a relationship derived from the Clausius-Clapeyron equation and the perfect gas law (Appendix K of Reference 3).

$$P_{wi} = P_o \exp\left\{ \frac{\lambda}{R_g T_o} \left[\frac{T_{Li} - T_o}{T_{Li}} \right] \right\}$$

Where P_o is known vapor pressure at a reference temperature T_o.

Three methods are available for determining mass and heat transfer coefficient. For tube lumps the equations from Reference 1 for gas flowing normal to the tube axis was assumed. Three different equations are used depending on the value of the Reynold's number.

$$Nu = 0.43 + .533 \, (Re)^{.5} \, (Pr)^{.31} \quad Re < 4000$$

$$Nu = 0.43 + .193 \, (Re)^{.618} \, (Pr)^{.31} \quad 4000 < Re < 40000$$

$$Nu = 0.43 + .0265 \, (Re)^{.805} \, (Pr)^{.31} \quad 40000 < Re < 400000$$

These equations were derived for an air-vapor mixture, but should be relatively accurate for other similar gases. The Nusselt and Reynold's numbers in the equations are defined using the tube diameter for the characteristic dimension, and the velocity in the Reynold's number is input at each lump and ratioed to the total cabin atmosphere flow rate.

$$\nu i = \nu io \frac{\dot{W}c}{\dot{W}co}$$

Where $\dot{W}co$ = nominal cabin atmosphere circulation rate
νio = velocity at lump at Wco
$\dot{W}_c$ = circulation rate at time of calculation

The second option assumes flat plate flow for cabin wall lumps. In this case the heat transfer coefficient, for laminar flow, varies along the plate. Hence, direction of gas flow and the location of an assumed leading edge must be assumed. The equation for flat plates from Reference 1 is:

$$N_u = 0.332 \, Re^{.5} \, Pr^{1/3}$$

where the Nusselt and Reynold's numbers are local values and are defined by the distance X from the assumed leading edge. For a wall lump of length L_i which is located a distance L_{io} from the assumed leading edge, the average Nusselt number can be defined as:

$$N_u = 0.664 \; Pr^{1/3} \left[(Re_1)^{.5} - (Re_o)^{.5} \right]$$

Where N_u is defined by L_i
Re_o is defined by L_{io}
Re_1 is defined by $L_{io} + L_i$

The third option is a direct user input for convective heat transfer coefficient.

For the determination of mass transfer coefficients, the same equations which were used for heat transfer coefficient can be used with the Sherwood number substituted for Nusselt number and Schmidt number for Prandtl number. However, if the diffusion coefficient for the cabin is approximately equal to thermal diffusivity, the Sherwood number is equal to the Nusselt number and the mass transfer coefficient can be determined directly from the heat transfer coefficient. That is:

$$Sh = Nu$$

$$\frac{K_m R T_g x}{D} = \frac{h_x}{k}$$

If $D \cong \alpha$ then

$$K_m = \frac{hD}{\alpha \rho C_p R T_g} \qquad (28)$$

$$K_m \cong \frac{h}{C_p P_c}$$

Equation (28) is the Lewis relationship (Reference 1). For a mixture of oxygen and water vapor characteristic values are .866 for the diffusion coefficient, D, and .879 for thermal diffusivity, α, so the relationship should be valid.

For cabin tube and wall lumps the values for ΔQ_{Li} and $\Delta Q_{\lambda i}$ are added to the basic heat balance equation for these lumps. Values for ΔQ_{Li}

are summed for all participating lumps for input to the cabin atmosphere heat balance. Values for ΔWL_i are also summed for all lumps for cabin humidity balance, and the value for total water condensed on each lump WL_i is maintained.

If the rate of evaporation or condensation is high it would be possible for the cabin humidity to change significantly during a single iteration. This could lead, for example, to overestimating condensation by assuming that the humidity is constant in the calculation. A test of the approximate vapor pressure in the cabin at the end of the iteration is made, and the condensation or evaporation at any lump is reduced, if the sign of the ΔWL_i term is changed. A value W_V' is calculated by:

$$W_V' = W_V^{i-1} - \Sigma W_L i$$

and

$$P_V' = \frac{W_V'}{144\ V_C} R_V T_g$$

Then for each lump if

$$\frac{P_V' - P_{wi}}{P_V - P_{wi}} < 0$$

a new value of $\Delta W_L i$ is calculated by:

$$\Delta W_{Li} = \Delta W_{Li} \left[\frac{P_V - P_{wi}}{P_V - P_V'} \right]$$

The new values of ΔW_{Li} are now again summed for the new value of $\Sigma \Delta W_L$ for establishing cabin humidity for the next iteration. A test is also made to assure that W_V' is never less than zero.

2.2 Fluid Flow Analysis

Subroutine FLOSOL was written as a SINDA user subroutine to provide the ability to perform fluid pressure/flow analysis for flow of an incompressible fluid in tubes. The fluid flow analysis of FLOSOL is integrated with the thermal analysis capability so that the temperature dependence of properties is included in the pressure balances. FLOSOL is called from the VARIBLES 2 user logic block.

FLOSOL performs a pressure-flow balance on a general flow network including the following effects:

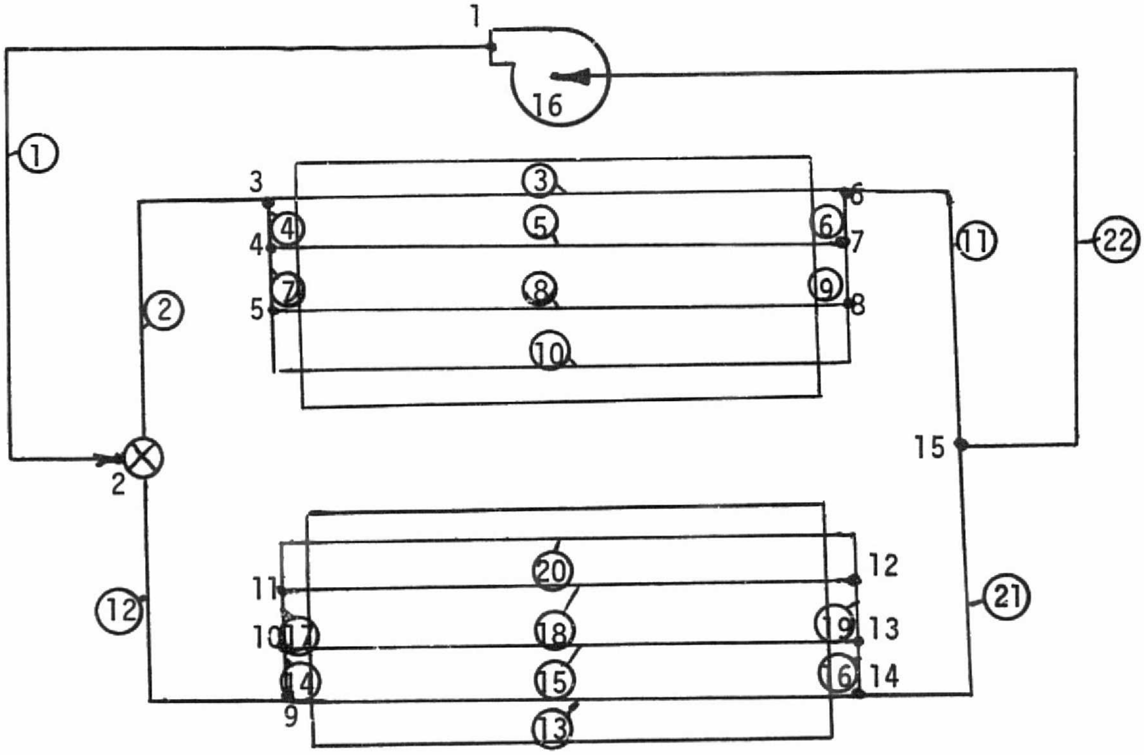
(1) Friction pressure drop
(2) Orifices and fitting type pressure losses
(3) Valves
(4) Pumps
(5) Incoming flow sources at any pressure point in the system

The user describes the flow model to the subroutine by supplying the tube network connections and information concerning fluid properties, flow geometry, temperature model lumps, orifices, valves and pumps. Using this information, the subroutine determines the flow distribution required to satisfy (1) the conservation of mass at each node point and (2) equal pressure drops across tubes in parallel. The model used to describe the flow system and the analytical methods for determining the solution are described below.

2.2.1 Overall Flow Model Description

A flow problem may be analyzed with FLOSOL, simultaneously with a thermal analysis, so that the flow solution is continually updated based on the thermal conditions. To perform a flow analysis, the user must input a mathematical model of the flow system. The flow system is assumed to consist of a set of interconnected tubes such as the example shown in Figure 1 , which consists of two radiator panels, each containing four tubes and connected so that they flow in parallel.

For clarity the following definitions are made at this point:



(X) Tube Numbers

XX Pressure Nodes

FIGURE 1 FLOW SYSTEM SCHEMATIC

(1) A tube is any single length of pipe between two pressure nodes. A tube "contains" fluid temperature nodes and may contain as many of these as required.

(2) A pressure node is located at each end of a tube. As many tubes as desired may be connected at a node junction and a node must exist at the junctions of two flow pipes.

We must make a mathematical model to describe the fluid flow information to the computer. The information required consists of:

(1) Identification of the pressure node numbers

(2) Identification of the tube numbers and the two pressure nodes connected by tube

(3) The fluid temperature nodes contained in each tube

(4) The flow geometry for each temperature fluid nodes

(5) The number of "head losses" for items such as orifices

(6) Fluid property information

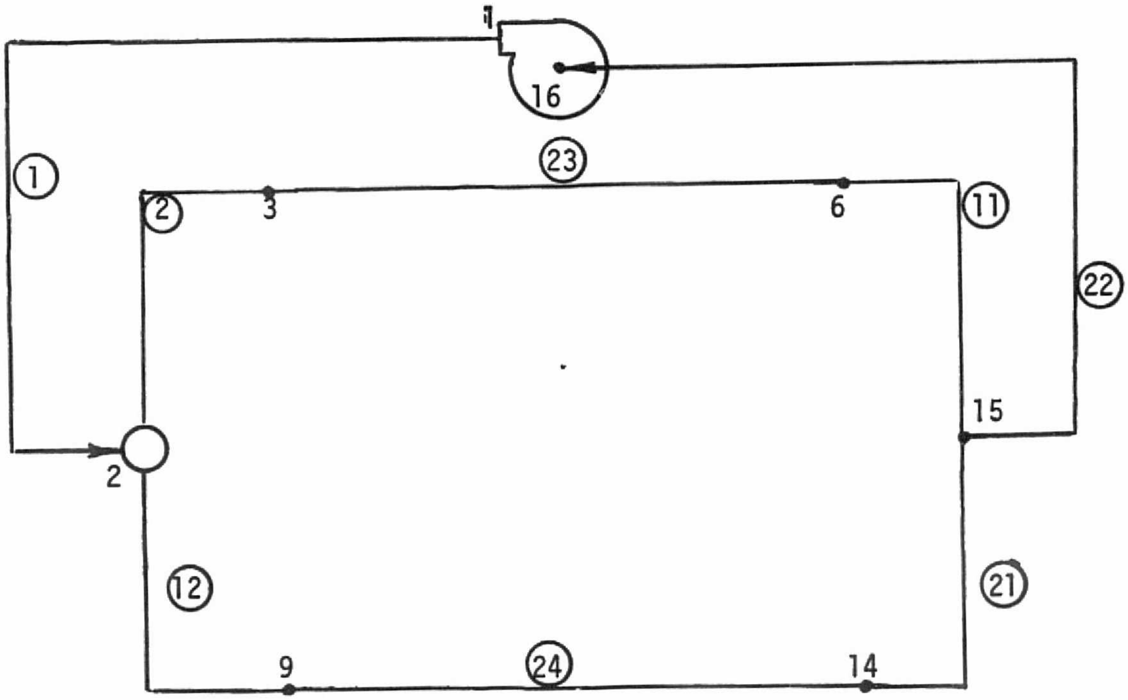
(7) Valve connections and characteristics

(8) Pump characteristics

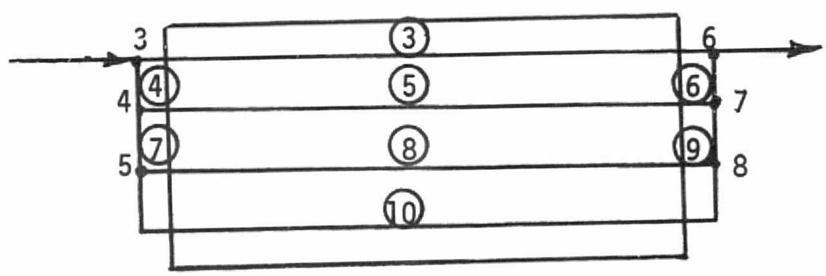
To build a flow mathematical model, a schematic of the flow system is needed. As shown in Figure 1, the pressure nodes and tubes may be superimposed on the schematic. It is also helpful to impose the fluid temperature lump numbers for each tube.

To facilitate speedy analysis on a general flow problem, provisions have been made for the user to divide the flow system network into subnetwork elements. For example, the flow system shown in Figure 1 could be divided as shown in Figure 2. Tubes 23 and 24 are added in the main network as shown in 2(a) to replace subnetwork elements 1 and 2. The subnetwork elements 1 and 2 which are shown in Figures 2(b) and 2(c) are then input as separate network elements. This type of subdivision allows the solution to be obtained by solving two sets of 6 simultaneous equations and one set of 8 equations rather than the original set of 16 simultaneous equations. This type of subdivision has been found to enhance the solution speed and accuracy for problems with a large number of nodes.

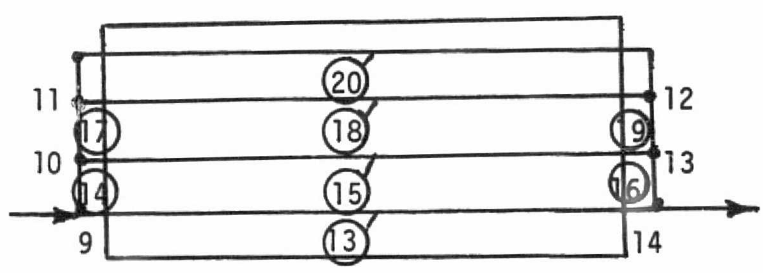
In summary, the pressure/flow solution is obtained by the following sequence:



a) Main Flow Network



b) Subnetwork No. 1



c) Subnetwork No. 2

FIGURE 2 MAIN NETWORK AND SUBNETWORKS

(1) The flow resistance is obtained for each fluid temperature lump in each tube including the effects of friction, orifices, and fitting type losses.

(2) The flow conductor value is obtained for each tube by summing all the resistances of the fluid lumps in the tube, adding the valve and user supplied resistance to the sum, and inverting the resistance.

(3) A set of simultaneous equations is set-up and solved for each main system and subnetwork to obtain the pressures.

(4) The flow rates are then calculated.

A detail discussion of each element in the above sequence is described in the following subsections.

2.2.2 Tube Conductor Determination

The value of the flow conductor is determined for each tube by first calculating the flow resistance for each temperature fluid lump contained in the tube, summing these resistances up to obtain the flow resistance of the tube and inverting the tube resistance to get the conductance. Flow conductance is defined by the relationship

$$\dot{w}_{ij} = GF_{ij}[P_i - P_j] \tag{29}$$

Where $\dot{w}_{ij}$ = flow rate between pressure nodes i and j
GF_{ij} = flow conductance between nodes i and j
P_i = pressure at pressure node i
P_j = pressure at pressure node j

The flow resistance for each lump is then

$$R_K = \frac{1}{GF} = \frac{\Delta P_k}{\dot{w}}$$

Where R_k = flow resistance for lump k
ΔP_k = pressure drop for lump k

But ΔP_k is given by

$$\Delta P_k = \left(f_k \cdot ffc \cdot \frac{L_k}{D_k} + K \right) \frac{\dot{w}^2}{2g_c \rho_k A^2} \tag{30}$$

Where f_k = the friction factor for lump k

ffc = the friction factor coefficient

L_k = the lump length for lump k

D = the lump hydraulic diameter for lump k

K = the dynamic head losses for lump k

$\dot{w}$ = the flow rate

g_c = the gravitational constant

ρ_k = the fluid density for lump k

A = the flow area

The flow resistance is then given by

$$R_k = \left(f_k \, ffc \, \frac{L_k}{D_k} + K \right) \frac{\dot{w}}{2 g_c \rho_k A^2} \tag{31}$$

Two options are available for obtaining the friction factor, f_k. These are (1) internal calculations for all flow regimes and (2) internal calculation for laminar flow and obtained from a table of f vs Re (where Re is the Reynold's number) for transition and turbulent flow. For the first option the internal calculations for the three flow regimes are:

<u>Laminar Regime</u>: $Re_k \leq 2000.$

$$f_k = \frac{64}{Re_k} \tag{32}$$

Where f_k = friction factor for lump k

Re_k = Reynolds number for lump k

<u>Transition Regime</u>: $2000 < Re_k < 4000$

$$f_k = .2086082052 - .1868265324 \left[\frac{Re_k}{1000}\right] + .06236703785\left[\frac{Re_k}{1000}\right]^2 - .0065545818\left[\frac{Re_k}{1000}\right]^3 \tag{33}$$

Turbulent Regime: $Re_k \geq 4000$

$$f_k = \frac{.316}{\left(Re_k\right)^{.25}} \tag{34}$$

Equation (33) for the transition regime is a curve fit between the laminar and turbulent regimes which was derived to match the two curves in a continuous manner. It is merely an arbitrary curve in this undefined region. A curve of the friction factor vs Reynold's number given by the above relations is shown in Figure 3.

The second option for friction factor uses equation (32) for the laminar regime and a user input curve of f_k ve Re for the other regimes. The options available for input of the dynamic head loss, $\mathcal{K}$, include (1) an input constant or (2) a tabulated curve of $\mathcal{K}$ vs Re.

To obtain the conductance for each tube, the flow resistances for all the lumps in the tube are added and then inverted, giving

$$GF_{ij} = \frac{1}{\sum_k R_k} \tag{35}$$

2.2.3 Valve Analysis

Two methods have been included in the FLOSOL subroutine for modeling valves. These are (1) pressure drop through the valve is included in the system flow balance and (2) valve position is used as a fraction for splitting the flow. The first method uses the following equation to characterize the pressure drop through each side of the valve:

$$\Delta P = E \left[\frac{\dot{W}}{X} \right]^2$$

where ΔP = valve pressure drop

E = valve pressure drop factor (user input)

$\dot{W}$ = flow rate through the side of the valve under consideration

X = the fraction of the valve opening

The second method for modeling valves uses the valve position as a fraction for splitting the flow into the valve according to the following equation:

$$\dot{W}_i = X_i \, \dot{W}_{in}$$

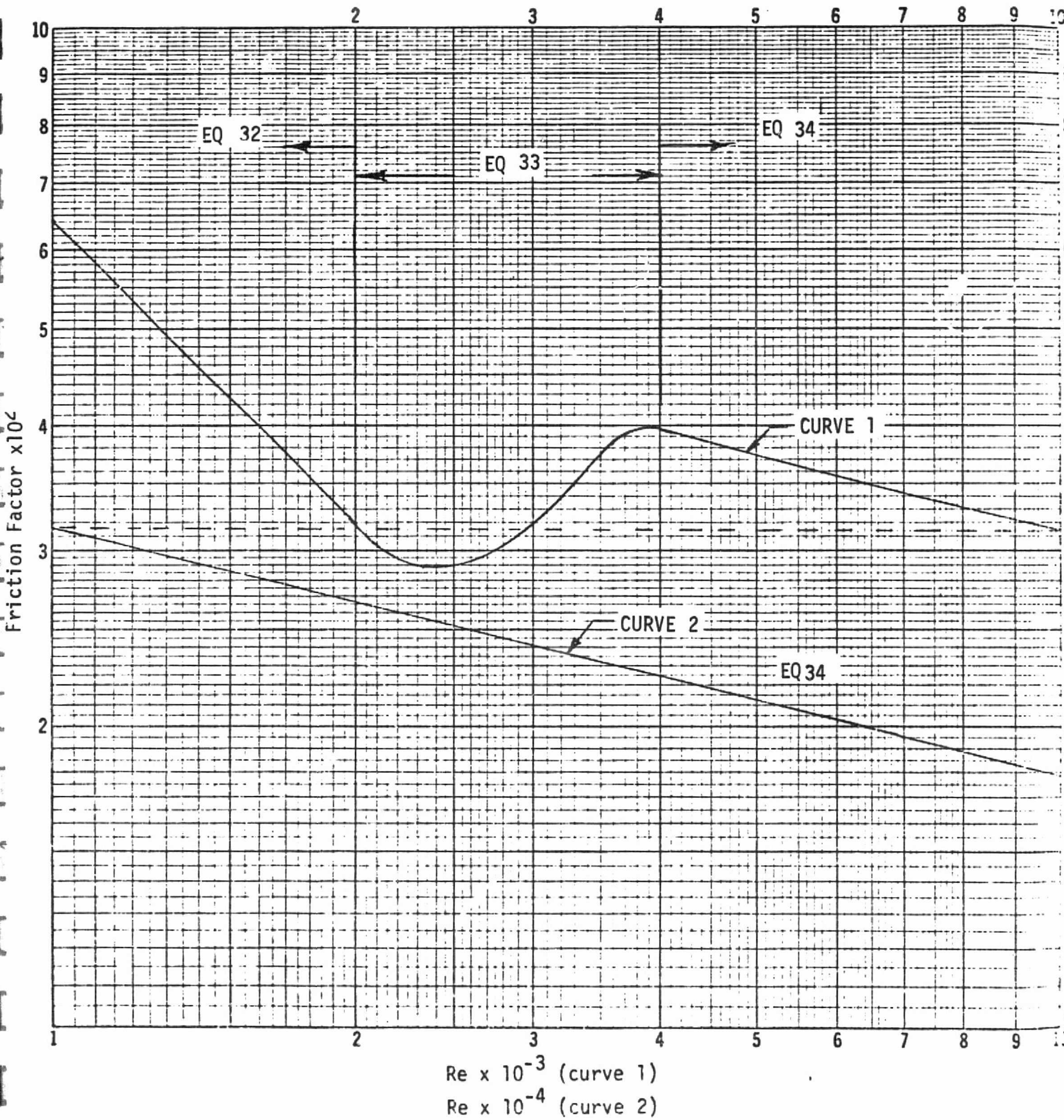


FIGURE 3 FRICTION FACTOR VS REYNOLDS NUMBER

where $\dot{w}_i$ = flow rate out side i of the valve
X_i = valve position of side i
$\dot{w}_{in}$ = flow rate into the valve

The pressure drop through the valve is not included in the system flow balance.

The valve pressure drop factor controls which method is used. The first method is used when the valve pressure drop factor is greater than 0. To specify the second method the user must input a 0 for the valve pressure drop factor. For either method the value of X must be greater than 0 and less than 1.

Three basic types of valves are available in FLOSOL for either the pressure drop or the flow splitting formulations which give different characteristics for the dynamics of the valve position X. These types are: (1) Rate Limited; (2) Polynomial, and (3) Shut-off.

A number of variations are available for each valve type. For instance, each of the above may be either one sided or two sided. If a valve is two sided, the valve position of side 2, X_2, is related to that of side one by

$$X_2 = 1.0 - X_1$$

If the valve is one sided, either side one or side two may be used. Provisions are included for a valve time constant to be included with the polynomial valve.

The methods used to obtain the valve positions for each of the three types are described below.

2.2.3.1 Rate Limited Valve

The valve position for the rate limited valve is obtained by an approximate integration of the valve rate of movement, $\dot{X}$. $\dot{X}$ depends on the temperature difference between the valve control set point temperature and the sensor temperature as shown in Figure 4. With this characteristic, the valve has no movement as long as the valve temperature error, ΔT, is within the dead band. Outside the dead band, the velocity of the valve increases linerarly as the error increases to a maximum rate, $\dot{X}$ max. The dead band, rate of velocity increase, $d\dot{X}/d(\Delta T)$, and the maximum velocity are controlled by user input.

The relations used to obtain the valve positions are as follows:

$$X^{i+1} = X^i + (\dot{X}^{i+1})\ (\Delta\tau) \tag{36}$$

Where X^{i+1} = valve position at iteration i+1
X^i = valve position at iteration i
$\dot{X}^{i+1}$ = valve velocity at iteration i+1
$\Delta\tau$ = the problem time increment

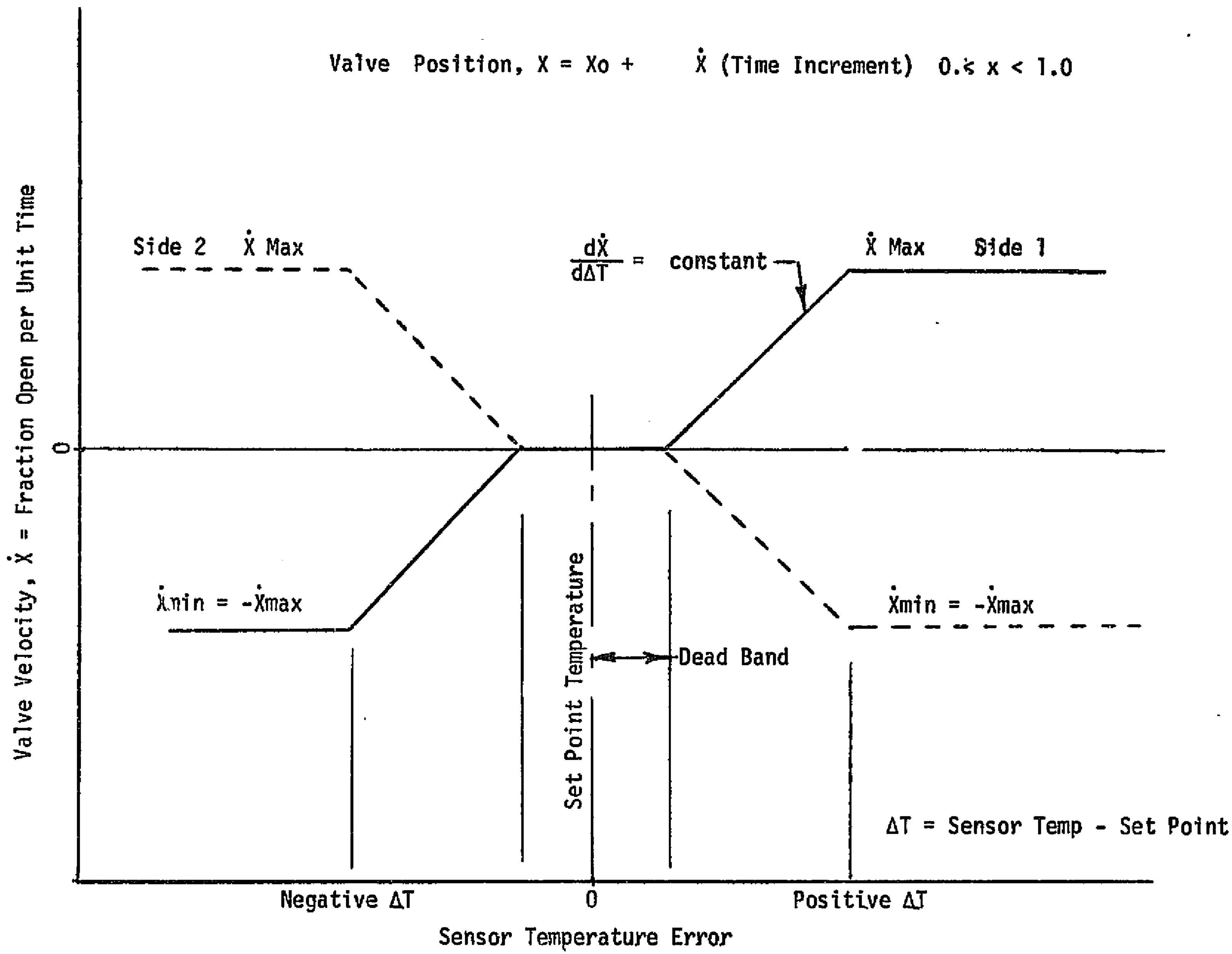


FIGURE 4 RATE LIMITED VALVE OPERATION

The valve position is limited by

$$X\ min \leq X^{i+1} \leq X\ max$$

Where X min and X max are input limits on the valve position. The valve velocity, $\dot{X}^{x+1}$, in equation (3E) is given by:

$$\dot{X}^{i+1} = 0 \qquad \text{if } \left| Tsen - Tset \right| \leq Tdb$$

where:

$$\dot{X}^{i+1} = \frac{d\dot{X}}{d(\Delta T)} [Tsen-Tset-Tdb] \qquad \text{if } Tsen > Tset + Tdb$$

$$\dot{X}^{i+1} = \frac{d\dot{X}}{d(\Delta T)} [Tsen-Tset+Tdb] \qquad \text{if } Tsen < Tset - Tdb$$

Tsen = sensor lump temperature

Tset = set point temperature

Tdb = valve dead band temperature

The valve velocity is limited by

$$\dot{X}min \leq \dot{X}^{i+1} \leq \dot{X}max$$

After the valve position for side 1 is obtained from equation (3F), the side 2 position is obtained from $X_2 = 1.0 - X_1$

2.2.3.2 Polynomial Valve

The polynomial valve determines the steady state valve position as a 4th degree polynomial function of the temperature error between the sensor lump and the set point. A valve time constant is then applied to determine how far between the previous position and the new steady state position the valve will move. The steady state position, X_{ss}, is given by

$$X_{ss} = A_0 + A_1 \Delta T + A_2 \Delta T^2 + A_3 \Delta T^3 + A_4 \Delta T^4$$

Where ΔT = Tsen - Tset

Tsen = the sensor lump temperature

Tset = the set point temperature

A_0, A_1, A_2, A_3, A_4 = input constants

The valve position, X^{i+1} is then determined by

$$X^{i+1} = X_{ss} + (X^{i}-X_{ss})\ e^{-\Delta\tau/\tau_c} \tag{37}$$

Where X^{i+1} = valve positon at iteration i+1
X^{i} = valve position at iteration i
$\Delta\tau$ = problem time increment
τ_c = valve time constant

The valve position for side 2 is given by

$$X_2 = 1.0 - X_1$$

where X_1 is given by equation (37)

If one desires to eliminate the effect of the time constant (and thus, give the valve an instantaneous response), a value for τ_c should be input which is small compared to the time increment, $\Delta\tau$. Also, either a constant value or a temperature lump number may be specified for the set point to permit use of the valve for proportioning between two sides.

2.2.3.3 Shut-off Valve

For side 1 of a shut-off valve the valve position decreases from X_{max} to X_{min} when the temperature of the sensor lump drops below the specified "off" temperature, T_{off}, and increased from X_{min} to X_{max} when the sensor lump exceeds a second specified temperature, T_{on}. T_{on} must be greater than T_{off}. Side 2 works in reverse of side 1. The valve position increased from X_{min} to X_{max} when the sensor temperature drops below the specified T_{on} and decreases from X_{max} to X_{min} when the sensor lump increases above the off temperature, T_{off}. For side 2, T_{off} must be greater than T_{on}. Note that, if the shut-off valve is a two sided valve with both sides active, the valve is a switching valve.

2.2.3.4 Valve Flow Resistance Calculations

The valve pressure drop on side one is assumed to be given by:

$$\Delta P = E\left[\frac{\dot{W}}{X}\right]^2 \tag{38}$$

Since flow resistance is $\Delta P/\dot{W}$, the valve flow resistance is given by

$$R_v = \frac{E\dot{W}}{X^2} \tag{39}$$

This value of flow resistance is calculated and added to the other flow resistances of the tube prior to performing the operation in equation (35) to find the value of the flow conductor for the tube.

Valves may be either one way or two way, i.e., be one tube or two tubes at the outlet. If only one tube exists on the valve outlet the flow resistance is calculated using equation (39) above. If a second tube exists, the resistance on side 2 is given by

$$R_{v2} = \frac{E_2\dot{W}_2}{(1-X)^2} \tag{40}$$

2.2.4 Pressure-Flow Network Solution

As previously stated, the user may subdivide a system flow network into a main network and subnetwork elements. The elements which are subnetworks to the main network may also contain subnetwork elements but the subdivision can go no lower than two levels.

After the flow conductor values have been obtained by the methods described in Sections 2.2.2 and 2.2.3 a set of simultaneous equations are set up and solved for the main system and for each subnetwork. The subnetwork elements are all solved first and then, their equivalent flow conductor value is calculated. The value is inserted in the main system network and the system solution is obtained. The procedure is repeated until the problem is balanced.

A set of simultaneous equations are obtained by conservation of mass at each pressure node for each network and subnetwork. For any node i the conservation equation can be written as follows:

$$\sum \dot{w}_{out} - \sum \dot{w}_{in} = 0 \qquad (41)$$

Let $\dot{w}_{in} = w_i$

and $\sum \dot{w}_{out} = \sum_{J=1}^{nc} GF_{ij} [P_j - P_i]$

Then equation (41) becomes

$$\sum_{J=1}^{n} GF_{ij} [P_j - P_i] - \dot{w}_i = 0 \qquad i=1,n \qquad (42)$$

Where GF_{ij} = flow conductor between pressure nodes i and j
P_i = pressure at node i
P_j = pressure at node j
$\dot{w}_i$ = flow rate added at node i
n = number of pressure nodes in the subnetwork

The above equation is a set of n simultaneous equations for P array. Pressure in the system or subsystem may be set at a specified level but the last (outlet) node must be specified. Equation (42) may be written in matrix form as:

$$GP = C \qquad (43)$$

Where

$$G = \begin{bmatrix} \sum GF_{ij} & -GF_{12} & -GF_{13} & \cdots \\ -GF_{21} & \sum GF_{2j} & -GF_{23} & \cdots \\ \cdot & \cdot & \cdot & \\ \cdot & \cdot & \cdot & \\ \cdot & \cdot & \cdot & \\ -GF_{n-1,1} & -GF_{n-1,2} & \cdots & \sum GF_{n-1,j} \end{bmatrix}$$

$$P = \begin{bmatrix} P_1 \\ P_2 \\ \cdot \\ \cdot \\ \cdot \\ P_{n-1} \end{bmatrix}$$

$$C = \begin{bmatrix} \dot{w}_1 + GF_{1n} \; P_n \\ \dot{w}_2 + GF_{2n} \; P_n \\ \cdot \\ \cdot \\ \cdot \\ \dot{w}_{n-1} + GF_{n-1 1} \; P_n \end{bmatrix}$$

P_n is the specified pressure. The above equations are solved for pressures at each point in the system and flow rates are then calculated for each tube by:

$$\dot{w}_i = GF_{ij} \; (P_i - P_j)$$

Since the coefficient matrix given by equation (43) is symetric and positive definite the efficient square root or Symmetric Cholesky method was programmed to obtain the solution. This method is more accurate and faster than any other methods studied for this application.

Since the flow conductors are functions of the flow rate, the set of equations given by (43) are solved numerous times on each temperature iteration with a new set of GF_{ij} values for each solution. The iteration process continues until the change in the flowrates is within some user specified tolerance before proceeding to the next iteration.

2.2.5 Pump and System Pressure - Flow Matching

Concurrent with iterating the system flow equation to solution on each temperature iteration, the overall system pressure drop and flowrate must be matched to a pump characteristic. Several types of pump characteristics are available to the user as options. These are (1) system flow rate specified as a constant, (2) system flowrate specified as a known function of time, (3) pressure drop specified as a function of the flowrate in a tabulated form and (4) pressure drop specified as a function of flowrate with a fourth degree polynomial curve.

The first two options require no balancing of the pump with the system. Balancing is required for options (3) and (4) and iterative procedures have been devised to obtain the solution of the pump curve to the system characteristics with as few passes as possible through the system pressure/flow balancing loop for these options. The procedures used for these options are described below.

2.2.5.1 Tabulated Pump Curve Solution

The matching of a tabulated pump pressure rise/flow characteristic to the system pressure drop/flow characteristic is accomplished by the following procedure. See Figure 5 to aid in understanding the procedure.

Step 1 : The initial flowrate, $\dot{W}_1$, at the system inlet is established either from user input on the first iteration or the system flow of the previous iteration for subsequent iterations.

Step 2 : Using $\dot{W}_1$, a solution to the flow network is obtained using the methods described in Sections 2.2.2, 2.2.3 and 2.2.4. Following this solution, ΔP_1 is available establishing point 1 on the true system characteristic curve shown in Figure 5.

Step 3 : Obtain an equation for the straight line approximation of the system characteristic (line 0, 1 for the first pass, line 1, 2 for the second pass, etc.)

$$\Delta P_S = C\,\dot{W}_S + D$$

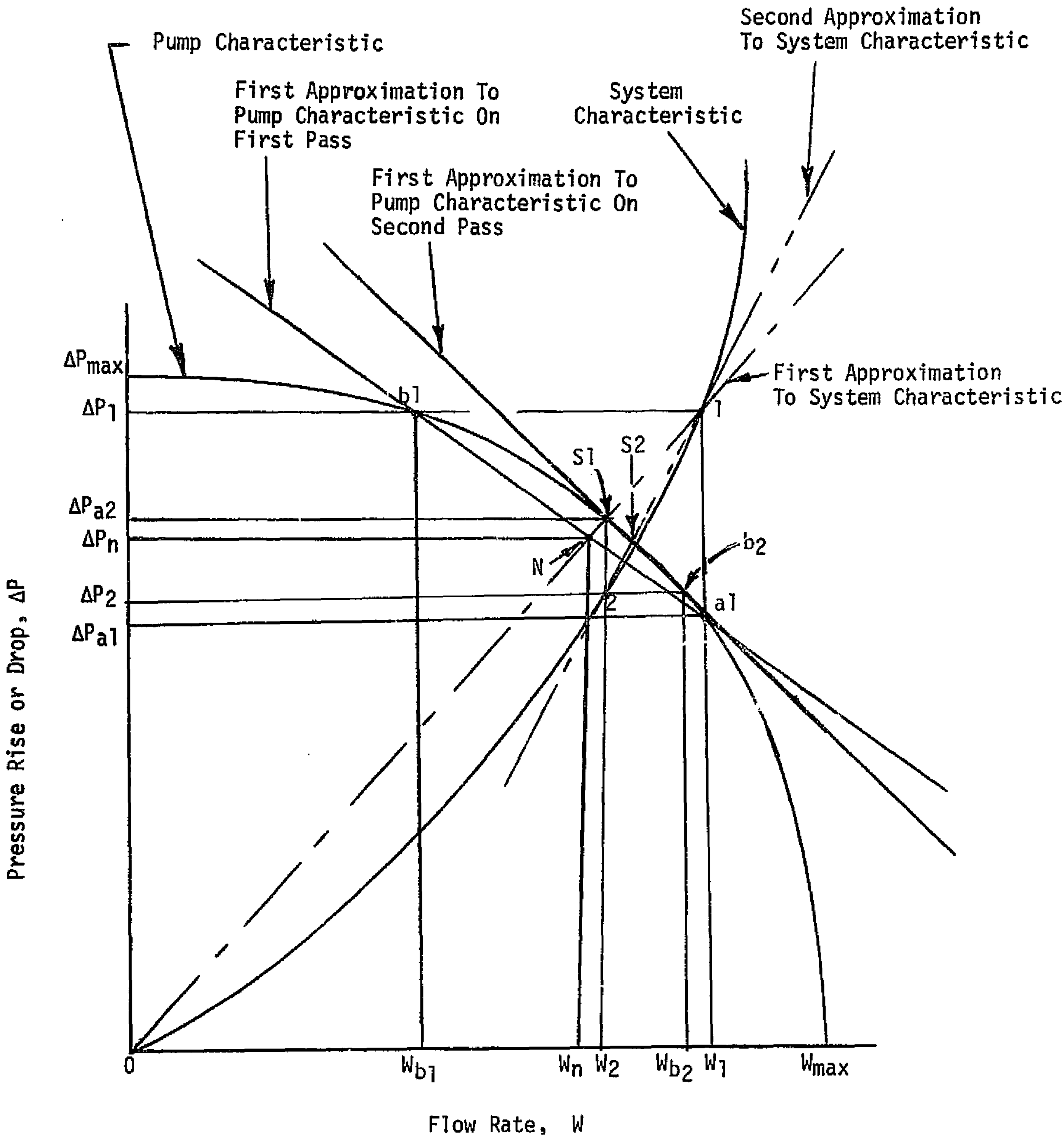


FIGURE 5 SYSTEM/PUMP CURVE SOLUTION

$$\text{where} \quad C = \frac{\Delta P_1 - \Delta P_0}{\dot{W}_1 - \dot{W}_0}$$

$$D = \Delta P_0 - \frac{\Delta P_1 - \Delta P_0}{\dot{W}_1 - \dot{W}_0} \dot{W}_0$$

ΔP_s, $\dot{W}_s$ are the system pressure drop and flowrate values given by the approximate equation

ΔP_1, $\dot{W}_1$ are the latest values for system pressure drop and corresponding system flowrate

ΔP_0, $\dot{W}_0$ are the values for system pressure drop and corresponding system flowrate for the previous pass (These values are zero for the first pass)

Step 4 : Obtain the equation of the line connecting points a_1 and b_1 which is an approximation of the pump characteristic.

(1) Two points are determined on the pump characteristic curve:

(a) interpolate the tabulated characteristic at $\dot{W}_1$ to obtain ΔP_{a1} (See Figure 5) to locate point a_1 at $\dot{W}_1$, ΔP_{a1}. If $\dot{W}_1$ is greater than $\dot{W}_{max}$, set $\dot{W}_1$ equal to $\dot{W}_{max}$ and ΔP_{a1} equal to zero.

(b) reverse interpolate the tabulated characteristic at ΔP_1 to obtain $\dot{W}_{b1}$ to locate point b_1 on the curve. If ΔP_1 is greater than ΔP_{max}, ΔP_1 is set to ΔP_{max} and $\dot{W}_{b1}$ is set to zero.

(2) Determine the coefficients A and B for the equation

$$\Delta P_p = A\dot{W}_p + B$$

$$\text{where} \quad A = \frac{\Delta P_1 - \Delta P_{a1}}{\dot{W}_{b1} - \dot{W}_1}$$

$$B = \Delta P_{a1} - \frac{\Delta P_1 - \Delta P_{a1}}{\dot{W}_{b1} - \dot{W}_1}$$

ΔP_p, $\dot{w}_p$ are the pump pressure rise and flowrate as given by the approximation.

Step 5 : Solve the approximate equations obtained in Steps 3 and 4 to obtain an approximate solution to the system characteristic and the pump characteristic (Point N) as follows:

$$\dot{w}_N = \frac{D - B}{A - C}$$

$$\Delta P_N = A\dot{w}_3 + B$$

Step 6 : Check the tolerance below where $\dot{w}_{n-1}$ is the previous $\dot{w}_N$ ($\dot{w}_1$ for the first time through)

$$\text{Is} \quad \frac{\dot{w}_N - \dot{w}_{N-1}}{\dot{w}_{N-1}} < .001$$

(1) If the above inequality equation is not satisfied repeat steps 4 through 6 substituting $\dot{w}_N$ for $\dot{w}_1$ and ΔP_N for ΔP_1

(2) If the inequality is satisfied the point S1 (Figure 5) has been located. Continue with step 7. The final flowrate is $\dot{w}_2$

Step 7 : Check the following tolerence

$$\text{Is} \quad \frac{\dot{w}_2 - \dot{w}_1}{\dot{w}_1} < \text{TOL}^*$$

(1) If the above inequality equation is not satisfied, repeat steps 2 through 7 using the value of $\dot{w}_2$ for $\dot{w}_1$.

(2) If the inequality is satisfied, $\dot{w}_2$ is the solution flowrate.

---

*TOL is the input pressure solution tolerance

2.2.5.2 Polynomial Pump Curve Solution

When the user describes the pump curve with a polynomial curve fit, the pump characteristic is described by the relation

$$\Delta P_p = A_o + A_1\dot{w} + A_2\dot{w}^2 + A_3\dot{w}^3 + A_4\dot{w}^4$$

When this option is used, the procedure for matching the pump characteristic to the system characteristic is identical to that described in Section 2.2.5.1 for the tabulated pump characteristic except Steps 4 and 5 are replaced with the following:

Step 4 : Obtain the coefficients of the 4th order equation to be solved

Since:

$$\Delta P_p - \Delta P_s = 0$$

$$\Delta P_s = C\ \dot{w}_s + D \text{ (C and D are obtained from Step 3)}$$

$$\Delta P_p = A_o + A_1\dot{w}_p + A_2\dot{w}_p^2 + A_3\dot{w}_p^3 + A_4\dot{w}_p^4$$

The solution occurs when

$$\Delta P_s = \Delta P_p$$

Then the equation for $\dot{w}_N$ is

$$(A_o - D) + (A_1 - C)\ \dot{w}_N + A_2\dot{w}_N^2 + A_3\dot{w}_N^3 + A_4\dot{w}_N^4 = 0$$

Step 5 : Solve the equation for $\dot{w}_N$ using the Newton-Raphson Method of solution for a fourth order polynomial

The remaining steps are identical to that given in Section 2.2.5.1.

3.0 SINDA ROUTINE MODIFICATIONS AND ADDITIONS

This section describes the actual modifications and additions to the SINDA program. Preprocessor changes are discussed in Section 3.1. Processor changes are discussed in Section 3.2. The specific changes can be seen in the listings in Appendix C.

3.1 Preprocessor Modifications and Additions

The preprocessor required four interface points to include the FLOW DATA block. The first point was in subroutine CODERD prior to the processing of the CONSTANTS DATA where a call is made to subroutine FLOW1 which reads and interprets the FLOW DATA cards. The second point is also in subroutine CODERD immediately following the processing of the ARRAY DATA where subroutine FLOW2 is called to process the FLOW DATA. The last two interface points involve setting up arrays in labelled common blocks. Subroutine FLOCOM does this when called from subroutine GENLNK and subroutine PRESUB.

Subroutine PSEUDO was modified to allow a node to not have any connections in the BCD 3CONDUCTOR DATA blcck. This was necessary since the tube lump to fluid lump connections are internally generated and not defined in the BCD 3CONDUCTOR DATA block.

3.2 Execution Routine Modifications

The requirements for integration of the Fluid Hybrid Temperature solution subroutine, FLUID, with the SINDA temperature solution subroutines were minimized at the interface point. A labelled common block which contains a code for flow problems was added to each of the temperature routines. When the code is tested for a flow problem, subroutine FLUID is called to calculate the fluid lump temperatures. In the explicit routines the tube lump temperatures are also calculated. In the implicit routines the convection conductance and adjacent fluid lump number are stored for the tube lump and after returning to the mainline temperature routines, the convection conductance is included in the calculation of the tube lump temperature. The SINDA routines were modified so that the node with the minimum natural time increment would not be a tube lump which does not have any connections from the conductor data block.

4.0 FLOW DATA BLOCK INPUT FORMAT

This section describes the input format for the SINFLO input data. The lumps referenced in this section must have been entered in the NODE DATA block. The fluid lumps must be entered as boundary nodes and the tube lumps must be entered as diffusion nodes.

The SINFLO input data for the fluid systems are supplied by the new data block headed by "BCD 3FLOW DATA" and five new subordinate blocks contained within the FLOW DATA block which will be headed by:

BCD 3NETWORK "Name"
BCD 3SUBNETWORK "Name" (Optional)
BCD 3FLUID LUMP DATA
BCD 3VALVE DATA (Optional)
BCD 3FLOW SOURCE DATA

Table 1 shows the overall organization of the input data blocks* including the new FLOW DATA block. The five subordinate flow blocks may be input in an arbitrary order within the FLOW DATA block. That is, the FLUID LUMP DATA block may be input first if desired instead of the order shown. The FLOW DATA block is optional. Thus, if the problem being analyzed contains no fluid flow or the fluid flow is being handled by another means, there will be no FLOW DATA block. As shown in Table 1, the FLOW DATA block will be added between the CONDUCTOR DATA and CONSTANTS DATA SINDA input blocks. The flow data input is initiated by the card (starting in column 8)

BCD 3FLOW DATA

and is terminated by the card

BCD 3END FLOW DATA

The NETWORK blocks and SUBNETWORK blocks may be supplied a multiple number of times. Each must reference a unique four character name. The user would normally supply one NETWORK block for each flow system being analyzed. At least one NETWORK block is required if a BCD 3FLOW DATA card exists. The NETWORK blocks may or may not reference SUBNETWORK blocks, but if one is referenced the data must be supplied in the block referenced by name in the NETWORK data. Division of a network into subnetwork elements is sometimes desirable to permit more efficient analysis on some problems. The NETWORK DATA, FLUID LUMP DATA, FLOW SOURCE DATA blocks are all required when a BCD 3FLOW DATA card exists. Each of these four blocks contain the required information for the entire flow problem.

Each of the subordinate flow blocks are discussed in the following sections.

---

*See Reference 7 for input other than FLOW DATA block

TABLE 1

SINFLO INPUT BLOCKS

```
BCD   3THERMAL LPCS
END
BCD   3NODE DATA
END
BCD   3SOURCE DATA (OPTIONAL)
END
BCD   3CONDUCTOR DATA
END
BCD   3FLOW DATA
BCD   3NETWORK (or SUBNETWORK) Name 1*
END                                         —Variable number of NETWORK or
BCD   3NETWORK (or SUBNETWORK) Name 2*        SUBNETWORK blocks. Must be a
END                                           NETWORK block for each flow
 '                                            system.
 '
BCD   3NETWORK (or SUBNETWORK) Name n*
END
BCD   3FLUID LUMP DATA                        FLOW DATA block optional
END
BCD   3VALVE DATA   (OPTIONAL)
END
BCD   3FLOW SOURCE DATA
END
BCD   3END FLOW DATA
BCD   3CONSTANTS DATA
END
BCD   3ARRAY DATA
END
BCD   3EXECUTION
END
BCD   3VARIABLES 1
END
BCD   3VARIABLES 2
END
BCD   3OUTPUT CALLS
END
BCD   3END OF DATA
```

---

* Unique four character name for each NETWORK or SUBNETWORK

4.1 NETWORK and SUBNETWORK Formats

The fluid flow tubes, pressure nodes connected by the tubes, and fluid lump/tube lump pairs contained in each tube are input in the NETWORK or SUBNETWORK data blocks. In addition to this connections data, the fluid thermophysical property data, network solution parameters, the value of acceleration of gravity and specified pressure nodes and values are input in the NETWORK data block. One NETWORK data block must be supplied for each fluid system or loop. Connections data for any subnetwork elements are supplied in the SUBNETWORK blocks. As many NETWORK and SUBNETWORK data blocks as required are supplied.

The input formats for the NETWORK and SUBNETWORK blocks are shown in Table II. Each network or subnetwork block is headed by

BCD 3NETWORK Name

or BCD 3SUBNETWORK Name

where the BCD starts in Column 8 and Name is any Alpha/Numeric word up to four characters which is different from the name of any other network or subnetwork. Each network or subnetwork block is terminated by an END starting in Column 8. The data values between the heading and the END card may be input free field between columns 12 and 72 consistent with the standard SINDA format. Each NETWORK block is a main network for a system. Thus, there are as many NETWORK blocks as there are systems in the problem. The NETWORK block contains (1) system data including information referencing fluid property data, system solution parameters and specified pressure nodes for the network (the SUBNETWORK blocks do not contain any of this information) and (2) the tube/pressure node connections and the fluid and tube temperature lumps in each tube. As shown in Table II, the systems data including the property data, solution parameters and specified pressure nodes for the network are input immediately following the heading card. These items may be input in any order and may be supplied one to a line or several to a line. The property values are identified by mnemonic names: CP for specific heat, RO for density, MU for viscosity, KT for thermal conductivity, and H for enthalpy. The property names are followed by an equal sign which is followed by a reference to the property value. For example, the property values could be supplied by:

CP = 0.25, MU = A25

RO = A37, KT = .073, H = A8

TABLE 2

INPUT FORMAT FOR THE NETWORK AND SUBNETWORK DATA BLOCKS

```
BCD 3NETWORK Name 1
        CP = AXX, RO = AXX, MU = AXX, KT = AXX, GC = XX.XXX, H = AXX
        MPASS = XX, TOL = XX, MXPASS = XX, FRDF = 0.XX, KOP = X
        P(N) = XX.X, END

        NT1, NPF1, NPT1 = FL11, TL11, FL12, T12, --- F1n, TL1n, END
        NT2, NPF2, NPT2 = FL21, TL21, (F22, TL22, FL2n, TL2n), END
        NT3, NPF3, NPT3 = (FL31, TL31, FL3n, TL3n, IFL, ITL), END
         .     .     .
         .     .     .
         .     .     .
        NTn, NPFn, NPTn = FLn1, TLn1 --- FLnn, TLnn, END
END
BCD 3SUBNETWORK Name 2
        NT1, NPF1, NPT2 = ------------------------, END
         .     .     .
         .     .     .
        NTn, NPFn, NPT2 = ------------------------, END
END
BCD 3NETWORK Name 3
        CP = --------------------- P(N) = XX.X, END
        NT, NPF, NPT = -----------, END
         .
         .
         .
END
BCD 3SUBNETWORK Name 4

END
```

The following definitions apply to the above:

Name i	-	any unique four character name
CP	-	indicates specific heat value
RO	-	indicates density value
MU	-	indicates viscosity value

TABLE 2 (CONT'D)

KT	-	indicates thermal conductivity value
H	-	enthalpy value
AXX	-	array in the ARRAY DATA with actual value of XX
GC	-	acceleration of gravity in the desired units. Default value = 416962080.
MPASS	-	a pressure/flow solution is performed every MPASS temperature iterations. Default value = 1
MXPASS	-	maximum number of passes permitted in the balancing loop to obtain a pressure/flow solution or any given network. Default value = 100
TOL	-	the solution tolerance on the fraction of change of flow rates from one pass in the flow solution to the next. Default value = .01
FRDF	-	flow rate damping factor which is a value between 0.5 and 1.0 to aid the convergence of the flow solution. Default value = 0.5
P(N)	-	references the value of the specified pressure for pressure node N
NT_i	-	tube number i which connects pressure nodes NPF_i and NPT_i
NPF_i	-	from pressure node number for tube no. i
NPT_i	-	to pressure node number for tube no. i
FL_{ij}	-	jth fluid lump in ith tube
TL_{ij}	-	jth tube lump in ith tube
IFL	-	increment for generating fluid lump numbers
ITL	-	increment for generating tube lump numbers
KOP	-	checkout print code (Default value = 0)
	-	0 : no checkout print is obtained for the network
	-	1 : a checkout print is obtained for the network

The value to the right of the equal may either be constant or reference an array in the ARRAY DATA. In the above example, the specific heat and thermal conductivity reference constant values of 0.25 and 0.073 while the viscosity and density reference arrays 25 and 37 in the array data. The enthalpy curve is supplied by array 8. The arrays referenced must be temperature dependent. The solution parameters which may be input in the systems data are MPASS, MXPASS, KOP, TOL, and FRDF (these are defined in Table II). These items are input by the same format as the property data except only integers are permitted for MPASS, KOP and MXPASS and only real numbers are permitted for TOL and FRDF. Any or all of the five solution parameters may be omitted and default values will be supplied. The default values are MPASS = 1, MXPASS = 100, KOP = 0, TOL = .01, FRDF = 0.5, when omitted. The acceleration of gravity, GC, is supplied in the systems data. This permits the user to analyze the flow problem in any desired units. The default value of GC is 416962080. ft/hr^2. Values of GC for various problem units are given in Table III.

The specified pressure nodes and their pressure values are also supplied in the systems data. For example, if pressure node 34 is set at 14.7, the input would read

P(34) = 14.7

The system data input is terminated by an END similar to ARRAY DATA input. An example of the systems data input is

```
BCD  3NETWORK SYSTM1
    CP = 0.25, MU = A25, RO = 37, KT = 0.073, H = A8
    TOL = 0.01, FRDF = 0.55, MPASS = 2, MXPASS = 120
    GC = 32.173, P(34) = 14.7, END
```

SUBNETWORK input blocks contain no systems data.

Tube to pressure node connections are supplied in the NETWORK blocks following the systems data described above and in the SUBNETWORK blocks. The format for the input of the tube cards is:

NT, NPF, NPT = FL_1, TL_1, FL_2, TL_2, ---

where NT, NPF, NPT are the tube number, "from" pressure node and "to" nodes respectively. FL, TL are the fluid lumps/tube lumps pairs contained in the tube.

A variation of the above format is available for the input of groups of fluid and tube lumps with a fixed interval between their numbers. The format for this option is:

TABLE 3 VALUE OF GC FOR VARIOUS PROBLEM UNITS

UNITS				GC
MASS	FORCE	LENGTH	TIME	
LB	LB_f	In.	Sec	386.1
			Min	$1.390X10^6$
			Hr	$5.004X10^9$
		Ft.	Sec	32.174
			Min	$1.1583X10^5$
			Hr	$4.1696X10^8$
		Yd.	Sec	10.725
			Min	$3.861X10^4$
			Hr	$1.3399X10^8$
GRAM	dyne	Centimeter	Sec	1.0
			Min	3600.
			Hr	$1.296X10^7$
KILOGRAM	Newton	Centimeter	Sec	1×10^{-2}
			Min	36
			Hr	$1.296X10^5$
		Meter	Sec	1.0
			Min	3600.
			Hr	$1.296X10^7$

$NT, NPF, NPT = FL_1, TL_1, ---(FL_i, TL_i, FL_j, TL_j, IF, IT),---FL_n, TL_n, END$

Where the lumps within the parenthesis are being incremented

FL_i is the first fluid lump number of the interval

FL_j is the last fluid lump number of the interval

IF is the increment between the lump numbers in the interval

TL_i is the first tube lump number of the interval

TL_j is the last tube lump number of the interval

IT is the increment between tube lump numbers

The values of $FL_i - FL_j$ must be a multiple of IF and $TL_i - TL_j$ must be a multiple of IT. If IF and IT are both the integer 1, they may be omitted.

An example of the input of a tube in the NETWORK block or SUBNETWORK is

8, 3, 5 = (1, 201, 10, 210), END

This statement indicates that tube No. 8 connects pressure nodes 3 and 5 and contains temperature fluid lumps 1 thru 10 with adjacent tube temperature lumps 201 thru 210. A tube card is supplied for each tube in the network.

Special tube cards are supplied when a subnetwork is referenced from a main network. This card consists of a dummy tube number and the first and last pressure nodes of the subnetwork on the left of the equal sign and the subnetwork name on the right of the equal sign. For example, an input in the main network of

46, 10, 21 = SUB1, END

references the block with the heading card of

BCD 3SUBNETWORK SUB1

for that portion of the network between pressure nodes 10 and 21. The dummy tube number is 46. Subnetwork elements may be referenced from "first level" subnetwork elements as well as network elements.

The input of negative fluid temperature lump numbers on the tube cards will indicate that no pressure drop calculations will be made for that fluid lump. Negative tube lump numbers indicate no temperature calculations will be made on the fluid lumps and tube lumps. This capability is useful for closed loop systems. For example, the input for the first tube in a closed system would be

1, 1, 2 = -200, -297, 97, 297, END

where fluid lump 200 is the last lump in the system.

Each tube must have at least one fluid lump. This requirement is necessary to provide thermal continuity in the network.

4.2 FLUID LUMP DATA Block Format

The FLUID LUMP DATA block contains the type data for all fluid lumps in all systems. The block is headed by

BCD 3FLUID LUMP DATA

and is terminated by

END

Where the BCD and END are each in columns 8, 9 and 10 consistent with SINDA input convention. The format for this block is the type data for each fluid lump type followed by an equal and the fluid lump numbers. The format is

CSA, WP, FLL, AHT, NHL, MFF, FFC, F1, F2 = FL_i, FL_2, --- FL_n, END

or = (FL_1, FL_n, INC), END

or = (FL_1, FL_n), END

or = FL_1, FL_2, ---, (FL_i, FL_j, INC),---,FL_n, END

where	CSA	=	cross sectional area to flow
	WP	=	wetted perimeter
	FLL	=	fluid lump length
	AHT	=	area for convection heat transfer
	NHL	=	a real constant : NHL is the number of head losses
		=	AXX : XX is an array number of head losses vs Reynolds number
	MFF	=	method for friction factor calculation
		=	0 : internal calculations used for friction factor
		=	AXX : XX is an array number of an array of friction factor vs Reynolds for Reynolds numbers greater than 2000.
	FFC	=	constant to be multiplied times the friction factor
	F1 & F2	:	F1 is a code to determine the method to be used for calculating heat transfer
	If F1	=	real number : F1 is the convection laminar flow fully developed coefficient; F2 is the entry length coefficient

If F1 = 1 : F2 is AXX where XX is an array of Stanton number versus Reynolds number from which the convection heat transfer coefficient will be obtained

If F1 = 2 : F2 is AXX where XX is an array of heat transfer coefficient versus flow rate

FL_i = ith fluid lump number in the tube

INC = the increment between lump numbers generated using the parenthesis option. If INC is 1 it may be ommited.

The parenthesis option may be inserted anywhere in the group of fluid nodes on the right of the equal sign. That is, lump numbers separated by commas may or may not be input before or after the lump generated by the paraenthesis option. Also, any number of parenthesis options may be used on one type card.

The values for MFF, FFC, F1, and F2 may be left off the type cards if the default values are desired for all these items. The default values are MFF = 0 and FFC, F1 and F2 = 1.0. The input would then be:

CSA, WP, FLL, AHT, NHL = FL_1, FL_2, --- (FL_i, FL_j, INC), --- FL_n, END

4.3 VALVE DATA Input Block (Optional)

The VALVE DATA input block contains the valve data for all valves in all flow systems. (That is, there is only one VALVE DATA block in the problem.) The block is headed by the card

BCD 3VALVE DATA

and is terminated by

END

Where the BCD and the END cards are each in columns 8, 9, and 10.

Three types of valves are available to the user: rate limited, polynomial, and switching (see Section 2.2.3). The input required for these valves is:

Rate Limited

NV, NTS1, NTS2 = XI, MODE, XMIN1, XMAX1, E, TSEN1, TSEN2, DB, RF, RL, END

Polynomial

NV, NTS1, NTS2 = XI, MODE, XMIN1, XMAX1, E, TSEN1, TSEN2, C0, C1, C2, C3, C5, VTC, END

Switching

NV, NTS1, NTS2 = XI, MODE, XMIN1, XMAX1, E, NSEN, T1, T2, END

The following definitions apply in the above formats:

NV	-	Valve number
NTS1	-	Tube number connected to side 1 of the valve
NTS2	-	Tube number connected to side 2 of the valve
XI	-	Initial valve position
MODE	-	Operating mode : 1 - operating; 0 - not operating
XMIN1	-	Side 1 minimum position; side 2 maximum position is (1.0 - XMIN1)
XMAX1	-	Side 1 maximum position; side 2 minimum position is (1.0 - XMAX1)
E	-	The valve geometric factor relating pressure drop through the valve by $\Delta P = E\ (\text{flowrate/valve position})^2$
TSEN1	-	Sensor lump for side 1 or set point for side 2; if TSEN1 is an integer, it identifies the side 1 sensor lump to be controlled to (a) the set point for side 1 or (b) the sensor lump for side 2 (TSEN2). If the variable is input as a floating point number it represents a set point to which the side 2 sensor lump will be controlled.
TSEN2	-	Sensor lump for side 2 or set point for side 1; if TSEN2 is an integer, it identifies the side 2 sensor lump to be controlled to (a) the set point for side 2 or (b) the sensor lump for side 1 (TSEN1). If the variable is input as a floating point number it represents a set point to which the side 1 sensor lump will be controlled.
C0,C1,C2,C3,C4,C5	-	Polynomial curve fit coefficients for a curve fit of the steady state valve position vs sensed temperature error for side 1: $X1SS = C0 + C1 \cdot \Delta T + C2 \cdot \Delta T^2 + C3 \cdot \Delta T^3 + C4 \cdot \Delta T^4 + C5 \cdot \Delta T^5$
DB	-	Dead band for the rate limited valve, degrees of temperature (Figure 4)
RF	-	Rate factor, the rate of change of valve velocity to sensed temperature error ($dx/d(\Delta T)$) as shown on Figure 4
RL	-	Rate limit, the maximum valve velocity, Xmax (see Figure 4)

VTC	-	Valve time constant as described in Section 2.2.3.2. If a valve is desired with no time lag, a time constant which is very small compared to the problem time increment should be input. (VTC must be greater than zero).
NSEN	-	Sensor lump for switching valve
T1	-	Side 1 off temperature or side 2 on temperature for switching valve
T2	-	Side 2 off temperature or side 1 on temperature for switching valve

4.4 FLOW SOURCE Data Block

The FLOW SOURCE data block contains specification of flow rate for all the systems in the problem. The heading card for this block is

BCD 3FLOW SOURCE DATA

and is terminated by

END

Three types of flow specifications are available. These are: (1) flow rate as a function of time; (2) pressure rise as a function of flow rate specified by a tabulated curve; and (3) pressure rise as a polynomial function of flow rate. The input for each of these is given below.

Flow as A Function of Time

NPI, AW, END

Pressure Rise as A Tabulated Function of System Flow Rate

NPI, NPO, ADP, END

Pressure Rise as A Polynomial Function of Flow Rate

NPI, NPO, C0, C1, C2, C3, C4, END

where:

NPI	=	system inlet pressure node
AW	:	W is an array number of an array which gives tabulated flow rate vs time if input as AXX
	:	AW is constant imposed flowrate for node NPI if AW is a floating point number.
NPO	=	system outlet pressure node
ADP	:	DP is an array number of an array which gives tabulated pump pressure rise as a function of flow rate

CO,C1,C2,C3,C4 = polynomial curve fit constants for pressure rise as a function of flowrate, i.e.,

$$\Delta P = C0 + C1 \cdot \dot{W} + C2 \cdot \dot{W}^2 + C3 \cdot \dot{W}^3 + C4 \cdot \dot{W}^4$$

The value of AW may be input as a floating point number if a constant system flow rate is desired.

4.5 Example of Flow Input

An example of the flow input described in Sections 4.1 and 4.4 is given in Table IV. This table gives the flow input for the sample problem given in Section 6.0 .

TABLE 4

FLOW DATA INPUT FOR SAMPLE PROBLEM

```
BCD 3FLOW DATA
BCD 3NETWORK MAIN
    GC=4.17312E8, CP=A1, RO=A2, MU=A5, KT=A6, MPASS=1, H=A8
    TOL=.01,MXPASS=100,FRDF=.7,P(24)=0.,END
    37, 23, 24 =  117,317            , END
     2,  2,  3 =   98,298            , END
     3,  3,  4 =   99,299            , END
    38,  4, 17 = SUB1                , END
    26, 17, 18 =  106,306            , END
    11,  3,  9 =  107,307            , END
    39,  9, 22 = SUB2                , END
    34, 22, 18 =  114,314            , END
    35, 18, 23 =  115,315            , END
    36,  2, 23 =  116,316            , END
     1,  1,  2 = -200,-297,97,297    , END
END
BCD 3SUBNETWORK SUB1
     4,  4,  6 =  100,300            , END
     5,  6,  7 = (  7,207,  12,212), END
     6,  6,  7 = (  1,201,   6,206), END
     7,  4,  5 = ( 13,213,  18,218), END
     8,  4,  5 = ( 19,219,  24,224), END
     9,  5,  7 =  101,301            , END
    10,  7,  8 =  102,302            , END
    19,  8, 14 =  103,303            , END
    20, 14, 16 =  104,304            , END
    21, 16, 17 = ( 37,237,  42,242), END
    22, 16, 17 = ( 43,243,  48,248), END
    23, 14, 15 = ( 31,231,  36,236), END
    24, 14, 15 = ( 25,225,  30,230), END
    25, 15, 17 =  105,305            , END
END
BCD 3SUBNETWORK SUB2
    12,  9, 11 =  108,308            , END
    13, 11, 12 = ( 61,261,  66,266), END
    14, 11, 12 = ( 67,267,  72,272), END
    15,  9, 10 = ( 55,255,  60,260), END
    16,  9, 10 = ( 49,249,  54,254), END
    17, 10, 12 =  109,309            , END
    18, 12, 13 =  110,310            , END
    27, 13, 19 =  111,311            , END
    28, 19, 21 =  112,312            , END
    29, 21, 22 = ( 79,279,  84,284), END
    30, 21, 22 = ( 73,273,  78,278), END
    31, 19, 20 = ( 85,285,  90,290), END
    32, 19, 20 = ( 91,291,  96,296), END
    33, 20, 22 =  113,313            , END
END
```

TABLE 4 (CONT'D)

```
BCD 3FLUID LUMP DATA
    0.001008, 0.1125, 12.0 , 1.35  ,  0.0 =
                1 ,    6 ,  19 ,  24 ,  25 ,  30 ,  43 ,  48
               49 ,   54 ,  67 ,  72 ,  73 ,  78 ,  91 ,  96 ,END
    0.000938, 0.36  ,  3.25, 1.17  , 117.0 =
             ( 2 ,   51),( 8 ,  11),( 14 ,  17),( 20 ,  23)
             ( 26 ,  29),( 32 ,  35),( 38 ,  41),( 44 ,  47),END
    0.001008, 0.1125,  5.0 , 0.5625,   0.0 =
                7 ,   12 ,  13 ,  18 ,  31 ,  36 ,  37 ,  42
               55 ,   60 ,  61 ,  66 ,  79 ,  84 ,  85 ,  90
               97 ,   98 , 117                                ,END
    0.853E-4, 0.0328,  0.25, 0.0082,   2.49=
             ( 50 ,  53),( 56 ,  59),( 62 ,  65),( 68 ,  71)
             ( 74 ,  77),( 80 ,  83),( 86 ,  89),( 92 ,  95),END
    0.001008, 0.1125, 20.0 , 2.25  ,   0.0 =
               99 , 106 , 107 , 114                           ,END
    0.001008, 0.1125,  2.5 , 0.281 ,   0.0 =
              102 , 103 , 110 , 111                           ,END
    0.001008, 0.1125, 50.0 , 5.62  ,   0.0 =
              115                                             ,END
    0.001008, 0.1125,  7.0 , 0.7875,   0.0 =
              100 , 101 , 104 , 105 , 108 , 109 , 112 , 113 ,END
    0.001008, 0.1125,  2.0 , 0.225 ,   0.0 =
              116                                             ,END
     0.0,0.0,0.0,0.0,0.0=200,END
END
BCD 3VALVE DATA
     3,2,36=.999,1,.001,.999,.01,117,35,,.75,.5,5.,END
     2,3,11=.99,1,.01,.99,.01,115,40.,.75,.5,5.,END
END
BCD 3FLOW SOURCE DATA
     1,24,A13,END
END
BCD 3END FLOW DATA
```

5.0 USER SUBROUTINES

This section describes the user subroutines which have been developed and modified by VSD for SINDA. Table 5 summarizes the subroutines and the page that each description of usage is found.

The subroutine inputs rely upon the ability to convert from actual array, node, and conductor numbers to relative numbers in the array data. To use the capability the user may supply an actual array number, node number, or conductor number by preceding the actual number with *A, *T, or *G respectively. This causes the preprocessor to replace the entry with the relative number. Consider the example for array number 2 shown below

2, *A14, *T5, *G7, END

In this example, following the preprocessor phase, *A14 would be replaced by the location in the A array of the array number 14 data, *T5 would be replaced by the relative node number for actual node number 5, and *G7 would be replaced by the relative conductor number for actual conductor number 7.

In addition, revisions have been made to some of the temperature solution subroutines to interface with the Fluid Hybrid solution subroutines. The following subroutines were revised:

CINDSL	-	Steady State
CINDSS	-	Steady State
CNBACK	-	Backward Differencing
CNFWBK	-	Mid-differencing
CNFRWD	-	Forward Differencing
CNFAST	-	Forward Differencing
FWDBCK	-	Mid-differencing
SNDSNR	-	Steady State
SNFRDL	-	Forward Differencing
SNFRWD	-	Forward Differencing
STDSTL	-	Steady State

TABLE 5

USER SUBROUTINES

SUBROUTINE NAME: ACOMB

See description for usage of OCOMB.

SUBROUTINE NAME: CABIN

PURPOSE:

This subroutine performs a thermal and mass balance on a cabin air system. The cabin air is assumed to be a two component gas mixture with one condensible component and one noncondensible component. The cabin air is assumed to be well mixed so that the temperature and specific humidity are constant throughout. The cabin may contain any number of entering streams each with different temperature and humidity conditions. The cabin air may transfer heat to any number of nodes in its surroundings with the heat transfer coefficient obtained by one of the the three options:

1. User input coefficient
2. Relations for flow over a flat plot
3. Relations for flow over a tube bundle

The relations describing the second and third options are given in Section 2.1.7. The mass transfer coefficient for determining the rate of condensation or evaporation is determined by the Lewis relation which relates the mass transfer coefficient directly to the convection heat transfer coefficient. By the Lewis Relation, if the diffusion coefficient is approximately equal to the thermal diffusivity, the Sherwood number is approximately equal to the Nusselt number, thus giving a direct relation. (See Section 2.1.7 for details). Mass and heat transfer rates are determined at each node that interfaces the cabin gas as well at entering and exiting streams and a new cabin gas temperature and humidity is determined each iteration based upon the heat and mass balance. An account is kept of the condensate on the walls when condensation occurs but the condensate is assumed to remain stationary and not flow to other wall nodes.

Limits are applied when necessary to prevent more condensation than the vapor existing under severe transient condition and to prevent evaporation of more liquid than exists at each wall lump.

As many cabins as desired may be analyzed in a given problem, but each must contain separate input information.

RESTRICTIONS:

CABIN must be called in VARIABLES 1.

CALLING SEQUENCE:

CABIN(A(IC) TC, TC, K1, K2)

The following definitions apply to the above calling sequence:

A — is an array containing arrays numbers which contain cabin input information

TC — The cabin gas temperature which must be a boundary node

K1,K2 — Storage locations needed by CABIN

The A array has the following format where the *A procedure is used:

A(IC),IF,PR,CN,H,FP,TB,SP,END

Where IF — Identifies an array containing the entering flow rate information. The format of the array is:

$IF(IC),NS,FR_1,PSI,TE_1,FR_2,PSI_2,TE_2----FR_{ns},PSI_{ns},TE_{ns}$

PR — Identifies an array identifying array numbers for property values. The format of the array is:

PR(IC),NFLC,NMUO,NMUV,NCPO,NCPV,NKO,NKV,NLAT

CN — Identifes an array containing pertinent constants. The format of the array is:

CN(IC),RA,RV,VC,PC,XC,WV,PSIC,PO,TO,CONV

H — Identifies an array containing node numbers and convection heat transfer coefficient values for nodes surrounding the cabin gas. The format of the array is:

$H(IC),LN_1, HA_1, LN_2, HA_2, - - - LN_{n1}, HA_{n1}$

FP — Identifies an array containing node numbers and information to permit calculation of convection coefficients for flat plates. The format is:

$FP(IC),LN_1,XX_1,XI_1,AI_1,VIWØ_1,LN_2,XX_2,XI_2,AI_2,$

$VINØ_2,-------LN_{n2},XX_{n2},XI_{n2},AI_{n2},VIWØ_{n2}$

TB — Identifies an array containing node numbers and information to permit calculation of convection coefficients for tube bundles. The format is:

$TB(IC),LN_1,DI_1,AI_1,VIWØ_1,LN_2,DI_2,AI_2,VIWØ_2,------LN_{n3},$

$DI_{n3},AI_{n3},VIWO_{n3}$

SP — Identifies an array which contains working space equal to or greater than three times the sum of the number of nodes with input heat transfer coefficients plus the number using flat plot relations plus the number using tube bundles.

The following symbol definitions apply in the above:

NS	Number of incoming streams
FR_i	Entering flow rate for stream i
PSI_i	Specific humidity for entering stream i
TE_i	Temperature of entering stream i
NFLC	Curve number for circulation flow rate vs time
NMUO	Curve number for noncondensible viscosity vs temperature
NMUV	Curve number for condensible viscosity vs temperature
NCPO	Curve number for noncondensible specific heat vs temperature
NCPV	Curve number for condensible specific heat vs temperature
NKO	Curve number for noncondensible thermal conduction vs temperature
NKV	Curve number for condensible thermal conduction vs temperature
NLAT	Curve number for latent heat of condensible vs temperature
RA	Gas constant for non-condensible component
RV	Gas constant for condensible component
VC	Cabin volume
PC	Cabin Pressure
XC	Molecular weight ratio, Mv/Mo
WV	Initial vapor weight in cabin
PSIC	Initial specific humidity for cabin
LN_i	Cabin wall lump
HA	Heat transfer coefficient times area
n1	Number of wall lumps which have input HA values
n2	Number of wall lumps which have HA calculated by flat plate relations
n3	Number of wall lumps which have HA calculated by tube bundle relations

xx_i	Distance from leading edge for flat plate heating for ith flat plate node
XI_i	Length of flat plate in flow direction for ith flat plate node
AI_i	Heat transfer area for flat plate or tube node
DI_i	Tube outside diameter for tubes in the bundle for ith tube node
VIWO	Ratio of velocity at the lump to the circulation flow rate
To	The reference temperature to be used for estimating the saturation pressure of the condensible component. Should be near the range of saturation temperature expected
Po	The saturation pressure at To for the condensible component
CONV	Conversion factor to make the quantity XLAM/Rv/To dimensionless where XLAM is the latent heat of vaporization and Rv is the gas constant for the vapor. If XLAM is BTU/lb, Rv is FT-LB/°R and To is °R, CONV=778.

SUBROUTINE NAME: CRVINT

PURPOSE:

This subroutine performs an integration of the doublet array, A, and stores the results in doublet array B. The independent variables (the odd data valves) of the A array are transferred directly to the B array. The dependent variables of the B array are calculated by

$$B(2) = 0.0$$

$$B(2*N) = B(2*(N-1)) + 0.5*[A(2*N) + A(2*(N-1)] *[A(2*N-1)-A(2*(N-1)-1] \quad N = 2, NP$$

where NP = number of points in the A array (half the integer count)

This subroutine was written primarily for integration of specific heat arrays to obtain enthalpy arrays but could be used for integration of any dependent variable over the independent variable range.

RESTRICTIONS:

Space in B array must be exactly equal to the space in the A array. Must be at least two points in A array (i.e., the integer count must be greater than or equal to 4).

CALLING SEQUENCE: CRVINT(A(IC), B(IC))

SUBROUTINE NAME: CYCLE

PURPOSE:

Subroutine CYCLE will automatically extend the range of independent variables in either direction for cyclic curves by adding (or subtracting) the cycle period to each independent variable when the curve range is exceeded. The total input range of the independent variables is assumed to be one period. CYCLE should be called prior to interpolation so that the necessary changes may be performed to the independent variables.

RESTRICTIONS:

None

CALLING SEQUENCE: CYCLE(X,A,NAME)

where	X	-	value of independent variable to be used in interpolation of A doublet array
	A	-	doublet array assumed to be cyclic
	NAME	-	one word Hollerith identifier

SUBROUTINE NAME: FLOSOL

PURPOSE:

Subroutine FLOSOL determines the flow distribution in a set of general parallel/series fluid flow tubes so that the pressure drop values between any parallel flow paths are equal and flow is conserved. The following effects are included in the pressure drop calculations:

(1) pipe flow friction

(2) orifices and fittings

(3) valves

The effect of temperature dependent properties are included in the calculations. The properties are evaluated at the temperature of each fluid lump in each tube in evaluating the flow resistance when setting up the equations to be solved. A balance is made between the flow/pressure drop characteristics of the system and the flow/pressure rise of a pump for each system concurrent with the system pressure flow solution to obtain the incoming system flowrate. A detailed discussion of the equations and techniques used are described in Section 2.1. General flow charts of FLOSOL and supporting subroutines are shown in Figures 6,7, and 8.

RESTRICTIONS:

FLOSOL should be called from EXECUTION prior to temperature solution call and from VARIABLES 2 for transient problems. For steady state solutions FLOSOL should be called from VARIABLES 1 and DTIMEU should be set in the CONSTANTS DATA if valve operation is required. The system of units used for the thermal and flow problem should be consistent.

CALLING SEQUENCE: FLOSOL

DYNAMIC STORAGE REQUIREMENTS:

Dynamic storage required for FLOSOL is $1/2(NPRN^2 + 7*NPRN + 12)$, where NPRN is the maximum of the number of pressure nodes in any network.

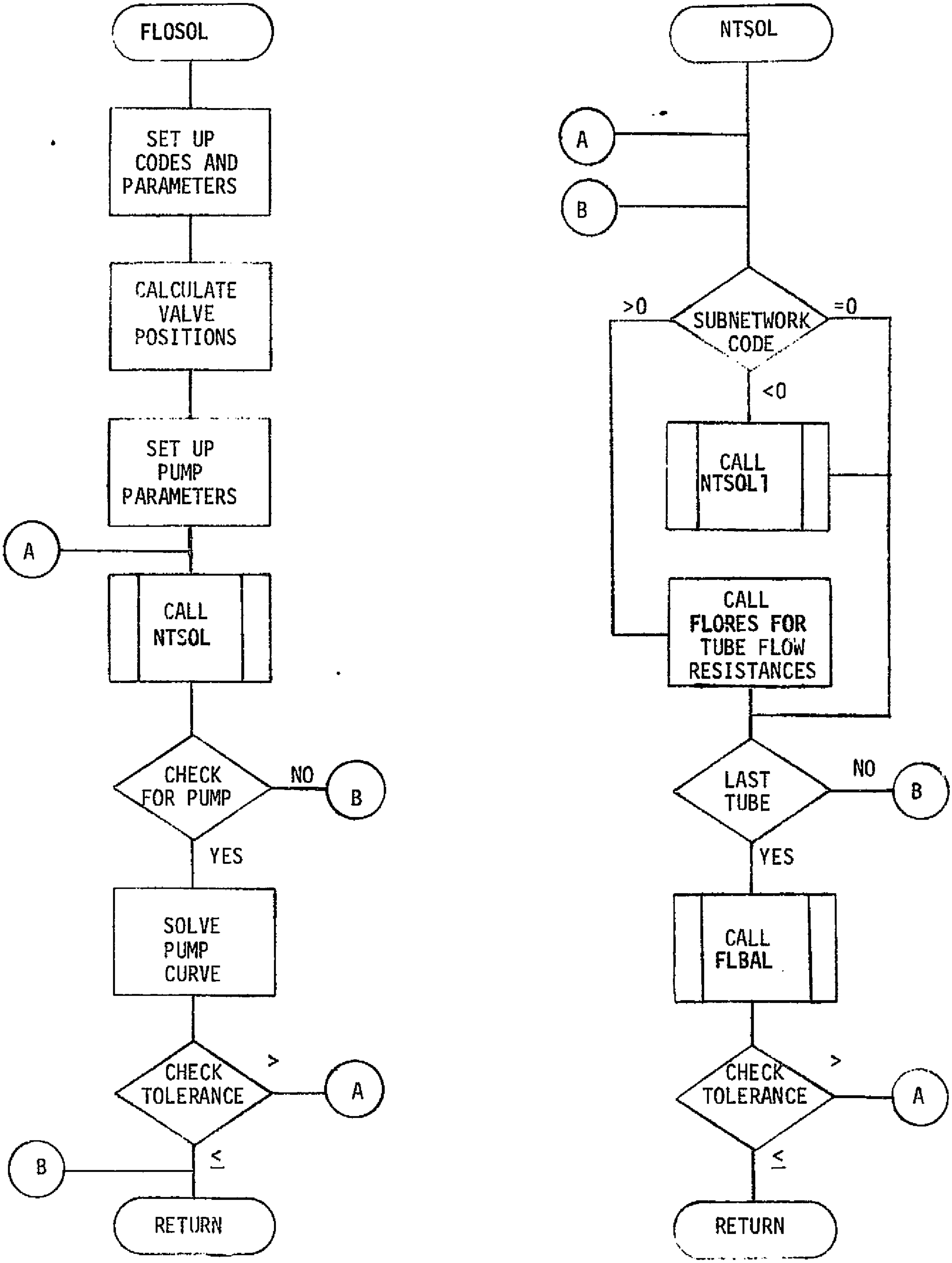


FIGURE 6 FLOW CHARTS OF FLOSOL AND NTSOL

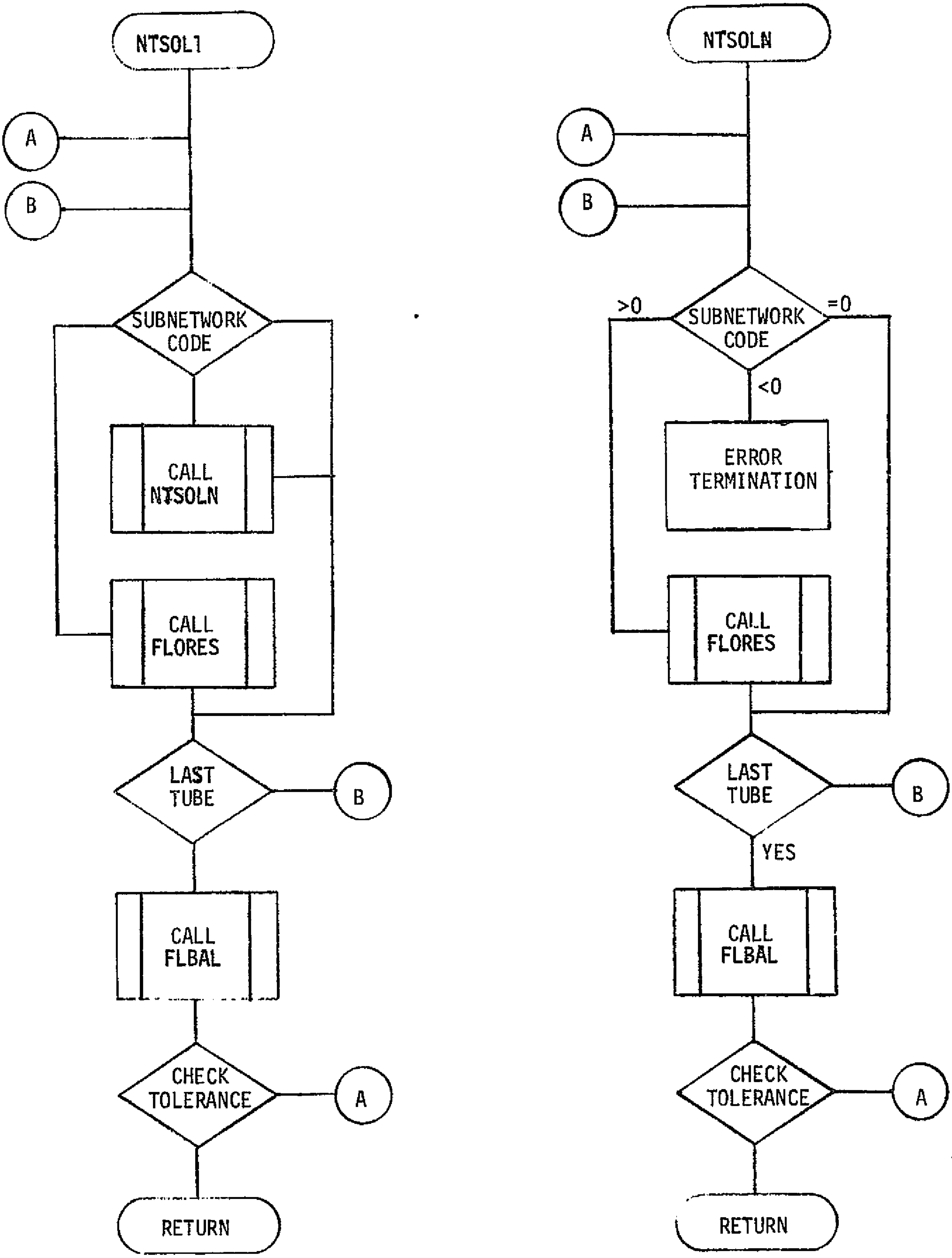


FIGURE 7 FLOW CHARTS OF NTSOL 1 AND NTSOLN

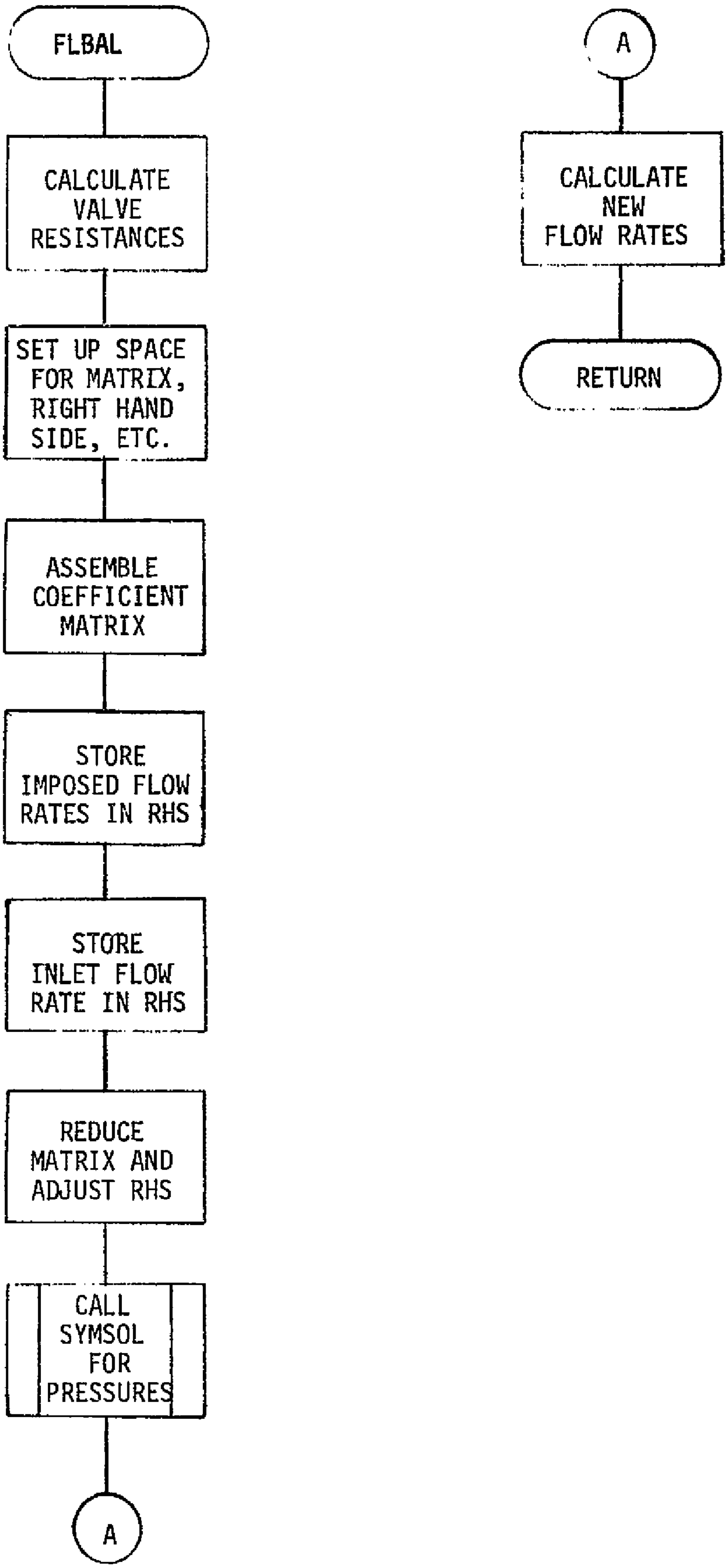


FIGURE 8 FLOW CHART OF FLBAL

SUBROUTINE NAME: FLOTMP

PURPOSE:

Subroutine FLOTMP will read the node temperatures, flowrates, pressures and valve positions at time TMPTIM from the history tape assigned to Unit U generated by subroutine HSTFLO for a previous run on Unit T to initiate a problem at these conditions. The time to read the tape, TMPTIM is the argument. The subroutine should be called in the execution block prior to the call to the temperature solution subroutine.

RESTRICTIONS:

Must be called in the EXECUTION block prior to the call to the appropriate temperature solution subroutine. The history tape must be assigned on Unit U.

CALLING SEQUENCE:

FLOTMP(TMPTIM)

SUBROUTINE NAME: FLPRNT

PURPOSE:

Subroutine FLPRNT will write the values of the DATA array of real numbers at 10 to a line. The array is labeled by the variable input HEAD which contains 9 six character alpha numeric words. The array location of every tenth value in the array is identified to the right of the appropriate line.

RESTRICTIONS:

Should be called from OUTPUT. The array must be real.

CALLING SEQUENCE:

FLPRNT(DATA(IC), HEAD(DV))

SUBROUTINE NAME: FLUX

PURPOSE:

Subroutine FLUX permits doublet time variant curve values stored on magnetic tape unit NFLXTP to be read into NCRV arrays starting at array DATA when the mission time exceeds DQTIME. The flux tape must be generated prior to the run using a GE routine LTVFTP. This routine generates the flux tape in the following format:

Record No. 1

First Read Time

Record No. 2

Number of points on first curve (Integer), first curve independent variables, first curve dependent variables, number of points on second curve, second curve independent variables, second curve dependent variables, etc. for all curves.

Record No. 3

Second Read Time

Record No. 4

Same as Record No. 2 except with new values

Record No. 5

Third Read Time

Etc. until all blocks of data are on tape.

Subroutine FLUX writes the values from the appropriate NFLXTP record into the arrays defined by DATA and NCRV in the proper doublet array format. Flux values should be input into the heat flux arrays ($DATA_1$---$DATA_{NCRV}$) initially if the user doesn't want the values to be read from the tape at the start of the problem. The value of QTIME should initially be the value of the time the first read is desired.

RESTRICTIONS:

The following restrictions apply:

(1) The initial block of curve data must be input on cards or data

[illegible] Particular curves must have the same number of [illegible] each block of data read [illegible] as were input on cards [illegible]

[illegible] Each curve may have a different number of points.

[illegible] The first point on each curve in each block of data must be the same as the last point on that curve in the previous block of data.

(5) All incident heat curves must be in a single block by themselves.

CALLING SEQUENCE:

FLUX(NFLXTP, DATA, NCRV, DQTIME, QTIME)

where

NFLXTP - logical unit to which the flux tape is assigned. Must be supplied by a user constant.

DATA - starting location (IC) for flux curves.

NCRV - number of flux curves to be updated from the flux tape.

DQTIME - time scale shift for flux curves. DQTIME is added to each independent value for each flux curve read from NFLXTP.

QTIME - the last point on the latest set of flux curves read from NFLXTP. (QTIME = FLXTIM + DQTIME, where FLXTIM is the time read from the flux tape) must be supplied by user constant.

SUBROUTINE NAMES: GENOUT, GENI OR GENR

PURPOSE:

These subroutines print out arrays of numbers 10 to a line. GENOUT prints either real numbers, integer or both. GENI and GENR print integers and real number arrays respectively. The integers are written in an I9 format and the real numbers in an E12.4 format.

RESTRICTIONS:

GENI writes arrays of integers only. GENR writes arrays of real numbers only.

CALLING SEQUENCE:

```
GENOUT (A, ISTRT, ISTP, 'NAME')
GENI   (A, ISTRT, ISTP, 'NAME')
GENR   (A, ISTRT, ISTP, 'NAME')
```

where A - is the array location

ISTRT - is the first value in A being written

ISTP - is the last value in A being written

'NAME' - is a title of 22 Hollerith words for identification

SUBROUTINE NAME: HSTFLO

PURPOSE:

Subroutine HSTFLO stores the problem time, the pressures of all pressure nodes, the valve positions for all valves, the flowrates for all tubes, and the temperatures of all temperature nodes at an input interval on a magnetic tape (the history tape) mounted on Unit T. The number of records written on the history tape is the number of history intervals plus two. The first record contains a title, an integer count of the number of items to be written for each of the five categories (pressure drops, pressures, valve positions, flowrates, and temperatures), the actual tube numbers, actual pressure node numbers, actual valve numbers, and the actual node numbers in order of relative numbers. The second through the next-to-last records contain the history records with one for each time point and the last record is the same as the next-to-last except the time is negative. The argument to HSTFLO is the history tape writing interval, TINC.

The format for the history tape is as follows:

Record No. 1

Tital (written internally) is 12A6 format 0,0,0,0,0, number of tubes, number of pressure nodes, number of valve positions, 0,0,0, number of tubes, 0,0, number of nodes, actual tube numbers in increasing order, actual pressure node numbers in increasing order, actual valve numbers in increasing order, and actual node numbers in increasing order of relative node numbers.

Record No. 2

Initial problem time, pressure drops, pressures, valve positions, flowrates, node temperatures

Record No. 3

Second history time, pressure drops, pressures, valve positions, flowrates, node temperatures

.

.

.

Record No. N+1 (Where N = number of history time slices to be written)

Last history time, pressure drops, pressures, valve positions, flowrates, node temperatures

Record No. N+2

Same as last record except time is negative

RESTRICTIONS:

Should be called in VARIABLES 2. An output history tape should be mounted on unit T. Subroutine TMCHK must be in VARIABLES 2 prior to the call to Subroutine HSTFLO if TIMCHK is called in the problem.

If the backup feature is used in VARIABLES 2, the call to subroutine HSTFLO should not be made until the last pass to avoid nonincreasing time records or invalid data. For example:

```
              BCD 3VARIABLES 2
                     .
                     .
                     .
         F    IF (T(16) .LT.  TMAX) BACKUP = 1.
                     .
                     .
                     .
         F    IF (BACKUP .GT.  C.) GO TO 10
                 HSTFLO (.01)
         F  10 CONTINUE
              END
```

CALLING SEQUENCE:

HSTFLO(TINC)

SUBROUTINE NAME: HXEFF

PURPOSE:

This subroutine obtains the heat exchanger effectiveness either from a user constant or from a bivariant curve of effectiveness versus the flow rates on the two sides. The effectiveness thus obtained is used with the supplied flow rates, inlet temperatures and fluid properties to calculate the outlet temperatures using the methods described in Section 2.1.6.4. The user may specify a constant effectiveness by supplying a real number or may reference an array number to specify the effectiveness as a bivariant function of the two flow rates. The user supplies flow rates, specific heat values, inlet temperatures and a location for the outlet temperatures for each of the two sides. The flow rate array may be referenced to obtain flow rates and the temperature array may be used for temperatures. The specific heat values may be supplied as a temperature dependent curve or a constant value may be supplied. The user also identifies enthalpy curves for each side which may be generated from the specific heat curve with user subroutine CRVINT.

RESTRICTIONS:

HXEFF should be called in the VARIABLES 1 block. The value for EFF, the first argument must never be zero. T_{out1} and T_{out2} must be boundary nodes.

CALLING SEQUENCE: HXEFF(EFF,W1,W2,CP1,CP2,TIN1,TIN2,TOUT1,TOUT2,H1,H2)

where EFF - is (1) the effectiveness if real, (2) a curve number of a bivariant curve of effectiveness versus W1 and W2 if an array

W1,W2 - are the flow rates for side 1 and 2 respectively. May reference the flow rate array, W (I)where I is the tube number

CP1,CP2 - are the specific heat value for side 1 and side 2 fluid respectively. Constant values may be input or arrays may be used for temperature dependent properties.

TIN1,TIN2 - are inlet lump temperatures - Usually T(IN1) and T(IN2) where IN1 and IN2 are the inlet lumps on side 1 and side 2

TOUT1,TOUT2 - are the outlet lump temperature locations sides 1 and 2 where the calculated values will be stored. Must be boundary nodes.

H1,H2 - are arrays which give enthalpy vs temperature for sides 1 and 2 respectively.

SUBROUTINE NAME: HXCNT

PURPOSE:

This subroutine calculates the heat exchanger effectiveness using the relation described in Section 2.1.6.1, for a counter flow type exchanger. The value of UA used in the calculations may be specified as a constant by supplying a real number or it may be specified as a bivariant function of the two flow rates by referencing an array number. The user supplies flow rates, specific heat values, inlet temperatures and a location for the outlet temperatures for each of the two sides. The flow rate array may be referenced to obtain flow rates and the temperature array may be used for temperatures. The specific heat values may be supplied as a temperature dependent curve or a constant value may be supplied. The user also identifies enthalpy curves for each side which may be generated from the specific heat curve with user subroutine CRVINT.

RESTRICTIONS:

HXCNT should be called in the VARIABLES 1 block. The value of UA, the first argument, must never be zero. T_{out1} and T_{out2} must be boundary nodes.

CALLING SEQUENCE: HXCNT(UA,W1,W2,CP1,CP2,TIN1,TIN2,TOUT1,TOUT2,H1,H2)

where

UA	is (1) the heat exchanger conductance if real, (2) a curve number of a bivariant curve of conductance versus W1 and W2 if an array
W1,W2	are the flowrates for side 1 and side 2 respectively. May reference the flowrate array,W (I) where is the tube number.
CP1,CP2	are the specific heat values for side 1 and 2 fluid respectively. Constant values may be input or arrays

may be used for temperature dependent properties.

TOUT1-TOUT2 are the outlet lump temperature locations (sides 1 and 2) where the calculated values will be stored. Must be boundary nodes.

H1,H2 are arrays which give enthalpy vs temperature for sides 1 and 2 respectively.

SUBROUTINE NAME: HXCOND

PURPOSE:

This subroutine performs thermal analysis on a condensing heat exchanger using relations described in section 2.1.6.5. The effectiveness may either be supplied as a constant or as a trivariant function of humidity, flow rate of the gas, and flow rate of the coolant. CRVINT may be used to integrate the specific heat curves to produce the enthalpy curves.

RESTRICTIONS:

HXCOND should be called in the VARIABLES 1 block. The value for EFF, the first argument, must never be zero. TGOUT, and TCONI must be boundary nodes.

CALLING SEQUENCE: HXCOND(EFF,WG,WC,NHG,NHC,TGIN,TCIN,PSIIN,P,XLAM,XMIMO, PSIOUT,WL,TGOUT,TCOUT)

where EFF is (1) the effectiveness if real, (2) a curve number of a trivariant curve of effectiveness versus PSIIN, WG, and WC

	WG	is the flow rate of the gas
	WC	is the flow rate of the coolant
	NHG	is the enthalpy curve for the gas
	NHC	is the enthalpy curve for the coolant
	TGIN	is the temperature of the incoming gas
	TCIN	is the temperature of the incoming coolant
	PSIIN	is the humidity of the incoming gas
	P	is the total gas pressure
	XLAM	is the latent heat of vaporization
	XMDMD	is the molecular weight ration M_V/M_O
	PSIOUT	is the outlet humidity

WL	is the flow rate of the liquid
TGOUT	is the temperature of the outgoing gas
TCOUT	is the temperature of the outgoing coolant

SUBROUTINE NAME: HXCROS

PURPOSE:

This subroutine calculates the heat exchanger effectiveness using the relations described in Section 2.1.6.3, for a cross flow type exchanger. The value of UA used in the calculations may be specified as a constant by supplying a real number or it may be specified as a bivariant function of the two flow rates by referencing an array number. Any one of the following four types of cross flow exchangers may be analyzed.

1) Both streams unmixed
2) Both streams mixed
3) Stream with smallest MCp product unmixed
4) Stream with largest MCp product unmixed

The type is specified by the last argument in the call statement. The user supplies flow rates, specific heat values, inlet temperatures and a location for the outlet temperatures for both sides. The flow rate array may be referenced to obtain flow rates and the temperature array may be used for temperatures. The specific heat values may be supplied as a temperature dependent curve or a constant value may be supplied. The user also identifies enthalpy curves for each side which may be generated from the specific heat curve with user subroutine CRVINT.

RESTRICTIONS:

HXCROS should be called in the VARIABLES 1 block. The value for UA, the first argument, must never be zero. T_{out1} and T_{out2} must be boundary nodes.

CALLING SEQUENCE: HXCROS(UA,W1,W2,CP1,CP2,TIN1,TIN2,TOUT1,TOUT2,K,H1,H2)

where UA is (1) the heat exchanger conductance if real, (2) a curve number of a bivariant curve of conductance versus W1 and W2 if an array.

W1,W2	are the flow rates for side 1 and 2 respectively. May reference the flow rate array, W (I)where I is the tube number.
CP1,CP2	are the specific heat values for side 1 and side 2 fluid respectively. Constant values may be input or arrays may be used for temperature dependent properties
TIN1,TIN2	are inlet lump temperatures - Usually T(IN1) and T(IN2) where IN1 and IN2 are the inlet lumps on side 1 and side 2
TOUT1,TOUT2	are the outlet lump temperature locations (sides 1 and 2) where the calculated values will be stored. Must be boundary nodes

K is the code specifying type of cross flow exchanger:

Both streams unmixed : K = 1

Both streams mixed : K = 2

Stream with small WCp unmixed : K = 3

Stream with large WCp unmixed : K = 4

H1,H2	are arrays which give enthalpy vs temperature for sides 1 and 2 respectively

SUBROUTINE NAME: HXPAR

PURPOSE:

This subroutine calculates the heat exchanger effectiveness using the relations described in Section 2.1.6.2, for a parallel flow type exchanger. The value of UA used in the calculations may be specified as a constant by supplying a real number or it may be specified as a bivariant function of the two flow rates by referencing an array. The user supplies flow rates, specific heat values, inlet temperatures and a location for the outlet temperatures for each of the two sides. The flow rate array may be referenced to obtain flow rates and the temperature array may be used for temperatures. The specific heat values may be supplied as a temperature dependent curve or a constant value may be supplied. The user also identifies enthalpy curves for each side which may be generated from the specific heat curve with user subroutine CRVINT.

RESTRICTIONS:

HXPAR should be called in the VARIABLES 1 block. The value for UA, the first argument, must never be zero. T_{out1} and T_{out2} must be boundary temperatures.

CALLING SEQUENCE: HXPAR(UA,W1,W2,CP1,CP2,TIN1,TIN2,TOUT1,TOUT2,H1,H2)

where UA		is (1) the heat exchanger conductance if real, (2) a curve number of a bivariant curve of conductance versus W1 and W2 if an array.
	W1,W2	are the flow rates for side 1 and 2 respectively. May reference the flow rate array, W (I)where I is the tube number
	CP1,CP2	are the specific heat values for side 1 and side 2 fluid respectively. Constant values may be input or arrays may be used for temperatures dependent curves.

TIN1,TIN2	are inlet lump temperatures - Usually T(IN1) and T(IN2) where IN1 and IN2 are the inlet lumps on side 1 and side 2
TOUT1,TOUT2	are the outlet lump temperature locations (sides 1 and 2) where the calculated values will be stored (should be boundary temperatures)
H1,H2	are arrays which give enthalpy vs temperature for sides 1 and 2 respectively

SUBROUTINE NAME: HYBRID

PURPOSE:

This subroutine calculates transient temperatures using an optimum mix between implicit and explicit methods of solution. The explicit stability criteria of each diffusion node, CSG, is calculated on each temperature iteration as the capacitance divided by the sum of the conductors. This criteria is then checked against the user supplied time increment, DTIMEL. The temperature of these nodes with CSG less than DTIMEL are calculated using the implicit method of solution. For these nodes with CSG greater than DTIMEL, the explicit method of solution is used.

The order of calculations is arranged such that energy is conserved in conductors between the implicit and explicit nodes. Calculations are made on the explicit nodes first. Next, the temperatures of implicit and arithmetic nodes are calculated using the latest explicit temperatures in the calculations.

The implicit calculations are made using the methods described in Ref. 1. Using this method, temperatures of each node are made using the latest calculated adjacent temperatures. "Passes" are made repeatedly through the temperature calculations until all temperature changes (between passes) have satisfied the user input tolerances DRLXCA and ARLXCA which must be supplied by the user. When the tolerance is satisfied for a node, the calculations of its temperature are temporarily suspended in the pass loop until all node tolerances are met. The calculation on all nodes are then resumed and the procedure is repeated until all node temperatures meet the tolerances on two successive passes. The calculations may be over-relaxed or damped using user constants DAMPD and DAMPA. The default values for these variables are 1.0 for each. The maximum number of passes allowed through the temperature calculation loop is supplied by the user constant NLOOP. Typical values for this variable are 500 to 1000.

The implicit calculations for diffusion nodes may be backward difference, mid difference, or anywhere between backward and mid-difference. The first argument of HYBRID, ALPHA, determines the point in the iteration for evaluating the heat flux. If ALPHA = 1.0 or 0.0 (with a default value of 1.0) backward difference results. If $0. < \alpha \leq 0.5$, ALPHA is set equal to 0.5 and mid-difference results. If ALPHA is between 0.5 and 1.0, the heat rate is ALPHA times that at the end of the iteration plus (1-ALPHA) times that at the start of the iteration. A second argument, KOP, will give a checkout print if $\neq 0$. Be prepared for a considerable amount of output if KOP $\neq 0$.

The problem output is supplied at OUTPUT interval where OUTPUT is supplied as a user constant. The user may also supply a maximum allowable temperature change for the diffusion and arithematic nodes by supplying values for DTMPCA and ATMPCA. If the changes are exceeded, the problem will be terminated. Default values for these are $1. \times 10^8$.

RESTRICTIONS:

The LPCS option is required and control constants TIMEND, OUTPUT, DTIMEL, NLOOP, DRLXCA, and ARLXCA must be specified. Other control constants used or activated are: TIMEN, TIMEØ, TIMEM, CSGMIN, DTIMEU, DTMPCA, DTMPCC, ATMPCA, ATMPCC, DAMPD, DAMPA, DRLXCC, ARLXCC, LOOPCT, BACKUP, OPEITR, LINECT, PAGECT.

CALLING SEQUENCE : HYBRID(ALPHA, KOP)

DYNAMIC STORAGE REQUIREMENTS:

This routine utilizes two dynamic storage core locations for each temperature node for non-flow problems or three dynamic storage locations for each temperature node for fluid flow problems.

SUBROUTINE NAME: INVRS

See description for usage of SINVRS.

SUBROUTINE NAME: QCOMB or ACOMB

PURPOSE:

QCOMB and ACOMB sum the interpolated value of the dependent variables of two arrays, A1 and A2, after multiplying A1 by α_1 and A2 by α_2 to form a third array, A3. For QCOMB, A3 contains all the independent variable values of both A1 and A2 except where these values are equal. For ACOMB, the combined array will contain the independent variables of the A1 array only.

RESTRICTIONS:

Adequate space must be set aside in A3 but the space isn't required to be the exact amount needed by A3.

CALLING SEQUENCE: QCOMB(A3,α1,A1,α2,A2) or ACOMB(A3,α1,A1,α2,A2)

where A3 is a doublet array with dependent variable values given by

$$A3(i) = \alpha 1 * A1(i) + \alpha 2 * A2(i)$$

α1 and α2 are constants to be multiplied times values of A1 and A2 at each point of A3

A1 and A2 are doublet arrays

C-2

SUBROUTINE NAME: RADIR

PURPOSE:

RADIR calculates the script-F values for infrared radiation heat transfer within an enclosure and uses these values to obtain the heat transfer during the problem. Several temperature nodes may be combined on a single surface for radiation heat transfer purposes. Also, the user may analyze problems with specular, diffuse or combinations of specular and diffuse radiation. See Section 2.1.8.1 for definitions and detailed description of methods.

RADIR calculates the script-F values on the initial call. This is performed by the procedure outlined in Section 2.1.8.1. These values replace the EFT values in the SC array for future use. The heat flux values are then calculated on all iterations by:

(1) Calculating the temperature of each surface

(2) Calculating the absorbed heat for each node

The value given by equation 38 is added to the conductor sum for each node so that the proper convergence time increment may be obtained. As many enclosures as desired may be analyzed by each enclosure but each enclosure requires a different call to RADIR. RADIR must be called in VARIABLES 1.

RESTRICTIONS:

Must be called from VARIABLES 1 Surface nodes must be boundary nodes

CALLING SEQUENCE:

RADIR (A(IC) , SIGMA, TZERO)

Where A is of the following format:

A(IC),SN,SE,SR,SC,NA,SP,END

SN,SE,SR,SC,NA, and SP are actual array numbers input using the *A procedure and are of the following formats

```
SN(IC),n,SN1,SA1,NN1,SN2,SA2,NN2,..............SNn,SAn,NNn,END
SE(IC),SE1,SE2-----SEn,END
SR(IC),SR1,SR2-----SRn,END
SC(IC),SNF1,SNT1,EFT1,SNF2,SNT2,EFT2,---SNFm,SNTm,EFTm,END
NA(IC),NNO(1,1),AN(1,1),NNO(1,2),AN(1,2)--NNO(1,NN1),AN(1,NN1)
       NNO(2,1),AN(2,1),NNO(2,2),AN(2,2)--NNO(2,NN2),AN(2,NN2)
          .        .        .       .        .          .
          .        .        .       .        .          .
          .        .        .       .        .          .
       NNO(n,1),AN(n,1),NNO(n,2),AN(n,2)--NNO(n,NNn),AN(n,NNn),END
SP(IC),SPACE,NSPACE,END
```

The following definitions apply in the above calling sequence:

A	Array idenitifcation for the array which identifies the other arrays containing the data
SN	Array number for the array containing surface numbers and areas
SE	Array number for the array containing the surface emissivities (may not be used in more than one call to RADIR)
SR	Array number for the array containing the surface reflectivities
SC	Array number for the array containing the surface connections data
NA	Array number for the array containing the temperature node numbers and areas
SP	Array number for the array containing the space which is used for obtaining script FA values and for subsequent temperature calculations
n	The number of surfaces
SN1,SN2,...SNn	Node number for surfaces - must be boundary nodes
SA1,SA2,....SAn	Total area for each surface
NN1,NN2,....NNn	Number of temperature nodes on each surface
SE1,SE2,....SEn	Emissivity values for each surface
SR1,SR2,....SRn	Diffuse reflectivity values for each surface
SNF1,SNT1,EFT1	Connections data: Surface number from, surface number to, E value from SNF1 to SNT1, etc.(SNF1 ≠ SNT1)
NNO(X,Y)	Temperature node numbers on surfaces; Node number Y on surface X
AN(X,Y)	Area of node Y on surface X
NSPACE	Number of spaces needed to store script-FA values. - NSPACE must be an integer values of n *n(n+1)/2
n	The number of surfaces
SIGMA	Stefan-Boltzmann constant
TZERO	Temperature of absolute zero in problem units

SUBROUTINE NAME: RADSOL

PURPOSE:

RADSOL calculates a pseudo script-F for radiation from an external source entering an enclosure and uses these values to calculate the net heat transfer to each node due to the entering source. A number of temperature nodes may be combined on a single surface for radiation purposes. Also, problems with specular, diffuse, or combinations of specular and diffuse radiation may be analyzed. Section 2.1.8.2 should be consulted for definitions and descriptions of methods.

RADSOL calculates the pseudo script-F values on the initial call, as described in Section 2.1.8.2. The values are stored in the EFT values of the SC array supplied by the user. The heat flux values are then calculated on each iteration.

The user may analyze as many enclosures as desired by supplying a call statement for each enclosure. Also, a user may analyze several wave length bands by supplying a call to RADSOL for each wave length band.

RESTRICTIONS:

Must be called from VARIABLES I; Surface nodes must be boundray nodes

CALLING SEQUENCE:

RADSOL (A(IC))

Where the A array is of the following format:

A(IC),SN,SE,SR,HT,SC,NA,SP,END

SN,SE,SR,HT,SC,NA, and SP are actual array numbers input using the *A procedure and are of the following formats:

```
SN(IC), n,SN1,SA1,NN1,SN2,SA2,NN2,------Snn,SAn,NNn,END
SE(IC),SE1,SE2,------SEn,END
SR(IC),SR1,SR2,------SRn,END
HT(IC),SHT1,SHT2-----SHTn,END
SC(IC),SNF1,SNT1,EFT1,SNF2,SNT2,EFT2,---SNFm,SNTm,EFTm,END
NA(IC),NNO(1,1),AN(1,1),NNO(1,2),AN(1,2)---NNO(1,NN1),AN(1,NN1),
       NNO(2,1),AN(2,1),NNO(2,2),AN(2,2)---NNO(2,NN2),AN(2,NN2),
          .        .        .        .        .         .
          .        .        .        .        .         .
          .        .        .        .        .         .
       NNO(n,1),AN(n,1),NNO(n,2),AN(n,2)---NNO(n,NNn),AN(n,NNn),END
SP(IC),SPACE,NSPACE,END
```

The following definitions apply in the above calling sequence

A	Array identification for the array which identifies the other arrays containing the data
SN	Array number for the array containing surface numbers and areas
SE	Array number for the array containing the surface emissivities (may not be used in more than one call to RADSOL)
SR	Array number for the array containing the surface reflectivities
HT	Array number for the array containing the incident heat curves or constant heat flux values
SC	Array number for the array containing the surface connections data
NA	Array number for the array containing the temperature node numbers and areas
SP	Array number for the array containing the space which is used for obtaining script values and for subsequent temperature calculations
SN1,SN2,...SNn	Node number for surfaces;<u>must be boundary nodes</u>
SA1,SA2,...SAn	Total area for each surface
NN1,NN2,...NNn	Number of temperature nodes on each surface
SE1,SE2,...SEn	Emissivity values for each surface
SR1,SR2,...SRn	Diffuse reflectivity values for each surface
SHT1,SHT2,...SHTn	Incident heat flow on surfaces; may identify curves containing incident values vs time
SNF1,SNT1,EFT1	Connections data: Surface number from surface number to, E value from SNF1 to SNT1, etc.(must include SNF1=SNT1)
NNO(X,Y)	Temperature node numbers on surfaces: Node number Y on surface X
AN(X,Y)	Area of node Y on surface X
NSPACE	Number of spaces needed to store script-FA values - NSPACE must be an integer values of n(n+1)/2
n	Number of surfaces

SUBROUTINE NAME: REVPOL

PURPOSE:

This subroutine performs single variable linear interpolation on a doublet array of X,Y pairs in the same manner as D1DEG1 except in reverse order. The array is interpolated in reverse order to obtain the value of independent variable, X, which corresponds to the input dependent variable, Y.

RESTRICTIONS:

All values must be floating point numbers.

CALLING SEQUENCE:

REVPOL (Y,A(IC),X)

where Y	-	input value of dependent variable
A	-	Doublet array of X,Y pairs
X	-	output value of independent variable

SUBROUTINE NAME: SINVRS or INVRS

PURPOSE:

These subroutines perform matrix inversion for symmetric, positive definite matrices using the efficient Square-Root or Symmetric Cholesky method. This method requires approximately half the computer time to obtain an inverse using the Gauss Elimination and Gauss-Jordan methods. Also, a significant increase in the accuracy has been observed. The symmetric matrix may be stored in half the square matrix space if desired. The inverse is returned in its original space of the A-matrix.

For SINVRS, the A matrix may be either a full square matrix or the upper triangular half of a square matrix. A check on the integer count relative to the matrix size is used to determine whether 1/2 matrix or full matrix is stored. INVRS assumes only the upper traingle of the symmetric matrix is stored. The (1,1) element is stored in the third data value of A for SINVRS and in the first data value of INVRS. The first data value of A contains the matrix size for SINVRS.

RESTRICTIONS:

The half symmetric matrix must be stored as shown below for INVRS and for the half symmetric matrix option of SINVRS. Subroutine INVRS contains no error checks and should be used with extreme caution.

CALLING SEQUENCE: SINVRS(A(IC),D) or INVRS(A(DV),N,D)

where A is the matrix to be inverted and also, the inverse upon return

D is the determinant of the original matrix to be inverted

N is the matrix size

The formats for A are as follows for SINVRS:

(A) Full symetric matrix

```
IC,N,BLANK,A(1,1),A(1,2), - - - A(1,N)
           A(2,1),A(2,2), - - - A(2,N)
              '      '             '
              '      '             '
              '      '             '
           A(N,1),A(N,2)  - - - A(N,N)
```

(B) Half symmetric matrix

```
IC,N,BLANK,A(1,1),A(1,2),A(1,3), - - - A(1,N)
                       A(2,2),A(2,3), - - - A(2,N)
                              - - - - - -      '
                                               '
                                            A(N,N)
```

The format for A is as follows for INVRS

```
A(1,1),A(1,2),A(1,3), - - - A(1,N)
       A(2,2),A(2,3), - - - A(2,N)
              - - - - - -      '
                               '
                            A(N,N)
```

SUBROUTINE NAME: TIMCHK

PURPOSE:

Subroutine TIMCHK compares the elapsed computer time against the requested computer time, RTIME, and terminates the run if RTIME is exceeded by the elapsed time. If the second argument, KODE, is non-zero an output of computer time used will be printed out on each call to TIMCHK. Thus, a call to TIMCHK in VARIABLES 2 should normally be with KODE=0. If the output of computer time used is desired, TIMCHK should be called from OUTPUT with KODE ≠ 0. The most desirable procedure is to supply two calls to TIMCHK : (1) a call in VARIABLES 2 with KODE = 0 and (2) a call in OUTPUT with KODE ≠ 0.

RESTRICTIONS:

KODE should zero when called from VARIABLES 1 or 2.

CALLING SEQUENCE:

TIMCHK (RTIME, KODE)

where RTIME = maximum computer time requested

KODE = print code: = 0, computer time used is not printed out

≠ 0, computer time used is printed out on each call to TIMCHK

SUBROUTINE NAME: WPRINT

PURPOSE:

Subroutine WPRINT will write all the values of the flowrates, pressure drops, pressures and valve positions. All values are printed out versus the actual numbers for which they occur.

RESTRICTIONS:

Should be called from OUTCAL

CALLING SEQUENCE: WPRINT (K1,K2,K3,K4)

where: K1 = 0, no flowrates will be printed
= 1, flowrates will be printed

K2 = 0, no pressure drops will be printed
1, pressure drops will be printed

K3 = 0, no pressures will be printed
1, pressures will be printed

K4 = 0, no valve positions will be printed
1, valve positions will be printed

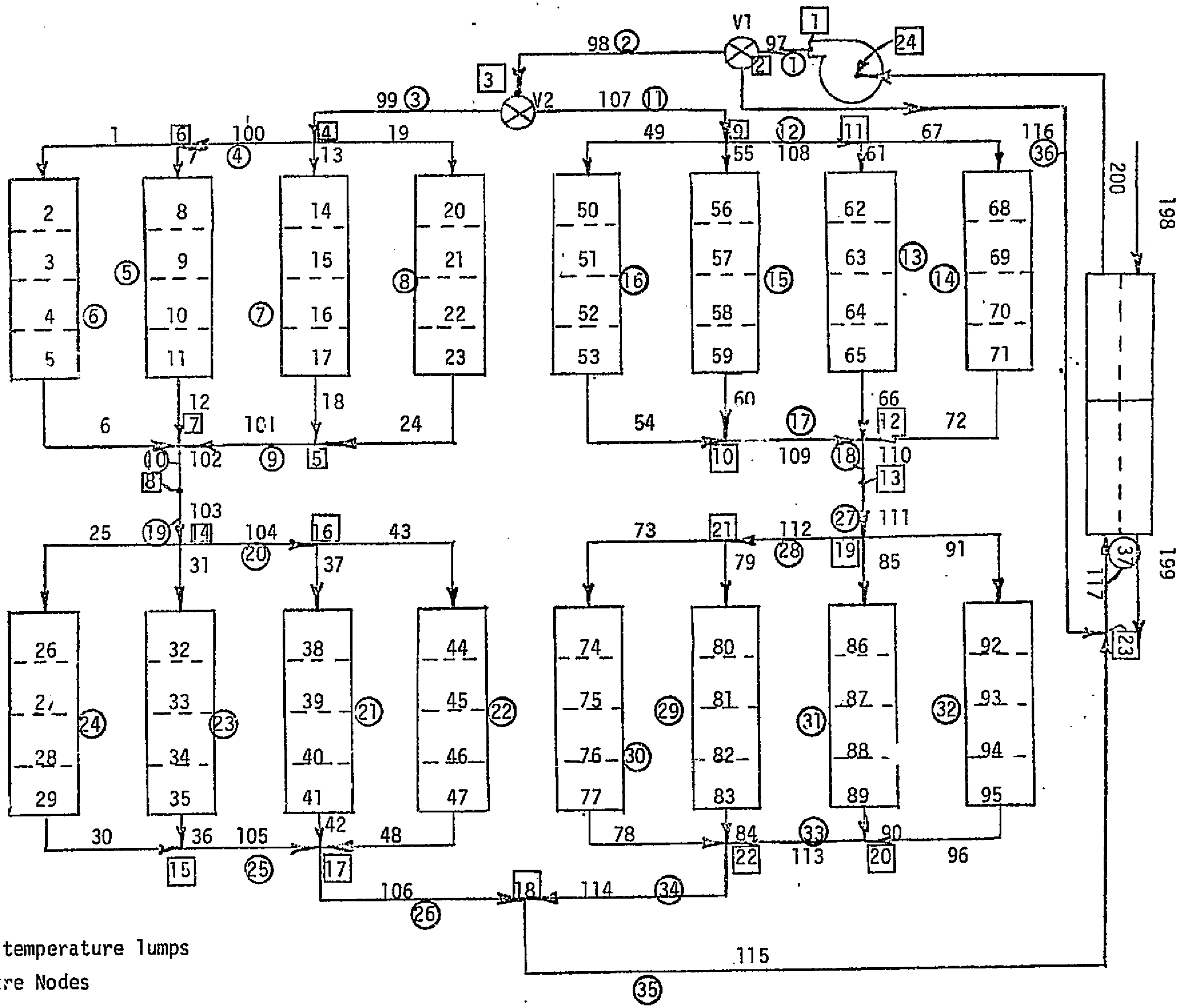
DYNAMIC STORAGE REQUIREMENTS:

Dynamic storage required by WPRINT is NW + NPR + NV where NW is the number of tubes, NPR is the number of pressure nodes, and NV is the number of valves.

6.0 SAMPLE PROBLEM

A sample problem was prepared for the SINFLO routine to demonstrate the input and output for a typical thermal/flow analysis problem. A schematic of the problem is shown in Figure 9 . The problem consists of 8 two dimensional radiator panels, each modeled by two flow paths (one for the main panel of 11 tubes and one for the prime bypass tube). Contained in the system are a pump, a bypass valve (valve No. 1) and a stagnation valve between the two flow paths. The heat load to the radiator system comes through a counter flow heat exchanger which has a controlled inlet temperature of 40°F. The fluid is Freon 21 in the radiator system and water on the cooled side of the heat exchanger. The nodal subdivision for the fluid system is shown in Figure 9 . The structural nodal subdivision is shown in Figure 10.

The sample problem was analyzed using the SNFRWD solution routine. The input for the problem is listed in Table 6 and the printed output is listed in Table 7. A few selected items were plotted using the plot package described in Appendix C. The plots of these items are presented in Figures 11 thru 17. The same sample problem was analyzed using the other temperature solution methods: CNFWBK, CNFWRD, CNFAST, HYBRID, CINDSS, SNFRWD FWDBCK, SNFRDL, CINDSL, and STDSTL.



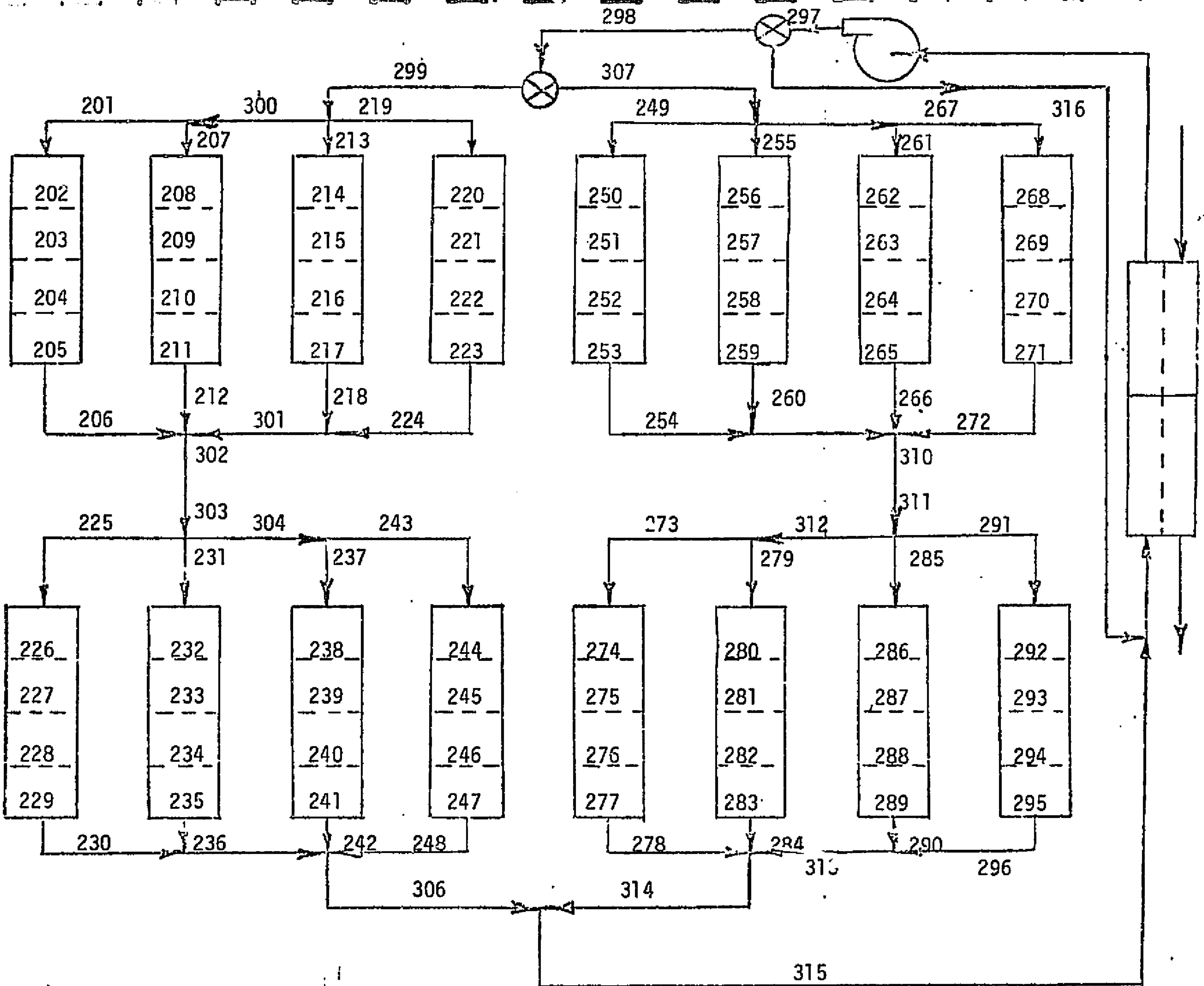
xx - Fluid temperature lumps

[x] - Pressure Nodes

(x) - Tube numbers

vx - Valve numbers

FIGURE 9 FLUID MODEL OF THE SAMPLE PROBLEM



xx - Structure Lumps

FIGURE 10 STRUCTURE MODEL FOR THE SAMPLE PROBLEM

TABLE 6

LISTING OF SAMPLE PROBLEM INPUT

SINDA/SINFLO PREPROCESSOR

```
BCD 3THERMAL SPCS
BCD 4SAMPLE PROBLEM / SNFRWD
END
BCD 3NODE DATA
REM NODE,NUM,INC , TI        ,A(T), CONST        $
GEN   -1,117,   1, 70,        ,  1.0             $      FLUID LUMPS
    -198            ,100.     ,  1.0             $        .      .
    -199            , 40.     ,  1.0             $        .      .
    -200            , 100.    ,  1.0             $      FLUID LUMPS
SIM  201,  8,   6,   70.      ,  A4,  .720       $      TUBE LUMPS
SIM  202,  8,   6,   70.      ,  A4,10.3         $
SIM  203,  8,   6,   70.      ,  A4,10.3         $
SIM  204,  8,   6,   70.      ,  A4,10.3         $
SIM  205,  8,   6,   70.      ,  A4,10.3         $
SIM  206,  8,   6,   70.      ,  A4,  .720       $
SIM  249,  8,   6,   70.      ,  A4,  .720       $
SIM  250,  8,   6,   70.      ,  A4,  .0718      $
SIM  251,  8,   6,   70.      ,  A4,  .0718      $
SIM  252,  8,   6,   70.      ,  A4,  .0718      $
SIM  253,  8,   6,   70.      ,  A4,  .0718      $
SIM  254,  8,   6,   70.      ,  A4,  .720       $
SIV  297            ,  70.    ,  A4,  .299       $
SIV  298            ,  70.    ,  A4,  .299       $
SIV  299            ,  70.    ,  A4, 1.20        $
SIV  300            ,  70.    ,  A4,  .419       $
SIV  301            ,  70.    ,  A4,  .419       $
SIV  302            ,  70.    ,  A4,  .150       $
SIV  303            ,  70.    ,  A4,  .150       $
SIV  304            ,  70.    ,  A4,  .419       $
SIV  305            ,  70.    ,  A4,  .419       $
SIV  306            ,  70.    ,  A4,  .720       $
SIV  307            ,  70.    ,  A4, 1.200       $
SIV  308            ,  70.    ,  A4,  .720       $
SIV  309            ,  70.    ,  A4,  .720       $
SIV  310            ,  70.    ,  A4,  .150       $
SIV  311            ,  70.    ,  A4,  .150       $
SIV  312            ,  70.    ,  A4,  .720       $
SIV  313            ,  70.    ,  A4,  .720       $
SIV  314            ,  70.    ,  A4, 1.200       $
SIV  315            ,  70.    ,  A4,  .299       $
SIV  316            ,  70.    ,  A4,  .012       $
SIV  317            ,  70.    ,  A4, 2.99        $
    -400            , -459.69 ,1.0               $
END
```

RELATIVE NODE NUMBERS			ACTUAL NODE NUMBERS									
1	THRU	10	201	207	213	219	225	231	237	243	202	208
11	THRU	20	214	220	226	232	238	244	203	209	215	221
21	THRU	30	227	233	239	245	204	210	216	222	228	234
31	THRU	40	240	246	205	211	217	223	229	235	241	247
41	THRU	50	276	212	218	224	230	236	242	248	249	255
51	THRU	60	261	267	273	279	285	291	250	256	262	268
61	THRU	70	274	280	286	292	251	257	263	269	275	281

TABLE 6 (CONTINUED)

```
SINDA;SINFLO PREPROCESSOR
      71  THRU   80        287   293   252   258   264   270   276   282   288   294
      81  THRU   90        253   259   265   271   277   283   289   295   254   260
      91  THRU  100        266   272   278   284   290   296   297   298   299   300
     101  THRU  110        301   302   303   304   305   306   307   300   309   310
     111  THRU  120        311   312   313   314   315   316   317     1     2     3
     121  THRU  130          4     5     6     7     8     9    10    11    12    13
     131  THRU  140         14    15    16    17    18    19    20    21    22    23
     141  THRU  150         24    25    26    27    28    29    30    31    32    33
     151  THRU  160         34    35    36    37    38    39    40    41    42    43
     161  THRU  170         44    45    46    47    48    49    50    51    52    53
     171  THRU  180         54    55    56    57    58    59    60    61    62    63
     181  THRU  190         64    65    66    67    68    69    70    71    72    73
     191  THRU  200         74    75    76    77    78    79    30    81    82    83
     201  THRU  210         84    85    86    87    88    89    90    91    92    93
     211  THRU  220         94    95    96    97    98    99   100   101   102   103
     221  THRU  230        104   105   106   107   108   109   110   111   112   113
     231  THRU  238        114   115   116   117   198   199   200   400
NODE ANALYSIS...  DIFFUSION =  117,  ARITHMETIC =   0,  BOUNDARY =  121,  TOTAL =  238

BCD 3SOURCE DATA
REM NODE,A(TIME),CONST $
SIT  202, A15,  16.270 $
SIT  203, A15,  16.270 $
SIT  204, A15,  16.270 $
SIT  205, A15,  16.270 $
SIT  208, A15,  16.270 $
SIT  209, A15,  16.270 $
SIT  210, A15,  16.270 $
SIT  211, A15,  16.270 $
SIT  214, A15,  16.270 $
SIT  215, A15,  16.270 $
SIT  216, A15,  16.270 $
SIT  217, A15,  16.270 $
SIT  220, A15,  16.270 $
SIT  221, A15,  16.270 $
SIT  222, A15,  16.270 $
SIT  223, A15,  16.270 $
SIT  224, A15,  16.270 $
SIT  227, A15,  16.270 $
SIT  228, A15,  16.270 $
SIT  229, A15,  16.270 $
SIT  232, A15,  16.270 $
SIT  233, A15,  16.270 $
SIT  234, A15,  16.270 $
SIT  235, A15,  16.270 $
SIT  230, A15,  16.270 $
SIT  239, A15,  16.270 $
SIT  240, A15,  16.270 $
SIT  241, A15,  16.270 $
SIT  244, A15,  16.270 $
SIT  245, A16,  16.270 $
SIT  246, A15,  16.270 $
SIT  247, A15,  16.270 $
SIT  250, A15,   0.431 $
SIT  251, A15,   0.431 $
SIT  252, A15,   0.431 $
SIT  253, A15,   0.431 $
```

```
SIT  256, A15,   0.431 $
SIT  257, A15,   0.431 $
SIT  258, A15,   0.431 $
SIT  259, A15,   0.431 $
SIT  262, A15,   0.431 $
SIT  263, A15,   0.431 $
SIT  264, A15,   0.431 $
SIT  265, A15,   0.431 $
SIT  268, A15,   0.431 $
SIT  269, A15,   0.431 $
SIT  270, A15,   0.431 $
SIT  271, A15,   0.431 $
SIT  274, A15,   0.431 $
SIT  275, A15,   0.431 $
SIT  276, A15,   0.431 $
SIT  277, A15,   0.431 $
SIT  280, A15,   0.431 $
SIT  281, A15,   0.431 $
SIT  282, A15,   0.431 $
SIT  283, A15,   0.431 $
SIT  286, A15,   0.431 $
SIT  287, A15,   0.431 $
SIT  288, A15,   0.431 $
SIT  289, A15,   0.431 $
SIT  292, A15,   0.431 $
SIT  293, A16,   0.431 $
SIT  294, A15,   0.431 $
SIT  295, A15,   0.431 $
END
BCD 3CONDUCTOR DATA
REM   NG    NOG    IG   NA   INA   NB   INB   G
GEN -401,    8,    1, 202,   6, 400,   0, 2.59E-8      $ RADIATION
GEN -409,    8,    1, 203,   6, 400,   0, 2.59E-8      $
GEN -417,    8,    1, 204,   6, 400,   0, 2.59E-8      $
GEN -425,    8,    1, 205,   6, 400,   0, 2.59E-8      $
GEN -433,    8,    1, 250,   6, 400,   0, 0.68E-9      $
GEN -441,    8,    1, 251,   6, 400,   0, 0.68E-9      $
GEN -449,    8,    1, 252,   6, 400,   0, 0.68E-9      $
GEN -457,    8,    1, 253,   6, 400,   0, 0.68E-9      $
END
```

RELATIVE CONDUCTOR NUMBERS	ACTUAL CONDUCTOR NUMBERS									
1 THRU 10	401	402	403	404	405	406	407	408	409	410
11 THRU 20	411	412	413	414	415	416	417	418	419	420
21 THRU 30	421	422	423	424	425	426	427	428	429	430
31 THRU 40	431	432	433	434	435	436	437	438	439	440
41 THRU 50	441	442	443	444	445	446	447	448	449	450
51 THRU 60	451	452	453	454	455	456	457	458	459	460
61 THRU 64	461	462	463	464						

```
CONDUCTOR ANALYSIS...  LINEAR =     0,  RADIATION =    64,  TOTAL =    64,  CONNECTIONS =    64

BCD 3FLOW DATA
BCD 3NETWORK MAIN
    GC=4.1696E8, CP=A1, RO=A2, MU=A5, KT=A6, HPASS=1, H=A8
    TOL=.01,MXPASS=100,FRDF=.7,P(24)=0.,END
    37, 23, 24 =  117.317        . END
```


TABLE 6 (CONT'D)

TABLE 6 (CONTINUED)

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```
SINDA;SINFLO PREPROCESSOR
          2,  2,  3 =    98,298          , END
          3,  3,  4 =    99,299          , END
         38,  4, 17 = SUB1               , END
         26, 17, 10 =   106,306          , END
         11,  3,  9 =   107,307          , END
         39,  9, 22 = SUB2               , END
         34, 22, 18 =   114,314          , END
         35, 18, 23 =   115,315          , END
         36,  2, 23 =   116,316          , END
          1,  1,  2 = -200,-297,97,297   , END
      END
      BCD 3SUBNETWORK SUB1
          4,  4,  6 =   100,300          , END
          5,  6,  7 = (   7,207,  12,212), END
          6,  6,  7 = (   1,201,   6,206), END
          7,  4,  5 = (  13,213,  18,218), END
          8,  4,  5 = (  19,219,  24,224), END
          9,  5,  7 =   101,301          , END
         10,  7,  8 =   102,302          , END
         19,  8, 14 =   103,303          , END
         20, 14, 16 =   104,304          , END
         21, 16, 17 = (  37,237,  42,242), END
         22, 16, 17 = (  43,243,  48,248), END
         23, 14, 15 = (  31,231,  36,236), END
         24, 14, 15 = (  25,225,  30,230), END
         25, 15, 17 =   105,305          , END
      END
      BCD 3SUBNETWORK SUB2
         12,  9, 11 =   108,308          , END
         13, 11, 12 = (  61,261,  66,266), END
         14, 11, 12 = (  67,267,  72,272), END
         15,  9, 10 = (  55,255,  60,260), END
         16,  9, 10 = (  49,249,  54,254), END
         17, 10, 12 =   109,309          , END
         18, 12, 13 =   110,310          , END
         27, 13, 19 =   111,311          , END
         28, 19, 21 =   112,312          , END
         29, 21, 22 = (  79,279,  84,284), END
         30, 21, 22 = (  73,273,  78,278), END
         31, 19, 20 = (  85,285,  90,290), END
         32, 19, 20 = (  91,291,  96,296), END
         33, 20, 22 =   113,313          , END
      END
      BCD 3FLUID LUMP DATA
         0,001008, 0,1125, 12,0 , 1,35  ,   0,0 =
                      1 ,   6 ,  19 ,  24 ,  25 ,  30 ,  43 ,  48
                     49 ,  54 ,  67 ,  72 ,  73 ,  78 ,  91 ,  96 ,END
         0,000938, 0,36  ,  3,25, 1,17  , 117,0 =
                    ( 2 ,   5),( 8 ,  11),( 14 ,  17),( 20 ,  23)
                    ( 26 ,  29),( 32 ,  35),( 38 ,  41),( 44 ,  47),END
         0,001008, 0,1125,  5,0 , 0,5625,   0,0 =
                      7 ,  12 ,  13 ,  18 ,  31 ,  36 ,  37 ,  42
                     55 ,  60 ,  61 ,  66 ,  79 ,  84 ,  85 ,  90
                     97 ,  98 , 117                          ,END
         0,853E-4, 0,0328,  0,25, 0,0082,   2,49=
                    ( 50 ,  53),( 56 ,  59),( 62 ,  65),( 68 ,  71)
                    ( 74 ,  77),( 80 ,  83),( 86 ,  89),( 92 ,  95),END
```

TABLE 6 (CONTINUED)

```
SINDA,SINFLO PREPROCESSOR
          0.001008, 0.1125, 20.0 , 2.25  ,   0.0 =
                  99 , 106 , 107 , 114                                .END
          0.001008, 0.1125,  2.5 , 0.281 ,   0.0 =
                  102 , 103 , 110 , 111                               .END
          0.001008, 0.1125, 50.0 , 5.62  ,   0.0 =
                  115                                                 .END
          0.001008, 0.1125,  7.0 , 0.7875,   0.0 =
                  100 , 101 , 104 , 105 , 108 , 109 , 112 , 113 .END
          0.001008, 0.1125,  2.0 , 0.225 ,   0.0 =
                  116                                                 .END
           0.0,0.0,0.0,0.0,0.0=200,END
* DIVIDE CHECK AT 023407
      END
      BCD 3VALVE DATA
           3,2,36=.99999,1.,.001,.99999,0,0,117,35.,.75,.5,5.,END
           2,3,11=.9999,1.,.01,.9999,0.0,115,90.,.75,.5,5.,END
      END
      BCD 3FLOW SOURCE DATA
          1,2500.,END
      END
      BCD 3END FLOW DATA
      BCD 3CONSTANTS DATA    $
          TIMEND,1.05
          DTIMEL,.0015
          DTIMEH,.015
          NLOOP ,100         $
          DRLXCA,0.01        $
          ARLXCA,0.01        $
          OUTPUT,1.0
           1,10.0 $
           2,DW243E  $
      END                    $
      CONSTANTS ANALYSIS...  USER =      2,  ADDED =     33        0       64,  TOTAL =     99

      BCD 3ARRAY DATA
          1      $ FREON-21 SPECIFIC HEAT
          -400.  , .223     , -218.   , .223    , -217.    ,3.723
          -212.  ,3.723     , -211.   , .223    , -160.    , .224
          -110.  , .228     ,  -60.   , .231    ,    0.    , .237
            40.  , .244     ,   90.   , .259    ,  120.    , .264
           140.  , .279     ,  150.   , .280    ,  180.    , .295
           246.  , .315
          END
          2      $ FREON-21 DENSITY
          -400.  , 110.     , -218.   , 110.    , -217.    , 110.
          -212.  , 110.     , -211.   , 110.    , -160.    , 109.
          -110.  ,  99.25   ,  -60.   ,  96.    ,    0.    ,  91.5
            40.  ,  88.5    ,   90.   ,  84.2   ,  120.    ,  81.8
           140.  ,  80.1    ,  150.   ,  79.9   ,  180.    ,  76.
           246.  ,  69.
          END
          3      $ FREON-21 DENSITY TIMES SPECIFIC HEAT
          -400.  ,  24.53   , -218.   ,  24.53  , -217.    , 409.53
          -212.  , 409.53   , -211.   ,  24.53  , -160.    ,  23.30
          -110.  ,  22.63   ,  -60.   ,  22.18  ,    0.    ,  21.69
            40.  ,  21.59   ,   90.   ,  21.39  ,  120.    ,  21.60
           140.  ,  21.95   ,  150.   ,  22.37  ,  180.    ,  22.42
```

```
SINDA,SINFLO PREPROCESSOR

         246.  ,  21.73
        END
         4      $ ALUMINUM SPECIFIC HEAT
        -400.  ,  .092   , -300.   , .129   , -200.   , .152
        -100.  ,  .175   ,    0.   , .192   ,  100.   , .204
         200.  ,  .214
        END
         5      $ FREON-21 VISCOSITY
        -400.  ,  19.1   , -212.   ,  19.1  , -211.   ,  19.1
        -209.  ,  18.5   , -206.   ,  16.55 , -203.   ,  14.75
        -200.  ,  13.7   , -194.   ,  11.5  , -191.   ,  10.8
        -188.  ,  10.08  , -184.   ,   9.25 , -178.   ,  18.1
        -172.  ,   7.12  , -166.   ,   6.36 , -160.   ,   5.72
        -154.  ,   5.21  , -148.   ,   4.75 , -142.   ,   4.32
        -136.  ,   3.96  , -130.   ,  3.68  , -124.   ,  3.42
        -118.  ,   3.16  , -112.   ,   2.81 ,  -76.   ,   2.02
         -49.  ,   1.62  ,    0.   ,   1.17 ,   30.   ,   .994
          60.  ,    .870 ,  100.   ,   .726 ,  160.   ,   .561
         260.  ,    .396
        END
         6      $ FREON-21 THERMAL CONDUCTIVITY
        -400.  ,  0.14   ,  0.0    ,  0.075 , 250.    , 0.035
        END
         7      $ EMISSIVITY
        -400.  ,  .92     , 260.    , 0.92     ,END
        8,SPACE,32,END $ ENTHALPY CURVE
         11     $ INLET TEMPERATURE VS TIME
           0.  ,   80.    , 20.     , 80.      ,END
         12     $ INLET FLOW RATE VS TIME
           0.  , 2500.    , 20.     , 2500.    ,END
         13     $ PUMP CURVE
           1000.0, 175000.0
           2000.0, 155660.0
           3000.0, 100000.0
           4000.0,  25000.0, END
         15     $ PANEL HEAT FLUX VS TIME
           0.  ,  40.     , 20.     , 40.      ,END
        16,-460.,1.,1000.,1.,END $
        17,SPACE,4,END
      END
      ACTUAL ARRAY NUMBERS VRS FORTRAN ADDRESSES

            A    1 = A(    1)  , A    2 = A(  34)  , A    3 = A(  67)  , A    4 = A( 100)  , A    5 = A( 115)  ,
            A    6 = A( 178)  , A    7 = A( 185)  , A    8 = A( 190)  , A   11 = A( 223)  , A   12 = A( 228)  ,
            A   13 = A( 233)  , A   15 = A( 242)  , A   16 = A( 247)  , A   17 = A( 252)  , A
      ARRAY ANALYSIS...  NUMBER OF ARRAYS =   14  TOTAL LENGTH =   256


 TUBE NUMBER LIST
       1          2          3          4          5          6          7          8          9         10         10
      11         12         13         14         15         16         17         18         19         20         20
      21         22         23         24         25         26         27         28         29         30         30
      31         32         33         34         35         36         37         38         39                    39

 PRESSURE NODE LIST
       1          2          3          4          5          6          7          8          9         10         10
```

111

TABLE 6 (CONTINUED)

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```
SINDA/SINFLO PREPROCESSOR

        11          12          13          14          15          16          17          18          19          20          20
        21          22          23          24                                                                                  24

 VALVE NUMBER LIST
        2           3                                                                                                           2

 INITIAL VALVE POSITIONS
    9.9990-01   9.9999-01
       BCD 3EXECUTION                                                                                                           2
      DIMENSION X(2000)                                    F
      NDIM = 2000                                          F
      NTH  = 0                                             F
           RESET
           CRVINT(A1,A8)
           CRVINT(A16,A17)
           TOPLIN
           GENOUT(A8+1,1,A8,3HOA8)
           FLOSOL
           SNFRAD
           STOREP(K2)
      END FILE 22                                          F
      END FILE 23                                          F
       END
       BCD 3VARIABLES 1
           DIDEG1(TIMEN,A11,T198)
      CALL HXEFF (0.9,500.,H(37),1.0,A1,T198,T117,T199,T200,A17,A8)   H
       END
       BCD 3VARIABLES 2
           FLOSOL
           TIMCHK(K1,0)
           HSTFLO(.01)
       END
       BCD 3OUTPUT CALLS
           TPRNT
           MPRINT(1,1,1,1)
           TIMCHK(K1,1)
       END
 * *DIVIDE CHECK HAS OCCURRED* *


@PMD,E


@FREE DATA.


@ADD,P SINFLO.PROC
```


TABLE 6 (CONTINUED)

```
SYSTEMS IMPROVED NUMERICAL DIFFERENCING ANALYZER   - - -  SINDA  - - -   UNIVAC-1108 FORTRAN-V VERSION        PAGE    1

SAMPLE PROBLEM / SNFRWD

AB
 -4.0000+02        0        -2.1800+02   4.0586+01  -2.1700+02   4.2559+01  -2.1200+02   6.1174+01  -2.1100+02   6.1147+01    10
 -1.6000+02   7.4595+01  -1.1000+02   8.5845+01  -6.0000+01   9.7320+01        0        1.1136+02   4.0000+01   1.2098+02    20
  9.0000+01   1.3343+02   1.2000+02   1.4120+02   1.4000+02   1.4658+02   1.5000+02   1.4935+02   1.6000+02   1.5798+02    30
  2.4600+02   1.7811+02                                                                                                        32
* DIVIDE CHECK AT 023224
* DIVIDE CHECK AT 023224

**********
TIME=        .00000 DTIMEU=   0.00000     CSGMIN(    250)=   1.42047-01 TEMPCC(    250)=   0.00000     RELXCC(    59)=   1.97618+01
T     1=  70.000   T     2=  70.000   T     3=  70.000   T     4=  70.000   T     5=  70.000   T     6=  70.000
T     7=  70.000   T     8=  70.000   T     9=  70.000   T    10=  70.000   T    11=  70.000   T    12=  70.000
T    13=  70.000   T    14=  70.000   T    15=  70.000   T    16=  70.000   T    17=  70.000   T    18=  70.000
T    19=  70.000   T    20=  70.000   T    21=  70.000   T    22=  70.000   T    23=  70.000   T    24=  70.000
T    25=  70.000   T    26=  70.000   T    27=  70.000   T    28=  70.000   T    29=  70.000   T    30=  70.000
T    31=  70.000   T    32=  70.000   T    33=  70.000   T    34=  70.000   T    35=  70.000   T    36=  70.000
T    37=  70.000   T    38=  70.000   T    39=  70.000   T    40=  70.000   T    41=  70.000   T    42=  70.000
T    43=  70.000   T    44=  70.000   T    45=  70.000   T    46=  70.000   T    47=  70.000   T    48=  70.000
T    49=  70.000   T    50=  70.000   T    51=  70.000   T    52=  70.000   T    53=  70.000   T    54=  70.000
T    55=  70.000   T    56=  70.000   T    57=  70.000   T    58=  70.000   T    59=  70.000   T    60=  70.000
T    61=  70.000   T    62=  70.000   T    63=  70.000   T    64=  70.000   T    65=  70.000   T    66=  70.000
T    67=  70.000   T    68=  70.000   T    69=  70.000   T    70=  70.000   T    71=  70.000   T    72=  70.000
T    73=  70.000   T    74=  70.000   T    75=  70.000   T    76=  70.000   T    77=  70.000   T    78=  70.000
T    79=  70.000   T    80=  70.000   T    81=  70.000   T    82=  70.000   T    83=  70.000   T    84=  70.000
T    85=  70.000   T    86=  70.000   T    87=  70.000   T    88=  70.000   T    89=  70.000   T    90=  70.000
T    91=  70.000   T    92=  70.000   T    93=  70.000   T    94=  70.000   T    95=  70.000   T    96=  70.000
T    97=  70.000   T    98=  70.000   T    99=  70.000   T   100=  70.000   T   101=  70.000   T   102=  70.000
T   103=  70.000   T   104=  70.000   T   105=  70.000   T   106=  70.000   T   107=  70.000   T   108=  70.000
T   109=  70.000   T   110=  70.000   T   111=  70.000   T   112=  70.000   T   113=  70.000   T   114=  70.000
T   115=  70.000   T   116=  70.000   T   117=  70.000   T   198=  100.00   T   199=  40.000   T   200=  100.00
T   201=  70.000   T   202=  70.000   T   203=  70.000   T   204=  70.000   T   205=  70.000   T   206=  70.000
T   207=  70.000   T   208=  70.000   T   209=  70.000   T   210=  70.000   T   211=  70.000   T   212=  70.000
T   213=  70.000   T   214=  70.000   T   215=  70.000   T   216=  70.000   T   217=  70.000   T   218=  70.000
T   219=  70.000   T   220=  70.000   T   221=  70.000   T   222=  70.000   T   223=  70.000   T   224=  70.000
T   225=  70.000   T   226=  70.000   T   227=  70.000   T   228=  70.000   T   229=  70.000   T   230=  70.000
T   231=  70.000   T   232=  70.000   T   233=  70.000   T   234=  70.000   T   235=  70.000   T   236=  70.000
T   237=  70.000   T   238=  70.000   T   239=  70.000   T   240=  70.000   T   241=  70.000   T   242=  70.000
T   243=  70.000   T   244=  70.000   T   245=  70.000   T   246=  70.000   T   247=  70.000   T   248=  70.000
T   249=  70.000   T   250=  70.000   T   251=  70.000   T   252=  70.000   T   253=  70.000   T   254=  70.000
T   255=  70.000   T   256=  70.000   T   257=  70.000   T   258=  70.000   T   259=  70.000   T   260=  70.000
T   261=  70.000   T   262=  70.000   T   263=  70.000   T   264=  70.000   T   265=  70.000   T   266=  70.000
T   267=  70.000   T   268=  70.000   T   269=  70.000   T   270=  70.000   T   271=  70.000   T   272=  70.000
T   273=  70.000   T   274=  70.000   T   275=  70.000   T   276=  70.000   T   277=  70.000   T   278=  70.000
T   279=  70.000   T   280=  70.000   T   281=  70.000   T   282=  70.000   T   283=  70.000   T   284=  70.000
T   285=  70.000   T   286=  70.000   T   287=  70.000   T   288=  70.000   T   289=  70.000   T   290=  70.000
T   291=  70.000   T   292=  70.000   T   293=  70.000   T   294=  70.000   T   295=  70.000   T   296=  70.000
T   297=  70.000   T   298=  70.000   T   299=  70.000   T   300=  70.000   T   301=  70.000   T   302=  70.000
T   303=  70.000   T   304=  70.000   T   305=  70.000   T   306=  70.000   T   307=  70.000   T   308=  70.000
T   309=  70.000   T   310=  70.000   T   311=  70.000   T   312=  70.000   T   313=  70.000   T   314=  70.000
T   315=  70.000   T   316=  70.000   T   317=  70.000   T   400= -459.69

Q     1= 2500.0    Q     2= 2500.0    Q     3= 2499.4    Q     4= 1249.4    Q     5= 627.25
Q     6= 622.11    Q     7= 627.25    Q     8= 622.11    Q     9= 1249.4    Q    10= 2498.7
```

TABLE 7

SAMPLE PROBLEM PRINTED OUTPUT

TABLE 7 (CONTINUED)

W 11= .24931	W 12= .12418	W 13= .64781-01	W 14= .59395-01	W 15= .64781-01
W 16= .59395-01	W 17= .12418	W 18= .24835	W 19= 2498.7	W 20= 1249.4

SAMPLE PROBLEM / SNFRWD

```
W     21= 627.25      W     22= 622.11      W     23= 627.25      W     24= 622.11      W     25= 1249.4
W     26= 2499.9      W     27= .24835      W     28= .12418      W     29= .64781-01   W     30= .59395-01
W     31= .64781-01   W     32= .59395-01   W     33= .12418      W     34= .24850      W     35= 2499.6
W     36= .23166-01   W     37= 2499.7      W     38= 2499.4      W     39= .24912

DP     1= 157.79      DP     2= 191.39      DP     3= 836.72      DP     4= 86.981      DP     5= 3210.0
DP     6= 3210.0      DP     7= 3210.0      DP     8= 3210.0      DP     9= 86.981      DP    10= 104.49
DP    11= 8978.9      DP    12= .51880-03   DP    13= .56763-02   DP    14= .56763-02   DP    15= .56763-02
DP    16= .56763-02   DP    17= .51880-03   DP    18= .33569-03   DP    19= 104.49      DP    20= 86.981
DP    21= 3210.0      DP    22= 3210.0      DP    23= 3210.0      DP    24= 3210.0      DP    25= 86.981
DP    26= 836.72      DP    27= .36621-03   DP    28= .51890-03   DP    29= .56458-02   DP    30= .56458-02
DP    31= .56763-02   DP    32= .56763-02   DP    33= .48828-03   DP    34= .28687-02   DP    35= 2092.2
DP    36= 10762.      DP    37= 209.22      DP    38= 6805.4      DP    39= .13123-01

P      1= 11129.      P      2= 10972.      P      3= 10780.      P      4= 9943.5      P      5= 6729.0
P      6= 9852.0      P      7= 6642.0      P      8= 6537.5      P      9= 2301.4      P     10= 2299.9
P     11= 2299.9      P     12= 2299.9      P     13= 2299.9      P     14= 6933.1      P     15= 3223.1
P     16= 6346.1      P     17= 3138.1      P     18= 2301.4      P     19= 2299.9      P     20= 2299.9
P     21= 2299.9      P     22= 2301.4      P     23= 209.22      P     24= .00000

VP     2= .99990      VP     3= .99999

COMPUTER TIME =     .000 MINUTES
* DIVIDE CHECK AT 023224
* DIVIDE CHECK AT 023224

***********
TIME=    1.00000 DTIMEU=  5.00008-03 CSGMIN(  262)=  1.45333-01 TEMPCC(  262)=  1.20617+01 RELXCC(   69)=  8.21785+01
T    1=  68.830   T    2=  50.458   T    3=  35.292   T    4=  22.513   T    5=  11.890   T    6=  11.907
T    7=  68.829   T    8=  50.577   T    9=  35.490   T   10=  22.751   T   11=  12.149   T   12=  12.154
T   13=  68.828   T   14=  50.579   T   15=  35.484   T   16=  22.744   T   17=  12.138   T   18=  12.147
T   19=  68.829   T   20=  50.455   T   21=  35.287   T   22=  22.507   T   23=  11.884   T   24=  11.900
T   25=  12.050   T   26=  4.3575   T   27= -3.3729   T   28= -10.057   T   29= -15.839   T   30= -15.856
T   31=  12.093   T   32=  3.1377   T   33= -4.0386   T   34= -10.407   T   35= -16.000   T   36= -15.982
T   37=  12.048   T   38=  3.1448   T   39= -4.0238   T   40= -10.389   T   41= -15.981   T   42= -15.963
T   43=  12.056   T   44=  4.4124   T   45= -3.3342   T   46= -10.032   T   47= -15.824   T   48= -15.842
T   49=  68.827   T   50=  68.493   T   51=  68.160   T   52=  67.829   T   53=  67.498   T   54=  67.500
T   55=  68.826   T   56=  68.493   T   57=  68.162   T   58=  67.831   T   59=  67.502   T   60=  67.503
T   61=  68.827   T   62=  68.494   T   63=  68.162   T   64=  67.832   T   65=  67.503   T   66=  67.504
T   67=  68.828   T   68=  68.494   T   69=  68.161   T   70=  67.829   T   71=  67.499   T   72=  67.500
T   73=  67.504   T   74=  67.175   T   75=  66.847   T   76=  66.520   T   77=  66.195   T   78=  66.196
T   79=  67.504   T   80=  67.176   T   81=  66.849   T   82=  66.523   T   83=  66.198   T   84=  66.199
T   85=  67.503   T   86=  67.175   T   87=  66.848   T   88=  66.522   T   89=  66.198   T   90=  66.199
T   91=  67.504   T   92=  67.175   T   93=  66.847   T   94=  66.520   T   95=  66.194   T   96=  66.196
T   97=  68.825   T   98=  68.825   T   99=  68.826   T  100=  68.827   T  101=  12.029   T  102=  12.031
T  103=  12.032   T  104=  12.037   T  105= -15.914   T  106= -15.901   T  107=  68.825   T  108=  68.826
T  109=  67.502   T  110=  67.502   T  111=  67.502   T  112=  67.503   T  113=  66.198   T  114=  66.198
T  115=  39.617   T  116=  67.978   T  117=  39.619   T  198=  80.000   T  199=  43.662   T  200=  68.825
T  201=  68.831   T  202=  38.475   T  203=  24.466   T  204=  12.495   T  205=  2.4716   T  206=  11.909
T  207=  68.830   T  208=  38.817   T  209=  24.877   T  210=  12.955   T  211=  2.9554   T  212=  12.160
```

TABLE 7 (CONTINUED)

TABLE 7 (CONTINUED)

```
SYSTEMS IMPROVED NUMERICAL DIFFERENCING ANALYZER   - - -  SINDA  - - -   UNIVAC-1108 FORTRAN-V VERSION        PAGE    3

SAMPLE PROBLEM / SNFRWD

 T   213=   68.829    T   214=   38.808    T   215=   24.867    T   216=   12.943    T   217=   2.9432    T   218=   12.153
 T   219=   68.830    T   220=   38.466    T   221=   24.455    T   222=   12.483    T   223=   2.4592    T   224=   11.903
 T   225=   12.053    T   226=  -7.1641    T   227=  -15.060    T   228=  -20.046    T   229=  -24.458    T   230=  -15.856
 T   231=   12.050    T   232=  -5.4646    T   233=  -15.203    T   234=  -20.120    T   235=  -24.463    T   236=  -15.971
 T   237=   12.055    T   238=  -5.4474    T   239=  -15.182    T   240=  -20.103    T   241=  -24.447    T   242=  -15.952
 T   243=   12.059    T   244=  -7.0389    T   245=  -15.055    T   246=  -20.047    T   247=  -24.461    T   248=  -15.843
 T   249=   68.827    T   250=   65.490    T   251=   65.168    T   252=   64.847    T   253=   64.527    T   254=   67.500
 T   255=   68.827    T   256=   65.498    T   257=   65.177    T   258=   64.857    T   259=   64.538    T   260=   67.504
 T   261=   68.828    T   262=   65.499    T   263=   65.178    T   264=   64.857    T   265=   64.538    T   266=   67.504
 T   267=   68.828    T   268=   65.491    T   269=   65.169    T   270=   64.847    T   271=   64.527    T   272=   67.501
 T   273=   67.504    T   274=   64.214    T   275=   63.896    T   276=   63.579    T   277=   63.264    T   278=   66.197
 T   279=   67.504    T   280=   64.222    T   281=   63.905    T   282=   63.589    T   283=   63.275    T   284=   66.200
 T   285=   67.504    T   286=   64.221    T   287=   63.904    T   288=   63.589    T   289=   63.274    T   290=   66.199
 T   291=   67.504    T   292=   64.213    T   293=   63.895    T   294=   63.579    T   295=   63.263    T   296=   66.196
 T   297=   68.825    T   298=   68.825    T   299=   68.826    T   300=   68.827    T   301=   12.031    T   302=   12.032
 T   303=   12.033    T   304=   12.038    T   305=  -15.913    T   306=  -15.901    T   307=   68.825    T   308=   68.826
 T   309=   67.502    T   310=   67.502    T   311=   67.502    T   312=   67.503    T   313=   66.198    T   314=   66.198
 T   315=   39.617    T   316=   67.978    T   317=   39.621    T   400=  -459.69

 W        1= 2500.0      W        2= 2500.0      W        3= 832.64      W        4= 416.38      W        5= 209.35
 W        6= 207.03      W        7= 209.29      W        8= 206.97      W        9= 416.26      W       10= 832.64
 W       11= 1667.3      W       12= 833.66      W       13= 417.51      W       14= 416.15      W       15= 417.51
 W       16= 416.15      W       17= 833.67      W       18= 1667.3      W       19= 832.64      W       20= 416.42
 W       21= 209.39      W       22= 207.03      W       23= 209.30      W       24= 206.93      W       25= 416.23
 W       26= 832.64      W       27= 1667.3      W       28= 833.66      W       29= 417.52      W       30= 416.15
 W       31= 417.52      W       32= 416.15      W       33= 833.67      W       34= 1667.3      W       35= 2500.0
 W       36= .24719-01   W       37= 2500.0      W       38= 832.69      W       39= 1667.3

 DP       1= 209.29      DP       2= 209.30      DP       3= 8113.7      DP       4= 12.724      DP       5= 343.26
 DP       6= 343.25      DP       7= 343.05      DP       8= 343.05      DP       9= 12.922      DP      10= 15.527
 DP      11= 412.08      DP      12= 42.879      DP      13= 3984.8      DP      14= 3984.8      DP      15= 3984.8
 DP      16= 3984.8      DP      17= 42.884      DP      18= 51.515      DP      19= 15.527      DP      20= 12.931
 DP      21= 337.79      DP      22= 337.79      DP      23= 337.51      DP      24= 337.51      DP      25= 13.210
 DP      26= 126.99      DP      27= 51.515      DP      28= 42.883      DP      29= 3980.6      DP      30= 3980.6
 DP      31= 3980.6      DP      32= 3980.6      DP      33= 42.887      DP      34= 412.15      DP      35= 2100.7
 DP      36= 11288.      DP      37= 210.07      DP      38= 737.75      DP      39= 8154.2

 P        1= 11700.      P        2= 11499.      P        2= 11289.      P        4= 3175.5      P        5= 2832.5
 P        6= 3162.8      P        7= 2819.6      P        8= 2804.0      P        9= 10877.      P       10= 6892.3
 P       11= 10839.      P       12= 6849.4      P       13= 6797.9      P       14= 2708.5      P       15= 2451.0
 P       16= 2775.6      P       17= 2437.8      P       18= 2310.8      P       19= 6746.4      P       20= 2765.8
 P       21= 6703.5      P       22= 2722.9      P       23= 210.07      P       24= .00000

 VP       2= .33306      VP       3= .99999

COMPUTER TIME =     .689 MINUTES
THE PROBLEM IDENTIFIED AS DR243F HAS BEEN STORED AT THIS POINT

     END OF DATA
* *DIVIDE CHECK HAS OCCURRED* *
```

SNFRWD PLOTS

P L O T   P R O G R A M

TITLE - SINFLO SAMPLE PROBLEM / SNFRWD

FROM .000 HRS. TO 3.000 HRS. , WITH 3.000 HRS. PER GRID

THE HISTORY TAPE LABEL IS

SAMPLE PROBLEM / SNFRWD

THE ITEM COUNTS ARE - 4AA 39DP 24PR 2VP 0BB UCC
0BT 39FR 0FT 0TT 238ST

1	ITEM	-98ST	AT	320
2	ITEM	106ST	AT	328
3	ITEM	114ST	AT	336
4	ITEM	115ST	AT	337
5	ITEM	-117ST	AT	339
6	ITEM	200ST	AT	342
7	ITEM	198ST	AT	340
8	ITEM	199ST	AT	341
9	ITEM	-1FR	AT	67
10	ITEM	2FR	AT	68
11	ITEM	36FR	AT	102
12	ITEM	-2FR	AT	68
13	ITEM	3FR	AT	69
14	ITEM	11FR	AT	77
15	ITEM	-1PR	AT	41
16	ITEM	2PR	AT	42
17	ITEM	3PR	AT	43
18	ITEM	24PR	AT	64
19	ITEM	-4PR	AT	44
20	ITEM	9PR	AT	49
21	ITEM	18PR	AT	58
22	ITEM	23PR	AT	63
23	ITEM	-2VP	AT	65
24	ITEM	3VP	AT	66

TABLE 8
PLOT RUN PRINTED OUT PUT

SNFRR PLOTS

POSITIONING AND READING THE HISTORY TAPE

```
                                         LOADED      .01000  HRS.     LOOKING FOR     3.00000 HRS.
    76.857     65.463     70.000         66.167      66.515     77.230     80.000     71.000   2499.996   2499.968
      .025   2499.968   2499.713           .250   11198.566  10970.183  10763.199       .000   9926.684   2302.739
  2302.722    209.338      1.000          1.000
                                         LOADED      .02000  HRS.     LOOKING FOR     3.00000 HRS.
    76.297     60.030     70.000         60.963      61.522     76.263     80.000     67.464   2499.996   2499.967
      .025   2499.967   2499.718           .250   11179.351  10972.363  10742.603       .000   9906.094   2303.408
  2303.390    209.398      1.000          1.000
                                         LOADED      .03000  HRS.     LOOKING FOR     3.00000 HRS.
    74.953     54.835     70.000         55.791      56.368     74.880     80.000     63.370   2499.997   2499.969
      .025   2499.969   2499.719           .250   11144.838  10935.638  10726.451       .000   9889.841   2305.313
  2305.295    209.556      1.000          1.000
                                         LOADED      .04000  HRS.     LOOKING FOR     3.00000 HRS.
    73.529     50.123     70.000         51.005      51.553     73.452     80.000     58.731   2499.997   2499.968
      .023   2499.968   2499.717           .247   11131.114  10921.897  10712.673       .000   9875.952   2307.159
  2307.140    209.727      1.000          1.000
                                         LOADED      .05000  HRS.     LOOKING FOR     3.00000 HRS.
    72.189     45.923     70.000         46.715      47.211     72.11.     80.000     54.397   2500.000   2499.970
      .025   2499.970   2499.719           .250   11119.098  10909.845  10700.595       .000   9863.773   2308.632
  2306.612    209.864      1.000          1.000
                                         LOADED      .06000  HRS.     LOOKING FOR     3.00000 HRS.
    70.979     42.214     70.000         42.917      43.358     70.914     80.000     50.490   2499.995   2499.973
      .025   2499.973   2499.720           .250   11119.116  10909.862  10690.007       .000   9853.098   2309.786
  2309.766    209.972      1.000          1.000
                                         LOADED      .07000  HRS.     LOOKING FOR     3.00000 HRS.
    69.904     38.972     69.999         39.593      39.981     69.846     80.000     47.022   2499.998   2499.973
      .025   2499.973   2499.719           .248   11108.580  10890.470  10681.174       .000   9844.191   2310.801
  2310.780    210.057      1.000          1.000
                                         LOADED      .08000  HRS.     LOOKING FOR     3.00000 HRS.
    68.962     36.110     69.999         36.671      37.022     68.911     80.000     43.983   2499.997   2499.970
      .025   2499.970   2498.731         51.249   11099.777  10713.397  10350.378       .000   9542.984   2322.517
  2312.337    210.201       .980          1.000
                                         LOADED      .09000  HRS.     LOOKING FOR     3.00000 HRS.
    68.231     33.590     69.539         34.721      34.972     68.192     80.000     41.319   2499.996   2499.969
      .025   2499.969   2373.364        126.605   10769.003  10306.680   9876.989       .000   9112.537   2372.023
  2313.335    210.296       .949          1.000
                                         LOADED      .10000  HRS.     LOOKING FOR     3.00000 HRS.
    67.722     31.338     67.348         33.452      33.621     67.694     80.000     39.475   2499.996   2473.356
    26.639   2473.356   2265.138        216.201   10293.401   9788.877   9228.996       .000   8522.790   2457.562
  2293.252    212.035       .913           .989
                                         LOADED      .11000  HRS.     LOOKING FOR     3.00000 HRS.
    67.283     29.295     64.289         32.505      33.054     67.259     80.000     38.459   2499.997   2439.658
    60.336   2439.658   2136.312        313.457    9640.966   9097.716   8450.561       .000   7812.693   2587.050
  2249.330    212.506       .872           .976
                                         LOADED      .12000  HRS.     LOOKING FOR     3.00000 HRS.
    67.101     27.407     61.893         32.047      32.924     67.091     80.000     37.749   2499.997   2404.329
    95.665   2404.329   1994.456        413.051    8520.132   7861.721   7598.742       .000   7034.300   2757.370
  2182.941    211.057       .828           .962
                                         LOADED      .13000  HRS.     LOOKING FOR     3.00000 HRS.
    67.150     25.607     60.449         31.701      33.134     67.153     80.000     37.031   2499.998   2371.628
   128.360   2371.628   1865.830        515.607    8000.927   7488.114   6929.897       .000   6426.573   3035.394
  2151.206    212.440       .783           .949
                                         LOADED      .14000  HRS.     LOOKING FOR     3.00000 HRS.
    67.117     23.866     59.802         31.792      33.599     67.115     80.000     37.020   2499.999   2344.740
   155.256   2344.740   1738.014        614.792    7327.940   6821.377   6275.360       .000   5831.04.   1350.238
```

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TABLE 8 (CONTINUED)

ORIGINAL PAGE IS
OF POOR QUALITY

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SNFRRD PLOTS

    68.825    -15.901     66.198     39.617     39.619     68.826     80.000      43.062   2499.997   2499.966
      .025   2499.966    832.693   1667.323  11707.790  11498.504  11289.205        .000   3175.534  10877.125
  2310.788    210.078       .333      1.000

    25  DATA VALUES HAVE BEEN STORED FOR EACH OF   101  TIME POINTS
  2500  DATA VALUES HAVE BEEN STORED
```

ORIGINAL PAGE IS
OF POOR QUALITY

TABLE 8 (CONTINUED)

SNFRWD PLOTS

	ITEM	TYPE	AVG	PLOTTING SYMBOL AND DESCRIPTION	Y-MIN	Y-MAX	STATUS
1	-98	ST		1 RADIATOR INLET TEMPERATURE -- DEGF	-1.590+01	7.686+01	320
2	106	ST		2 MAIN RADIATOR OUTLET TEMPERATURE -- DEGF	0.000	0.000	328
3	114	ST		3 PRIME TUBE OUTLET TEMPERATURE -- DEGF	0.000	0.000	336
4	115	ST		4 MIXED RADIATOR OUTLET TEMPERATURE -- DEGF	0.000	0.000	337
5	-117	ST		1 RADIATOR CONTROLLED OUTLET, HX INLET -- DEGF	3.292+01	8.000+01	339
6	200	ST		2 HX OUTLET ON RADIATOR SIDE -- DEGF	0.000	0.000	342
7	198	ST		3 HX INLET ON WATER SIDE -- DEGF	0.000	0.000	340
8	199	ST		4 HX OUTLET ON WATER SIDE -- DEGF	0.000	0.000	341
9	-1	FR		1 TOTAL PUMP FLOW RATE -- LB/HR	2.307-02	2.500+03	67
10	2	FR		2 TOTAL RADIATOR FLOW RATE -- LB/HR	0.000	0.000	68
11	36	FR		3 BYPASS FLOW RATE -- LB/HR	0.000	0.000	102
12	-2	FR		1 TOTAL RADIATOR FLOW RATE -- LB/HR	2.471-01	2.500+03	68
13	3	FR		2 MAIN RADIATOR FLOW RATE -- LB/HR	0.000	0.000	69
14	11	FR		3 PRIME TUBE FLOW RATE -- LB/HR	0.000	0.000	77
15	-1	PR		1 PUMP OUTLET PRESSURE -- PSF	0.000	1.171+04	41
16	2	PR		2 VALVE 1 INLET PRESSURE -- PSF	0.000	0.000	42
17	3	PR		3 VALVE 2 INLET PRESSURE -- PSF	0.000	0.000	43
18	24	PR		4 PUMP INLET PRESSURE -- PSF	0.000	0.000	64
19	-4	PR		1 MAIN RADIATOR INLET PRESSURE-- PSF	2.083+02	1.068+04	44
20	9	PR		2 PRIME TUBE INLET PRESSURE -- PSF	0.000	0.000	49
21	18	PR		3 PRESSURE AT RADIATOR OUTLET -- PSF	0.000	0.000	50
22	23	PR		4 PRESSURE AT HX INLET -- PSF	0.000	0.000	63
23	-2	VP		1 VALVE 2 POSITION	3.331-01	1.000+00	65
24	3	VP		2 VALVE 3 POSITION	0.000	0.000	66

TABLE 8 (CONTINUED)

TABLE 8 (CONTINUED)

```
SNFRW. PLOTS

                                        STARTING PLOTS

        PLOTTING     1   RADIATOR INLET TEMPERATURE              -- DEGF
        PLOTTING     2   MAIN RADIATOR OUTLET TEMPERATURE        -- DEGF
        PLOTTING     3   PRIME TUBE OUTLET TEMPERATURE           -- DEGF
        PLOTTING     4   MIXED RADIATOR OUTLET TEMPERATURE       -- DEGF
        PLOTTING     1   RADIATOR CONTROLLED OUTLET, HX INLET    -- DEGF
        PLOTTING     2   HX OUTLET ON RADIATOR SIDE              -- DEGF
        PLOTTING     3   HX INLET ON WATER SIDE                  -- DEGF
        PLOTTING     4   HX OUTLET ON WATER SIDE                 -- DEGF
        PLOTTING     1   TOTAL PUMP FLOW RATE      -- LB/HR
        PLOTTING     2   TOTAL RADIATOR FLOW RATE  -- LB/HR
        PLOTTING     3   BYPASS FLOW RATE          -- LB/HR
        PLOTTING     1   TOTAL RADIATOR FLOW RATE  -- LB/HR
        PLOTTING     2   MAIN RADIATOR FLOW RATE   -- LB/HR
        PLOTTING     3   PRIME TUBE FLOW RATE      -- LB/HR
        PLOTTING     1   PUMP OUTLET PRESSURE          -- PSF
        PLOTTING     2   VALVE 1 INLET PRESSURE        -- PSF
        PLOTTING     3   VALVE 2 INLET PRESSURE        -- PSF
        PLOTTING     4   PUMP INLET PRESSURE           -- PSF
        PLOTTING     1   MAIN RADIATOR INLET PRESSURE-- PSF
        PLOTTING     2   PRIME TUBE INLET PRESSURE     -- PSF
        PLOTTING     3   PRESSURE AT RADIATOR OUTLET   -- PSF
        PLOTTING     4   PRESSURE AT HX INLET          -- PSF
        PLOTTING     1   VALVE 2 POSITION
        PLOTTING     2   VALVE 3 POSITION

      COMPUTER TIME =      .14435   MINUTES

QPMD,

QMSG,N END OW243E

QBRKPT PRINTS

1234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890**SEQ NO. 0A
```

FIGURE 11

RADIATOR TEMPERATURE PLOTS

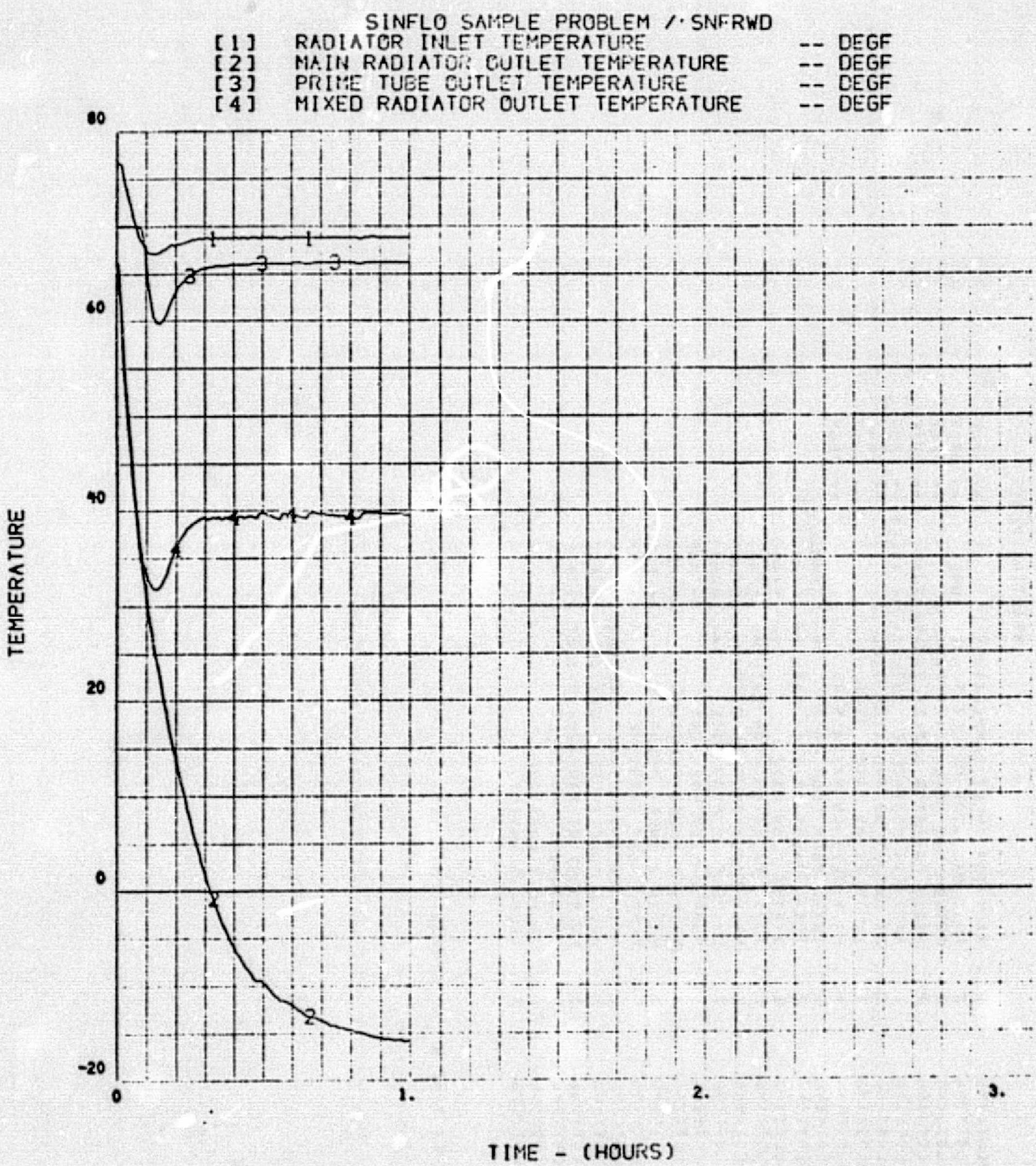


FIGURE 12

SYSTEM TEMPERATURES PLOTS

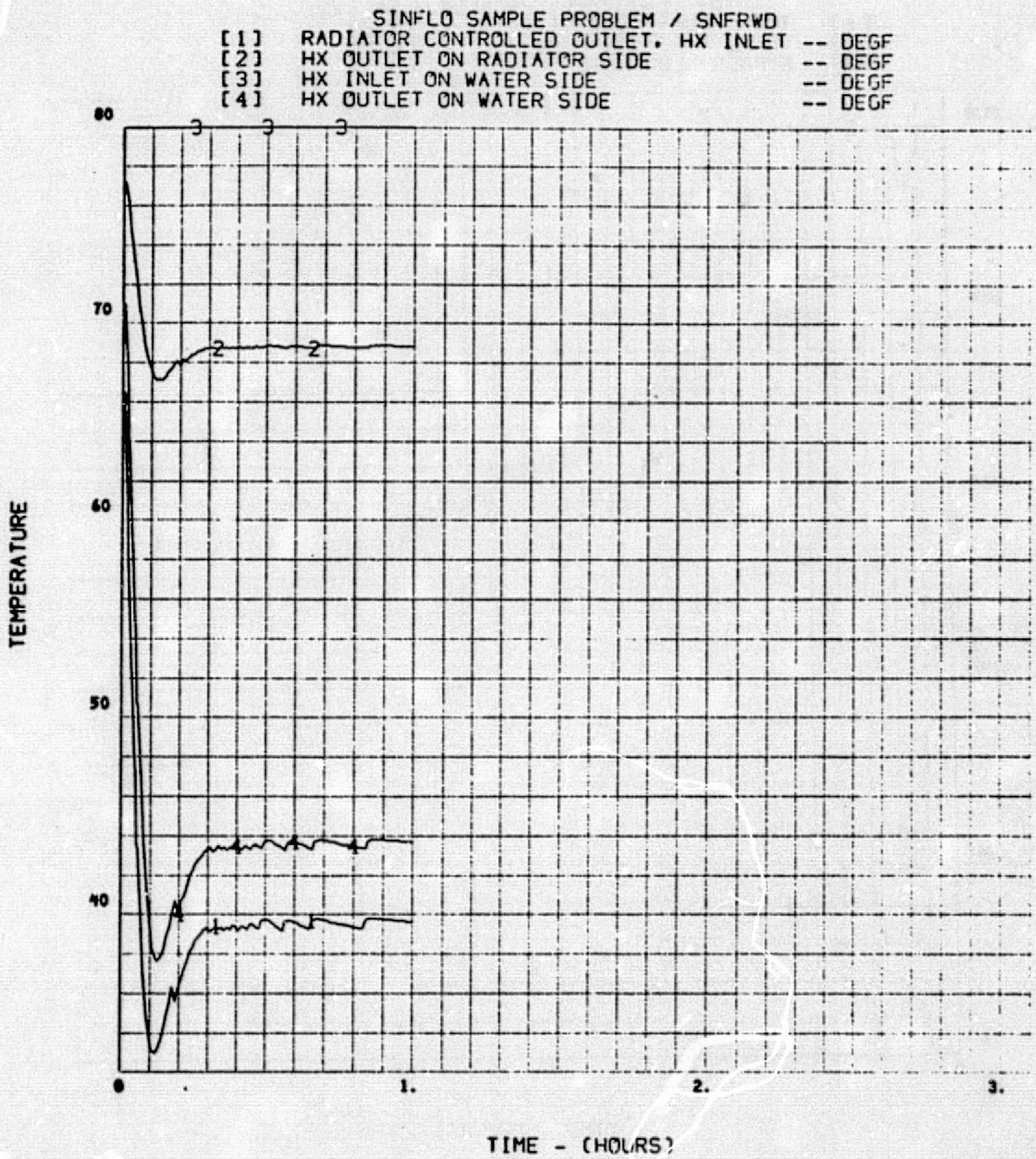


FIGURE 13

SYSTEM FLOW RATE PLOTS

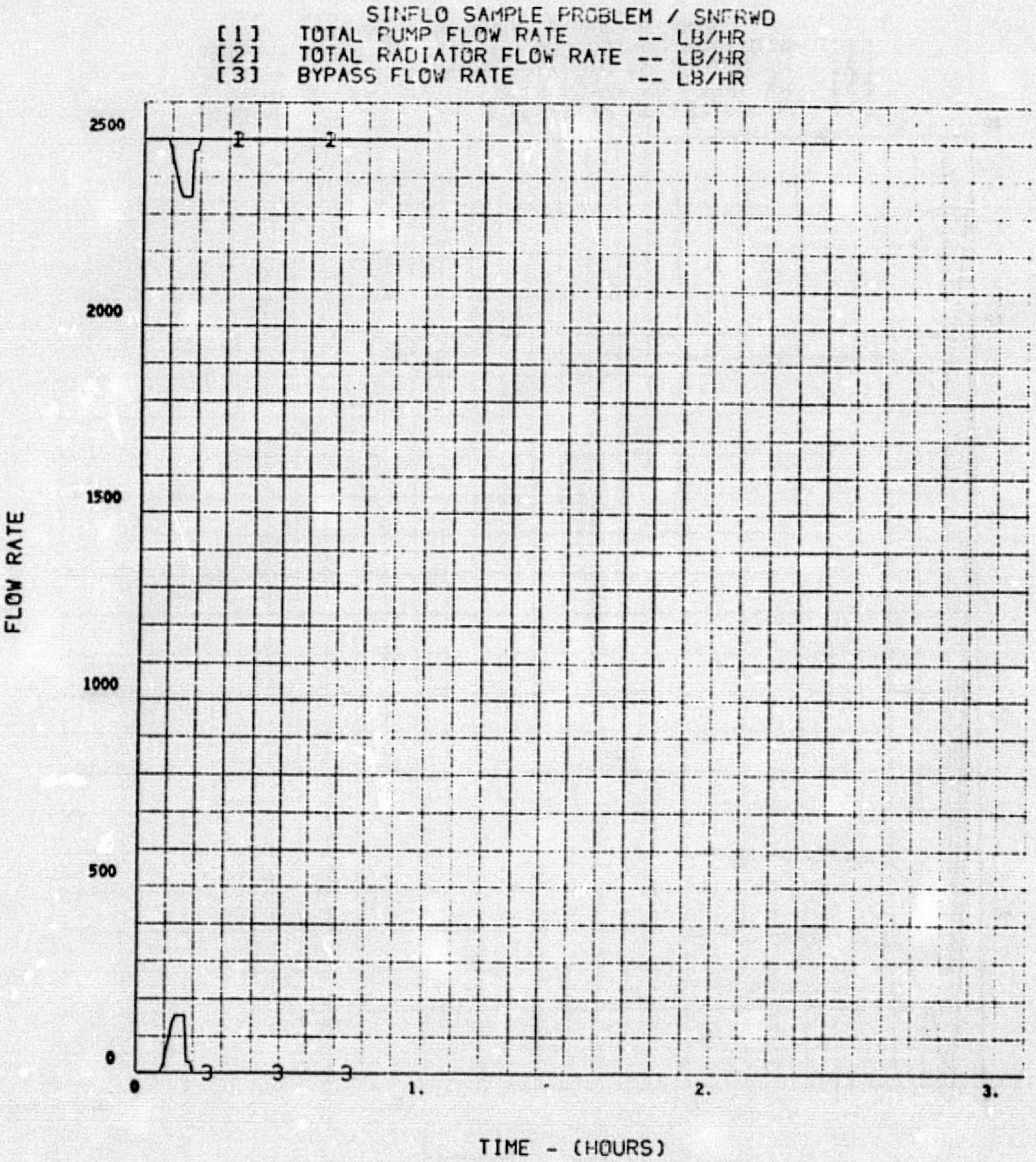


FIGURE 14

RADIATOR FLOW RATE PLOTS

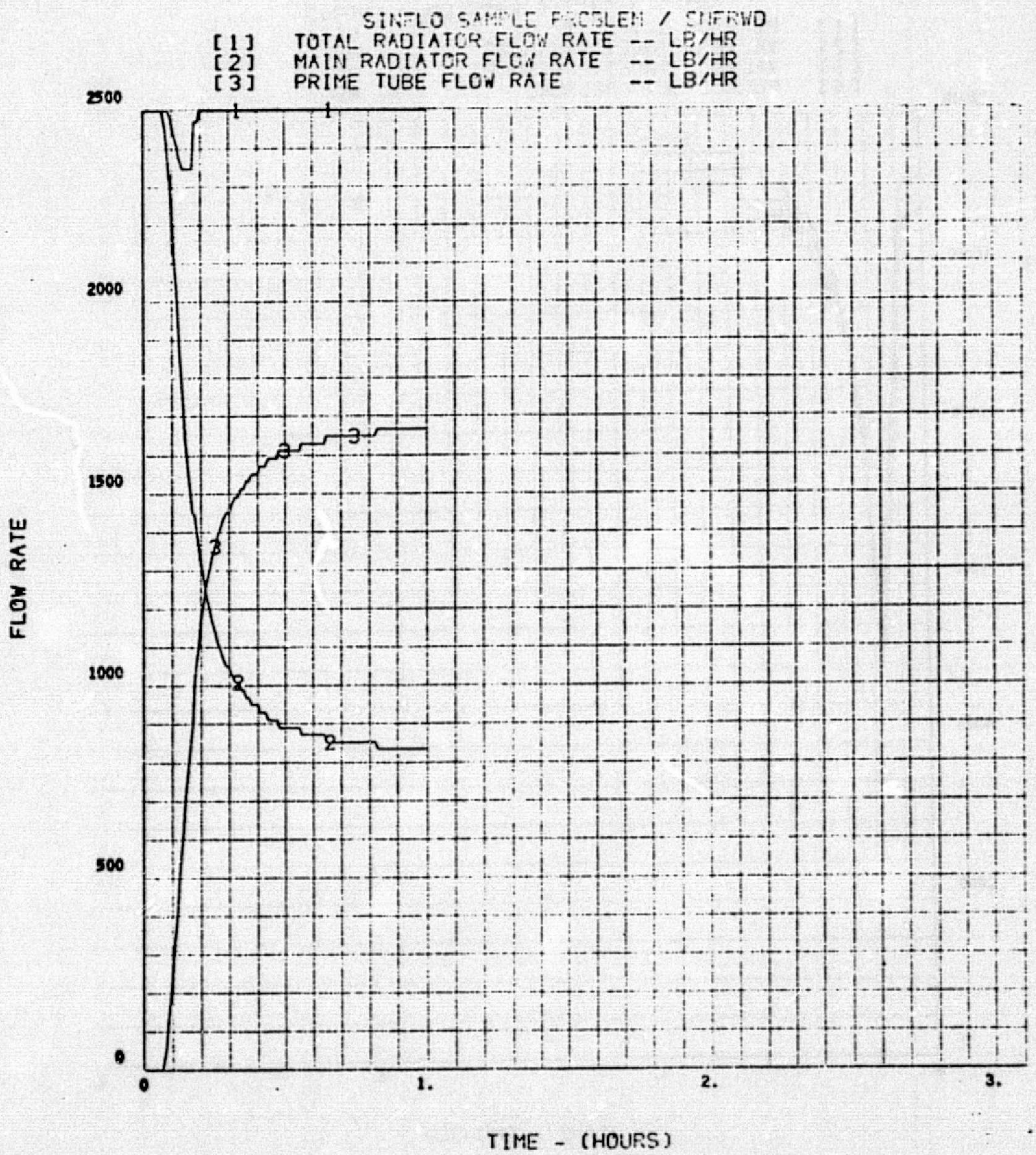


FIGURE 15

SYSTEM PRESSURE PLOTS

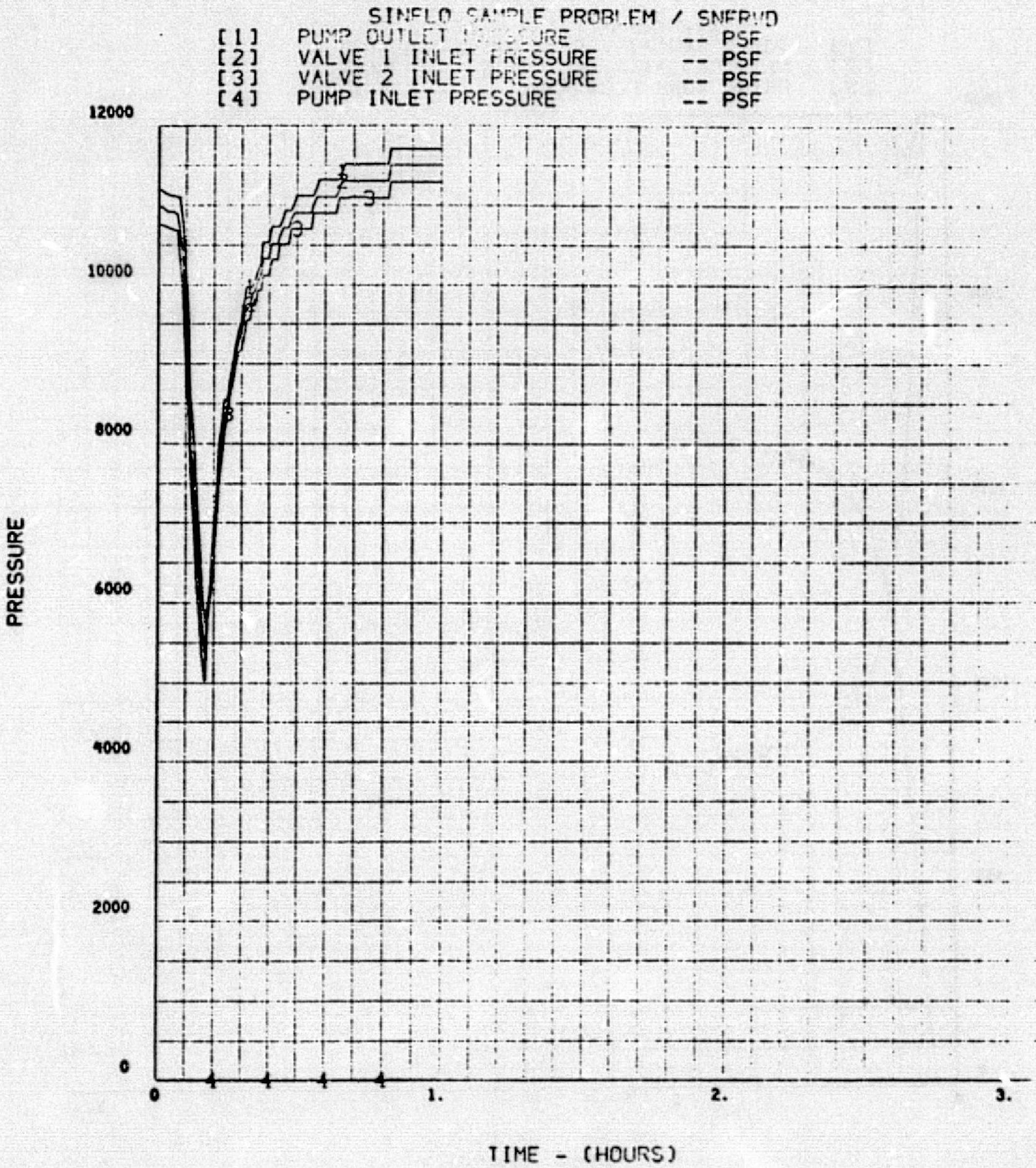


FIGURE 16

RADIATOR PRESSURE PLOTS

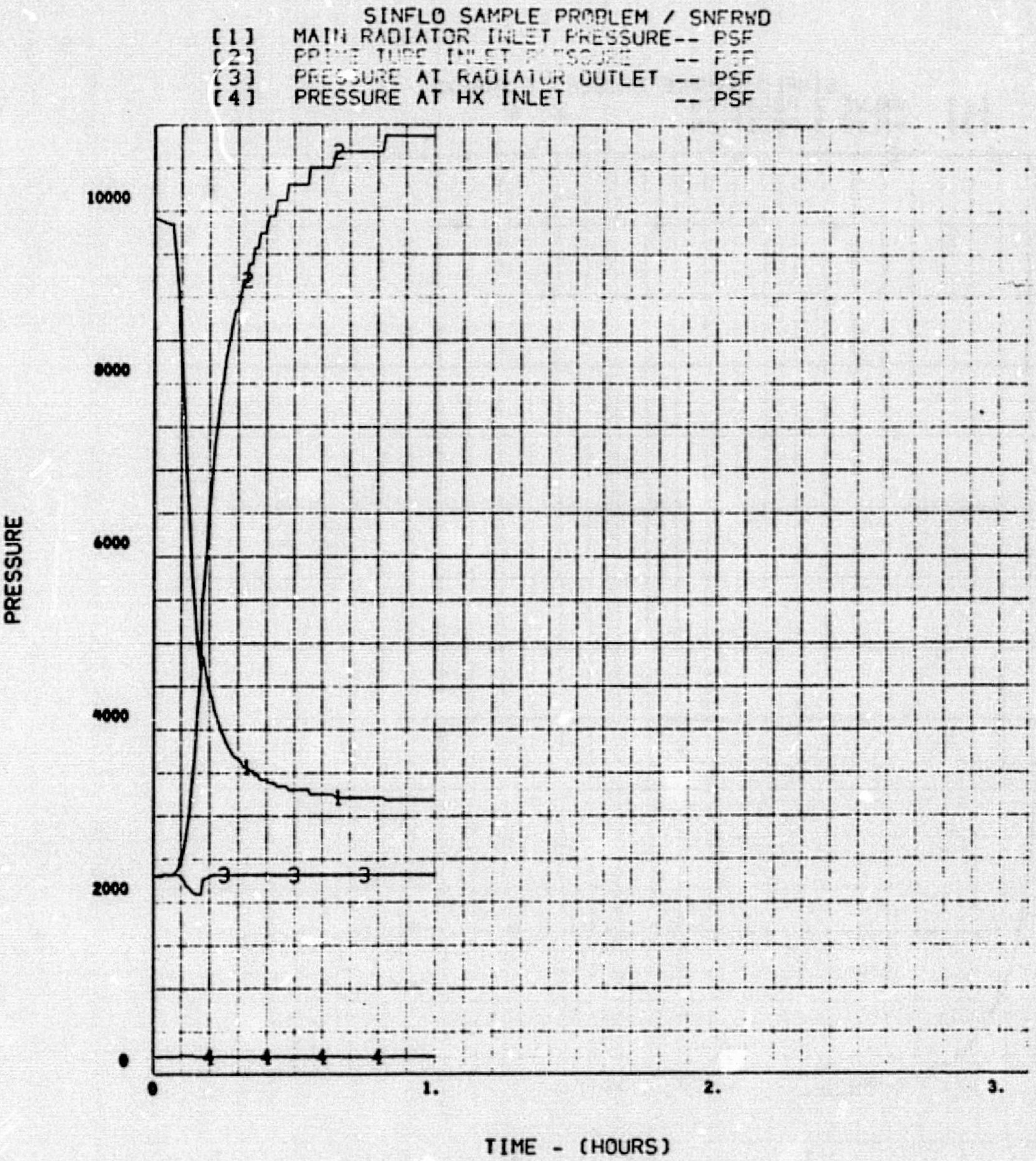
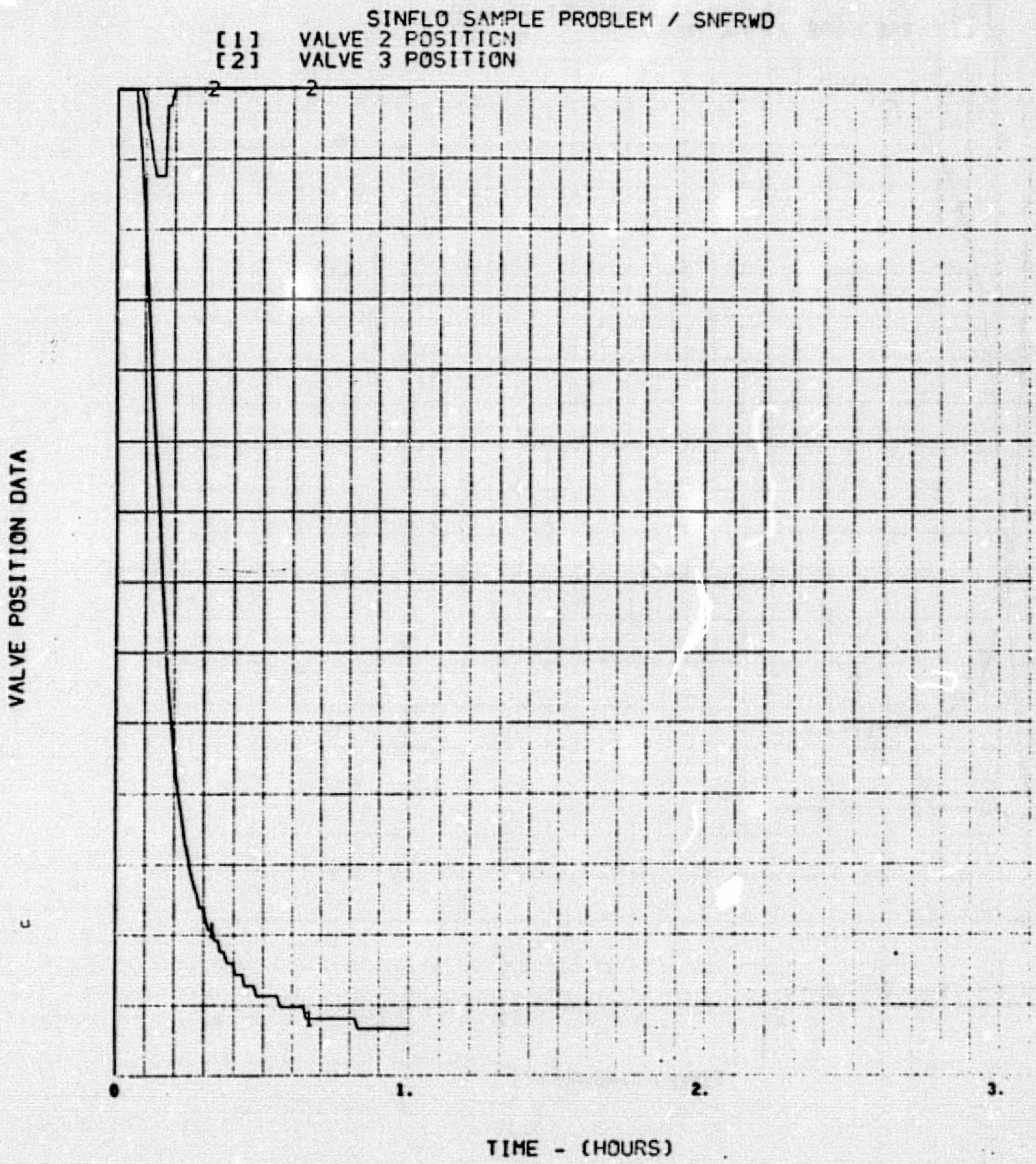


FIGURE 17
VALVE POSITION PLOTS



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APPENDIX A

RADIATION INTERCHANGE ANALYSIS

Capabilities have been incorporated into subroutines for use with SINDA to facilitate the analysis of radiation heat transfer in an enclosure. The capabilities include the ability to:

(1) Analyze diffuse and/or specular infrared radiation in an enclosure

(2) Analyze diffuse and/or specular radiation from an external source for as many wave bands as desired

(3) Consolidate several temperature nodes into a single surface to improve computational efficiency

A radiation surface is defined as a group of temperature nodes which may be assumed to have identical radiating properties, angle factors and interchange factors.

The subroutines account for the net radiation heat transfer between a number of surfaces due to the emitted radiation from each surface, reflected radiation from each surface, and radiation from any number of incident sources. The reflection of the energy originally emitted by another surface or from an external source may be either diffuse, specular, or any combination of the two.

Emitted Radiation In A Cavity

The radiosity of a surface is defined as the flux of infrared radiation leaving that surface with a diffuse distribution (according to Lambert's Law). That energy leaving a surface which has been reflected in a specular manner does not contribute to the radiosity of that surface. The incident infrared radiosity is denoted by the symbol H. The reflectance $(1 - \varepsilon)$ of a surface is separated into two components, the diffuse reflectance (ρ), and the specular reflectance (ρ^S). Here ε is the emittance of the surface and is equivalent to the absorptance for long wavelength radiation With the angle factors (F_{ij}) defined in the normal way, there exist similar angle factors which relate the geometrical ability of surface i to radiate to surface j by means of a mirror-like reflection from specular surface k. Reference to Figure A-1 indicates the method of imagery which will enable the calculation of these reflected angle factors. Here the angle factor to surface j is identical with the angle factor to the image of surface j. Also the angle factor is limited by the ability of surface i to "see" through the "window" of surface k. With the specular surface angle factors so defined, an interchange factor E_{ij} is defined similarly to reference 8 as follows:

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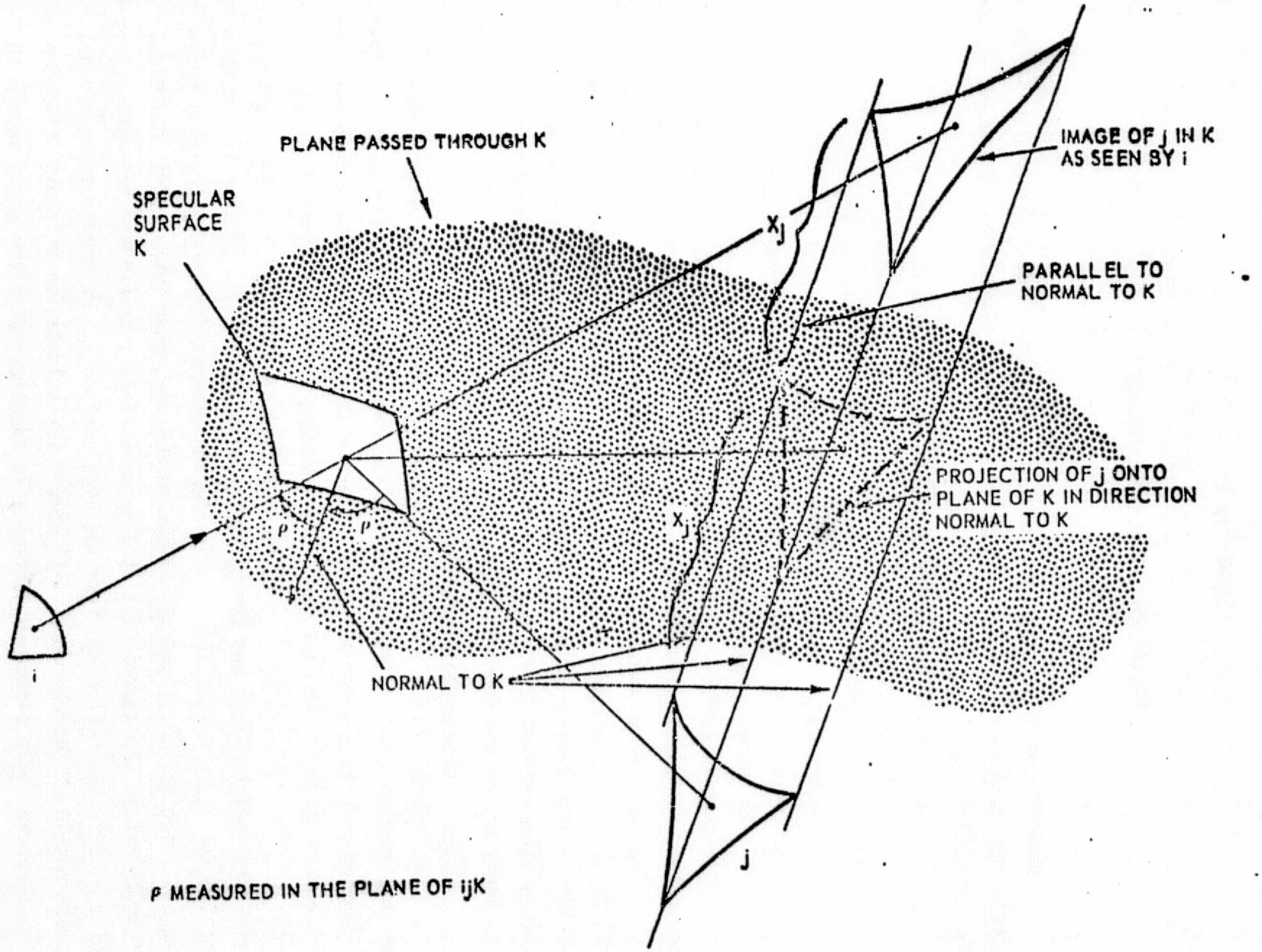

FIGURE A-1 ILLUSTRATION OF METHOD USED TO DETERMINE SPECULAR SURFACE REFLECTED VIEW FACTORS

$$E_{ij} = \sum_k \rho_k^s F_{ij(k)} + \sum_k \sum_l (\rho_k^s)(\rho_l^s) F_{ij(k,l)} + \cdots \quad \text{(A-1)}$$

Here $F_{ij(k)}$ is the angle factor from i to j as seen in the specular surface k, $F_{ij(k,l)}$ is the angle factor from i to j as seen in the double specular reflection from k and l. There are an infinite number of possible combinations of these multi-reflections. It is evident that the interchange factors account for the specularly reflected radiant flux from the reflecting surface. This portion of total leaving flux is not a component of the radiosity of that surface. The radiosity may be written

$$B_i = \epsilon_i \sigma T_i^4 + \rho_i H_i, \quad \text{(A-2)}$$

and, for ns surfaces,

$$H_i = \frac{1}{A_i} \sum_{j=1}^{ns} B_j A_j E_{ji}$$

Now the interchange factors obey the reciprocity relation

$$A_i E_{ij} = A_j E_{ji}$$

So,

$$H_i = \sum_j B_j E_{ij}$$

Substitution into the equation for B results in

$$\sum_j (\delta_{ij} - \rho_i E_{ij}) B_j = \epsilon_i \sigma T_i^4 \quad \text{(A-3)}$$

This equation represents a set of linear, simultaneous, inhomogeneous algebraic equations for the unknowns (B_j). The symbol δ_{ij} is the Kronecker delta function which is 1 when $i = j$ and is 0 when $i \neq j$.

Note that the coefficients of B_j in equation (A-3) do not form a symetric coefficient matrix since the off diagonal terms contain $-\rho_i E_{ij}$. This equation can be made symetric by multiplying each equation by A_i/ρ_i.

This gives

$$\sum_{j}\left(\frac{\delta_{ij}\ A_i}{\rho_i} - E_{ij}A_i\right) B_i = \frac{\epsilon_i\ A_i}{\rho_i}\sigma T^4 \qquad i = 1, ns$$

Written in matrix form this equation is

$$E\ B = T \tag{A-4}$$

Where E is a symetric coefficient matrix. The solution is

$$B = E^{-1}T = [e_{ij}^{-1}]\,T$$

or

$$B_i = \sum_{J=1}^{ns} e_{ij}^{-1} \frac{\epsilon_i\ A_j}{\rho_j}\sigma\ T_j^4 \tag{A-5}$$

The net heat transfer rate asorbed by surface i is given by

$$Q_i = A_i\epsilon_i\ [\ H_i - \sigma\ T_i^4\ ]$$

Where H_i is given from equation (A-2) as

$$H_i = \frac{1}{\rho_i}\ [\ B_i - \epsilon\,\sigma T_i^4\ ]$$

Substituting in for H_i gives

$$Q_i = A_i\ \epsilon_i\left\{\frac{1}{\rho_i}\ [\ B_i - \epsilon_i\ \sigma\ T_i^4\ ] - \sigma\ T_i^4\right\}$$

$$= \frac{A_i\ \epsilon_i}{\rho_i}\left\{\ B_i - [\ \rho_i + \epsilon_i\ ]\ \sigma\ T_i^4\right\} \tag{A-6}$$

Substituting in for B_i from equation (A-5) into equation (A-6) gives

$$Q_i = \frac{A_i \epsilon_i}{\rho_i} \left\{ \sum_{j=1}^{ns} \frac{e_{ij}^{-1} \epsilon_j A_j}{\rho_j} \sigma T_j^4 - [\rho_i + \epsilon_j] \sigma T_i^4 \right\}$$

$$= \frac{A_i \epsilon_i}{\rho_i} \left\{ \sum_{\substack{j=1 \\ j \neq i}}^{ns} \frac{e_{ij}^{-1} \epsilon_j A_j}{\rho_j} \sigma T_j^4 - \left[\rho_i + \epsilon_i - \frac{e_{ij}^{-1} \epsilon_i A_i}{\rho_i}\right] \sigma T_i^4 \right\} \qquad \text{(A-7)}$$

Since, in steady state, $Q_i = o$, and $T_i^4 = T_j^4$ for all i and j we can conclude that

$$\rho_i + \epsilon_i - \frac{e_{ij}^{-1} \epsilon_i A_i}{\rho_i} = \sum_{\substack{j=1 \\ j \neq i}}^{ns} e_{ij}^{-1} \frac{\epsilon_j A_j}{\rho_j}$$

Making the above substitution in equation (A-7) gives

$$Q_i = \sum_{j=1}^{ns} \sigma \frac{\epsilon_i \epsilon_j A_i A_j e_{ij}^{-1}}{\rho_i \rho_j} \left[T_j^4 - T_i^4\right]$$

If we define $\mathcal{F}$ as

$$\mathcal{F}_{ij} = \frac{\epsilon_i \epsilon_j A_j e_{ij}^{-1}}{\rho_i \rho_j} \qquad i \neq j \qquad \text{(A-8)}$$

$$\mathcal{F}_{ij} = \frac{\varepsilon_i \varepsilon_j A_i}{\rho_i \rho_j} [e_{ij}^{-1} - \rho_i / A_i] \qquad i = j$$

Then

$$Q_i = \sum_{j=1}^{ns} \sigma \mathcal{F}_{ij} A_i \left[T_j^4 - T_i^4\right]$$

This equation gives the heat flux between surfaces. However, each surface can contain several nodes. The heat absorbed by for each node is determined by:

$$Q_n = \frac{A_n}{A_i} \sum_{J=1}^{ns} \sigma \mathcal{F}_{ij} A_i \left[T_j^4 - T_n^4 \right] \qquad \text{(A-9)}$$

Where n = the node number on surface i

Prior to each iteration, the temperature of the surfaces are determined by

$$T_i^4 = \frac{\sum_{n=1}^{nn} A_n T_n^4}{\sum_{n=1}^{nn} A_n} = \frac{\sum_{n=1}^{nn} A_n T_n^4}{A_i} \qquad \text{(A-10)}$$

Where nn = the number of nodes on surface i

Since the heat transfer rate given by equation (A-9) depends on the node temperature, stability considerations must be taken into account. This is handled by storing the following relation into the array containing the sum of the conductors used for time increment calculation

$$CON_n = 4 \frac{A_n}{A_i} \sigma T_n^3 \sum_{J=1}^{nc} \mathcal{F} A_{ij} \qquad \text{(A-11)}$$

Subroutine RADIR makes the calculations necessary to obtain Qn given by equation (A-9) and CONn given by equation (A-11). The following is a summary of the calculations:

A. The following are performed the first time through RADIR:
   1. From the user input values of E_{ij}, A_i, and ρ_i, the E matrix given by equation (A-4) is formed. Only half of the symetric matrix is stored to save space.
   2. The E matrix is inverted in its own space to get E^{-1} with elements e_{ij}^{-1}
   3. The $\mathcal{F} A_{ij}$ values are determined from equation (A-8) and stored in the surface connections data.

B. The following calculations are performed on each temperature iterations:
   1. The temperature of each surface is calculated by equation (A-10).
   2. The heat absorbed for each node is determined using equation (A-9) and is added to the Q array.

The routine utilizes data used for obtaining $\mathcal{F} A_{ij}$ in step A as working space for step B, thus, maximizing space utilization.

Radiation From External Source

As with the internally generated radiation, the solar (or any other external source radiation) interchange factor is defined by

$$E_{ij}^{*} = F_{ij} + \sum_{k} \rho_k^{*s} F_{ij}(k) + \sum_{k} \sum_{l} \rho_k^{*s} \rho_l^{*s} F_{ij}(k,l) + \cdots$$

Where ρ_k^{*s} is the solar specular reflectance of surface K

$F_{ij}(K)$ is the angle factor from i to j as seen in the specular surface κ

$F_{ij}(K,l)$ is the angle factor from i to j as seen in a double specular reflection from j to l to k back to i

The interchange factors as defined above accounts for the specularly flux reflected from the surface. Thus, since the specular component of the flux is assumed to go directly from surface i to surface j by the interchange factor, Eij, this portion of the total flux is not a component of the radiosity for the intermmediate surfaces (k and l above). The radiosity of surface i is given by

$$B_i^{*} = \rho_i^{*} H_i^{*} \tag{A-12}$$

Where B_i^{*} is the radiosity (energy leaving)

H_i^{*} is the incident energy

ρ_i^{*} is the diffuse reflectance

The energy incident upon a surface is given by

$$H_i = \sum_{J=1}^{ns} B_j^{*} E_{ij}^{*} + S_i \tag{A-13}$$

Where S_i is the energy directly incident on surface i from an external source

Substituting equation (A-12) into (A-13), multiplying by A_i/ρ_i^* and simplifying gives the following relation for the radiosity

$$\left[\frac{A_i}{\rho_i^*} - E_{ii}^* A_i\right] B_i^* - \sum_{\substack{J=1 \\ J\neq i}}^{n} E_{ij}^* A_i B_j^* = S_i A_i \qquad i=1,n \tag{A-14}$$

This set of n equations can be written in matrix form as

$$E^* B^* = S \tag{A-15}$$

Note that the equations are written so that E* is a symetric matrix, which has the solution for B*

$$B^* = E^{*-1} S \quad \text{or} \quad B_i = \sum_{J=1}^{n} [e_{ij}^*]^{-1} S_j \; A_j \tag{A-16}$$

Where $[e_{ij}^*]^{-1}$ is the ijth element of the inverse of the E* matrix

The heat flux absorbed by the i th surface is given by

$$\frac{Q_i^*}{A_i} = \alpha H_i \tag{A-17}$$

But from equation (A-12)

$$H_i = \frac{B_i}{\rho_i^*} \tag{A-18}$$

Combining equations (A-16), (A-17), and (A-18) gives

$$Q_i^* = \sum_{J=1}^{n} e_{ij}^{*-1} \frac{\alpha_i}{\rho_i^*} A_j A_i S_j \tag{A-19}$$

If we define

$$\mathcal{F}_{ij}^* = e_{ij}^{*-1} \frac{\alpha_i}{\rho_i^*} A_j \tag{A-20}$$

Then the absorbed heat flux is given by

$$Q_i^* = \sum_{J=1}^{n} \mathcal{F}_{ij}^* A_i S_j \tag{A-21}$$

Equation (A-21) gives the heat absorbed by each surface. However, each surface may contain several temperature nodes. The absorbed heat for each node is given by:

$$Q_n^* = \frac{A_n}{A_i} Q_i^* \qquad \text{(A-22)}$$

Where A_n is the area of the node

Subroutine RADSØL was written to make necessary calculations to obtain Q_n^* given by equation (A-22). The following is a summary of the calculations:

A. The following calculations are made the first time through RADSOL:

1. From the user input values of E^*_{ij}, ρ_i^*, and Ai, the E* matrix given by equation (A-15) is formed. Only one half is stored since E* is symetric.
2. The E* matrix is inverted in its own space to get E^{*-1} with elements, e^{*-1}_{ij}.
3. The $\mathcal{F}^*_{ij}$ A_i values are determined from equation (A-20) and stored in the surface connections data.

B. The following calculations are performed on each temperature iteration:

1. The heat flux absorbed by each node is calculated by

$$\frac{Q_i^*}{A_i} = \frac{1}{A_i} \sum_{J=1}^{n} \mathcal{F}^*_{ij} A_i S_i$$

2. The net heat absorbed by this wavelength radiation is calculated for each temperature node on each surface by

$$Q_n^* = A_n \frac{Q_i^*}{A_i}$$

This quantity of absorbed heat is added to the Q array for node n.

Note that the user may specify subroutine RADSOL for as many bands of radiation from an external source as desired. A single call is required for each band.

APPENDIX B
FLOW DATA STORAGE

The flow data which is input in the FLOW DATA block described in Section 4.1 is stored by the preprocessor in labled common arrays. These arrays will be included in the main processor phase routine and the routines generated from the four operation blocks (EXECTN, VARBL1, VARBL2, and OUTCAL). The arrays will be dimensioned in the main processor routine. The following is a list of the arrays:

1. Flow Data : /FLODAT/FLOW(ND), where ND is the amount of space required for the flow data array. This array includes tube connections data and tube data for all systems, specified pressure nodes, valve data, pump data and enthalpy curve
2. System Data : /SYSDAT/SYSTEM(15,NS), where NS is the number of systems. Systems data include property data, solution parameters and specified pressures.
3. Fluid Lump Type Data : /TYPDAT/TYPE(10, NTP), where NTP is the number of fluid types.
4. Flowrates : /WDOT/W(LT), where LT is the largest input tube number.
5. Pressures : /PRESS/P(LP), where LP is the largest input pressure node number.
6. Flow Conductors : /FLOWG/GF(LT)
7. Valve Positions : /VALVP/VP(LV), where LV is the largest input valve number.
8. Imposed Flowrates : /WDOTI/WI(LP)
9. Added Flow Resistances : /FLOWR/AFR(LT)
10. Pressure Drops : /DELTAP/DP(LT)
11. Dimensions : /FDIMNS/NTYPE, NSYS, NTB, NP, NV, NFD

where NTYPE is given the value NTP (above)
NSYS is given the value NS
NTB is given the value LT
NP is given the value LP
NV is given the value LV
NFD is given the value ND

The items to be stored in the above are discussed in more detail below.

1.0 FLOW Array

The FLOW array contains flow data that is not easily addressable by the user. Items contained are (1) the network and subnetwork connections data, (2) the tube data which includes the fluid lump/tube lump pairs and the fluid lump type, (3) the specified pressure nodes, (4) the valve data, (5) the network valve data, (6) the pump data, and (7) valve data locations. The format for storing each item is discussed below.

1.1 Network and Subnetwork Connections

The network and subnetwork connections data is stored in the following order for each network or subnetwork:

```
IC1,'NAME1', LOCPR1, LOCV1, NTB11, NFRM11, NTO11, LOCD11
                            NTB12, NFRM12, NTO12, LOCD12
                              .      .       .      .
                              .      .       .      .
                              .      .       .      .
                            NTB1n, NFRM1n, NTO1n, LOCD1n
IC2,'NAMEn', LOCPR2, LOCV2, NTB21, NFRM21, NTO21, LOCD21
                              .      .       .      .
                              .      .       .      .
                            NTB2n, NFRM2n, NTO2n, LOCD2n
 .      .        .       .
 .      .        .       .
 .      .        .       .
ICn,'NAMEn', LOCPRn, LOCVn, NTBn1, NFRMn1, NTOn1, LOCDn1
                              .      .       .      .
                              .      .       .      .
                            NTBnn, NFRMnn, NTOnn, LOCDnn
```

where ICi is the integer count of the number of spaces in the connections data for the ith network or subnetwork

NAMEi is the 4 character name of the ith network or subnetwork input on the heading card

LOCPRi is the location in the flow data array of the specified pressure nodes for the ith network or subnetwork

LOCVi is the location of the ith network or subnetwork valve data (which is an array of locations of the actual valve data)

NTBij is the tube number of the jth tube of the ith network of subnetwork

NFRMij is the "from" pressure node for the jth tube of the ith network or subnetwork

NTOij is the "to" pressure node for the jth tube of the ith network or subnetwork

LOCDij is the location of tube data (or subnetwork connections) for the jth tube of the ith network or subnetwork

If LOCD > 0 it is the location of the tube data (fluid/tube lump pairs and type no's.)

If LOCD < 0 it is the location of the subnetwork connections data for tube j

If LOCD = 0, the user is supplying the flow resistance for tube j in the added flow resistance array, AFR

A sort is required on the connections data for each network or subnetwork. The connections must be arranged so that for each pressure node, all NTO references for that node must occur in the list prior to any NFRM references. The four data values (NTB, NFRM, NTO, LOCD) must remain intact as a group during the sort. Tubes whose "from" node, NFRM, is not referenced as a "to" node, NTO, should come first in the connections data.

1.2 Tube Data

The tube data portion of the FLOW array contains the fluid lumps, fluid lump types and tube lumps for each tube. This data is referenced by the LOCD values in the connections data for each tube described in Section 4.1. The format for the tube data portion of the FLOW array is:

```
IC1, NFLMP11, NTYPE11, NTBLMP11, ---, NFLMP1n, NTYPE1n, NTBLMP1n
 .     .        .        .             .        .        .
 .     .        .        .             .        .        .
 .     .        .        .             .        .        .
ICn, NFLMPn1, NTYPEn1, NTBLMPn1, ---, NFLMPnn, NTYPEnn, NTBLMPnn
```

where ICi is the integer count for the tube data for tube i (must be a multiple of 3)

NFLMPij is the relative fluid lump number of the jth fluid lump in tube i

NTYPEij is the type number of the jth fluid lump in tube i

NTBLMPij is the relative tube lump number for the jth fluid lump in tube i

Notice that NFLMP and NTBLMP are relative lump numbers. Thus, during storage these numbers must be converted from actual numbers which are input to relative numbers.

1.3 Specified Pressure Node Data

The specified pressure node data is a list of the pressure nodes whose pressures are not calculated. One such list exists for each network in the problem and may also exist for any subnetwork if it contains any specified pressures. The format for each specified pressure node list is:

$$IC, NSP_1, NSP_2 - - - NSP_{IC}$$

where IC is the integer count which is also the number of specified pressure nodes in the network or subnetwork

NSP_i is the ith specified pressure node

1.4 Valve Data

The valve data described in Section 4.3 is stored in the FLOW array. The format for this is slightly different for the different types of valves. For the rate limited valve the format is:

IC, NV, NTS1, NTS2, MODE, XMIN, XMAX, E, TSEN1, TSEN2, DB, RF, RL

For the polynomial valve it is

IC, NV, NTS1, NTS2, MODE, XMIN, XMAX, E, TSEN1, TSEN2, CO, C1, C2, C3, C4, C5, VTC

For the switching valve it is

IC, NV, NTS1, NTS2, MODE, XMIN, XMAX, E, NSEN, T1, T2

where the symbols are described in Section 4.3 The integer count for each is the number of data values and is 12 for a rate limited valve, 16 for the polynomial and 10 for the switching valve.

1.5 Network Valve Locations

The network valve locations is a list of locations in the FLOW array for the valve data of the valves in a network or subnetwork. One such list is needed in the FLOW array for each network or subnetwork that contains valves. The location of the network valve data list is provided in the fourth location of the Network Connections Data.

The format of the network valve locations is:

IC, LOCV1, - - - LOCVIC

where IC is the number of valves in the network
LOCVi is the location in the FLOW array of the valve data for the ith valve in the network

1.6 Flow Source Data

The flow source data lists are supplied in the FLOW array for each flow specification statement input in the BCD FLOW SOURCE data block described in Section 4.4.. The input statements from the FLOW SOURCE data are transfered directly to the FLOW array except an integer count is added to each list and array numbers are converted from actual to relative numbers.

The formats for storage are as follows for the three types of flow sources:

<u>Flow As A Function of Time</u>

IC, NPI, AW

<u>Pressure Rise As a Tabulated Function of Flowrate</u>

IC, NPI, NPO, ADP

<u>Pressure Rise As A Polynomial Function of Flowrate</u>

IC, NPI, NPO, CO, C1, C2, C3, C4

where IC is the integer count of the list (2, 3, and 7 respectively)

All other variables are described in Section 4.4. The actual numbers of arrays referenced by AW and ADP must be converted to relative locations prior to storage in the FLOW array. Only one flow source data list per network is to be stored in the FLOW array and the location is referenced from the SYSTEM array (to be discussed later).

An option on AW is that it may be input as an array or a real constant. If AW is supplied as a real constant, the flow source list is not stored in the FLOW array. Rather, the constant, AW, is stored in the imposed flowrate array, WI, (to be discussed later).

1.7 Valve Locations

The valve locations list is a list of locations of the valve data (whose input is described in Section 4.2 and storage is described in the Appendix)for all the valves in the problem in order of valve number. There is only one valve location list in the FLOW array and the location of this list is given as the seventh item in the FDIMNS labled common block (described below).

The format for storage of the valve locations is

IC, LOCV1, LOCV2, - - - -, LOCVIC

where IC is the interger count and is the total number of valves in the problem

LOCVi is the location in the FLOW array for the valve data for valve number i

2.0 SYSTEM Array

The system array contains fluid property data (or locations of property data), the gravitational constant (gc), solution parameters, and the locations in the FLOW array for the flow source list, the network connections data and the enthalpy curve for each system. The SYSTEM array is a two dimensional array dimensioned to 15 by NSYS where NSYS is the number of systems. Thus 15 locations are allocated for each system (only 13 are currently used leaving 2 blank spaces per system). The system array is in the labled common block SYSDAT.

The format for storage of the SYSTEM array is

$ACP_1, ARO_1, AMU_1, AKT_1, GC_1, MPASS_1, TOL_1, MXPASS_1, FRDF_1, KOP_1, LOCP_1, LOCNET_1, LOCH_1, 0, 0$

$ACP_2, ARO_2, AMU_2, AKT_2, GC_2, MPASS_2, TOL_2, MXPASS_2, FRDF_2, KOP_2, LOCP_2, LOCNET_2, LOCH_2, 0, 0$

$\vdots$

$ACP_n, ARO_n, AMU_n, AKT_n, GC_n, MPASS_n, TOL_n, MXPASS_n, FRDF_n, KOP_n, LOCP_n, LOCNET_n, LOCH_n, 0, 0$

where ACP_i, ARO_i, AMU_i, and AKT_i are the relative array numbers for the arrays or the values of the constant values for the specific heat, density, viscosity and thermal conductivity for the ith system

GC is the gravitational constant for the ith system

$MPASS_i$ is the number of temperature iterations between pressure solutions for system i

$MXPASS_i$ is the maximum number of passes in the balancing loop permitted to obtain a pressure/flow solution for system i

$FRDF_i$ is the flowrate damping factor for system i

TOL_i is the solution tolerance on the fraction of change of flowrates from one pass in the flow solution to the next for system i

KOP_i is the check-out-print code for system i

$LOCP_i$ is the location of the flow source data in the FLOW array for the ith system

$LOCNET_i$ is the location of the network connections data in the FLOW array for the ith system

$LOCH_i$ is the location of the enthalpy curve in the FLOW array for the ith system

The values for ACP_i, ARO_i, AMU_i, AKT_i, GC_i, $MPASS_i$, $MXPASS_i$, $FRDF_i$, TOL_i and KOP_i are taken from the systems input supplied in the BDC 3NETWORK block except that array numbers are converted to relative array locations for ACP, ARO, AMU and AKT and default values are supplied for GC, MPASS, MXPASS, FRDF, TOL and KOP if no values are input (Default values are shown in Section 4.1). The values for LOCP, LOCNET and LOCH which are storage locations in the FLOW array are determined as the FLOW array is built during the preprocessor phase.

3.0 Fluid Type Array

The fluid lump type data is stored in the TYPE array which is in the TYPDAT labled common block. This array contains the fluid lump type information which is input in the BCD 3FLUID LUMP DATA input block on the left of the equal sign for all type cards. The TYPE array is a two dimensional array, dimensioned to 10 by NTP, where NTP is the number of types. The format for the TYPE array is

$$CSA_1, WP_1, FLL_1, AHT_1, NHL_1, MFF_1, FFC_1, F1_1, F2_1, \frac{FLL_1 * WP_1}{4.0 * CSA_1}$$

$$CSA_2, WP_2, FLL_2, AHT_2, NHL_2, MFF_2, FFC_2, F1_2, F2_2, \frac{FLL_2 * WP_2}{4.0 * CSA_2}$$

$$\vdots$$

$$CSA_n, WP_n, FLL_n, AHT_n, NHL_n, MFF_n, FFC_n, F1_n, F2_n, \frac{FLL_n * WP_n}{4.0 * CSA_n}$$

where

CSA_i is the fluid flow cross sectional area for fluid lump type i

WP_i is the fluid wetted perimeter for fluid lump type i

FLL_i is the fluid lump length for fluid lump type i

AHT_i is the area for heat transfer for connection for fluid lump type i (usually WP*FLL)

NHL_i is the number of head losses for fluid lump type i if input as a real constant

is stored as the relative location in the array data for the user input array of head losses vs Reynolds number if input as AXX where XX is the array number

MFF_i is the code to determine the method used for calculating friction factor for type i. If MFF = 0, the internal methods are used to calculate friction factor. If MFF = AXX, XX is an array (the relative location is stored) of the Friction Factor vs Reynolds number.

FCC_i is a constant to be multiplied times the friction factor for type i

$F1_i$ is a code to determine the method for calculating convection heat transfer coefficient for type i. If F1 is real, the internal equation for flow in a tube is used and F1 is the laminar fully developed coefficient. F2 is the laminar entry

length coefficient.
If F1 = 1, F2 is AXX, XX is an array(stored as the relative array location) of Stanton Number vs Reynolds number array.
If F1 = 2, F2 is AXX, XX is an array (stored as the relative array location) of an array giving heat transfer coefficient vs tube flowrate.

$F2_i$ is described under F1 above

The tenth item in the list for each type is FLL*WP/(4.0*CSA) which is the L/D for the type. This item must be calculated and stored for each type during the preprocessor phase.

The TYPE array is shown in Table B-I for the sample problem.

4.0 Other Arrays

Eight arrays must be set up for the flow problem in addition to the three primary flow problem arrays discussed in Sections 1.0, 2.0, 3.0. These arrays are each in a separate labled common block to provide ready access to them for user input and output in the user logic block. The labeled common block and the array name for each is given below:

/WDOT/W(LT) - Array of flowrates per tube
/PRESS/P(LP) - Array of pressures per pressure node
/FLOWG/GF(LT) - Array of flow conductors per tube
/VALVP/VP(LV) - Array of valve positions per valve
/WDOTI/WI(LP) - Array of imposed flowrate per pressure node
/FLOWR/AFR(LT) - Array of added flow resistance per tube
/DELTAP/DP(LT) - Array of pressure drops per tube
/FDIMNS/NTYPE,NSYS,NTB,NP,NV,NFD - Dimensions for the flow problem

The dimensions in the above arrays are as follows:

LT is the largest tube number
LP is the largest pressure node number
LV is the largest valve number

TABLE B-I FLUID TYPE ARRAY

CSA	WP	FLL	AHT	NHL	MFF	FFC	F1	F2	FLL/D*	
0.001008	0.1125	12.0	1.35	0.0	0	1.0	1.0	1.0	334.821	10
0.000938	0.36	3.25	1.17	117.0	0	1.0	1.0	1.0	311.834	20
0.001008	0.1125	5.0	.5625	0.0	0	1.0	1.0	1.0	139.509	30
0.853E-4	0.0328	0.25	.0082	2.49	0	1.0	1.0	1.0	.24E-6	40
0.001008	0.1125	20.0	2.25	0.0	0	1.0	1.0	1.0	558.036	50
0.001008	0.1125	2.5	.281	0.0	0	1.0	1.0	1.0	69.75	60
0.001008	0.1125	50.0	5.62	0.0	0	1.0	1.0	1.0	1395.09	70
0.001008	0.1125	7.0	.7875	0.0	0	1.0	1.0	1.0	195.31	80
0.001008	0.1125	2.0	.225	0.0	0	1.0	1.0	1.0	55.80	90
0.853E-4	0.328	0.25	0.0	0.0	0	1.0	1.0	1.0	.24E-6	100

*D = 4.0 X CSA/WP

The variables in the FDIMNS labeled common array indicate the size of various aspects of the total flow problem. The following values are assigned:

NTYPE	-	Number of types
NSYS	-	Number of systems
NTB	-	Number of tubes
NP	-	Number of pressure nodes
NV	-	Number of valves
NFD	-	Number of spaces in the FLOW array

APPENDIX C

USERS DESCRIPTION FOR PLOT PROGRAM

This Appendix presents user descriptions for a SINDA plotting routine, FLOPLT and a tape combining routine, MCOMB. Both routines are available on the ES3*SINDA Secure File. A brief description of the routines and the user input description is given below.

FLOPLT DESCRIPTION

The plot routine which is available on *SINDA can be used with a history file from a previous SINDA run to generate microfilm output. The items available for plotting are (1) pressure drop for each tube, (2) pressure for each pressure node, (3) valve positions for each valve, (4) flow rates for each tube, and (5) temperatures for each temperature lump. Each of these items may be plotted as a function of mission time. The user specifies the grid time range to be plotted, a time label, and the itmes to be plotted. A number of history files may be combined prior to plotting the results. The user has the option of averaging any portion of the plotted curve and of specifying the range of the ordinate axis.

The system control cards and the data input card for FLOPLT are described below:

SYSTEM CONTROL CARDS FOR FLOPLT

```
@ RUN
@ QUAL ES3
@ ASG,A *SINDA
@ USE  7,XXX (First file to    combined)
@ USE  8,XXX (Second file to be combined)
            Add additional USE cards as required for files to be combined.
@ MAP *SINDA, SINFLOPLOT/MAP,TPF$.RUN
@ XQT RUN
  Data cards
@ FIN
```

FLOPLT DATA CARDS

Columns	Format	Title	Description
Card 1 (Title Card)			
1-72	12A6	TITLEA	Any 72 alphammeric characters to be used as heading for each frame of plots
Card 2 (Parameter Card)			
1-10	F10.0	TA	First value of time to be plotted (hours).
11-20	F10.0	TZ	Last value of time to be plotted (hours).
21-30	F10.0	TPG	Time range for each grid. Number of grids drawn will be (TZ-TA)/TPG. (If TPG is left blank, the job will terminate.)
31-35	I5	ITMX	Time scale lable: = 1, "SECONDS" = 2, "MINUTES" = 3, "HOURS" Any other value, "*****"
36-40	I5	MPNT	Print control code = 1, prints information to be plotted while loading the plot tape ≠ 1, will not print information to be plotted
41-45	I5	NTP	Number of tapes to be combined. Use a negative number if start and/or stop times are specified on Card 3 for any tape to be combined.
46-50	I5	KT	File number to which file to be plotted is assigned. If left blank, file 23 is assumed. The combined file is assigned to this unit.
51-55	I5	INC	= 1, every time point and associated data value from the tanes tn be combined will be transferred to the combined tape. = 2, every second time point and associated data values will be transferred to the combined tape. etc.

Columns	Format	Title	Description
56-60	I5	IUNIT	Logical unit number to which first tape to be combined is assigned. If left blank, unit 7 is assumed.
61-70	F10.0	ASTRT	Beginning time for averages (hours).
71-80	F10.0	ASTØP	Ending time for averages (hours).

Card 3 (Required only if NTP < 0. See Card 2 columns 41-45)

1-5	F5.3	XSTART	First time point from first tape to be combined which will be transferred to the combined tape.
6-10	F5.3	XSTØP	Last time point from first tape to be combined which will be transferred to the combined tape.

Repeat XSTART and XSTØP in five column fields for each tape to be combined.

Card 4 (Item Card)

1-5	I5	ITEM	The item number to be plotted. Use a negative value if this item is to start a

Repeat Card 4 for each item to be plotted.

Card 5

1-80 Blank

Card 6

1-80 Blank

If additional history tapes are to be plotted, repeat Card 1 and subsequent cards for each additional history tape.

COMBINE ROUTINE DESCRIPTION

The combine routine, MCOMB, can be used to combine history files into one history file prior to its being plotted or being compared to another file. The combined file which is generated can be saved for future use if required. The user selects the frequency with which the time points and associated data values on the original files are added to the new file. That is, every time point on the original file can be added to the new file or every second, third, etc., point can be added depending on the requirements for the combined file.

The combine routine is a very useful feature if several history files are generated on a long mission run. By combining these files before plotting, a continuous plot of the mission can be obtained. The convenience of the combine routine can also be observed when mission runs made with different time increments are compared. Obviously, the run made with the smaller time increment will take more computer time than the run made with the larger time increment, and will probably require at least one "restart". In such a situation, there would be two history files with the smaller time increment to compare to one with the larger time increment. The two files with the smaller time increment can be combined and then compared to the file with the larger time increment on the same run.

The system control cards and the data input cards for MCOMB are described below:

SYSTEM CONTROL CARDS FOR MCOMB ROUTINE

```
@ RUN
@ ASG, A ES3*SINDA
@ USE  7,XXX (First file to be combined)
@ USE  8,XXX (Second file to be combined)

          Add additional USE cards as required for files to be combined.
@ MAP ES3*SINDA, MCOMB/MAP,TPF$.RUN
@ XQT RUN
  Data cards
@ FIN
```

Columns	Format	Title	Description

Repeat XSTART and XSTOP in five columns fields for each file to be combined.

Card 3 (Required only if KODE2 > 0. See Card 1 columns 16-20

1-10	F10.0	ADD	Time to be added to each time read from first file to be combined.

Repeat ADD in 10 column fields for each file to be combined.