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University of California

Heat Pipe Computer Program (HTPIPE)

User's Manual

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F. C. Prenger, Jr.

HEAT PIPE COMPUTER PROGRAM (HTPIPE) USER'S MANUAL

by

F. C. Prenger, Jr.

ABSTRACT

Program HTPIPE is a hydrodynamic model of heat pipe performance. The program was developed for high-performance liquid metal heat pipes but can easily be adapted to other working fluids if thermal transport property values are known. Several liquid return geometries can be analyzed including homogeneous wick, screen covered grooves, circular arteries and gutters. The program can be used to optimize the heat pipe design, to calculate performance limits, and to determine axial temperature and pressure profiles. The program is written in FORTRAN and is operational on CDC-6000 series computers. Sample problems are included.

I. INTRODUCTION

HTPIPE is a computer program developed at the Los Alamos Scientific Laboratory as an aid in the design and analysis of high-performance heat pipes. The program is written in FORTRAN and is operational on a CDC-6000 series computer.

The program utilizes a hydrodynamic model of the heat pipe which is capable of handling several liquid return geometries as shown in Fig. 1. Also the program can analyze heat pipes containing liquid metal working fluids and water. Additional working fluids can be easily added if the thermodynamic and transport property data are known.

The program is both a design and analysis tool. The design portion enables the optimization of the heat pipe internal dimensions for maximum

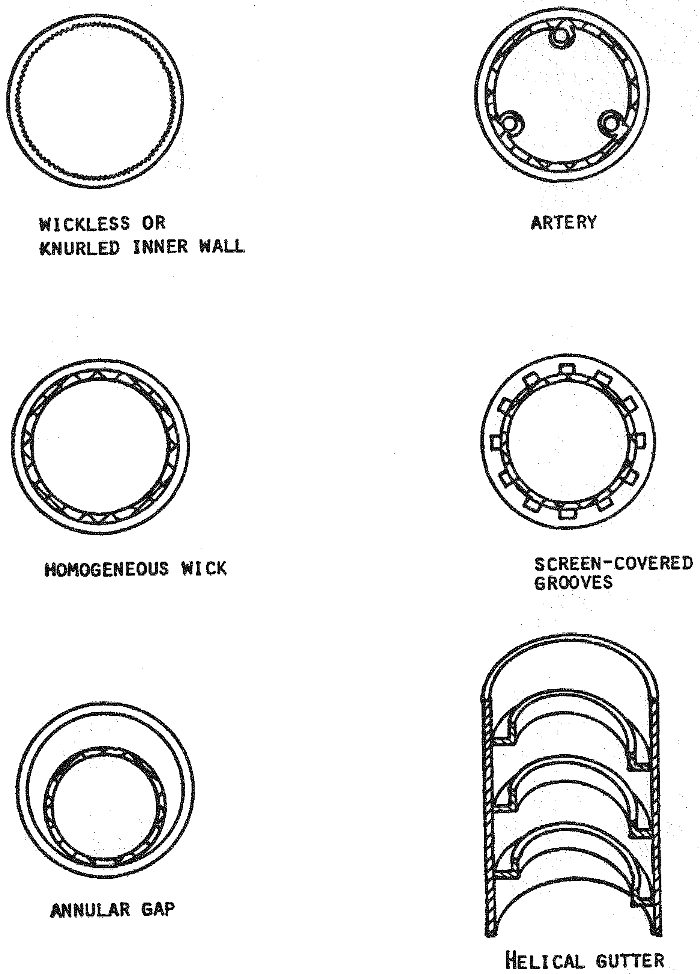

Fig. 1. Heat pipe liquid return geometries.

performance and the analysis portion predicts performance limits and calculates temperature and pressure profiles along the heat pipe axis. The model is based on a pressure balance in the flow direction for both the liquid and vapor. This pressure balance defines the wicking limit. Other limits to heat pipe performance include the sonic limit and the entrainment limit and both are included in the model. The boiling limit which is a heat flux limitation in the evaporator is not included since radial temperature distributions are not calculated.

A brief discussion of the hydrodynamic model is contained in the following section. Sections III and IV define the program structure and the input and output. The Appendix contains the program listing, sample problems, and plots.

II. THEORY

The heat pipe program is a hydrodynamic model of heat pipe operation which contains four input options. For three of the four options, the model treats the power transported by the heat pipe as the dependent variable and is calculated from

$$Q = \dot{m} h_{fg}$$

where

Q is the power

$\dot{m}$ is the maximum fluid flow rate; and

h_{fg} is the latent heat of vaporization of the working fluid.

The fluid flow rate is determined from a pressure balance on the heat pipe. The vapor and liquid frictional pressure drops are given by

$$\Delta P_f = 2f \rho V^2 \frac{L}{D} ,$$

where

ΔP_f is the frictional pressure drop;

f is the Fanning friction factor;

ρ is the density;

V is the radial-average axial velocity;

L is the length; and

D is the heat pipe diameter.

The friction factor for laminar flow is

$$f = 16/Re,$$

and, for turbulent flow

$$f = 0.0791\ Re^{-1/4}.$$

For the liquid pressure drop the friction factor is expressed in terms of a wick permeability[1] that is related to the tortuosity, pore size, and void fraction of the wick. The permeability is usually determined empirically. Both the laminar and turbulent form of the friction factor are given and the user must specify which form is used for the vapor pressure drop term. Because of the two-dimensional flow in the evaporator, which results from mass addition, the flow in the evaporator is usually laminar. However, transition to turbulent flow can occur in the adiabatic section, where the boundary condition is changed, if the axial Reynolds number is sufficiently large. For this reason the capability to analyze both types of flow is included.

The inertial pressure drop is

$$\Delta P_I = A\rho V^2,$$

where A is a velocity profile correction factor (see below); and

V is the average axial vapor velocity at the evaporator exit.

The velocity profile correction term is defined as

$$A = \frac{\overline{u^2}}{V^2}$$

where u is the local velocity at any axial location in the heat pipe and varies across the radius. The bar indicates a spatial average at any axial location.

For laminar flow[4], A is a function of the pressure ratio in the evaporator and has a maximum value of 1.234. For fully developed turbulent flow[5], the value of A is 2.22.

The pressure drop due to the hydrostatic head of the liquid is given by

$$\Delta P_z = \rho_f g Z \sin\theta ,$$

where

ΔP_Z is the hydrostatic pressure drop;

Z is the height of the liquid column;

θ is the elevation angle,

g — is the acceleration due to gravity, and

ρ_f — is the liquid density.

In this equation, Z does not always correspond to the total length of the heat pipe. In general, Z equals the height of the liquid column up to the wet point. The location of the wet point is discussed below.

The maximum pressure difference across the liquid-vapor interface is calculated using

$$\Delta P_c = \frac{2\sigma}{R} ,$$

where

ΔP_c — is the pressure drop across the interface;

σ — is the surface tension; and

R — is the effective pore radius of the capillary.

Compressibility effects are considered in the adiabatic section. Wall friction accelerates the vapor flow and thus increases the vapor pressure drop. A one-dimensional treatment of this phenomenon is given by Shapiro(2) and is included in the heat pipe model.

The capillary limit of the heat pipe is based on pressure gradient limitations across the vapor-liquid interface. Although it is theoretically possible for the capillary structure to support a negative pressure gradient, i.e., $P_{liquid} > P_{vapor}$, this condition in heat pipes is an unstable one and generally does not exist. Instead, a wet point, defined as the location where liquid and vapor pressures are equal, is formed at some axial location in the heat pipe; i.e., other than at the end of the condenser. This wet point can occur at the condenser inlet or in gravity-assist heat pipes at the evaporator exit. The location of the wet point influences heat pipe performance and since its location is dependent upon the pressure gradient in both the liquid and vapor phase it is sometimes called a pressure gradient limit.(3) The program first determines the location of the wet point which defines the lengths for the ΔP terms and then calculates the capillary limit of the heat pipe.

The heat pipe capacity can also be limited by sonic vapor flow. Such a condition results in a choking of the flow and consequently limits the heat transport of the heat pipe. Considering the effect of two-dimensional flow in the evaporator, the axial heat flux in the heat pipe is given by[4]

$$q = \frac{h_{fg}(\rho_0 P_0)^{1/2}}{A^{1/2}} \left[\frac{P}{P_0}\left(1 - \frac{P}{P_0}\right)\right]^{1/2} ,$$

where

q	is the axial heat flux,
ρ	is the vapor density,
P	is the pressure,
A	is the velocity profile correction factor (see above), and
h_{fg}	is the latent heat of vaporization of the liquid.

while the subscript zero denotes conditions at the beginning of the evaporator. The above equation is used to calculate the sonic limit where P is the pressure at the condenser inlet, the location where the MACH number is one.

Another performance limit included in the model is the entrainment limit. This limit is a result of a shear interaction between the counterflowing liquid and vapor streams. The shear stress exerted by the vapor on the liquid prevents the liquid from returning to the evaporator and a subsequent dry-out of the wick in the evaporator occurs. Prior to the onset of entrainment, waves are formed at the interface. The wavelength that results is governed by the geometry of the underlying surface. In the case of screened wicks, the wavelength corresponds to the screen mesh. The stability of the interface[6] is related to a critical value of the Weber number that is taken to be 1. This relationship defines a critical vapor velocity that can then be related to the heat pipe capacity. If

$$W_e = \frac{\lambda \rho V^2}{2\pi\sigma} = 1 ,$$

where

λ is the wavelength, and

σ is the surface tension,

then

$$V = \left[\frac{2\pi\sigma}{\rho\lambda}\right]^{1/2},$$

and

$$q_E = h_{fg}\left[\frac{2\pi\rho\sigma}{\lambda}\right]^{1/2}.$$

The above equation defines the entrainment limit where λ is determined from the heat pipe geometry. For the case of smooth-wall, wickless heat pipes, a countercurrent flooding correlation[7] of the form

$$(j_g^*)^{1/2} + (j_f^*)^{1/2} = C_W ,$$

where

$$j_g^* = \left[\frac{\rho_g V_g^2}{gL(\rho_f-\rho_g)}\right]^{1/2}$$

and

$$j_f^* = \left[\frac{\rho_f V_f^2}{gL(\rho_f-\rho_g)}\right]^{1/2}$$

is used. The subscript g refers to the vapor phase and f to the liquid phase. The constant C_W is given by[8]

$$C_W = \sqrt{3.2}\ \text{TANH}\ (0.5\ \text{Bo}^{1/4}) \quad ,$$

where the bond number is

$$\text{Bo} = D \left[g(\rho_f - \rho_g)/\sigma \right]^{1/2} \quad .$$

The flooding correlation can be related to the heat flux using

$$q = h_{fg} \rho_g V_g ,$$

to give

$$q_E = C_K^2\ h_{fg} \frac{\left[g\, \sigma\, (\rho_f - \rho_g) \right]^{1/4}}{\left[\rho_f^{-1/4} + \rho_g^{-1/4} \right]^2} \quad .$$

The above equation is used to calculate the entrainment limits for smooth-wall, wickless heat pipes.

The pressure drop relationships along with the performance limits discussed above are the basis of the heat pipe hydrodynamic model. The program was developed in close coordination with numerous heat pipe test programs, with the test results being carefully compared against the model predictions. Where appropriate changes to the model were incorporated to achieve better agreement with the test results. Fortunately, these modifications have been minimal, indicating good compatibility between theory and experiment.

III. PROGRAM STRUCTURE

The basic structure of the program is shown in Fig. 2. The first group of user inputs defines the heat pipe geometry. This includes the evaporator, condenser, and adiabatic section lengths, and the heat pipe inside diameter. The heat pipe operating condition comprises the second input group. Operating temperature at the evaporator exit, total power transported by the heat pipe, elevation angle of the evaporator, and whether or not the analysis is based on laminar or turbulent flow of the liquid or vapor are specified in this group. The heat pipe working fluid is input thirdly. Property data for most liquid metals are contained in the program. Currently, the working fluids include lithium, sodium, potassium, mercury, and water. The last input group specifies the wick design. These input include screen dimensions, artery characteristics, and effective capillary pumping radius.

The type of output provided by the program depends on which of four options are selected. The first two options are design aids where the program optimizes either the number of liquid flow passages, if appropriate, or the dimension of the liquid flow passage. The results are for a specified operating temperature with heat pipe capacity as the dependent variable. The remaining two options are used for performance analyses. One calculates performance limits due to pressure drop, sonic flow, and vapor entrainment as a function of operating temperature. The fourth option calculates heat pipe temperature and pressure profiles for a given operating condition (power and temperature both specified). For all options, the range and increment of the independent variable is specified by the user.

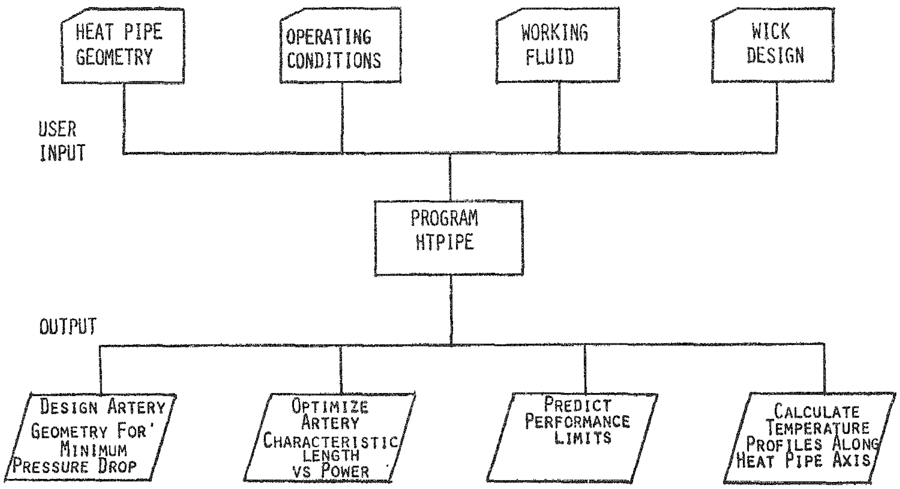

Fig. 2. Heat pipe program schematic.

IV. PROGRAM INPUT AND OUTPUT

Program input is accomplished using 24 floating point constants. The FORTRAN format is 4E20.10 per line. Input of the constants is preceded by an alphanumeric title containing a maximum of 60 characters and blanks. The constants are numbered C1 through C24 and are defined in Table I.

Values for all 24 input parameters are not required for every option. Those necessary for each program option are indicated in Table I.

The four program options are defined as follows:

Option 1. This option is used to optimize the heat pipe cross-sectional configuration by treating the number of liquid flow passages as the independent variable. It is only applicable for circular and grooved-wall arteries since it applies to multiple independent liquid passages. Increasing the number of liquid flow passages reduces the liquid pressure drop but decreases the vapor flow area and conversely. Therefore, the heat pipe capacity can be maximized with an optimum number of liquid flow passages.

Option 2. This option calculates the heat pipe power limits which include capillary, sonic, and entrainment effects. The independent variable for this option is evaporator exit temperature.

Option 3. This option calculates pressure and temperature profiles along the heat pipe axis. Length along the heat pipe axis is the independent variable and both the power and evaporator exit temperature must be specified.

Option 4. This option optimizes the characteristic dimension of the artery or wick in the heat pipe. Since there is a design trade-off between liquid and vapor flow area, the artery size or wick thickness is a critical parameter. The independent variable for this option is the artery or wick characteristic dimension.

Program output is arranged in column format with abbreviated headings printed once across the top of the page. The headings for options 1 through 4 are given in Tables II through V. It should be noted that a negative value for the capillary pumping limit in option 2 indicates the sonic limit is numerically less and will therefore govern the heat pipe capacity. Also, when adiabatic sections are present, the capillary pumping limit may require a flowrate with a corresponding velocity that exceeds the sonic velocity at the condenser inlet. In this case, a message is printed to this effect and precedes the data in question.

Plotting of the output for options 2, 3, and 4 is available by placing a nonzero integer in column 61 on line one of the input file. The plot package makes use of the DISSPLA* system and is executed in subroutine DRaw. The plots can be deleted without affecting the remainder of the code.

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*DISSPLA is a proprietary software product developed by Integrated Software Systems Corporation, San Diego, CA.

ACKNOWLEDGEMENT:

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REFERENCES

1. P. Dunn and D. A. Reay, Heat Pipes, Pergamon Press Ltd., 1976.

2. A. H. Shapiro, The Dynamics and Thermodynamics of Compressible Fluid Flow, Ronald Press, VI, Chap. 6, 1953.

3. C. A. Busse and J. E. Kemme, "The Dry-out Limits of Gravity-Assist Heat Pipes with Capillary Flow," Third International Heat Pipe Conference, Palo Alto, CA., May 1978.

4. C. A. Busse, "Theory of the Ultimate Heat Transfer Limit of Cylindrical Heat Pipes," Int. J of Heat Mass Transfer V 16, pp 163-186, 1973.

5. R. M. Olson and E. R. G. Eckert, "Experimental Studies of Turbulent Flow in a Porous Circular Tube with Uniform Fluid Injection Through the Tube Wall," J. of Appl. Mech., March, 1966.

6. H. Lamb, Hydrodynamics, Dover Press Publications, Art. 268.

7. G. B. Wallis, One Dimensional Two-Phase Flow, McGraw-Hill Co. 1969.

8. C. L. Tien and K. S. Chung, "Entrainment Limits in Heat Pipes," Third International Heat Pipe Conference, Palo Alto, CA, May 1978.

TABLE I

INPUT VARIABLES FOR HEAT PIPE PROGRAM

Variable Number	Definition
1	Vapor temperature at evaporator exit (K)
2	Heat transfer rate of heat pipe (W)
3	Evaporator length (cm)
4	Adiabatic length (cm)
5	Condenser length (cm)
6	Velocity profile correction factor, 1.234 for laminar, 2.2 for turbulent
7	Elevation angle of heat pipe, positive for evaporator down (degrees)
8	Pipe inside wall radius (cm)
9	Distribution screen thickness (cm); porosity if ARTG = 4
10	Wall friction factor if ARTG = 0
	Artery screen thickness (cm) if ARTG = 1
	Thickness between arteries (cm) if ARTG = 2
	Gutter wall thickness (cm) if ARTG = 3
	Screen tortuosity if ARTG = 4
11	Not used if ARTG = 0
	Artery radius (cm) if ARTG = 1
	Groove depth (cm) if ARTG = 2
	Gutter width (cm) if ARTG = 3
	Wick thickness (cm) if ARTG = 4
12	1/2 peak-to-peak spacing of wall roughness (cm) if ARTG = 0
	Effective pore radius for maintaining ΔP at liquid-vapor interface (cm) if ARTG = 1, 2 or 4
	Gutter height (cm) if ARTG = 3
13	Number of arteries operating satisfactorily (must be $\geq$ 1)
14	Number of arteries not operating satisfactorily

15 Artery geometry (ARTG): 0 for wickless pipe, 1 for circular arteries, 2 for groove-wall, 3 for helical gutter, 4 for homogeneous wick

16 Number of turns of helical gutter (used only if ARTG = 3)

17 Working fluid; 1 for lithium, 2 for sodium, 3 for potassium, 4 for mercury, 5 for water

18 Flag for laminar or turbulent flow
1 for laminar vapor and liquid flow
2 for turbulent vapor and laminar liquid flow
3 for laminar vapor and turbulent liquid flow
4 for turbulent vapor and turbulent liquid flow

22 Option number
1 to optimize number of liquid flow passages (for ARTG = 1 or 2 only)
2 to calculate performance limits vs evaporator exit temperature
4 to optimize artery dimension
3 to calculate temperature and pressure profiles

23 Wire diameter for screen wick (cm)

24 Screen mesh (for ARTG = 4 only)

	Option Number			
	1	2	3	4
19	Fewest arteries considered	Lowest evaporator exit temperature (K)	Increments in evaporator	Smallest artery dimension (cm)
20	Most arteries considered	Highest evaporator exit temperature (K)	Increments in adiabatic section	Largest artery dimension (cm)
21	Increment	Increment (K)	Increments in condenser	Increment (cm)

TABLE II

OUTPUT PARAMETERS FOR OPTION 1

(OPTIMIZE NUMBER OF LIQUID FLOW PASSAGES)

Variable	Definition
NA	Number of arteries
XA	Artery dimension (cm)
DPL	Liquid pressure drop (d/cm^2)
DPZ	Hydrostatic pressure drop (d/cm^2)
DPV	Vapor pressure drop, laminar (d/cm^2)
DPI	Inertial pressure drop (d/cm^2)
DPT	Vapor pressure drop, turbulent (d/cm^2)
DPE	Pressure drop in evaporator (d/cm^2)
DPA	Pressure drop in adiabatic section (d/cm^2)
DPC	Pressure drop in condenser (d/cm^2)
DPCAP	Maximum pressure difference from capillary force (d/cm^2)
TBE	Temperature at beginning of evaporator (K)
REFF	Effective capillary pore radius (cm)
AV	Area of vapor passage (cm^2)

TABLE III
OUTPUT PARAMETERS FOR OPTION 2
(PERFORMANCE LIMITS VERSUS EVAPORATOR EXIT TEMPERATURE)

Variable	Definition
TEE	Evaporator exit temperature (K)
Liquid	Liquid pressure drop (d/cm^2)
Vapor (L)	Vapor pressure drop, laminar (d/cm^2)
Inertial	Inertial pressure drop (d/cm^2)
Hydrostatic	Hydrostatic pressure drop (d/cm^2)
Vapor (T)	Vapor pressure drop, turbulent (d/cm^2)
Capillary	Maximum pressure difference from capillary force (d/cm^2)
Evaporator	Pressure drop in evaporator (d/cm^2)
Adiabatic	Pressure drop in adiabatic section (d/cm^2)
Condenser	Pressure drop in condenser (d/cm^2)
TBE	Temperature at beginning of evaporator (K)
TBC	Temperature at beginning of condenser (K)
TBESON	Temperature at beginning of evaporator at sonic limit (K)
TBCSON	Temperature at beginning of condenser at sonic limit (K)
Power	Capillary limit (w)
QSONIC	Sonic limit (w)
QENTRN	Entrainment limit (w)

TABLE IV

OUTPUT PARAMETERS FOR OPTION 3 (TEMPERATURE AND PRESSURE PROFILES)

Variable	Definition
Dist	Axial location along heat pipe (cm)
Power	Local transport power (w)
Temp	Local vapor temperature (K)
Press	Local vapor pressure (d/cm^2)
DPL	Liquid pressure drop from X = 0 to X = DIST (d/cm^2)
DPZ	Hydrostatic pressure drop from X = 0 to X = DIST (d/cm^2)
DPV	Vapor pressure drop from X = 0 to X = DIST, laminar (d/cm^2)
DPI	Inertial pressure drop from X = 0 to X = DIST (d/cm^2)
DPT	Vapor pressure drop from X = 0 to X = DIST, turbulent (d/cm^2)
DPE	Pressure drop in evaporator (d/cm^2)
DPA	Pressure drop in adiabatic section (d/cm^2)
DPC	Pressure drop in condenser (d/cm^2)
AV	Vapor flow area (cm^2)
TBE	Temperature at beginning of evaporator (K)
QSONIC	Sonic limit (w)

TABLE V

OUTPUT PARAMETERS FOR OPTION 4

(OPTIMIZE ARTERY CHARACTERISTIC DIMENSION)

Variable	Definition
X	Artery dimension (cm)
Power	Capillary limit (w)
DPL	Liquid pressure drop (d/cm^2)
DPZ	Hydrostatic pressure drop (d/cm^2)
DPV	Vapor pressure drop, laminar (d/cm^2)
DPI	Inertial pressure drop (d/cm^2)
DPT	Vapor pressure drop, turbulent (d/cm^2)
DPE	Pressure drop in evaporator (d/cm^2)
DPA	Pressure drop in adiabatic section (d/cm^2)
DPC	Pressure drop in condenser (d/cm^2)
AV	Vapor flow area (cm^2)
TBE	Temperature at beginning of evaporator (K)
QSONIC	Sonic limit (w)

APPENDIX

The following includes a sample input file, output file, and plots for options 2, 3, and 4. Also included is a listing of the program. LASL Identification No. LP-1018.

```
rewind,lgo,samp2,htpipe
$REWIND,LGO,SAMP2,HTPIPE.
/list,fn=samp2
SEPS RADIATOR HEAT PIPE (STRINGER)                                   1
     7.7500000000E+02   12.5000000000E+03   35.0000000000E+00    0.0000000000E+00
   450.0000000000E+00    1.2340000000E+00    0.0000000000E+00    1.8500000000E+00
     0.0304800000E+00    0.0304800000E+00    0.1250000000E+00    0.0025000000E+00
     3.0000000000E+00    0.0000000000E+00    1.0000000000E+00    0.0000000000E+00
     3.0000000000E+00    0.0000000000E+00  500.0000000000E+00  900.0000000000E+00
    50.0000000000E+00    2.0000000000E+00    0.0050800000E+00  150.0000000000E+00
0.0
960,3,0,1
 EOI ENCOUNTERED.
/
```

```
ftn (i=htpipe,l=l)
    20.744 CP SECONDS COMPILATION TIME
/attach(disftn/un=library)
/x,library(disftn)
LIBRARY(DISFTN)
/lgo(samp2)
```

```
..... DISSPLA VERSION 7.2 .....
NO. OF FIRST PLOT  0

ENTER LINE SPEED (CPS), TERM TYPE, ERASE, FAST PLOT
```

SEPS RADIATOR HEAT PIPE (STRINGER)

HEAT PIPE ANALYSIS: POWER VS TEE

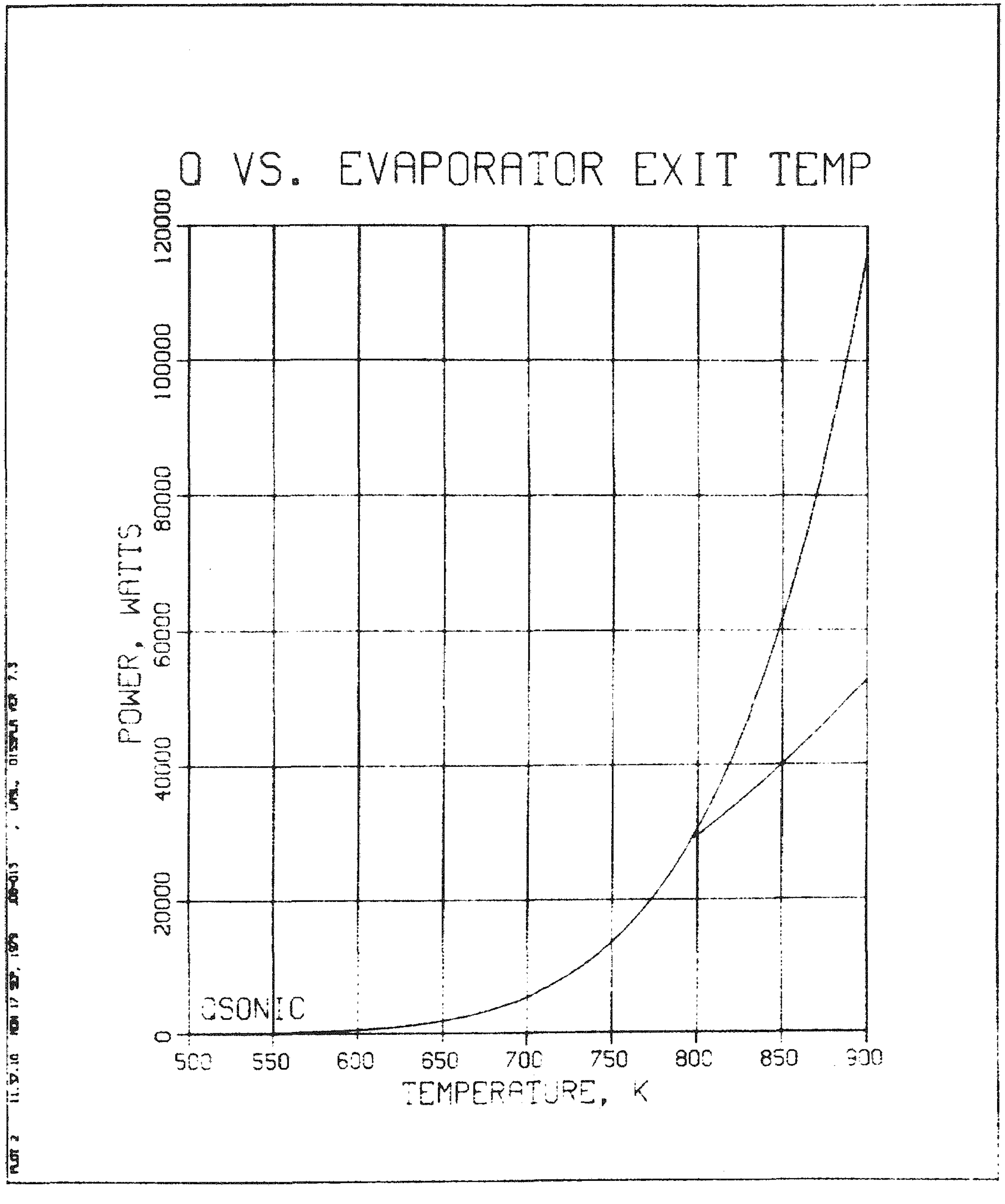
```
NO. OF ARTERIES OPERATING=    3
ARTERY DIMENSION          =     .12500E+00
ARTERY PUMPING RADIUS     =     .25000E-02
ARTERY GEOMETRY           =    1   CIRCULAR
NO. OF ART. NOT OPERATING=    0
ARTERY SCREEN THICKNESS   =     .30480E-01
DISTRIB. SCREEN THICKNESS=     .30480E-01
EVAPORATOR LENGTH         =     .35000E+02
ADIABATIC LENGTH          =    0.
CONDENSER LENGTH          =     .45000E+03
ANGLE FROM HORIZONTAL     =    0.
PIPE INSIDE RADIUS        =     .18500E+01
WORKING FLUID NO.         =    3   K
A-RATIO(LAMIN OR TURB)    =     .12340E+01
PIPE EFFECTIVE LENGTH     =     .24250E+03
VAPOR PASSAGE AREA        =     .10173E+02
TOTAL LIQUID FLOW AREA    =     .14726E+00
```

TEE / POWER	LIQUID / HYDROSTATIC (PRESSURE DROPS)	VAPOR(L) / VAPOR(T) (PRESSURE DROPS)	INERTIAL / CAPILLARY (PRESSURE DROPS)	EVAPORATOR / ADIABATIC / CONDENSER (PRESSURE DROPS)	TBE / TBESON (TEMPERATURE)	TBC / TBCSON (TEMPERATURE)	QSONIC / QENTRN (LIMITS)
500.	1051.	62201.	78435.	82924.	819.	500.	20.
-965.	0.	0.	83000.	0.	519.	500.	974.
				-51647.			
550.	2322.	28477.	78197.	80252.	817.	550.	120.
-2287.	0.	0.	80420.	0.	573.	550.	2274.
				-37523.			
600.	4448.	14870.	76446.	77519.	815.	600.	530.
-4621.	0.	0.	77840.	0.	627.	600.	4572.
				-49237.			
650.	7656.	8611.	74086.	74707.	815.	650.	1855.
-8289.	0.	0.	75260.	0.	682.	650.	8192.
				-53525.			
700.	12134.	5409.	71414.	71804.	818.	700.	5410.
-13656.	0.	0.	72680.	0.	737.	700.	13410.
				-54631.			
750.	18001.	3624.	68539.	68801.	828.	750.	13627.
-20697.	0.	0.	70100.	0.	793.	750.	20425.
				-54179.			
800.	25310.	2557.	65509.	65694.	848.	800.	30480.
29474.	0.	0.	67520.	0.	849.	800.	29341.
				-52871.			
850.	34038.	1881.	62348.	62484.	878.	850.	61837.
40136.	0.	0.	64940.	0.	905.	850.	40165.
				-51038.			
900.	44098.	1432.	59074.	59178.	917.	900.	115660.
52419.	0.	0.	62360.	0.	962.	900.	52810.
				-48858.			

1

PLOTTING COMMENCING

....


Q VS. EVAPORATOR EXIT TEMP
POWER, WATTS
0
20000
40000
60000
80000
100000
120000
QSONIC
500
550
600
650
700
750
800
850
900
TEMPERATURE, K

```
list,in=samp3
SEPS RADIATOR HEAT PIPE (STRINGER)                                   1
     7.7500000000E+02   12.5000000000E+03   35.0000000000E+00    0.0000000000E+00
   450.0000000000E+00    1.2340000000E+00    0.0000000000E+00    1.8500000000E+00
     0.0304800000E+00    0.0304800000E+00    0.1250000000E+00    0.0025000000E+00
     3.0000000000E+00    0.0000000000E+00    1.0000000000E+00    0.0000000000E+00
     3.0000000000E+00    0.0000000000E+00    7.0000000000E+00    0.0000000000E+00
     9.0000000000E+00    3.0000000000E+00    0.0050800000E+00  150.0000000000E+00
0.0
960,3,0,1
 EOI ENCOUNTERED.
```

```
†n ‘i=htpipe,l=l)
    20.964 CP SECONDS COMPILATION TIME
 attach(disftn/un=library)
 (.library(disftn)
LIBRARY(DISFTN)
 lgo(samp3)
```

SEPS RADIATOR HEAT PIPE (STRINGER)

HEAT PIPE ANALYSIS: TEMP VS LEN

EVAPORATOR EXIT TEMP	=	.77500E+03
POWER	=	.12500E+05
NO. OF ARTERIES OPERATING	=	3
ARTERY DIMENSION	=	.12500E+00
ARTERY PUMPING RADIUS	=	.25000E-02
ARTERY GEOMETRY	=	1 CIRCULAR
NO. OF ART. NOT OPERATING	=	0
ARTERY SCREEN THICKNESS	=	.30480E-01
DISTRIB. SCREEN THICKNESS	=	.30480E-01
EVAPORATOR LENGTH	=	.35000E+02
ADIABATIC LENGTH	=	0.
CONDENSER LENGTH	=	.45000E+03
ANGLE FROM HORIZONTAL	=	0.
PIPE INSIDE RADIUS	=	.18500E+01
WORKING FLUID NO.	=	3 K
A-RATIO(LAMIN OR TURB)	=	.12340E+01
PIPE EFFECTIVE LENGTH	=	.24250E+03
VAPOR PASSAGE AREA	=	.10173E+02
TOTAL LIQUID FLOW AREA	=	.14726E+00

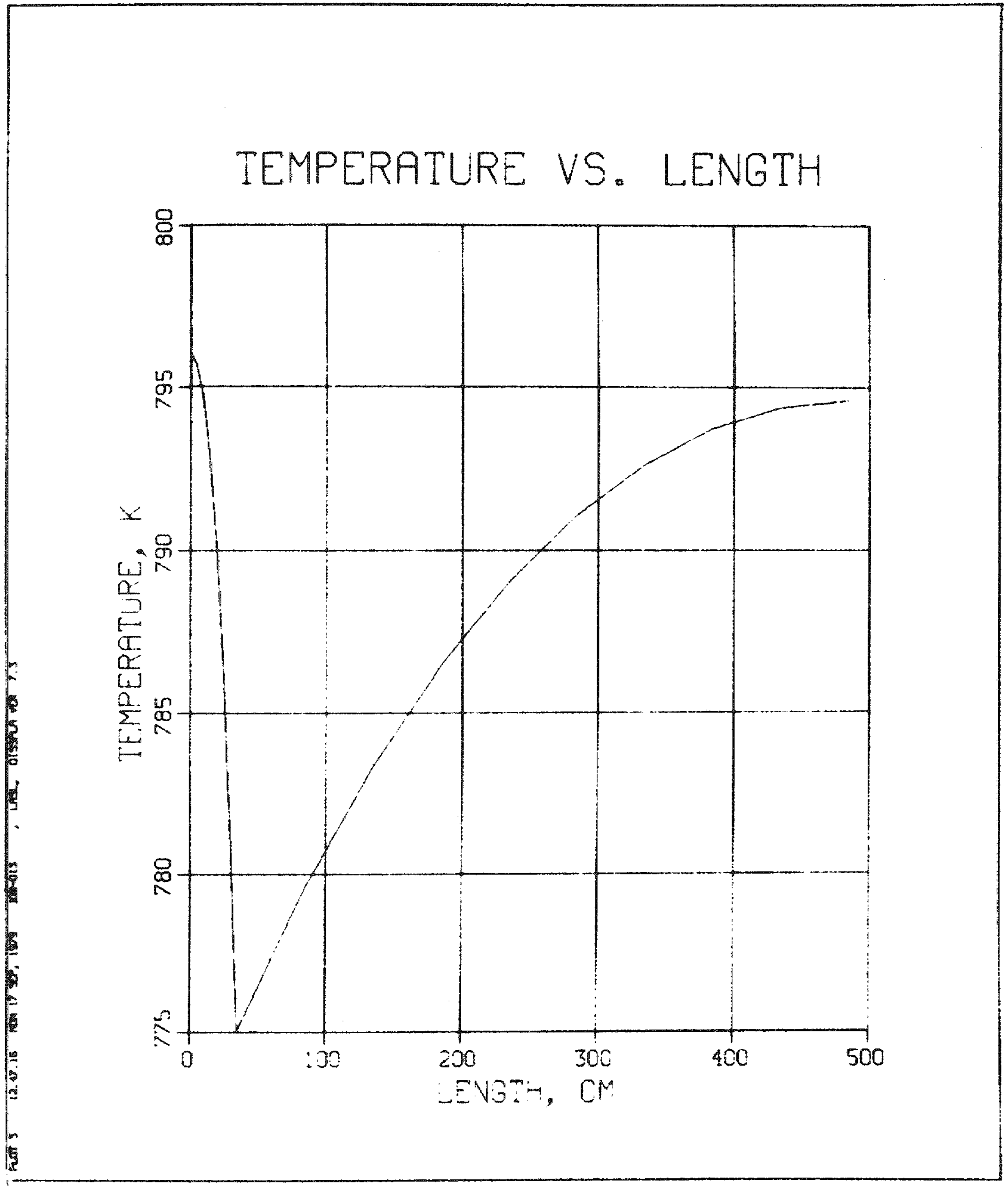
DIST.	POWER	TEMP	PRESS	DPL	PZ	DPV	DPI	DPT	DPA
0.00	12500.	796.1	58160.	10821.	0.	1525.	17023.	0.	0.
5.00	1786.	795.7	57811.	16.	0.	2.	347.	0.	0.
10.00	3571.	794.6	56763.	47.	0.	5.	1042.	0.	0.
15.00	5357.	792.6	55018.	79.	0.	9.	1737.	0.	0.
20.00	7143.	789.8	52574.	111.	0.	12.	2432.	0.	0.
25.00	8929.	786.1	49430.	143.	0.	16.	3127.	0.	0.
30.00	10714.	781.2	45588.	175.	0.	21.	3822.	0.	0.
35.00	12500.	775.0	41045.	207.	0.	27.	4516.	0.	0.
85.00	11111.	779.6	44320.	2107.	0.	297.	-3573.	0.	0.
135.00	9722.	783.4	47227.	1856.	0.	246.	-3152.	0.	0.
185.00	8333.	786.5	49757.	1607.	0.	202.	-2732.	0.	0.
235.00	6944.	789.1	51905.	1358.	0.	164.	-2312.	0.	0.
285.00	5556.	791.1	53667.	1110.	0.	129.	-1891.	0.	0.
335.00	4167.	792.7	55040.	863.	0.	98.	-1471.	0.	0.
385.00	2778.	793.7	56023.	616.	0.	68.	-1051.	0.	0.
435.00	1389.	794.4	56613.	370.	0.	40.	-630.	0.	0.
485.00	0.	794.6	56809.	123.	0.	13.	-210.	0.	0.

1

PLOTTING COMMENCING
....

..... DISSPLA VERSION 7.2 .....
NO. OF FIRST PLOT 0

ENTER LINE SPEED (CPS), TERM TYPE, ERASE, FAST PLOT


TEMPERATURE VS. LENGTH
TEMPERATURE, K
LENGTH, CM
800
795
790
785
780
775
0
100
200
300
400
500

```
list.fn=samp4
SEPS RADIATOR HEAT PIPE (STRINGER)                                        1
    7.7500000000E+02   12.5000000000E+03   35.0000000000E+00    0.0000000000E+00
  450.0000000000E+00    1.2340000000E+00    3.0000000000E+00    1.8500000000E+00
    0.0304800000E+00    0.0304800000E+00    0.1250000000E+00    0.0025000000E+00
    3.0000000000E+00    0.0000000000E+00    1.0000000000E+00    0.0000000000E+00
    3.0000000000E+00    0.0000000000E+00    0.0500000000E+00    0.1500000000E+00
    0.0100000000E+00    4.0000000000E+00    0.0050800000E+00  150.0000000000E+00
0.0
960,3,0,1
 EOI ENCOUNTERED.
 rewind,samp4
$REWIND,SAMP4.
```

```
ftn (i=htpipe,l=l)
    20.674 CP SECONDS COMPILATION TIME
/attach(disftn/un=library)
/x,library(disftn)
LIBRARY(DISFTN)
/lgo(samp4)
```

SEPS RADIATOR HEAT PIPE (STRINGER)

HEAT PIPE ANALYSIS: OPTIMIZE X

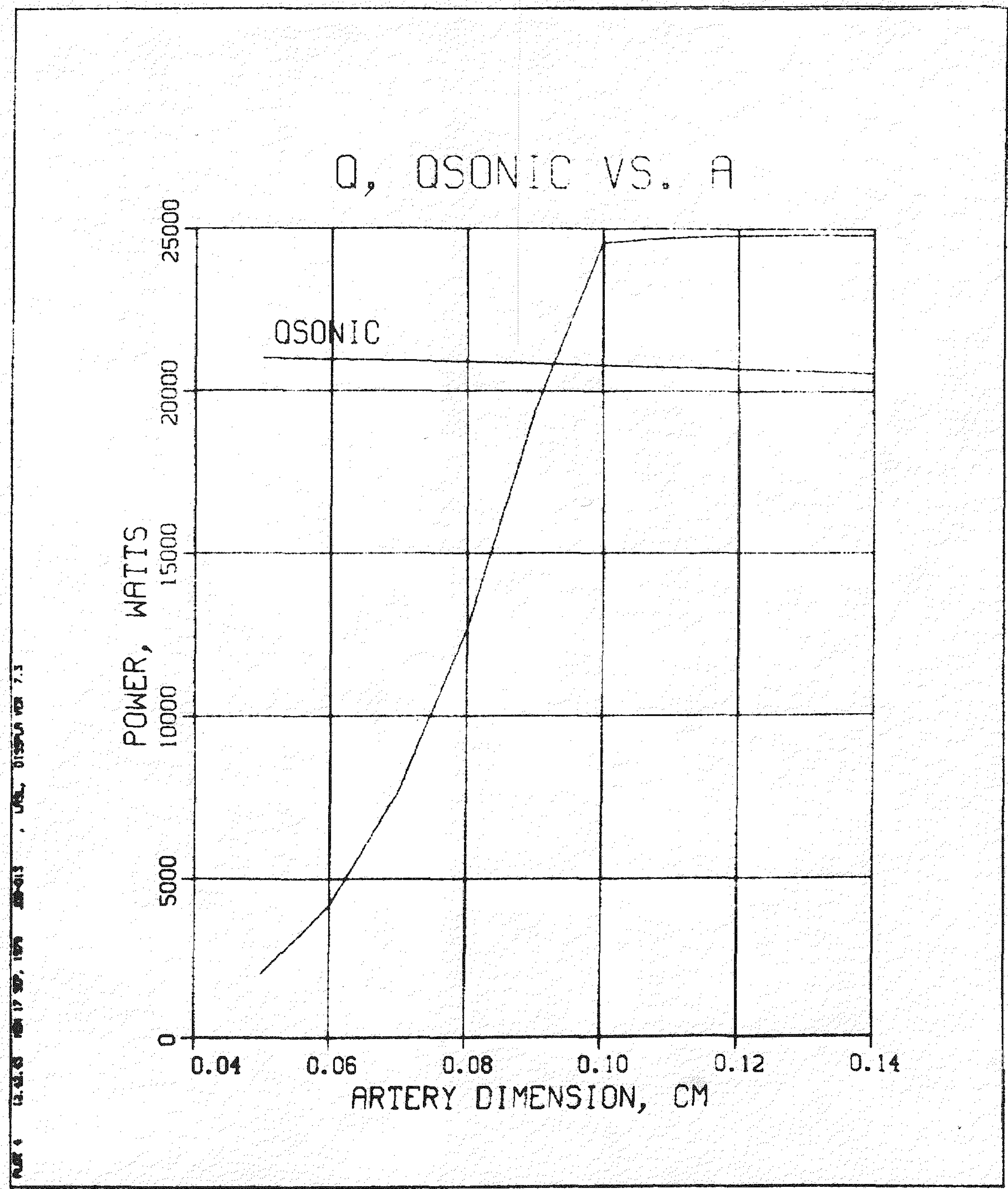
EVAPORATOR EXIT TEMP	=	.77500E+03
NO. OF ARTERIES	=	3
REFF	=	.25000E-02
ARTERY GEOMETRY	=	1 CIRCULAR
NO. OF ART. NOT OPERATING	=	0
ARTERY SCREEN THICKNESS	=	.30480E-01
DISTRIB. SCREEN THICKNESS	=	.30480E-01
EVAPORATOR LENGTH	=	.35000E+02
ADIABATIC LENGTH	=	0.
CONDENSER LENGTH	=	.45000E+03
ANGLE FROM HORIZONTAL	=	0.
PIPE INSIDE RADIUS	=	.18500E+01
WORKING FLUID NO.	=	3 K
A-RATIO(LAMIN OR TURB)	=	.12340E+01
PIPE EFFECTIVE LENGTH	=	.24250E+03
PRESSURE	=	.41027E+05
VAPOR DENSITY	=	.24896E-04
LIQUID DENSITY	=	.72223E+00
VAPOR VISCOSITY	=	.10815E-03
LIQUID VISCOSITY	=	.15549E-02
HEAT OF VAPORIZATION	=	.20967E+04
SURFACE TENSION	=	.86013E+02

X	POWER	DPL	DPZ	DPV	DPI	DPT	DPE	DPA	DPC	AV	TBE	QSONIC
.0500	2026.	68527.	0.	233.	433.	0.	450.	0.	-167.	10.34	776.	20993.
.0600	4178.	68129.	0.	495.	1846.	0.	1882.	0.	-1202.	10.32	778.	20961.
.0700	7643.	67278.	0.	909.	6201.	0.	6267.	0.	-4735.	10.31	783.	20924.
.0800	12706.	65564.	0.	1517.	17206.	0.	17315.	0.	-14070.	10.29	796.	20884.
.0900	19385.	62445.	0.	2324.	40216.	0.	40384.	0.	-34019.	10.26	817.	20840.
.1000	24559.	51907.	0.	2957.	64851.	0.	65064.	0.	-55590.	10.24	835.	20792.
.1100	24718.	35682.	0.	2991.	66013.	0.	66235.	0.	-56610.	10.21	836.	20740.
.1200	24791.	25268.	0.	3016.	66763.	0.	66987.	0.	-57261.	10.19	836.	20684.
.1300	24811.	18361.	0.	3036.	67266.	0.	67485.	0.	-57689.	10.16	837.	20624.
.1400	24798.	13643.	0.	3053.	67605.	0.	67825.	0.	-57979.	10.13	837.	20561.

```
1
                    PLOTTING COMMENCING
                    ...................

 ..... DISSPLA VERSION 7.2 .....
 NO. OF FIRST PLOT  0

ENTER LINE SPEED (CP
```


Q, QSONIC VS. A
QSONIC
POWER, WATTS
0
5000
10000
15000
20000
25000
0.04
0.06
0.08
0.10
0.12
0.14
ARTERY DIMENSION, CM

```
p*
      PROGRAM HPQ3(INPUT,OUTPUT,DUMMY,TAPE30=INPUT,TAPE15=OUTPUT,
     *TAPE59=DUMMY,TEKIN=/1030,TEKOUT=/20480)
C       INPUT FILENAME IS SAMP
      REAL LE,LA,LC,LEFFV,LEFFL,LT,LTOT,MUV,MUL,MW
      INTEGER ARTG,PLT
      DIMENSION H(6),C(30),D(30),RNC(30),XP(50),YP(50),Y1P(50),
     1Y2P(50)
      DIMENSION NFLUID(10),NARTG(5,2),NCALCS(8),NSON(2),NOARTG(2)
      EQUIVALENCE (C(1),TEE),(C(2),QTOTAL),(C(3),LE)
     1,(C(4),LA),(C(5),LC),(C(6),AR),(C(7),THETA),(C(8),RO)
     2,(C(9),TSD,PORO),(C(10),TSA,TBAX,TWG,TORT),(C(11),A),(C(12),GH)
      DATA PI,GRAV,EXPC,RBAR/3.1416,980.,2.3026,8.314E7/
      DATA (NFLUID(I),I=1,5)/2HLI,2HNA,2HK ,2HHG,5HWATER/
      DATA (NOARTG(I),I=1,2)/6HWICKLE,6HSS    /
      DATA (NARTG(1,I),I=1,2)/6HCIRCUL,6HAR    /
      DATA (NARTG(2,I),I=1,2)/6HGROOVE,6H WALL /
      DATA (NARTG(3,I),I=1,2)/6HHELIC ,6HGUTTER/
      DATA (NARTG(4,I),I=1,2)/6HHOMOGE,6HNEOUS /
      DATA (NCALCS(I),I=1,2)/6HDESIGN,6H      /
      DATA (NCALCS(I),I=3,4)/6HPOWER ,6HVS TEE/
      DATA (NCALCS(I),I=5,6)/6HTEMP V,6HS LEN /
      DATA (NCALCS(I),I=7,8)/6HOPTIMI,6HZE X  /
      DATA NSON(1),NSON(2)/5H     ,5HSONIC/
      DATA (H(I),I=1,3)/10HHHHHHHHHHH,10HHHHHHHHHHH,10HHHHHHHHHHH/
      DATA (H(I),I=4,6)/10HHHHHHHHHHH,10HHHHHHHHHHH,10HHHHHHHHHHH/
      PRESSR(RMACH,RK) = SQRT((RK+1.)/2./(1.+(RK-1.)/2.*RMACH**2))/RMACH
      FLMAX(RMACH,RK) = (1.-RMACH**2)/RK/RMACH**2 +
     * (RK+1.)/2./RK*ALOG((RK+1.)*RMACH**2/2./(1.+(RK-1.)/2.*RMACH**2))
C       READ INPUT DATA
      DO 9273 I=1,30
      C(I)=0
 9273 CONTINUE
      READ(30,5010)(H(I),I=1,6),NPLOT,(C(I),I=1,24)
C
C
  100 REFF=GH
      NA=C(13)
      IF(ARTG.EQ.4)NA=1
      NANO=C(14)
      ARTG=C(15)
      NT=C(16)
      IFLUID=C(17)
      PLT=C(18)
      DCO=C(19)
      DO1=C(20)
      DDO=C(21)
      ITV=C(22)
      WS = C(23)
      RMESH = C(24)
      IT3=0
      FCONV=.00001
      IBACK = 0
      IF(ARTG-3)110,105,110
  105 REFF=A
C-----IF(C(23).GT.0)REFF=C(23)
      IF(ITV.NE.3)PLT=0
  110 IF(DDO.LT.0)DDO=1
      DOOP=DOO
      DO1P=DO1
      DDOP=DDO
      Q=QTOTAL
      T2=TEE
      T=TEE
      TBA=TBAX
      GWMAX=RO-TSD-TWG
      X6=1.
      Y6=1.
      I7=C(19)+C(20)+C(21)+1
      LTOT=LE+LA+LC
```

```
C
C-----GO TO 3100 TO PRINT HEADING ! INPUT DATA
      GO TO 3100
C
C-----INITIALIZE GEOMETRIC DATA
  120 LEFFL=LA+(LE+LC)/2
      LEFFV=LEFFL-LA
      LT=4./11.*(LE+LC)
      WRITE(59,5200)LEFFL
      WRITE(15,5200)LEFFL
      DPV=0.
      DPI=0.
      DPT=0.
      I=0
      GO TO (135,3200,3200,3300),ITV
  135 A=RO/(NA+10)
      GO TO 3300
C-----PRINT FLUID PROPERTIES ! HEADING
  140 WRITE(15,5250)PV,RHOV,RHOL,MUV,MUL,HFG,SIG
C-----WRITE(59,5250)PV,RHOV,RHOL,MUV,MUL,HFG,SIG
      GO TO (145,150,150,189),ITV
  145 WRITE(59,5210)
      WRITE(15,5211)
      GO TO 190
  150 WRITE(59,5303)AV,AL*NA
      WRITE(15,5303)AV,AL*NA
      GO TO (190,160,170,189),ITV
  160 WRITE(15,5215)
      WRITE(15,5216)
      WRITE(15,5217)
      WRITE(15,5218)
C-----INITIALIZE POWER DATA FOR CALCULATING WICK LIMIT
      QTOTAL=5000*(AV+AL*NA)
      GO TO 190
  170 WRITE(59,5230)
      WRITE(15,5231)
      DOO=1
      DDO=1
  185 IT3=IT3+1
      DO1=C(IT3+17)
      IF(IT3.EQ.1)DO1=1
      IF(DO1.LT.1)GO TO 1205
      GO TO 190
  189 WRITE(59,5240)
      WRITE(15,5241)
C-----CHOOSE INDEPENDENT VARIABLE
  190 RDOMAX=1.+(DO1-DOO)/DDO
      IDOMAX=RDOMAX
      DO 1200 IDOV1=1,IDOMAX
      RDOV=DOO+(IDOV1-1)*DDO
      IDOV=RDOV
      RDO1=DO1
      I=I+1
      IT1=0
      GO TO (200,210,220,232),ITV
  200 NA=IDOV
      GO TO 235
  210 T=IDOV
      GO TO 235
  220 T=T2
      GO TO (235,224,226,228),IT3
  224 XL=LE*RDOV/RDO1
      DX=LE/RDO1
      DXI=(RDOV*RDOV-(RDOV-1)**2)/(RDO1*RDO1)
      DXA = 0.0
      Q1 = QTOTAL*XL/LE
      Q = QTOTAL*(RDOV-.5)/RDO1
      GO TO 230
```

```
  226 XL=LE+LA*RDOV/RDO1
      DX = LA/RDO1
      DXA =LA/RDO1
      DXI = 0.0
      Q = QTOTAL
      Q1 = QTOTAL
      GO TO 230
  228 XL=LE+LA+LC*RDOV/RDO1
      DX=LC/RDO1
      DXI=((RDO1-RDOV)**2-(RDO1+1-RDOV)**2)/(RDO1*RDO1)
      DXA = 0.0
      Q = QTOTAL*(1.-(RDOV-0.5)/RDO1)
      Q1 = QTOTAL*(1.0-RDOV/RDO1)
  230 DXV=DX
      IF(IT3.EQ.3)  DXV = 0.0
      DXT=DX
      IF(IT3.EQ.3)  DXT = 0.0
      DXL=DX
      DXZ=DX
      GO TO 239
  232 A=RDOV
C-----IF(C(23).EQ.0)REFF=A
  235 XL=LE
      DXV=LEFFV
      DXI=LEFFV
      DXT=LT
      DXL=LEFFL
      DXZ=LTOT
      DXA = LA
      Q=QTOTAL
      IF(ITV.NE.1)GO TO 239
  238 A1=A
  239 DO 845 IT4=1,2
      IF(ITV.NE.1) GO TO 240
      A=(.97+.02*IT4)*A1
  240 GO TO (270,330,330,270),ITV
C
C-----GO TO 3200 FOR WICK CHARACTERISTICS
  270 GO TO 3200
C
C
C-----GO TO 3300 FOR FLUID PROPERTIES
  330 GO TO 3300
C
C-----START ITERATION ON Q
  390 QHFG=Q/HFG
      IT1=IT1+1
C     CALCULATE LIQUID LAYER THICKNESS FOR WICKLESS PIPE
      IF(ARTG.NE.0)  GO TO 395
      DPL = 0
      REYGAM = 2.0*QHFG/(PI*MUL*RO)
      TORT = 16.0/REYGAM
      IF(REYGAM.GT.1000.0)  TORT = .079/REYGAM**0.25
      DELSTR = 0.315*(REYGAM*TORT**.5)**.667
      DEL = DELSTR * MUL **.667/(GRAV*(RHOL-RHOV)*RHOL)**.333
      AL = PI*(RO**2-(RO-DEL)**2)
      AV = PI*(RO-DEL)**2
      RH = DEL
      RV = RO-DEL
      CIRC = 2.0*PI*RV
      GO TO 400
C-----CALCULATE PRESSURE CHANGES
  395 REYNL=2*RH*QHFG/(MUL*AL*NA)
      IF(PLT.GE.2)FRE=.079*REYNL**.75
      DPL=FRE/2*MUL*QHFG*DXL/(NA*RHOL*AL*RH*RH)
  400 DPV=PI*8*DXV/(AV*AV)*MUV*QHFG/RHOV
      IF(PLT.EQ.1.OR.PLT.EQ.3)DPV=0
  500 GO TO (510,510,520,510),ITV
  510 DPI=(QHFG/AV)**2*AR/RHOV
      GO TO 600
```

```
  520 IF(I-2)510,530,530
  530 DPI=DPI1*DXI
  600 DPT=.028*(CIRC**5*MUV*QHFG**7)**.25*DXT/(AV**3*RHOV)*PLT
      IF(PLT.EQ.0.OR.PLT.EQ.2)DPT=0
  700 DPZ=DXZ*RHOL*GRAV*SIN(THETA*PI/180.)
      DPCAP = 0.0
      IF (ITV.NE.1.AND.REFF.NE.0.0) DPCAP=2.*SIG/REFF
      IF(ARTG.EQ.0)  DPCAP = 0
      DPE=DPI+DPV*LE/(2*LEFFV)+DPT*4./11.*LE/LT
C     EVALUATE PRESS DROP IN ADIABATIC SECTION (COMPRESSIBLE FLOW)
C     COMPUTE MACH NUMBER AT EVAPORATOR EXIT
      RM1 = QHFG/AV/RHOV/SQRT(REAR*T/MW)
      IF(LA.EQ.0.0) GO TO 770
C     EVALUATE FRICTION FACTOR
      REY = 4.0*QHFG/PI/2./RV/MUV
      F = 16.0/REY
      IF(REY.GT.2300.) F = 0.079/REY**.25
      IF(REY.GT.20000.)  F = 0.046/REY**.2
      IF(PLT.EQ.0.OR.PLT.EQ.2)  F = 16.0/REY
      FL2 = FLMAX(RM1,RK) - 4.0*F*DXA/2./RV
C     CHECK TO SEE IF FL2 LT 0, IF SO FLOW AT EXIT IS SONIC
      IFLAG = 0
      IF(FL2.GT.0.0001) GO TO 750
      IFLAG = 1
      RM2 = 1.0
      GO TO 760
  750 CALL FMAX(FL2,RK,RM2,RM1)
  760 CONTINUE
C     EVALUATE PRESSURE RATIO
      PR = PRESSR(RM1,RK)/PRESSR(RM2,RK)
      IF(PR.GT.2.08)  PR = 2.08
C     EVALUATE PRESSURE AT ADIABATIC SECTION OUTLET
      PA2 = PV/PR
      CALL TSAT(IFLUID,PA2,TEC)
      DPA = PV - PA2
      GO TO 780
  770 DPA = 0.0
      TEC = T
      RM2 = RM1
  780 DPIC = RHOV*1.11*RM2**2*REAR*TEE/MW
      DPC = -DPIC + DPV*LC/(2.0*LEFFV) + DPT*4./11.*LC/LT
      GO TO (790,790,1050,790),ITV
  790 IF(ARTG.EQ.0)  GO TO 800
      GO TO (800,800,900,800),ARTG
C     CHECK FOR GRAVITY ASSIST
  800 IGRAV = 0
      IF(IBACK.GT.0)  GO TO 805
      IF(DPZ.GT.0.0)  IGRAV = 1
      IF(DPZ) 805,805,812
  805 DPLC=DPL*LC/(2*LEFFL)-DPZ*LC/LTOT
C     LOCATE WET POINT
      DPLVC=DPC+DPLC
      IF(DPLVC)810,820,820
  810 DPCAPL=DPE+DPA+DPL-DPLC-DPZ
      JFLAG = 2
      ZC = 0
      GO TO 830
C     GRAVITY ASSIST MODE, CHECK LIQ AND VAP PRESS GRADS IN ADIABATIC SEC
  812 DPLA = DPL*LA/LEFFL - DPZ*LA/LTOT
      IF(DPA.GT.-DPLA)  GO TO 818
C     WET POINT AT EVAPORATOR EXIT
      JFLAG = 3
C    DETERMINE CRITICAL POINT, ZC [D(DELTA P)/DZ=0]
  815 ZC = RHOL*RHOV*GRAV/AR/2.0*(AV*LE/QHFG)**2
      DPLEV = DPL*LE/2./LEFFL
      DPZE = DPZ*LE/LTOT
      DPCAPL = DPE + DPLEV - DPZE + DPZE*DPZE/4.0/(DPE+DPLEV)
      GO TO 830
```

```
C       WET POINT AT CONDENSER INLET
  818 JFLAG = 4
      GO TO 815
  820 DPCAPL=DPL+DPE+DPA+DPC-DPZ
      JFLAG = 1
      ZC = 0
  830 CONTINUE
C     WRITE(15,5001) JFLAG,DPCAPL,ZC
 5001 FORMAT(10X,*JFLAG = *,I2,2X,*DPCAPL = *,F10.0,2X,*ZC = *,F5.1)
      GO TO (840,870,1050,900),ITV
  840 DPCAP=DPCAPL
  843 D(IT4)=DPCAP
  845 CONTINUE
      Y2=(D(2)-D(1))/(.02*A1)
      A=A1
      X2=A
      IT1=IT1-1
      GO TO 3600
C     X3=A
C     GO TO 3500
  850 A=X
      GO TO 238
  870 DP=DPCAPL-DPCAP
      Y2=DP
      X2=Q
      GO TO 3600
  880 IF(ITV.EQ.1)GO TO 850
      Q=X
      GO TO 239
  900 X2=Q
      IF(ARTG.EQ.0)  GO TO 910
      GO TO (910,910,920,910),ARTG
  910 Y2=DPCAP-DPCAPL
      GO TO 930
  920 DPZE=DPZ*LE/LTOT
      Y2=DPI+(DPV+DPL)*LE/(2*LEFFV)-.5*(DPCAP+DPZE+SQRT(DPCAP*
     1(DPCAP+2.*DPZE)))
  930 GO TO 3600
 1000 IF(DPL.GT.DPZ.AND.IGRAV.EQ.1)  GO TO 1010
      IBACK = 0
      GO TO 1015
 1010 IGRAV = 0
      IT1 = 0
      IBACK = 1
      GO TO 880
 1015 GO TO (1020,1050,1050,1050),ITV
C-----ITERATION COMPLETE, DETERMINE EFFECTIVE CAPILLARY SIZE.
 1020 IF(DPCAP)1030,1030,1040
 1030 REFF=100000.
      GO TO 1050
 1040 REFF=2*SIG/DPCAP
C-----DETERMINE TEMP OF BEGINNING OF EVAPORATOR ! SONIC TRANSFER RATE
 1050 DPTOT=DPE
      IF(ITV.NE.3.OR.IT3.EQ.1)GO TO 1060
      DPTOT=-DPV-DPI-DPT-DPA
 1060 PV2=PV+DPTOT
C
C     CALCULATE TEMPERATURE CORRESPONDING TO PV2
      CALL TSAT(IFLUID,PV2,T2)
      IF(ITV.NE.3.OR.IT3.EQ.1)  TEE = T2
C
C     COMPUTE SONIC LIMIT (MACH=1 AT OUTLET OF ADIABATIC SECTION)
      IDUM = 0
      QS = QHFG
 1065 REYS = 4.0*QS/PI/2.0/RV/MUV
      F = 16.0/REYS
      IF(REYS.GT.2300.) F = 0.079/REYS**.25
      IF(REYS.GT.20000.) F = 0.046/REYS**.20
      IF(PLT.EQ.0.OR.PLT.EQ.2)  F = 16.0/REYS
      FL1 = 4.0*F*LA/2.0/RV
```

```
C     CHECK TO SEE IF ADIABATIC SECTION PRESENT
      IF(FL1.GE.0.0001) GO TO 1070
C     SONIC LIMIT AT EVAPORATOR OUTLET
C     COMPUTE SONIC STAGNATION PRESSURE AND SONIC LIMIT
      POS = 2.08*PV
      CALL TSAT(IFLUID,POS,TBESON)
      TEE = T
      TBCSON = T
      QSONIC = .474*2.08*HFG*AV*SQRT(PV*RHOV*TEE/TBESON)
      GO TO 1089
C     DETERMINE INFLUENCE OF ADIABATIC SECTION
 1070 CALL FMAX(FL1,RK,RM1S,0.0)
C     COMPUTE VELOCITY AT EVAPORATOR EXIT
      TEE = T
      W1 = 0.986*RM1S*SQRT(RBAR*TEE/MW)
C     COMPUTE PRESSURE DROP IN EVAPORATOR
C     VISCOUS (BUSSE EQ. 4A)
      DPVS = 8.0*MUV*W1/RV**2*LE/2.0
C     INERTIA (BUSSE EQ. 4A)
      AB = 1.11
      DO 1080 I1=1,2
      DPIS = RHOV*AB*W1**2
      POS = PV + DPIS + DPVS
      POR = POS/PV
 1080 AB = 1.2117/POR**.1035
C     CALCULATE SONIC LIMIT
      IF(POS.GT.0) GO TO 1085
C     WRITE(15,5420) POS,PV,DPIS,DPVS,POR,REY,W1,RM1S
      POS = PV
 1085 CALL TSAT(IFLUID,POS,TBESON)
      QSONIC = SQRT((1.-1./POR)/POR*RHOV*PV*TEE/TBESON/AB)*POR*AV*HFG
C     CALCULATE SONIC LIMIT BASED ON PRESSURE RATIO OF 2.08 (PO/PCI)
      PCI = PV/PRESSR(RM1S,RK)
      CALL TSAT(IFLUID,PCI,TBCSON)
      RHOV2 = MW*PCI/(RBAR*TBCSON)
      POSS = PCI*2.08
      CALL TSAT(IFLUID,POSS,TBES)
      QSON = .474*2.08*HFG*AV*SQRT(PCI*RHOV2*TBCSON/TBES)
      DQ = ABS(QSONIC-QS*HFG)
 1089 IF(DQ.LE.1) GO TO 1090
      QS = QSONIC/HFG
      IDUM = IDUM + 1
      IF(IDUM.GT.20)  GO TO 1090
      GO TO 1065
 1090 CONTINUE
      IF(QSONIC-Q)1102,1102,1104
 1102 KSON=2
      GO TO 1106
 1104 KSON=1
C
 1106 IF(IFLAG.GT.0) WRITE(15,5410)
C
C     CALCULATE ENTRAINMENT LIMIT
C
      IF(ARTG.EQ.0.AND.REFF.EQ.0)  GO TO 1145
      WL = 2.0*REFF + WS
C
C     CHECK TO SEE IF ADIABATIC SECTION PRESENT
      IF(LA.EQ.0.0) GO TO 1140
      P2E = PCI
      TCIE = TBCSON
      JDUM = 0
 1110 RHOVE = MW*P2E/(RBAR*TCIE)
      W2E = SQRT(2.0*PI*SIG/WL/RHOVE)
      RM2E = W2E/SQRT(RK*RBAR/MW*TCIE)
      IF(RM2E.GT.1.0)  RM2E = 1.0
      REYE = 2.*RV*RHOVE*W2E/MUV
      F = 16.0/REYE
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      IF(REYE.GT.2300.) F = 0.079/REYE**.25
      IF(REYE.GT.20000.)  F = 0.046/REYE**.20
      IF(PLT.EQ.0.OR.PLT.EQ.2)  F = 16.0/REYE
      FL2E = 4.0*F*LA/2.0/RV
      FL1E = FL2E + FLMAX(RM2E,RK)
      CALL FMAX(FL1E,RK,RM1E,0,0)
      P2E = PV*PRESSR(RM2E,RK)/PRESSR(RM1E,RK)
      CALL TSAT(IFLUID,P2E,TCIE2)
      IF(ABS(TCIE2-TCIE).LT.1.0) GO TO 1130
      IF(JDUM.GT.30) GO TO 1120
      JDUM = JDUM + 1
C     WRITE(15,5420)RM1E,RM2E,P2E,TCIE,TCIE2,RHOVE,FL2E,REYE
      TCIE = TCIE2
      GO TO 1110
 1120 DT = ABS(TCIE2-TCIE)
      WRITE(15,5430) DT
 1130 QENTRN = SQRT(2.0*PI*RHOVE*SIG/WL)*HFG*AV
C     WRITE(15,5420)RM1E,RM2E,P2E,TCIE,TCIE2,RHOVE,FL2E,REYE
      GO TO 1150
 1140 QENTRN = SQRT(2.0*PI*RHOV*SIG/WL)*HFG*AV
      GO TO 1150
 1145 CONTINUE
      BO = 2.0*RO*SQRT(GRAV*(RHOL-RHOV)/SIG)
      BOA = 0.5*BO**.25
      CK = SQRT(3.2)*(EXP(BOA)-EXP(-BOA))/(EXP(BOA)+EXP(-BOA))
      QENTRN = CK**2*AV*HFG*(GRAV*SIG*(RHOL-RHOV))**.25/(RHOL**(-.25)
     * +RHOV**(-.25))**2
 1150 CONTINUE
      IF(ARTG.EQ.0)  WRITE(15,5303)  AV,AL
C-----GO TO 3900 TO PRINT RESULTS
      GO TO 3900
C
 1200 CONTINUE
      NP=I
 1205 IF(ITV.EQ.3.AND.IT3.NE.4)GO TO 185
C
      GO TO 9999
C
C-----PRINT HEADING AND INPUT DATA
 3100 WRITE(15,5112)(H(I),I=1,6),NCALCS(2*ITV-1),NCALCS(2*ITV)
      WRITE(59,5112)(H(I),I=1,6),NCALCS(ITV)
      GO TO (3110,3120,3110,3125),ITV
 3110 WRITE(59,5114)T,Q
      WRITE(15,5114)T,Q
      GO TO (3130,3120,3120,3125),ITV
 3120 WRITE(59,5116)NA,A,REFF
      WRITE(15,5116)NA,A,REFF
      GO TO 3130
 3125 WRITE(59,5120)T,NA,REFF
      WRITE(15,5120)T,NA,REFF
 3130 IF(ARTG.NE.0)  GO TO 3135
      WRITE(15,5140)  ARTG,(NOARTG(I),I=1,2),NANO
      TSD1 = TSD
      GO TO 3140
 3135 WRITE(59,5140)ARTG,(NARTG(ARTG,I),I=1,2),NANO
      WRITE(15,5140)ARTG,(NARTG(ARTG,I),I=1,2),NANO
      TSD1=TSD
      GO TO (3150,3160,3170,3180),ARTG
 3140 WRITE(15,5149) TORT
      GO TO 3195
 3150 WRITE(59,5150)TSA
      WRITE(15,5150)TSA
      GO TO 3195
 3160 WRITE(59,5160)TBA
      WRITE(15,5160)TBA
      GO TO 3195
 3170 WRITE(59,5170)GH,TWG
      WRITE(15,5170)GH,TWG
      GO TO 3195
 3180 WRITE(59,5180)PORO,TORT
      WRITE(15,5180)PORO,TORT
      TSD1=A
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 3195 WRITE(59,5190)TSD1,LE,LA,LC,THETA,RO,IFLUID,NFLUID(IFLUID),AR
      WRITE(15,5190)TSD1,LE,LA,LC,THETA,RO,IFLUID,NFLUID(IFLUID),AR
      GO TO 120
C-----CALCULATE ARTERY CHARACTERISTICS
 3200 IF (TEAX.GE.10) TBA=A
      AV = PI*RO**2
      IF(ARTG.EQ.0)  GO TO 3290
      GO TO (3210,3220,3230,3240),ARTG
C-----CIRCULAR ARTERIES (ARTG=1)
 3210 RADIUS=A
      RH=A
      RV=RO-TSD
      AL=PI*RADIUS*RADIUS
      AV=PI*(RV*RV-(NA+NANO)*(RADIUS+TSA)**2)
      FRE=16.
      GO TO 3290
C-----ANNULAR SECTION ARTERIES (ARTG=2)
 3220 RV=RO-A-TSD
      B=(RO+RV+TSD)*PI/(NA+NANO)-TBA
      AV=PI*RV*RV
 3222 RH=A*B/(A+B)
      AL=A*B
      RAB=A/B
      IF(RAB-1)3226,3226,3224
 3224 RAB=B/A
 3226 FRE=14.25+9.75*(1-RAB)**2.85
      IF(ARTG.EQ.2.AND.NA+NANO.EQ.1)FRE=FRE/2.5
      GO TO 3290
C-----HELICAL GUTTERS (ARTG=3)
 3230 CL=(RO-A/2.-TSD)*2.*PI
      LEFFL=SQRT(LTOT*LTOT+CL*CL*NT*NT)*(LA+(LE+LC)/2.0)/LTOT
      IF(ITV.EQ.4)DXL=LEFFL
      RI=RO-TSD
      BETA=ATAN(NT*CL/LTOT)
      AV=PI*RI*RI-(GH+TWG)/COS(BETA)*(TWG+A)*NA
      RV=SQRT(AV/PI)
      B=GH
      GO TO 3222
C-----HOMOGENEOUS WICK (ARTG=4)
 3240 CONTINUE
      AL=PI*(2*RO-A)*A*PORO
      RH = (1.0/RMESH*2.54 - WS)/2.0
      IF(RH.LE.0)  RH = REFF
      RV=RO-A
      AV=PI*RV*RV
      FRE=2*TORT
 3290 CIRC=2.*PI*RV
      GO TO (390,150,150,390),ITV
C-----PROPERTY DATA
 3300 GO TO (3310,3320,3330,3340,3350),IFLUID
C-----LITHIUM, IFLUID=1
 3310 PV=10**(7.67-7740/T)*1333.
      MW=6.94
      RHOL=0.555-0.934E-4*T
      MUV=1.2E-7*T-6.E-6
      MUL=.00142*EXP(5.48E10/(RBAR*T))
      HFG=.2412E5+T*(-.6952+T*(-.2282E-2+T*.6281E-6))
      SIG=453.-.148*T
      RK = 1.7997 - .0001479*T
      GO TO 3390
C-----SODIUM, IFLUID=2
 3320 PV=3.83E10/EXP(12180./T)
      MW=23.
      RHOL=1.018-2.34E-4*T
      MUV=1.6E-7*T-5.E-6
      MUL=10**(-3.0494+330.9/T)
      HFG=5.226E3+T*(-1.474+T*(3.292E-4-T*5.462E-8))
      SIG=220.-.091*T
      RK = 1.7590 - .0001720*T
      GO TO 3390
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```
C-----POTASSIUM, IFLUID=3
 3330 PV=2.197E10/EXP(10223./T)
      MW=39.1
      RHOL=.909-2.41E-4*T
      MUV=1.46E-7*T-5.E-6
      MUL=.75*10**(-2.9995+245./T)
      HFG=2.92E3+T*(-1.84+T*(.001323-4.123E-7*T))
      SIG=136.-.0645*T
      RK = 1.7402 - .0001238*T
      GO TO 3390
C-----MERCURY, IFLUID=4
 3340 PV = 1.332E3*EXP(17.85-7059.5/T)
      MW=200.59
      RHOL=12.75-2.50E-3*T
      MUV=1.033E-6*T-2.00E-5
      MUL=5.138E-3*EXP(364.3/T)
      HFG=355.0*EXP(-3.45E-4*T)
      SIG=562.4-0.308*T
      RK = 1.667
      GO TO 3390
C     WATER, IFLUID=5
 3350 PV=3.975E11*EXP(-4872./T)
      MW=18.0
      RHOL=1.49-1.40E-3*T
      MUV=6.91E-5*EXP(4.67E-6*T*T)
      MUL=6.22E-5*EXP(1.478E3/T)
      HFG=3800.-4.333*T
      SIG=133.5-0.205*T
      RK = 1.324
      GO TO 3390
 3390 RHOV=MW*PV/(RBAR*T)
      GO TO (140,390,390,140),ITV
C-----IS DEPENDENT VARIABLE ZERO&  IF NOT, TRY A NEW INDEPENDENT VARIABLE
 3600 IF(IT1-2)3610,3620,3620
 3610 X=1.1*X2
      CONVB=1.
      CONV=1.
      GO TO 3640
 3620 CONV=(X2-X1)/X1
      IF(ABS(CONV)-FCONV)1000,1000,3630
 3630 SLOPE=(Y2-Y1)/(X2-X1)
      X=X2-Y2/SLOPE
C     CHECK TO SEE IF X IS NEGATIVE
      IF(X.LE.0) X=0.01
 3640 Y1=Y2
      X1=X2
      IF(ABS(CONV).LT.CONVB)CONVB=ABS(CONV)
      IF(ABS(CONV/CONVB).GE.10)X=.9*X2+.1*X
      IF(IT1-100)880,3690,3690
 3690 WRITE(59,5400)CONV
      WRITE(15,5400)CONV
      GO TO 1000
C-----PRINT RESULTS
 3900 GO TO (3910,3930,3947,3970),ITV
 3910 WRITE(59,5500)NA,A,DPL,DPZ,DPV,DPI,DPT,DPE,DPA,DPC,DPCAP,T2
     1,REFF,AV,NSON(KSON)
      WRITE(15,5510)NA,A,DPL,DPZ,DPV,DPI,DPT,DPE,DPA,DPC,DPCAP,T2
     1,REFF,AV,NSON(KSON)
      XP(I)=NA
      Y1P(I)=DPCAP
      Y2P(I)=DPCAP
      A=A*SQRT(NA/(NA+DDO))
      GO TO 1200
 3930 Q=Q*ABS(QSONIC-Q)/(QSONIC-Q)
      WRITE(59,5600)T,Q,DPL,DPZ,DPV,DPI,DPT,DPE,DPA,DPC,DPCAP,T2,QSONIC
      WRITE(15,5611)TEE,DPL,DPV,DPI,DPE,TBE,TBC,QSONIC
      WRITE(15,5612)Q,DPZ,DPT,DPCAP,DPA,TEESON,TBCSON,QENTRN
      WRITE(15,5613)DPC
C     WRITE(15,5620) TECSON,PCI,QSON,TBES,POSS,RM1S
C     WRITE(15,5420) POS,PV,DPIS,DPVS,POR,REY,W1,RM1S
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      XP(I)=T
      Y1P(I)=ABS(Q)
      Y2P(I)=QSONIC
      GO TO 1200
 3947 IF(IT3-1)3948,3948,3950
 3948 XL=0.
      Q1=QTOTAL
      DPIT=DPI
      PVEE=PV2
      WRITE(59,5450)NSON(KSON)
      WRITE(15,5450)NSON(KSON)
 3950 WRITE(59,5700)XL,Q1,T2,PV2,DPL,DPZ,DPV,DPI,DPT
      WRITE(15,5710)XL,Q1,T2,PV2,DPL,DPZ,DPV,DPI,DPT,DPA
      Y1P(I)=T2
      Y2P(I)=T2
      XP(I)=XL
      GO TO 1200
 3970 WRITE(59,5800)A,Q,DPL,DPZ,DPV,DPI,DPT,DPE,DPA,DPC,AV,T2,QSONIC
      WRITE(15,5810)A,Q,DPL,DPZ,DPV,DPI,DPT,DPE,DPA,DPC,AV,T2,QSONIC
      Y1P(I)=Q
      Y2P(I)=QSONIC
      XP(I)=A
      GO TO 1200
 5010 FORMAT(6A10,I2/6(4E20.10/))
 5112 FORMAT(/10X,6A10//10X,*HEAT PIPE ANALYSIS: *,2A6,/)
 5114 FORMAT(10X,*EVAPORATOR EXIT TEMP        =*,E15.5/
     110X,*POWER                       =*,E15.5)
 5116 FORMAT(10X,*NO. OF ARTERIES OPERATING=*,I5/
     110X,*ARTERY DIMENSION            =*,E15.5/
     210X,*ARTERY PUMPING RADIUS       =*,E15.5)
 5120 FORMAT(10X,*EVAPORATOR EXIT TEMP        =*,E15.5/
     110X,*NO. OF ARTERIES             =*,I5/
     210X,*REFF                        =*,E15.5)
 5140 FORMAT(10X,*ARTERY GEOMETRY             =*,I5,3X,2A6/
     110X,*NO. OF ART. NOT OPERATING=*,I5)
 5149 FORMAT(10X,*WALL FRICTION FACTOR        =*,E15.5)
 5150 FORMAT(10X,*ARTERY SCREEN THICKNESS     =*,E15.5)
 5160 FORMAT(10X,*DISTANCE BETWEEN ARTERIES=*,E15.5)
 5170 FORMAT(10X,*GUTTER HEIGHT               =*,E15.5/
     110X,*GUTTER WALL THICKNESS       =*,E15.5)
 5180 FORMAT(10X,*WICK POROSITY               =*,E15.5/
     110X,*WICK TORTUROSITY            =*,E15.5)
 5190 FORMAT(10X,*DISTRIB. SCREEN THICKNESS=*,E15.5/
     110X,*EVAPORATOR LENGTH           =*,E15.5/
     210X,*ADIABATIC LENGTH            =*,E15.5/
     310X,*CONDENSER LENGTH            =*,E15.5/
     410X,*ANGLE FROM HORIZONTAL       =*,E15.5/
     510X,*PIPE INSIDE RADIUS          =*,E15.5/
     610X,*WORKING FLUID NO.           =*,I5,3X,A2/
     710X,*A-RATIO(LAMIN OR TURB)      =*,E15.5)
 5200 FORMAT(10X,*PIPE EFFECTIVE LENGTH       =*,E15.5)
 5210 FORMAT(/3X,*NA          XA          DPL          DPZ          DPV*
     17X,*DPI          DPT*/6X,*DPE          DPA          DPC          DPCAP*
     26X,* TBE        REFF          AV*)
 5211 FORMAT(/3X,*NA     XA          DPL          DPZ          DPV          DPI*
     16X*DPT          DPE          DPA          DPC          DPCAP          TBE     REFF*,
     24X,*AV*)
 5215 FORMAT(/8X,*-----------------PRESSURE DROPS---------------*,
     *3X,*TEMPERATURE*,3X,*LIMITS*)
 5216 FORMAT(1X,*TEE*,8X,*LIQUID*,4X,*VAPOR(L)*,4X,*INERTIAL*,2X,
     **EVAPORATOR*,4X,*TBE*,4X,*TBC*,4X,*QSONIC*)
 5217 FORMAT(1X,*POWER*,1X,*HYDROSTATIC*,4X,*VAPOR(T)*,3X,*CAPILLARY*,
     *3X,*ADIABATIC*,1X,*TBESON*,1X,*TBCSON*,4X,*QENTRN*)
 5218 FORMAT(45X,*CONDENSER*)
 5222 FORMAT(/6X,*TEE          POWER          DPL          DPZ          DPV          DPI*,
     17X,*DPT*/11X,*DPE          DPA          DPC          DPCAP          TBE*,
     24X,*QSONIC*)
 5221 FORMAT(/5X,*TEE      POWER          DPL          DPZ          DPV          DPI*
     14X,*DPT          DPE          DPA          DPC          DPCAP          TEE     QSONIC*)
 5230 FORMAT(/* DIST     POWER     TEMP     PRESS     DPL     DPZ     DPV*,
     1*        DPI          DPT*)
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 5231 FORMAT(/*      DIST.       POWER       TEMP      PRESS        DPL        D
     1PZ       DPV         DPI*,/7X,*DPT*,7X,*DPA*)
 5240 FORMAT(/6X,* X        POWER         DPL         DPZ         DPV         DPI*,
     17X,*DPT*/11X,*DPE          DPA          DPC        AV           TEE*,
     24X,*QSONIC*)
 5241 FORMAT(/5X,* X       POWER        DPL        DPZ        DPV        DPI*
     14X,*DPT        DPE        DPA          DPC        AV          TEE    QSONIC*)
 5250 FORMAT(10X,*PRESSURE                          =*,E15.5/
     110X,*VAPOR DENSITY             =*,E15.5/
     210X,*LIQUID DENSITY            =*,E15.5/
     310X,*VAPOR VISCOSITY           =*,E15.5/
     410X,*LIQUID VISCOSITY          =*,E15.5/
     510X,*HEAT OF VAPORIZATION      =*,E15.5/
     610X,*SURFACE TENSION           =*,E15.5)
 5303 FORMAT(10X,*VAPOR PASSAGE AREA       =*,E15.5/
     110X,*TOTAL LIQUID FLOW AREA   =*,E15.5)
 5400 FORMAT(* THE NEXT DATA FAILED TO CONVERGE FOR WICK LIMIT.*,
     1*   CONVERGENCE=*,F9.5)
 5410 FORMAT(* FLOW IS CHOKED, MACH NUMBER EXCEEDS UNITY AT EXIT*)
 5420 FORMAT(8E10.3)
 5430 FORMAT(*ITERATION LIMIT EXCEEDED ON ENTRAINMENT LIMIT, DELTA T= *,
     *F10.3)
 5450 FORMAT(10X,A10)
 5500 FORMAT(I5,F10.3,5F10.0/5F10.0,F10.4,F7.2,A10)
 5510 FORMAT(I5,F7.3,10F9.0,2F7.3,A9)
 5600 FORMAT(/7F10.0/5X,6F10.0)
 5611 FORMAT(F5.0,4X,4(F10.0,2X),2(F5.0,2X),F7.0)
 5612 FORMAT(F7.0,2X,4(F10.0,2X),2(F5.0,2X),F7.0)
 5613 FORMAT(45X,F10.0)
 5620 FORMAT(10X,5F8.0,F6.3)
 5700 FORMAT(F6.2,F8.0,F7.1,F9.0,2(F6.0,F8.0),F8.0)
 5710 FORMAT(F10.2,F10.0,F10.1,5F10.0,/2F10.0)
 5800 FORMAT(F10.4,6F10.0/5X,3F10.0,F10.2,2F10.0)
 5810 FORMAT(F9.4,9F9.0,F9.2,2F9.0)
 9999 CONTINUE
      IF(NPLOT.NE.0)CALL DRAW(ITV,NP,XP,Y1P,Y2P)
      CALL BKP
      CALL EXIT
      END
      SUBROUTINE TSAT(IFLUID,PRESS,TEMP)
C     THIS SUBROUTINE CALCULATES THE SATURATION TEMPERATURE CORRESPONDING
C     TO THE INPUT PRESSURE, PRESS. IFLUID SPECIFIES THE WORKING FLUID
C
      GO TO (10,20,30,40,50),IFLUID
C     LITHIUM
   10 TEMP = 7740.0/(7.67-ALOG10(PRESS/1333.0))
      GO TO 99
C     SODIUM
   20 TEMP = 12180.0/ALOG(3.83E10/PRESS)
      GO TO 99
C     POTASSIUM
   30 TEMP = 10223.0/ALOG(2.197E10/PRESS)
      GO TO 99
C     MERCURY
   40 TEMP = 7059.5/(17.85+ALOG(1.332E3/PRESS))
      GO TO 99
C     WATER
   50 TEMP = 4872.0/ALOG(3.975E11/PRESS)
   99 CONTINUE
      RETURN
      END
      SUBROUTINE FMAX(FMX,RK,RMACH,RMACHO)
C     THIS SUBROUTINE CALCULATES THE MACH NUMBER CORRESPONDING TO VALUES
C     OF FMAX. NEWTONS METHOD IS USED.
C     FMX = INDEPENDENT VARIABLE
C     RK = SPECIFIC HEAT RATIO
C     RMACH = EXIT MACH NUMBER
C     RMACHO = INLET MACH NUMBER
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C
C      CALCULATE INITIAL GUESS
       PHI = (.3403/FMX**.2550)**2
       IF(RMACHO.GT.1.0) PHI = (1.0286*EXP(2.4938*FMX))**2
       I = 0
   10  F = (1.0-PHI)/RK/PHI + (RK+1.0)/2./RK*
     * ALOG((RK+1.0)*PHI/2./(1.0+(RK-1.0)/2.*PHI)) - FMX
       IF(ABS(F).LT.0.0001) GO TO 40
       DF = (RK+1.0)/(2.*RK*PHI*(1.0+(RK-1.0)/2.*PHI)) - 1.0/RK/PHI**2
       PHINEW = PHI - F/DF
       IF(PHINEW.LE.0)  PHINEW = 1.0E-6
       IF(RMACHO.LT.1.0.AND.PHINEW.GT.1.0)  PHINEW = 0.9999
       IF(RMACHO.GE.1.0.AND.PHINEW.LT.1.0)  PHINEW = 1.0001
       I = I+1
       IF(I.GT.50) GO TO 30
       PHI = PHINEW
       GO TO 10
   30  WRITE(15,5430) I,F
   40  CONTINUE
       RMACH = SQRT(PHI)
 5430  FORMAT(*CONVERGENCE FAILED IN FMAX, I = *,I3,* AND F = *,E10.3)
       RETURN
       END
       SUBROUTINE DRAW(IOPT,NP,XP,Y1P,Y2P)
       DIMENSION XP(NP),Y1P(NP),Y2P(NP),LABELX(3),LABELY(3),LABELZ(3)
       DIMENSION W(50),A(50),B(50),C(50),IOP(2),ANS(3)
       DIMENSION XS(201),Y1S(201),Y2S(201)
       IF(IOPT.LT.2) RETURN
       CALL TEKTRN
       CALL BGNPL(0)
       CALL PAGE(9.5,11.0)
       CALL HEIGHT(0.2)
       YMAX= 0.0
       YMIN= 10000.
       XVAL= XP(1) + .02*(XP(NP)-XP(1))
       GO TO (40,10,20,30) IOPT
   10  IJ = 1
       IOP(1) = 5
       IOP(2) = 5
       NS = 200
       NS1 = NS + 1
C       NS1 IS THE NUMBER OF POINTS IN THE SMOOTHED FUNCTION
C       NS IS THE NUMBER OF INTERVALS IN THE SMOOTHED FUNCTION
C       W WILL CONTAIN THE SECOND DERIVATIVES
C       IJ GIVES THE SPACING OF POINTS IN THE ORIGINAL ARRAY
C       IOP SETS THE BOUNDARY CONDITIONS AT THE END POINTS
C       A, B, C ARE WORKSPACES
C       ANS(1) WILL CONTAIN THE Y-VALUE AT THE CALCULATED POINT
C       ANS(2) WILL CONTAIN THE FIRST DERIVATIVE
C       ANS(3) WILL CONTAIN THE SECOND DERIVATIVE
C       FIRST SET UP THE X-VALUES FOR THE SMOOTHED FUNCTION
       XS(1) = XP(1)
       DX = (XP(NP)-XP(1))/NS
       DO 1 I=1,NS
    1  XS(I+1) = XS(1) + I*DX
       NZ=26
       ENCODE (NZ,11,LABELZ)
   11  FORMAT(26HQ VS. EVAPORATOR EXIT TEMP)
       NY=12
       ENCODE (NY,12,LABELY)
   12  FORMAT(12HPOWER, WATTS)
       NX=14
       ENCODE (NX,13,LABELX)
   13  FORMAT(14HTEMPERATURE, K)
       CALL INTAXS
       DO 14 I=1,NP
       YMIN= AMIN1(YMIN,Y2P(I))
       YMAX= AMAX1(YMAX,Y2P(I))
```

```
   14 CONTINUE
      YVAL= (YMAX-YMIN)*.02 + Y2P(1)
      CALL TITLE(LABELZ,NZ,LABELX,NX,LABELY,NY,6.5,7.5)
      CALL GRAF(XP(1),10HSCALE      ,XP(NP),YMIN,10HSCALE      ,YMAX)
      CALL SPL1D1(NP,XP,Y1P,W,IOP,IJ,A,B,C)
C      THIS PUTS THE SECOND DERIVATIVES OF Y1P INTO W
      DO 15 I=1,NS1
      CALL SPL1D2(NP,XP,Y1P,W,IJ,XS(I),ANS)
   15 Y1S(I) = ANS(1)
C      NOW REPEAT THE PROCESS FOR THE SECOND CURVE
      CALL SPL1D1(NP,XP,Y2P,W,IOP,IJ,A,B,C)
      DO 16 I=1,NS1
      CALL SPL1D2(NP,XP,Y2P,W,IJ,XS(I),ANS)
   16 Y2S(I) = ANS(1)
C      NOW CHECK FOR POINTS OF Y1S WHICH ARE ABOVE Y2S
      NPQ = NS1
      DO 17 I=1,NS1
      IF(Y1S(I).LT.Y2S(I)) GO TO 18
      NPQ = NPQ-1
   17 CONTINUE
   18 CALL CURVE(XS,Y2S,NS1,0)
      CALL RLMESS(6HQSONIC,6,XVAL,YVAL)
      NSTART = NS1+1-NPQ
      CALL CURVE(XS(NSTART),Y1S(NSTART),NPQ,0)
      GO TO 35
   20 NZ=22
      ENCODE(NZ,21,LABELZ)
   21 FORMAT(22HTEMPERATURE VS. LENGTH)
      NY=14
      ENCODE(NY,22,LABELY)
   22 FORMAT(14HTEMPERATURE, K)
      NX=10
      ENCODE(NX,23,LABELX)
   23 FORMAT(10HLENGTH, CM)
      CALL INTAXS
      DO 24 I=1,NP
      YMIN= AMIN1(YMIN,Y2P(I))
      YMAX=AMAX1(YMAX,Y2P(I))
   24 CONTINUE
      CALL TITLE(LABELZ,NZ,LABELX,NX,LABELY,NY,6.5,7.5)
      CALL GRAF(XP(1),10HSCALE      ,XP(NP),YMIN,10HSCALE      ,YMAX)
      CALL CURVE(XP,Y2P,NP,0)
      GO TO 35
   30 NZ=15
      ENCODE(NZ,31,LABELZ)
   31 FORMAT(15HQ, QSONIC VS. A)
      NY=12
      ENCODE(NY,32,LABELY)
   32 FORMAT(12HPOWER, WATTS)
      NX=20
      ENCODE(NX,33,LABELX)
   33 FORMAT(20HARTERY DIMENSION, CM)
      CALL YINTAX
      DO 34 I=1,NP
      YMIN= AMIN1(YMIN,Y1P(I))
      YMAX= AMAX1(YMAX,Y1P(I))
   34 CONTINUE
      YVAL= (YMAX-YMIN)*.02 + Y2P(1)
      CALL TITLE(LABELZ,NZ,LABELX,NX,LABELY,NY,6.5,7.5)
      CALL GRAF(XP(1),10HSCALE      ,XP(NP),YMIN,10HSCALE      ,YMAX)
      CALL CURVE(XP,Y1P,NP,0)
      CALL CURVE(XP,Y2P,NP,0)
      CALL RLMESS(6HQSONIC,6,XVAL,YVAL)
   35 CONTINUE
      CALL GRID(1,1)
      CALL ENDPL(IOPT)
      CALL DONEPL
```

```
   40 RETURN
      END
      SUBROUTINE SPL1D1(N,X,F,W,IOP,IJ,A,B,C)
C     WHERE N= NUMBER OF POINTS IN THE INTERPOLATION
C           X= ORIGIN OF TABLE OF INDEPENDENT VARIABLE
C           F= ORIGIN OF TABLE OF DEPENDENT VARIABLE
C           W= AN ARRAY OF DIMENSION N WHICH CONTAINS THE CALCULATED
C              SECOND DERIVATIVES UPON RETURN
C           IOP= AN ARRAY OF DIMENSION 2 WHICH CONTAINS COMBINATIONS OF
C                THE INTEGERS 1 THRU 5 USED TO SPECIFY THE BOUNDARY
C                CONDITIONS
C           IJ= SPACING IN THE F AND W TABLES
C           A,B,C= ARRAYS OF DIMENSION N USED FOR TEMPORARY STORAGE
C
      DIMENSION IOP(2),X(2),F(2),W(2),A(2),B(2),C(2),COMM(6)
      DATA (COMM(J),J=1,6)/8HSPL1D1 N,8H LESS TH,8HAN 4. RE,8HSULTS IN,
     18HCORRECT.,8H        /
      K=N-1
      A(2)=-(X(2)-X(1))/6.
      B(2)=(X(3)-X(1))/3.
      W(IJ+1)=(F(2*IJ+1)-F(IJ+1))/(X(3)-X(2))-(F(IJ+1)-F(1))
     1/(X(2)-X(1))
      IF (N-3)3,4,3
    3 DO 10 I=3,K
      M=(I-1)*IJ+1
      J1=M+IJ
      J2=M-IJ
      CON=(X(I+1)-X(I-1))/3.
      DON=(X(I)-X(I-1))/6.
      B(I)=CON-(DON**2)/B(I-1)
      E=(F(J1)-F(M))/(X(I+1)-X(I))-(F(M)-F(J2))/
     1(X(I)-X(I-1))
      W(M)=E-(DON*W(J2))/B(I-1)
   10 A(I)=-(DON*A(I-1))/B(I-1)
    4 K1=(N-2)*IJ+1
      C(N-1)=-((X(N)-X(N-1))/6.)/B(N-1)
      W(K1)=W(K1)/B(N-1)
      A(N-1)=A(N-1)/B(N-1)
      K2=K-1
      IF (N-3)7,8,7
    7 DO 20 I=2,K2
      J=N-I
      CON=(X(J+1)-X(J))/6.
      A(J)=(A(J)-CON*A(J+1))/B(J)
      C(J)=-(CON*C(J+1))/B(J)
      K3=(J-1)*IJ+1
      M=K3+IJ
   20 W(K3)=(W(K3)-CON*W(M))/B(J)
    8 K4=(N-1)*IJ+1
      IF (IOP(1)-5) 201,200,201
  201 C1=W(1)
      IF (IOP(2)-5) 203,202,203
  203 C2=W(K4)
      GO TO 205
  200 IF (N-4)300,302,302
  302 A1=X(1)-X(2)
      A2=X(1)-X(3)
      A3=X(1)-X(4)
      A4=X(2)-X(3)
      A5=X(2)-X(4)
      A6=X(3)-X(4)
      W(1)=F(1)*(1./A1+1./A2+1./A3)-A2*A3*F(IJ+1)/(A1*A4*A5)+
     1 A1*A3*F(2*IJ+1)/(A2*A4*A6 )-A1*A2*F(3*IJ+1)/(A3*A5*A6)
      GO TO 201
  202 IF (N-4)300,303,303
  303 B1=X(N)-X(N-3)
      B2=X(N)-X(N-2)
      B3=X(N)-X(N-1)
      B4=X(N-1)-X(N-3)
      B5=X(N-1)-X(N-2)
```

```
      B6=X(N-2)-X(N-3)
      L1=K4-IJ
      L2=L1-IJ
      L3=L2-IJ
      W(K4)=-B2*B3*F(L3)/(B6*B4*B1)+B1*B3*F(L2)/(B6*B5*B2)
     1 -B1*B2*F(L1)/(B4*B5*B3)+F(K4)*(1./B1+1./B2+1./B3)
      GO TO 203
  205 DO 50 I=1,K
      M=(I-1)*IJ+1
      GO TO 60
   70 IF (I-1)80,50,80
   80 W(1)=W(1)-BOB*W(M)
      W(K4)=W(K4)-BILL*W(M)
      A(1)=A(1)-BOB*A(I)
      A(N)=A(N)-BILL*A(I)
      C(1)=C(1)-BOB*C(I)
      C(N)=C(N)-BILL*C(I)
   50 CONTINUE
      GO TO 100
   60 MK=IOP(1)
      GO TO (62,64,66,68,66),MK
   62 IF (I-1)71,63,71
   63 A(1)=-1.
      C(1)=0.
      GO TO500
   71 BOB=0.
      GO TO 500
   64 IF (I-1)73,76,73
   76 A(1)=-1.
      C(1)=0.
      W(1)=0.
      GO TO 500
   73 IF (I-2)81,81,82
   81 BOB=-C1
      GO TO 500
   82 BOB=0.
      GO TO 500
   66 IF (I-1)83,84,83
   84 A(1)=-(X(2)-X(1))/3.
      C(1)=0.
      W(1)=-C1+(F(IJ+1)-F(1))/(X(2)-X(1))
      GO TO 500
   83 IF (I-2)85,85,86
   85 BOB=(X(2)-X(1))/6.
      GO TO 500
   86 BOB=0.
      GO TO 500
   68 IF (I-1)87,88,87
   88 A(1)=-1.
      C(1)=1.
      W(1)=0.
      GO TO 500
   87 BOB=0.
  500 ML=IOP(2)
      GO TO (120,130,140,150,140),ML
  120 IF (I-1)121,122,121
  122 A(N)=0.
      C(N)=-1.
      GO TO 70
  121 BILL=0.
      GO TO 70
  130 IF (I-1)131,132,131
  132 A(N)=0.
      C(N)=-1.
      W(K4)=0.
      GO TO 70
  131 IF (I-K)134,133,134
  133 BILL=-C2
      GO TO 70
  134 BILL=0.
      GO TO 70
```

```
 140 IF (I-1)141,142,141
 142 A(N)=0.
     C(N)=(X(N-1)-X(N))/3.
     W(K4)=C2-(F(K4)-F(K1))/(X(N)-X(N-1))
     GO TO 70
 141 IF (I-K)143,144,143
 144 BILL=(X(N)-X(N-1))/6.
     GO TO 70
 143 BILL=0.
     GO TO 70
 150 IF (I-1)151,152,151
 152 A(N)=0.
     C(N)=(X(N-1)+X(1)-X(N)-X(2))/3.
     W(K4)=(F(IJ+1)-F(1))/(X(2)-X(1))-(F(K4)-F(K1))/(X(N)-X(N-1))
     GO TO 70
 151 IF (I-2)153,154,153
 154 BILL=(X(2)-X(1))/6.
     GO TO 70
 153 IF (I-K)155,156,155
 156 BILL=(X(N)-X(N-1))/6.
     GO TO 70
 155 BILL=0.
     GO TO 70
 100 CON=A(1)*C(N)-C(1)*A(N)
     D1=-W(1)
     D2=-W(K4)
     W(1)=(D1*C(N)-C(1)*D2)/CON
     W(K4)=(A(1)*D2-D1*A(N))/CON
     DO 110 I=2,K
     M=(I-1)*IJ+1
 110 W(M)=W(M)+A(I)*W(1)+C(I)*W(K4)
     GO TO 305
 300 CALL LABRT(1,COMM,1)
 305 RETURN
     END
     SUBROUTINE SPL1D2(N,X,F,W,IJ,Y,TAB)
C    WHERE N= NUMBER OF POINTS IN THE INTERPOLATION
C          X= ORIGIN OF TABLE OF THE INDEPENDENT VARIABLE
C          F= ORIGIN OF TABLE OF THE DEPENDENT VARIABLE
C          W= ORIGIN OF TABLE OF SECOND DERIVATIVES AS CALCULATED BY
C             SPL1D1
C          IJ= SPACING IN THE TABLES F AND W
C          Y= THE POINT AT WHICH INTERPOLATION IS DESIRED
C          TAB= AN ARRAY OF DIMENSION 3 WHICH CONTAINS THE FUNCTION
C               VALUE, FIRST DERIVATIVE, AND SECOND DERIVATIVE AT Y
C
     DIMENSION X(3),F(3),W(3),TAB(3)
C
C    LOCATE Y IN THE X TABLE
C
     IF(Y-X(1))10,10,20
  10 I=1
     GO TO 30
  20 IF(Y-X(N))15,40,40
  40 I=N-1
     GO TO 30
  15 CALL SEARCH(Y,X,N,I,MFLAG)
  30 MI=(I-1)*IJ+1
     K1=MI+IJ
     FLK=X(I+1)-X(I)
C
C    CALCULATE F(Y)
C
     A=(W(MI)*(X(I+1)-Y)**3+W(K1)*(Y-X(I))**3)/(6.*FLK)
     B=(F(K1)/FLK-W(K1)*FLK/6.)*(Y-X(I))
     C=(F(MI)/FLK-FLK*W(MI)/6.)*(X(I+1)-Y)
     TAB(1)=A+B+C
C
C    CALCULATE THE FIRST DERIVATIVE AT Y
```

```
C
      A=(W(K1)*(Y-X(I))**2-W(MI)*(X(I+1)-Y)**2)/(2.*FLK)
      B=(F(K1)-F(MI))/FLK
      C=FLK*(W(MI)-W(K1))/6.
      TAB(2)=A+B+C
C
C     CALCULATE THE SECOND DERIVATIVE AT Y
C
      TAB(3)=(W(MI)*(X(I+1)-Y)+W(K1)*(Y-X(I)))/FLK
      RETURN
      END
```