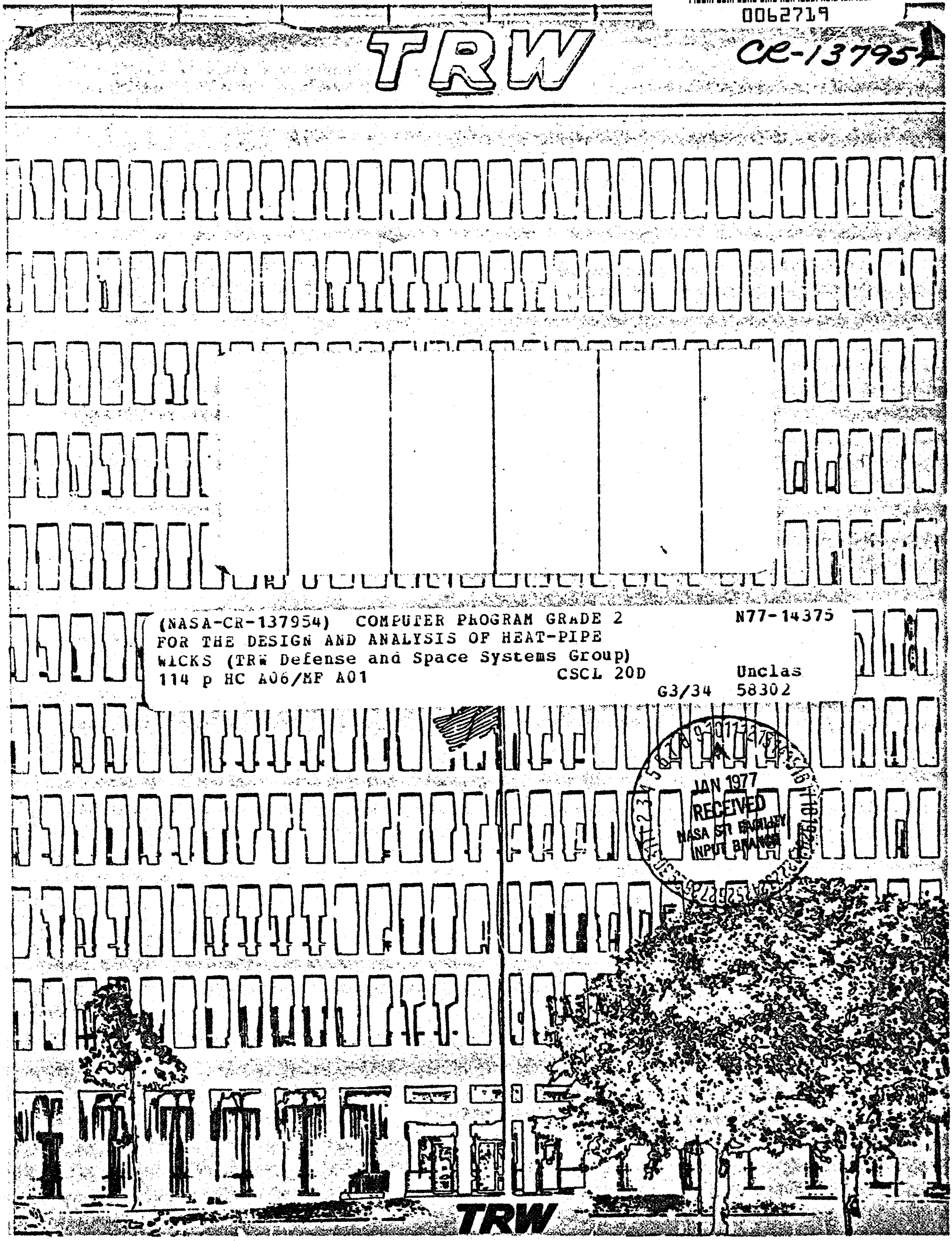
CR-137954



(NASA-CR-137954) COMPUTER PROGRAM GRADE 2 FOR THE DESIGN AND ANALYSIS OF HEAT-PIPE WICKS (TRW Defense and Space Systems Group) 114 p HC A06/MF A01 CSCL 20D

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COMPUTER PROGRAM GRADE II FOR THE DESIGN AND ANALYSIS OF HEAT-PIPE WICKS

November 1976

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Moffett Field, California 94035

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COMPUTER PROGRAM GRADE II
FOR THE DESIGN AND ANALYSIS OF HEAT-PIPE WICKS

1.0 INTRODUCTION

This user's manual describes the revised version of the computer program GRADE(1), which designs and analyzes heat pipes with graded-porosity fibrous slab wicks. The revisions, which are based on work done under contract NAS 2-8310 with NASA Ames Research Center and reported in Reference (2), were incorporated so that the mathematical model more completely describes an actual graded-porosity-wick heat pipe. In particular, GRADE II now includes:

- Automatic calculation of the minimum condenser-end stress that will not result in an excess-liquid puddle or a liquid slug in the vapor space,
- Numerical solution of the equations describing flow in the circumferential grooves to assess the burnout criterion,
- Calculation of the contribution of excess liquid in fillets and puddles to the heat-transport,
- Calculation of the effect of partial saturation on the wick performance,
- Calculation of the effect of vapor flow, which includes viscous-inertial interactions.

In addition to these extended capabilities, the new version retains the capabilities of the original program:

- Calculation of the optimum porosity variation and the corresponding maximum heat-transport rate,
- Calculation of the maximum heat-transport rate at other than the wick's design condition (different temperature, elevations, gravitational field, etc.),
- Calculation of the maximum heat-transport rate for a specified porosity distribution, which includes a uniform-porosity wick,

- The heat pipe can have multiple sections each having different tilts,
- Multiple heat input and output zones,
- Calculation of the total fluid charge.

The theoretical basis for GRADE II is described in Section 2.0 and the instructions for preparing the input are given in Section 3.0. If excess-liquid effects are to be included in the calculations, a separate program FILLET must be run, whose output is a binary file that becomes additional input for GRADE II. This program is described in Section 4.0. Two sample programs are described in Section 5.0. The Appendix contains descriptions and listings of GRADE II and FILLET.

2.0 THEORETICAL BASIS FOR GRADE II

This section describes the application of fundamental theoretical and experimental results for capillary flow through fibrous media previously reported in Reference (3) and (4) to the optimum design of heat-pipe wicks. To be specific, we consider a heat pipe, as depicted in Figure 1, with a fibrous slab wick for the axial transport of liquid and circumferential grooves for the transport across the evaporation and condensation surfaces. The slab wick is ultimately limited in heat-transport capacity because the factors that affect its performance, the capillary-pressure limit and the permeability, are related inversely. Any change in the wick structure that increases its capillary-pressure limit decreases its permeability and vice versa. The simple uniform-porosity wick is optimized by selecting the fiber diameter and porosity that maximizes its heat transport. Such a wick, however, has an unnecessarily low permeability, everywhere along its length except where it begins to dry out under maximum load. A further capacity increase is possible if one considers a wick whose porosity varies along its length. With a graded-porosity wick, the porosity is optimally varied such that at every axial location it is only as low as required to ensure the wick remains nearly saturated. Thus, the permeability is everywhere as high as possible. The potential increase in capacity over a uniform porosity wick depends on the particular applications, but it is often greater than a factor of two.

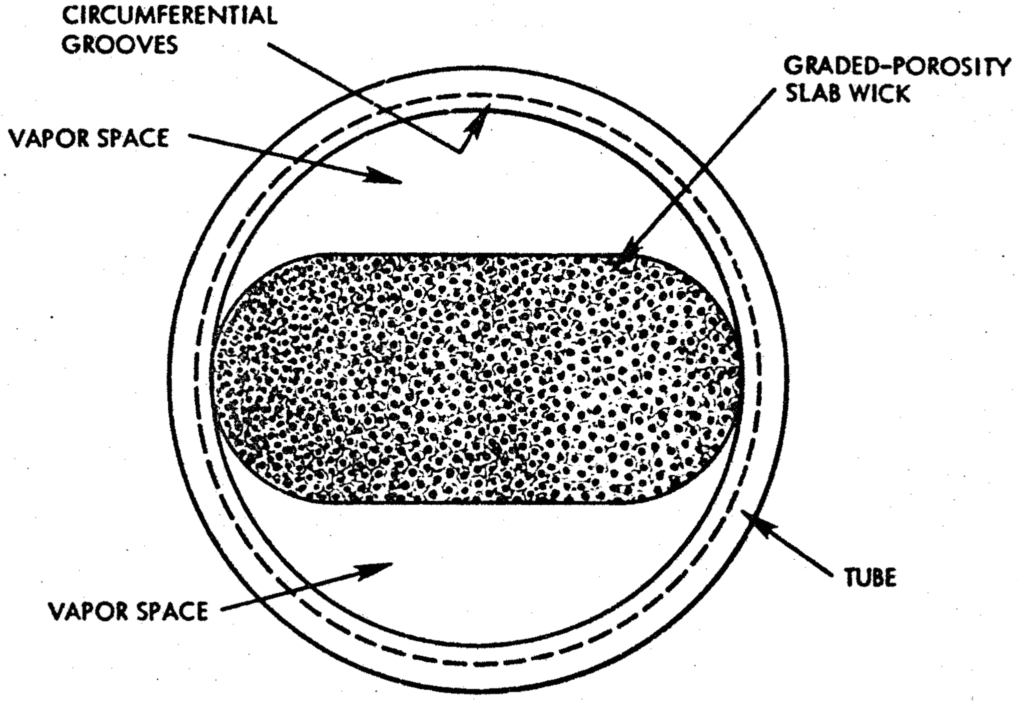

Figure 1. Cross-Section of a Fibrous-Slab-Wick Heat Pipe

2.1 PROPERTIES OF A FIBROUS WICK

We first summarize the results of Reference (3) and (4) for capillary flow through porous media and then derive the relationships that are required for the design of a wick. Expressions for the capillary-pressure limit P_c and the permeability K_0 for a wick of uniform porosity ε consisting of a three-dimensional random distribution of fibers of diameter δ were shown to be

$$P_c = 3.2465\ H(\sigma/\delta)(1 - \varepsilon)/\varepsilon \tag{1}$$

and

$$K_0 = (3/8)\delta^2\ [\varepsilon/(1 - \varepsilon)]/ \left\{ \frac{4\varepsilon}{4(1 - \varepsilon) - (1 - \varepsilon)^2 - 2\ \ln(1 - \varepsilon) - 3} - \frac{8}{\ln(1 - \varepsilon) + [1 - (1 - \varepsilon)^2]/[1 + (1 - \varepsilon)^2]} \right\} \tag{2}$$

where σ is the surface tension and H is the hysteresis constant that is unity if the liquid front is advancing in the wick and an empirically found value of 1.955 if it is receding. Actually, the wick does not empty abruptly when the capillary-pressure limit is exceeded, but rather it progressively desaturates. The wick is envisioned as consisting of local regions having porosities that are normally distributed with a mean value ε_0 and a standard deviation σ_d. The fraction of the wick with a porosity that lies between ε and $\varepsilon + d\varepsilon$ is given by

$$f(\varepsilon, \varepsilon_0, \sigma_d) = \frac{1}{\sqrt{2\pi}\ \sigma_d}\ e^{-(\varepsilon - \varepsilon_0)^2/2\sigma_d^2} \tag{3}$$

The standard deviation was found experimentally to correlate with the mean porosity by the expression

$$\sigma_d = 0.22(1 - \varepsilon_0) \tag{4}$$

When the wick is subject to a vapor-liquid pressure difference P, which we call the capillary stress, a local region is filled with liquid if its porosity is sufficiently low that the capillary-pressure limit given by Eq. (1) exceeds the capillary stress. The saturation fraction, which is the ratio of the liquid content of the wick to the content when it is completely saturated, was shown to be

$$S = F[(\varepsilon^* - \varepsilon_0)/\sigma_d] - (\sigma_d/\varepsilon_0)f[(\varepsilon^* - \varepsilon_0)/\sigma_d] \qquad (5)$$

where f(z) is the standardized normal distribution and F(z) is the standardized cumulative distribution, and ε^* is the critical value of the local porosity for which the capillary pressure limit equals the capillary stress. Its value, obtained from Eq. (1), is

$$\varepsilon^* = \{1 + \frac{P\delta/\sigma}{3.465\,H}\}^{-1} \qquad (6)$$

To obtain an expression for the permeability of the partially saturated wick, Eq. (2) is applied to those regions with a porosity below the critical value. The resulting expression is

$$K(\varepsilon_0, \varepsilon^*, \delta, \sigma_d) = \int_0^{\varepsilon^*} K_0(\delta, \varepsilon)f(\varepsilon, \varepsilon_0, \sigma_d)d\varepsilon \qquad (7)$$

To this point, we have summarized the results of Reference (3) and (4). We now calculate the mean porosity that maximizes the permeability for a prescribed capillary stress. If the porosity is too high, the wick is unable to hold liquid at the prescribed stress which results in a low permeability. If, on the other hand, the porosity is too low, the wick will remain nearly saturated, but the fibers are unnecessarily close together which also results in a low permeability. Equation (7) is the basis for the optimization. A specified value of the capillary stress fixes ε^* by way of Eq. (6). The dependence of the permeability on the fiber diameter δ is eliminated from Eq. (7) by using δ^2 to nondimensionalize K, and the dependence on δ_d is eliminated with Eq. (4). The resulting expression for the dimensionless permeability $\overline{K} = K/\delta^2$ is

$$\overline{K}(\varepsilon_0, \varepsilon^*) = \int_0^{\varepsilon^*} \frac{3}{8}\frac{\varepsilon}{1 - \varepsilon}\{\frac{4\varepsilon}{4(1 - \varepsilon) - (1 - \varepsilon)^2 - 2\ln(1 - \varepsilon)} - \frac{8}{\ln(1 - \varepsilon) + \frac{1 - (1 - \varepsilon)^2}{1 + (1 - \varepsilon)^2}}\}^{-1}\frac{1.8}{1 - \varepsilon_0}e^{-\frac{10.3(\varepsilon - \varepsilon_0)^2}{(1 - \varepsilon_0)^2}}d\varepsilon \qquad (8)$$

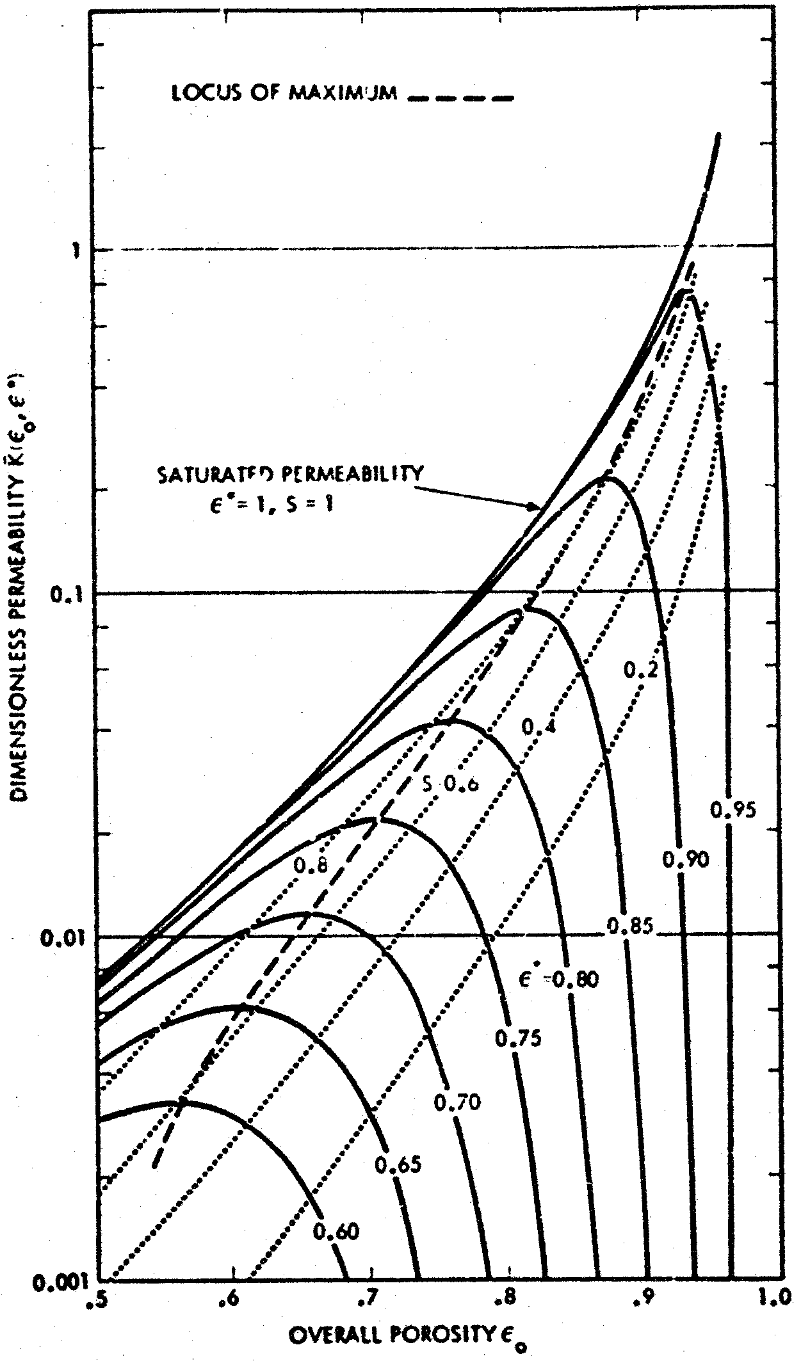

Figure 2. Dimensionless Permeability $K = K/\delta^2$ of a Partially Saturated Wick

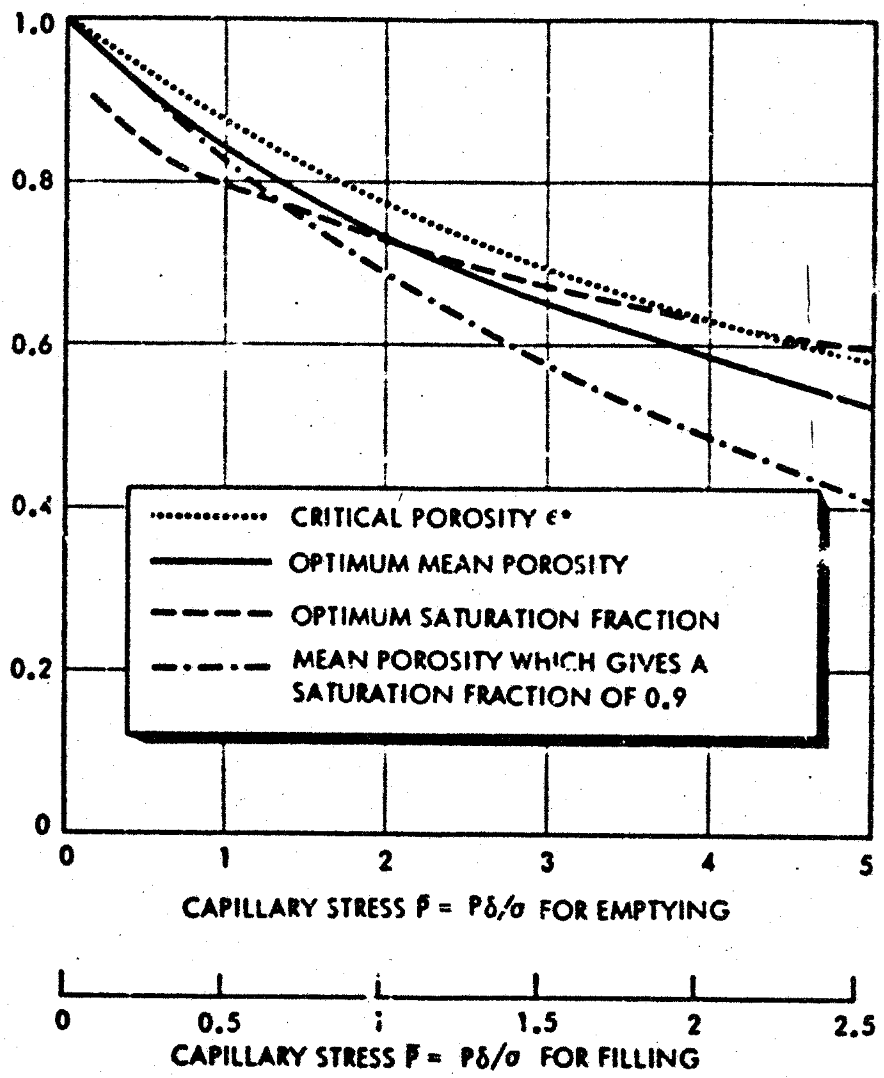

Figure 3. Key Relationships for Design of a Graded-Porosity Wick

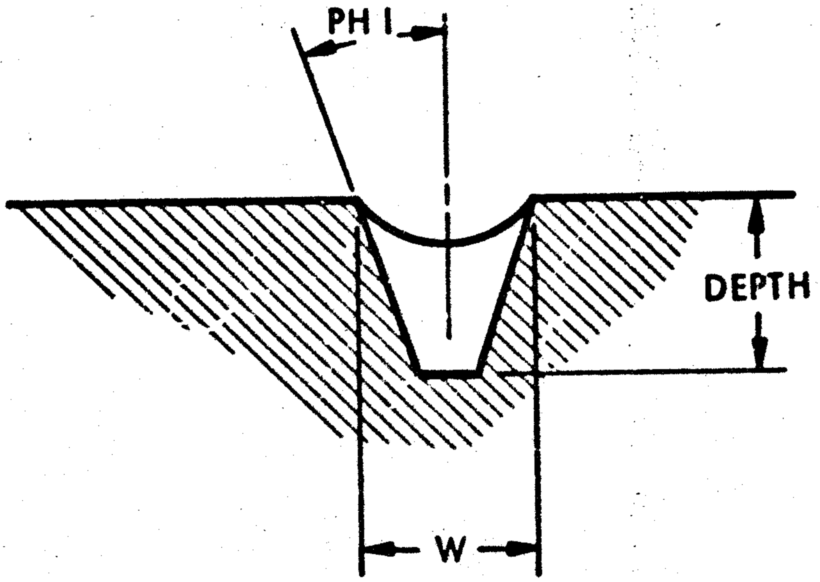

Figure 4. Cross-Sectional Geometry of a Circumferential Groove

This integral was evaluated numerically with Simpson's rule on a computer. The results are shown in Figure 2. Also shown are lines of constant saturation fraction, which were calculated from Eq. (5) with σ_d given by Eq. (4), and the locus of points for which the permeability is maximum.

Figure 3 relates the critical porosity ε^* to the dimensionless capillary stress $P\sigma/\gamma$ and displays the optimum mean porosity and the corresponding saturation fraction as a function of the stress. A graded-porosity wick ideally would have a porosity variation that follows the optimum-porosity curve as the capillary stress builds from a low value at the end of the condenser to a high value at the end of the evaporator. The optimum saturation fraction would range from a value above 0.8 at a low stress typical of the condenser region to a value below 0.7 at a high stress typical of the evaporator region. The fact that such a wick operates with a liquid fill well below that required to saturate it presents practical problems. If, for example, a fluid charge is used that is sufficient to completely saturate the wick, then at the maximum heat-transport rate liquid will be given up that could result in flooding of the condenser. If, on the other hand, a fluid charge is used that is just sufficient to provide the optimum saturation fraction at the maximum heat-transport rate, then there is no guarantee that the liquid will be properly distributed along the wick. To avoid these problems, the wicks are designed with a porosity variation that provides a uniform high-level of saturation. Thus, instead of operating along the peaks of the partially saturated permeability curves of Figure 2, the wick is designed to operate to the left of the peaks along a line of constant saturation fraction. Equation (5) is used to obtain the expression for the porosity that provides the desired saturation fraction. The equation is transcendental in ε_0, and it must be solved iteratively. For high levels of saturation, however, the second term of Eq. (5) is small compared to the first, and an accurate approximation for ε_0 can be obtained by neglecting it, which results in

$$\varepsilon_0 = \frac{\varepsilon^* - F^{-1}(S)/4.5}{1 - F^{-1}(S)/4.5} \qquad (9)$$

where we have used Eq. (4) to eliminate σ_d. Equation (9) was used to calculate the curve of Figure 3 which gives the porosity as a function of capillary stress that provides a saturation fraction of 0.9. [The critical porosity is first calculated as a function of stress from Eq. (6)].

2.2 DESIGN OF A WICK

We now focus attention on the hydrodynamic optimization of a heat pipe for maximum heat transport in a given application. One must be alert, however, to the possibility that other limiting factors may come into play before the hydrodynamic wicking limit is reached. Such factors are, for example, the heat-flux limit due to boiling in the wick, and the sonic vapor-flow limit. The procedure described herein is used to calculate the optimum wick porosity variation for a fixed heat-pipe geometry. For the heat-pipe diameter considered, a change in wick area may further increase the capacity. If the capillary stress is due primarily to liquid flow through the wick, an increase in wick area will increase the capacity. If, on the other hand, the stress is due primarily to vapor-flow pressure drop, or if there is a relatively large vapor-space capillary back pressure, which we will see presently can adversely affect the porosity variation, a reduction in wick area will increase the capacity. In fact, for a given heat-pipe diameter, there is always an optimum wick area.

The key equation describing the heat-pipe hydrodynamics governs the axial variation of the capillary stress. In a gravitational field, however, it varies hydrostatically across the heat pipe as well; so to have a unique value at every axial location, we take its value at the top of the wick. The equation governing the rate of increase of stress P with axial distance x from the condenser end is

$$\frac{dP}{dx} = \frac{\nu_\ell \, \dot{m}(x)}{K(\epsilon_0, \epsilon^*)A_w} + (\rho_\ell - \rho_v)\, g\, \frac{dh}{dx} + \frac{\overline{K}}{Re}\, \frac{\rho_v \overline{U}^2}{2D} - F_s \frac{d}{dx}(\rho_v \overline{U}^2) \qquad (10)$$

The first term on the right of the equal sign gives thre stress increase due to liquid of kinematic viscosity ν_ℓ flowing through a wick of cross-sectional area A_w at a mass rate $\dot{m}(x)$. The permeability K depends on the local porosity ϵ_0 and on the capillary stress through the critical porosity ϵ^*.

The second term gives the change in hydrostatic pressure in the liquid of density ρ_ℓ due to changes of heat-pipe elevation h(x) measured from a horizontal reference plane to the top of the wick.

The third and fourth terms are due to vapor flow, as discussed in Reference (2). Here $\overline{U}$ is the average velocity in the vapor space, R_e is the Reynolds number, and D is the hydraulic diameter of the vapor space. The third term is due to viscous shear on the walls, and the fourth is due to inertial effects. $\overline{K}$ and F_s are, respectively, an average friction-factor coefficient and shape factor, which are calculated according to Reference (2) to give the proper balance between inertial and viscous effects. The mass flow rate is related to the latent heat of vaporization h_{fg} and the heat input per unit length Q(x) (assumed negative in regions of condensation) by

$$\dot{m}(x) = -(1/h_{fg}) \int_0^x Q(x)\,dx \tag{11}$$

The optimum porosity distribution is calcualted by numerically integrating Eq. (1) with an assumed value for the heat load. At each step of the integration, the critical porosity ε^* and the wick porosity ε_0 are calculated from Eqs. (6) and (9) with a specified high level of saturation fraction S and with the hysteresis constant H = 1.955 for liquid on the verge of emptying. Because of hysteresis, however, the calculated porosity ε_0 may be too high for the wick to self-fill to the specified level of saturation under a zero heat load. Therefore, Eqs. (6) and (9) are used again with H = 1 for liquid filling the wick and the stress given by integration of Eq. (10) with $\dot{m}(x) = 0$ to calculate ε^* and ε_0 for the wick to fill. These latter values are used if the porosity required to fill the wick under zero load is lower than the porosity required to sustain the stress under the assumed load.

Once ε_0 and ε^* have been determined, the value of the permeability at the particular integration step is calculated from Eq. (8). In regions of evaporation, the circumferential grooves are checked at each step to see whether or not they dry up. The subroutine DRY, which is based on the mathematical model of Reference (2), is called to make this check. It takes into account viscous flow in the groove under the action of surface tension and gravity. If the grooves are found to dry up, the integration is stopped, the assumed heat load is reduced, and the integration is repeated. If the integration continues to the evaporator end of the heat pipe without groove dry-up occurring, the assumed heat load is increased, and the integration is repeated. A binary search is used to find the maximum heat load that does not result in groove dry-up.

The calculation of the condenser-end stress used to begin the integration is crucial. The stress must be high enough to prevent a liquid puddle or slug from forming in the lowest vapor space. If, however, the stress is set too high, the wick must begin with an unnecessarily low porosity to enable the wick to fill. In the condenser region, where the wick porosity is relatively high, a small reduction in porosity can result in a large reduction in permeability. For example, if a saturation fraction of 0.9 is specified, then we see from Figure 2 that a 1 percent reduction in a typical condenser-end porosity of 0.88 leads to a 15 percent reduction in the permeability. Therefore, for a high heat-transport capacity, the condenser-end stress should be kept as low as possible. This is one reason why, as discussed previously, a reduction in wick area can result in an increase in capacity. The increased size of the vapor space reduces its capillary back pressure and allows a higher condenser-end porosity.

The first requirement on the condenser-end stress is that it must be high enough that a puddle does not form in the lower vapor space. For simplicity, we restrict our attention to the situation depicted in Figure 1 where the slab wick is horizontal. If the capillary stress at the top of the wick has been increased to a point where a puddle is just about to disappear, the radius of curvature of the meniscus of the puddle is nearly equal to the tube radius R. The stress σ/R at the puddle surface is related hydrostatically to the stress at the top of the wick; thus the stress required to prevent a puddle is

$$P_0 = \sigma/R + (\rho_\ell - \rho_V)\, g\, h_W \qquad (12)$$

where h_W is the distance between the top of the wick and the bottom of the tube. The second requirement on the condenser-end stress is that it should be high enough to prevent a liquid slug in the lower vapor space.

The conditions under which a slug will form, presented in Reference (2), are calculated by subroutine VSBKS. The stress used to begin the integration is the greater of the value for the formation of a puddle and a liquid slug.

3.0 INPUT FOR GRADE II

The input is in Fortran NAMELIST form. The required parameters are defined and discussed below. An input form is given in Table 1.

3.1 HEADINGS

After writing on the first card or line the NAMELIST identifier $GRDATA, the user then inputs two lines of descriptive information by writing on one card or line HD1 = 60H followed by up to 60 characters of title and on the next card or line HD2 = 60H followed by another 60 characters. GRADE II will print these two lines at the beginning of the output.

3.2 FLUID PROPERTIES

GRADE II automatically computes the required fluid properties for one of several fluids, which the user specifies by selecting a value of LIQ from the following list:

	Fluid	Temperature Range
LIQ = 1	Water	(0C < T < 204C)
LIQ = 2	Ammonia	(-78C < T < 88C)
LIQ = 3	Methyl Alcohol	(-96C < T < 193C)
LIQ = 4	FREON-21	(-48C < T < 152C)
LIQ = 5	Ethane	(-93C < T < 27C)
LIQ = 6	Methane	(-173C < T < -84C)
LIQ = 7	Nitrogen	(-207C < T < -157C)

The properties are for a temperature TKELVN that the user inputs in degrees Kelvin. All other fluid properties are automatically computed for that temperature. If another fluid is used, set LIQ = 0. Then, values must be specified for the following quantities:

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TABLE I

Problem No.

NAMELIST INPUT FORM

Keypunched by

No. of Cards

1

Verified by

1 2 TITLE: GRADE II INPUT 80 COMMENT

$ GRDATA
HD1 = 60H
HD2 = 60H
LIQ =
TKELVN =
RHOL =
RHOV =
VISL =
VISV =
ST =
HFG =

Input only if LIQ = 0

HPID =
WKTH =
IGEOM =
NQ =
XQ =
FQ =
QDOT =
NELEV =
XELEV =
ELEV =
GEE =
GRVS =
W =

NL

SYSTEMS 2404 REV. 6-73

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Date
Name
Problem No
No. of Cards

TABLE I

NAMELIST INPUT FORM

1

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Keypunched by
Verified by

1 2 TITLE: GRADE II INPUT (CONT'D) 80 COMMENTS

DEPTH=
PHI=
ANGWET=
DIAF=
S=
EPSMIN=
LASTEPS=
NEPS=
XEPS=
EPSX=
DX=
ISLFPRM=
ROUGH=
IFLTS=
NCASE=
$END
$GRDATA

For another case, input only parameters that are changed

NL
$END

SYSTEMS 2994 REV. 6-73

Quantity	Symbol	Units
Liquid density	RHOL	Kg/cu. m
Vapor density	RHOV	Kg/cu. m
Liquid viscosity	VISL	N·s/sq. m
Vapor viscosity	VISV	N·S/sq. m
Surface tension	ST	N/m
Latent heat	HFG	J/Kg

3.3 GEOMETRICAL PARAMETERS OF THE HEAT-PIPE CROSS SECTION

As shown in Figure 1, the heat pipe uses a slab wick in either a horizontal or vertical orientation. The input parameters that specify the cross-sectional geometry are:

Quantity	Symbol	Units
Tube inside diameter	HPID	cm
Slab-wick thickness	WKTH	cm
Geometrical parameter:		
Horizontal slab wick	IGEOM = 0	
Vertical slab wick	IGEOM = 1	

All other parameters of the heat-pipe cross section, such as the wick area, vapor-space hydraulic diameter, etc. are automatically calculated.

3.4 HEAT INPUT

The user specifies the heat-input distribution by specifying the fraction of the total heat-transfer rate for up to ten segments of the heat pipe. Heat transfer is assumed to be constant along the given segment. Values for the following parameters are required:

NQ - The number of segments, which must not exceed ten, into which the heat pipe is divided.

XQ(I) - The length of the I^{th} segment in cm. The segments must be numbered consecutively along the heat pipe beginning at the condenser end.

FQ(I) - The fraction of the total heat-transfer rate entering the I^{th} segment. If the I^{th} segment is a condenser, FQ(I) is negative. If the I^{th} segment is adiabatic, FQ(I) is zero.

QDOT - A nominal heat-transfer rate in watts, which is the user's best guess at the maximum. A close guess reduces the number of iterations to the final answer.

3.5 ELEVATIONS

The user specifies the heat-pipe orientation in a gravitational field by inputing values for elevations of points along the heat pipe where the slope changes. Between points, GRADE assumes a linear variation of elevation. Values of the following parameters are required (except for zero gravity):

NELEV - The total number of points along the heat pipe, which must not exceed 10.

XELEV(I) The distance along the heat pipe in cm to the I^th point. Both ends of the heat pipe must be input, therefore the first point must be at zero distance [XELEV(1) = 0.0], and the last at the total heat-pipe length [XELEV(NELEV) = L].

ELEV(I) - The elevation in cm of the I^th point relative to a horizontal reference plane.

GEE - Gravitational acceleration in standard gravities.

3.6 CIRCUMFERENTIAL GROOVE PARAMETERS

The cross-section of the circumferential grooves is trapezoidal as shown in Figure 4.

The following parameters must be input:

Quantity	Symbol	Units
Number of grooves per cm	GRVS	cm^{-1}
Groove opening	W	cm
Groove depth	DEPTH	cm
Groove half angle	PHI	degrees
Wetting angle	ANGWET	degrees

3.7 WICK PARAMETERS

The user can use the program either to design an optimum graded-porosity wick and compute its capacity, or he can use it to compute the capacity of a wick with a specified porosity distribution.

3.7.1 Design of a Graded-Porosity Wick

To design a graded-porosity wick, the user must specify:

Quantity	Symbol	Units
Fiber diameter	DIAF	cm
Saturation fraction	S	
Minimum allowable porosity	EPSMIN	

The saturation fractions are the uniform high level of saturation that the wick is to maintain. We have been using S = 0.9. When the porosity variation is to be designed, the parameters LASTEPS and NEPS must be set to zero or, equivalently, just not included in the NAMELIST. The minimum porosity EPSMIN is set so that a wick will not be designed that is too dense to manufacture.

3.7.2 Capacity at Off-Optimum Operation

The program is set up to run several cases; one NAMELIST input is simply followed by another. When a wick is designed and the user desires to calculate the performance of that wick at off-optimum conditions (a different temperature or evaporator elevation, for example), he simply sets the parameter LASTEPS = 1. This causes the porosity variation to be that of the previous case (be sure to set NEPS = 0).

3.7.3 Specified Porosity Distribution

If the user desires to compute the capacity of a wick with a specified porosity distribution, he specifies the local porosity of a number of points along its length. Between points, values of the porosity are calculated by linear interpolation. The required input parameters are:

Quantity	Symbol	Units
Number of porosity points (up to 10)	NEPS	
Distance to I^{th} point	XEPS(I)	cm
Porosity of I^{th} point	EPSX(I)	
Wick fiber diameter	DIAF	cm

The first point must be at the condenser end [XEPS(1) = 0] and the last point must be at the evaporator end [XEPS(NPHI) = heat-pipe length]. Set S = 0 and LASTEPS = 0.

3.8 OTHER INPUT PARAMETERS

DX - The integration step size in cm.

IPRIMED - Equals 0 if the user requires the wick to self-prime under no load at the operating elevations.
- Equals 1 if the wick is allowed to self-prime level under no load before the heat pipe is raised to the operating elevations.

ROUGH - The average surface roughness of the vapor spaces, which is used for the calculation of the turbulent friction-factor coefficient.

IFLTS - Equals 1 if the contribution of excess-liquid fillets and puddles are to be included, in which case an additional input file is needed (see Section 4).
- Equals 0 if the excess-liquid contribution is not to be included.

NCASE - Equals 1 if a NAMELIST input for another case is to follow, which is exactly like the first except only those parameters that are to be different in the new case are included.
- Equals 0 if the present case is the last case.

$END - Ends present NAMELIST input.

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TABLE II

NAMELIST INPUT FORM

Problem No | Keypunched by

No. of Cards | 1 | Verified by

TITLE: FILLET INPUT | 80 | COMMENTS

```
$ FILLETD
LIQ =
TKELVN =
RHO =                }  Input only
ST =                 }   if LIQ = 0
IGECM =
WKTH =
HPID =
SEE =
$ END
```

NL

4.0 THE PROGRAM FILLET

If the user includes the effect of excess-liquid fillets and puddles, he sets IFLTS = 1 in the NAMELIST input for GRADE II. This causes GRADE II to read data from a binary file, TAPE 7, which is the output of the program FILLET. The theoretical basis for FILLET is described in Reference (2). In essence, it numerically integrates the differential equations that describe the free-surface shape of fillets and puddles that can exist in the heat pipe. The output from FILLET is a table of total cross-sectional area and hydraulic diameter of the excess liquid as a function of stress.

4.1 INPUT TO FILLET

FILLET also uses NAMELIST input. An input form is given in Table II. The NAMELIST identifier is $FILLETD. The input variable, which have the same definitions as those for GRADE II are:

LIQ TKELVN RHO* ST*	Refer to Section 3.2
IGEOM WKTH HPID	Refer to Section 3.3
GEE	Refer to Section 3.5

*RHO, which is the difference between the liquid and and vapor density (RHOL-RHOV), and the surface tension ST are input only if LIQ = 0.

The NAMELIST ends with the line $END.

5.0 SAMPLE CALCULATIONS

In this section we describe two sample problems. The first is selected to illustrate the option for including excess liquid, while the second is selected to illustrate the design of a graded-porosity wick.

5.1 A SIMPLE METAL-FELT SLAB-WICK HEAT PIPE

The input file for the first heat pipe we are considering is given in Table III. The heat pipe is 30-cm long, with condenser, adiabatic and evaporator lengths of 10 cm each (XQ = 3* 10.). The inside diameter of the tube is 1. cm (HPID = 1.), the wick thickness is .4 cm (WKTH = .4) and it is vertical (IGEOM = 1). The wick is a slab of felt metal which has a fiber diameter of 0.002 cm (DIAF = .002). To specify a uniform porosity, we specify the porosity of two points (NEPS = 2) at the condenser end and the evaporator end (XEPS = 0., 30.). At each point we set the porosity to 0.80 (EPSX = 2* .80), and thus a linear interpolation for points in between results in the desired uniform porosity. The circumferential grooves have a width at the top of 0.015 cm (W = .015), a depth of 0.015 cm (DEPTH = .015) and a half angle of 20 degrees (PHI = 20.). We specified 100 grooves per cm (GRVS = 100.). Upon reflection one sees that it would be impossible to cut such grooves so close together; however, they will serve for purposes of this illustration. Several cases are run with the evaporator elevated 2., 0., 4., and 6. cm higher than the condenser end. The fluid is ammonia (LIQ = 2) at 300K (TKELVN = 300.).

Since the effect of liquid fillets are to be included, IFLTS is set equal to unity, and the program FILLET must be run first. The NAMELIST input to FILLET is shown in Table IV. The output from FILLET is written in binary on TAPE 7, which is read by GRADE II along with the input of Table III.

The output from GRADE II is shown for the first case (evaporator elevation of 2. cm) in Table V. First the input parameters and calculated parameters are listed. Most of the calculated parameters are clearly explained by their name, i.e., wick area, etc. We will comment on those that require elaboration:

TABLE III
SAMPLE INPUT TO GRADE II

```
$GRDATA
H01=60H1SIMPLE FELT-METAL SLAB-WICK HEAT PIPE
H02=60H FILE NAME  X13        9/20/76
LIO=2
THELVN=300.
HPID=1.
WKTH=.4
IGEOP=1
NG=3
XG=3*10.
FQ=-1.,0.,1.
QDOT=100.
NELEV=2
XELEV=0.,30.
ELEV=0.,2.
GEE=1.
GRVS=100.
W=.019
DEPTH=.019
PHI=20.
ANGWET=0.
DIAF=.002
NEPS=2
XEPS=0.,30.
EPSX=2*.8
DX=1.
IPRIMED=1
ROUGH=.02
IFLTS=1
NCASE=1
$END
$GRDATA
ELEV=0.,0.
$END
$GRDATA
ELEV=0.,4.
$END
$GRDATA
ELEV=0.,[illegible]
NCASE=[illegible]
$END
```

```
$FILLETD
LIQ=2
TKELVN=300.
IGEOM=1
WKTH=.4
HPID=1.
GEE=1.
$END
```

TABLE IV. SAMPLE INPUT TO FILLET FOR SIMPLE FELT-METAL SLAB-WICK HEAT PIPE

TABLE V - OUTPUT FROM GRADE II

```
1SIMPLE FELT-METAL SLAB-WICK HEAT PIPE
 FILE NAME  X13        9/20/76


 INPUT VARIABLES AND FLUID PROPERTIES:


      LIQUID NUMBER....................     LIQ =  2
      TEMPERATURE......................  TKELVN =  3.00000E+02  DEGREES KELVIN
      LIQUID DENSITY...................    RHOL =  6.00409E+02  KG/CU. M
      VAPOR DENSITY....................    RHOV =  6.26329E+00  KG/CU. M
      SURFACE TENSION..................      ST =  1.95290E-02  NEWTONS/M
      LIQUID VISCOSITY.................    VISL =  1.30130E-04  NEWTON-SEC/SQ. M
      VAPOR VISCOSITY..................    VISV =  9.99266E-06  NEWTON-SEC/SQ. M
      LATENT HEAT......................     HFG =  1.16066E+06  JOULES/KG
      VAPOR PRESSURE...................      PV =  1.06096E+06  N/SQ. M
      THERMAL CONDUCTIVITY OF LIQ...        XKL =  5.09329E-01  WATTS/M K
      SPECIFIC HEAT RATIO..........        SHRV =  1.31000E+00
      MOLECULAR WEIGHT.............         XMW =  1.70320E+01
      FREEZING TEMPERATURE.........          TF =  1.95444E+02  DEGREES KELVIN

      GRAVITATIONAL ACCELERATION....        GEE =  1.00000E+00  STANDARD GRAVITIES

      HEAT-PIPE GEOMETRY............      IGEOM =  1
           (0=HORIZ. SLAB, 1=VERT. SLAB, 3=GENERAL)

      HEAT-PIPE INSIDE DIAMETER.....       HPID =  1.00000E+00  CM
      WICK THICKNESS................       WKTH =  4.00000E-01  CM

      WICK AREA.....................         AW =  3.89061E-01  SQ. CM
      WICK HEIGHT...................         HW =  9.58259E-01  CM
      WICK FIBER DIAMETER...........       DIAF =  2.00000E-03  CM
      SPECIFIED SATURATION FRACTION.          S =  0.
      MINIMUM ALLOWABLE POROSITY....     EPSMIN =  0.

      NO. SPECIFIED-POROSITY PTS....       NEPS =  2
      POROSITY POINT NO.    1
           DISTANCE TO POINT........       XEPS =  0.           CM
           POROSITY AT POINT........       EPSX =  8.00000E-01
      POROSITY POINT NO.    2
           DISTANCE TO POINT........       XEPS =  3.00000E+01  CM
           POROSITY AT POINT........       EPSX =  8.00000E-01
```

```
NO. OF EQUAL VAPOR SPACES.....       NVS =  2
AREA OF EACH VAPOR SPACE......       AVS =  1.98168E-01  SQ. CM
VAPOR-SPACE DIAMETER..........     DIAVS =  3.41665E-01  CM
HEIGHT TO TOP OF LOWEST V.S. .       HVS =  9.16515E-01  CM
TOTAL ACTIVE PERIMETER OF V.S.     PERIM =  1.15924E+00  CM

GROOVE OPENING................         W =  1.50000E-02  CM
GROOVE DEPTH..................     DEPTH =  1.50000E-02  CM
GROOVE HALF-ANGLE.............       PHI =  2.00000E+01  DEGREES
WETTING ANGLE.................    ANGWET =  0.           DEGREES
FIRST GROOVE FEED LOCATION....       TH1 = -1.56442E+02  DEGREES FROM TOP
SECOND GROOVE FEED LOCATION...       TH2 = -2.35782E+01  DEGREES FROM TOP
RADIAL INPUT FRACTION.........     FCGRV =  5.00000E-01
WICK HEIGHT REL. TO TUBE AXIS.      HREF =  5.00000E-01  CM
NO. GROOVES PER CM............      GRVS =  1.00000E+02  /CM

NOMINAL HEAT-TRANSFER RATE....      QDOT =  1.00000E+02  WATTS
NO. HEAT-INPUT SECTIONS.......        NC =  3
SECTION NUMBER    1
     SECTION LENGTH...........        XC =  1.00000E+01  CM
     HEAT-INPUT FRACTION......        FC = -1.00000E+00
SECTION NUMBER    2
     SECTION LENGTH...........        XC =  1.00000E+01  CM
     HEAT-INPUT FRACTION......        FC =  0.
SECTION NUMBER    3
     SECTION LENGTH...........        XC =  1.00000E+01  CM
     HEAT-INPUT FRACTION......        FC =  1.00000E+00

NO. ELEVATION POINTS..........     NELEV =  2
ELEVATION POINT NO.    1
     DISTANCE TO POINT........     XELEV =  0.           CM
     ELEVATION OF POINT.......      ELEV =  0.           CM
ELEVATION POINT NO.    2
     DISTANCE TO POINT........     XELEV =  3.00000E+01  CM
     ELEVATION OF POINT.......      ELEV =  2.00000E+00  CM

INTEGRATION STEP SIZE.........        DX =  1.00000E+00  CM

WICK PRIMED LEVEL (1=YES).....   IPRIMED =  1

LIQUID EFFECTS ALONG WICK.....     IEFTS =  1
```

```
ANOTHER CASE (0=NO, 1=YES)....    NCASE =  1
USE LAST POROSITY DISTN.......  LASTEPS =  0
ONLY ONE INTEGRATION PASS.....    IPASS =  0
PLOT POROSITY.................    IPLOT =  0
VAPOR SPACE SURFACE ROUGHNESS.    ROUGH =  2.00000E-02  CM
```

```
FINAL SOLUTION

     THE MAXIMUM HEAT-TRANSFER RATE IS.......  3.13477E+01  WATTS
     THE TOTAL LIQUID IN WICK IS.............  5.69332E+00  GRAMS
     THE VAPOR REYNOLDS NUMBER IS............  2.60414E+02
     THE MAX. VAPOR VELOCITY HEAD IS.........  4.84206E-04  CM LIQ.
     THE RADIAL REYNOLDS NUMBERS ARE:
          FOR SECTION NO.  1................ -2.22577E+00
          FOR SECTION NO.  2................  0.
          FOR SECTION NO.  3................  2.22577E+00


          DISTANCE        STRESS      STATIC HEAD     POROSITY     SATURATION    VAPOR PRESSURE
            (CM)        (CM LIQ.)      (CM LIQ.)                                  (CM LIQ.)


          0.             1.0256E+00    0.             8.0000E-01    0.             0.
          1.0000E+00     1.0924E+00    6.6667E-02     8.0000E-01    9.9999E-01     1.1207E-05
          2.0000E+00     1.1605E+00    1.3333E-01     8.0000E-01    9.9999E-01     4.4829E-05
          3.0000E+00     1.2321E+00    2.0000E-01     8.0000E-01    9.9998E-01     1.0086E-04
          4.0000E+00     1.3124E+00    2.6667E-01     8.0000E-01    9.9998E-01     1.7931E-04
          5.0000E+00     1.4137E+00    3.3333E-01     8.0000E-01    9.9998E-01     2.8018E-04
          6.0000E+00     1.5564E+00    4.0000E-01     8.0000E-01    9.9998E-01     4.0346E-04
          7.0000E+00     1.7755E+00    4.6667E-01     8.0000E-01    9.9998E-01     5.4915E-04
          8.0000E+00     2.0516E+00    5.3333E-01     8.0000E-01    9.9998E-01     7.1726E-04
          9.0000E+00     2.3754E+00    6.0000E-01     8.0000E-01    9.9998E-01     9.0776E-04
          1.0000E+01     2.7383E+00    6.6667E-01     8.0000E-01    9.9997E-01     1.1337E-03
          1.1000E+01     3.1164E+00    7.3333E-01     8.0000E-01    9.9996E-01     1.4305E-03
          1.2000E+01     3.4957E+00    8.0000E-01     8.0000E-01    9.9995E-01     1.7274E-03
          1.3000E+01     3.8762E+00    8.6667E-01     8.0000E-01    9.9993E-01     2.0245E-03
          1.4000E+01     4.2577E+00    9.3333E-01     8.0000E-01    9.9991E-01     2.3211E-03
          1.5000E+01     4.6395E+00    1.0000E+00     8.0000E-01    9.9989E-01     2.6160E-03
          1.6000E+01     5.0215E+00    1.0667E+00     8.0000E-01    9.9986E-01     2.9148E-03
          1.7000E+01     5.4040E+00    1.1333E+00     8.0000E-01    9.9982E-01     3.2117E-03
          1.8000E+01     5.7867E+00    1.2000E+00     8.0000E-01    9.9977E-01     3.5095E-03
          1.9000E+01     6.1594E+00    1.2667E+00     8.0000E-01    9.9971E-01     3.8054E-03
          2.0000E+01     6.5531E+00    1.3333E+00     8.0000E-01    9.9962E-01     4.1023E-03
          2.1000E+01     6.9701E+00    1.4000E+00     8.0000E-01    9.9954E-01     [illegible]
          2.2000E+01     7.2670E+00    1.4667E+00     8.0000E-01    9.9944E-01     4.6911E-03
          2.3000E+01     7.5700E+00    1.5333E+00     8.0000E-01    9.9933E-01     4.9879E-03
```

```
2.4000E+01     7.8528E+00     1.6000E+00     8.0000E-01     9.9922E-01     5.7093E-03
2.5000E+01     8.0974E+00     1.6667E+00     8.0000E-01     9.9911E-01     5.9914E-03
2.6000E+01     8.3096E+00     1.7333E+00     8.0000E-01     9.9900E-01     6.2223E-03
2.7000E+01     8.4659E+00     1.8000E+00     8.0000E-01     9.9890E-01     6.4016E-03
2.8000E+01     8.6376E+00     1.8667E+00     8.0000E-01     9.9882E-01     6.5301E-03
2.9000E+01     8.7529E+00     1.9333E+00     8.0000E-01     9.9874E-01     6.6071E-03
3.0000E+01     8.8358E+00     2.0000E+00     8.0000E-01     9.9869E-01     6.6327E-03
```

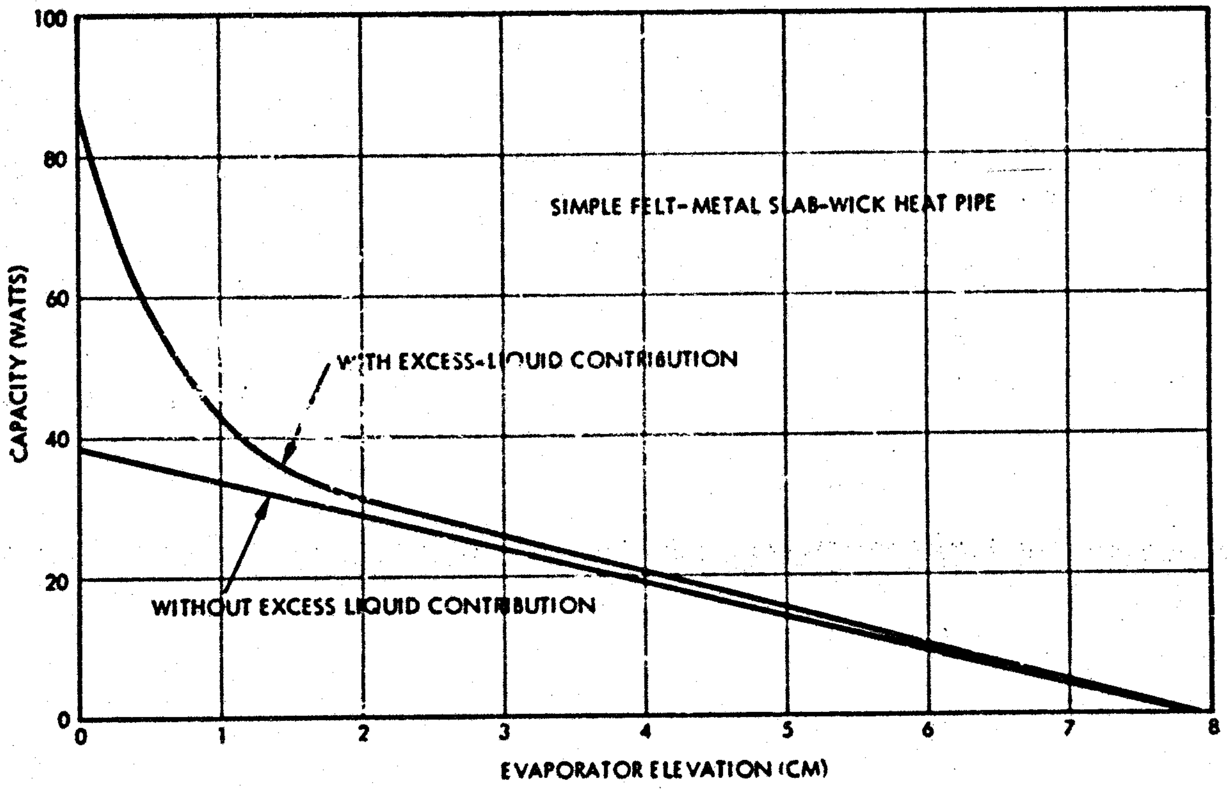

Figure 5. Capacity Vs. Elevation for Metal-Felt Slab-Wick Heat Pipe

HW - The wick height is the height in the heat-pipe cross section to the top of the wick from the lowest point in the vapor spaces.

DIAVS - The vapor-space diameter is the hydraulic diameter, four times the area divided by the wetted perimeter.

HVS - The height to the top of the lowest vapor space from the lowest point in the vapor spaces.

PERIM - Active perimeter of vapor space is the perimeter over which evaporation or condensation occurs.

TH1, TH2 - Angular groove feed locations measured positively counterclockwise from the top of the heat pipe [see Reference (2)].

FQGRV - Radial input fraction is the fraction of heat input to a single vapor space.

Under the heading "FINAL SOLUTION," the pertinent data on the heat pipe at its maximum capacity are printed. In this case, the maximum capacity is 31 watts, the fluid charge is 5.7 grams, the vapor Reynolds number based on the average vapor velocity $\overline{u}$ in the adiabatic section and the hydraulic diameter of the vapor space is 260, and the vapor velocity head $1/2\ \rho_v \overline{u}^2$ is 4.8×10^{-4} cm of liquid. The radial Reynolds numbers, which are based on the normal velocity of the vapor, negative when towards the condensing surface and positive when away from the evaporating surface, is -2.22 in the condenser and +2.22 for the evaporator. Next the distribution of stress, static head, porosity, saturation fraction and static pressure of the vapor are listed. The static head is the contribution to stress from the gravitational acceleration.

The results of several runs for the capacity of this heat pipe as a function of elevation are shown in Figure 5. Two curves both with (IFLTS = 1) and without (IFLTS = 0) the effect of excess liquid are shown. The wick in this heat pipe was intentionally selected to have a low permeability in order to show the marked effect excess liquid can have on a heat pipe.

5.2 EXAMPLE OF GRADED-POROSITY-WICK DESIGN

In the second sample problem, we focus on the design of a graded-porosity wick. The input is given in Table VI and the output is given in Table VII. The heat pipe has an inside diameter of 1.1 cm (HPID = 1.1), a wick thickness of 0.51 cm (WKTH = 0.51) with a fiber diameter of 0.0127 cm (DIAF = .0127). In this case the wick is horizontal (IGEOM = 0). The condenser, adiabatic and evaporator lengths are, respectively, 50, 60 and 30 cm (XQ = 50., 60., 30.).

The wick is being designed for maximum capacity when the evaporator end is elevated 2 cm (ELEV = 0., 2.). By setting IPRIMED = 0, we are requiring the wick to self-prime at the operating tilt. Because fibrous wicks exhibit capillary hysteresis, a wick with a higher capacity could be designed if the user accepts the operating constraint of first leveling the heat pipe with no load to prime the wick before elevating the evaporator end. If this option is elected, IPRIMED is set to 1.

The TRW version of GRADE II has the provision to automatically plot the wick volume density profile (the volume density is one minus the porosity). This plotting capability, which is activated by setting IPLOT = 1, utilizes plotting routines outside of standard FORTRAN, and thus it is not included in the user's manual. The plot of the volume-density distribution is shown in Figure 6. The wick begins with a porosity of .873 at the condenser end and ends with a porosity of .631 which is above the set minimum of .60 (EPSMIN = .60). The output of Table VII shows that the maximum heat-transfer rate is 85 watts, and the fluid charge is 31.1 grams of ammonia.

TABLE VI - GRADE II INPUT

GRADED-POROSITY-WICK DESIGN

```
$GRDATA
HD1=60H EXAMPLE OF GRADED-POROSITY-WICK DESIGN
HD2=60H FILE NAME  HITILT    9/20/76
LIQ=2
TKELVN=300.
HPID=1.1
WKTH=.51
IGEOM=0
NQ=3
XQ=50.,60.,30.
FQ=-1.,0.,1.
QDOT=100.
NELEV=2
XELEV=0.,140.
ELEV=0.,2.
GLE=1.
GRVS=40.
W=.018
DEPTH=.020
PHI=20.
ANGWET=0.
DIAF=.0127
S=.9
EPSMIN=.6
DX=5.
IPRIMED=0
ROUGH=.02
IPLOT=1
$END
```

TABLE VII - GRADE II OUTPUT

```
EXAMPLE OF GRADED-POROSITY-WICK DESIGN
FILE NAME  HITILT     4/29/76

INPUT VARIABLES AND FLUID PROPERTIES:

     LIQUID NUMBER......................     LIQ =  2
     TEMPERATURE........................  TKELVN =  3.00000E+02  DEGREES KELVIN
     LIQUID DENSITY.....................    RHOL =  [illegible]E+02  KG/CU. M
     VAPOR DENSITY......................    RHOV =  9.2[illegible]E+00  KG/CU. M
     SURFACE TENSION....................      ST =  1.95290E-02  NEWTONS/M
     LIQUID VISCOSITY...................    VISL =  1.30130E-04  NEWTON-SEC/SQ. M
     VAPOR VISCOSITY....................    VISV =  [illegible]E-06  NEWTON-SEC/SQ. M
     LATENT HEAT........................     HFG =  1.1[illegible]E+06  JOULES/KG
     VAPOR PRESSURE.....................      PV =  1.06[illegible]E+06  N/SQ. M
     THERMAL CONDUCTIVITY OF LIQ...          XKL =  5.09325E-01  WATTS/M K
     SPECIFIC HEAT RATIO.............       SHRV =  1.31000E+00
     MOLECULAR WEIGHT..................      XMW =  1.70320E+01
     FREEZING TEMPERATURE............         TF =  1.95444E+02  DEGREES KELVIN

     GRAVITATIONAL ACCELERATION....          GEE =  1.00000E+00  STANDARD GRAVITIES

     HEAT-PIPE GEOMETRY.............       IGEOM =  0
          (0=HORIZ. SLAB, 1=VERT. SLAB, 2=GENERAL)

     HEAT-PIPE INSIDE DIAMETER.....         HPID =  1.10000E+00  CM
     WICK THICKNESS.................        WKTH =  5.10000E-01  CM

     WICK AREA........................        AW =  5.40190E-01  SQ. CM
     WICK HEIGHT......................        HW =  8.[illegible]E-01  CM
     WICK FIBER DIAMETER...........         DIAF =  1.27000E-02  CM
     SPECIFIED SATURATION FRACTION,            S =  9.00000E-01
     MINIMUM ALLOWABLE POROSITY....       EPSMIN =  6.00000E-01

     NO. SPECIFIED-POROSITY PTS....         NEPS =  0

     NO. OF EQUAL VAPOR SPACES......         NVS =  2
     AREA OF EACH VAPOR SPACE.......         AVS =  2.[illegible]E-01  SQ. CM
     VAPOR-SPACE DIAMETER..........        DIAVS =  3.77[illegible]E-01  CM
     HEIGHT TO TOP OF LOWEST V.S. .          HVS =  2.4[illegible]E-01  CM
     TOTAL ACTIVE PERIMETER OF V.S.        PERIM =  1.[illegible]E+00  CM
```

```
GROOVE OPENING..................        W =  1.00000E-02  CM
GROOVE DEPTH....................    DEPTH =  2.00000E-02  CM
GROOVE HALF-ANGLE...............      PHI =  2.00000E+01  DEGREES
WETTING ANGLE...................   ANGLEI =  0.           DEGREES
FIRST GROOVE FEED LOCATION......      TH1 = -6.23780E+01  DEGREES FROM TOP
SECOND GROOVE FEED LOCATION.....      TH2 =  6.23780E+01  DEGREES FROM TOP
RADIAL INPUT FRACTION...........    FRADV =  5.00000E-01
WICK HEIGHT REL. TO TUBE AXIS...     HREL =  2.55000E-01  CM
NO. GROOVES PER CM..............     GPCS =  4.00000E+01  /CM

NOMINAL HEAT-TRANSFER RATE......     QDOT =  1.00000E+02  WATTS
NO. HEAT-INPUT SECTIONS.........       NQ =  3
SECTION NUMBER    1
      SECTION LENGTH............       XQ =  5.00000E+01  CM
      HEAT-INPUT FRACTION.......       FQ = -1.00000E+00
SECTION NUMBER    2
      SECTION LENGTH............       XQ =  6.00000E+01  CM
      HEAT-INPUT FRACTION.......       FQ =  0.
SECTION NUMBER    3
      SECTION LENGTH............       XQ =  3.00000E+01  CM
      HEAT-INPUT FRACTION.......       FQ =  1.00000E+00

NO. ELEVATION POINTS............    NELEV =  2
ELEVATION POINT NO.    1
      DISTANCE TO POINT.........    XELEV =  0.           CM
      ELEVATION OF POINT........     ELEV =  0.           CM
ELEVATION POINT NO.    2
      DISTANCE TO POINT.........    XELEV =  1.40000E+02  CM
      ELEVATION OF POINT........     ELEV =  2.00000E+00  CM

INTEGRATION STEP SIZE...........       DX =  5.00000E+00  CM

WICK PRIMED LEVEL (1OR3)......   IPRIMD =  3

LIQUID FILLETS ALONG WICK.......    IFLTS =  0

ANOTHER CASE (1=YES,0=NO).......    NCASE =  0
USE LAST POROSITY DIST..........  ILASTPS =  0
ONLY ONE INTEGRATION PASS.......    IPASS =  [illegible]
PLOT POROSITY...................    IPLOT =  1
EXTRA WICK AT BEGINNING.........      XWB =  0.           CM
```

```
EXTRA WICK ON END..............      XXL =  [illegible]               IN
HIGH TOLERANCE ON VOL. DENSITY      HIGH =  [illegible]               PERCENT
LOW TOLERANCE ON VOL. DENSITY.       LOW =  [illegible]               PERCENT
VAPOR SPACE SURFACE ROUGHNESS.     [illegible] =  [illegible]         IN
```

FINAL SOLUTION

```
     THE MAXIMUM HEAT-TRANSFER RATE IS........  [illegible]  WATTS
     THE TOTAL LIQUID IN WICK IS..............  [illegible]  GRAMS
     THE VAPOR REYNOLDS NUMBER IS.............  [illegible]E+02
     THE MAX. VAPOR VELOCITY HEAD IS..........  1.[illegible]E-01  CM LIQ.
     THE RADIAL REYNOLDS NUMBERS ARE:
          FOR SECTION NO. 1 .................  [illegible]E+00
          FOR SECTION NO. 2 .................  0.
          FOR SECTION NO. 3 .................  [illegible]E+00


          DISTANCE        STRESS         STATIC HEAD       POROSITY        SATURATION      VAPOR PRESSURE
            (CM)        (CM LIQ.)        (CM LIQ.)                                            (CM LIQ.)

          0.            1.01[illegible]E+00    0.             [illegible]E-01    0.              0.
          5.0000E+00    1.0[illegible]E+00     7.[illegible]E-03    [illegible]E-01    [illegible]E-01    1.7[illegible]E-04
          1.0000E+01    1.1[illegible]E+00     1.[illegible]E-02    [illegible]E-01    [illegible]E-01    [illegible]E-04
          1.5000E+01    1.2[illegible]E+00     2.[illegible]E-02    [illegible]E-01    [illegible]E-01    1.[illegible]E-03
          2.0000E+01    1.3471[illegible]E+00  2.[illegible]E-02    [illegible]E-01    [illegible]E-01    2.77[illegible]E-03
          2.5000E+01    1.4[illegible]E+00     1.[illegible]E-01    [illegible]E-01    [illegible]E-01    [illegible]E-03
          3.0000E+01    1.[illegible]E+00      [illegible]E-01      [illegible]E-01    [illegible]E-01    [illegible]E-03
          3.5000E+01    [illegible]E+00        [illegible]E-01      [illegible]E-01    [illegible]E-01    [illegible]E-03
          4.0000E+01    1.[illegible]E+00      [illegible]E-01      [illegible]E-01    [illegible]E-01    [illegible]E-02
          4.5000E+01    1.[illegible]E+00      [illegible]E-01      [illegible]E-01    [illegible]E-01    1.[illegible]E-02
          5.0000E+01    2.[illegible]E+00      7.[illegible]E-01    7.[illegible]E-01  [illegible]E-01    1.7[illegible]E-02
          5.5000E+01    2.[illegible]E+00      7.[illegible]E-01    7.[illegible]E-01  [illegible]E-01    2.[illegible]E-02
          6.0000E+01    2.[illegible]E+00      [illegible]E-01      7.[illegible]E-01  [illegible]E-01    2.[illegible]E-02
          6.5000E+01    2.7[illegible]E+00     [illegible]E-01      7.[illegible]E-01  [illegible]E-01    [illegible]E-02
          7.0000E+01    2.[illegible]E+00      [illegible]          7.[illegible]E-01  [illegible]E-01    [illegible]E-02
          7.5000E+01    3.[illegible]E+00      [illegible]E+00      7.[illegible]E-01  [illegible]E-01    [illegible]E-02
          8.0000E+01    3.[illegible]E+00      [illegible]E+00      7.[illegible]E-01  [illegible]E-01    [illegible]E-02
          8.5000E+01    3.7[illegible]E+00     [illegible]E+00      7.[illegible]E-01  [illegible]E-01    [illegible]E-02
          9.0000E+01    [illegible]E+00        1.[illegible]E+00    7.[illegible]E-01  [illegible]E-01    [illegible]E-02
          9.5000E+01    [illegible]E+00        [illegible]E+00      7.[illegible]E-01  [illegible]E-01    [illegible]E-02
          1.0000E+02    [illegible]E+00        [illegible]E+00      7.[illegible]E-01  [illegible]E-01    [illegible]E-02
          1.0500E+02    [illegible]E+00        [illegible]E+00      7.[illegible]E-01  [illegible]E-01    [illegible]E-02
          1.1000E+02    [illegible]E+00        [illegible]E+00      7.[illegible]E-01  [illegible]E-01    [illegible]E-02
          1.1500E+02    [illegible]E+00        [illegible]E+00      [illegible]E-01    [illegible]E-01    7.[illegible]E-02
```

```
1.2000E+02   6.0433E+00   1.7493E+00   6.7336E-01   9.0000E-01   7.7526E-02
1.2500E+02   6.4732E+00   1.8857E+00   6.5374E-01   9.0000E-01   6.1335E-02
1.3000E+02   6.7124E+00   1.9571E+00   6.4361E-01   9.0000E-01   [illegible]
1.3500E+02   [illegible]  [illegible]  [illegible]  9.0000E-01   6.8772E-02
1.4000E+02   7.1732E+00   2.0000E+00   6.3117E-01   9.0000E-01   6.7593E-02
```

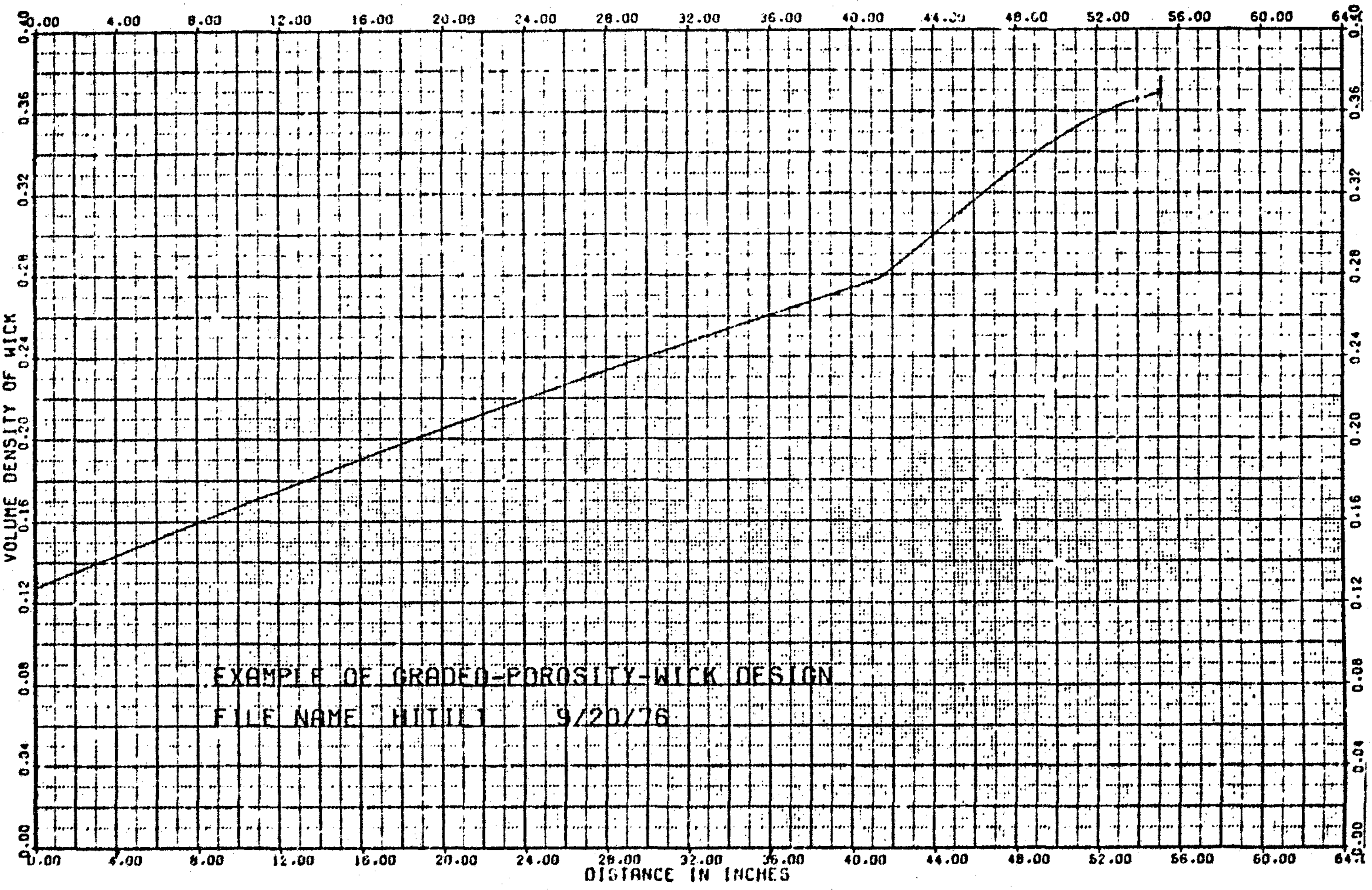

Figure 6. Example of Graded-Porosity-Wick Design, File Name Hitilt 9/20/76

6.0 REFERENCES

1. Eninger, J. E., "Computer Program GRADE for Design and Analysis of Graded-Porosity Heat-Pipe Wicks," NASA CR137618, 1974.
2. Eninger, J. E., Edwards, D. K., and Luedke, E. E., "Flight Data Analysis and Further Developments of Variable-Conductance Heat Pipes, Research Report No. 2," NASA CR137953, 1976.
3. Eninger, J. E., "Capillary Flow Through Heat-Pipe Wicks," American Institute of Aeronautics and Astronautics Paper 75-661, May 1975, Denver, Colo. To be published in the 1975 Thermophysics Volume of the AIAA Progress in Aeronautics and Astronautics series.
4. Eninger, J. E., Luedke, E. E. and Wanous, D. J., "Flight Data Analysis and Further Developments of Variable-Conductance Heat Pipes, Research Report No. 1," NASA CR137782, 1976.

APPENDIX
DESCRIPTION AND LISTING OF
GRADE II
AND
FILLET

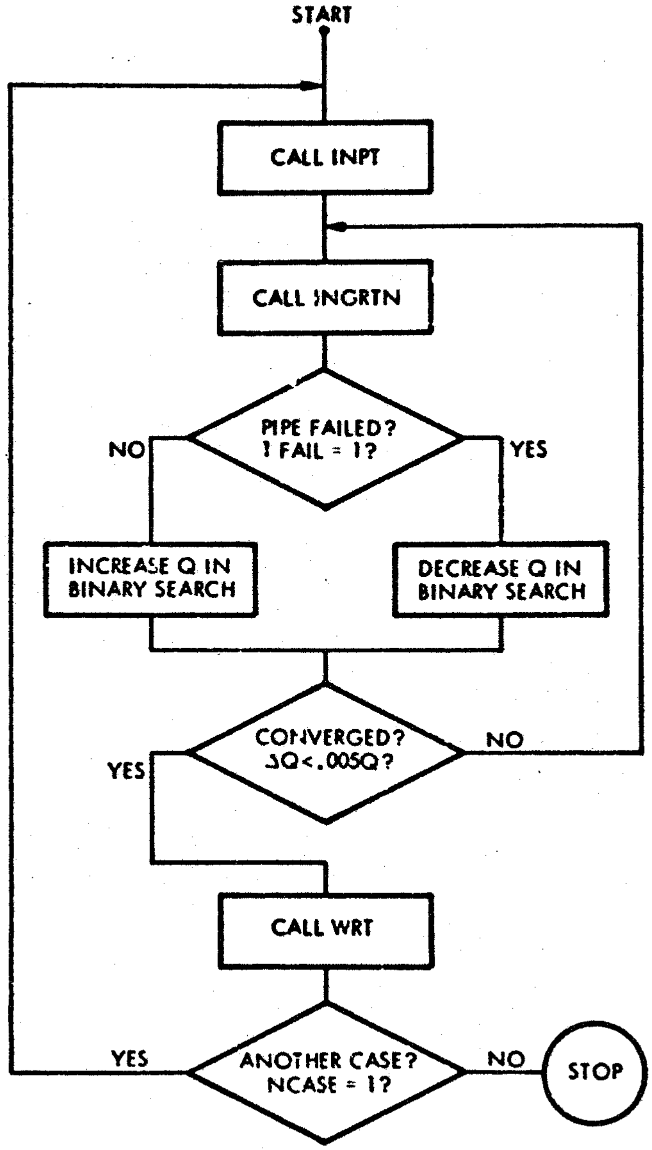

Figure 7. Flow Diagram for the Main Program, Which Searches for the Maximum Q

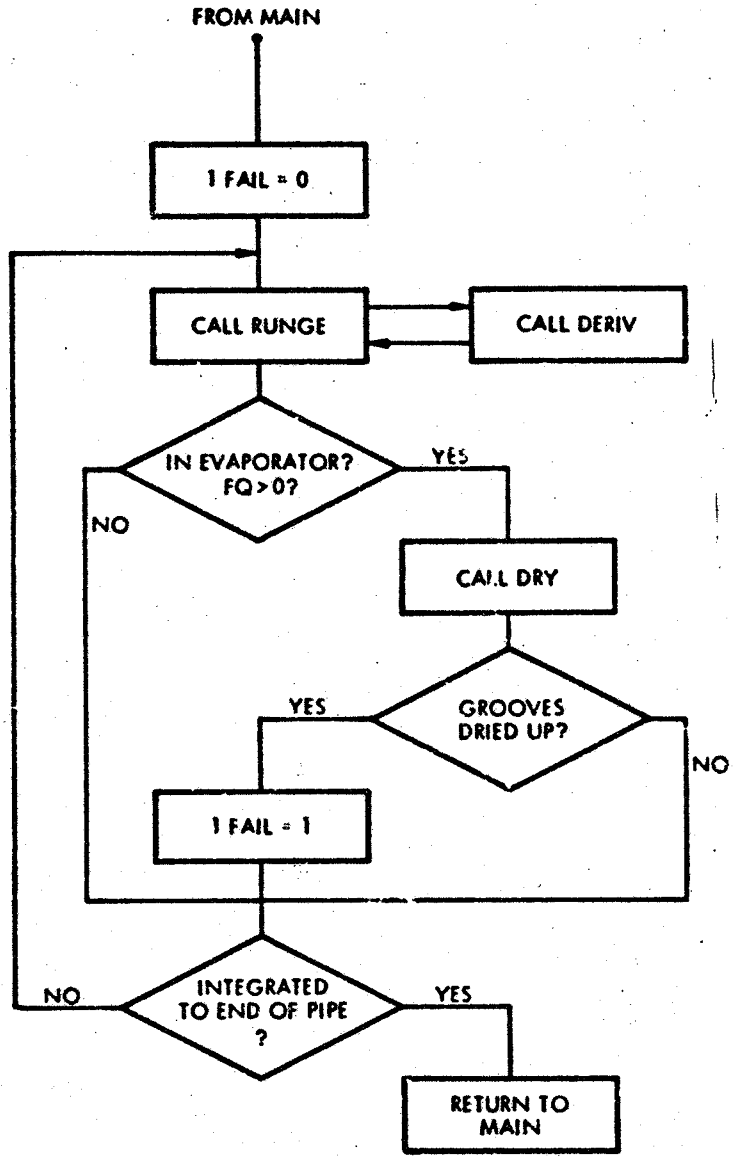

Figure 8. Flow Diagram for Subroutine INGRTN, Which Integrates Along the Pipe and Reports Whether There is a Failure

A.1 DESCRIPTION OF GRADE II

The structure of GRADE II is given in Figure 7 where the flow chart for the main program is displayed. The main program begins witn a call to INPT , which reads the data, computes parameters and calls PROPS, which calculates the fluid properties. INPT then writes all of this information. The main program next calls INGRTN, which integrates the differential equations from the condenser to the evaporator end with an assumed value Q for the heat-transport rate. If the grooves are found to dry up, INGRTN reports this by setting IFAIL = 1. Q is increased if the heat pipe has failed or decreased if it has not, in a binary search for the maximum rate. When the change in Q is less than 1/2%, the program is assumed to have converged. A call to WRT writes the final solution.

The structure of subroutine INGRTN is displayed in Figure 8. IFAIL is initialized to zero and then RUNGE, which makes a single integration step DX along the pipe, is called repeatedly. RUNGE relies on subroutine DERIV to supply values of the derivatives of the key variables. When the integration is in a region of evaporation, a call to DRY is made to check whether the grooves dry up. If they have, IFAIL is set to unity. INGRTN returns control to the main program when the evaporator end is reached.

A brief description of each subroutine is included in the listing, where the subroutines appear alphabetically.

```
                PROGRAM MAIN(INPUT,TAPE5=INPUT,OUTPUT,TAPE6=OUTPUT,TAPE7,TAPE50)
          C
          C     MAIN  DESIGNS GRADED-POROSITY WICKS AND PREDICTS THE
          C     CAPACITY OF WICKS WITH A SPECIFIED POROSITY VARIATION
          C
000004          COMMON /PARAM/ EPS,EPSO,PNO,GEE,G,NI,NIP1,HW,ICFCM,WNTH,FFIL,
000004         1               NC,FO(10),NELEV,XELEV(10),ZELEV(10),ELEV(10),
000004         2               ELEVB(10),H,FNUB,AW,AB,XTOT,DX,DZ,QDTB,QDCT,FB,
000004         3               DIAF,A(8,500),XO(10),ZO(10),PBS,CRVS,HREF,FCGRV,
000004         4               NCASE,LASTEPS,SAVEPS(500),IFAIL,PBO,IMX,NW,EPSS,
000004         5               NVS,AVS,VFF,DIAVS,W,DEPTH,PHI,ANGWET,S,IPRIMED,
000004         6               NEFS,XEFS(20),EFSX(20),NOB,SS,HVS,AAA(40),DDF(40),
000004         7               VELHD,ZOE(10),XMOP(10),XOB(10),IFLTS,STRS(40),
000004         8               IPASS,PERIM,ROUGH,TH1,TH2,IEV(10),NEV,PI,FFM1,
000004         9               IPLOT,XX0,XX1,EPSMIN,HIGH,LOW,HD1(6),HD2(6)
000004          COMMON /CPROPS/ XMW,SHRV,HFG,PV,RHOL,RHOV,VISL,VISV,XKL,ST,TF
          C
000004          DO 500 K=1,10
          C
000006          CALL INPT
          C     INPUT READS IN THE DATA, MAKES PRELIMINARY CALCULATIONS,
          C     AND PRINTS THE DATA
          C
          C     COMMENCE BINARY SEARCH FOR MAXIMUM  Q
          C     IT = 1  IF MAX Q HAS NOT BEEN BRACKETED
          C     IT = 2  IF MAX Q HAS BEEN BRACKETED
          C
000007          IT=1
000010          QDTB=1.
000012          DQDTB=.5
          C
000014          CALL INGRTN
          C     INGRTN  INTEGRATES THE DIFFERENTIAL EQUATIONS FROM THE CONDENSER
          C     TO THE EVAPORATOR FOR A SPECIFIED Q AND REPORTS WHETHER GROOVE
          C     DRY-OUT HAS OCCURRED (IFAIL=0 FOR NO DRY-OUT, IFAIL=1 FOR DRY-OUT)
          C
000015          IF(IPASS.EQ.1) GO TO 202
```

```
RUNX COMPILER (VER.2.3M)                    09/26/76. 13.24.02.          MAIN

000017          DO 404 I=1,40
000021          IF(IFAIL .EQ. 1) GO TO 303
            C
000023          IF(II.EQ.1) DQDTB=2.*DQDTB
000027          IF(II.EQ.2) DQDTB=.5*DQDTB
000033          QDTB=QDTB+DQDTB
000035          CALL INCRIN
000036          IF(IFAIL.EQ.1) II=2
000041          GO TO 305
            C
000042      303 IF(II.EQ.2) DQDTB=.5*DQDTB
000046          QDTB=QDTB-DQDTB
000050          CALL INCRIN
000051          IF(IFAIL.EQ.0) II=2
            C
000053      305 IF(DQDTB .LT. .005*QDTB) GO TO 202
000057      404 CONTINUE
000061      202 CONTINUE
            C
000061          CALL WRT
            C   WRT PRINTS THE FINAL SOLUTION
            C
000062          IF(IPLOT.EQ.1) CALL PLOTEM
            C   PLOTEM  PLOTS THE POROSITY VARIATION
            C
000065          IF(NCASE.EQ.0) GO TO 501
            C
000066      500 CONTINUE
000070      501 CONTINUE
000070          STOP
000072          END
```

```
RUNX COMPILER (VER.2.3M)                       09/28/76. 13.24.02.

                    SUBROUTINE ALFA(ACON)
              C
              C     ALFA COMPUTES FRICTION FACTOR  FRF  GIVEN CONTACT ANGLE
              C     ACON  IN DEGREES
              C
000003              COMMON /AALFA/ AFIT,BFIT,CFIT,FRF
              C
000003              FRF=AFIT+BFIT*ACON+CFIT*ACON**2
000011              RETURN
000012              END
```

```
RUNX COMPILER (VER.2.3M)              09/28/76. 13.24.02.

                    SUBROUTINE GCALCS
             C
             C      GCALCS  MAKES PRELIMINARY CALCULATIONS FOR GROOVE DRY-UP
             C
000002              COMMON /PARAM/ EPS,EPSO,RND,GEE,C,NI,NIP1,MM,ICFCM,WKTH,FFIC,
000002             1               NG,FC(10),NELEV,XELEV(10),ZELEV(10),ELEV(10),
000002             2               ELEVB(10),H,FNUF,AW,AB,XTCT,DA,DZ,DDTO,CDCT,PB,
000002             3               DIAF,A(2,500),XC(10),ZC(10),PBS,GRVS,HREF,FCGPV,
000002             4               NCASE,LASTEPS,SAVEPS(500),IFAIL,PBC,IMK,HM,EPSS,
000002             5               NVS,AVS,VFF,DIAVS,W,DEPTH,PHI,ANGWET,S,IPRIMED,
000002             6               NEPS,XEPS(20),EFSX(20),NOB,SS,HVS,AAA(40),CCH(40),
000002             7               VELHD,ZOB(10),XROB(10),XJB(10),IFLTS,STKS(40),
000002             8               IPASS,FFRIM,RCLCH,TH1,TH2,IEV(10),NEV,FI,IFP1,
000002             9               IPLOT,XX0,XX1,EPSMIN,HIGH,LOW,HO1(6),HO2(6)
000002              COMMON /CPROPS/ XMW,SHRV,HFG,FV,RHOL,RHOV,VISL,VISV,XKL,ST,TF
000002              COMMON /GRVDTA/ ACR,PHIR,SP,CP,TP,SMAX,CMAX,PSIMR,HG,ATRI,RFRIF,
000002             1                RMIN,CLAV,HCT,FLC,GFAC,VFAC,RWPK,RPD
             C
000002              PI=3.141592654
000004              RPD=PI/180.
             C
             C      GROOVE DATA
             C
000006              VISLK=VISL/RHOL
000010              ACR=ANGWET*RPD
000012              PHIR=PHI*RPD
000014              SP=SIN(PHIR)
000017              CP=COS(PHIR)
000022              TP=SP/CP
000024              PSIMAX=90.-PHI-ANGWET
000027              PSIMR=PSIMAX*RPD
000031              SMAX=SIN(PSIMR)
000034              CMAX=COS(PSIMR)
000037              HC=(W/100.)/(2.*TP)-(DEPTH/100.)
000046              HCT=2.*HC*(1.-SP)/CP
000053              ATRI=HC*HC*TP
000055              RFRIF=(W/200.)/SP-HCT
```

```
RUNX COMPILER (VER.2.3M)                04/28/76. 13.24.02.          DCALCS

000061          RMIN=(V/300.)/(2.*SMAR)
000065          DWMN=1./(200./DEPTH+200./6)
000071          CHPV=CFF*G*(RHOL-RHOV)/ST
000076          GFAC=(RHOL-RHOV)*9.80*GEE*(HPID/100.)/(2.*ST)
000110          VFAC=((HPID/100.)/4.)*VISLK/ST
000114          RETURN
000115          END
```

```
RUNX COMPILER (VER.2.3M)                       09/28/76. 13.24.02.

                        SUBROUTINE DERIV(YP,Y)
                  C
                  C     DERIV  CALCULATES THE DERIVATIVES OF THE STRESS, HEAT INPUT,
                  C     WICK LIQUID, AND PRESSURE OF THE VAPOR
                  C
     000005             COMMON /PARAM/ EPS,EPSO,PRO,CEE,C,XI,NIPI,HW,ICLUM,WKTH,HPIL,
     000005           1                NW,FC(10),NELEV,XELEV(10),ZELEV(10),ELEVA(10),
     000005           2                ELEVB(10),H,FALB,AW,AB,XTOT,DX,DZ,ROTB,GOCT,FB,
     000005           3                DIAF,A(F,500),XC(10),ZC(10),PBS,GPVS,HPEF,FUGRV,
     000005           4                NCASE,LASTEPS,SAVEPS(500),IFAIL,PBO,IMK,NH,EFSS,
     000005           5                NVS,AVT,VFF,DIAVS,W,DEPTH,PHI,ANGLET,S,IPRIPD,
     000005           6                NEPS,NEPS(20),EPSX(20),NUR,SS,HVS,AAA(40),CDH(40),
     000005           7                VELHD,ZOP(10),XKOB(10),XJE(10),IFLTS,STRS(40),
     000005           8                IPASS,PERIM,ROUGH,TH1,TH2,IEV(10),NEV,PI,FFM1,
     000005           9                IPLOT,AXO,XX1,EPSMIN,HIGH,LOW,HD1(6),HD2(6)
     000005             COMMON /PROPS/ XMW,SHHV,HFG,PV,RHOL,RHOV,VISL,VISV,XKL,ST,TF
                  C
     000005             DATA B1/.32435153/,B2/-3.6563792/,B3/1.781477937/,
     000005           1      B4/-1.821255978/,B5/1.330274429/,R/.2316419/,D/1.66/
                  C
     000005             DIMENSION YP(5),Y(5),X(11),WW(11),WP(11)
                  C
     000005             YP(1)=1.
     000007             PP=Y(2)
                  C
                  C     CALCULATION OF THE ELEVATION  HB  AT LOCATION  Z
                  C
     000011             N=NELEV-1
     000013             DO 101 I=1,N
     000015             Z=Y(1)
     000016             IF(Z.GE.ZELEV(I) .AND. Z.LE.ZELEV(I+1)) IMK=I
     000031         101 CONTINUE
     000034             DELEV=(ELEVB(IMK+1)-ELEVB(IMK))/(ZELEV(IMK+1)-ZELEV(IMK))
     000041             HB=ELEVB(IMK)+(ELEVB(IMK+1)-ELEVB(IMK))*(Z-ZELEV(IMK))/
     000041           1                 (ZELEV(IMK+1)-ZELEV(IMK))
                  C
     000053             PBFS=1./(1.+PH/PBS)
```

```
RUNX COMPILER (VER.2.3M)                    09/28/76. 13.24.02.          DERIV

000057          EPSS1=1./(1.+R*(RHC+(1-IPRIME)*GE*HB)/P3S)
000072          IF(EPSS.GT.EPSS1) EPSS=EPSS1
000075          IF(LASTEPS.NE.0 .OR. NEPS.NE.0) GO TO 103
         C
         C      CALCULATION OF THE POROSITY FOR A SPECIFIED SATURATION FRACTION
         C
000103          EPS=(EPSS-FIP/4.5)/(1.-FIP/4.5)
000112          SS=S
000114          GO TO 106
         C
         C      CALCULATION OF THE SATURATION FRACTION FOR A SPECIFIED POROSITY
         C
000115      103 IZ=INT((Z+1.E-6*DZ)/DZ)
000121          EPS=SAVEPS(NZ+1)
000123          IF(IZ .EQ. NZ+1) GO TO 105
000125          EPS=SAVEPS(IZ)+(SAVEPS(IZ+1)-SAVEPS(IZ))*(Z-(IZ-1)*DZ)/DZ
000137      105 CONTINUE
000137          ZZ=4.55*(EPS1-EPS)/(1.-EPS)
000145          IF(ZZ .LT. 0.) ZZ=-ZZ
000147          F=(1./SQRT(2.*PI))*EXP(-ZZ*ZZ/2.)
000163          T=1./(1.+R*ZZ)
000167          T2=T*T
000171          T3=T2*T
000173          T4=T3*T
000175          T5=T4*T
000177          FF=1.-F*(B1*T+B2*T2+B3*T3+B4*T4+B5*T5)
000213          IF(EPSS.LT.EPS) FF=1.-FF
000220          SS=FF-(.22*(1.-EPS)/(EPS)*F
         C
         C      CALCULATION OF THE HEAT-INPUT REGION IN WHICH  Z  FALLS
         C
000226      106 DIST=0.
000227          DO 112 I=1,NQ
000231          DIST=DIST+ZQ(I)
000234          IMK=I
000236          IF(Z.LT.DIST) GO TO 113
000241      112 CONTINUE
000244      113 YQ(3)=-QOIN*QL(IMK)/ZQ(IMK)
```

```
             C
             C        BEGIN THE CALCULATION OF VAPOR FLOW
             C
000250                RCRIT=2300.
000252                VW=ABS(FQ(IMK)*QDT**QDOT/HFG)/(RHOV*(XG(IMK)/100.)*
000252              1    FLOAT(NVS)*PERIM/100.)
000270                REVO=(DIAVS/100.)*VW/(VISV/RHOV)
000275                XMDOT=Y(7)*(QDOT/HFG)
000300                VVAP=XMDOT/(FLOAT(NVS)*(AVS*1.0E-4)*RHOV)
000305                REV=VVAP*(DIAVS/100.)/(VISV/RHOV)
000312                VELHD=.5*RHOV*VVAP**2
000315                IF(REV.LE.RCRIT) GO TO 11
             C
             C        TURBULENT VAPOR FLOW
             C
             C        NEWTON ITERATION OF THE COLEBROOK EQ. FOR THE TURBULENT
             C        FRICTION FACTOR
             C
000320                X(1)=4.
000322                DO 50 I=1,10
000324                P1=X(I)
000326                P2=2.*ALOG10(2.51*X(I)/REV+ROUGH/(3.7*DIAVS))
000342                TEST=-P1/P2
000344                IF(ABS(TEST-1.) .LT. .001) GO TO 60
000351                WW(I)=P1+P2
000354                WP(I)=1.+(5.02/REV)/(2.51*X(I)/REV+ROUGH/(3.7*DIAVS))
000370                X(I+1)=X(I)-WW(I)/WP(I)
000374             50 CONTINUE
000376             60 FFAC=1./X(I)**2
             C
000401                GO TO 12
000402             11 CONTINUE
             C
             C        LAMINAR-VAPOR-FLOW FRICTION FACTOR
             C
000402                FFAC=0.
000403                IF(REV.GT.0.) FFAC=62./REV
000406             12 CONTINUE
```

```
              C
000406                FFAVE=FFAC
000410                IF(FO(IMK).EQ.0) GO TO 22
              C
000412                A0=.6
000414                AA=.13
000416                BB=.008
000420                FS=6./5.
000422                IF(FO(IMK) .LT. 0.) GO TO 18
              C
000424                A0=3.3
000426                AA=0.10
000430                BB=0.
000431                FS=1.65
              C
000433             18 IF(REV.GT.RCRIT) FS=1.
000437                BO=REV*FFAC/8.
000442                IF(FO(IMK).GT.0) BO=-BO
000445                IF(REVR.GT.0.) RCF=A0-(BO/REVR)*EXP(-AA*REVR-BB*REVR*REVR)
000461                FFAVE=0.
000462                IF(REV.GT.0) FFAVE=8.*REVR*(2.*FS-RCF)/REV
000471                IF(FO(IMK).GT.0) FFAVE=-FFAVE
              C
000474             22 DPVDX=(FFAVE/(DIAVS/100.))*VELHD
000500                DPVDX=DPVDX-2.*FS*VVAP*YP(3)*((QDOT/HFG)/(XTOT/100.))/
000500           1         (FLOAT(NVS)*(AVS*1.0E-4))
              C
              C       CALCULATION OF FILLET CONTRIBUTION TO FLOW
              C
000516                AAAA=0.
000517                FKA=0.
000520                IF(IFLTS.EQ.0) GO TO 61
000521                HWC=WKTH/200.
000523                IF(IGEOM.EQ.0) GO TO 40
000524                HWC=HRID/200.
000526                IF(IGEOM.EQ.1) GO TO 40
000530                HWC=(HW-HRID/2.)/100.
              C
```

```
RUNX COMPILER (VER.2.3M)              09/28/76. 13.24.02.          DERIV
          C      HWC  IS THE WICK HEIGHT RELATIVE TO THE TUBE CENTER
          C
000534        40 SSTRS=PR*HW/100.-HWC
000540           DDDH=DDH(1)
000542           AAAA=AAA(1)
000544           IF(SSTRS.LT.STRS(1)) GO TO 80
000547           DO 61 I=1,NH
000551           IF(STRS(I).GE.SSTRS) GO TO 70
000554        61 CONTINUE
000557           FKA=0.
000560           AAAA=0.
000561           GO TO 81
000562        70 AAAA=AAA(I-1)+(AAA(I)-AAA(I-1))*(SSTRS-STRS(I-1))/
000562         1       (STRS(I)-STRS(I-1))
000574           DDDH=DDH(I-1)+(DDH(I)-DDH(I-1))*(SSTRS-STRS(I-1))/
000574         1       (STRS(I)-STRS(I-1))
000606        80 FKA=(AAAA/(HW/100.)**2)*(DDDH**2/(DIAF/100.)**2)/32.
000616        81 CONTINUE
          C
000616           YP(2)=FNUB*Y(3)/(D*FERM(EPS,EPSS)*AB+FKA)+DELEV*GEE
000616         1       +((XTOT/100.)/PND)*DPVDX
000636           YP(5)=((XTOT/100.)/PND)*DPVDX
000642           YP(4)=EPS*SS+AAAA/(AW/10000.)
000647           RETURN
000650           END
```

```
RUNX COMPILER (VER.2.3M)                      09/28/76. 13.24.02.

                      SUBROUTINE DRY
              C
              C       DRY, GIVEN AN EVAPORATOR HEAT LOAD, GROOVE SHAPE, A BACK STRESS
              C       AT SOME REFERENCE HEIGHT, AND A PAIR OF FEED ANGLES, DETERMINES
              C       WHETHER DRY UP, DEFINED AS MENISCUS CONTACT ON THE TRAPEZOIDAL
              C       GROOVE BOTTOM, OCCURS BETWEEN THE ANGLES.
              C
000002                COMMON /PARAM/ EPS,EPSO,RND,GEE,G,NI,NIP1,HW,IGEOM,WKTH,HPID,
000002               1               NQ,FQ(10),NELEV,XELEV(10),ZELEV(10),ELEV(10),
000002               2               ELEVB(10),H,FNUB,AW,AB,XTGT,DX,DZ,QDTB,QDOT,PB,
000002               3               DIAF,A(6,500),XQ(10),ZQ(10),PBS,GRVS,HREF,FCGRV,
000002               4               NCASE,LASTEPS,SAVEPS(500),IFAIL,PBO,IMK,NF,EPSS,
000002               5               NVS,AVS,VFF,DIAVS,W,DEPTH,PHI,ANGWET,S,IPRIMED,
000002               6               NEPS,XEPS(20),EPSX(20),NOB,SS,HVS,AAA(40),CDH(40),
000002               7               VELHD,ZCP(10),XKOB(10),XOP(10),IFLTS,STRS(40),
000002               8               IPASS,PERIM,ROUGH,TH1,TH2,IEV(10),NEV,PI,FFM1,
000002               9               IPLOT,XX0,XX1,EPSMIN,HIGH,LOW,HD1(6),HD2(6)
000002                COMMON /CPROPS/ XMW,SHRV,HFG,PV,RHOL,RHOV,VISL,VISV,XKL,ST,TF
000002                COMMON /GRVDTA/ ACR,PHIR,SP,CP,TP,SMAX,CMAX,PSIMR,HG,ATRI,PERIF,
000002               1                RMIN,CURV,BCT,FLO,GFAC,VFAC,RWMN,RPD
              C
000002                DQDL=QDTB*QDOT*FQ(IMK)/(XQ(IMK)/100.)
000007                FLO=(DQDL/(GRVS*100.))*FCGRV/HFG
000013                RCAP=ST/(PB*RND)
              C
              C       CONDITIONS AT ANGLE 1
              C
000016                I1=1
000017                H1=((HPID/100.)/2.)*COS(TH1*RPD)-(HREF/100.)
000033                R1=1./((1./RCAP)+(H1*CURV))
000040                IF(R1.LT.RWMN) I1=0
              C
              C       CONDITIONS AT ANGLE 2
              C
000044                I2=1
000045                H2=((HPID/100.)/2.)*COS(TH2*RPD)-(HREF/100.)
000061                R2=1./((1./RCAP)+(H2*CURV))
```

```
RUNX COMPILER (VER.2.3M)                     09/26/76. 13.24.02.            DRY

000066             IF(R2.LT.RWMN) I2=0
           C
           C       START OF SEARCH FOR POSSIBLE DRY ZONE
           C
000072             IF(I1.NE.1 .AND. I2.NE.1) GO TO 999
           C       THE ENTIRE REGION IS DRY BY VIRTUE OF THE WICK-MENISCUS
           C       CONTACT POSTULATE
           C
000101             ISRCH=1
000102             DTSTGN=(TH2-TH1)/2.
000105             TSTGN=TH1
           C
000107         101 CONTINUE
000107             TSTGN=TSTGN+DTSTGN
           C
000111             CALL WET(TSTGN,R1,R2,TL1,TL2)
           C       WET MARCHES FROM  TH1  POSITIVELY TO  TSTGN  AND FROM
           C       TH2  NEGATIVELY TO  TSTGN  AND REPORTS THE ANGLE, IF ANY,
           C       AT WHICH THE GROOVES CEASE TO BE WET
           C
000115             IF(I1.EQ.0) TL1=TH1
000120             IF(I2.EQ.0) TL2=TH2
           C
000123             IF(TL1.GE.TSTGN-.001*ABS(TSTGN) .AND.
000123            1   TL2.LE.TSTGN+.001*ABS(TSTGN)) GO TO 997
           C       THE REGION IS FULLY WET IF THIS STATEMENT EXECUTES
           C
000141             IF(TL1.LT.TSTGN-.001*ABS(TSTGN) .AND.
000141            1   TL2.GT.TSTGN+.001*ABS(TSTGN))GO TO 998
           C       DRY OUT IS CERTAIN TO EXIST SOMEWHERE IN THE REGION
           C
000157             DTSTGN=ABS(DTSTGN)/2.
000162             IF(ABS(TL1-TSTGN) .GT. ABS(TL2-TSTGN)) DTSTGN=-DTSTGN
000171             ISRCH=ISRCH+1
000173             IF(ISRCH.LT.20) GO TO 101
000176             GO TO 999
           C
000177         997 CONTINUE
```

```
RUNX COMPILER (VER.2.3M)                    09/28/76. 13.24.02.          DRY

              C      THE GROOVES ARE WET
000177               IFAIL=0
000200               GO TO 999
000201           998 CONTINUE
              C      THE GROOVES ARE DRY
000201               IFAIL=1
000202           999 CONTINUE
000202               RETURN
000203               END
```

```
000017             IF(ILOW.GT.6) ILOW=6
000023             IF(IHI.GT.6) IHI=6
000027             FAC=(PHI-10.*ILOW)/10.
000034             DO 100 I=1,3
000036         100 FR(I)=FRIC(ILOW,I)+FAC*(FRIC(IHI,I)-FRIC(ILOW,I))
              C
              C    ALLOWANCE FOR TRAPEZOIDAL SHAPE
              C
000051             AA=(W/100.)/2.
000054             BB=AA/TAN(3.1415965*PHI/180.)
000062             CC=SQRT(AA**2+BB**2)
000070             EPSLN=(BB-(DEPTH/100.))/CC
000074             IF(EPSLN.GT.0.4) GO TO 101
000100             IF(EPSLN.GT.0.2) GO TO 102
000104             DO 103 I=1,3
000106             FUDGE=1.0+FF(1,I)*(1.-((0.2-EPSLN)/0.2)**2)
000116         103 FR(I)=FR(I)*FUDGE
000122             GO TO 104
000123         102 CONTINUE
000123             DO 105 I=1,3
000125             FUDGE=1.0+FF(1,I)+(FF(2,I)-FF(1,I))*(EPSLN-0.2)/0.2
000137         105 FR(I)=FR(I)*FUDGE
000143             GO TO 104
000144         101 CONTINUE
000144             DO 106 I=1,3
000146             FF1=1.+FF(1,I)
000151             FUDGE=(96./FR(1)-FF1)*((EPSLN-0.4)/0.6)**2
000160         106 FR(I)=FR(I)*FUDGE
000164         104 CONTINUE
              C
              C    PARABOLIC FIT FOR VARIATION WITH CONTACT ANGLE
              C
000164             X1=0.0
000166             X2=15.
000170             X3=90.-PHI
000172             Y1=FR(1)
000174             Y2=FR(2)
000176             Y3=FR(3)
```

```
RUNX COMPILER (VER.2.3M)                    09/28/76. 13.24.02.

                          SUBROUTINE FACTOR
                C
                C         FACTOR  CALCULATES CURVE FIT FOR THE GROOVE FRICTION FACTOR
                C
000002                    COMMON /PARAM/ EPS,EPSC,PNO,GEE,C,NI,NIP1,HW,ICEOM,WRTH,HFIO,
000002                1                  NG,FC(10),NELEV,XELEV(10),ZELEV(10),ELEV(10),
000002                2                  ELEVB(10),H,FNCB,AW,AB,XICT,JX,DZ,COTB,DUCT,FB,
000002                3                  DIAF,A(F,500),XG(10),ZG(10),PBS,GPVS,HREF,FCCRV,
000002                4                  NCASE,LASTEPS,SAVEPS(500),IFAIL,PBO,IMK,NH,EPSS,
000002                5                  NVS,AVS,VFF,DIAVS,W,DEPTH,PHI,ANGWET,S,IPRINEC,
000002                6                  NEPS,XEPS(20),EPSX(20),NOB,SS,HVS,AAA(40),DDH(40),
000002                7                  VELHG,ZOB(10),XKOB(10),XOB(10),IFLTS,STRS(40),
000002                8                  IPASS,PERIM,ROUGH,TH1,TH2,IEV(10),NEV,FI,FIP1,
000002                9                  IPLOT,XX0,XX1,EPSMIN,HIGH,LOW,HD1(6),HD2(6)
000002                    COMMON /PPROPS/ XMW,SHRV,HFG,PV,RHOL,RHOV,VISL,VISV,XKL,ST,TF
000002                    COMMON /CRVDTA/ ACR,PHIP,SF,CF,TP,SMAX,CMAX,PSIMR,HG,ATRI,PERIF,
000002                1                   RMIN,CURV,BCT,FLO,SFAC,VFAC,RWMN,RFU
000002                    COMMON /AALFA/ AFIT,BFIT,CFIT,FRFC
                C
000002                    DIMENSION FRIC(6,3),FF(2,3),FR(3),Y(3),ALPHA(10),FRF(10)
                C
                C         FRICTION-FACTOR DATA FOR TRIANGULAR SHAPE
                C
000002                    DATA (FRIC(I),I=1,18) /43.78,40.59,37.80,35.22,32.80,30.45,
000002                1                            46.72,46.22,46.03,46.06,46.42,47.36,
000002                2                            49.79,52.78,55.32,56.73,56.72,55.32/
                C
                C         CORRECTION FACTOR FOR TRAPEZOIDAL SHAPE
                C
000002                    DATA (FF(I),I=1,6) /0.00,0.36,0.13,0.14,0.17,0.25/
                C
                C         FRICTION FACTOR FOR TRIANGULAR SHAPE BY INTERPOLATION
                C
000002                    ILOW=PHI/10.
000005                    IHI=ILOW+1
000007                    IF(ILOW.LT.1) ILOW=1
000013                    IF(IHI.LT.1) IHI=1
```

```
RUNX_COMPILER (VER.2.3M)                    09/26/76. 13.24.02.          FACTOR

000200          D1=X2*X3**2-X3*X2**2
000205          D2=X1*X3**2-X3*X1**2
000212          D3=X1*X2**2-X2*X1**2
000217          DD=D1-D2+D3
000222          XA=Y1*D1-Y2*D2+Y3*D3
000230          AFIT=XA/DD
000232          XB1=Y2*X3**2-Y3*X2**2
000237          XB2=Y1*X3**2-Y3*X1**2
000244          XB3=Y1*X2**2-Y2*X1**2
000251          XB=XB1-XB2+XB3
000254          BFIT=XB/DD
000256          XC=(X2*Y3-Y2*X3)-(X1*Y3-Y1*X3)+(X1*Y2-Y1*X2)
000271          CFIT=XC/DD
        C
000273          RETURN
000274          END
```

```
RUNX COMPILER (VER.2.3M)                    09/28/76. 13.24.02.

                     FUNCTION FINT(EPSO,EPS)
                C
                C    FINT  CALCULATES THE INTEGRAND FOR THE CALCULATION OF
                C    THE PERMEABILITY BY  PERM
                C
000005               OME=1.-EPS
000007               OMEO=1.-EPSO
000011               OME2=OME*OME
000013               FK=(3./8.)*(EPS/OME)/(4.*EPS/(4.*OME-OME2-2.*ALOG(OME)-3.)
000013              1   -8./(ALOG(OME)+(1.-OME2)/(1.+OME2)))
000044               F=(1.8/OMEO)*EXP(-10.3*(EPS-EPSO)*(EPS-EPSO)/(OMEO*OMEO))
000057               FINT=F*FK
000061               RETURN
000063               END
```

```
                       SUBROUTINE INGRTN
                C
                C      INGRTN  INTEGRATES THE DIFFERENTIAL EQUATIONS THE LENGTH
                C      OF THE HEAT PIPE AND REPORTS WHETHER THE GROOVES DRY-UP
                C
000002                 COMMON /PARAM/ EPS,EPSO,PNO,GFE,G,WI,NIP1,HW,IGEOM,WNTH,HRIC,
000002                1               NC,FC(10),NELEV,XELEV(10),ZELEV(10),ELEV(10),
000002                2               ELEVB(10),H,FNUB,AW,AB,KTOT,DX,DZ,QDTB,QDCT,FB,
000002                3               DIAF,A(8,500),XC(10),ZO(10),PBS,GFVS,HREF,ECCRV,
000002                4               NCASE,LASTEPS,SAVEPS(500),IFAIL,PRO,IMR,NH,EPSS,
000002                5               NVS,AVS,VFF,DIAVS,W,DEPTH,PHI,ANGWET,S,IPRIMED,
000002                6               NEPS,XEPS(20),EPSX(20),NOR,SS,HVS,AAA(40),DDH(40),
000002                7               VELHC,ZOH(10),XPOH(10),XOB(10),IFLTS,STPS(40),
000002                8               IPASS,FEPIN,POUCH,TH1,TH2,IEV(10),NEV,PI,FFP1,
000002                9               IPLOT,XX0,XA1,EPSMIN,HIGH,LOW,HE1(6),HE2(6)
000002                 DIMENSION Y(5),YP(5)
000002                 COMMON /PROPS/ XMW,SHPV,HFG,PV,RHOL,RHOV,VISL,VISV,XKL,ST,TF
                C
                C      A(1,J)  IS THE DISTANCE  (=Y(1))
                C      A(2,J)  IS THE STRESS  (=Y(2))
                C      A(3,J)  IS THE MASS-FLOW RATE  (=Y(3))
                C      A(4,J)  IS THE MASS OF LIQUID IN THE WICK  (=Y(4))
                C      A(5,J)  IS THE POROSITY  EPS
                C      A(6,J)  IS THE CONTRIBUTION TO STRESS FROM CHANGE OF ELEVATION
                C      A(7,J)  IS THE SATURATION FRACTION
                C      A(8,J)  IS THE VAPOR PRESSURE  (=Y(5))
                C
000002                 A(1,1)=0.
000003                 A(2,1)=PRO
000005                 A(3,1)=0.
000006                 A(4,1)=0.
000007                 A(8,1)=0.
000010                 Y(1)=A(1,1)
000012                 Y(2)=A(2,1)
000014                 Y(3)=A(3,1)
000016                 Y(4)=A(4,1)
000020                 Y(5)=A(8,1)
```

```
RUNX COMPILER (VER.2.3M)                    09/28/76. 13.24.02.          INCRTN

000022             IFAIL=0
             C
000023             CALL DERIV(YP,Y)
             C     DERIV  CALCULATES THE DERIVATIVES OF  Y(1) THRU Y(5)
             C
000025             IOP=1
000026             ICHK=0
000027             A(6,1)=EPS
000031             DO 121 I=2,NIP1
             C
000033             CALL RUNGE(Y,YP,DZ)
             C     RUNGE  MAKES ONE INTEGRATION STEP BY THE RUNGE-KUTTA METHOD
             C
             C     IF THE STRESS IS EXCESSIVE, THE INTEGRATION IS ABORTED
             C
000036             IF(EPSS .LT. 0.2) IFAIL=1
000042             IF(EPSS .LT. 0.2) GO TO 125
             C
000045             DO 110 J=1,4
000047             A(J,I)=Y(J)
000053         110 CONTINUE
000055             A(6,I)=EPS
000060             IF(EPS.LT.EPSMIN) ICHK=1
000064             A(7,I)=SS
000067             A(8,I)=Y(5)
             C
             C     THE STRESS IS INCREASED IF THERE IS A VAPOR-SPACE OBSTRUCTION
             C
000072             IF(MOB.EQ.0)GO  TO 120
000073             IF(Y(1).LT.ZOP(ICM)) GO TO 120
000076             Y(2)=Y(2)+XKOP(ICM)*VELMD/PND
000102             Y(5)=Y(5)+XKOP(ICM)*VELMD/PND
000106             A(2,I)=Y(2)
000111             A(8,I)=Y(5)
000114             IOP=IOP+1
000116         120 CONTINUE
             C
             C     THE GROOVES ARE CHECKED WHERE THE STRESS IS MAXIMUM
```

```
RUNW COMPILER (VER.2.3M)                  09/28/76. 13.24.02.          INGFTN

           C       IN EACH EVAPORATOR
           C
000116             IF(FO(IMW).LE.0) GO TO 121
000120             IF(A(2,I-1).GE.A(2,I)) GO TO 33
000126             DO 40 K=1,NEV
000130             IF(I.EQ.IEV(K)) GO TO 33
000133          40 CONTINUE
000136             GO TO 121
000137          33 PB=Y(2)
           C
000141             CALL DRY
           C       DRY  DETERMINES WHETHER THE GROOVES DRY-UP (IFAIL=1 FOR DRY-UP)
           C
000142         121 CONTINUE
000145             IF(LASTEPS.NE.0 .OR. NEPS.NE.0) GO TO 125
000153             IF(ICHK.EQ.1) IFAIL=1
000156         125 RETURN
000157             END
```

```
RUNX COMPILER (VER.2.3M)                    09/28/76. 13.24.32.

                    SUBROUTINE INPT
             C
             C      INPT  READS IN THE DATA, MAKES PRELIMINARY CALCULATIONS,
             C      AND WRITES THE DATA
             C
 000002             COMMON /PARAM/ EPS,EPSC,EPO,GEE,C,NI,NIP1,NW,ICCM,WNTH,HFIC,
 000002           1                NO,FC(10),FLEV,XFLEV(10),ZLEV(10),ELEV(10),
 000002           2                ELEVB(10),L,FNLB,AW,AO,XTLT,DX,DZ,DOTB,QDOT,FW,
 000002           3                DIAF,AIF,SCD,XC(10),ZC(10),PBS,CRVS,HREF,FCCRV,
 000002           4                NCASE,LASTEPS,SAVEPS(500),IFAIL,PBO,IMK,NF,EPSS,
 000002           5                NVS,AVS,VFF,DIAVS,WDEPTH,PHI,ANGLT,S,IPHIPC,
 000002           6                NZ,S,XEPS(20),EPSX(20),NOO,SS,MLS,AAA(40),DCF(40),
 000002           7                VELMC,ZCF(10),XPOR(10),XMB(10),IFLTS,STPS(40),
 000002           8                IPASS,PERIM,ROUCH,TH1,TH2,IEV(10),NFV,PI,FFP1,
 000002           9                IPLOT,XBG,XX1,EPSMIN,HIGH,LOW,HD1(6),HD2(6)
 000002             COMMON /PROPS/ XMW,SHRV,HFG,PV,RHOL,RHOV,VISL,VISV,XKL,ST,TF
 000002             DATA HD1/6*1H /,HD2/6*1H /
 000002             DATA W/1.055/,C/3.60/,PI/3.141592654/,E/2.16/
 000002             DATA C0/2.515517/,C1/.802853/,C2/.010328/,
 000002           1      D1/1.432788/,D2/.189269/,D3/.001308/
             C
 000002             NAMELIST /GRDATA/ LIC,TKELVN,RHOL,ST,VISL,HFG,CEE,AW,HW,DIAF,
 000002           1                     DIAVS,CCCT,FC,FC,NELEV,XELEV,ELEV,ICCM,WNTH,
 000002           2                     DX,HD1,HD2,XC,NCASE,LASTEPS,HPIJ,W,IPHIPC,
 000002           3                     NVS,AVS,HVS,FEPS,XEPS,EPSX,DEPTH,PHI,ANGLT,
 000002           4                     NCB,RHOV,ROUCH,VISV,FOCRV,IFLTS,
 000002           5                     XNFAC,XNLB,XCB,IPASS,PERIM,TH1,TH2,S,HREF,
 000002           6                     EPSMIN,CRVS,IPLOT,XBG,XX1,HIGH,LOW
             C
 000002             READ(5,GRDATA)
 000005             IF(IFLTS.EQ.0) GO TO 2
 000006             REWIND 7
 000010             READ(7) NM,(STPS(I),I=1,NF),(AAA(I),I=1,NM),(DCF(I),I=1,NF)
 000040           2 TRANK=1.8*TKELVN
 000042             CALL PROPS(LIC,TRANK)
 000044             IF(ICC.EQ.0) GO TO 10
 000045             ST=6.48E-3*2*1*ST
```

```
000047               RHOL=.4536*3.281**3*RHOL
000052               RHOV=.4536*3.281**3*RHOV
000055               VISL=4.448*3.281**2*3600.*VISL
000061               VISV=4.448*3.281**2*3600.*VISV
000065               HFG=(1055.*2.205)*HFG
000070               PV=4.448*39.37**2*PV
000073               XKL=.2930*3.281*1.8*XKL
000075               TF=TF/1.8
000077            10 CONTINUE
            C
000077               CALL DCALCS
            C        DCALCS  MAKES PRELIMINARY CALCULATIONS NEEDED FOR GROOVE-
            C        DRY-OUT PREDICTIONS
            C
000100               CALL FACTOR
            C        FACTOR COMPUTES FRICTION FACTOR COEFFICIENTS
            C
000101               IF(IGEOM.EQ.2) GO TO 11
000103               ALPHA=ASIN(WKTH/HPID)
000110               AW=.5*HPID*HPID*(ALPHA+SIN(ALPHA)*COS(ALPHA))
000121               AVS=PI*HPID*HPID/8.-AW/2.
000126               PERIM=(PI/2.-ALPHA)*HPID
000132               DIAVS=4.*AVS/(PERIM+HPID*COS(ALPHA))
000141               HW=(HPID+WKTH)/2.
000144               NVS=2
000145               HVS=(HPID-WKTH)/2.
000150               TH1=-(PI/2.-ALPHA)*180./PI
000154               TH2=-TH1
000156               FCGPV=.5
000160               WEFF=WKTH/2.
000162               IF(IGEOM.EQ.0) GO TO 11
000163               HVS=HPID*COS(ALPHA)
000167               HW=.5*HPID*(1.+COS(ALPHA))
000175               TH1=-(PI-ALPHA)*180./PI
000201               TH2=-ALPHA*180./PI
000204               WEFF=HPID/2.
000206            11 CONTINUE
            C
```

```
RUNX COMPILER (VER.2.3M)                09/28/76. 13.24.02.        INPT
000206          WRITE(6,900) HD1,HD2
000216          WRITE(6,901)
000222          WRITE(6,902) LIQ
000230          WRITE(6,904) TKELVN
000236          WRITE(6,906) RHOL
000244          WRITE(6,907) RHOV
000252          WRITE(6,908) ST
000260          WRITE(6,910) VISL
000266          WRITE(6,911) VISV
000274          WRITE(6,912) HFG
000302          WRITE(6,986) PV
000310          WRITE(6,988) XKL
000316          WRITE(6,990) SHRV
000324          WRITE(6,992) XMW
000332          WRITE(6,994) TF
000340          WRITE(6,914) GEE
000346          WRITE(6,922) IGEOM
000354          WRITE(6,924) HPID
000362          WRITE(6,925) WKTH
000370          WRITE(6,916) AW
000376          WRITE(6,918) HW
000404          WRITE(6,920) DIAF
000412          WRITE(6,959) S
000420          WRITE(6,968) EPSMIN
000426          WRITE(6,970) NEPS
000434          IF(NEPS.EQ.0) GO TO 4
000435          DO 3 I=1,NEPS
000437          WRITE(6,972) I,XEPS(I),EPSX(I)
000451        3 CONTINUE
000454        4 WRITE(6,960) NVS
000462          WRITE(6,962) AVS
000470          WRITE(6,926) DIAVS
000476          WRITE(6,927) HVS
000504          WRITE(6,929) PERIM
000512          WRITE(6,974) W
000520          WRITE(6,978) DEPTH
000526          WRITE(6,976) PHI
000534          WRITE(6,980) ANGWET
```

```
RUNX COMPILER (VER.2.3M)                 09/28/76. 13.24.02.          INPT

000542          WRITE(6,982) TH1
000550          WRITE(6,984) TH2
000556          WRITE(6,996) FOGRV
000564          WRITE(6,998) HREF
000572          WRITE(6,999) GRVS
000600          WRITE(6,928) QDOT
000606          WRITE(6,930) NQ
000614          DO 5 I=1,NQ
000616          WRITE(6,932) I,XQ(I),FQ(I)
000630        5 CONTINUE
000633          WRITE(6,934) NELEV
000641          DO 6 I=1,NELEV
000643          WRITE(6,936) I,XELEV(I),ELEV(I)
000655        6 CONTINUE
000660          WRITE(6,938) DX
000666          WRITE(6,971) IPRIMED
000674          WRITE(6,909) IFLTS
000702          WRITE(6,940) NCASE
000710          WRITE(6,942) LASTEPS
000716          WRITE(6,945) IPASS
000724          WRITE(6,946) IPLOT
000732          IF(IPLOT.EQ.0) GO TO 7
000733          WRITE(6,947) XX0
000741          WRITE(6,948) XX1
000747          WRITE(6,950) HIGH
000755          WRITE(6,956) LOW
000763        7 CONTINUE
000763      900 FORMAT(1H1,4X,6A10,/5X,6A10)
000763      901 FORMAT(//5X,38H INPUT VARIABLES AND FLUID PROPERTIES://)
000763        1             5X,37H INPUT VARIABLES AND FLUID PROPERTIES*//)
000763      902 FORMAT( 10X,42HLIQUID NUMBER.................     LIQ = ,I2)
000763      904 FORMAT( 10X,42HTEMPERATURE...................   TKELVN = ,
000763        1             F12.5,16H  DEGREES KELVIN)
000763      906 FORMAT( 10X,42HLIQUID DENSITY................     RHOL = ,
000763        1             F12.5,16H  KG/CU. M      )
000763      907 FORMAT( 10X,42HVAPOR DENSITY.................     RHOV = ,
000763        1             F12.5,16H  KG/CU. M      )
000763      908 FORMAT( 10X,42HSURFACE TENSION...............       ST = ,
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```
000763        1          F12.5,16H  NEWTONS/M       )
000763      910 FORMAT( 10X,42HLIQUID VISCOSITY...............     VISL = ,
000763        1          F12.5,18H  NEWTON-SEC/SQ. M)
000763      911 FORMAT( 10X,42HVAPOR VISCOSITY................     VISV = ,
000763        1          F12.5,18H  NEWTON-SEC/SQ. M)
000763        1          F12.5)
000763      912 FORMAT( 10X,42HLATENT HEAT....................      HFG = ,
000763        1          F12.5,16H  JOULES/KG       )
000763      986 FORMAT( 10X,42HVAPOR PRESSURE.................       PV = ,
000763        1          F12.5,16H  N/SQ. M         )
000763      988 FORMAT( 10X,42HTHERMAL CONDUCTIVITY OF LIQ...      XKL = ,
000763        1          F12.5,16H  WATTS/M K       )
000763      990 FORMAT( 10X,42HSPECIFIC HEAT RATIO...........     SHRV = ,
000763        1          F12.5,16H                  )
000763      992 FORMAT( 10X,42HMOLECULAR WEIGHT..............      XMW = ,
000763        1          F12.5,16H                  )
000763      994 FORMAT( 10X,42HFREEZING TEMPERATURE..........       TF = ,
000763        1          F12.5,16H  DEGREES KELVIN)
000763      914 FORMAT(/10X,42HGRAVITATIONAL ACCELERATION....      GEE = ,
000763        1          F12.5,20H  STANDARD GRAVITIES)
000763      916 FORMAT(/10X,42HWICK AREA.....................       AW = ,
000763        1          F12.5,16H  SQ. CM          )
000763      918 FORMAT( 10X,42HWICK HEIGHT...................       HW = ,
000763        1          F12.5,16H  CM              )
000763      920 FORMAT( 10X,42HWICK FIBER DIAMETER...........     DIAF = ,
000763        1          F12.5,16H  CM              )
000763      922 FORMAT(/10X,42HHEAT-PIPE GEOMETRY............    IGEOM = ,
000763        1          I2/15X,40H(0=HORIZ. SLAB, 1=VERT. SLAB, 3=GENERAL) ,/)
000763      924 FORMAT( 10X,42HHEAT-PIPE INSIDE DIAMETER.....     HPID = ,
000763        1          F12.5,16H  CM              )
000763      925 FORMAT( 10X,42HWICK THICKNESS................     WKTH = ,
000763        1          F12.5,16H  CM              )
000763      450 FORMAT( 10X,42HSPECIFIED SATURATION FRACTION.        S = ,
000763        1          F12.5)
000763      968 FORMAT( 10X,42HMINIMUM ALLOWABLE POROSITY....   EPSMIN = ,
000763        1          F12.5)
000763      970 FORMAT(/10X,42HNO. SPECIFIED-POROSITY PTS....     NPPS = ,
000763        1          I2)
```

```
000763       971 FORMAT(/10X,42HWICK PRIMED LEVEL (1=YES).....  IPRIMED = ,
000763         1          I2)
000763       909 FORMAT(/10X,42HLIQUID FILLETS ALONG WICK.....    IFLTS = ,
000763         1          I2)
000763       972 FORMAT(10X,21HPOROSITY POINT NO.    ,I2/
000763         1          15X,37HDISTANCE TO POINT.........     XEPS = ,
000763         2          F12.5,10H  CM      /
000763         3          15X,37HPOROSITY AT POINT.........     EPSX = ,
000763         4          F12.5)
000763       960 FORMAT(/10X,42HNO. OF EQUAL VAPOR SPACES.....      NVS = ,
000763         1          I2)
000763       962 FORMAT( 10X,42HAREA OF EACH VAPOR SPACE......      AVS = ,
000763         1          F12.5,16H  SQ. CM          )
000763       924 FORMAT( 10X,42HVAPOR-SPACE DIAMETER..........    DIAVS = ,
000763         1          F12.5,16H  CM              )
000763       927 FORMAT( 10X,42HHEIGHT TO TOP OF LOWEST V.S. .      HVS = ,
000763         1          F12.5,16H  CM              )
000763       920 FORMAT( 10X,42HTOTAL ACTIVE PERIMETER OF V.S.    PERIM = ,
000763         1          F12.5,16H  CM              )
000763       928 FORMAT(/10X,42HNOMINAL HEAT-TRANSFER RATE....     QDOT = ,
000763         1          F12.5,16H  WATTS           )
000763       930 FORMAT( 10X,42HNO. HEAT-INPUT SECTIONS.......       NC = ,
000763         1          I2)
000763       932 FORMAT( 10X,16HSECTION NUMBER  ,I2/
000763         1          15X,37HSECTION LENGTH............       XO = ,
000763         2          F12.5,10H  CM      /
000763         3          15X,37HHEAT-INPUT FRACTION.......       FO = ,
000763         4          F12.5)
000763       934 FORMAT(/10X,42HNO. ELEVATION POINTS..........    NELEV = ,
000763         1          I2)
000763       936 FORMAT(10X,21HELEVATION POINT NO.   ,I2/
000763         1          15X,37HDISTANCE TO POINT.........    XELEV = ,
000763         2          F12.5,10H  CM      /
000763         3          15X,37HELEVATION OF POINT........     ELEV = ,
000763         4          F12.5,10H  CM      )
000763       938 FORMAT(/10X,42HINTEGRATION STEP SIZE..........       DX = ,
000763         1          F12.5,16H  CM              )
000763       940 FORMAT(/10X,42HANOTHER CASE (0=NO, 1=YES)....    NCASE = ,
```

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RUNX COMPILER (VER.2.3M)                    09/28/76. 13.24.02.          INPT

000763          1         I2)
000763      942 FORMAT( 10X,42HUSE LAST POROSITY DISTN........  LASTEPS = ,
000763          1         I2)
000763      945 FORMAT( 10X,42HONLY ONE INTEGRATION PASS.....    IPASS = ,
000763          1         I2)
000763      974 FORMAT(/10X,42HGROOVE OPENING..................       W = ,
000763          1         F12.5,16H  CM             )
000763      978 FORMAT( 10X,42HGROOVE DEPTH....................   DEPTH = ,
000763          1         F12.5,16H  CM             )
000763      976 FORMAT( 10X,42HGROOVE HALF-ANGLE...............     PHI = ,
000763          1         F12.5,16H  DEGREES        )
000763      980 FORMAT( 10X,42HWETTING ANGLE...................  ANGWET = ,
000763          1         F12.5,16H  DEGREES        )
000763      982 FORMAT( 10X,42HFIRST GROOVE FEED LOCATION....      TH1 = ,
000763          1         F12.5,18H  DEGREES FROM TOP)
      C
000763      984 FORMAT( 10X,42HSECOND GROO'    FED LOCATION...     TH2 = ,
000763          1         F12.5,18H  DEGREES     ' TOP)
000763      996 FORMAT( 10X,42HRADIAL INPUT ..ACTION.........    FCGRV = ,
000763          1         F12.5)
000763      998 FORMAT( 10X,42HWICK HEIGHT REL. TO TUBE AXIS.     HREF = ,
000763          1         F12.5,18H  CM                 )
000763      990 FORMAT( 10X,42HNO. GROOVES PER CM............     GRVS = ,
000763          1         F12.5,16H  /CM                )
000763      946 FORMAT( 10X,42HPLOT POROSITY...................  IPLOT = ,
000763          1         I2)
000763      947 FORMAT( 10X,42HEXTRA WICK AT BEGINNING.......      XX0 = ,
000763          1         F12.5,16H  CM             )
000763      948 FORMAT( 10X,42HEXTRA WICK ON END.............      XX1 = ,
000763          1         F12.5,16H  CM             )
000763      950 FORMAT( 10X,42HHIGH TOLERANCE ON VOL. DENSITY     HIGH = ,
000763          1         F12.5,16H  PERCENT        )
000763      956 FORMAT( 10X,42HLOW TOLERANCE ON VOL. DENSITY.      LOW = ,
000763          1         F12.5,16H  PERCENT        )
000763           RND=(RHOL-RHOV)*G*(HW/100.)
000770           RRS=2.24E*E*H*ST/((DIAF/100.)*RND)
      C
000776           CALL VSRKS
```

```
RUNX COMPILER (VER.2.3M)              09/28/76. 13.24.02.         INPT
          C      VSBKS  CALCULATES THE VAPOR-SPACE BACK STRESS (THE INITIAL STRESS FBO)
          C
000777           XTOT=0.
001000           DO 16 I=1,NQ
001002           XTOT=XTOT+XQ(I)
001005        16 CONTINUE
001010           AB=AW/HW**2
001013           DO 18 I=1,NELEV
001015           ZELEV(I)=XELEV(I)/XTOT
001020           ELEVB(I)=ELEV(I)/HW
001023        18 CONTINUE
001026           DO 20 I=1, NQ
001030           ZQ(I)=XQ(I)/XTOT
001033        20 CONTINUE
001036           NI=XTOT/DX
001041           NIP1=NI+1
001043           DZ=DX/XTOT
          C
          C      CALCULATION OF THE NUMBER OF STEPS TO THE END OF
          C      EACH EVAPORATOR SECTION
          C
001045           II=1
001046           NEV=0
001047           DO 25 I=1,NQ
001051           II=II+XQ(I)/DX
001056           IF(FQ(I).LE.0.) GO TO 25
001060           NEV=NEV+1
001062           IEV(NEV)=II
001064        25 CONTINUE
          C
001067           FNUP=(VISL/RHOL)*(QDCT/HFG)*(XTOT/100.)/
001067         1     (RND*(DIAF/100.)**2*(HW/100.)**2)
          C
          C      CALCULATION OF THE INVERSE CUMULATIVE DISTRIBUTION FUNCTION
          C
001104           IF(LASTEPS.NE.0 .OR. NEPS.NE.0) GO TO 30
001112           Q=1-P
001115           T=SQRT(ALOG(1./(Q*Q)))
```

```
RUNX COMPILER (VER.2.3M)                  09/28/76. 13.24.02.          INPT

001124          FERMI=T-(C0+C1*T+C2*T*T)/(1.+D1*T+D2*T*T+D3*T*T*T)
           C
001141       30 CONTINUE
           C
001141          IF(NEPS.EQ.0) GO TO 101
001142          EPS0=EPSX(1)
001144          J=1
001145          DO 100 I=1,NIP1
001147          X=DX*(I-1)
001153          IF(X.GT.XEPS(J+1)) J=J+1
001160          SAVEPS(I)=EPSX(J)
001163          IF(XEPS(J+1).EQ.XEPS(J)) GO TO 100
001166          SAVEPS(I)=EPSX(J)+(EPSX(J+1)-EPSX(J))*(X-XEPS(J))/
001166         1                       (XEPS(J+1)-XEPS(J))
001201      100 CONTINUE
001204      101 CONTINUE
001204      801 FORMAT(/10X,42HNO.VAPOR FLOW OBSTRUCTIONS....       NOB = ,
001204         1         I2)
           C
001204          WRITE(6,955) ROUGH
001212      955 FORMAT( 10X,42HVAPOR SPACE SURFACE ROUGHNESS.    ROUGH = ,
001212         1         F12.5,16H  CM            )
001212          IF(NOB.EQ.0) GO TO 205
001213          DO 204 I=1,NOB
001215          ZOB(I)=XOB(I)/XTOT
001220      204 CONTINUE
001223          WRITE(6,801) NOB
001231          DO 202 J=1,NOB
001233          WRITE(6,800) J,XOB(J),XKOB(J)
001245      202 CONTINUE
001250      800 FORMAT(10X,21HFLOW OBSTRUCTION NO. ,I2/
001250         1         15X,37HDISTANCE TO OBSTRUCTION..      XOB = ,
001250         2         F12.5,10H  CM      /
001250         3         15X,37HVELOCITY HEADS LOST......     XKOB = ,
001250         4         F12.5)
001250      205 CONTINUE
001250       99 CONTINUE
001250          RETURN
```

```
RUNX COMPILER (VER.2.3*)                          09/28/76. 13.24.02.          INPT
001251         END
```

```
RUNX COMPILER (VER.2.3M)                 09/28/76. 13.24.02.

                      FUNCTION PERM(EPSO,EPSS)
              C
              C       PERM  CALCULATES THE DIMENSIONLESS PERMEABILITY OF A PARTIALLY
              C       SATURATED WICK OF OVERALL POROSITY  EPSO  FOR A CRITICAL
              C       POROSITY  EPSS
              C
000005                PERM=1.E-10
000007                IF(EPSS .LE. EPSI) GO TO 70
000012                EPSI=2.*EPSO-1.
000015                DEPS=(EPSS-EPSI)/10.
000020                PERM=0.
000021                DO 50 I=2,10,2
000023                PERM=PERM+4.*FINT(EPSO,EPSI+(I-1)*DEPS)*DEPS/3.
000040             50 CONTINUE
000042                DO 60 I=3,9,2
000044                PERM=PERM+2.*FINT(EPSO,EPSI+(I-1)*DEPS)*DEPS/3.
000061             60 CONTINUE
000063                PERM=PERM+(FINT(EPSO,EPSI)+FINT(EPSO,EPSS))*DEPS/3.
000076             70 CONTINUE
000076                RETURN
000100                END
```

```
RUNX COMPILER (VER.2.3M)                    09/28/76. 13.24.02.

                  SUBROUTINE PLOTEM
          C
          C       PLOTEM  PLOTS THE WICK POROSITY VARIATION
          C
000002            COMMON /PARAM/ EPS,EPSO,PND,GEE,C,NI,NIP1,HW,IGEOM,WKTH,HFIC,
000002           1                NC,FC(10),NELEV,XELEV(10),ZELEV(10),ELEV(10),
000002           2                ELEVF(10),H,FNUB,AW,AB,XTCT,DX,DZ,ODTD,COCT,FB,
000002           3                DIAF,A(8,500),XO(10),ZO(10),PBS,GPVS,HREF,IOGRV,
000002           4                NCASE,LASTEPS,SAVEPS(500),IFAIL,PBO,IPK,NH,EPSS,
000002           5                NVS,AVS,VFF,DIAVS,W,DEPTH,PHI,ANGWET,S,IPRINED,
000002           6                NEPS,XEPS(20),EPSX(20),NOTSS,HVS,AAA(40),CCH(40),
000002           7                VELMG,ZCB(10),XKCB(10),YCB(10),TILTS,STRS(40),
000002           8                IPASS,PEFIP,PCLCH,TH1,TH2,IEV(10),NEV,PI,FIP1,
000002           9                IPLOT,XX0,XX1,EPSMIN,HIGH,LOW,HD1(6),HD2(6)
000002            DIMENSION X(504),Y(504),XT(6),YT(6)
000002            DATA (XT(I),I=1,6) /2.0,2.2,2.4,2.6,0.,1./
000002            DATA (YT(I),I=1,6) /5.,5.,5.,5.,0.,1./
          C
000002            NPTS=NIP1+2
000004            NPTSM1=NPTS-1
000006            NPTSP1=NPTS+1
000010            NPTSP2=NPTS+2
          C
          C       SET UP ARRAYS TO BE PLOTTED
          C
000012            DO 50 I=2,NPTSM1
000014            X(I)=(A(1,I-1)+XX0)/2.54
000021            Y(I)=1.-A(5,I-1)
000025         50 CONTINUE
000030            X(NPTS)=X(NPTSM1)+XX1/2.54
000035            Y(NPTS)=Y(NPTSM1)
000040            X(1)=0.
000041            Y(1)=Y(2)
          C
          C       OPEN PLOT FILE USING FORTRAN DEFINED BUFFER
          C
000043            CALL IOPK(50)
```

```
          C
          C     GENERATE SCALING FOR  X AND Y  ARRAYS
          C
000045          CALL SCALE(X,10.,NPTS,1)
000050          Y(NPTSP1)=0.
000052          Y(NPTSP2)=.04
000054          IF(Y(NPTS)*(1.+HIGH/100.) .GT. .4) Y(NPTSP2)=.05
          C
          C     DRAW AXES
          C
000064          CALL AXIS(0,0,18HDISTANCE IN INCHES,-18,16.,0.,
000064        1           X(NPTS+1),X(NPTSP2))
000100          CALL AXIS(0,0,23H VOLUME DENSITY OF WICK,23,10.,90.,
000100        1           Y(NPTSP1),Y(NPTSP2))
000114          CALL AXIS(0.,10.,1H ,1,16.,0.,
000114        1           X(NPTSP1),X(NPTSP2))
000130          CALL AXIS(16.,0.,1H ,-1,10.,90.,
000130        1           Y(NPTSP1),Y(NPTSP2))
          C
          C     PLOT  X AND Y  ARRAYS
          C
000144          CALL LINE(X,Y,NPTS,1,0,0)
          C
          C     DENOTE THE CONDENSER AND EVAPORATOR ENDS
          C
000150          XC=X(2)/X(NPTSP2)
000153          YC=Y(2)/Y(NPTSP2)
000156          XE=X(NPTSP1)/X(NPTSP2)
000161          YE=Y(NPTSP1)/Y(NPTSP2)
000164          CALL SYMBOL(XC,YC,.4,13,0.,-1)
000170          CALL SYMBOL(XE,YE,.4,13,0.,-1)
          C     ADD TOLERANCE BANDS TO PLOT
          C
000174          IF(HIGH.EQ.0. .AND. LOW.EQ.0.)GO TO 20
000203          DO 10 I=1,NPTS
000205          Y(I)=Y(I)*(1.+HIGH/100.)
000212       10 CONTINUE
000215          CALL LINE(X,Y,NPTS,1,1,74)
```

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RUNX COMPILER (VER.2.3M)              09/28/76. 13.24.02.        PLOTEM

000221          DO 15 I=1,NPTS
000223          Y(I)=Y(I)*(1.-LOW/100.)/(1.+HIGH/100.)
000234       15 CONTINUE
000237          CALL LINE(X,Y,NPTS,1,1,74)
          C
          C     ANNOTATE PLOT
          C
000243          CALL SYMBOL(2.,6.,.2,HD1,0.,60)
000247          CALL SYMBOL(2.,5.5,.2,HD2,0.,60)
000253          IF(HIGH.EQ.0. .AND. LOW.EQ.0.) GO TO 17
000262          CALL LINE(XT,YT,4,1,1,74)
000266          CALL SYMBOL(3.,5.,.2,25HTOLERANCE ON WICK DENSITY,0.,25)
000272       17 CONTINUE
          C
          C     CLOSE PLOT FILE
          C
000272       20 CALL PLOT(0,0,999)
000275          RETURN
000276          END
```

```
RUNX COMPILER (VER.2.3M)                    09/28/76. 13.24.32.

                     SUBROUTINE PROPS(L,I)
          C
          C            THIS ROUTINE COMPUTES FLUID PROPERTIES FROM DATA FITS
          C
000005               COMMON /CPROPS/ XMW,SHPV,  J,PV,RHOL,RHOV,VISL,VISV,XHL,ST,TF
000005               DIMENSION A11(7), A21(7),
000005              1   A31(7), A32(7), A33(7), A34(7), A35(7),
000005              2   A41(7), A42(7), A43(7), A44(7), A45(7),
000005              3   A51(7), A52(7), A53(7), A54(7), A55(7),
000005              4   A61(7), A62(7), A63(7), A64(7), A65(7),
000005              5   A71(7), A72(7), A73(7), A74(7), A75(7),
000005              6   A81(7), A82(7), A83(7), A84(7), A85(7),
000005              7   A91(7), A92(7), A93(7), A94(7), A95(7),
000005              8   A101(7), A102(7), A103(7), A104(7), A105(7),
000005              9   A111(7), A112(7), A113(7), A114(7), A115(7)
          C
          C              WATER (32<T<400F)
          C
000005               DATA   A11(1),       A21(1)/
000005              *         491.7,       18.016/
000005               DATA   A31(1),       A32(1),       A33(1),       A34(1),       A35(1)/
000005              *    1.3555636,-4.957576E-5,           0.,           0.,           0./
000005               DATA   A41(1),       A42(1),       A43(1),       A44(1),       A45(1)/
000005              *    1300.5506,-5.765511E-2,-4.454588E-4,           0.,           0./
000005               DATA   A51(1),       A52(1),       A53(1),       A54(1),       A55(1)/
000005              *    14.199322,  -6.5267262,  -.81013069,           0.,           0./
000005               DATA   A61(1),       A62(1),       A63(1),       A64(1),       A65(1)/
000005              *    58.481766, 2.598296E-2,-3.547212E-5,           0.,           0./
000005               DATA   A71(1),       A72(1),       A73(1),       A74(1),       A75(1)/
000005              *    7.4472132,  -6.0175647,  -.75994942,           0.,           0./
000005               DATA   A81(1),       A82(1),       A83(1),       A84(1),       A85(1)/
000005              *    72.925745,  -.26276099, 5.033276E-4,-4.411823E-7, 1.469628E-10/
000005               DATA   A91(1),       A92(1),       A93(1),       A94(1),       A95(1)/
000005              *    -13.45456,   1.1041377,           0.,           0.,           0./
000005               DATA  A101(1),      A102(1),      A103(1),      A104(1),      A105(1)/
000005              *   -7.6595695,5.3526992E-3,-6.446039E-6,2.5352227E-9,           0./
000005               DATA  A111(1),      A112(1),      A113(1),      A114(1),      A115(1)/
```

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RUNX COMPILER (VER.2.3M)                    09/26/76. 13.24.02.          PROPS

000005          * -9.637395E-3, 4.717222E-5,-2.230757E-7,2.117195E-10,-7.550916E-14/
           C
           C         AMMONIA (-107.9F<T<190F)
           C
000005           DATA   A11(2),      A21(2)/
000005          *        391.8,      17.032/
000005           DATA   A31(2),      A32(2),       A33(2),      A34(2),       A35(2)/
000005          *         1.31,          0.,            0.,          0.,           0./
000005           DATA   A41(2),      A42(2),       A43(2),      A44(2),       A45(2)/
000005          *  1.009791E+3,-2.462995E+0, 4.576430E-3,-4.474567E-6,           0./
000005           DATA   A51(2),      A52(2),       A53(2),      A54(2),       A55(2)/
000005          *  1.999774E+1,-4.021740E+0, 2.665010E-1,-7.570547E-2,           0./
000005           DATA   A61(2),      A62(2),       A63(2),      A64(2),       A65(2)/
000005          *  7.043746E+1,-1.172405E-1, 1.931737E-4,-1.649913E-7,           0./
000005           DATA   A71(2),      A72(2),       A73(2),      A74(2),       A75(2)/
000005          *  1.269996E+2,-1.113379E+1, 2.693120E+0,-4.095769E-1,           0./
000005           DATA   A81(2),      A82(2),       A83(2),      A84(2),       A85(2)/
000005          *  1.537046E+1,-2.496424E-1, 6.623150E-4,-7.941605E-7,3.552154E-10/
000005           DATA   A91(2),      A92(2),       A93(2),      A94(2),       A95(2)/
000005          * -1.079390E+2, 1.906094E+3,-4.726715E+2, 5.034060E+1,-2.024364E+0/
000005           DATA   A101(2),     A102(2),      A103(2),     A104(2),      A105(2)/
000005          * -4.340196E-1, 3.644710E-3,-6.537242E-6, 3.009435E-9,           0./
000005           DATA   A111(2),     A112(2),      A113(2),     A114(2),      A115(2)/
000005          *  6.424501E-3,-7.504643E-6,-7.695754E-9,8.023533E-12,           0./
           C
           C         METHYL ALCOHOL (-140F<T<370F)
           C
000005           DATA   A11(3),      A21(3)/
000005          *        922.7,      32.042/
000005           DATA   A31(3),      A32(3),       A33(3),      A34(3),       A35(3)/
000005          *        1.205,          0.,            0.,          0.,           0./
000005           DATA   A41(3),      A42(3),       A43(3),      A44(3),       A45(3)/
000005          *  8.790540E+0,-2.476105E+0, 6.410624E-3,-7.064195E-6, 2.214439E-9/
000005           DATA   A51(3),      A52(3),       A53(3),      A54(3),       A55(3)/
000005          *  1.505411E+1,-4.240635E+0, 3.306130E+0,-1.969100E+0, 3.349515E-1/
000005           DATA   A61(3),      A62(3),       A63(3),      A64(3),       A65(3)/
000005          *  1.097090E+0, 2.932030E-1,-8.417072E-4, 9.761207E-7,-4.300120E-10/
000005           DATA   A71(3),      A72(3),       A73(3),      A74(3),       A75(3)/
```

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RUNX COMPILER (VER.2.3M)                    09/28/76. 13.24.02.          PROFS

000005          *  1.593164E+1,-2.109098E+1, 1.144326E+1,-4.276643E+0, 5.809908E-1/
000005           DATA   A81(3),        A82(3),        A83(3),        A84(3),        A85(3)/
000005          *  2.285363E+1,-1.153169E-1, 2.303795E-4,-2.155127E-7, 7.55172E-11/
000005           DATA   A91(3),        A92(3),        A93(3),        A94(3),        A95(3)/
000005          *  1.922596E+2,-1.266769E+2, 3.113344E+1,-3.318410E+0, 1.325051E-1/
000005           DATA  A101(3),       A102(3),       A103(3),       A104(3),       A105(3)/
000005          *  9.044433E-2, 2.097417E-4,-6.310697E-7,7.394364E-10,-3.19696E-13/
000005           DATA  A111(3),       A112(3),       A113(3),       A114(3),       A115(3)/
000005          *  5.799525E-3,-1.404494E-5, 1.205620E-8,3.516629E-12,-8.67029E-15/
       C
       C             FREON-21 (-55F<T<305F)
       C
000005           DATA   A11(4),        A21(4)/
000005          *        248.7,        102.[illegible]/
000005           DATA   A31(4),        A32(4),        A33(4),        A34(4),        A35(4)/
000005          *        1.175,            0.,            0.,            0.,            0./
000005           DATA   A41(4),        A42(4),        A43(4),        A44(4),        A45(4)/
000005          *  8.657875E+1, 4.636558E-1,-1.631685E-3, 2.056597E-6,-1.018948E-9/
000005           DATA   A51(4),        A52(4),        A53(4),        A54(4),        A55(4)/
000005          *  3.270732E+0, 1.573170E+1,-1.607959E+1, 5.259243E+0,-6.269501E-1/
000005           DATA   A61(4),        A62(4),        A63(4),        A64(4),        A65(4)/
000005          *  1.332756E+2,-3.261757E-1, 1.111655E-3,-1.611728E-6,6.906674E-10/
000005           DATA   A71(4),        A72(4),        A73(4),        A74(4),        A75(4)/
000005          *  8.534322E+1,-1.062575E+2, 1.252681E+2,-4.265662E+1, 5.375463E+0/
000005           DATA   A81(4),        A62(4),        A83(4),        A84(4),        A85(4)/
000005          * -8.347479E+0, 8.530116E-2,-2.757886E-4, 3.643724E-7,-1.75387E-10/
000005           DATA   A91(4),        A92(4),        A93(4),        A94(4),        A95(4)/
000005          * -1.838532E+3, 1.199366E+3,-2.944711E+2, 3.215076E+1,-1.315728E+0/
000005           DATA  A101(4),       A102(4),       A103(4),       A104(4),       A105(4)/
000005          *  4.750194E-1,-2.403548E-3, 5.713512E-6,-6.391302E-9, 2.65040E-12/
000005           DATA  A111(4),       A112(4),       A113(4),       A114(4),       A115(4)/
000005          * -5.748871E-3, 4.984869E-5,-1.133747E-7,9.235658E-11,-2.25956E-14/
       C
       C             ETHANE (-135F<T<80F)
       C
000005           DATA   A11(5),        A21(5)/
000005          *        101.6,         30.07/
000005           DATA   A31(5),        A32(5),        A33(5),        A34(5),        A35(5)/
```

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RUNX COMPILER (VER.2.3M)                    09/28/76. 13.24.02.        PROFS

000005          *       1.18,          0.,          0.,          0.,          0./
000005           DATA   A41(5),      A42(5),      A43(5),      A44(5),      A45(5)/
000005          * -4.278934E+3, 4.573254E+1,-1.719481E-1, 2.840439E-4,-1.756889E-7/
000005           DATA   A51(5),      A52(5),      A53(5),      A54(5),      A55(5)/
000005          *  4.513520E+1,-5.803273E+1, 3.388505E+1,-9.165778E+0, 9.154704E-1/
000005           DATA   A61(5),      A62(5),      A63(5),      A64(5),      A65(5)/
000005          * -3.433014E+2, 3.901041E+0,-1.478827E-2, 2.451166E-5,-1.518862E-8/
000005           DATA   A71(5),      A72(5),      A73(5),      A74(5),      A75(5)/
000005          *  9.831080E+1,-1.463731E+2, 6.422928E+1,-2.191841E+1, 2.129803E+0/
000005           DATA   A81(5),      A82(5),      A83(5),      A84(5),      A85(5)/
000005          * -1.723943E+1, 2.931920E-1,-7.953422E-4, 1.385103E-6,-8.90506E-10/
000005           DATA   A91(5),      A92(5),      A93(5),      A94(5),      A95(5)/
000005          *  2.099855E+4,-2.017435E+4, 5.085813E+3,-5.697099E+2, 2.392870E+1/
000005           DATA  A101(5),     A102(5),     A103(5),     A104(5),     A105(5)/
000005          * -1.142960E+0, 1.317096E-2,-5.072525E-5, 8.390294E-8,-5.11860E-11/
000005           DATA  A111(5),     A112(5),     A113(5),     A114(5),     A115(5)/
000005          *  1.123709E-2,-8.339622E-5, 2.759121E-7,-4.39343E-10,2.651466E-13/
          C
          C             METHANE (-280F<T<-120F)
          C
000005           DATA   A11(6),      A21(6)/
000005          *      163.2,       16.04/
000005           DATA   A31(6),      A32(6),      A33(6),      A34(6),      A35(6)/
000005          *       1.32,          0.,          0.,          0.,          0./
000005           DATA   A41(6),      A42(6),      A43(6),      A44(6),      A45(6)/
000005          * -1.124091E+3, 2.425142E+1,-1.589307E-1, 4.547110E-4,-4.908714E-7/
000005           DATA   A51(6),      A52(6),      A53(6),      A54(6),      A55(6)/
000005          *  1.365684E+0, 8.557617E+0,-3.746570E+0, 5.803347E-1,-3.257158E-2/
000005           DATA   A61(6),      A62(6),      A63(6),      A64(6),      A65(6)/
000005          *  1.449081E+1, 3.814831E-1,-3.223542E-3, 1.076420E-5,-1.353123E-8/
000005           DATA   A71(6),      A72(6),      A73(6),      A74(6),      A75(6)/
000005          *  6.381082E+1,-5.445063E+1, 1.637493E+1,-2.759041E+0, 1.547555E-1/
000005           DATA   A81(6),      A82(6),      A83(6),      A84(6),      A85(6)/
000005          * -9.826486E+0, 2.024132E-1,-1.540820E-3, 4.719715E-6,-5.211675E-9/
000005           DATA   A91(6),      A92(6),      A93(6),      A94(6),      A95(6)/
000005          *  9.119631E+3,-6.766529E+3, 1.880522E+3,-2.321585E+2, 1.074409E+1/
000005           DATA  A101(6),     A102(6),     A103(6),     A104(6),     A105(6)/
000005          *  3.486470E-1,-1.720996E-3, 3.699297E-7, 1.840747E-9,-3.73323E-11/
```

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RUNX COMPILER (VER.2.3M)                   09/28/76. 13.24.02.           PROFS

000005          DATA  A111(6),      A112(6),      A113(6),      A114(6),      A115(6)/
000005         *  5.412797E-3,-5.463947E-5, 2.856240E-7,-7.81700E-10,8.146455E-13/
           C
           C          NITROGEN (-340F<T<-250F)
           C
000005          DATA   A11(7),       A21(7)/
000005         *        113.9,       28.016/
000005          DATA   A31(7),       A32(7),       A33(7),       A34(7),       A35(7)/
000005         *         1.40,          0.,           0.,           0.,           0./
000005          DATA   A41(7),       A42(7),       A43(7),       A44(7),       A45(7)/
000005         *  7.649074E+1,-2.305556E-1, 5.317599E-3,-2.340715E-5,           0./
000005          DATA   A51(7),       A52(7),       A53(7),       A54(7),       A55(7)/
000005         *  3.217173E+1,-1.431289E+1, 3.064764E+0,-3.133777E-1, 1.176449E-2/
000005          DATA   A61(7),       A62(7),       A63(7),       A64(7),       A65(7)/
000005         *  7.298716E+1,-3.323232E-1, 2.281469E-3,-7.478632E-6,           0./
000005          DATA   A71(7),       A72(7),       A73(7),       A74(7),       A75(7)/
000005         *  2.102802E+1,-7.503727E+0, 9.613273E-1,-4.861116E-2,           0./
000005          DATA   A81(7),       A82(7),       A83(7),       A84(7),       A85(7)/
000005         * -1.130769E+1, 3.560937E-1,-3.880943E-3, 1.687014E-5,-2.609665E-8/
000005          DATA   A91(7),       A92(7),       A93(7),       A94(7),       A95(7)/
000005         *  1.718670E+4,-1.371991E+4, 4.103945E+3,-5.453515E+2, 2.716624E+1/
000005          DATA  A101(7),      A102(7),      A103(7),      A104(7),      A105(7)/
000005         *  1.178000E-1,-7.992424E-5,-1.401515E-6,          0.,           0./
000005          DATA  A111(7),      A112(7),      A113(7),      A114(7),      A115(7)/
000005         *  1.636031E-3,-3.768939E-6,-4.379371E-8,1.270396E-10,           0./
           C
000005          IF (L.EQ.0) GO TO 20
           C
000006          T2 = T*T
000007          T3 = T2*T
000011          T4 = T2*T2
000013          TR = 1000./T
000015          TR2 = TR*TR
000017          TR3 = TR2*TR
000021          TR4 = TR2*TR2
000023          ALT=ALPC(I)
000027          ALT2=ALT*ALT
000031          ALT3=ALT2*ALT
```

```
000033          ALT4=ALT2*ALT2
          C
          C        FLUID PROPERTIES
          C
000035          TF = A11(L)
000037          YMW=A21(L)
000041          SHPV = A31(L)+A32(L)*T+A33(L)*T2+A34(L)*T3+A35(L)*T4
000053          HFG = A41(L)+A42(L)*T+A43(L)*T2+A44(L)*T3+A45(L)*T4
000065          PV = EXP(A51(L)+A52(L)*TR+A53(L)*TR2+A54(L)*TR3+A55(L)*TR4)
000103          RHOL = A61(L)+A62(L)*T+A63(L)*T2+A64(L)*T3+A65(L)*T4
000115          RHOV = EXP(A71(L)+A72(L)*TR+A73(L)*TR2+A74(L)*TR3+A75(L)*TR4)
000133          VISL = EXP(A81(L)+A82(L)*T+A83(L)*T2+A84(L)*T3+A85(L)*T4)
000151          VISV = EXP(A91(L)+A92(L)*ALT+A93(L)*ALT2+A94(L)*ALT3+A95(L)*ALT4)
000167          YKL = A101(L)+A102(L)*T+A103(L)*T2+A104(L)*T3+A105(L)*T4
000201          ST = A111(L)+A112(L)*T+A113(L)*T2+A114(L)*T3+A115(L)*T4
000213          VISV = VISV/4.1697504E8
000215          VISL=VISL/4.1697504E8
000217          RETURN
          C
000220       20 CONTINUE
000220          RETURN
000221          END
```

```
RUNX COMPILER (VER.2.3M)                    09/25/76. 13.24.02.

                SUBROUTINE RECEDE(R,DH,AC,IREC)
          C
          C     RECEDE  CALCULATES THE PARAMETERS FOR A GROOVE WITH A
          C     CIRCULAR MENISCUS
          C
000007          COMMON /PARAM/ EPS,EPSO,PND,GEF,G,NI,NIP1,HW,IGEOM,WKTH,HPIC,
000007         1               NC,FC(10),NFLEV,XELEV(10),ZELEV(10),ELEV(10),
000007         2               ELEVB(10),H,FNUB,AW,AB,XTCT,DX,DZ,QDTB,QDOT,FB,
000007         3               DIAF,A(6,500),XG(10),ZG(10),PBS,GRVS,HREF,FCCRV,
000007         4               NCASE,LASTEPS,SAVEPS(500),IFAIL,PBO,IPK,NH,EPSS,
000007         5               NVS,AVS,VFF,DIAVS,W,DEPTH,PHI,ANGWET,S,IPRINEC,
000007         6               NEPS,XEPS(20),EPSX(20),NOB,SS,HVS,AAA(40),DDF(40),
000007         7               VELHD,ZOB(10),XKOB(10),XOB(10),IFLTS,STRS(40),
000007         8               IPASS,PERIM,ROUGH,TH1,TH2,IEV(10),NEV,FI,FFM1,
000007         9               IPLOT,XX0,XX1,EPSMIN,HIGH,LOW,HD1(6),HD2(6)
000007          COMMON /FPROPS/ XMW,SHRV,HFG,PV,RHOL,RHOV,VISL,VISV,XKL,ST,TF
000007          COMMON /CRVDTA/ ACR,PHIP,SP,CP,TP,SMAX,CMAX,PSIMR,HC,ATRI,PERIF,
000007         1                RMIN,CURV,BOT,FLO,GFAC,VFAC,RWMN,RPD
000007          COMMON /AALFA/ AFIT,BFIT,CFIT,FRF
          C
          C     IREC=1  MEANS MENISCUS ATTACHED TO GROOVE TIPS
          C     IREC=2  MEANS MENISCUS RECEDED FROM TIPS
          C     IREC=3  MEANS MENISCUS TOUCHING THE GROOVE BOTTOM
          C
000007          IF(R.LT.RMIN) GO TO 100
          C
          C     MENISCUS ATTACHED TO GROOVE TIPS
          C
000012          SPSI=(W/100.)/(2.*R)
000015          CPSI=SQRT(1.-SPSI*SPSI)
000024          PSIR=ATAN(SPSI/CPSI)
000033          ACON=90.-PHI-(PSIR/RPD)
000037          CALL ALFA(ACON)
000044          AC=((W/100.)/2.)*(((W/100.)/(2.*TF))+R*CPSI)-PSIR*R*R
000057          AC=AC-ATRI
000061          DH=4.*AC/PERIF
000064          TEST=R*(1.-CPSI)
```

```
RUNX COMPILER (VER.2.3M)                 09/28/76. 13.24.02.

                  SUBROUTINE RUNGE(Y,YP,DZ)
           C
           C      RUNGE  TAKES ONE INTEGRATION STEP BY THE RUNGE-KUTTA METHOD
           C
000006            DIMENSION Y(5),YP(5),YP1(5),YP2(5),YP3(5),YP4(5),YD(5)
000006            DO 1 I=1,5
000010            YP1(I)=YP(I)
000013          1 YD(I)=Y(I)+YP1(I)*DZ/2.
000022            CALL DERIV(YP2,YD)
000026            DO 2 I=1,5
000030          2 YD(I)=Y(I)+YP2(I)*DZ/2.
000037            CALL DERIV(YP3,YD)
000043            DO 3 I=1,5
000045          3 YD(I)=Y(I)+YP3(I)*DZ
000053            CALL DERIV(YP4,YD)
000057            DO 4 I=1,5
000061          4 Y(I)=Y(I)+(YP1(I)+2.*YP2(I)+2.*YP3(I)+YP4(I))*(DZ/6.)
000076            CALL DERIV(YP,Y)
000102            RETURN
000103            END
```

```
000067           IREC=1
000070           IF(TEST.GE.(DEPTH/100.)) IREC=2
000075           RETURN
           C
000076       100 CONTINUE
           C     MENISCUS RECEDED INTO GROOVE
000076           IREC=2
000077           ACON=ANGWET
000101           CALL ALFA(ACON)
000106           PERI=2.*R*SMAX/SP-BCT
000113           AC=R*SMAX*(R*SMAX/TP+R*CMAX)-PSIMR*R*R
000123           AC=AC-ATP1
000125           DH=4.*AC/PERI
000130           TEST1=R*SMAX/TP-HG
000134           TEST2=R*(1.-CMAX)
000137           IF(TEST2.GE.TEST1) IREC=3
000143           RETURN
000144           END
```

```
RUNX COMPILER (VER.2.3M)                    09/28/76. 13.24.02.

                     SUBROUTINE VSBKS
              C
              C      VSBKS  CALCULATES THE VAPOR-SPACE BAK STRESS, WHICH SETS
              C      THE INITIAL STRESS  PBO
              C
000002               COMMON /PARAM/ EPS,EPSC,PND,GEE,G,NI,NIP1,HW,ICEOM,WKTH,HFIC,
000002             1                NC,FC(10),NELEV,XELEV(10),ZELEV(10),ELEV(10),
000002             2                ELEVP(10),H,FNUP,AW,AB,XTOT,DX,DZ,QDTO,QDOT,FB,
000002             3                DIAF,A(8,500),XC(10),ZC(10),PBS,GPVS,HWEF,FCGHV,
000002             4                NCASE,LASTEPS,SAVEPS(500),IFAIL,PBO,IPK,NH,EPSS,
000002             5                NVS,AVS,VFF,DIAVS,W,DEPTH,PHI,ANGWET,S,IPRIPRD,
000002             6                NEPS,XEPS(20),EPSX(20),NJB,SS,HVS,AAA(40),CCH(40),
000002             7                VELHC,ZOB(10),XKOB(10),XJB(10),IFLTS,STPS(40),
000002             8                IPASS,PFRIM,ROUGH,TH1,TH2,IEV(10),NEV,PI,FFM1,
000002             9                IPLOT,XXO,XX1,EPSMIN,HIGH,LOW,HD1(6),HD2(6)
000002               COMMON /CPROPS/ XMW,SHRV,HFG,PV,RHOL,RHOV,VISL,VISV,XKL,ST,TF
000002               DIMENSION SA(3),SB(3),SG(3),SN(3)
000002               DATA (SA(I),I=1,3) /.68,1.5,2.2447/,
000002             1      (SB(I),I=1,3) /.40,.50,.50/,
000002             2      (SG(I),I=1,3) /1.5,1.0,1.5/,
000002             3      (SN(I),I=1,3) /1.9,1.2,1./
              C
000002               IF(GEE.EQ.0.) GO TO 10
000002               PBO=(ST/(HPIL/200.)+(RHOL-RHOV)*GEE*G*HW/100.)/PND
000003               B=1./(4.*ST/((RHOL-RHOV)*GEE*G*(DIAVS/100.)**2))
000015               J=IGEOM+1
000026               YTR=1./B+(SA(J)/B**SB(J))*(1.-SN(J)*EXP(-SG(J)*SQRT(B)))
000030               YT=YTR*DIAVS/100.
000051               PBO1=(YT+(HW-HVS)/100.)*(RHOL-RHOV)*GEE*G/PND
000054               IF(PBO.LT.PBO1) PBO=PBO1
000066               RETURN
000071            10 PBO=(4.*ST/(DIAVS/100.))/PND
000072               RETURN
000077               END
000100
```

```
                    SUBROUTINE WET(TSTGN,R1,R2,TL1,TL2)
             C
             C      WET  INTEGRATES ALONG THE GROOVE FROM  TH1  AND  TH2  AND
             C      REPORTS LOCATIONS  TL1  AND  TL2  WHERE DRY-UP OCCURS
             C
000010              COMMON /PARAM/ EPS,EPSO,PNO,GEE,G,NI,NIP1,HW,IGEOM,WKTH,HPID,
000010             1               NC,FC(10),NELEV,XELEV(10),ZELEV(10),ELEV(10),
000010             2               ELEVB(10),H,FNLB,AW,AB,XTCT,DX,DZ,COTB,COCT,PB,
000010             3               DIAF,A(8,500),XC(10),ZC(10),PBS,GRVS,HREF,FCGRV,
000010             4               NCASE,LASTEPS,SAVEPS(500),IFAIL,PBO,IMK,NH,EPSS,
000010             5               NVS,AVS,VFF,DIAVS,W,DEPTH,PHI,ANGWET,S,IPWIPEC,
000010             6               NEPS,AEPS(20),EPSX(20),NOP,SS,HVS,AAA(40),CCH(40),
000010             7               VELHD,ZCB(10),XCB(10),XOH(10),IFLTS,STPS(40),
000010             8               IPASS,PERIM,ROUGH,TH1,TH2,IEV(10),NEV,PI,FFP1,
000010             9               IPLOT,XXO,XX1,EPSMIN,HIGH,LOW,HD1(6),HD2(6)
000010              COMMON /CPROPS/ XMW,SHRV,HFG,PV,RHOL,RHOV,VISL,VISV,XKL,ST,TF
000010              COMMON /GRVDTA/ ACK,PHIR,SP,CP,TP,SPAN,CMAX,PSIPR,HG,ATRI,PERIF,
000010             1                RMIN,CURV,BCT,FLC,GFAC,VFAC,RWPN,RPD
000010              COMMON /ALFA/ AFIT,BFIT,CFIT,FRF
             C
000010              NT1=TSTGN-TH1
000013              IF(NT1.EQ.0) NT1=1
000015              XT1=NT1
000017              DT1=(TSTGN-TH1)/XT1
000022              NT2=TH2-TSTGN
000025              IF(NT2.EQ.0)NT2=1
000027              XT2=NT2
000031              DT2=(TH2-TSTGN)/XT2
000034              FLO1=FLO*(TSTGN-TH1)/(TH2-TH1)
000041              FLO2=FLO*(TH2-TSTGN)/(TH2-TH1)
000045              DFLO1=FLO1/XT1
000047              DFLO2=FLO2/XT2
000051              R1=1./R1
000053              R2=1./R2
000055              N=NT1
000057              R=R1
000061              FFLO=FLO1
```

```
000063              DFLO=DFLO1
000065              DT=DT1
000067              T=TH1
000071              IFLAG=0
000072          100 CONTINUE
000072              DO 101 I=1,N
000074              R=1./P
000076              CALL RECEDE(R,DH,AC,IREC)
000104              IF(IREC.EQ.3) GO TO 102
000106              DPDT=-GFAC*SIN(RPD*T)+FRF*VFAC*FFLO/(AC*DH**2)
000125              DPDT=DPDT*RPD
000127              P=P+DPDT*DT
000132              FFLO=FFLO-DFLO
000134              T=T+DT
000136          101 CONTINUE
              C
000141          102 CONTINUE
000141              IFLAG=IFLAG+1
000143              IF(IFLAG.EQ.2) GO TO 103
000145              TL1=T
000146              N=NT2
000150              P=P2
000152              FFLO=-FLO2
000154              DFLO=-DFLO2
000156              DT=-DT2
000160              T=TH2
000162              GO TO 100
000163          103 CONTINUE
000163              TL2=T
000164              RETURN
000165              END
```

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RUNX COMPILER (VER.2.3M)                09/28/76. 13.24.02.

                    SUBROUTINE WRT
              C
              C     WRT  WRITES THE RESULTS
              C
000002              COMMON /PARAM/ EPS,EPSO,END,CEF,G,NI,NIP1,HW,IGEOM,WKTH,HFID,
000002           1                 NG,FC(10),NELEV,XELEV(10),ZELEV(10),FLEV(10),
000002           2                 ELEVB(10),H,FNLB,AW,AB,XTCT,DX,DZ,ODTB,ODCT,HB,
000002           3                 DIAF,A(8,500),XC(10),ZC(10),PBS,GRVS,HREF,FCCPV,
000002           4                 NCASE,LASTEPS,SAVEPS(500),IFAIL,PRO,IMH,NH,EPSS,
000002           5                 NVS,AVS,VFF,DIAVS,W,DEPTH,PHI,ANGWET,S,IPRIPED,
000002           6                 [illegible]S,XEPS(20),EPSX(20),NOP,SS,HVS,AAA(40),CCH(40),
000002           7                 VELHD,ZOB(10),XKOB(10),XOB(10),IFLTS,STRS(40),
000007           8                 IPASS,FLHIP,ROUGH,TH1,TH2,IEV(10),NEV,PI,FIP1,
000002           9                 IPLOT,XXO,XX1,EPSMIN,HIGH,LOW,HD1(6),HD2(6)
000002              COMMON /CPROPS/ XMW,SHPV,HFG,PV,RHOL,RHOV,VISL,VISV,XKL,ST,TF
000002              DIMENSION REVP(10),X(11),WW(11),WP(11)
000002              IMK=1
000003              GMASS=A(4,NIP1)*(AW/10000.)*RHOL*(XTCT/100.)*1000.
000014              CDT=ODTB*ODCT
000016              VVAP=(CDT/HFG)/(FLOAT(NVS)*(AVS*1.E-4)*RHOV)
000024              REV=VVAP*(DIAVS/100.)/(VISV/RHOV)
000031              VELHD=100.*(.5*RHOV*VVAP**2)/((RHOL-RHOV)*G)
000040              IF(REV.LT.REVP(1)) GO TO 61
000043              X(1)=4.
000045              DO 51 I=1,10
000047              P1=X(I)
000051              P2=2.*ALOG10(2.51*X(I)/REV+ROUGH/(3.7*DIAVS))
000064              WW(I)=P1+P2
000067              TEST=-P1/P2
000071              WP(I)=1.+(5.02/REV)/(2.51*X(I)/REV+ROUGH/(3.7*DIAVS))
000105              X(I+1)=X(I)-WW(I)/WP(I)
000111              F=1./X(I+1)**2
000114              IF(ABS(TEST-1.) .LT. .001) GO TO 61
000121           51 CONTINUE
000123           61 CONTINUE
000123              DO 70 I=1,NG
000125              VVAPP=(FC(I)*CDT/HFG)/(RHOV*(XC(I)/100.)*(NVS*[illegible]/100.))
```

```
RUNX COMPILER (VER.2.3M)                      09/28/76. 13.24.02.          WRT

000140            REVR(I)=VVAPR*(DIAVS/200.)/(VISV/RHOV)
000147         20 CONTINUE
000152            DO 50 J=1,NIP1
000154            A(1,J)=XTOT*A(1,J)
000160            A(2,J)=A(2,J)*HW
000163            IF(A(1,J).GE.XELEV(IPK)) IPK=IPK+1
000172            A(6,J)=(ELEV(IPK-1)+(A(1,J)-XELEV(IPK-1))*(ELEV(IPK)-ELEV(IPK-1))
000172          1         /(XELEV(IPK)-XELEV(IPK-1)))*GEE
000210            IF(GEE .EQ. 0.) A(6,J)=0.
000213            SAVEPS(J)=A(5,J)
000216            A(8,J)=A(8,J)*HW
000221         50 CONTINUE
000224            WRITE(6,960)
000230            WRITE(6,962) CDT,GMASS,REV,VELHD
000244            IF(REV .GT. 2300.) WRITE(6,967) F
000254            WRITE(6,961)
000260            DO 60 I=1,NC
000262            WRITE(6,963) I,REVR(I)
000272         60 CONTINUE
000275            WRITE(6,964)
000301            DO 90 J=1,NIP1
000303            WRITE(6,966) A(1,J),A(2,J),A(6,J),A(5,J),A(7,J),A(8,J)
000332         90 CONTINUE
000335        960 FORMAT(1H1,4X,15HFINAL SOLUTION //)
000335        962 FORMAT(10X,40HTHE MAXIMUM HEAT-TRANSFER RATE IS....... ,
000335          1         F12.5,7H  WATTS/
000335          2         10X,40HTHE TOTAL LIQUID IN WICK IS............. ,
000335          3         F12.5,7H  GRAMS/
000335          4         10X,40HTHE VAPOR REYNOLDS NUMBER IS............ ,
000335          5         F12.1/
000335          6         10X,40HTHE MAX. VAPOR VELOCITY HEAD IS......... ,
000335          7         F12.5,9H  CM LIQ.)
000335        967 FORMAT(10X,40HTHE MAX. TURBULENT FRICTION FACTOR IS.. ,
000335          1         F12.5/)
000335        961 FORMAT(10X,33HTHE RADIAL REYNOLDS NUMBERS ARE: )
000335        963 FORMAT(15X,16HFOR SECTION NO. ,I2,17H................ ,
000335          1         F12.5)
000335        964 FORMAT(///
```

```
RUNW COMPILER (VER.2.3M)                    09/28/76. 13.24.02.          ART

000335          1    10X,8HDISTANCE,8X,6HSTRESS,7X,11HSTATIC HEAD,6X,8HPOROSITY,
000335          2    5X,12H SATURATION ,3X,14HVAPOR PRESSURE/17X,4H(CM),9X,
000335          1    9H(CM LIQ.),6X,9H(CM LIQ.),36X,9H(CM LIQ.)//)
000335        966 FORMAT(10X,6E13.4)
000335            RETURN
000336            END
```

A.2 PROGRAM FILLET

The mathematical methods employed by FILLET are described in Reference (2). The first part of the program computes a separate table, for each type of fillet or puddle that can exist in the heat pipe, of the area, free perimeter, wetted perimeter and hydraulic diameter for various values of stress. By statement 500 this is accomplished. The rest of the program manipulates the data into a usable form. For the fillet that forms at the bottom of a vertical wick and the puddle, the values of stress in the tables does not increase monotonically. Subroutine REARNG rearranges these tables for increasing stress.

The next step is to obtain total values for the area and hydraulic diameter for all fillets and puddles in the heat pipe. For a specified value of stress, subroutine INTER interpolates the tables, and the areas and wetted perimeters are summed from which a total hydraulic diameter is calculated. This is done for a range of values of stress to construct a table of total area and hydraulic diameter as a function of stress. This table is then written on TAPE 7.

```
              PROGRAM FILLET (INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT,TAPE7)
          C
          C   FILLET CALCULATES THE MENISCUS SHAPE, AREA, FREE PERIMETER,
          C   WETTED PERIMETER AND HYDRAULIC DIAMETER FOR FILLETS IN A
          C   SLAB-WICK HEAT PIPE AND A BILGE IN A CIRCULAR TUBE.
          C
00004         NAMELIST /FILLETD/ HPID,WKTH,RHO,ST,GEE,IGEOM,TKELVN,LIQ
          C
          C   R  IS THE TUBE RADIUS IN CM
          C   T  IS THE WICK THICKNESS IN CM
          C   RHO  IS THE DENSITY DIFFERENCE BETWEEN LIQUID AND VAPOR
          C        IN KG/M**3
          C   ST  IS THE SURFACE TENSION IN N/M
          C   GEE IS THE GRAVITATIONAL ACCELERATION IN STANDARD GRAVITIES
          C   LIQ  IS THE LIQUID PARAMETER
          C   TKELVN IS THE TEMPERATURE
          C
          C   ICNFG = 1   FOR A VERTICAL WICK
          C         = 2   FOR A HORIZONTAL WICK
          C         = 3   FOR NO WICK (BILGE ONLY)
          C
00004         DIMENSION STRESS1(80),STRESS2(40),STRESS3(40),STRESS4(40),
00004        1          STRESS5(40),STRESS6(80),SF1(80),SF2(40),SF3(40),
00004        2          SF4(40),SF5(40),SF6(80),D1(80),D2(40),D3(40),D4(40),
00004        3          D5(40),D6(80),A1(80),A2(40),A3(40),A4(40),A5(40),
00004        4          A6(80),SW1(80),SW2(40),SW3(40),SW4(40),SW5(40),SW6(80),
00004        5          DDH(80),AAA(80),STRS(80)
          C
00004         COMMON /CPROPS/ XMW,SHRV,HFG,PV,RHOL,RHOV,VISL,VISV,XKL,ST,TF
          C
          C   DIMENSIONLESS PARAMETERS
          C
00004         READ FILLETD
00007         IF(LIQ.EQ.0) GO TO 10
00010         TRANK=TKELVN*1.8
00012         CALL PROPS(LIQ,TRANK)
00014         RHO=.4536*3.281**3*(RHOL-RHOV)
```

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```
UNX COMPILER (VER.2.3M)                      09/28/76. 13.05.23.        FILLET

00020          ST=4.448*3.281*ST
        C
00022       10 G=9.80
00024          ICNFG=IGEOM
00026          TF(IGEOM.EQ.0) ICNFG=2
00030          A=SOPT(2.*ST/(RHO*GEE*G))
00037          R=HPID/2.
00041          T=WKTH
00043          RB=(R/100.)/A
00046          TB=(T/100.)/A
00051          PI=3.141592654
00053          DALPHA=PI/180.
        C
        C      SET RANGE FOR THE STRESS  H  AT THE INTEGRATION STARTING POINT
        C
00055          HO=1./(10.*RB)
00060          HF=20.
00062          NH=40.
00064          GG=(HF/HO)**(1./(NH-1))
        C
        C      CALCULATION OF AREA, WETTED PERIMETER, FREE PERIMETER,
        C      HYDRAULIC DIAMETER AND STRESS AT EACH VALUE OF  H.
        C
00075          DO 500 K=1,NH
00077          H=HO*GG**(K-1)
        C
        C      TOP FILLET -- WICK VERTICAL (CASE 3)
        C
00106          IF(ICNFG.NE.1) GO TO 44
00110          X=-TB/2.
00112          ALPHA=PI/2.
00114          Y=H
00116          XO=X
00120          YO=Y
00122          ALPHAO=ALPHA
00124          AA=0.
00125          SF=0.
00126          DO 20 I=1,180
```

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```
00130              CALL SIMPSN(X,Y,AA,SF,ALPHA,DALPHA,X0,Y0,ALPHA0)
00141              CRIT=X-RB*SIN(ALPHA)
00146              IF(CRIT .GE. 0.) GO TO 22
00150           20 CONTINUE
00152              GO TO 24
00153           22 W0=-TB/2.
00155              W1=0.
00156              W2=X
00160              W3=W0
00162              V0=H
00164              V1=Y+RB*COS(ALPHA)
00171              V2=Y
00173              V3=V1+SQRT(RB*RB-W0*W0)
             C
             C     ELIMINATE UNSTABLE SOLUTIONS
             C
00201              IF(STRESS3(K-1).NE.0. .AND. V1.GT.STRESS3(K-1)) GO TO 26
00211              STRESS3(K-1)=0.
00213              A3(K-1)=0.
00215              SF3(K-1)=0.
00217              SW3(K-1)=0.
00221              D3(K-1)=0.
00223           26 CALL SANF(A3(K),PW,W0,W1,W2,W3,V0,V1,V2,V3,AA)
00236              STRESS3(K)=V1
00240              SF3(K)=SF
00242              SW3(K)=PW+V3-V0
00246              D3(K)=4.*A3(K)/SW3(K)
             C
             C     LOWER AND UPPER BOTTOM FILLETS -- WICK VERTICAL (CASES 1 ^ 2)
             C
000252          24 X=TB/2.
000254             ALPHA=-PI/2.
000256             Y=H
000260             X0=X
000262             Y0=Y
000264             IF(Y0.LE.1.0) GO TO 44
000267             ALPHA0=ALPHA
000271             AA=0.
```

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```
00272           SF=0.
00273           IFLAG=0
00274           DO 30 I=1,360
00276           CALL SIMPSN(X,Y,AA,SF,ALPHA,DALPHA,XO,YO,ALPHAO)
00307           CRIT=X-RB*SIN(ALPHA)
00314           IF(IFLAG.EQ.1) GO TO 28
00316           IF(CRIT .LE. O. .AND. ALPHA .LT. PI/2.) GO TO 34
00330        28 IF(CRIT .GT. O. .AND. I .EQ. 180) GO TO 44
00341           IF(CRIT .GT. O. .AND. ALPHA .GE. PI/2.) GO TO 34
00353        29 CONTINUE
00353        30 CONTINUE
00355        34 WO=TB/2.
00357           W1=0.
00360           W2=X
00362           W3=WO
00364           VO=H
000366          V1=Y+RB*COS(ALPHA)
000373          V2=Y
000375          V3=V1-SQRT(RB*RB-WO*WO)
000403          CALL SANF(AA1,PW,WO,W1,W2,W3,VO,V1,V2,V3,AA)
000416          K1=K
000420          IF(IFLAG .EQ. 1) K1=K+NH
000424          IF(IFLAG.EQ.1 .AND. IQ1.EQ.1) GO TO 44
000433          IF(IFLAG.EQ.1 .AND. STRESS1(K1-1).EQ.0.) GO TO 35
000444          IF(IFLAG.EQ.1 .AND. V1.GT.STRESS1(K1-1)) IQ1=1
000457          IF(IFLAG.EQ.1 .AND. IQ1.EQ.1) GO TO 44
000466       35 CONTINUE
000466          A1(K1)=AA1
000470          STRESS1(K1)=V1
000472          SW1(K1)=PW+VO-V3
000476          SF1(K1)=SF
000500          D1(K1)=4.*A1(K1)/SW1(K1)
000504          IF(IFLAG .EQ. 1) GO TO 44
000506          IFLAG=1
000507          GO TO 29
         C
         C      LOWER FILLET -- HORIZONAL WICK (CASE 4)
         C
```

```
 00510       44 IF(ICNFG.NE.2) GO TO 68
 00512          X=0.
 00513          Y=H
 00515          ALPHA=PI
 00517          XO=X
 00521          YO=Y
 00523          IF(YO.LE.2.) GO TO 58
 00526          ALPHAO=ALPHA
 00530          AA=0.
 00531          SF=0.
 00532          DO 50 I=1,180
 00534          CALL SIMPSN(X,Y,AA,SF,ALPHA,DALPHA,XO,YO,ALPHAO)
 00545          CRIT=RB*COS(ALPHA)+Y-H-TB/2.
 00555          IF(CRIT .GE. 0.) GO TO 52
000557       50 CONTINUE
000561          GO TO 58
000562       52 W0=0.
000563          W1=X-RB*SIN(ALPHA)
000570          W2=X
000572          W3=W1-SQRT(RB*RB-TB*TB/4.)
000601          V0=H
000603          V1=H+TB/2.
000606          V2=Y
000610          V3=H
000612          CALL SANF(A4(K),PW,W0,W1,W2,W3,V0,V1,V2,V3,AA)
000625          STRESS4(K)=V1
000627          SF4(K)=SF
000631          SW4(K)=PW+(WO-W3)
000635          D4(K)=4.*A4(K)/SW4(K)
          C
          C     UPPER FILLET -- WICK HORIZONTAL (CASE 5)
          C
000641       58 X=0.
000642          Y=H
000644          ALPHA=0.
000645          YO=Y
000647          YO=Y
000651          ALPHAO=ALPHA
```

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```
000653          AA=0.
000654          SF=0.
000655          DO 60 I=1,180
000657          CALL SIMPSN(X,Y,AA,SF,ALPHA,DALPHA,XO,YO,ALPHAO)
000670          CRIT=Y+RB*COS(ALPHA)-H+TB/2.
000701          IF(CRIT .LE. 0.) GO TO 62
000703       60 CONTINUE
000705          GO TO 68
000706       62 WO=0.
000707          W1=X-RB*SIN(ALPHA)
000714          W2=X
000716          W3=W1+SQRT(RB*RB-TB*TB/4.)
000725          VO=H
000727          V1=H-TB/2.
000732          V2=Y
000734          V3=H
000736          CALL SANF(A5(K),PW,WO,W1,W2,W3,VO,V1,V2,V3,AA)
000751          STRESS5(K)=V1
000753          SF5(K)=SF
000755          SW5(K)=PW+W3-WO
000761          D5(K)=4.*A5(K)/SW5(K)
        C
        C       BILGE -- NO WICK (CASE 6 ^ 7)
        C
000765       68 X=0.
000766          ALPHA=0.
000767          Y=H
000771          XO=X
000773          YO=Y
000775          ALPHAO=ALPHA
000777          AA=0.
001000          SF=0.
001001          IFLAG=0
001002          IF(1./(2.*YO) .LE. RB .AND. IFLAG .EQ. 0) IFLAG=1
001016          DO 70 I=1,180
001020          CALL SIMPSN(X,Y,AA,SF,ALPHA,DALPHA,XO,YO,ALPHAO)
001031          CRIT=X-RB*SIN(ALPHA)
001036          IF(IFLAG.EQ.1) GO TO 65
```

```
RUNX COMPILER (VER.2.3M)                    09/28/76. 13.05.23.          FILLET

001040               IF(CPIT .LE. C. .AND. ALPHA .LT. PI/2.) GO TO 74
001052            65 IF(CPIT .GT. 0. .AND. I .EQ. 90) GO TO 84
001063               IF(CRIT .GT. 0. .AND. ALPHA .GT. PI/2.) GO TO 74
001075            69 CONTINUF
001075            70 CONTINUE
C01077            74 W0=0.
001100               W1=0.
001101               W2=X
001103               W3=0.
001104               V0=H
001106               V1=Y+RB*COS(ALPHA)
001113               V?=Y
001115               V3=V1-RB
001117               CALL SANF(AA6,PW,W0,W1,W2,W3,V0,V1,V2,V3,AA)
001132               K1=K
001134               IF(IFLAG.EQ.1) K1=K+NH
001140               IF(IFLAG.EQ.1 .AND. I06.EQ.1) GO TO 84
001147               IF(IFLAG.EQ.1 .AND. STRESS6(K1-1).EQ.0.) GO TO 75
001160               IF(IFLAG.EQ.1 .AND. V1.GT.STRESS6(K1-1)) IC6=1
001173               IF(IFLAG.EQ.1 .AND. IC6.EQ.1) GO TO 84
001202            75 CONTINUE
001202               A6(K1)=2.*AA6
001205               STRESS6(K1)=V1
001207               SW6(K1)=2.*PW
001212               SF6(K1)=2.*SF
001215               D6(K1)=4.*A6(K1)/SW6(K1)
001221               IF(IFLAG.EQ.1) GO TO 84
001223            78 IFLAG=1
001224               GO TO 69
001225            84 CONTINUF
001225           500 CONTINUF
001230               CALL RFARNG(STRESS1,NH)
0C1232               CALL PEAFNG(SF1,NH)
001234               CALL RFARNG(SW1,NH)
001236               CALL RFARNG(A1,NH)
CC1240               CALL PFAPNG(STRESS6,NH)
CC1242               CALL RFAPNG(SF6,NH)
001244               CALL RFAPNG(SW6,NH)
```

```
001246              CALL REARNG(A6,NH)
001250              N=2*NH
001252              DO 600 I=1,NH
001254              STRS(I)=HO*GG**(I-1)
001263              IF(ICNFG.NE.1) GO TO 507
001265              CALL INTER(A3,STRESS3,NH,STRS(I),YA3)
001271              CALL INTER(SW3,STRESS3,NH,STRS(I),YSW3)
001275              CALL INTER(A1,STRESS1,N,STRS(I),YA1)
001301              CALL INTER(SW1,STRESS1,N,STRS(I),YSW1)
001305              AAA(I)=2.*(YA1+YA3)*A*A
001312              IF(AAA(I).EQ.0.) GO TO 600
001314              SSW=2.*(YSW3+YSW1)*A
001320              DDH(I)=4.*AAA(I)/SSW
001324              STRS(I)=STRS(I)*A
001327              GO TO 600
001330          507 IF(ICNFG.EQ.3) GO TO 517
001332              CALL INTER(A4,STRESS4,NH,STRS(I),YA4)
001336              CALL INTER(SW4,STRESS4,NH,STRS(I),YSW4)
001342              CALL INTER(A5,STRESS5,NH,STRS(I),YA5)
001346              CALL INTER(SW5,STRESS5,NH,STRS(I),YSW5)
001352          517 CALL INTER(A6,STRESS6,N,STRS(I),YA6)
001356              CALL INTER(SW6,STRESS6,N,STRS(I),YSW6)
001362              AAA(I)=(2.*(YA4+YA5)+YA6)*A*A
001370              IF(AAA(I).EQ.0.) GO TO 600
001372              SSW=(2.*(YSW4+YSW5)+YSW6)*A
001377              DDH(I)=4.*AAA(I)/SSW
001403              STRS(I)=STRS(I)*A
001406          600 CONTINUE
              C
001411              WRITE(7) NH,(STRS(I),I=1,NH),(AAA(I),I=1,NH),(DDH(I),I=1,NH)
              C
              C     THE OUTPUT IS A TABLE OF AREA IN M**2 AND HYDRAULIC
              C     DIAMETER IN M AS A FUNCTION OF STRESS AT THE TUBE CENTER
              C     IN M OF LIQUID.
              C
001441              STOP
001443              END
```

```
RUNX COMPILER (VER.2.3M)                    09/28/76. 13.05.23.

               SUBROUTINE DRV(ALPHA,DX,DS,DA,X,Y,XO,YO,ALPHAO)
               Y=SQRT(YO*YO+COS(ALPHAO)-COS(ALPHA))
000014         DX=COS(ALPHA)/(2.*Y)
000040         DS=1./(2.*Y)
000050         DA=ABS((X-XO)*SIN(ALPHA)-(Y-YO)*COS(ALPHA))/(4.*Y)
000052         RETURN
000075         END
000076
```

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```
RUNX COMPILER (VER.2.3M)                    09/28/76. 13.05.23.

                       SUBROUTINE INTER(F,X,N,XX,Y)
               C
               C       SUBROUTINE  INTER  INTERPOLATES THE CALCULATIONED DATA
               C
000010                 DIMENSION F(1),X(1)
               C
000010                 XMIN=1.E6
000012                 XMAX=-1.E6
000014                 DO 40 I=1,N
000016                 IF(X(I).EQ.0.) GO TO 40
000020                 IF(X(I).GE.XMIN) GO TO 30
000024                 XMIN=X(I)
000026                 IMIN=I
000030              30 IF(X(I).LE.XMAX) GO TO 40
000034                 XMAX=X(I)
000036                 IMAX=I
000040              40 CONTINUE
000043                 IF(XX.GT.XMIN) GO TO 50
000047                 Y=F(IMIN)
000051                 RETURN
000052              50 IF(XX.LT.XMAX) GO TO 60
000055                 Y=0.
000056                 RETURN
000057              60 CONTINUE
000057                 F2=0.
000060                 X2=0.
000061                 DO 70 I=1,N
000063                 IF(X(I).EQ.0.) GO TO 70
000065                 F1=F2
000067                 F2=F(I)
000071                 X1=X2
000073                 X2=X(I)
000075                 IF(X2.GT.XX .AND. X1.LT.XX) GO TO 80
000105              70 CONTINUE
000110              80 Y=F1+(F2-F1)*(XX-X1)/(X2-X1)
000117                 RETURN
000120                 END
```

ORIGINAL PAGE IS
OF POOR QUALITY

```
RUNX COMPILER (VER.2.3M)                    09/28/76. 13.05.23.

                      SUBROUTINE REARNG(A,NH)
            C
            C         REARNG  REARRANGES THE PARAMETERS FOR THE BILGE AND
            C         BOTTOM FILLET/VERTICAL WICK FOR INCREASING STRESS
            C
000005                DIMENSION A(60), DUMMY(60)
000006                DO 10 I=1,NH
000007                I1=NH+I
000011                DUMMY(I)=A(2*NH-I+1)
000014                DUMMY(I1)=A(I)
000017             10 CONTINUE
000022                N=NH*2
000023                DO 20 I=1,N
000025                A(I)=DUMMY(I)
000030             20 CONTINUE
000033                RETURN
000034                END
```

```
RUNX COMPILER (VER.2.3M)                C9/28/76. 13.05.23.

                  SUBROUTINE PROPS(L,T)
          C
          C          THIS ROUTINE COMPUTES FLUID PROPERTIES FROM DATA FITS
          C
000005            COMMON /CPROPS/ XMW,SHRV,HFG,PV,RHOL,RHOV,VISL,VISV,XKL,ST,TF
000005            DIMENSION A11(7), A21(7),
000005          1   A31(7), A32(7), A33(7), A34(7), A35(7),
000005          2   A41(7), A42(7), A43(7), A44(7), A45(7),
000005          3   A51(7), A52(7), A53(7), A54(7), A55(7),
000005          4   A61(7), A62(7), A63(7), A64(7), A65(7),
000005          5   A71(7), A72(7), A73(7), A74(7), A75(7),
000005          6   A81(7), A82(7), A83(7), A84(7), A85(7),
000005          7   A91(7), A92(7), A93(7), A94(7), A95(7),
000005          8   A101(7), A102(7), A103(7), A104(7), A105(7),
000005          9   A111(7), A112(7), A113(7), A114(7), A115(7)
          C
          C            WATER (32F<T<400F)
          C
000005            DATA   A11(1),      A21(1)/
000005          *         491.7,      18.016/
000005            DATA   A31(1),      A32(1),        A33(1),       A34(1),       A35(1)/
000005          *    1.3555636,-4.957576E-5,             0.,           0.,           0./
000005            DATA   A41(1),      A42(1),        A43(1),       A44(1),       A45(1)/
000005          *    1209.5506,-5.705515E-2,-4.454588E-4,             0.,           0./
000005            DATA   A51(1),      A52(1),        A53(1),       A54(1),       A55(1)/
000005          *    14.199322,  -6.5267262,   -.81013069,             0.,           0./
000005            DATA   A61(1),      A62(1),        A63(1),       A64(1),       A65(1)/
000005          *    58.491766, 2.566296E-2,-3.547212E-5,             0.,           0./
000005            DATA   A71(1),      A72(1),        A73(1),       A74(1),       A75(1)/
000005          *    7.4432132,  -6.0175647,   -.79940952,             0.,           0./
000005            DATA   A81(1),      A82(1),        A83(1),       A84(1),       A85(1)/
000005          *    52.825785,  -.26276099, 5.033270E-4,-4.411623E-7, 1.46962E-10/
000005            DATA   A91(1),      A92(1),        A93(1),       A94(1),       A95(1)/
000005          *   -10.66486,   1.1641567,             0.,           0.,           0./
000005            DATA  A101(1),     A102(1),       A103(1),      A104(1),      A105(1)/
000005          *  -1.0535655,5.3522992E-3,-6.446056E-6,2.5152327E-9,           0./
000005            DATA  A111(1),     A112(1),       A113(1),      A114(1),      A115(1)/
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000005        * -9.437350E-3, 9.717223E-5,-2.230757E-7,2.117195E-10,-7.530815E-14/
          C
          C          AMMONIA (-107.9F<T<190F)
          C
000005          DATA   A11(2),       A21(2)/
000005        *         351.8,        17.032/
000005          DATA   A31(2),       A32(2),       A33(2),       A34(2),       A35(2)/
000005        *         1.31,          0.,           0.,           0.,           0./
000005          DATA   A41(2),       A42(2),       A43(2),       A44(2),       A45(2)/
000005        *  1.093251E+3,-2.482955E+0, 4.976430E-3,-4.474967E-6,           0./
000005          DATA   A51(2),       A52(2),       A53(2),       A54(2),       A55(2)/
000005        *  1.392374E+1,-4.921740E+0, 2.065018E-1,-7.579597E-2,           0./
000005          DATA   A61(2),       A62(2),       A63(2),       A64(2),       A65(2)/
000005        *  7.063766E+1,-1.172405E-1, 1.931707E-4,-1.649913E-7,           0./
000005          DATA   A71(2),       A72(2),       A73(2),       A74(2),       A75(2)/
000005        *  1.266986E+1,-1.113379E+1, 2.993128E+0,-4.689769E-1,           0./
000005          DATA   A81(2),       A82(2),       A83(2),       A84(2),       A85(2)/
000005        *  3.537046E+1,-2.496424E-1, 6.623156E-4,-7.941805E-7,3.552154E-10/
000005          DATA   A91(2),       A92(2),       A93(2),       A94(2),       A95(2)/
000005        * -3.070396E+3, 1.966094E+3,-4.728715E+2, 5.054066E+1,-2.024369E+0/
000005          DATA  A101(2),      A102(2),      A103(2),      A104(2),      A105(2)/
000005        * -4.160186E-1, 3.944710E-3,-6.537242E-6, 3.089435E-9,           0./
000005          DATA  A111(2),      A112(2),      A113(2),      A114(2),      A115(2)/
000005        *  6.426501E-3,-7.004641E-6,-7.695759E-9,8.023533E-12,           0./
          C
          C          METHYL ALCOHOL (-140F<T<360F)
          C
000005          DATA   A11(3),       A21(3)/
000005        *         322.7,        32.042/
000005          DATA   A31(3),       A32(3),       A33(3),       A34(3),       A35(3)/
000005        *         1.203,         0.,           0.,           0.,           0./
000005          DATA   A41(3),       A42(3),       A43(3),       A44(3),       A45(3)/
000005        *  8.790546E+2,-2.478105E+0, 6.416629E-3,-7.004195E-6, 2.214439E-9/
000005          DATA   A51(3),       A52(3),       A53(3),       A54(3),       A55(3)/
000005        *  1.505411E+1,-9.240630E+0, 3.366136E+0,-1.969200E+0, 3.389658E-1/
000005          DATA   A61(3),       A62(3),       A63(3),       A64(3),       A65(3)/
000005        *  1.007865E+1, 2.932836E-1,-6.417672E-4, 9.761262E-7,-4.305022E-10/
000005          DATA   A71(3),       A72(3),       A73(3),       A74(3),       A75(3)/
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005          *  1.593164E+1,-2.109098E+1, 1.144326E+1,-4.278643E+0, 5.809908E-1/
005           DATA   A81(3),        A82(3),        A83(3),        A84(3),        A85(3)/
005          *  2.285363E+1,-1.153169E-1, 2.303795E-4,-2.155127E-7, 7.55172E-11/
005           DATA   A91(3),        A92(3),        A93(3),        A94(3),        A95(3)/
005          *  1.922596E+2,-1.286769E+2, 3.113344E+1,-3.318410E+0, 1.325051E-1/
005           DATA  A101(3),       A102(3),       A103(3),       A104(3),       A105(3)/
005          *  9.944433E-2, 2.097417E-4,-6.310697E-7,7.394364E-10,-3.19696E-13/
005           DATA  A111(3),       A112(3),       A113(3),       A114(3),       A115(3)/
005          *  5.790525E-3,-1.404494E-5, 1.205620E-8,3.516629E-12,-8.67029E-15/
      C
      C             FREON-21 (-55F<T<305F)
      C
005           DATA   A11(4),        A21(4)/
005          *        248.7,        102.93/
005           DATA   A31(4),        A32(4),        A33(4),        A34(4),        A35(4)/
005          *        1.175,            0.,            0.,            0.,            0./
005           DATA   A41(4),        A42(4),        A43(4),        A44(4),        A45(4)/
005          *  8.687825E+1, 4.636556E-1,-1.631685E-3, 2.056597E-6,-1.018948E-9/
005           DATA   A51(4),        A52(4),        A53(4),        A54(4),        A55(4)/
005          *  3.270732E+0, 1.573170E+1,-1.607959E+1, 5.259243E+0,-6.209501E-1/
0005          DATA   A61(4),        A62(4),        A63(4),        A64(4),        A65(4)/
0005         *  1.332756E+2,-3.261757E-1, 1.111655E-3,-1.611728E-6,6.906674E-10/
0005          DATA   A71(4),        A72(4),        A73(4),        A74(4),        A75(4)/
0005         *  8.534322E+1,-1.662575E+2, 1.252681E+2,-4.265882E+1, 5.375463E+0/
0005          DATA   A81(4),        A82(4),        A83(4),        A84(4),        A85(4)/
0005         * -8.347479E+0, 8.530116E-2,-2.757886E-4, 3.643724E-7,-1.75367E-10/
0005          DATA   A91(4),        A92(4),        A93(4),        A94(4),        A95(4)/
0005         * -1.838588E+3, 1.199366E+3,-2.944711E+2, 3.215076E+1,-1.315728E+0/
0005          DATA  A101(4),       A102(4),       A103(4),       A104(4),       A105(4)/
0005         *  4.750199E-1,-2.403548E-3, 5.713512E-6,-6.391302E-9, 2.650408E-12/
0005          DATA  A111(4),       A112(4),       A113(4),       A114(4),       A115(4)/
0005         * -5.248971E-3, 4.984869E-5,-1.133747E-7,9.235658E-11,-2.25959E-14/
      C
      C             ETHANE (-135F<T<80F)
      C
0005          DATA   A11(5),        A21(5)/
0005         *        161.8,         30.07/
0005          DATA   A31(5),        A32(5),        A33(5),        A34(5),        A35(5)/
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NX COMPILER (VER.2.3M)                     09/28/76. 13.05.23.            PROPS

C005          *       1.18,          0.,           0.,           0.,           0./
0005           DATA    A41(5),       A42(5),       A43(5),       A44(5),       A45(5)/
0005          * -4.278934E+3, 4.573254E+1,-1.719481E-1, 2.840439E-4,-1.756889E-7/
0005           DATA    A51(5),       A52(5),       A53(5),       A54(5),       A55(5)/
0005          *  4.513520E+1,-5.803273E+1, 3.388505E+1,-9.165778E+0, 9.154764E-1/
0005           DATA    A61(5),       A62(5),       A63(5),       A64(5),       A65(5)/
0005          * -3.433014E+2, 3.901041E+0,-1.478827E-2, 2.451166E-5,-1.518662E-8/
C005           DATA    A71(5),       A72(5),       A73(5),       A74(5),       A75(5)/
0005          *  9.831080E+1,-1.463731E+2, 8.422928E+1,-2.191841E+1, 2.129803E+0/
0005           DATA    A81(5),       A82(5),       A83(5),       A84(5),       A85(5)/
0005          * -1.723943E+1, 1.931920E-1,-7.953422E-4, 1.385103E-6,-8.90506E-10/
0005           DATA    A91(5),       A92(5),       A93(5),       A94(5),       A95(5)/
0005          *  2.999855E+4,-2.017435E+4, 5.085813E+3,-5.697099E+2, 2.392870E+1/
0005           DATA   A101(5),      A102(5),      A103(5),      A104(5),      A105(5)/
0005          * -1.142860E+0, 1.317096E-2,-5.072525E-5, 8.390294E-8,-5.11860E-11/
0005           DATA   A111(5),      A112(5),      A113(5),      A114(5),      A115(5)/
0005          *  1.123709E-2,-8.339622E-5, 2.759121E-7,-4.39343E-10,2.65146FE-13/
        C
        C          METHANE (-250F<T<-120F)
        C
00005          DATA    A11(6),       A21(6)/
00005         *      163.2,         16.04/
00005          DATA    A31(6),       A32(6),       A33(6),       A34(6),       A35(6)/
00005         *       1.32,          0.,           0.,           0.,           0./
00005          DATA    A41(6),       A42(6),       A43(6),       A44(6),       A45(6)/
00005         * -1.124091E+3, 2.425142E+1,-1.589307E-1, 4.547110E-4,-4.908714E-7/
00005          DATA    A51(6),       A52(6),       A53(6),       A54(6),       A55(6)/
00005         *  1.365684E+0, 8.557617E+0,-3.746570E+0, 5.803347E-1,-3.257158E-2/
00005          DATA    A61(6),       A62(6),       A63(6),       A64(6),       A65(6)/
00005         *  1.460051E+1, 3.614831E-1,-3.223542E-3, 1.076420E-5,-1.353123E-8/
00005          DATA    A71(6),       A72(6),       A73(6),       A74(6),       A75(6)/
00005         *  6.381082E+1,-5.455063E+1, 1.837493E+1,-2.799046E+0, 1.567545E-1/
00005          DATA    A81(6),       A82(6),       A83(6),       A84(6),       A85(6)/
00005         * -9.526486E+0, 2.024132E-1,-1.540820E-3, 4.719715E-6,-5.211675E-9/
00005          DATA    A91(6),       A92(6),       A93(6),       A94(6),       A95(6)/
00005         *  9.119631E+3,-6.766529E+3, 1.680522E+3,-2.321565E+2, 1.074409E+1/
00005          DATA   A101(6),      A102(6),      A103(6),      A104(6),      A105(6)/
00005         *  3.486478E-1,-1.720959E-3, 3.699297E-7, 1.640747E-8,-3.73323E-11/
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UNX COMPILER (VER.2.3M)                 C9/28/76. 13.05.23.          PROFS

00005         DATA  A111(6),     A112(6),     A113(6),     A114(6),     A115(6)/
C0005          *  5.412797E-3,-5.463947E-5, 2.856240E-7,-7.81700E-10,8.146495E-13/
          C
          C           NITROGEN (-340F<T<-250F)
          C
000005        DATA   A11(7),       A21(7)/
000005         *        113.9,       28.016/
000005        DATA   A31(7),       A32(7),       A33(7),      A34(7),       A35(7)/
000005         *         1.40,          0.,           0.,          0.,           0./
000005        DATA   A41(7),       A42(7),       A43(7),      A44(7),       A45(7)/
000005         *  7.648974E+1,-2.305556E-1, 5.317599E-3,-2.340715E-5,           0./
000005        DATA   A51(7),       A52(7),       A53(7),      A54(7),       A55(7)/
000005         *  3.217173E+1,-1.431289E+1, 3.064764E+0,-3.133777E-1, 1.176449E-2/
000005        DATA   A61(7),       A62(7),       A63(7),      A64(7),       A65(7)/
000005         *  7.298716E+1,-3.323232E-1, 2.281469E-3,-7.478632E-6,           0./
000005        DATA   A71(7),       A72(7),       A73(7),      A74(7),       A75(7)/
000005         *  2.102802E+1,-7.503727E+0, 9.613273E-1,-4.861116E-2,           0./
000005        DATA   A81(7),       A82(7),       A83(7),      A84(7),       A85(7)/
000005         * -1.130709E+1, 3.580937E-1,-3.880943E-3, 1.687014E-5,-2.609266E-8/
000005        DATA   A91(7),       A92(7),       A93(7),      A94(7),       A95(7)/
000005         *  1.718670E+4,-1.371991E+4, 4.103945E+3,-5.453515E+2, 2.716624E+1/
000005        DATA  A101(7),      A102(7),      A103(7),     A104(7),      A105(7)/
000005         *  1.178000E-1,-7.992424E-5,-1.401515E-6,          0.,           0./
000005        DATA  A111(7),      A112(7),      A113(7),     A114(7),      A115(7)/
000005         *  1.636031E-3,-3.768939E-6,-4.379371E-8,1.270396E-10,           0./
          C
000005        IF (L.EQ.0) GO TO 20
          C
000006        T2 = T*T
000007        T3 = T2*T
000011        T4 = T2*T2
000013        TR = 1000./T
000015        TR2 = TR*TR
000017        TR3 = TR2*TR
000021        TR4 = TR2*TR2
000023        ALT=ALOG(T)
000027        ALT2=ALT*ALT
000031        ALT3=ALT2*ALT
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00033          ALT4=ALT2*ALT2
          C
          C       FLUID PROPERTIES
          C
00035          TF = A11(L)
00037          XMW=A21(L)
00041          SHPV = A31(L)+A32(L)*T+A33(L)*T2+A34(L)*T3+A35(L)*T4
00053          HFG = A41(L)+A42(L)*T+A43(L)*T2+A44(L)*T3+A45(L)*T4
00065          PV = EXP(A51(L)+A52(L)*TR+A53(L)*TR2+A54(L)*TR3+A55(L)*TR4)
00103          RHOL = A61(L)+A62(L)*T+A63(L)*T2+A64(L)*T3+A65(L)*T4
00115          RHOV = EXP(A71(L)+A72(L)*TR+A73(L)*TR2+A74(L)*TR3+A75(L)*TR4)
00133          VISL = EXP(A81(L)+A82(L)*T+A83(L)*T2+A84(L)*T3+A85(L)*T4)
00151          VISV = EXP(A91(L)+A92(L)*ALT+A93(L)*ALT2+A94(L)*ALT3+A95(L)*ALT4)
00167          XKL = A101(L)+A102(L)*T+A103(L)*T2+A104(L)*T3+A105(L)*T4
00201          ST = A111(L)+A112(L)*T+A113(L)*T2+A114(L)*T3+A115(L)*T4
00213          VISV = VISV/4.1697504E8
00215          VISL=VISL/4.1697504E8
00217          RETURN
          C
00220       20 CONTINUE
00220          RETURN
00221          END
```

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UNX COMPILER (VER.2.3M)                09/28/76. 13.05.23.

                  SUBROUTINE SANF(A,P,W0,W1,W2,W3,V0,V1,V2,V3,AA)
00016             R=SQRT((V1-V3)**2+(W1-W3)**2)
00032             THETA=ACOS(((W3-W1)*(W2-W1)+(V3-V1)*(V2-V1))/
00032         1        SQRT(((W3-W1)**2+(V3-V1)**2)
00032         2        *((W2-W1)**2+(V2-V1)**2)))
00067             P=R*THETA
00071             A023=.5*ABS((W2*V3-V2*W3)-(W0*V3-V0*W3)+(W0*V2-V0*W2))
00107             A12B3=.5*THETA*R*R
00112             A123=.5*ABS((W2*V3-V2*W3)-(W1*V3-V1*W3)+(W1*V2-V1*W2))
00130             A=A023+A12B3-A123-AA
00134             RETURN
00135             END
```

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RUNX COMPILER (VER.2.3M)                    09/28/76. 13.05.23.

                SUBROUTINE SIMPSN(X,Y,AA,SF,ALPHA,DALPHA,XC,YC,ALPHA0)
000014          CALL DRV(ALPHA,DX1,DS1,DA1,X,Y,X0,Y0,ALPHA0)
000032          ALPHA=ALPHA+DALPHA/2.
000035          X1=X+(DX1/2.)*DALPHA
000041          CALL DRV(ALPHA,DX2,DS2,DA2,X1,Y,XC,Y0,ALPHA0)
000057          ALPHA=ALPHA+DALPHA/2.
000062          X2=X+DX2*DALPHA
000065          CALL DRV(ALPHA,DX3,DS3,DA3,X2,Y,X0,Y0,ALPHA0)
000103          X=X+(DX1+4.*DX2+DX3)*DALPHA/6.
000112          AA=AA+(DA1+4.*DA2+DA3)*DALPHA/6.
000121          SF=SF+(DS1+4.*DS2+DS3)*DALPHA/6.
000130          RETURN
000131          END
```

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