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LOFCON-LOFT CONDENSER PROGRAM

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EG&G Idaho, Inc.

IDAHO NATIONAL ENGINEERING LABORATORY

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TECHNICAL REPORT

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IDAHO NATIONAL ENGINEERING LABORATORY
LOFT TECHNICAL REPORT
LOFT PROGRAM

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ABSTRACT

LOFCON is a program developed for the LOFT air condenser system contained in the secondary coolant system. Although the basic theory described herein is general, the program given is not--it is specifically for the LOFT configuration. LOFCON is presented in subroutine form so that it may be easily incorporated into a larger program describing the complete secondary side. Specifically LOFCON was written to be incorporated into the detailed CSMP model of the LOFT secondary coolant system simulation.

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LOFCON is a program developed for the LOFT air condenser system contained in the secondary coolant system. Although the basic theory described herein is general, the program given is not--it is specifically for the LOFT configuration. LOFCON is presented in subroutine form so that it may be easily incorporated into a larger program describing the complete secondary side. Specifically LOFCON was written to be incorporated into the detailed CSMP model of the LOFT secondary coolant system simulation.

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1.0 INTRODUCTION

The LOFT facility uses an air cooled condenser system to eject the heat generated within the primary coolant system and transferred to the secondary coolant system. The heat is discharged to the environment during operations with one, two, or three air condenser bays.

Simulation of the LOFT facility requires the air condenser system be modeled. The air condenser model described herein was developed to simulate the performance of the LOFT air condenser system in the complete LOFT facility simulation.

2.0 BASIC CONFIGURATION

Each condenser is designed with four horizontal levels of parallel tubes as partially illustrated below (end view):

Figure 1 - Partial End View of Condenser Tube Bank

Generally, air enters below the bottom level of tubes and flows upward transversing each level, and exits above the top level of tubes. Steam which flows inside the tubes is distributed to each level of tubes by a series of orifices. These are installed at the inlet ends to control the steam flow rate (for heat transfer purposes) on each level. Small orifices

are used on the top level (Row 4) while none are used on the bottom level (Row 1). Intermediate sizes are used on the two intermediate levels. In principle, the orifices are designed to reduce the steam flow in proportion to the loss in heat transfer resulting from the temperature rise in the air as it flows upward past the tubes. The condenser tubes employ tapered annular fins on the outside to increase the heat transfer from the condensing steam to the exterior air.

3.0 BASIC PROBLEM DEFINITION

The heat transfer at any point from the interior flowing, condensing steam to the exterior air is dependent on many items such as (1) the internal energy balance, (2) external energy balance, (3) the thermal resistance of the water film on the interior tube wall, (4) the thermal resistance of the tube wall, and (5) the heat transfer characteristics of the annular fins. Obviously, many of these items are dependent on upstream history effects of the steam and air. That is, an overall energy balance must be kept on both the condensing steam and the exterior air.

3.1 Internal Energy Balance

For the axisymmetric system illustrated

an energy balance may be written as (following the method suggested by References 1 and 2):

- heat released by condensation of small amount of steam =
- + heat lost to environment
- + energy involved in change of sensible heat of the steam water mixture (assumed to be at the same temperature)
- + energy required to change the kinetic energy of the steam water mixture.

The individual terms may be written as (note that dx , dT , etc. are here used as finite changes - not necessarily true differentials):

heat released by
condensation of
small amount of
steam

$$= h_{fg} dw_L$$

heat lost to
environment

$$= \bar{q} dx, \text{ where } \bar{q} \text{ is heat transfer per unit length}$$

Energy involved in
change of sensible
heat of the steam/
water mixture

$$= (w_L + \cancel{\frac{dw_L}{2}}) c_{pL} dT + (w_g + \cancel{\frac{dw_g}{2}}) c_{pg} dT,$$

neglect neglect

where the two terms can
be safely neglected if
 $dw_L \ll w_L$ and $dw_g \ll w_g$

energy required to
change the kinetic
energy of the fluid

$$= \text{kinetic energy in} - \text{kinetic energy out}$$

where

$$\text{kinetic energy in} = \frac{U^2 w_g}{2g_c J} + \frac{V^2 w_L}{2g_c J}$$

$$\text{kinetic energy out} = \frac{(U+dU)^2 (w_g+dw_g)}{2g_c J} + \frac{(V+dV)^2 (w_L+dw_L)}{2g_c J}$$

The above kinetic energy change can be reduced to the following, if differential products are neglected

$$\text{energy required to change the kinetic energy of the fluid} = \frac{U^2 dw_g + V^2 dw_L}{2g_c J} + \frac{U(dU)w_g + V(dV)w_L}{g_c J}$$

The resulting energy balance equation then is

$$h_{fg} dw_L = \bar{q} dx + (w_L c_{pL} + w_g c_{pg}) dT + \frac{U^2 dw_g + V^2 dw_L}{2g_c J} + \frac{U(dU)w_g + V(dV)w_L}{g_c J} \quad (3.1)$$

For a condensation process at saturation conditions, the Clapeyron equation specifies that

$$\frac{dP}{dT} = \frac{h_{fg} J}{T_{sat} v_{fg}} \quad (3.2)$$

From this equation, the temperature gradient dT can be written as

$$dT = \frac{T_{sat} dP}{h_{fg} \rho_g J} \quad (3.3)$$

if $\frac{1}{\rho_g} \gg \frac{1}{\rho_L}$, which is a safe assumption. Using this information from the Clapeyron equation, gives for the energy balance the following:

$$h_{fg} dw_L = \bar{q} dx + \frac{(w_L C_{PL} + w_g C_{pg}) T_{sat} dP}{h_{fg} \rho_g J} + \frac{U^2 dw_g + V^2 dw_L}{2g_c J} + \frac{U(dU)w_g + V(dV)w_L}{g_c J} \quad (3.4)$$

Employing the two continuity equations (where A is the tube cross sectional area)

$$w_L = \rho_L V A R_L, \quad R_L \text{ is the fraction of } A \text{ occupied by liquid}$$

$$w_g = \rho_g U A R_g, \quad R_g \text{ is the fraction of } A \text{ occupied by steam} \quad (3.5)$$

in differential form

$$\frac{dw_L}{w_L} = \frac{d\rho_L}{\rho_L} + \frac{dV}{V} + \frac{dR_L}{R_L}$$

$$\frac{dw_g}{w_g} = \frac{d\rho_g}{\rho_g} + \frac{dU}{U} + \frac{dR_g}{R_g} \quad (3.6)$$

where dp_L and dp_g are neglected in comparison to the other terms

This gives

$$\frac{dU}{U} = \frac{dR_L}{R_g} - \frac{dw_L}{w_g} \quad (3.7)$$

Note, the above is also based on the fact that $R_L + R_g = 1$ (or $dR_L = -dR_g$) and that $dw_g = -dw_L$.

Substituting this into the energy balance gives

$$h_{fg} dw_L = \frac{\bar{q}}{h_{fg} \rho_g J} dx + \frac{(w_L c_{pL} + w_g c_{pg}) T_{sat}}{h_{fg} \rho_g J} dp + \frac{3(V^2 - U^2)}{2g_c J} dw_L + \left(\frac{w_g U^2}{R_g} - \frac{w_L V^2}{R_L} \right) \frac{dR_L}{g_c J} \quad (3.8)$$

Now the pressure change (dp) is due to two effects, i.e., friction and momentum changes. This can be expressed as

$$dp = dp_f + dp_m = \frac{dp_f}{dx} dx + \frac{dp_m}{dw_L} dw_L \quad (3.9)$$

The friction part is difficult to evaluate. It may be approximately evaluated using the two phase multiplier approach for separated flow.

That is, it is assumed that

$$\frac{dp_f}{dx} = \phi_g^2 \frac{dp_{gf}}{dx} = \phi_L^2 \frac{dp_{Lf}}{dx} \quad (3.10)$$

where $\frac{dp_{gf}}{dx}$ is for the case of the given amount of steam only in the tube. In other words, in determining $\frac{dp_{gf}}{dx}$ it is assumed that steam flowing at the same flowrate (as the steam only) occupies the whole tube. Similar definitions apply for $\frac{dp_{Lf}}{dx}$.

The Martinelli Parameter (x_i^2) defined as

$$x_i^2 = \frac{\phi_g^2}{\phi_L^2} = \frac{\frac{dP_L}{dx} f}{\frac{dP_g}{dx}} \quad (3.11)$$

gives a measure of the degree to which the two phase separated flow behaves as a liquid ($x_i^2 \rightarrow \infty$) or as a gas ($x_i^2 \rightarrow 0$). Martinelli's correlation gives the relationship between x_i^2 and ϕ_g for the following four combinations:

- (1) laminar gas, laminar liquid
- (2) laminar gas, turbulent liquid
- (3) turbulent gas, laminar liquid
- (4) turbulent gas, turbulent liquid

In general, the pressure drop due to friction in a single phase fluid is

$$\frac{dP}{dx} = \frac{f}{D} \frac{\rho V_e^2}{2g_c} \quad (3.12)$$

where f is the friction factor. The effective velocity (V_e) in this case is obtained by assuming the same flow rate, but using the complete cross sectional area of the tube. Hence, for the steam

$$V_e = U R_g \quad (\text{from } w_g = \rho_g U A R_g)$$

and for the liquid

$$V_e = V R_L \quad (\text{from } w_L = \rho_L V A R_L). \quad (3.13)$$

The Martinelli parameter can then be expressed as

$$x_i^2 = \frac{\frac{dP_L}{dx} f}{\frac{dP_g}{dx}} = \frac{f_L \rho_L V^2 R_L^2}{f_g \rho_g U^2 R_g^2} \quad (3.14)$$

The friction factor (f) can be expressed as a function of Reynolds number

$$(Re = \frac{DV_e \rho}{\mu}) \quad \text{as}$$

$$f = \frac{64}{Re} \quad (3.15)$$

for laminar flow over a smooth surface and as

$$f = \frac{.184}{Re^{.2}} \quad (3.16)$$

for turbulent flow over a smooth surface. Hence, for the following four conditions, x_i can be determined as indicated:

$$\begin{array}{ll} 1) \text{ laminar gas,} & x_i^2 = \frac{\mu_L \rho_g w_L}{\mu_g \rho_L w_g} \\ \text{laminar liquid} & \end{array} \quad (3.17)$$

$$\begin{array}{ll} 2) \text{ laminar gas,} & x_i^2 = \frac{.184}{64} \left(\frac{4}{\pi D} \right)^{.8} \frac{\rho_g}{\rho_L} \left(\frac{\mu_L^2}{\mu_g} \right) \frac{w_L}{w_g}^{1.8} \\ \text{turbulent liquid} & \end{array} \quad (3.18)$$

$$\begin{array}{ll} 3) \text{ turbulent gas,} & x_i^2 = \frac{.64}{.184} \left(\frac{\pi D}{4} \right)^{.8} \frac{\rho_g}{\rho_L} \left(\frac{\mu_L}{\mu_g^2} \right) \left(\frac{w_L}{w_g} \right)^{1.8} \\ \text{laminar liquid} & \end{array} \quad (3.19)$$

$$\begin{array}{ll} 4) \text{ turbulent gas,} & x_i^2 = \frac{\rho_g}{\rho_L} \left(\frac{\mu_L}{\mu_g} \right)^{.2} \left(\frac{w_L}{w_g} \right)^{1.8} \\ \text{turbulent liquid} & \end{array} \quad (3.20)$$

Thus, the value of x_i^2 can be calculated for the flow conditions at any point in the tube. Then from the Martinelli correlation, ϕ_g and ϕ_L can be determined. With the value of x_i determined, the void fraction (α) can be determined also from Martinelli's correlation as

$$\alpha = (1 + x_i^{.8})^{-.378} \quad (3.21)$$

Hence, since $R_g = \alpha$ and $R_g + R_L = 1$,

$$R_L = 1 - (1 + x_i^{.8})^{-.378} \quad (3.22)$$

With this information, the pressure drop due to friction can be approximated.

The pressure change due to momentum change (dP_m) in the two phase flow is obtained from a single force momentum balance ($F = w (V_{out} - V_{in})$) as illustrated

or

$$PA - (PA + dPA) = \frac{1}{g_c} \left[\rho_L A R_L V^2 + d(\rho_L A R_L V^2) + \rho_g A R_g U^2 + d(\rho_g A R_g U^2) - \rho_L A R_L V^2 - \rho_g A R_g U^2 \right] \quad (3.23)$$

Now assuming that the densities remain constant over the short distance dx (and using the relationships, $dV = V \left(\frac{dw_L}{w_L} - \frac{dR_L}{R_L} \right)$, $dU = U \left(\frac{dR_L}{R_g} - \frac{dw_L}{w_g} \right)$, $dR_L = -dR_g$, and $dw_L = -dw_g$) the following is obtained

$$dP = \frac{\rho_g R_g U^2}{g_c w_g} \left[\frac{w_g dR_g}{R_g} - 2 dw_g \right] + \frac{\rho_L R_L V^2}{g_c w_L} \left[\frac{w_L dR_L}{R_L} - 2 dw_L \right] \quad (3.24)$$

Where dR_L is obtained by recalling that $R_L = R_L(x_i)$ and $dR_L = \frac{dR_L}{dx_i} \frac{dx_i}{dw_L} dw_L$

From the relationship of $R_L = R_L(x_i)$

$$\frac{dR_L}{dx_i} = .302 \frac{(1 + x_i^{.8})^{-1.378}}{x_i^{.2}} \quad (3.25)$$

and dx_i/dw_L will depend on the flow regime as follows:

$$1) \text{ laminar gas} \quad \text{laminar liquid} \quad \frac{dx_i}{dw_L} = \frac{x_i}{2} \frac{w}{w_L w_g} \quad (3.26)$$

$$2) \text{ laminar gas} \quad \text{turbulent liquid} \quad \frac{dx_i}{dw_L} = \frac{x_i (1.8 w_g + w_L)}{2 w_g w_L} \quad (3.27)$$

$$3) \text{ turbulent gas} \quad \text{laminar liquid} \quad \frac{dx_i}{dw_L} = \frac{x_i (w_g + 1.8 w_L)}{2 w_g w_L} \quad (3.28)$$

$$4) \text{ turbulent gas,} \quad \text{turbulent liquid} \quad \frac{dx_i}{dw_L} = \frac{x_i}{2} \frac{1.8 w}{w_g w_L} \quad (3.29)$$

The energy equation may now be written as follows using the previously obtained information on dP_f and dP_m :

$$dw_L \left[h_{fg} - \frac{(w_L Cp_L + w_g Cp_g) T_{sat}}{h_{fg} \rho_g J} \frac{dP_m}{dw_L} - \frac{3(V^2 - U^2)}{2g_c J} - \frac{\left(\frac{w_g U^2}{R_g} - \frac{w_L V^2}{R_L} \right)}{g_c J} \frac{dR_L}{dx_i} \frac{dx_i}{dw_L} \right]$$

$$= dx \left[\bar{q} + \frac{(w_L Cp_L + w_g Cp_g) T_{sat}}{h_{fg} \rho_g J} \frac{dP_f}{dx} \right] \quad (3.30)$$

The above equation is essentially the form used in the program. In principle, the way it is used is as follows:

The overall heat transfer for one tube per unit length ($\bar{q}$) is determined from

$$\bar{q} = \frac{\Delta T_{\text{overall}}}{\sum R} \quad (3.31)$$

where

$$\sum R = R_{\text{film}} + R_{\text{wall}} + R_{\text{fin}}$$

$$\Delta T_{\text{overall}} = T_{\text{sat}} - T_a$$

Once the internal energy balance is satisfied, the values of w_g and w_L at the midpoint of the section of interest will be known. The change in temperature across the section (of length dx) is then simply obtained from the Clapeyron relationship, i.e.,

$$dT = \frac{T_{\text{sat}}}{h_{fg} \rho_g J} dp \quad (3.32)$$

The midpoint temperature in the section is then

$$T_{\text{mid point}} = T_{\text{in}} + \frac{dT}{2} \quad (3.33)$$

3.2 External Energy Balance

For the system illustrated

an energy balance may be written as

heat lost from the finned tube = energy involved in change
of sensible heat of air

or

$$q = w_a c_{p_a} \Delta T_a \quad (3.34)$$

where ΔT_a is the change in temperature incurred by the air in crossing a tube bank (of length dx) at one level. The average temperature seen by the finned tube is then

$$\bar{T}_a = T_{a,\text{in}} + \frac{\Delta T_a}{2} \quad (3.35)$$

3.3 Water Film Thermal Resistance

The main resistance to heat transfer from a condensing vapor to a cooler solid surface is the film of liquid that forms on the solid surface. As the film increases in thickness, thermal resistance of the film changes. The thickness of the film depends on the rate of condensation and the forces acting on the film. A study of both theoretical relationships and experimental data led Carpenter and Colburn (Reference 3, p.324) to recommend that the local condensing heat transfer coefficient (h_x) for filmwise condensation inside tubes be estimated as

$$h_x = a \left(\frac{c_{pL} \mu_L}{k_L} \right)^{1/2} \frac{k_L}{\mu_L} (\tau_w g_c \rho_L)^{1/2} \quad (3.36)$$

where

h_x = film heat transfer coefficient (Btu/hr ft² F)

$a = .045$

c_{pL} = liquid specific heat (Btu/lbm °F)

μ_L = liquid viscosity (lbm/ft °F)

k_L = liquid thermal conductivity (Btu/hr ft F)

ρ_L = liquid density (lbm/ft³)

$g_c = (32.2) (3600)^2$ (lbm ft/lbf hr²)

τ_w = shear stress at the wall (lbf/ft²)

Previous explanations have indicated how the pressure change in a section would be calculated. In general the overall force balance for the configuration shown

gives

$$-dP \frac{\pi D^2}{4} = \tau_w \pi D dx \quad (3.37)$$

or

$$-\frac{dP}{dx} = \frac{4\tau_w}{D} \quad (3.38)$$

Hence, the heat transfer coefficient is

$$h_x = a \left(\frac{c_{pL} \mu_L}{k_L} \right)^{1/2} \frac{k_L}{\mu_L} \left(\rho_L g_c \frac{D}{4} \left| \frac{dP}{dx} \right| \right)^{1/2} \quad (3.39)$$

Once condensation is complete, the heat transfer coefficient (h_x) between the fluid and the wall may be simply obtained as

$$h_x = .023 \left(\frac{D G}{\mu_L} \right) \frac{k_L}{D} \left(\frac{c_{pL} \mu_L}{k_L} \right)^{.4} \quad (3.40)$$

if the flow is turbulent (see Reference 4, p. 219) and as

$$h_x = 4.364 \frac{k_L}{D} \quad (3.41)$$

if the flow is laminar (see Reference 5, p.109). The flow is considered turbulent if the Reynolds number based on D is over 2000. In the above, G is the mass flux in lbm/hr ft².

In terms of a resistance, h_x or h_x may be cast as

$$\bar{q} \text{ (heat rate per unit length (} \frac{\text{Btu}}{\text{hr ft}} \text{))} = \frac{\Delta T}{R_{\text{film}}} \text{(resistance per unit length)}$$

where

$$R_{\text{film}} = \frac{1}{h \pi D} \left(\frac{\text{hr ft F}}{\text{Btu}} \right) \quad (3.42)$$

ΔT = temperature difference across film (F)

3.4 Resistance on Tube Wall

The resistance of the tube wall is simply obtained as

$$\bar{q} \text{ (heat rate per unit length (} \frac{\text{Btu}}{\text{hr ft}} \text{))} = \frac{\Delta T}{R_{\text{wall}}} \text{(resistance per unit length)} \quad (3.43)$$

where

$$R_{\text{wall}} = \frac{\ln \frac{D_o}{D_i}}{2 \pi k_w} \left(\frac{\text{hr ft F}}{\text{Btu}} \right)$$

ΔT = temperature difference across wall (F)

3.5 Transverse Fin Heat Transfer Characteristics

The Sieder-Tate heat-transfer factor (j_h) is defined as

$$j_h = \left(\frac{h_f D_e}{k_a} \right) \left(\frac{C_a \mu_a}{k_a} \right)^{-1/3} \quad (\text{see Reference 6 p. 104}) \quad (3.34)$$

The data of Jameson (see Reference 6 page 553) for air flow past transverse fins have been correlated with j_h as a function of the air Reynolds number

$$Re_a = \frac{D_e G_m}{\mu_a} \quad (3.35)$$

in Figure 16.18 of Reference 6, p. 555. In equation form, the correlation is

$$\ln(j_h) = .731 \ln(Re_a) - 2.4515. \quad (3.36)$$

In the definition of j_h and Re_a , the following definitions apply

C_a = Specific heat capacity of air $\left(\frac{\text{Btu}}{\text{lbm F}} \right)$

μ_a = viscosity of air $\left(\frac{\text{lbm}}{\text{ft hr}} \right)$

k_a = conductivity of air $\left(\frac{\text{Btu}}{\text{hr ft F}} \right)$

h_f = heat transfer coefficient between air and finned tube $(\text{Btu/hr ft}^2 \text{ F})$

G_m = mass flux of air through fins based on the minimum cross sectional area seen by the air in transversing a single bank of fins at right angles to the gas flow (lbm/hr ft²)

D_e = an equivalent diameter (ft) defined as

$$= \frac{2 (A_f + A_o)}{\pi (L_p)}$$

where

A_f = external fin area (ft²/ft) on one tube per unit length

A_o = base tube area (ft²/ft) on one tube per unit length

L_p = projected perimeter on one tube per unit length (ft/ft) = the sum of all external distances in the plan view of a transverse finned tube per unit length of tube

The performance of the transverse fins is not only a function of the heat transfer coefficient, but also the specific fin geometry. In general, the performance of a fin is expressed as fin effectiveness (η_c) where

$$\eta_c = \frac{\text{actual heat transferred}}{\text{heat which would be transferred if the entire fin area were at the base temperature}} \quad (3.37)$$

The fins on the LOFT condenser are tapered, making η_c somewhat difficult to obtain. The fin effectiveness program described in Appendix C was used to obtain η_c . In general, the effectiveness program determines η_c given the three parameters F_h , ϕ_r and δ_r where

$$\begin{aligned} F_h &= \frac{2 h_f r_h^2}{k_f \delta_h} \\ \phi_r &= D_f/D_o \\ \delta_r &= \delta_c/\delta_h \end{aligned} \quad (3.38)$$

where

- r_h = fin root thickness (ft)
- k_f = fin thermal conductivity (Btu/hr ft F)
- δ_h = fin thickness at root (ft)
- δ_c = fin thickness at tip (ft)
- D_f = fin diameter (ft)
- D_o = tube outside diameter (ft)

The effectiveness program results are as illustrated in Figure 2 for values of δ_r of 1.0 and .368 (which applies to the LOFT condenser).

The curve for $\delta_r = 1$ is given only as a check on the program, as these results (for an untapered fin $\delta_r = 1$) may be found in various texts, such as Reference 5, p. 542. For $\delta_r = .368$, the curve may be represented as

$$\eta_c = 0.536 F_h^2 - 0.86555 F_h + 0.99555 \quad (3.39)$$

The exterior resistance of the finned tube may then be obtained as

$$\bar{q} \text{ (heat transfer per unit length (} \frac{\text{Btu}}{\text{hr ft}} \text{))} = \frac{\Delta T}{R_{fin} \text{ (resistance per unit length)}} \quad (3.40)$$

where

$$R_{fin} = \frac{1}{h_f (A_f \eta_c + A_o)} \quad \left(\frac{\text{hr ft F}}{\text{Btu}} \right)$$

ΔT = temperature difference between air and tube wall (F)

Fig.2 Effectiveness of Tapered Annular Fins

4.0 LOFCON PROGRAM

The basic strategy used in LOFCON is described in this section. Before continuing, the reader is reminded that LOFCON is built specifically for the LOFT Condensers and has many internal constants that apply to the LOFT configuration (see Appendix A).

4.1 Basic Strategy

Each condenser or bay has four horizontal levels of condenser tubes, and in LOFCON, each condenser is split into 8 sections as illustrated in Figure 3. The air flow is upward in Sections 1 to 4, but it may be either upward or downward in Sections 5 to 8, as specified in the input. Based on this preliminary information, the basic steps followed by LOFCON for one condenser are:

- a) For the lowest horizontal level (NHLEV=1) an overall energy balance is made on a typical tube on that level for the first vertical section. The process basically determines the change in w_L and w_g across the section (the amount of condensation), the change in pressure and temperature of the condensing stream, and also the change in the air temperature of the air flowing across the one tube. The temperature of the air entering below the tube is at the ambient value (T_a^*). This overall process is explained in greater detail in Section 4.2.
- b) Using the exit values of the condensing mixture at the end of the first section as the entry values into the 2nd section, the energy balance is again carried out using entry cross flow air at T_a^* .
- c) The above general process is repeated for the third section, and then the fourth section on the first horizontal level.

Fig. 3 Condenser Analysis

- d) This overall information determined for four of the eight vertical sections of one typical condenser tube on the lowest level is assumed to equally apply to any other tube on that horizontal level. Based on this, all of the information on the state of the condensing mixture for tubes on the bottom horizontal at the mid-plane level is known. Also, the temperature of the air exiting (in a vertical direction) from each of the four vertical sections of the condenser tube is known. These values will be used as entry values of the air temperature into the next higher tube bank.
- e) The basic process explained above is now repeated for the first four vertical sections of tubes on the second horizontal level (NHLEV=2). Where, of course, the entry air values are as explained in part d.
- f) The basic process of (e) is now carried out for the third and fourth horizontal levels.
- g) If the program input specifies that IUP=0, then for the second half of the condenser (Sections 5 through 8) the air flow is up. In this case, the process of steps a through f are repeated for the second half of the condenser. For example, the entry condensing steam valves for the fifth section, first horizontal level are the exit valves from the fourth section, first horizontal level, etc. Also the entry air values for the fifth section, first horizontal level is the ambient values. If, however, IUP=1, LOFCON takes a volumetric

flow weighted average of the air exiting the fourth horizontal level of the first four sections as the entry air values into the top of the fourth horizontal level of the second half of the condenser for the downward flowing air. In this case, the energy balances are made on the fourth horizontal level first, then the third, then the second, and lastly the first.

- h) After the above process is completed (steps a through g) the state of the condensing steam (which may all be condensed) at the exit of all condenser tubes is known. An energy balance is made on all condensing steam entering the exit plenum of the condenser to determine the final state of all the fluid leaving the condenser. This process is explained in greater detail in section 4.3.

4.2 Basic Condenser Tube Energy Balance

As explained previously, the energy balance on one small section of a condenser tube ($dx = L_w$) involves an iteration on the amount of steam that is condensed in that length. Initially, it is assumed that about 1/8 of the remaining steam will be condensed in a the distance L_w . It is also assumed that the average air temperature of the air crossing the tube, is the entry value. These assumptions give dw_L , $w_L^{\text{mid point}}$, $w_g^{\text{mid point}}$, and $T_a^{\text{mid point}}$, from which the overall energy balance can be made. The result is L_{w2} , which is the length actually required to condense the dw_L guessed if the average air temperature across the tube was the value assumed. In general, $L_w \neq L_{w2}$ as illustrated in Figure 4 (note, previously X was used for length but will now also be used for quality). Iterations are now made by adjusting both the dw_L guessed and T_a . A false position algorithm is used which should always converge.

Fig. 4. Section Analysis

In practice two to four iterations are required to get sufficient accuracy. The final result of the energy balance is the condensing steam temperature, pressure and quality at the exit of the small section of condenser tube and the exiting air temperature.

4.3 Energy Balance on Exit Plenum

The first law of thermodynamics for the exit plenum can be written as

$$w h = \sum_{i=1}^4 w_i h_i \quad (4.1)$$

where w is the exit flow rate from the plenum, h the enthalpy, and w_i is the total flow rate entering the plenum from the i^{th} horizontal level (at an enthalpy of h_i). The above formulation of course assumes no accumulation, heat transfer, or work, and also neglects kinetic and potential energy changes. Also by definition,

$$h_g = h_L + x h_{fg}$$

where $h_L = c_{pL} (T-32)$

With the above, the first law becomes

$$\left(\sum_{i=1}^4 w_i \right) \left[c_{pL} (T-32) + x h_{fg} \right] = \sum_{i=1}^4 w_i \left[c_{pL} (T_i-32) + x_i h_{fg} \right] \quad (4.2)$$

The pressure in the plenum is calculated as

$$P = \frac{\sum_{i=1}^4 w_i P_i}{\sum_{i=1}^4 w_i} \quad (4.3)$$

Now assume that $x = 0$, then

$$T_{\text{guess}} = \frac{\sum_{i=1}^4 w_i (C_{pL} (T_i - 32))}{C_{pL} \sum_{i=1}^4 w_i} + 32 \quad (4.4)$$

But if $x = 0$, then T_{guess} must be less than or equal to T_{sat} at the P value previously calculated. Hence if $T_{\text{guess}} \leq T_{\text{sat}}$, then

$$\begin{aligned} T &= T_{\text{guess}}, \text{ and} \\ x &= 0 \end{aligned} \quad (4.5)$$

If however, $T_{\text{guess}} > T_{\text{sat}}$, then

$$x = \frac{\sum_{i=1}^4 w_i (C_{pL} (T_i - 32) + x_i h_{fg})}{h_{fg} \sum_{i=1}^4 w_i} - \frac{C_{pL} (T_{\text{sat}} - 32)}{h_{fg}} \quad (4.6)$$

A similar type of approach is used to get the mixture temperature, pressure and quality out of the plenum receiving the output of the one, two or three LOFT condensers.

4.4 RESULTS

LOFCON results can be compared with lumped calculations if it is assumed (for the purposes of the lumped calculation) that there is no pressure drop through the condensers, that there is no resistance to heat transfer, and that each condenser responds in a lumped manner. Under these assumptions, if

$$\frac{w}{w_a} < \frac{C_{p_a} (T_{sat} - T_a)}{x_{in} h_{fg}} \quad (4.7)$$

then all the steam in the condenser will condense ($x_{in} > 0$, of course). When this occurs, the fluid temperature at the exit of the condenser will be

$$T_f = \frac{w h_{fg} x_{in} + w C_{p_L} T_{sat} + w_a C_{p_a} T_a}{w C_{p_L} + w_a C_{p_a}} \quad (4.8)$$

assuming the outlet air temperature is the same as the outlet fluid temperature.

If, however, condensation is incomplete, the exit quality will be

$$x_{out} = x_{in} - \frac{w_a}{w} \frac{C_{p_a} (T_{sat} - T_a)}{h_{fg}} \quad (4.9)$$

assuming the outlet air temperature is T_{sat} .

Figure 5 and 6 show a comparison of the results of LOFCON with the lumped calculation method just explained. These results cover the following range of parameters:

$$.001 \leq \frac{w}{w_a} \leq 1.15$$

$$1,200 \text{ lbm/hr} \leq w \leq 73,200 \text{ lbm/hr}$$

$$65,000 \text{ lbm/hr} \leq w_a \leq 1,300,000 \text{ lbm/hr}$$

$$297^\circ\text{F} \leq (T_{\text{sat}} - T_a) \leq 457^\circ\text{F}$$

$$-40^\circ\text{F} \leq T_a \leq +120^\circ\text{F}$$

$$0. \leq x_{\text{in}} \leq 1.$$

The results show the general trends expected. The exit quality predicted by LOFCON should be greater than that predicted by the lumped model due to the resistance to heat transfer in the system. As the ratio w_a/w increases and as $(T_{\text{sat}} - T_a)$ increases, T_f predicted by LOFCON will be below the lumped model prediction. Conversely, as w_a/w becomes small, the air temperature will approach the fluid temperature, and with the resistance to heat transfer in the system, the T_f predicted by LOFCON will be above that predicted by the lumped model. The data verifies this trend.

Figure 5. T_f Comparison, LOFCON to Lumped Calculation

Figure 6. x_{out} Comparison, LOFCON to Lumped Calculation

5.0 LOFCON USERS MANUAL

LOFCON is actually a subroutine which drives many other subroutines. It was arranged in this method as it will be used by a much larger program on the complete LOFT secondary system. The use of LOFCON is best explained with an example. Since LOFCON is a subroutine, the user must build his own master driver program. A call to LOFCON requires about one second of execution time.

5.1 Driver Programs

The following is an example of a possible driver program:

```

C      EXAMPLE DRIVER OF SUBROUTINE LOFCON
C      DIMENSION CARD(20)
C      CALL ECHO
C      SET MATERIAL PROPERTIES INITIALLY
C      PASS=0.
10    CONTINUE
C      READ DATA
C      READ 521, CARD
521   FORMAT (20A4)
C      PRINT 522, CARD
522   FORMAT ('1',20A4//// )
C      INPUT STEAM VALUES
C      WDOT - FLOW RATE      LB/HR
C      TSTAR - FLUID TEMPERATURE  F
C      PSTAR - FLUID PRESSURE    PSF
C      QALSTR - WEIGHT FRACTION OF STEAM OR VAPOR  UNITLESS
C      READ 9, WDOT, TSTAR, PSTAR, QALSTR
C      INPUT FLOW SPLIT VALUES
C      PC1 - FRACTION OF TOTAL STEAM FLOW TO CONDENSER NUMBER 1
C      PC2 - FRACTION OF TOTAL STEAM FLOW TO CONDENSER NUMBER 2
C      PC3 - FRACTION OF TOTAL STEAM FLOW TO CONDENSER NUMBER 3
C      READ 9, PC1, PC2, PC3
C      INPUT AIR VALUES
C      WDA - WDOT OF AIR - TOTAL  LBM/HR
C      TASTAR - AIR TEMPERATURE  F
C      PASTAR - AIR PRESSURE PSF
C      READ 9, WDA, TASTAR, PASTAR
9     FORMAT( 8F10.2)
C      STF1=FRACTION OF FLOW ON LOWEST LEVEL
C      STF2=FRACTION OF FLOW ON NEXT TO LOWEST LEVEL
C      STF3=FRACTION OF FLOW ON NEXT TO HIGHEST LEVEL
C      STF4=FRACTION OF FLOW ON HIGHEST LEVEL
C      IUP=0, ON SECOND VERTICLE PASS - WORK UP
C      IUP=1, ON SECOND VERTICLE PASS - WORK DOWN
C      ISPILL =1 - PRINT OUT ALL VALUES,  ISPILL = 0 - NO PRINT OUT

```

```

READ 1, STF1,STF2,STF3,STF4,IUP,ISPILL
1 FORMAT(4F10.0,2I10)
PRINT 8,WDOT,TSTAR,PSTAR,QALSTR
8 FORMAT('      WDOT,TSTAR,PSTAR,QALSTR      '/4(3X,1PE10.3))
PRINT 6, PC1,PC2,PC3
6 FORMAT(' PC1,PC2,PC3 '/3(3X,1PE10.3))
PRINT 7,WDA,TASTAR,PASTAR
7 FORMAT('      WDA,TASTAR,PASTAR      '/3(3X,1PE10.3))
PRINT 2, STF1,STF2,STF3,STF4,IUP,ISPILL
2 FORMAT(' STF1,STF2,STF3,STF4,IUP,ISPILL '/4(2X,1PE10.3),2I10)
CALL LOFCON(WDOT,TSTAR,PSTAR,QALSTR,PC1,PC2,PC3,TASTAR,PASTAR,WDA,
*STF1,STF2,STF3,STF4,IUP,ISPILL,PASS,TOUT,POUT,QALOUT)
C OUTPUT STEAM/WATER VALUES
C TCUT - FLUID TEMPERATURE F
C POUT - FLUID PRESSURE PSF
C QALOUT - WEIGHT FRACTION OF STEAM UNITLESS
PRINT 17,TOUT,PCUT,QALOUT
17 FORMAT(' TOUT,POUT,QALOUT      '/3(2X,1PE10.3))
GO TO 10
STOP
END

```

Sufficient comment statements are given so that the driver should be self-explanatory. WDOT, TSTAR, PSTAR and QALSTR, are the input fluid properties into the tri-condenser bank. The total flow is divided up among the three separate condensers as specified by PC1, PC2 and PC3. The steam flow in each condenser is divided among the four horizontal levels as specified by STF1, STF2, STF3 and STF4. WDA, TASTAR and PASTAR are the incoming air values. Note that if IUP=0, WDA is the total flow rate of the air through each condenser. If, however, IUP=1, WDA is twice the total flow rate through one condenser. However, either way, the flow rate through each half of the condenser is the same. This is as illustrated below:

ISPILL is simply a flag to indicate if all debugging prints in LOFCON are to be employed. Normally, the user should choose ISPILL=0. The fluid state at the output of the tri-condenser bank is given by TOUT, POUT and QALOUT. An example of the results of this sample driver are given in the next section.

5.2 Sample Output

Shown below is a data echo of typical data required to run LOFCON via the example driver previously given:

```

1      LOFT CONDENSER
73200.  417.33  43200.  1.
-----
1.
1300000.  70.  1800.
.25      .25      .25      .25      1
-----
0000000001111111112222222222333333333344444444445555555556
123456789012345678901234567890123456789012345678901234567890

```

These two lines are not input, but are here given help the reader confirm which columns the above data is in.

The output resulting from the submission of the above data is as follows:

```

1      LOFT CONDENSER
-----
      WDOT,TSTAR,PSTAR,QALSTR
7.320E 04  4.173E 02  4.320E 04  1.000E 00
PC1,PC2,PC3
1.000E 00  0.0      0.0
      WDA,TASTAR,PASTAR
1.300E 06  7.000E 01  1.800E 03
STF1,STF2,STF3,STF4,IUP,ISPILL
2.500E-01  2.500E-01  2.500E-01  2.500E-01  1      0
TOUT,POUT,QALOUT
4.171E 02  4.309E 04  1.669E-01
-----

```

This information indicates that for steam, at a flow rate of 7.52×10^4 lbm/hr, entering the tri-condenser bank at a temperature of 417.3°F and a pressure of 4.32×10^4 psf and a quality of 1.0, that the output values from the tri-condenser bank is $T=417.1$ °F, $P=4.309 \times 10^4$ psf and $x=.1669$. These values result from a total air flow of 1.3×10^6 lbm/hr $\div 2$ (IUP=1) at 70°F and 1.8×10^3 psf. Note that the condensers were in the IUP=1 mode, i.e., the air entered at the bottom of the first half and then was mixed at the top of the first half and then reentered the top of the second half, finally exiting at the bottom of the second half. For this particular run, only one condenser was actually used, i.e., $PC1=1$ where $PC2 = PC3 = 0$. Also, in that condenser the flow was evenly distributed between the four horizontal levels. ISPILL was zero, hence only printout generated by the driver program results.

6.0 REFERENCES

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2. MacKay, D. B., "Systems Heat Transfer," an unpublished text.
3. Collier, J. G., "Connective Boiling and Condensation," McGraw Hill, 1972.
4. McAdams, W. H., "Heat Transmission," McGraw Hill, 1945.
5. Kraup, W. M., "Convective Heat and Mass Transfer," McGraw Hill, 1966.
6. Kern, D. Q., "Process Heat Transfer," McGraw Hill, 1950.

7.0 NOMENCLATURE

A	area (ft^2)
C_p	specific heat ($\frac{\text{Btu}}{\text{lbm} \cdot ^\circ\text{F}}$)
D	Diameter (ft)
f	friction factor (unitless)
F	fin parameter group
G	mass flux (lbm/hr ft^2)
g_c	dimensional constant with a value dependent only on the units selected for force, mass, and acceleration ($g_c = (32.2) (3600) (3600) \text{ lbm-ft/lbf-hr}^2$)
h	heat transfer coefficient ($\text{Btu/hr-ft}^2\text{-}^\circ\text{F}$) and enthalpy (Btu/lb)
J	proportionality factor relating units of work and heat ($J = 778.165 \text{ ft lb}_f/\text{Btu}$)
j_h	Sieder-Tate heat-transfer factor (unitless)
k	thermal conductivity ($\text{Btu/hr-ft-}^\circ\text{F}$)
P	pressure (psf)
$\bar{q}$	heat transfer rate per unit length ($\frac{\text{Btu}}{\text{hr-ft}}$)
r	radius (ft)
R	thermal resistance per unit length ($\text{hr-ft-}^\circ\text{F/Btu}$), and area fraction (unitless)
Re	Reynolds number (unitless)
T	temperature ($^\circ\text{F}$)
U	velocity of vapor (ft/hr)
V	velocity of liquid (ft/hr)
v	specific volume
w	flow rate (lb/hr)
x	length (ft) and quality
α	void fraction (unitless)
η_c	fin effectiveness (unitless)
μ	viscosity ($\text{lbm/ft-}^\circ\text{F}$)
ρ	density (lbm/ft^3)
τ	shear stress (lb_f/ft^2)
δ	thickness and thickness ratio

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ϕ two phase flow multiplier (unitless) and diameter ratio
 x_i^2 Martinelli Parameter (unitless)

Subscripts

a air
e effective
f friction and fin and fluid
fg latent vaporization
g vapor or gas
in into
l between fluid and wall
L liquid
m minimum
o outer and base
out out of
p projected
sat at saturation conditions
w wall
x condensing film

APPENDIX A

SPECIFIC CONSTANTS USED INTERNALLY IN LOFCON

APPENDIX A

SPECIFIC CONSTANTS USED INTERNALLY IN LOFCON

Figure A1 gives extensive information relating the specific constants used internally in LOFCON. As illustrated, each condenser has four levels of tube banks, for a total of 230 tubes ($58 + 57 + 58 + 57$). The triangular pitch is as shown. The length of a condenser tube is 44 ft. Within LOFCON, this length has been divided up into 8 different sections with the respective lengths as shown in Figure A1. These section lengths are the dx previously referred to. Calculated minimum flow areas are shown for the air stream in each of the eight sections. The percentage of air flow through each section when operating in the normal mode with air flowing upward through all sections is also shown. The air flows were calculated from velocity measurements made during a test of the unit. Except where noted these percentages were taken for all air flow conditions.

For this specific geometry, several constants are required and internally programed into LOFCON. They are the following:

Section Number	Percentage of Air Flow	Minimum Flow Area (Sq ft.)
1	10.33	29.643
2	12.48	32.113
3	13.97	32.113
4	13.22	32.113
5	12.86	32.113
6	13.39	32.113
7	13.54	32.113
8	10.21	29.643

Tube Data

Row #1 58 tubes (bottom)
 Row #2 57 tubes
 Row #3 58 tubes
 Row #4 57 tubes (top)

Tube O.D. = 0.0833 ft. (D_o)

Tube I.D. = 0.0691 ft. (D_i)

Fin O.D. = 0.1875 ft. (D_f)

Fins = 10 per inch.

Fin material - Aluminum ($k = 120$)

Fin Root thickness = 0.019 inches

Fin tip thickness = 0.007 inches

Tube material - A214 Carbon steel ($k = 28$)

Fig. A1 Condenser Design

- 1) External fin area on one tube per unit length (A_f).

$$A_f = \frac{\pi}{4} (D_f^2 - D_o^2) \left(\frac{ft^2}{side\ of\ fin} \right) 2 \left(\frac{sides}{fin} \right) 10 \left(\frac{fins}{inch} \right) 12 \left(\frac{inches}{foot} \right)$$

$$= 5.319 (ft^2/ft\ of\ tube)$$

- 2) Bare tube area on one tube per unit length (A_o). Note that 19% of the area on the tube exterior is covered by fins, i.e., there are 10 fins per inch and each fin is .019 inches thick.

Hence 81% of the exterior tube surface is not covered by fins, to give

$$A_o = \pi D_o .81 \left(\frac{ft^2}{ft\ of\ tube} \right)$$

$$= .212 \left(\frac{ft^2}{ft\ of\ tube} \right)$$

- 3) Projected perimeter on one tube per unit length (L_p)

L_p = Sum of all external distances in the plan view of a transverse finned tube per unit length

Consider the geometry illustrated

Since there are 120 fins per foot of tube length and in a plan view, each fin has a mirror image, the solid line shown

above is equal to $\left(\frac{1}{120 \times 2}\right)$ th of L_p . Hence

$$L_p = 240 (L + \delta_c + L + \delta_h)$$

where

$$L = \sqrt{\left(\frac{D_f}{2} - \frac{D_o}{2}\right)^2 + \left(\frac{\delta_h}{2} - \frac{\delta_c}{2}\right)^2} \quad \text{neglect}$$

$$L \approx \frac{D_f}{2} - \frac{D_o}{2} = \frac{.1875}{2} - \frac{.0833}{2} = .0521 \text{ ft}$$

$$\delta_c \approx .007 \text{ in} = .000583 \text{ ft}$$

$$\delta_h \approx \frac{.81 \text{ ft}}{120} = .00675 \text{ ft}$$

Hence

$$L_p = 240 (.0521 + \cancel{.000583} + .0521 + .00675) \quad \text{neglect}$$

$$\approx 26.6 \text{ (ft/ft of tube)}$$

4) Equivalent diameter (D_e)

$$D_e = \frac{2(A_f + A_o)}{\pi L_p} = \frac{2(5.319 + .212)}{\pi (26.6)} \approx 0.132 \text{ (ft)}$$

APPENDIX B

PROPERTIES

APPENDIX B

PROPERTIES

All of the material properties are preset in LOFCON. Ample comment statements are given in the program to describe each one, and its units. Any properties that are considered to be variable, are stored in the DA array. Linear interpolation is used in conjunction with the preset tables. The values initially set by a data statement correspond to the following.

DA(I)

I =	Property Table
100 to 199	liquid temperature (°F) vs viscosity (lb/ft sec)
200 to 299	liquid temperature (°F) vs thermal conductivity (Btu/hr ft °F)
300 to 399	liquid temperature (°F) vs density (lb/cu ft)
400 to 499	air temperature (°F) vs viscosity (lb/hr ft)
500 to 599	air temperature (°F) vs thermal conductivity (Btu/hr ft °F)
600 to 699	vapor temperature (°F) vs viscosity (lb/hr ft)
700 to 799	vapor pressure (psia) vs specific volume (cu ft/lb)
800 to 899	vapor pressure (psia) vs latent heat (Btu/lb)
900 to 999	vapor temperature (°F) vs specific heat (Btu/lb °F)

The way the data is actually stored in each array is best explained with an example. For example, consider DA(I), I = 300 to 399, for which a data statement follows:

```
DATA (DA(I), I=300,399)/
* 18., 32., 62.4, 40., 62.4,
* 50., 62.4, 60., 62.3, 70.,
* 62.3, 80., 62.2, 90., 62.1,
* 100., 62.0, 150., 61.2, 200.,
* 60.1, 250., 58.8, 300., 57.3,
* 350., 55.6, 400., 53.6, 450.,
* 51.6, 500., 49.0, 550., 45.9,
* 600., 42.4,
*62*0.0/
```

The first entry (DA(300)) indicates the number of entry pairs in the table, i.e., 18 in this case. There after each two consecutive entries represent one data pair, i.e., at $T = 32^{\circ}\text{F}$, $\rho_{\ell} = 62.4 \text{ lbm/ft}^3$, etc. The presetting of the data tables is done in the Subroutine DECRD, which is only called once since some unit changes are made on the viscosity units (from lbm/ft sec to lbm/ft hr) after the initializing of the DA array.

APPENDIX C
FIN EFFECTIVENESS PROGRAM

D. B. MacKay
Author

FIN EFFECTIVENESS PROGRAM

Abstract

A numerical integration program is presented for calculating heat transfer from tapered annular fins in radiative and or convective environments. Basic heat exchange equations were reduced to parametric forms suitable for both specific and parametric studies. Equations derived for flat plates were used for obtaining initial approximations and these approximations are refined in a closed loop until the desired accuracy is obtained. Heat transfer and derived parameters are printed as output data. Instructions for the use of the program are also presented.

1.0 Heat Transfer From Annular Fins

The transfer of heat from an annular fin is difficult to accurately evaluate because of the peculiar nature of the problem. Flat circular fins in convective environments can be evaluated by the use of Bessel functions but for trapezoidal profiles and for fins in radiative environments the basic differential equations are nonlinear and only numerical solutions are possible. The program presented in this report employs a Runge-Kutta-Gill numerical integration routine taken from Ref. C1 and can be used for evaluating fin performance in convective and/or radiative environments. The immediate need in the LOFT program is the evaluation of a finned tube steam condenser operating with air blowing across the tubes. For this configuration the closely spaced fins essentially eliminate radiative heat exchange and little error is introduced by neglecting its effect. Therefore, little time will be devoted to discussing radiative problems. The interested reader is referred to Refs. C2 and C3 for information on this subject.

Program Description

The basic equation solved by the program is:

$$\left[\phi_r - \delta_r + \phi(\delta_r - 1) \right] \frac{d^2 Z}{d\phi^2} = - \left[\frac{\phi_r - \delta_r}{\phi} + 2(\delta_r - 1) \right] \frac{dZ}{d\phi} + (\phi_r - 1) \left[\zeta_e(Z^4 - C_3) + F_h Z - F_{ah} \right] \quad (C-1)$$

where

$$Z = \frac{T}{T_h}, \quad \phi = \frac{r}{r_h}, \quad \phi_r = r_c/r_h, \quad \delta_r = \frac{\delta_c}{\delta_h}, \quad C_3 = \frac{C_2}{C_1 T_h^4},$$

$$F_h = \frac{r_h^2 (h_a + h_b)}{12k\delta_h}, \quad F_{ah} = \frac{r_h^2 (h_a T_{aa} + h_b T_{ab})}{12k\delta_h T_h}, \quad \text{and} \quad \zeta_e = \frac{C_1 T_h^3 r_h^2}{12k\delta_h}$$

and where,

T = element temperature, $^{\circ}\text{R}$

T_{hl} = temperature at the root of the fin, $^{\circ}\text{R}$

r = radius of a fin element, ft

r_h = root radius of the fin, ft

r_c = far end fin radius, ft

δ_c = fin thickness at far end, ft

δ_h = fin thickness at the root section, ft

h_a = convective heat transfer coefficient on side "a",
Btu/hr sq ft $^{\circ}\text{R}$

h_b = convective heat transfer coefficient on side "b",
Btu/hr sq ft $^{\circ}\text{R}$

k = thermal conductivity of the fin material, Btu/hr sq ft $^{\circ}\text{R}$

T_{aa} = ambient temperature on side "a", $^{\circ}\text{R}$

T_{ab} = ambient temperature on side "b", $^{\circ}\text{R}$

C_1 = radiative heat transfer term, $(E_a + E_b) \sigma$, Btu/hr sq ft $^{\circ}\text{R}^4$

C_2 = radiative heat transfer term, Btu/hr sq ft $^{\circ}\text{R}^4$ (heat transfer
from environment to both sides of a unit of fin area)

E_a = emissivity on side "a"

E_b = emissivity on side "b"

σ = Stefan-Boltzman Constant = 0.1713×10^{-8} , Btu/hr sq ft $^{\circ}\text{R}^4$

There are several advantages in combining the variables in the form shown in Eq. C1. The use of dimensionless variables Z and ϕ separates the main constants into dimensionless numbers, i.e., F_h , F_{ah} , C_3 , $\bar{\epsilon}_e$, ϕ_r and δ_r . Since the solution of Eq. C1 depends only upon values for these numbers, parametric or specific solutions can be made. The equation is derived in a form where radiation and convection can be studied either

independently or in combination. In fact solutions are available even though the radiative heat exchange may be opposite in direction to the convective exchange.

In solving Eq.C1 a method of successive approximations is used for the heat transfer conditions prevailing. The integration then proceeds from root toward the far end until it is obvious that the original approximation is in error and the direction of the error is established. New approximations are made and the process repeated. Eventually the solution with the desired accuracy is attained.

The key to successful results with reasonable machine time lies in the program's ability to start the integration procedures with close approximations. For radiant heat transfer a curve fitting technique for data compiled for flat plates (see Ref.C4) is used. For convective heat exchange, an approximated rectangular flat plate is used. Radiative and convective effects are added as though each were acting independently of the other. These approximations usually permit acceptable convergence to be completed within 10 to 12 loops.

The fundamental feature used in fin heat transfer calculations is the concept that at the far end, no internal heat passes out of the section and the accumulated exchange with the environment will pass the root section. This overall heat exchange is proportional to the magnitude of the dimensionless temperature gradient, $(dZ/d\phi)_1$ but it is of opposite sign. The subscript 1 is added to denote that this is the value at the root of the fin. With an approximation for $(dZ/d\phi)_1$ and known values for ζ_e , C_3 , F_h , F_{ah} , ϕ_r , and ϕ_r the program will calculate the corresponding values for $d^2Z/d\phi^2$. A step by step integration procedure then moves

incrementally down the surface. Unfortunately, any error made in approximating the value of $(dZ/d\phi)_1$ becomes magnified as the integration proceeds, and if the error is appreciable, calculated values of Z and $dZ/d\phi$ at the far end of the fin will be quite absurd. Illustrative curves of the process are shown for both heating and cooling situations in Fig.C1. Two possibilities exist for the first approximation and these are labeled DSW DZO. Curve 3 has an absolute value for DZW which is too large to satisfy far end conditions and Curve 2 has a value for DZO too small. As the integration proceeds toward the far end, Curve 2 crosses the line where $dZ/d\phi$ is equal zero. By contrast Curve 3 is shown to reverse direction before reaching the far end and does not cross the zero line. The later condition was called "wilt" and this accounts for the "W" designation in DZW. It should also be pointed out that while most DZW curves experience a reversal in direction, some do not. A value of $(dZ/d\phi)_1$ sufficiently close to the actual value will proceed to the far end without reversing directions. If the correct value $(dZ/d\phi)_1$ is assumed, the integration will follow the solid curve labeled 1 and the value of $dZ/d\phi$ will be exactly equal to zero at the far end where $\phi = \phi_r$. This is seldom the case even during the latter stages of the repeating integration process. Tests are provided in the program after each step in the integration to detect if the curve either crosses zero, wilts, or proceeds to the far end without wilting. The latter condition is treated as a wilt in the program. If a zero condition occurs, a new DZO is calculated with an absolute value 10 per cent larger and the process is repeated. Similarly, for a wilt, 90 per cent of the original value is taken and the case repeated. This procedure continues until both wilt and zero curves, as shown in Fig.C1, are obtained.

Fig.C1. Relationship of Variables for Numerical Integration

The correct answer lies between the two curves and a positive systematic method is used in the program for reducing the error. Succeeding attempts use values midway between those found for DZW and DZO. Integration along the new line is tested after each step to see if the curve either passes zero or wilts. The new value is taken to be DZW if the curve wilts and DZO if the curve crosses zero. The possible error for each new approximation is thus reduced by 50 per cent from the error of the preceding case.

The process of improved approximations is continued until the difference between absolute values of DZW and DZO divided by the absolute value of $(DZ/d\phi)_1$ is less than 0.0025. At this point, the approximation process is stopped and the values of Z , $dZ/d\phi$ and $d^2Z/d\phi^2$ along the curve are assumed to be satisfactory. Also other items of interest are calculated and printed out for the fin using these data.

2.0 Heat Transfer Rate and Fin Effectiveness

The rate of heat transfer from a fin is calculated using the temperature gradient $dZ/d\phi$ within the fin. The heat passing any section is

$$q_i = \frac{-\pi k T_h r \delta}{6 r_h} \frac{dZ}{d\phi} \quad (C-2)$$

At the root section the total heat exchange becomes

$$q_e = \frac{-\pi k T_h \delta h}{6} \left(\frac{dZ}{d\phi} \right)_1 \quad (C-3)$$

In selecting a suitable fin configuration for a given application, it is desirable to have a model (ideal fin) for comparison purposes and to relate the actual performance to this model. Since it is the function of a fin to transfer heat, it is natural to compare a given fin to the one whose performance is high. The one item which reduces fin capability to transfer heat is the fact that the far end fin temperature approaches that of the environment and a given area at the far end will transfer less heat than would the same area at the root section. The maximum heat exchange with the environment would take place if the fin were of uniform temperature and equal to the temperature at the root. This is impossible for an actual fin, since this would require the fin material to have infinite thermal conductivity. A thicker fin of a given material will, of course, have less temperature change from root to far end than will a thin fin. However, the thicker fin while transferring more heat will also weigh more and use more material. It would, therefore, seem desirable to establish a model which will provide guide lines for fin selection. The assumption of constant temperatures equal to the root temperature appears best able to satisfy the prescribed requirements and has been adopted in this text.

With the above definition, the convective heat transfer, q_m , from the model fin is

$$q_m = \pi (r_c^2 - r_h^2) [h_a (T_h - T_{aa}) + h_b (T_h - T_{ab})] \quad (C-4)$$

for the LOFT condenser

$$h_a = h_b = h \quad \text{and} \quad T_{aa} = T_{ab} = T_{air}$$

and

$$q_m = 2\pi h (r_c^2 - r_h^2) (T_h - T_{air}) \quad (C-5)$$

The ratio of actual to the model heat transfer is defined as efficiency or effectiveness and will be designated by the symbol η_c . The latter term, effectiveness, will be used in this text. With this definition

$$\eta_c = \frac{q_e}{q_m} = \frac{\delta_h k T_h}{h(r_c^2 - r_h^2)} \left(\frac{dZ}{d\phi} \right)_1 \quad (C-6)$$

combining Eqs. (1), (3), (5) and (6)

$$\eta_c = \frac{2}{(\phi_r^2 - 1)(F_h - F_{ah})} \left(\frac{dZ}{d\phi} \right)_1 \quad (C-7)$$

Fin effectiveness, shown by Eq.(C7), appears to be a function of three variables ϕ_r , F_h and F_{ah} . However, for all fins in convective environments, where exact solutions are attainable, the effectiveness is independent of the environment parameter F_{ah} . Fins used in the LOFT condenser were checked to assure that they conformed to the same rule. However, radiation effectiveness is effected by the environment but not as severely as one might expect. Thus in convective environments the effect of increasing the value of F_{ah} simply reduces the value of $(dZ/d\phi)_1$ without altering the value of η_c . However, the program requires an input value for F_{ah} even though an arbitrary value selected at random is adequate.

Values for η_c derived by the program for convective heat exchange depends only on the values for F_h , and this is independent of the fin geometry required to get F_h . Normal steps for calculating fin heat transfer is to evaluate the parameter F_h , the effectiveness η_c , the modle heat transfer, and finally the q_m actual heat transfer q_e . Mathematically this can be written as

$$q_e = \eta_c q_m \quad (C-8)$$

Procedures using Eq.(C8) have advantages over direct process. For economy of material the fin effectiveness is usually known within narrow limits and may be selected prior to the evaluation of the fin size. Evaluations of q_m are simple processes that introduce minimum chances of error. The effectiveness is independent of the root temperature and can be calculated without regard to heat transfer. However, F_h is a function of the convective heat transfer coefficient, h , and this item is temperature dependent.

Program listing solution to a simple problem and notes to the user are shown in Appendix E.

REFERENCES

- C1. Wang, P. Numerical and Matrix Methods in Structural Mechanics, John Wiley and Sons, Inc., New York, 1966.
- C2. MacKay, D.B., Design of Space Power Plants, Prentice-Hall, Inc., Englewood Cliffs, N. J., 1963.
- C3. MacKay, D. B., Systems Heat Transfer, An unpublished text.
- C4. MacKay, D. B., "Space Radiator Analysis and Design," Aeronautical Systems Division, ASD, Technical Report 61-30, Parts I and II, Contract AF 33(616)-8323, 1962.

APPENDIX D
LOFCON LISTING

COMPILER OPTIONS - NAME= MAIN,OPT=00,LINECNT=58,SIZE=0000K,

SOURCE,EBCDIC,NOLIST,NODECK,LOAD,MAP,NCEDIT,NOID,XREF

```
ISN 0002      SUBROUTINE LOFCON(WDOT,TSTAR,PSTAR,QALSTR,PC1,PC2,PC3,TASTAR,  
              * PASTAR,WDA,STF1,STF2,STF3,STF4,IUP,ISPILL,PASS,TOUT,POUT,QALOUT)  
ISN 0003      COMMON/VALUES/DA(999)  
ISN 0004      DIMENSION CONBK(3,4),PC(3)  
ISN 0005      IF(PASS.NE.0.)GO TO 10  
ISN 0007      CALL DECRD  
ISN 0008      PASS =1.  
ISN 0009      10 CPL=1.0039  
ISN 0010      PC(1)=PC1  
ISN 0011      PC(2)=PC2  
ISN 0012      PC(3)=PC3  
ISN 0013      DO 1 I=1,3  
ISN 0014      IF(PC(I).EQ.0.0) GO TO 2  
ISN 0016      IF(ISPILL.EQ.1) PRINT 4  
ISN 0018      4 FORMAT(1H1)  
ISN 0019      WDOTI=WDOT*PC(I)  
ISN 0020      IF(I.GE.2.AND.PC(I).EQ.PC(I-1)) GO TO 3  
ISN 0022      CALL CONDEN(WDOTI,TSTAR,PSTAR,QALSTR,WDA,TASTAR,PASTAR,  
              * TOUT,POUT,QALOUT,STF1,STF2,STF3,STF4,IUP,ISPILL)  
ISN 0023      IF(PC(2).EQ.0.0.AND.PC(3).EQ.0.0) GO TO 83  
ISN 0025      3 CONTINUE  
ISN 0026      CCNBK(I,1)=TOUT  
ISN 0027      CONBK(I,2)=POUT  
ISN 0028      CONBK(I,3)=QALOUT  
ISN 0029      CCNBK(I,4)=WDOTI  
ISN 0030      IF(ISPILL.EQ.1)  
              *PRINT 5, I,PC(I),WDOTI,TOUT,POUT,QALOUT  
ISN 0032      5 FORMAT(' I,PC(I),WDOTI,TOUT,POUT,QALOUT '/110,5(3X,1PE10.3))  
ISN 0033      GO TO 1  
ISN 0034      2 TOUT=0.  
ISN 0035      POUT=0.  
ISN 0036      QALOUT=0.  
ISN 0037      WDOTI=0.  
ISN 0038      GO TO 3  
ISN 0039      1 CONTINUE  
ISN 0040      PSUM=0.  
ISN 0041      HSUM=0.  
ISN 0042      DO 8 I=1,3  
ISN 0043      T=CONBK(I,1)  
ISN 0044      P=CONBK(I,2)  
ISN 0045      PSUM=PSUM+P*PC(I)  
ISN 0046      PSIA=P/144.  
ISN 0047      FHH=ENTERP(PSIA,DA(800))  
ISN 0048      QAL=CONBK(I,3)  
ISN 0049      WLV=CONBK(I,4)  
ISN 0050      HSUM=HSUM+WLV*(CPL*(T-32.)+QAL*FHH)  
ISN 0051      8 CONTINUE  
ISN 0052      POUT=PSUM  
ISN 0053      PSIA=POUT/144.  
ISN 0054      FHH=ENTERP(PSIA,DA(800))  
ISN 0055      TDRY=(HSUM/(WDOT*CPL))+32.  
ISN 0056      PLN=ALOG(POUT)  
ISN 0057      TWET=-(8.404E3/(PLN-20.2524))-460.  
ISN 0058      IF(TWET.LT.TDRY) GO TO 81
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ISN 0060      TOUT=TDY
ISN 0061      QALOUT=0.
ISN 0062      GO TO 83
ISN 0063      81 TOUT=TWET
ISN 0064      QALOUT=((HSUM/WDOT)-CPL*(TOUT-32.))/FHH
ISN 0065      83 CONTINUE
ISN 0066      IF(ISPILL.EQ.1)
               *PRINT 9, TOUT,POUT,QALOUT
ISN 0068      9 FORMAT(' TOUT,POUT,QALOUT '/3(3X,1PE10.3))
ISN 0069      RETURN
ISN 0070      END
```


COMPILER OPTIONS - NAME= MAIN,OPT=00,LINECNT=58,SIZE=0000K,

SOURCE,EBCDIC,NOLIST,NODECK,LCAD,MAP,NOEDIT,NOID,XREF

```

      ISN 0002      SUBROUTINE CONDENSEDUM,TSTAR,PSTAR,QALSTR,WDA,TASTAR,PASTAR,
      *              TOUT,POUT,QALOUT,STF1,STF2,STF3,STF4,IUP,ISPILL)
      ISN 0003      COMMON/GEOM/PI,DI,PERIM,CO,          GJ,ZERO,          ENT,AD,GDI
      ISN 0004      COMMON/LIQUID/FMUL,RHOL,CPL,FJH,FHH,FKL
      ISN 0005      COMMON/INSIDE/WG,WL,W,QAL,RLP,RGP,V,U,T,P,WDOT
      ISN 0006      COMMON/VAPOR/RHOGS,FMUG,CPG,R
      ISN 0007      COMMON/FIN/FNK
      ISN 0008      COMMON/SUMS/QSUM
      ISN 0009      COMMON/AIRP/AIRCP,AIRWT,RAIR,PA
      ISN 0010      COMMON/VALUES/DA(999)
      ISN 0011      COMMON/SPIL/SPILL

      C      TUBESV(I,J,K) - I SMALL VERTICLE CUT, J LEVEL, K PROP IDEN
      C      AIRSV(I,J,K) - I INBETWEEN CUTS, J ENTRY POSITION, K PROP IDEN
      ISN 0012      DIMENSION TUBESV(10,4,10),AIRSV(10,10,10)
      ISN 0013      DIMENSION STFRAC(4)
      ISN 0014      DIMENSION SLW(8),SWFA(8),SAM(8),NTB(4)
      C      SLW - 8 SECTION LENGTHS
      C      UNITS-FT
      ISN 0015      DATA SLW/5.1764,6*5.6078,5.1764/
      C      SWFA - WEIGHT FRACTION PER SECTION
      ISN 0016      DATA SWFA/.1033,.1248,.1397,.1322,.1286,.1339,.1354,.1021/
      C      SAM - MIN AREA PER SECTION- USED FOR HEAT TRAN CALC
      C      UNITS-FT2
      ISN 0017      DATA SAM/29.643,6*32.113,29.643/
      C      NTB - NUMBER OF TUBES PER LEVEL
      ISN 0018      DATA NTB/58,57,58,57/
      ISN 0019      WDOT=WDUM
      ISN 0020      SPILL=ISPILL
      ISN 0021      SW=0
      ISN 0022      5000 CONTINUE
      ISN 0023      CALL LIMIA(PSTAR,TSTAR,QALSTR,WDA,WAC,WDOT,TASTAR,POUT,TOUT,
      *              QALOUT,IUP)
      ISN 0024      IF(SW.EQ.1) RETURN
      ISN 0026      WSD=WDOT
      ISN 0027      IF(WSD.LT.1.2E3) RETURN
      ISN 0029      IF(WDA.LT.6.5E4) RETURN
      C      PRINT MATERIAL PROPERTIES
      ISN 0031      IF(SPILL.EQ.1)
      *PRINT 1235
      ISN 0033      1235 FORMAT(96H1  FLUID PROPERTIES  (-) = CONSTANT,      TABLE FORMAT
      V= NO PTS, X1,Y1,--XN,YN, X = TEMP (F) /3X
      V 90HLOC 100 = FLUID VISC, LB/HR-FT , 200 = FLUID K,BTU/HR FT F, 3
      V00 = FLUID DENSITY, LB/CU FT /
      * 60H      400 = AIR VISC, LB/HR-FT,      500 = AIR K, BTU/HR FT F /
      * 60H      600 = STEAM VISC, LB/HR-FT,
      * 60H      700 = STEAM SPECIFIC VOL (FT3/LBM), X =PRESSURE (PSIA) /
      * 60H      800 = LATENT HEAT (BTU/LBM), X =PRESSURE (PSIA) /
      * 60H      900 = STEAM SPECIFIC HEAT (BTU/LBM-F) )
      ISN 0034      K=100
      ISN 0035      DO 1900 KKK=1,9
      ISN 0036      K8=DA(K)
      ISN 0037      K9=K+2*K8
      ISN 0038      IF(SPILL.EQ.1)
      *PRINT 2500,(K1,DA(K1),K1=K,K9)

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ISN 0040 2500 FORMAT(5(I8,1PE10.3))
 ISN 0041 K=K+100
 ISN 0042 1900 CONTINUE
 C INPUT VALUES
 C WDOT - FLOW RATE LB/HR
 C TSTAR - FLUID TEMPERATURE F
 C PSTAR - FLUID PRESSURE PSF
 C QALSTR - WEIGHT FRACTION OF STEAM OR VAPOR UNITLESS
 ISN 0043 IF(SPILL.EQ.1)
 *PRINT 8,WDOT,TSTAR,PSTAR,QALSTR
 ISN 0045 8 FORMAT(' WDOT,TSTAR,PSTAR,QALSTR '/4(3X,1PE10.3))
 C WDA - WDOT OF AIR - TOTAL LBM/HR
 C TASTAR - AIR TEMPERATURE F
 C PASTAR - AIR PRESSURE PSF
 ISN 0046 IF(SPILL.EQ.1)
 *PRINT 7,WDA,TASTAR,PASTAR
 ISN 0048 7 FORMAT(' WDA,TASTAR,PASTAR '/3(3X,1PE10.3))
 C STFRAC(1) = FRACTION OF STEAM ON ITH LEVEL MUST BE INPUT
 ISN 0049 STFRAC(1)=STF1
 ISN 0050 STFRAC(2)=STF2
 ISN 0051 STFRAC(3)=STF3
 ISN 0052 STFRAC(4)=STF4
 C SPILL=1 - PRINT OUT ALL VALUES, SPILL=0 - NO PRINT OUT
 C IUP=0 ON SECOND VERTICAL PASS WORK UP,=1 WORK DOWN
 ISN 0053 IF(SPILL.EQ.1)
 *PRINT 18, STF1,STF2,STF3,STF4,IUP,ISPILL
 ISN 0055 18 FORMAT(' STF1,STF2,STF3,STF4,IUP,ISPILL '/4(2X,1PE10.3),2I10)
 C CONSTANTS
 ISN 0056 PI=355./113.
 ISN 0057 GJ=778.*32.17
 ISN 0058 ZERO=1.E-8
 C TUBE VALUES
 ISN 0059 DO - OUTSIDE DIA OF TUBE FT
 DO=.0833
 C DI - INSIDE DIA OF TUBE FT
 ISN 0060 DI=.0691
 C PERIM - INSIDE TUBE PERIMETER
 ISN 0061 PERIM=PI*DI
 C AD - FLOW AREA IN TUBE - FT2
 ISN 0062 AD=PI*DI**2/4.
 C GDI -
 ISN 0063 GDI=32.17*DI
 C ENT -NUMBER OF TUBES PER LEVEL
 C NS -SECTION OR BAY NUMBER
 C ENT= NTB(NS)
 C GAS (WATER) VALUES
 C CPG - SPECIFIC HEAT OF GAS BTU/LB-F
 C CPG=ENTERP(TSTEAM,DA(900))
 C FMUG - VISCOSITY OF GAS LBM/HR-FT
 C FMUG=ENTERP(TSTEAM,DA(600))
 C RHOGS - DENSITY OF GAS (STEAM) LB/FT3
 C RHOGS=1./ENTERP(PRESSURE IN PSI,DA(700))
 C LIQUID (WATER) VALUES
 C CPL - SPECIFIC HEAT OF LIQUID BTU/LE-F
 ISN 0064 CPL=1.0039
 C RHOL - DENSITY OF LIQUID LB/FT3

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C      RHOL=ENTERP(TWATER,DA(300))
C      FMUL - VISCOSITY OF LIQUID LBM/HR-FT
C      FMUL=ENTERP(TWATER,DA(100))
C      FKL - K OF LIQUID BTU/HR-FT-F
C      FKL=ENTERP(TWATER,DA(200))
C      FHH - LATENT HEAT CF STEAM-WATER BTU/LB
C      FHH=ENTERP(PRESSURE IN PSI,DA(800))
C      FJH - LATENT HEAT FT-LBF/LBM
C      FJH=778.*FHH
C
C      AIR VALUES
C      TAIR - AIR TEMPERATURE -F
C      AIRCP -AIR SPECIFIC HEAT BTU/LBM-F
ISN 0065 AIRCP=.24
C      RAIR=GAS CONSTANT FOR AIR
ISN 0066 RAIR=53.3
C      AIRMU - AIR VISCOSITY LB/HR-F
C      AIRMU=ENTERP(TAIR,DA(400))
C      AIRK - AIR K BTU/HR-FT-F
C      AIRK=ENTERP(TAIR,DA(500))
C      FIN VALUES
C      FNK -THERMAL CONDUCTIVITY OF FIN MATERIAL BTU/HR-FT-F
ISN 0067 FNK=120.
ISN 0068 IF(SPILL.EQ.1)
*PRINT 200,PI,GJ,ZERO,DO,DI,PERIM,AD,GDI
ISN 0070 200 FORMAT(' PI,GJ,ZERO,CO,DI,PERIM,AD,GDI '/8(2X,1PE10.3))
ISN 0071 IF(SPILL.EQ.1)
*PRINT 201,
CPL, AIRCP,RAIR,FNK
ISN 0073 201 FORMAT(' CPL, AIRCP,RAIR,FNK '/ 4(2X,1PE10.3))
ISN 0074 QSUM=0.0
ISN 0075 IMESH=8
C      TOTAL LENGTH OF TUBE - FT
ISN 0076 FMESH5=0.
ISN 0077 DO 9000 I=1,IMESH
ISN 0078 9000 FMESH5=FMESH5+SLW(I)
ISN 0079 TUBESV(1,1,1)=TSTAR
ISN 0080 TUBESV(1,2,1)=TSTAR
ISN 0081 TUBESV(1,3,1)=TSTAR
ISN 0082 TUBESV(1,4,1)=TSTAR
ISN 0083 TUBESV(1,1,2)=PSTAR
ISN 0084 TUBESV(1,2,2)=PSTAR
ISN 0085 TUBESV(1,3,2)=PSTAR
ISN 0086 TUBESV(1,4,2)=PSTAR
ISN 0087 TUBESV(1,1,3)=QALSTR
ISN 0088 TUBESV(1,2,3)=QALSTR
ISN 0089 TUBESV(1,3,3)=QALSTR
ISN 0090 TUBESV(1,4,3)=QALSTR
ISN 0091 AIRSV(1,1,1)=TASTAR
ISN 0092 AIRSV(2,1,1)=TASTAR
ISN 0093 AIRSV(3,1,1)=TASTAR
ISN 0094 AIRSV(4,1,1)=TASTAR
ISN 0095 IF(IUP.EQ.1) GO TO 8004
ISN 0097 AIRSV(5,6,1)=TASTAR
ISN 0098 AIRSV(6,6,1)=TASTAR
ISN 0099 AIRSV(7,6,1)=TASTAR
ISN 0100 AIRSV(8,6,1)=TASTAR
ISN 0101 8004 CONTINUE

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C      BREAK CONDENSER INTO TWO SECTIONS WITH MID-CUT
ISN 0102      DO 8000 NVCUT=1,2
ISN 0103      IF(IUP.EQ.0) GO TO 8005
ISN 0105      IF(NVCUT.EQ.1) GO TO 8005
ISN 0107      TAVE=0.
ISN 0108      FSUM=0.
ISN 0109      DO 8006 IXX=1,4
ISN 0110      FSUM=FSUM+SWFA(IXX)
ISN 0111      8006 TAVE=TAVE+AIRSV(IXX,5,1)*SWFA(IXX)
ISN 0112      TAVE=TAVE/FSUM
ISN 0113      AIRSV(5,10,1)=TAVE
ISN 0114      AIRSV(6,10,1)=TAVE
ISN 0115      AIRSV(7,10,1)=TAVE
ISN 0116      AIRSV(8,10,1)=TAVE
ISN 0117      8005 CONTINUE
C      BREAK CONDENSER INTO 4 HORIZONTAL LEVELS
ISN 0118      DO 8001 NHLEV=1,4
ISN 0119      IF(NVCUT.EQ.1) NHCUT=NHLEV
ISN 0121      IF(NVCUT.EQ.2.AND.IUP.EQ.0) NHCUT=NHLEV
ISN 0123      IF(NVCUT.EQ.2.AND.IUP.EQ.1) NHCUT=5-NHLEV
C      ENT - NUMBER OF TUBES FOR THIS LEVEL
ISN 0125      ENT=NTB(NHCUT)
C      W - FOR ONE TUBE AT THIS LEVEL LBM/SEC
ISN 0126      W= (WDOT*STFRAC(NHCUT))/(ENT*3600.)
ISN 0127      IF(NVCUT.EQ.1) KNS=0
ISN 0129      IF(NVCUT.EQ.2) KNS=4
C      BREAK TYPICAL TUBE UP INTO 4 SEGMENTS
ISN 0131      DO 8002 NDX=1,4
ISN 0132      IF(SPILL.EQ.1)
*PRINT 8765
ISN 0134      8765 FORMAT(1H1)
C      KNS=VERTICLE CUT NUMBER MINUS ONE
C      KNS = INBETWEEN VERTICAL CUT NUMBER
ISN 0135      KNS=KNS+1
C      INPUT PROPERTIES
ISN 0136      T=TUBESV(KNS,NHCUT,1)
ISN 0137      P=TUBESV(KNS,NHCUT,2)
ISN 0138      PSIS=P/144.
ISN 0139      QAL=TUBESV(KNS,NHCUT,3)
ISN 0140      IENTRY=(NHCUT+1)+(NVCUT-1)*5-1
ISN 0141      IF(NHLEV.NE.NHCUT) IENTRY=IENTRY+1
ISN 0143      TA=AIRSV(KNS,IENTRY,1)
ISN 0144      PA=PASTAR
ISN 0145      FMUL=ENTERP(T,DA(100))
ISN 0146      RHOL=ENTERP(T,DA(300))
ISN 0147      FKL=ENTERP(T,DA(200))
ISN 0148      FHH=ENTERP(PSIS,DA(800))
ISN 0149      FJH=778.*FHH
ISN 0150      FMUG=ENTERP(T,DA(600))
ISN 0151      RHOGS=1.7*ENTERP(PSIS,DA(700))
ISN 0152      CPG=ENTERP(T,DA(900))
ISN 0153      FKG=ENTERP(T,DA(700))
ISN 0154      AIRPU=ENTERP(TA,DA(400))
ISN 0155      AIRK=ENTERP(TA,DA(500))
ISN 0156      AIRRHO=PA/((TA +460.)*RAIR)
ISN 0157      IF(SPILL.EQ.1)

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*PRINT 2, NVCUT,NHCUT,KNS,IENTRY
ISN 0159 2 FORMAT(' NVCUT,NHCUT,KNS,IENTRY '/4I10)
ISN 0160 IF(SPILL.EQ.1)
*PRINT 5, T,P,QAL,FMUL,RHOL,FKL
ISN 0162 5 FORMAT(' T,P,QAL,FMUL,RHOL,FKL '/6(2X,1PE10.3))
ISN 0163 IF(SPILL.EQ.1)
*PRINT 4, FMUG,FKG,RHOGS,FHH,CPG
ISN 0165 4 FORMAT(' FMUG,FKG,RHOGS,FHH,CPG '/5(2X,1PE10.3))
ISN 0166 IF(SPILL.EQ.1)
*PRINT 3, TA,PA,AIRMU,AIRK,AIRRHQ
ISN 0168 3 FORMAT(' TA,PA,AIRMU,AIRK,AIRRHQ '/5(2X,1PE10.3))
C SECTION CALCULATIONS
C W,WL,WG UNITS LBM/SEC
C WL- WEIGHT FLOW RATE OF LIQUID FOR 1 TUBE
C WG- WEIGHT FLOW RATE OF GAS FOR 1 TUBE
ISN 0169 502 WL=(1.-QAL)*W
ISN 0170 WG=W-WL
ISN 0171 WG1=WG
ISN 0172 IF(SPILL.EQ.1)
*PRINT 1, W,WL,WG
ISN 0174 1 FORMAT(' W,WL,WG '/3(2X,1PE10.3))
C MIXTURE VEL FT/SEC
ISN 0175 UFS=(WL/RHOL+WG/RHOGS)/AD
ISN 0176 IF(SPILL.EQ.1)
*PRINT 49, UFS
ISN 0178 49 FORMAT (F15.5,5X,'MIXTURE VELOCITY AT TUBE ENTRANCE, FT/SEC'/)
ISN 0179 UFS2=UFS**2
C MOMENTUM PRESSURE LBF/FT2
ISN 0180 PMS=W*UFS/(32.17*AD)
C KINETIC ENERGY BTU/L3F
ISN 0181 EKS=UFS2/(2.*GJ)
ISN 0182 J=KNS
C DX SET VALUE FT
ISN 0183 DXS=SLW(J)
C WDA -W DOT OF AIR -TOTAL WEIGHT FLOW RATE OF AIR (LBSM/HR)
C WFA -WEIGHT FRACTION PER SECTION OR BAY
C GM - AIR MASS FLUX PER SECTION LBM/HR-FT2
ISN 0184 GM= WDA*SWFA(J)/SAM(J)
C AIRWT - AIR FLOW RATE PAST ONE TUBE LBM/SEC
ISN 0185 AIRWT=WDA*SWFA(J)/(ENT*3600.)
ISN 0186 IF(SPILL.EQ.1)
*PRINT 12,GM,AIRWT
ISN 0188 12 FORMAT(' GM,AIRWT '/2(2X,1PE10.3))
ISN 0189 QINCRE=0.
ISN 0190 CALL PDROP(DXS,DX,FMESHS,WG1,J,GM,TA,QINCRE,DXSM,SW)
ISN 0191 IF(SW.EQ.1) GO TO 5000
ISN 0193 IF(WG1.GT.ZERO) GO TO 9006
ISN 0195 IF(DX.GE.DXSM) GO TO 9006
C SECTION WHERE PHASE CHANGE IS COMPLETED -BUT SOME SECTION LENGTH
C IS LEFT UNUSED
ISN 0197 IF(SPILL.EQ.1)
*PRINT 13
ISN 0199 13 FORMAT('/////' PHASE CHANGE COMPLETE - BUT SOME SECTION LENGTH LEFT
* '////')
ISN 0200 DXS=DXS-DX
ISN 0201 CALL PDROP(DXS,DX,FMESHS,WG1,J,GM,TA,QINCRE,DXSM,SW)

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ISN 0202      IF(SW.EQ.1) GO TO 5000
ISN 0204      9006 CONTINUE
ISN 0205      PSIE=P/144.
ISN 0206      RHOGE=1./ENTERP(PSIE,DA(700))
ISN 0207      WLE=WL
ISN 0208      WGE=W-WLE
ISN 0209      UFEND=(WLE/RHOL+WGE/RHOGE)/AD
ISN 0210      UFE2=UFEND**2
ISN 0211      PMEND=W*UFEND/(32.17*AD)
ISN 0212      DPM=PMS-PMEND
ISN 0213      EKEND=UFE2/(2.*GJ)
ISN 0214      IF(SPILL.EQ.1)
               *PRINT 81, PMS, EKS, PMEND, EKEND, DPM
ISN 0216      81 FORMAT (F15.5,5X,'MOMENTUM PRESSURE AT INLET, LBS/SQFT'/
               IF15.5,5X,'KINETIC ENERGY OF FLUID AT INLET, BTU/LB
               2F15.5,5X,'MOMENTUM PRESSURE AT END, LBS/SQFT'/F15.5,5X,'KINETIC EN
               3ERGY OF FLUID AT END, BTU/LB
               4'CHANGE IN MOMENTUM PRESSURE, LBS/SQFT')
ISN 0217      6 CONTINUE
ISN 0218      KNS1=KNS+1
ISN 0219      TUBESV(KNS1,NHCUT,1)=T
ISN 0220      TUBESV(KNS1,NHCUT,2)=P
ISN 0221      TUBESV(KNS1,NHCUT,3)=QAL
ISN 0222      C QINCRE - Q INCREMENT FOR DX FOR ONE TUBE - BTU/SEC
               TAC=(QINCRE/(AIRCP*AIRWT))
ISN 0223      TA=TA+TAC
ISN 0224      IF(SPILL.EQ.1)
               *PRINT 205,TAC,TA
ISN 0226      205 FORMAT(' TAC,TA '/2(2X,1PE10.3))
ISN 0227      IENTRY=(NHCUT+1)+(NVCUT-1)*5
ISN 0228      IF(NHLEV.NE.NHCUT) IENTRY=IENTRY-1
ISN 0230      AIRSV(KNS,IENTRY,1)=TA
ISN 0231      8002 CONTINUE
ISN 0232      8001 CONTINUE
ISN 0233      8000 CONTINUE
ISN 0234      QSUM=QSUM*3600.
ISN 0235      IF(SPILL.EQ.1)
               *PRINT 42, QSUM
ISN 0237      42 FORMAT (//
               1 F15.5,5X,
               2'ACCUMULATED SUM OF HEAT LOST, BTL/HR'//)
ISN 0238      PSUM=0.
ISN 0239      HSUM=0.
ISN 0240      DO 8010 I=1,4
ISN 0241      T=TUBESV(9,I,1)
ISN 0242      P=TUBESV(9,I,2)
ISN 0243      PSUM=PSUM+P*STFRAC(I)
ISN 0244      PSIA=P/144.
ISN 0245      FHH=ENTERP(PSIA,DA(800))
ISN 0246      QAL=TUBESV(9,I,3)
ISN 0247      WLV=(WDOT*STFRAC(I))
ISN 0248      HSUM=HSUM+WLW*(CPL*(T-32.))+QAL*FHH
ISN 0249      IF(SPILL.EQ.1)
               *PRINT 8011,WLV,T,P,QAL,FHH
ISN 0251      8011 FORMAT(' WLV,T,P,QAL,FHH '/5(2X,1PE10.3))
ISN 0252      8010 CONTINUE

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ISN 0253      POUT=PSUM
ISN 0254      PSIA=POUT/144.
ISN 0255      FHH=ENTERP(PSIA,DA(800))
ISN 0256      TDRY=(HSUM/(WDOT*CPL))+32.
ISN 0257      PLN=ALOG(POUT)
ISN 0258      TWET=-((8.404E3/(PLN-20.2524))-460.
ISN 0259      IF(TWET.LT.TDRY) GC TO 8012
ISN 0261      TOUT=TDRY
ISN 0262      QALOUT=0.
ISN 0263      GC TO 8013
ISN 0264      8012 TOUT=TWET
ISN 0265      QALOUT=((HSUM/WDOT)-CPL*(TOUT-32.))/FHH
ISN 0266      8013 CONTINUE
ISN 0267      IF(SPILL.EQ.1)
      *PRINT 8014,FHH,TDRY,TWET
ISN 0269      8014 FORMAT('  FHH,TDRY,TWET',/3(2X,1PE10.3))
      C      OUTPUT STEAM/WATER VALUES
      C      TOUT - FLUID TEMPERATURE  F
      C      POUT - FLUID PRESSURE  PSF
      C      QALOUT - WEIGHT FRACTION OF STEAM  UNITLESS
ISN 0270      IF(SPILL.EQ.1)
      *PRINT 17,TOUT,POUT,QALOUT
ISN 0272      17 FORMAT(' TOUT,POUT,QALOUT  ',/3(2X,1PE10.3))
ISN 0273      10 CONTINUE
ISN 0274      RETURN
ISN 0275      END

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00001990

COMPILER OPTIONS - NAME= MAIN,CPT=00,LINECNT=58,SIZE=0000K,

SOURCE,EBCDIC,NOLIST,NODECK,LOAD,MAP,NOEDIT,NOID,XREF

ISN 0002 SUBROUTINE PDROP(DXS,DX,FMESH,WG1,J,GM,TA,QINCRE,DXSM,SW)
 ISN 0003 COMMON/GEOM/PI,DI,PERIM,DO, GJ,ZERO, ENT,AD,GDI
 ISN 0004 COMMON/LIQUID/FMUL,RHCL,CPL,FJH,FHH,FKL
 ISN 0005 COMMON/INSIDE/WG,WL,W,QAL,RLP,RGP,V,U,T,P,WDO
 ISN 0006 COMMON/VAPOR/RHOGS,FMUG,CPG,R
 ISN 0007 COMMON/SUMS/QSUM
 ISN 0008 COMMON/AIRP/AIRCP,AIRWT,RAIR,PA
 ISN 0009 COMMON/SPIL/SPILL

C DX CONVERGENCE BOUNDS,+ OR - 1 PERCENT

ISN 0010 DXSP=DXS*1.01

ISN 0011 DXSM=DXS*.99

ISN 0012 DELWL=0.

ISN 0013 WL1=W

ISN 0014 DTA=0.

ISN 0015 IF(WG1.LE.ZERO) GO TO 200

ISN 0017 JGUESS=0

ISN 0018 DX=0.

ISN 0019 DXF1=0.

ISN 0020 FMESH1=0.

C LENGTH FRACTION

ISN 0021 FMESHF=DXS/FMESH

ISN 0022 9002 CONTINUE

ISN 0023 JGUESS=JGUESS+1

ISN 0024 IF(JGUESS.GT.50) GO TO 10

ISN 0026 9005 CONTINUE

C WEIGHT FLOW RATE CHANGE FROM STEAM TO LIQUID IN DX LBM/SEC

ISN 0027 DELWL=WG*FMESHF

ISN 0028 IF(SPILL.EQ.1)

*PRINT 9004,JGUESS,DX,DXS,FMESHF,DELWL

ISN 0030 9004 FORMAT(' JGUESS,DX,DXS,FMESHF,DELWL '/15,4(3X,1PE10.3)/)

C LIQUID FLOW RATE AT MID POINT LBM/SEC

ISN 0031 WL1=WL+DELWL/2.

00000620

ISN 0032 WL1T=WL+DELWL

ISN 0033 IF(WL1T.GT.W) FMESHF=(W-WL) /WG

ISN 0035 IF(WL1T.GT.W) GO TO 9005

C GAS FLOW RATE AT MID POINT LBM/SEC

ISN 0037 200 CONTINUE

ISN 0038 WG1=W-WL1

00000630

ISN 0039 IF(WG1.LE.ZERO) WG1=ZERO

ISN 0041 QAL=WG1/W

00000730

C GAS DENSITY LBM/FT3

ISN 0042 RHOGA=RHOGS

C REYNOLDS NUMBER

ISN 0043 REGP=(4.*WG1)/(PI*DI*FMUG)*3600.

ISN 0044 RELP=(4.*WL1)/(PI*DI*FMUL)*3600.

ISN 0045 IF(SPILL.EQ.1)

*PRINT 1,WL1,WG1,QAL,REGP,RELP

ISN 0047 1 FORMAT(' WL1,WG1,QAL,REGP,RELP '/5(2X,1PE10.3))

ISN 0048 IF(REGP-2000.)28,28,29

00000770

ISN 0049 28 IF(RELP-2000.)30,30,31

00000780

ISN 0050 29 IF(RELP-2000.)32,32,33

00000790

ISN 0051 30 CHIC1=(FMUL*RHOGA)/(FMUG*RHOL)

00000800

ISN 0052 CHI=SQRT((WL1*CHIC1)/WG1)

00000810

ISN 0053 DCHI=W*CHI/(2.*WL1*WG1)

00000820

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ISN 0054      F=64./REGP
ISN 0055      GO TO 34
ISN 0056      31 CHIC1=(.046*4.**.8)/(16.*(PI*DI)**.8)*(RHOGA/RHOL)*(FMUL**2/FMUG)00000840
                C UNIT CORRECTION
ISN 0057      CHIC1=CHIC1*699.91
ISN 0058      CHI=SQRT((WL1**1.8/WG1)*CHIC1)00000860
ISN 0059      DCHI=(1.8*WG1*WL1)*CHI/(2.*WG1*WL1)00000870
ISN 0060      F=64./REGP
ISN 0061      GO TO 34
ISN 0062      32 CHIC1=(16.*(PI*DI)**.8)/(.046*4.**.8)*(RHOGA/RHOL)*(FMUL/FMUG**2)00000900
                C UNIT CORRECTION
ISN 0063      CHIC1=CHIC1/699.91
ISN 0064      CHI=SQRT((WL1/WG1**1.8)*CHIC1)00000910
ISN 0065      DCHI=((WG1+1.8*WL1)*CHI)/(2.*WG1*WL1)00000920
ISN 0066      F=.184/REGP**2
ISN 0067      GO TO 34
ISN 0068      33 CHIC1=(RHOGA/RHOL)*(FMUL/FMUG)**2
ISN 0069      CHI=SQRT((WL1/WG1)**1.8*CHIC1)00000950
ISN 0070      DCHI=(.9*W*CHI)/(WG1*WL1)00000960
ISN 0071      F=.184/REGP**2
ISN 0072      34 CALL RLAFEG (CHI,PHI,RLP,DRLDX,REGP,RELP)
ISN 0073      IF(SPILL.EQ.1)
                *PRINT 2, F,CHIC1,CHI,DCHI,PHI,RLP,DRLDX,REGP,RELP
ISN 0075      2 FORMAT(' F,CHIC1,CHI,DCHI,PHI,RLP,DRLDX,REGP,RELP ' /10(2X,1PE10.3
                *))
ISN 0076      RGP=1.-RLP
ISN 0077      C PHASE VELOCITIES FT/SEC
ISN 0078      V=WL1/(RLP*AD*RHOL)00001000
ISN 0079      U=WG1/(RGP*AD*RHOGA)00001010
ISN 0080      V2=V**200001020
ISN 0081      U2=U**200001030
ISN 0082      UP2=(WG1/(AD*RHOGA))**200001040
ISN 0083      U2COEF=1.-((WG1*DCHI*DRLDX)/RGP)00001050
ISN 0084      V2COEF=1.-((WL1*DCHI*DRLDX)/RLP)00001060
ISN 0085      DPXF=-PHI**2*UP2*RHOGA*F/(2.*GDI)00001070
ISN 0086      DPMDW1=DRLDX*DCHI00001090
ISN 0087      DPMDW2=2.-((DPMDW1*WG1)/RGP)00001100
ISN 0088      DPMDW3=2.-((DPMDW1*WL1)/RLP)00001110
ISN 0089      DPMDW4=RHOGA*U2*RGP*DPMDW2/(32.17*WG1)00001120
ISN 0090      DPMDW5=RHOL*V2*RLP*DPMDW3/(32.17*WL1)00001130
ISN 0091      DPMDWX=DPMDW4-DPMDW500001140
ISN 0092      DPC1=(CPL*WL1+CPG*WG1)*T/(FJH*RHOGA)00001150
                C PRESSURE CHANGE FOR LENGTH DX PSF
ISN 0093      DP=DPMDWX*DELWL+DPXF*DXS
ISN 0094      DPP=ABS(DPMDWX*DELWL)+ABS(DPXF*DXS)
                *PRINT 3, V,U,DP,DPMDWX,DPXF,DPP
ISN 0096      3 FORMAT(' V,U,DP,DPMDWX,DPXF,DPP ' /6(2X,1PE10.3))
ISN 0097      DX=DXS
ISN 0098      TT=T
ISN 0099      IPS=0
ISN 0100      300 CONTINUE
ISN 0101      TAIR=TA+DTA/2.
ISN 0102      IPS=IPS+1
ISN 0103      IF(SPILL.EQ.1)
                *PRINT 303,TAIR,TT

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ISN 0105      303 FORMAT(' TAIR,TT          ',2(2X,1PE10.3))
ISN 0106      C   QS2 - HEAT REJECTION PER ONE FOOT LENGTH PER TUBE      BTU/HR- FT
ISN 0107      IFLAG=0
ISN 0109      CALL QS2V(QS2,GM,DPP,DXS,TT,TAIF,IFLAG)
ISN 0110      C   QS2 - HEAT REJECTION PER ONE FOOT LENGTH PER TUBE      BTU/SEC-FT
ISN 0111      QS2=QS2/3600.
ISN 0112      DX1=QS2+DPC1*DPXF
ISN 0112      DX2=FHH-V2*V2COEF/GJ+U2*U2COEF/GJ-DPC1*DPMOWX+(U2-V2)/(2.*GJ)
ISN 0113      C   CALCULATED SECTION LENGTH      FT
ISN 0114      DX=DX2*DELWL/DX1
ISN 0114      IF(SPILL.EQ.1)
ISN 0114      *PRINT 4, DX,DX2,DX1
ISN 0116      4 FORMAT(' DX,DX2,DX1 ',3(2X,1PE10.3))
ISN 0117      IF(DX)35,35,36
ISN 0118      35 CONTINUE
ISN 0119      IF(DELWL.GT.0.0) GO TO 10
ISN 0121      DX=DXS
ISN 0122      DP=DPXF*DX
ISN 0123      DELT=-(QS2*DX)/(WL1*CPL)
ISN 0124      TT=T+DELT/2.
ISN 0125      DTA=QS2*DXS/(AIRCP*AIRWT)
ISN 0126      TAIRC=TA+DTA/2.
ISN 0127      IF(T.GT.TA.AND.TT.LT.TAIRC) GO TO 10
ISN 0129      IF(IPS.EQ.2) GO TO 301
ISN 0131      GO TO 300
ISN 0132      301 CONTINUE
ISN 0133      U=0.
ISN 0134      GO TO 201
ISN 0135      36 CONTINUE
ISN 0136      DP=DPMOWX*DELWL+DPXF*DX
ISN 0137      C   TEMP CHANGE
ISN 0138      DELT=(T+460.)*DP/(FJH*RHOGA)
ISN 0139      TT=T+DELT/2.
ISN 0140      DTA=QS2*DXS/(AIRCP*AIRWT)
ISN 0141      TAIRC=TA+DTA/2.
ISN 0141      IF(T.GT.TA.AND.TT.LT.TAIRC) GO TO 10
ISN 0143      IF(IPS.EQ.2) GO TO 302
ISN 0145      GO TO 300
ISN 0146      302 CONTINUE
ISN 0147      201 CONTINUE
ISN 0148      IF(SPILL.EQ.1)
ISN 0148      *PRINT 44, J
ISN 0150      44 FORMAT ('0',5X,'SECTION',110)
ISN 0151      IF(SPILL.EQ.1)
ISN 0151      *PRINT 110, QAL
ISN 0153      110 FORMAT (F15.5,5X,'QUALITY AT MIDDLE OF SECTION')
ISN 0154      IF(SPILL.EQ.1)
ISN 0154      *PRINT 111, V
ISN 0156      111 FORMAT(F15.5,5X,'LIQUID VEL AT MID SECTION (FT/SEC)')
ISN 0157      IF(SPILL.EQ.1)
ISN 0157      *PRINT 41, U, QS2, DX, DELT, DP
ISN 0159      41 FORMAT(F15.5,5X,'VAPOR VEL AT MID SECTION (FT/SEC)'/F15.5,5X,
ISN 0159      1'QUANTITIES OF HEAT REJECTED PER FOOT OF TUBE LENGTH,(BTU/SEC-FT)'/00001380
ISN 0159      2F15.5,5X,'DIFFERENTIAL LENGTH OF TUBE, (FT.)'/F15.5,5X,
ISN 0159      3'CHANGE IN TEMPERATURE PER DIFFERENTIAL LENGTH, (DEGREES F)'/

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00001300

00001320

00001340

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00001380

4F15.5,5X,'CHANGE IN PRESSURE PER DIFFERENTIAL LENGTH, (PSF)')

ISN 0160 IF(WG1.LE.ZERO) GO TO 9001
 ISN 0162 IF(FMESHF.EQ.1.0) GO TO 9001
 ISN 0164 DXF2=DXF1
 ISN 0165 DXF1=DX
 ISN 0166 FMESH2=FMESH1
 ISN 0167 FMESH1=FMESHF
 ISN 0168 IF(WG1.LE.ZERO) GO TO 9001
 ISN 0170 IF(DX.LE.DXSP.AND.DX.GE.DXSM) GO TO 9001
 ISN 0172 IF(JGUESS.GT.1) GO TO 9003
 ISN 0174 IF(DX.LT.DXS) FMESHF=FMESHF*(DXS-DX)/DXS
 ISN 0176 IF(DX.GT.DXS) FMESHF=FMESHF*(DX-DXS)/DX
 ISN 0178 IF(FMESHF.GT.1.) FMESHF=1.
 ISN 0180 GO TO 9002
 ISN 0181 9003 CONTINUE
 ISN 0182 DXX12=DXF1-DXF2
 ISN 0183 F1F=(DXS-DXF2)/DXX12
 ISN 0184 F2F=(DXF1-DXS)/DXX12
 ISN 0185 FMESHF=F1F*FMESH1+F2F*FMESH2
 ISN 0186 GO TO 9002
 ISN 0187 9001 CONTINUE
 ISN 0188 PF=P+DP
 ISN 0189 IF(PF.LE.0.0) GO TO 10
 ISN 0191 P=PF
 ISN 0192 T=T+DELT
 ISN 0193 WL1=WL +DELWL
 ISN 0194 WG1=W-WL1
 ISN 0195 QAL=WG1/W
 ISN 0196 IF(WG1.LE.ZERO) WG1=ZERO
 ISN 0198 QSUM=QSUM+QS2*DX*ENT
 ISN 0199 C HEAT RATE FOR TUBE FOR LENGTH DX BTU/SEC
 QINCRE=QINCRE+QS2*DX
 ISN 0200 WL=WL1
 ISN 0201 IF(SPILL.EQ.1)
 *PRINT 5, T,WG1,WL1,QAL,P,WL
 ISN 0203 5 FORMAT(' T,WG1,WL1,QAL,P,WL '/6(2X,1PE10.3))
 ISN 0204 RETURN
 ISN 0205 10 CONTINUE
 ISN 0206 SW=1
 ISN 0207 RETURN
 ISN 0208 END

00001420

00001450

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4R15-28

COMPILER OPTIONS - NAME= MAIN,CPT=00,LINECNT=58,SIZE=0000K,

SOURCE,EBCDIC,NOLIST,NODECK,LOAD,MAP,NOEDIT,NOID,XREF

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ISN 0002      SUBROUTINE LIMIA(PSTAR,TSTAR,QALSTR,WDA,WAD,WDOT,TASTAR,POUT,  
              *      TCUT,QALOUT,IUP)  
ISN 0003      COMMON/VALUES/DA(999)  
ISN 0004      CPL=1.0039  
ISN 0005      AIRCP=.24  
ISN 0006      WAD=WDA/FLOAT(IUP+1)  
ISN 0007      WSD=WDOT  
ISN 0008      PCUT=PSTAR  
ISN 0009      TCUT=TSTAR  
ISN 0010      QALOUT=QALSTR  
ISN 0011      IF(WDA.LE.0.0) RETURN  
ISN 0013      TCUT=TASTAR  
ISN 0014      QALOUT=0.  
ISN 0015      IF(WDOT.LE.0.0) RETURN  
ISN 0017      PSIA=PSTAR/144.  
ISN 0018      FHH=ENTERP(PSIA,DA(800))  
ISN 0019      FHH=FHH*QALSTR  
ISN 0020      IF(FHH.LE.0.0) GO TO 1  
ISN 0022      WCTH=WAD*AIRCP*(TSTAR-TASTAR)/FHH  
ISN 0023      IF(WSD.LE.WCTH) GO TO 1  
ISN 0025      QALOUT=1.-WAD*AIRCP*(TSTAR-TASTAR)/(WSD*FHH)  
ISN 0026      QALCUT=QALOUT*QALSTR  
ISN 0027      TCUT=TSTAR  
ISN 0028      RETURN  
ISN 0029      1 CONTINUE  
ISN 0030      *  
ISN 0031      TCUT=(WSD*(FHH+CPL*TSTAR)+WAD*AIRCP*TASTAR)/  
ISN 0032      (WSD*CPL+WAD*AIRCP)  
ISN 0033      QALOUT=0.  
ISN 0033      RETURN  
ISN 0033      END
```

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LRI15 28

COMPILER OPTIONS - NAME= MAIN,OPT=00,LINECNT=58,SIZE=0000K,

SOURCE,EBCCIC,NOLIST,NODECK,LOAD,MAP,NCEDIT,NOID,XREF

ISN 0002	SUBROUTINE RLAFEG (CHI,PHI,RLP,DRLDX,REGP,RELX)	00002000
ISN 0003	DIMENSION A(5),B(5),C(5),AA(5),BB(5),CC(5),AAA(5),BBB(5),CCC(5),	00002070
	VD(5),E(5),G(5)	
ISN 0004	DATA A / .961729, .052676, .17996, .108387, .022224/	000
ISN 0005	DATA B / 4.28577, .222, .509048, .653052, .81402/	
ISN 0006	DATA C / 4.74133, .250008, .409772, .409772, .334969/	
ISN 0007	DATA AA / .957448, .062721, .201257, .138803, .050525/	
ISN 0008	DATA BB / 4.29955, .292137, .584971, .530757, .691175/	
ISN 0009	DATA CC / 4.82121, .385293, .539591, .539591, .46745/	
ISN 0010	DATA AAA / .0344006, .0728001, .1368, .13, .079999/	
ISN 0011	DATA BBB / .239203, .3784, .4928, .481, .562003/	
ISN 0012	DATA CCC / .448004, .572802, .6232, .631, .600998/	
ISN 0013	DATA D / -.29093, -.28915, -.20092, -.092062, -.075481/	
ISN 0014	DATA E / -.3407, -.060579, .45461, .461834, .456419/	
ISN 0015	DATA G / -1.6256, -1.0725, -.63827, -.63827, -.65665/	
	C	00002220
ISN 0015	IF(CHI-1.E+2)1,1,2	00002230
ISN 0017	1 ELX=ALOG10(CHI)	00002240
ISN 0018	IF(.001-CHI)3,3,5	00002250
ISN 0019	5 NA=0.0	00002260
ISN 0020	GO TO 6	00002270
ISN 0021	3 NA=4.+ELX	00002280
ISN 0022	GO TO 6	00002290
ISN 0023	2 CHI=99.99	00002300
ISN 0024	GO TO 1	00002310
ISN 0025	6 IF(NA)7,7,8	00002320
ISN 0026	7 PHI=1.	00002330
ISN 0027	GO TO 11	00002340
ISN 0028	8 IF(REGP-2000.)15,15,16	00002350
ISN 0029	15 IF(RELP-2000.)17,17,18	00002360
ISN 0030	16 IF(RELP-2000.)18,18,19	00002370
ISN 0031	17 X=ELX*(ELX*A(NA)+B(NA))+C(NA)	00002380
ISN 0032	PHI=10.**X	00002390
ISN 0033	GO TO 11	00002400
ISN 0034	18 X=ELX*(ELX*AA(NA)+BB(NA))+CC(NA)	00002410
ISN 0035	PHI=10.**X	00002420
ISN 0036	GO TO 11	00002430
ISN 0037	19 X=ELX*(ELX*AAA(NA)+BBB(NA))+CCC(NA)	00002440
ISN 0038	PHI=10.**X	00002450
ISN 0039	11 IF(NA)12,12,13	00002460
ISN 0040	12 RLP=10.**ELX	00002470
ISN 0041	DRLDX=10.**ELX/CHI	00002480
ISN 0042	GO TO 14	00002490
ISN 0043	13 RLP=ELX*(ELX*D(NA)+E(NA))+G(NA)	00002500
ISN 0044	RLP=10.**RLP	00002510
ISN 0045	DRLDX=RLP*(2.*ELX*D(NA)+E(NA))/CHI	00002520
ISN 0046	14 RETURN	00002530
ISN 0047	END	00002540

COMPILER OPTIONS - NAME= MAIN,OPT=00,LINECNT=58,SIZE=0000K,
SOURCE,EBCCIC,NOLIST,NODECK,LOAD,MAP,NOEDIT,NOID,XREF

ISN 0002 SUBROUTINE RESFLW(RF)
ISN 0003 COMMON/GEOM/PI,DI,PERIM,DO, GJ,ZERO, ENT,AD,GDI
ISN 0004 COMMON/LIQUID/FMUL,RHOL,CPL,FJH,FHH,FKL
ISN 0005 COMMON/INSIDE/WG,WL,W,CAL,RLP,RGP,V,U,T,P,WDOT
ISN 0006 COMMON/SPIL/SPILL
ISN 0007 WDOTD=WL
ISN 0008 RHO=RHOL
ISN 0009 VISC=FMUL
ISN 0010 FLK=FKL
ISN 0011 REN=WDOTD*DI*3600./AD
ISN 0012 RE=REN/VISC
ISN 0013 PR=CPL*FMUL/FKL
ISN 0014 IF (RE-2000.) 410,410,500
ISN 0015 410 CONTINUE
ISN 0016 CKH=4.364
ISN 0017 ACH=CKH*FLK/DI
ISN 0018 GO TO 600
ISN 0019 500 CONTINUE
ISN 0020 ACH=.023*(RE**.8)*(PR**.4)*FKL/DI
ISN 0021 600 CONTINUE
C FILM RESISTANCE PER FOOT HR-FT-F/BTU
ISN 0022 RF=1./((ACH*PI*DI)
ISN 0023 IF(SPILL.EQ.1)
*PRINT 1, PR,REN,RE,ACH,RF
ISN 0025 1 FORMAT(' PR,REN,RE,ACH,RF ',/5(2X,1PE10.3))
ISN 0026 RETURN
ISN 0027 END

COMPILER OPTIONS - NAME= MAIN,CPT=00,LINECNT=58,SIZE=0000K,

SOURCE,EBCDIC,NOLIST,NODECK,LOAD,MAP,NOEDIT,NOID,XREF

```
ISN 0002      SUBROUTINE RESFLM(RF,DP,DX)
ISN 0003      COMMON/LIQUID/FMUL,RHCL,CPL,FJH,FHH,FKL
ISN 0004      COMMON/SPIL/SPILL
ISN 0005      F=(7.2019E+6)*DP/DX
ISN 0006      F=ABS(F)
ISN 0007      PR=CPL*FMUL/FKL
ISN 0008      FKMU=FKL/FMUL
ISN 0009      FR=F*RHCL
ISN 0010      HFLM=.045*PR**.5*FKMU*FR**.5
ISN 0011      RF=HFLM*.217
ISN 0012      RF=1./RF
ISN 0013      IF(SPILL.EQ.1)
ISN 0013      *PRINT 1, RF,DP,DX,F,PR,CPL,FMUL,FKL,FR,HFLM
ISN 0015      1 FORMAT(' RF,DP,DX,F,PR,CPL,FMUL,FKL,FR,HFLM '/10(2X,1PE10.3))
ISN 0016      RETURN
ISN 0017      END
```


COMPILER OPTIONS - NAME= MAIN,CPT=00,LINECNT=58,SIZE=0000K,
SOURCE,EBCDIC,NOLIST,NODECK,LOAD,MAP,NOEDIT,NOID,XREF

```

ISN 0002      SUBROUTINE RESFA(RFA,GM,TAIR)
ISN 0003      COMMON/AIRP/AIRCP,AIRWT,RAIR,PA
ISN 0004      COMMON/VALUES/DA(999)
ISN 0005      COMMON/FIN/FNK
ISN 0006      COMMON/SPIL/SPILL
              C   RFA-RESISTANCE PER FCCT OF COMBINED FIN AND AIR   HR-FT-F/BTU
              C   GM -MASS FLUX   -   PER SECTION BASED ON MIN AREA PER SECTION
              C   UNIT = LBSM/(HR-FT2)
              C   DE - EQUIVALENT DIAMETER FOR CONFIGURATION -FT
ISN 0007      DE=.1323
ISN 0008      AIRMU=ENTERP(TAIR,DA(400))
ISN 0009      AIRK=ENTERP(TAIR,DA(500))
ISN 0010      AIRRHO=PA/((TAIR+460.)*RAIR)
              C   AIRMU - AIR VISCOSITY   LBSM/(HR-FT)
              C   REN - REYNOLDS NUMBER
ISN 0011      REN=DE*GM/AIRMU
ISN 0012      IF(REN.LT.50.) REN=50.
ISN 0014      XJLN=.731*ALOG(REN)-2.4515
ISN 0015      XJ=EXP(XJLN)
              C   AIRH - COEFFICIENT - BTU/(HR-FT2-F)
              C   AIRK - AIR CONDUCTIVITY   BTU/(HR-FT-F)
              C   AIRCP -AIR SPECIFIC HEAT   BTU/LBM-F
ISN 0016      AIRH=(XJ*AIRK/DE)*(AIRCP*AIRMU/AIRK)**.33
ISN 0017      FH=2.193*AIRH/FNK
              C   EFF - FIN EFFICIENTLY
ISN 0018      EFF=0.536*FH*FH-0.865*FH+0.996
ISN 0019      RFA=AIRH*(5.319*EFF+.2094)
              C   FILM RESISTANCE PER FOOT   HR-FT-F/3TU
ISN 0020      RFA=1./RFA
ISN 0021      IF(SPILL.EQ.1)
ISN 0023      *PRINT 1, RFA,GM,REN,XJ,AIRH,AIRMU,AIRK,AIRCP,FH,EFF
              1 FORMAT(' RFA,GM,REN,XJ,AIRH,AIRMU,AIRK,AIRCP,FH,EFF '/10(2X,1PE10.
              *3))
ISN 0024      RETURN
ISN 0025      END

```


COMPILER OPTIONS - NAME= MAIN,OPT=00,LINECNT=58,SIZE=0000K,
SOURCE,EBCCIC,NOLIST,NODECK,LOAD,MAP,NOEDIT,NOIC,XREF

```
ISN 0002      SUBROUTINE QS2V(QS2,GM,DP,DX,TS,TAIR,IFLAG)
ISN 0003      COMMON/SPIL/SPILL
ISN 0004      C      WALL RESISTANCE PER FOOT              HR-FT-F/BTU
ISN 0004      RW=1.062E-3
ISN 0004      C      COMBINED AIR-FIN RESISTANCE PER FOOT  HR-FT-F/BTU
ISN 0005      CALL RESFA(RFA,GM,TAIR)
ISN 0005      C      INSIDE FILM RESISTANCE PER FOOT        HR-FT-F/BTU
ISN 0006      IF(IFLAG.EQ.1) GO TO 10
ISN 0008      CALL RESFLM(RF,DP,CX)
ISN 0009      GO TO 11
ISN 0010      10 CONTINUE
ISN 0011      CALL RESFLW(RF)
ISN 0012      11 CONTINUE
ISN 0012      C      TOTAL RESISTANCE PER FOOT              HR-FT-F/BTU
ISN 0013      SUMR=RW+RFA+RF
ISN 0013      C      QS2-HEAT TRANSFER FOR SECTION LENGTH DX  BTU/HR
ISN 0014      QS2=(TS-TAIR) /SUMR
ISN 0015      IF(SPILL.EQ.1)
ISN 0015      *PRINT 1, QS2,GM,DP,DX,TS,TAIR,RW,RFA,RF,SUMR
ISN 0017      1 FORMAT(' QS2,GM,DP,DX,TS,TAIR,RW,RFA,RF,SUMR '/10(2X,1PE10.3))
ISN 0018      RETURN
ISN 0019      END
```


COMPILER OPTIONS - NAME= MAIN,OPT=00,LINECNT=58,SIZE=0000K,
SOURCE,EBCCIC,NOLIST,NODECK,LOAD,MAP,NOEDIT,NOID,XREF

ISN 0002	SUBROUTINE DECRD			
ISN 0003	COMMON/VALUES/DB(999)			
ISN 0004	DIMENSION DA(999)			
	C	FILL DA VIA DATA STATEMENTS		
ISN 0005		DATA DA(100)/18.	/,DA(101)/32.	/,DA(102)/ 1.20E-3/
ISN 0006		DATA DA(103)/40.	/,DA(104)/	1.04E-3/,DA(105)/ 50./
ISN 0007		DATA DA(106)/ 0.88E-3/	,DA(107)/ 60./	,DA(108)/ 0.76E-3/
ISN 0008		DATA DA(109)/ 70./	,DA(110)/ 0.658E-3/	,DA(111)/ 80./
ISN 0009		DATA DA(112)/ 0.578E-3/	,DA(113)/ 90./	,DA(114)/ 0.514E-3/
ISN 0010		DATA DA(115)/ 100./	,DA(116)/ 0.458E-3/	,DA(117)/ 150./
ISN 0011		DATA DA(118)/ 0.292E-3/	,DA(119)/ 200./	,DA(120)/ 0.205E-3/
ISN 0012		DATA DA(121)/ 250./	,DA(122)/ 0.158E-3/	,DA(123)/ 300./
ISN 0013		DATA DA(124)/ 0.126E-3/	,DA(125)/ 350./	,DA(126)/ 0.105E-3/
ISN 0014		DATA DA(127)/ 400./	,DA(128)/ 0.091E-3/	,DA(129)/ 450./
ISN 0015		DATA DA(130)/ 0.080E-3/	,DA(131)/ 500./	,DA(132)/ 0.071E-3/
ISN 0016		DATA DA(133)/ 550./	,DA(134)/ 0.064E-3/	,DA(135)/ 600./
ISN 0017		DATA DA(136)/ 0.058E-3/	,DA(200)/ 18./	,DA(201)/ 32./
ISN 0018		DATA DA(202)/ 0.319/	,DA(203)/ 40./	,DA(204)/ 0.325/
ISN 0019		DATA DA(205)/ 50./	,DA(206)/ 0.3320/	,DA(207)/ 60./
ISN 0020		DATA DA(208)/ 0.340/	,DA(209)/ 70./	,DA(210)/ 0.347/
ISN 0021		DATA DA(211)/ 80./	,DA(212)/ 0.3530/	,DA(213)/ 90./
ISN 0022		DATA DA(214)/ 0.359/	,DA(215)/ 100./	,DA(216)/ 0.364/
ISN 0023		DATA DA(217)/ 150./	,DA(218)/ 0.384/	,DA(219)/ 200./
ISN 0024		DATA DA(220)/ 0.394/	,DA(221)/ 250./	,DA(222)/ 0.396/
ISN 0025		DATA DA(223)/ 300./	,DA(224)/ 0.395/	,DA(225)/ 350./
ISN 0026		DATA DA(226)/ 0.391/	,DA(227)/ 400./	,DA(228)/ 0.381/
ISN 0027		DATA DA(229)/ 450./	,DA(230)/ 0.367/	,DA(231)/ 500./
ISN 0028		DATA DA(232)/ 0.349/	,DA(233)/ 550./	,DA(234)/ 0.325/
ISN 0029		DATA DA(235)/ 600./	,DA(236)/ 0.292/	,DA(300)/ 18./
ISN 0030		DATA DA(301)/ 32./	,DA(302)/ 62.4/	,DA(303)/ 40./
ISN 0031		DATA DA(304)/ 62.4/	,DA(305)/ 50./	,DA(306)/ 62.4/
ISN 0032		DATA DA(307)/ 60./	,DA(308)/ 62.3/	,DA(309)/ 70./
ISN 0033		DATA DA(310)/ 62.3/	,DA(311)/ 80./	,DA(312)/ 62.2/
ISN 0034		DATA DA(313)/ 90./	,DA(314)/ 62.1/	,DA(315)/ 100./
ISN 0035		DATA DA(316)/ 62.0/	,DA(317)/ 150./	,DA(318)/ 61.2/
ISN 0036		DATA DA(319)/ 200./	,DA(320)/ 60.1/	,DA(321)/ 250./
ISN 0037		DATA DA(322)/ 58.8/	,DA(323)/ 300./	,DA(324)/ 57.3/
ISN 0038		DATA DA(325)/ 350./	,DA(326)/ 55.6/	,DA(327)/ 400./
ISN 0039		DATA DA(328)/ 53.6/	,DA(329)/ 450./	,DA(330)/ 51.6/
ISN 0040		DATA DA(331)/ 500./	,DA(332)/ 49.0/	,DA(333)/ 550./
ISN 0041		DATA DA(334)/ 45.9/	,DA(335)/ 600./	,DA(336)/ 42.4/
ISN 0042		DATA DA(400)/ 7./	,DA(401)/ 0.0/	,DA(402)/ 1.110E-5/
ISN 0043		DATA DA(403)/ 32./	,DA(404)/ 1.165E-5/	,DA(405)/ 100./
ISN 0044		DATA DA(406)/ 1.285E-5/	,DA(407)/ 200./	,DA(408)/ 1.440E-5/
ISN 0045		DATA DA(409)/ 300./	,DA(410)/ 1.610E-5/	,DA(411)/ 400./
ISN 0046		DATA DA(412)/ 1.750E-5/	,DA(413)/ 500./	,DA(414)/ 1.890E-5/
ISN 0047		DATA DA(500)/ 7./	,DA(501)/ 0.0/	,DA(502)/ 0.0133/
ISN 0048		DATA DA(503)/ 32./	,DA(504)/ 0.0140/	,DA(505)/ 100./
ISN 0049		DATA DA(506)/ 0.0154/	,DA(507)/ 200./	,DA(508)/ 0.0174/
ISN 0050		DATA DA(509)/ 300./	,DA(510)/ 0.0193/	,DA(511)/ 400./
ISN 0051		DATA DA(512)/ 0.0212/	,DA(513)/ 500./	,DA(514)/ 0.0231/
ISN 0052		DATA DA(600)/ 4./	,DA(601)/ 0.0/	,DA(602)/ 0.02154/
ISN 0053		DATA DA(603)/ 200./	,DA(604)/ 0.03100/	,DA(605)/ 400./
ISN 0054		DATA DA(606)/ .04222/	,DA(607)/ 600./	,DA(608)/ 0.05846/

ISN 0055	DATA DA(700)/	19./,DA(701)/	50./,DA(702)/	8.515/
ISN 0056	DATA DA(703)/	75./,DA(704)/	5.816/,DA(705)/	100./
ISN 0057	DATA DA(706)/	4.432/,DA(707)/	125./,DA(708)/	3.587/
ISN 0058	DATA DA(709)/	150./,DA(710)/	3.015/,DA(711)/	176./
ISN 0059	DATA DA(712)/	2.587/,DA(713)/	200./,DA(714)/	2.288/
ISN 0060	DATA DA(715)/	226./,DA(716)/	2.0422/,DA(717)/	250./
ISN 0061	DATA DA(718)/	1.8438/,DA(719)/	275./,DA(720)/	1.6804/
ISN 0062	DATA DA(721)/	300./,DA(722)/	1.5433/,DA(723)/	320./
ISN 0063	DATA DA(724)/	1.4485/,DA(725)/	350./,DA(726)/	1.3260/
ISN 0064	DATA DA(727)/	370./,DA(728)/	1.2550/,DA(729)/	400./
ISN 0065	DATA DA(730)/	1.1613/,DA(731)/	420./,DA(732)/	1.1061/
ISN 0066	DATA DA(733)/	450./,DA(734)/	1.0320/,DA(735)/	470./
ISN 0067	DATA DA(736)/	0.9878/,DA(737)/	500./,DA(738)/	0.9278/
ISN 0068	DATA DA(800)/	10./,DA(801)/	50./,DA(802)/	924.0/
ISN 0069	DATA DA(803)/	100./,DA(804)/	888.8/,DA(805)/	150./
ISN 0070	DATA DA(806)/	863.6/,DA(807)/	200./,DA(808)/	843.0/
ISN 0071	DATA DA(809)/	250./,DA(810)/	825.1/,DA(811)/	300./
ISN 0072	DATA DA(812)/	809.0/,DA(813)/	350./,DA(814)/	794.2/
ISN 0073	DATA DA(815)/	400./,DA(816)/	780.5/,DA(817)/	450./
ISN 0074	DATA DA(818)/	767.4/,DA(819)/	500./,DA(820)/	755./
ISN 0075	DATA DA(900)/	7./,DA(901)/	200./,DA(902)/	.487/
ISN 0076	DATA DA(903)/	250./,DA(904)/	0.527/,DA(905)/	300./
ISN 0077	DATA DA(906)/	0.575/,DA(907)/	350./,DA(908)/	0.629/
ISN 0078	DATA DA(909)/	400./,DA(910)/	0.708/,DA(911)/	450./
ISN 0079	DATA DA(912)/	0.825/,DA(913)/	500./,DA(914)/	1.0/

C CORRECT INPUT VISCOSITY UNITS

ISN 0080 DO 8998 I=1,49

ISN 0081 J=101+2*I-1

ISN 0082 JJ=401+2*I-1

ISN 0083 DA(J)=DA(J)*3600.

ISN 0084 DA(JJ)=DA(JJ)*3600.

ISN 0085 8998 CONTINUE

ISN 0086 DO 8999 I=1,999

ISN 0087 8999 DB(I)=DA(I)

ISN 0088 RETURN

ISN 0089 END

00003130

COMPILER OPTIONS - NAME= MAIN,OPT=00,LINECNT=58,SIZE=C000K,
SCURCE,EBCCIC,MOLIST,NODECK,LCAD,MAP,NOEDIT,NOID,XREF

ISN 0002 FUNCTION ENTERP(X,TAB)
ISN 0003 COMMON/SPIL/SPILL
ISN 0004 DIMENSION TAB(101)
ISN 0005 IF(TAB(1))9,9,8
ISN 0006 9 ENTERP=-TAB(1)
ISN 0007 RETURN
ISN 0008 8 N=TAB(1)
ISN 0009 DO 5 I=1,N
ISN 0010 1 IF(TAB(2*I)-X)5,4,3
ISN 0011 3 IF(I-1)6,6,7
ISN 0012 7 ENTERP=TAB(2*I-1)+(X-TAB(2*I-2))*(TAB(2*I+1)-TAB(2*I-1))/
V(TAB(2*I)-TAB(2*I-2))
ISN 0013 RETURN
ISN 0014 4 ENTERP=TAB(2*I+1)
ISN 0015 RETURN
ISN 0016 5 CONTINUE
ISN 0017 M=2*N+1
ISN 0018 K=M
ISN 0019 IF(SPILL.EQ.1)
*PRINT 10,X,TAB(K),(TAB(J),J=1,M)
ISN 0021 105 CONTINUE
ISN 0022 10 FORMAT(///39H LIMITS OF TABLE EXCEEDED BY ARGUMENT = F12.4/
VF12.4,24H = VALUE USED FROM TABLE/(5F12.4))
ISN 0023 ENTERP=TAB(K)
ISN 0024 RETURN
ISN 0025 6 M=2*N+1
ISN 0026 K=3
ISN 0027 GO TO 105
ISN 0028 END

D-22

APPENDIX E

FIN EFFECTIVENESS PROGRAM LISTING

This appendix contains Input Data for the Program, Compiled Listing of the Program, Subroutines, ECHO of input data, and output from an Illustrative Problem.

INPUT DATA FOR PROGRAM

Data
Number

1. Code for type of data input
 1. Input of parameters ϵ_e , C_3 , F_h , and F_{ah}
 0. Program calculates parameters from other input data
 - 1. Radiation parameters C_1 and C_2 are entered as input data.
2. Code for print out of temperature profile
 1. Print profile
 0. No print
3. Iteration limit for loop counter
4. Fin thickness ratio, δ_c/δ_h
5. Fin root radius, inches
6. Root temperature, °F
7. Radiation parameter, C_1 (optional input), Btu/hr, sq ft °F⁴
8. Radiation parameter, C_2 (optional input), Btu/hr sq ft
9. Fin thermal conductivity, Btu/hr ft °R
10. Radiation view factor for side "a" to surface "m"
11. Absorptivity of side "a" for solar radiation
12. Emissivity of surface "a"
13. Radiation view factor for side "a" to surface "x"
14. Radiation view factor for side "b" to surface "m"
15. Absorptivity of side "b" to radiation
16. Emissivity of side "b"
17. Radiation view factor for side "b" to surface x
18. Temperature of surface "m" °R
19. Sun angle to normal from surface "m", degrees
20. Reflectivity of surface "m" to solar radiation

21. Temperature of surface "x", °R
22. Sun angle to normal from surface "x", degrees
23. Reflectivity of surface "x" to solar radiation
24. Sun angle to normal from surface "a" degrees
25. Emissivity of surface "x"
26. Radiative profile number, τ_e (optional input)
27. Radiation Constant C_3 (optional input)
28. $(dZ/d\phi)$, (optional input)
29. Printout option if integration fails
 1. Diagnostic data requested
 0. No Printout
30. Number of integration steps to be taken by program (if zero the program will take 25)
31. Convective heat transfer coefficient on side "a", Btu/hr sq ft °R
32. Convective heat transfer coefficient on side "b", Btu/hr sq ft °R
33. Ambient temperature on side "a" for convective heat transfer, °R
34. Ambient temperature on side "b" for convective heat transfer, °R
35. Convective parameter, F_h (optional input)
36. Convective parameter, F_{ah} (optional input)
37. Fin root thickness, inches
38. Fin radius ratio, r_c/r_h

C
C
C
CANALYSIS OF HEAT TRANSFER BY RADIATION AND CONVECTION
FOR SINGLE SECTION CIRCULAR SHAPED EXTENDED SURFACES

```

DIMENSION A(3),B(3),C(3),CM(5),FC(5)
DIMENSION DA(100),T(100),PHI (150),Z(150),ELH(150),TF(150)
DIMENSION F1( 72), F2( 36), F3( 18), F4( 18), F5( 36),
*      F6( 18), F7( 36), F8( 72), F9( 18),F10( 36),
*      F11(126),F12( 36),F13( 18),F14( 36),F15( 54),
*      F16( 54),F17( 18),F18( 18),F19( 18),F20( 18),
*      F21( 18),F22( 18),F23( 18),F24( 36),F25( 18)
EQUIVALENCE (DA(4),THRAT), (DA(5),RH), (DA(6),TH),
V      (DA(9),FNK), (DA(10),FA), (DA(11),ALPHA A),
V      (CA(12),EPSA), (CA(13),FAX), (DA(14),FB),
V      (DA(15),ALPHA B), (CA(16),EPSB), (DA(17),FBX),
V      (DA(18),TM), (DA(19),THETAM), (DA(20),RHOM),
V      (DA(21),TX), (DA(22),THETAX), (DA(23),RHOX),
V      (DA(24),THETAP), (CA(25),EPSX), (DA(31),HA),
V      (DA(32),HB), (DA(33),TAA), (DA(34),TAB),
V      (DA(37),FINTH), (DA(38),PHIR)
ABSF(X)=ABS(X)
CCSCF(X)=COS(X*.01745329)
D2Z(T2,T4,T5)=-(((PHIR-THRAT)/T2+2.*(THRAT-1.))*T5-(PHIR-1.)*
V(ZETA E*(T4**4-C3)+FH*T4-FAH))/ (PHIR-THRAT+T2*(THRAT-1.))
DC 200 I=1,100
200 CA(I)=0.
CALL ECHC
C**** READ PCLLERITH DATA (FORMAT STATEMENTS)
300 READ 310,F1,F2,F3,F4,F5,F6,F7,F8,F9,F10,F11,F12,F13,F14,F15,
V F16,F17,F18,F19,F20,F21,F22,F23,F24,F25
310 FORMAT(18A4)
READ 315,(A(I),I=1,3),(B(I),I=1,3),(C(I),I=1,3)
315 FORMAT(3F12.0)
PRINT F17,A,B,C
320 CALL DECRO (DA)
ITER = 0
ITLT = CA(3)
ISO=0
ISW=0
CZO=0.
DZW=0.
PI=3.1415926
C PRINT INPUT DECIMAL DATA
PRINT F1, (JP,DA(JP),JP=1,6)
PRINT F21,(JP,DA(JP),JP=38,38)
IF (DA(1)) 375,390,350
350 ZETA E=DA(26)
C3 = DA(27)
FH=CA(35)
FAH=CA(36)
PRINT 3001,FH,FAH
3001 FORMAT(/' FH= ',1PE10.3,' FAH= ',1PE10.3)
IF(ZETA E)360,355,360
355 PRINT F18,(JP,DA(JP),JP=9,9)

```

Fig. E1, Program Compiled Listing

```

      PRINT F16,(JP,DA(JP),JP=31,34)
      PRINT F19,(JP,DA(JP),JP=37,37)
      GC TO 430
360 PRINT F12,(JP,DA(JP),JP=26,27)
      PRINT F20,(JP,DA(JP),JP=35,36)
      IF(HA)361,430,361
361 PRINT F18,(JP,DA(JP),JP=9,9)
      PRINT F16,(JP,DA(JP),JP=31,34)
      PRINT F19,(JP,DA(JP),JP=37,37)
      GC TO 430
375 C1 = DA(7)
      C2 = CA(8)
      PRINT F10,(JP,CA(JP),JP=7,9)
      PRINT F13,(JP,DA(JP),JP=37,37)
      IF(HA)376,425,376
376 PRINT F16,(JP,DA(JP),JP=31,34)
      GC TO 425
C**** CALCULATE C1 AND C2
390 PRINT F11,(JP,CA(JP),JP=9,25)
      PRINT F19,(JP,DA(JP),JP=37,37)
      IF(HA)391,400,391
391 PRINT F16,(JP,DA(JP),JP=31,34)
400 C1 = .1713E-8*(EPSA+EPSB)
      C2 = 443.*(ALPHAA*COSDF(THETAP)+ FA*ALPHAA*RHOM*COSDF(THETAM)
V+FA*ALPHAA*RHOX*CCSCF(THETAX)+FB*ALPHAB*RHOM*COSDF(THETAM)
V+FB*ALPHAB*RHOX*CCSCF(THETAX))
V+TM**4*.1713E-8*(FA*EPSA+FB*EPSB)
V+EPSX*TX**4*.1713E-8*(FAX*EPSA+FBX*EPSB)
V+.01*(EPSA+EPSB)
C**** COMPUTE ZETA E AND C3
425 ZETA E=(C1*TH**3*RH**2)/(12.*FNK*FINTH)
      IF(C1.EQ.0.0) C3=0.
      IF(C1.EQ.0.0) GC TO 426
      C3 = C2/(C1*TH**4)
426 CCNTINUE
      FH=(RH**2*(HA+HB))/(12.*FNK*FINTH)
      FAH=(RH**2*(HA*TAA+HB*TAB))/(12.*FNK*FINTH*TH)
430 ZETAP=2.*ZETA E*(PHIR-1.)**2/(THRAT+1.)
      IF(ZETAP-100.)436,435,435
435 NA=3
      GC TO 437
436 IF(ZETAP)438,437,438
438 NA=2.+ALOG1J(ZETAP)
      IF(NA.LT.1)NA=1
437 EFR=(1.-C3)*(ZETAP*(ZETAP*A(NA)+B(NA))+C(NA))
      FM=(PHIR-1.)*SQRT((2.*FH)/(THRAT+1.))
      EFC=TANH(FM)/FM
      IF(ZETA E)541,543,541
541 IF(FH)544,542,544
542 TR=SQRT(SQRT(C3))
      GC TO 549
543 TR=FAH/FH
      GC TO 549
544 LC=0
      TR=.5*(SQRT(SQRT(C3))+FAH/FH)
545 LC=LC+1

```

Fig. E1, Program Compiled Listing (Continued)

```

      IF(LC-25)547,547,546
546  PRINT F23,TR
      GC TO 320
547  FE=C1*TH**3*(TR**4-C3)+TR*(HA+HB)-(HA*TAA+HB*TAB)/TH
      IF(ABS(FE)-.001)549,549,548
548  DFECTR=4.*C1*(TH*TR)**3+HA+HB
      TR=TR-FE/DFECTR
      PRINT 3000,TR,FE
3000 FORMAT(' TR= ',E10.3,' FE= ',E10.3)
      GC TO 545
549  TE=TH*TR
      IF (DA(28)) 1000,1025,1000
1000 T(5) = DA(28)
      GC TO 1050
1025 T(5)=-((PHIR**2-1.)/(2.*PHIR**.3796))*(ZETA*EFR+(FH-FAH)*EFC)
1050 WILT = 500.
      T(4) = 1.
      IF(CA(30))1061,1060,1061
1060 PRINT F25
      CA(30)=25.
1061 T(3)=(PHIR-1.)/CA(30)
      T(2)=1.
      MESH=DA(30)
      K = 0
      DZ1=T(5)
      ITER=ITER+1
      IF (ITLT - ITER) 1125,1130,1130
1125 PRINT F3
      IF (DA(29)) 1400,320,1400
1130 DO 1390 J=1,MESH
      FC(2)=0.
      FC(3)=T(3)/2.
      FC(4)=T(3)/2.
      FC(5)=T(3)
      CM(1)=0.
      DO 2 I=2,5
      CM(I)=DZ1*(T(2)+FO(I),T(4)+FO(I)*T(5),T(5)+FC(I)*CM(I-1))
2  CCNTINUE
      T(2)=T(2)+T(3)
      DT4 =T(3)/6.*(CM(2)+CM(3)+CM(4))*T(3)+T(3)*T(5)
      T(4)=T(4)+DT4
      DT5 =T(3)/6.*(CM(2)+2.*CM(3)+2.*CM(4)+CM(5))
      T(5)=T(5)+DT5
      K = K + 1
      Z(K) = T(4)
      PHI(K)=T(2)
      IF(T(5))1200,1260,1200
1200 IF(ABS(DZ1)+ABS(T(5))-ABS(DZ1+T(5)))1250,1250,1205
1205 IF(ISW)1225,1235,1225
1225 DZ0=DZ1
      T(5)=.5*(DZ0+DZW)
      GC TO 1210
1235 DZ0=DZ1
      T(5)=1.10*DZ1
      IF(ISW)1210,1220,1210
1210 IF((ABS(DZW)-ABS(DZ0))/ABS(T(5))-.0025)1400,1400,1220

```

Fig. E1, Program Compiled Listing (Continued)

```

1220 CCR = 1.
      EFF1=(-2./((PHIR**2-1.)*DZ1)/(ZETAE+FH-FAH)
      PRINT F2,ITER,COR,T(2),T(5),DZ1,EFF1
1239 ISO=1
      IF(ITLT-ITER) 1125,1125,1050
C**** TEST FOR WILT
1250 IF (ABSF(WILT)-ABSF(T(5))) 1260, 1380,1380
1260 IF (ISO)1278,1277,1278
1277 T(5)=.90*DZ1
      DZW=DZ1
      GC TC 1265
1278 DZW=DZ1
      T(5)=.5*(DZ0+DZW)
1265 IF ((ABS(DZW)-ABS(DZ0))/ABS(T(5))-.0025)1400,1400,1270
1270 CCR = 2.
      EFF1=(-2./((PHIR**2-1.)*DZ1)/(ZETAE+FH-FAH)
      PRINT F2,ITER,CCR,T(2),T(5),DZ1,EFF1
      ISW=1
      IF(ITLT-ITER) 1125,1125,1050
1380 WILT = T(5)
1390 CCNTINUE
      GC TO 1260
C**** CONVERGENCE ACCOMPLISHED, STORE EFF FOR PRINTING AND RETURN
1400 EFF2=(-2./((PHIR**2-1.)*DZ1)/(ZETAE+FH-FAH)
      IF (DA(1)) 1415,1415,1410
1410 PRINT F15,ZETAE,Z(K),DZ1,T(2),FH,FAH
      GC TC 1420
1415 CCNTINUE
      PRINT F8,C1,C2,C3,ZETAE,Z(K),DZ1,T(2),FH,FAH
1420 ETAA=(-2./((PHIR**2-1.)*DZ1)/(ZETAE*(1.-C3)+FH-FAH)
      AP =PI*RH**2*(PHIR**2-1.0)
      AEFF = ETAA*AP
      PRINT F24,TR,TE
      PRINT F4, EFF2
      PRINT F7,AP,AEFF,ETAA
      Q=-(PI*TH)/6.*FNK*FINTH*DZ1
      PRINT F22,Q
C**** TEST FOR PRINT AND PLOT OF TEMPERATURE PROFILE
1440 IF (DA(2)) 320,320,1520
1520 PRINT F5
      DO 1570 L = 1, K
      ELH(L)=RH*(PHI(L)-1.)
      ELHFT = ELH(L)/12.
      TRA=Z(L)*CA(6)
      TF(L)=TRA-460.
1570 PRINT F6,L,ELHFT,TRA,ELH(L),TF(L)
2600 GC TO 320
      END

```

Fig. E1, Program Compiled Listing (Continued)

```

SUBROUTINE DECRD(DATA)
C   READS A VARIABLE NUMBER OF ITEMS OF FLOATING-POINT DATA INTO
C   SPECIFIED ELEMENTS OF AN ARRAY IN BLOCKS OF 5 CONSECUTIVE ITEMS.
C   ONE OR MORE BLANK FIELDS ON A DATA CARD CAUSE THE VALUES IN CORE
C   TO REMAIN UNCHANGED
C   THE FORTRAN INTEGER INDEX IN THE FIRST FIELD OF EACH CARD DEFINES
C   THE POSITION OF THE ARRAY OF THE FIRST ITEM OF EACH BLOCK OF FIVE.
C   THE BLOCKS NEED NOT BE SEQUENTIAL NOR CONTINUOUS.
C   THE INDEX IS PLACED AT THE END OF ITS FIELD. IT MAY NOT BE ZERO
C   OR BLANK. IT SHALL NOT CONTAIN A DECIMAL POINT.
C   A DECIMAL POINT MUST ALWAYS BE PLACED IN EACH DATA ITEM, THEREFORE,
C   THE VALUE MAY BE PLACED ANYWHERE IN EACH OF THE FIELDS PER CARD.
C   THE DECIMAL SCALE, IF ANY, FOR A DATA ITEM MUST BE PLACED AT THE
C   END OF THE FIELD.
C   A 0. MUST BE ENTERED TO READ IN A ZERO. A -0. IS THE SAME AS A
C   BLANK FIELD. THE READING OF DATA IS TERMINATED BY ENTERING A
C   NEGATIVE INDEX ON THE LAST CARD OF EACH SERIES.
C   TO USE THE ROUTINE ---- CALL DECRD(DATA)
      DIMENSION DRBU (5), DATA (6)
      1 READ 2, IND, (DRBU(I),I=1,5)
      2 FORMAT(I12, 5E12.0)
      IF (IND. EQ. (-999)) STOP
      3 J = IABS(IND)
      4 DO 7 I=1,5
      5 IF(DRBU(I)) 6,10,6
      10 IF(SIGN(1.,DRBU(I))) 7,11,6
      6 DATA(J) = DRBU(I)
      7 J = J+1
      8 IF(IND) 9,11,1
      9 RETURN
      11 CALL EXIT
      RETURN
      END

```

Fig. E2, Subroutine DECRD
(for reading input data)

```

(1H1,59HEFFECTIVENESS FOR CIRCULAR PLAN FINS AND OPTIONAL TEMP PROF/
/I9,F12.6,24H CODE FOR INITIAL VALUES/ I9,F12.6,22H CODE FOR TEMP PROFIL
E/I9,F12.6,17H ITERATION LIMITS/I9,F12.6,16H THICKNESS RATIO/I9,F12.6,
17H ROOT RADIUS (IN)/I9,F12.6,24H ROOT EDGE TEMP (DEG(R))
(/I5,10H CCR = F4.1,9H PHI = F10.6,17H LAST DZ/DQ = F10.6,10H
DZ1 = F10.6,9H EFF1 = F10.6)
(//38F*** NO CONVERGENCE, TRY A SECOND GUESS)
(/22H FINAL EFFECTIVENESS = F10.6)
(1H165H TEMPERATURE PROFILE INCREMENT FT FROM ROOT EDGE TEMP (R)
10X,33H INCHES FROM ROOT EDGE TEMP (F))
(I34,F19.8,F12.1,10X,F21.3,F12.1)
(/19H PLAN AREA =F12.6,9H(SQ. IN.)19HEFFECTIVE AREA =F12.6,9H(
SQ. IN.)19H AREA EFFECTIVENESS=F12.6)
(/ 5X,13HC1 =E15.8/5X,13HC2 =E15.8/5X,13HC3
=E15.8/5X,13HZETA E =E15.8/5X,13HFINAL Z =E15.8/5X,13HFINAL DZ
1 =E15.8/5X,13HFINAL PHI =E15.8/5X,13HFH =,E15.8/
5X,13HFAH =,E15.8//)
(//26H ***XERRCR FACTORS FC =F10.8, 9H NE =F10.8)
(/5X,28H **C1 AND C2 ENTERED AS DATA/I9,E16.8, 3H C1/I9,E16.8, 3H C2/
I9,E16.8,33H FIN THER COND (BTU/HR-FT-DEG(R)))
(/5X,47H **THE FOLLOWING QUANTITIES ARE ENTERED AS DATA/I9,F12.6,33H FIN
THER COND (BTU/HR-FT-DEG(R))/I9,F12.6, 3H FA/I9,F12.6,8H ALPHA A/
I9,F12.6, 6H EPS A/I9,F12.6, 4H FAX/I9,F12.6, 3H FB/I9,F12.6, 8H ALPHA B
/I9,F12.6, 6H EPS B/I9,F12.6, 4H FBX/ I9,F12.6,17H TM (DEG RANKINE)/
I9,F12.6,14H THETA M (DEG)/I9,F12.6, 6H RHO M/I9,F12.6,17H TX (DEG RANKI
NE)/I9,F12.6,14H THETA X (DEG)/I9,F12.6, 6H RHO X/
I9,F12.6,14H THETA P (DEG)/I9,F12.6,5H EPSX)
(/5X,62H **PRCFILE NUMBER (ZETA E) AND ENVIRON PARAM C3 ENTERED AS DATA/
I9,F12.6,15H PROFILE NUMBER/I9,F12.6, 22H ENVIRONMENT PARAMETER)
(/I9,E16.8,29H ROOT EDGE THICKNESS (INCHES))
(//5X,50HC3 IS GREATER THAN 1. VARIABLE DATA IS INCORRECT. // 10X,
4HC3 =E15.8)
(/ 5X,13HZETA E =E15.8/5X,13HFINAL Z =E15.8/5X,13HFINAL DZ1
=E15.8/5X,13HFINAL PHI =E15.8/5X,13HFH =,E15.8/
5X,13HFAH =,E15.8//)
(//32H INPUT DATA FOR CONVECTION STUDY/I9,F12.6,33H HEAT TRANSFER COEFFI
CIENT SIDE A/I9,F12.6,33H HEAT TRANSFER COEFFICIENT SIDE B/
I9,F12.6,15H AMBIENT TEMP A/I9,F12.6,15H AMBIENT TEMP B)
(14H1EFF CURVE FIT/1HC,3F12.8/1H 3F12.8/1H 3F12.8)
(I9,F12.6,44H FIN THERMAL CONDUCTIVITY (BTU/HR-FT-DEG(R)))
(I9,F12.6,31H FIN THICKNESS AT ROOT (INCHES))
(I9,F12.6,3H FH/I9,F12.6,4H FAH)
(I9,F12.6,5H PHIR)
(//20H C =,F12.6,7H BTU/HR)
(/36H TEMP RATIO FAILED TO CONVERGE TR= E12.8)
(/22H TEMP RATIO (TE/TH) = E12.6/20H EFF ENVIRON TEMP = E12.6,
9H (DEG(R)))
(54H0NC. OF INTEGRATION STEPS NOT ENTERED-PROGRAM USES 25.)
.41199999 .00533150 .00002362
-.87831999 -.09625650 -.00406435
1.00000000 .6246049 .23347166
END OF DATA
-999

```

Fig. E3, ECHO Print out of Program Data

EFFECTIVENESS FOR CIRCULAR PLAN FINS AND OPTIONAL TEMP PROF

1	1.000000	CODE FOR INITIAL VALUES
2	0.0	CODE FOR TEMP PROFILE
3	15.000000	ITERATION LIMITS
4	0.440000	THICKNESS RATIO
5	0.0	ROOT RADIUS (IN)
6	0.0	ROOT EDGE TEMP (DEG(R))
38	2.250000	PHIR

FH=	4.000E-01	FAH=	8.000E-02
9	0.0	FIN THERMAL CONDUCTIVITY (BTU/HR-FT-DEG(R))	

INPUT DATA FOR CONVECTION STUDY

31	0.0	HEAT TRANSFER COEFFICIENT SIDE A
32	0.0	HEAT TRANSFER COEFFICIENT SIDE B
33	0.0	AMBIENT TEMP A
34	0.0	AMBIENT TEMP B
37	0.0	FIN THICKNESS AT ROOT (INCHES)

Fig. E4, Input Data for Illustrative Program

1	COR = 1.0	PHI = 1.949986	LAST DZ/DQ = -0.412561	DZ1 = -0.375056	EFF1 = 0.577008
2	COR = 1.0	PHI = 2.049984	LAST DZ/DQ = -0.453817	DZ1 = -0.412561	EFF1 = 0.634709
3	COR = 1.0	PHI = 2.199982	LAST DZ/DQ = -0.499198	DZ1 = -0.453817	EFF1 = 0.698179
4	COR = 2.0	PHI = 2.249981	LAST DZ/DQ = -0.476507	DZ1 = -0.499198	EFF1 = 0.767997
5	COR = 1.0	PHI = 2.249981	LAST DZ/DQ = -0.487853	DZ1 = -0.476507	EFF1 = 0.733088
6	COR = 2.0	PHI = 2.249981	LAST DZ/DQ = -0.482180	DZ1 = -0.487853	EFF1 = 0.750542
7	COR = 2.0	PHI = 2.249931	LAST DZ/DQ = -0.479344	DZ1 = -0.482180	EFF1 = 0.741815
8	COR = 1.0	PHI = 2.249981	LAST DZ/DQ = -0.480762	DZ1 = -0.479344	EFF1 = 0.737452
9	COR = 1.0	PHI = 2.249981	LAST DZ/DQ = -0.481471	DZ1 = -0.480762	EFF1 = 0.739633

E-11

ZETAE = 0.0
 FINAL Z = 0.71385300E 00
 FINAL DZ1 = -0.48147088E 00
 FINAL PHI = 0.22499809E 01
 FH = 0.39999998E 00
 FAH = 0.79999983E-01

TEMP RATIO (TE/TH) = 0.200000E 00
 EFF ENVIRON TEMP = 0.0 (DEG(R))

FINAL EFFECTIVENESS = 0.740724

Fig. E5, Output Data from Illustrative Problem