HEAT PIPE COOLED HEAT REJECTION SUBSYSTEM MODELLING FOR NUCLEAR ELECTRIC PROPULSION (TASK ORDER NO. 18)

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Foreword

Systems engineering efforts initiated by NASA's Lewis Research Center (LeRC) in FY92 under RTOP 593-72. for Nuclear Electric Propulsion (NEP), have enabled the development of detailed mathematical (computer) models to predict NEP subsystem performance and mass. The computer models are intended to help provide greater depth to NEP subsystem (and system) modeling, required for more accurately verifying performance projections and assessing the impact of specific technology developments.

The following subsystem models have been developed:
1) liquid-metal-cooled pin-type, and
2) gas-cooled NERVA (Nuclear Engine for Rocket Vehicle Applications) - derived for reactor/shield;
3) Potassium-Rankine, and
4) Brayton for power conversion;
5) heat rejection general model (includes direct Brayton, pumped loop Brayton, and shear flow condenser (Potassium-Rankine);
6) power management and distribution (PMAD) general model; and
7) ion electric engine, and
8) magnetoplasmadynamic thruster for the electric propulsion subsystem.

These subsystem models for NEP were authored by the Oak Ridge National Laboratory (ORNL) for the reactor (NASA CR-191133), by the Rocketdyne Division of Rockwell International for the Potassium Rankine (NASA CR-191134) and Brayton (NASA CR-191135) power conversion, heat rejection (NASA CR-191132), and power management and distribution (NASA CR-191136), and by Sverdrup Technology for thr thrusters (NASA CR-191137).

At the time of this writing, these eight VAX/FORTRAN source and executable codes are resident on one of LeRC's Scientific VAX computers.
SUMMARY

NASA LeRC is currently developing a FORTRAN based computer model of a complete nuclear electric propulsion (NEP) vehicle that can be used for piloted and cargo missions to the Moon or Mars. Proposed designs feature either a Brayton or a K-Rankine power conversion cycle to drive a turbine coupled with rotary alternators. Both ion and MPD thrusters will be considered in the model. In support of the NEP model, Rocketdyne is developing power conversion, heat rejection, and power management and distribution (PMAD) subroutines. The subroutines will be incorporated into the NEP vehicle model which will be written by NASA LeRC. The purpose of this report is to document the heat pipe cooled heat rejection subsystem model and its supporting subroutines.

The heat pipe cooled heat rejection subsystem model is designed to provide estimates of the mass and performance of the equipment used to reject heat from Brayton and Rankine cycle power conversion systems. The subroutine models the ductwork and heat pipe cooled manifold for a gas cooled Brayton; the heat sink heat exchanger, liquid loop piping, expansion compensator, pump and manifold for a liquid loop cooled Brayton; and a shear flow condenser for a K-Rankine system. In each case, the final heat rejection is made by way of a heat pipe radiator. The radiator is sized to reject the amount of heat necessary.

The calculations proceed from first principles and normally will require that a relatively extensive amount of information be made available to the code. For normal use, a complete description of the component geometry must be specified. However, for preliminary design purposes, the code provides an option that will generate a workable design for the heat rejection system that can be used as the basis for further optimization.

The code computes the performance of each equipment item in the flow path. Performance for specific elements such as the heat exchanger, piping and manifolds is usually expressed as a pressure and a temperature drop. The pressure drops are summed to size the pumps, while the temperature drops are used to determine the mean effective temperature of the radiator which is then sized to reject the amount of heat required to operate the cycle at the specified conditions. Code output is in the form of labeled variable values and the output for each option includes a detailed mass summary of the equipment items in the selected flow path.

A detailed discussion of the derivation of the algorithms incorporated in the various subroutines used forms the major portion of the report. The model documentation includes as an appendix a detailed users manual which provides definition of the input variables required, subroutine usage instructions, and applications examples to illustrate the output resulting from invoking the different code options.
1.0 INTRODUCTION

The objective of this task was to characterize potential heat pipe based radiator subsystems for use in megawatt sized nuclear electrical propulsion systems. The approach to developing this characterization was to develop a mass/performance estimating computational methodology that proceeds from first principles to provide valid estimates of the performance and mass of candidate heat pipe based radiators and the auxiliary devices required to use them in both Brayton and Rankine system designs. Heat rejection subsystem characteristics of interest are radiator size (area, length, width, heat pipe lengths, heat exchanger dimensions) and mass. It was required that these characteristics be developed for both a potassium Rankine cycle with a constant temperature condensation process, as well as for a Brayton cycle with a varying temperature cooling process. Input variables to be considered in the characterization include temperature, working fluids, cycle type, radiator geometry and materials of construction.

It was deemed desirable to provide as many default values for variables as possible, in order to minimize the amount of effort required to use the program. This desire conflicts with the necessity of developing algorithms with sufficient detail to permit rational optimization when the code is used as part of an overall systems model. A compromise solution was developed in the form of an option to the basic code that determines a radiator design on a relatively simplified and non-optimized basis. The inputs developed as a result of running the optional portion of the code are intended to provide sufficient detail to the user who can then construct an operating model of the system which can then be optimized by manipulation of this more complete data set.

This report provides documentation of the methodology used in developing the heat rejection subsystem analysis subroutine and includes a discussion of the technical approach developed, the design of the main driver program, and the design and integration of the various equipment algorithms and supporting routines used. A users manual for the code and a complete FORTRAN source code listing are presented as Appendices. Users familiar with the analysis of space based heat rejection systems should be able to use the code with only the information given in the users manual, Appendix A.
2.0 TECHNICAL APPROACH

2.1 Requirements

The heat rejection subsystem will be required to operate over a wide range of temperatures and pressures, and with a variety of working fluids. The ranges of these parameters are shown in Table 1. These requirements are met primarily by supplying materials properties for materials used at the pressures and temperatures of interest. For the heat pipes, sufficient options are provided to cover an even larger range than required.

TABLE 1
HEAT REJECTION SUBSYSTEM
GROUND RULES AND REQUIREMENTS

<table>
<thead>
<tr>
<th>Input parameter ranges of interest:</th>
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</thead>
<tbody>
<tr>
<td>Power Conversion System Outlet Temperatures (k):</td>
</tr>
<tr>
<td>K-Rankine: 750 - 1250</td>
</tr>
<tr>
<td>Brayton: 300 - 1000</td>
</tr>
<tr>
<td>Power Conversion Working Fluids:</td>
</tr>
<tr>
<td>K-Rankine</td>
</tr>
<tr>
<td>Helium</td>
</tr>
<tr>
<td>Helium-Xenon Mixtures</td>
</tr>
<tr>
<td>Power Levels: 100-50000 KWe</td>
</tr>
<tr>
<td>Lifetime: 2 - 10 Years</td>
</tr>
</tbody>
</table>

Code options that provide for automated selection of heat pipe working fluids and containment materials will use the Values in Table 2. The user, however, can specify any of the working fluids in Table 2 at any time. The code will run with the selected fluid if its use at the specified temperature is possible. Inappropriate selections will cause the code to stop with the appropriate heat pipe related error message.

TABLE 2
HEAT PIPE WORKING FLUID TEMPERATURE RANGES
AND CONTAINMENT MATERIALS RECOMMENDED

<table>
<thead>
<tr>
<th>TEMPERATURE RANGE (K)</th>
<th>FLUID USED</th>
<th>CONTAINER MATERIAL</th>
</tr>
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<tbody>
<tr>
<td>250 - 305</td>
<td>AMMONIA</td>
<td>ALUMINUM</td>
</tr>
<tr>
<td>305 - 560</td>
<td>WATER</td>
<td>MONEL (COPPER)</td>
</tr>
<tr>
<td>560 - 750</td>
<td>MERCURY</td>
<td>347 STAINLESS</td>
</tr>
<tr>
<td>750 - 950</td>
<td>POTASSIUM</td>
<td>NIIOBIUM</td>
</tr>
<tr>
<td>950 - 1150</td>
<td>SODIUM</td>
<td>NIIOBIUM</td>
</tr>
<tr>
<td>1150 - 1800</td>
<td>LITHIUM</td>
<td>MOLYBDENUM</td>
</tr>
</tbody>
</table>

3.
2.2 Subsystem Definitions

The code developed for the characterization of potential heat pipe cooled heat rejection subsystems is designed to be applicable to both the Brayton and Rankine cycle power conversion systems. Brayton systems have been proposed that feature both direct heat extraction from the cycle working fluid and heat extraction by use of a gas/liquid heat exchanger and a liquid loop as shown on the flow diagrams given as Figures 1 and 2. The direct heat extraction cycle uses a gas to heat pipe cooled heat exchanger/manifold to extract the heat directly from the cycle working fluid. In most cases the heat exchanger for this application will be finned on the gas side. In those cases in which a liquid loop is used, a fluid loop is placed between the cycle working fluid and the radiator, primarily to permit the transfer of heat without the use of extensive, high mass ducting. The radiator manifold/heat pipe heat exchanger will usually be unfinned in the liquid loop cooled systems. In general, the larger sized systems will favor the use of an intermediate loop in the heat rejection system. The Flow diagram for the Rankine cycle systems is shown in Figure 3. The Rankine cycle makes use of a shear-flow condenser because other types are not considered practical for use in the absence of a gravity field.

2.3 Overall Code Design

Figure 4 presents an overall logic flow diagram for the Brayton and Rankine cycle heat rejection subsystems. Figure 4 illustrates the steps required to estimate the performance and mass of a subsystem for rejecting heat to space. The steps required to accomplish this objective are:

1. Select the method of heat rejection to be used for the system. Three options will be available. The options are described above and illustrated in Figures 1, 2 and 3.
2. Compute the performance of the gas/liquid heat exchanger if required.
3. Compute the performance of the liquid loop system, if one is used.
4. Size or select the pump if one is used. The code will only provide for the use of a liquid metal (NaK) loop for secondary cooling. For liquid metals, an EM pump is most often specified. The mass and performance of the pump will generally be estimated from semi-empirical curves generated for other purposes.
5. Compute the performance of the heat exchanger/manifold or condenser as needed.
6. Size the heat pipe radiator.

Several of the equipment size performance estimating subroutines are supported by other subroutines which describe the operating environment or describe the thermal property variations with temperature or pressure. The interactions of these routines are
Figure 1: DIRECT GAS COOLED BRAYTON RADIATOR

Figure 2: LIQUID LOOP COOLED BRAYTON RADIATOR
Figure 3: RANKINE CYCLE SHEAR FLOW CONDENSER
FIGURE 4: OVERALL CODE LOGIC DIAGRAM
shown on Figure 4. In the case of the main radiator subroutine, other subroutines are used to supply armor thickness calculations and heat pipe performance calculations as well as environment and thermal property estimates.

The overall approach to computing heat rejection system performance is to estimate the performance of each equipment element in the string and then design a radiator to be compatible with the specified equipment string and the heat rejection requirements for the power conversion system. Each equipment element results in a temperature loss which is reflected in the mean operating temperature of the radiator. In addition to a temperature drop, the mass of the subsystem and the performance of the power conversion system is affected by the pressure drop of each of the equipment elements. The pressure drop of each element is also computed and is available for use in the system code as well as for pump sizing purposes.

The mass and performance of each equipment element is estimated from first principles using well established thermo-hydraulic analysis methods. The analytical methods generally require that a relatively complete geometrical description of the component be supplied as input. Since such inputs are dependent on having a defined design concept available, it is seen as desirable to have an option in the code where a workable set of design parameters can be generated with only state point and system type inputs required. This option is supplied with the code and it consists of design rules based on previous experience. The option will not generally supply an optimized (namely, area constrained minimum mass) subsystem. However, the data from the option can be used in the primary section of the code to develop optimized configurations for the heat rejection subsystems of Brayton and Rankine power conversion subsystems.
3.0 EQUIPMENT SUBROUTINE/ALGORITHM DEVELOPMENT

3.1 Main Driver Routine (HREJEC)

This subroutine, HREJEC, is the main driver routine which is used to organize the problem, read in the required data inputs, call the appropriate subroutines and print out the results. The logic of HREJEC is reflected in the flow diagram given as Figure 4. The following steps are followed in estimating the mass and performance of heat pipe cooled heat rejection systems in either Brayton or Rankine power conversion systems:

1. Select the heat rejection equipment train and define the equipment elements required. Three options are supplied and the flag, Iprob, is used to select the appropriate option, as:
   a) Direct cooled gas manifold for Braytons.
   b) Liquid loop (NaK only) cooled heat exchanger loop for Braytons.
   c) Shear flow condenser (Potassium only) directly cooled by heat pipes for Rankine cycles.

2. Analyze the Hydraulic loop for the pressure drops required by the heat sink heat exchanger, the liquid loop piping and the heat pipe cooled manifold, if a liquid loop is used.

3. Determine the weight of the pump required.

4. Determine the temperature drop associated with the heat pipe cooled liquid or gas manifold or shear flow condenser.

5. Size a heat pipe radiator to accommodate the temperature drops seen in the loop equipment train and to accommodate the system heat rejection loads.

6. Printout component sizes and masses.

An option selected by the flag, Iselec, can be activated to supply most of the variables needed to run a case is included. A detailed listing of the variables required by the various options is included in Appendix A, the users manual.

3.2 Heat Sink Heat Exchanger

The heat sink heat exchanger in a Brayton system is required to transfer heat from the gas working fluid to a liquid metal coolant loop. It has been demonstrated by numerous prior studies that the most mass efficient of the conventional heat exchanger designs that could be used for this purpose is the shell and tube configuration. A schematic of a typical shell and tube layout is shown in Figure 5. In its usual embodiment, the gas stream is confined to the shell side, while the liquid metal is confined to the tube side.
of the heat exchanger. Since the gas and liquid streams in the Brayton application are at relatively low pressures, the use of relatively thin shells and tube materials is possible.

The heat sink heat exchanger size estimating subroutine is based on a computation of the overall heat transfer coefficient developed in a shell and tube heat exchanger with gas on the shell side of the exchanger and liquid on the tube side. The details of the computation roughly follow the development due to Bell [1]. Most of the construction details are assumed to be optimum with this method and the distance between tube rows in the direction perpendicular to the flow is assumed to be equal to the tube pitch. Several correlations are available for the heat transfer and friction factor coefficients on the shell side. The ranges of these correlations is shown on Figure 6. The correlation due to Bell was selected for use in the heat rejection subsystem design and analysis code since it is relatively conservative and nearly identical to the proprietary HTRI correlation. The tube side heat transfer correlation used is due to Lyon as quoted by Kreith [2]. This is the generally accepted correlation for the heat transfer to liquid metals under conditions of uniform heat flux. The Lyon correlation is represented by equation 1, below.

\[ N_u = 7.0 + 0.025 \times (Re_d \times Pr)^{0.8} \]  

\[ \text{(1)} \]

where:

- \( N_u \) = Nusselt Number
- \( Re_d \) = Reynolds Number based on diameter
- \( Pr \) = Prandtl Number

The friction factor for the turbulent flow of liquids or gases in tubes is given by an equation due to Miller [3]. This relation, as given by equation 2, gives a reasonably good representation of the Moody diagram and has the advantage of being an explicit expression, thereby not requiring an iterative calculation.

\[ f = \frac{0.25}{[\log_{10}(\frac{e}{3.7d} + \frac{5.74}{Re_d^{0.5}})]^{2.0}} \]

\[ \text{(2)} \]

where:

- \( e \) = Mean Surface roughness height
- \( d \) = Tube Diameter
Figure 6: SHELL-SIDE HEAT TRANSFER COEFFICIENT CORRELATION COMPARISON
The calculation proceeds by guessing an overall heat transfer coefficient, sizing the exchanger and then checking if the guess was correct. If the resulting exchanger is larger than required, the code reduces the overall diameter and repeats the calculation until a reasonably close approximation to the required exchanger duty is found. Conversely, if the resulting exchanger is smaller than required, the code increases the overall diameter and repeats the calculation, as above. Once the proper overall size is determined, the code proceeds to compute the mass of the component parts of the heat exchanger. Shell thickness is derived from an empirical representation of the results of prior calculations. Masses are computed by simple density times part volume relations. The components included are the insulation, heat exchanger heads, shell, plates, tubesheets, and tubes. The supporting structure for the heat exchanger is estimated as five percent of the overall mass of the heat exchanger unit. It is to be noted that the material thicknesses used for the design of these heat exchangers are near the absolute minimum possible and are representative of heat exchangers operated under very precisely defined conditions, manufactured using state of the art techniques and fully utilizing the latest in materials advances. As a result they will be very expensive to fabricate and develop. A more economical unit on the other hand will have significantly higher mass.

3.3 NaK Piping

The heat absorbed by the heat rejection heat exchanger is transferred to a heat pipe cooled manifold by a piping system. The piping system affects system mass by providing resistance to the pump, requiring a volume of metal to provide fluid containment and finally by requiring an inventory of fluid with which to transfer the heat and incidentally keep the piping system filled. Aerospace liquid metal loop systems are usually designed not to exceed a certain maximum flow velocity. This velocity is usually less than about 10 to 12 meters/second. In order to minimize erosion problems with velocities of this magnitude, it is necessary to have an extremely low oxygen content in the flowing fluid. A usually satisfactory value for pipe wall thickness is given by assuming schedule 10 pipe. The use of thinner sections should be carefully evaluated.

The pressure drop in the NaK piping system is estimated from input values of flowrate, pipe diameter, pipe length and number of 90 degree bends in the system. Pipe bend resistances are estimated by use of an empirical equation derived from a cross plot of bend resistance data published by Miller [3]. Pipe friction factors are estimated by means of equation 2. Masses are computed by simple density times part volume relations. The elements included in the mass estimate are the pipe insulation, pipe material and the volume of NaK contained in the piping.
3.4 EM Pump

NaK circulation in the liquid metal heat transfer loop is provided for by an electromagnetic (EM) pump. A sketch of a typical NaK loop based heat rejection plumbing layout showing the integration of EM pump, the volume accumulator and the radiator inlets and outlets is shown in Figure 7. Rocketdyne has performed detailed EM pump design and configuration selection studies over the past several years. The results of these studies can be roughly correlated by an expression for pump mass as a function of hydraulic pumping power required to operate a NaK loop. This expression is given as:

$$M_{pump} = 16.783 + 0.1465 \times P_{hyd}$$  \hspace{1cm} (3)

where:

- $M_{pump}$ = Pump and Power Control Mass (Kg)
- $P_{hyd}$ = Hydraulic Power Required to Operate Loop (Watts)

Equation 3 is based on several designs for DC conduction EM pumps which featured a two throat configuration. One of the throats is plumbed to the cold leg of the loop, while the other is plumbed to the hot leg. A detailed analysis of the performance and mass of EM pumps is given by Baker and Tessier [4].

3.5 Expansion Compensator

The expansion compensator or volume accumulator unit (VAU) provides for NaK expansion during system startup and provides for overpressure on the NaK to prevent the initiation of local boiling. The VAU is usually located on the radiator manifold outlet line (the lowest temperature point in the system) and is connected to the main branch line by smaller diameter tubing. The design of VAU's is based on the amount of NaK volume change expected in the heat transfer loop between a nominal 311 K temperature level and the maximum operating temperature of the loop. A safety factor of 1.2 is customarily applied to the estimate of NaK volume change. Rocketdyne has conducted several design and selection studies of VAU's for other programs. Details of a typical VAU design are given in Figure 8. The mass of material used in these designs is well correlated by the following equation:

$$M_{vac} = 0.4536 \times [10.0^{0.66 \log_{10} \left( \frac{V_{vac}}{0.0164} - 0.26 \right)}]$$  \hspace{1cm} (4)

14.
Figure 7: TYPICAL NaK LOOP PLUMBING FOR POWER SYSTEM HEAT REJECTION

Figure 8: VOLUME ACCUMULATOR UNIT DESIGN CONCEPT DETAILS
where:

\[ V_{\text{acc}} = \text{Loop volume change (_liters)} \]
\[ M_{\text{vac}} = \text{Mass of volume accumulator unit (dry)_ (Kg)} \]

A detailed computer code for the analysis of the performance and mass of VAU units of the type illustrated in Figure 8 is given by Whitaker and Shimazaki [5].

3.6 Gas/Liquid Heat Pipe Manifold

Heat is transferred to the heat pipe/fin assemblies by means of a heat pipe cooled manifold. The basic configuration of the manifold is a single line of tubes contained in a shroud. Braze cans are used to provide for the attachment of the heat pipe fin assemblies into the shroud. It is assumed that the flow pattern in the manifold can be tailored to simulate the flow in a heat exchanger tube bundle. Tailoring the flow in this manner will require that an undulating wall shape be used to contain the flow. A close approximation to the required shape of this wall can be determined with CFD methods. A diagram of the manifold layout is given in Figure 9.

The heat transfer and friction factor correlation used for the manifold is given as Figure 10. This correlation is adapted from the correlation given by Bell [1] for the case where a large number of tube rows is used. Heat transfer through the walls of the manifold is by conduction through a braze can, a braze joint, the heat pipe wall to the evaporating fluid of the heat pipe. An option is provided for the use of fins around the braze cans. This may be useful in cases where gas is used in the manifold. The fins are assumed to span the entire manifold since the use of unfinned areas would result in bypassing of the flow which is not accounted for in this code.

The heat balance across the wall of a can/braze joint/heat pipe assembly is solved to give the film temperature drop through the manifold. A closed form expression was derived to estimate this parameter. The heat flux used for the estimation of average film temperature drop was the average heat flux value. In practice, the film temperature drop will be highest at the manifold inlet and decreasing toward the manifold outlet. The average value, however, will give the average film temperature drop which is used to estimate the average radiator operating temperature.

Manifold mass is computed by simple density times part volume relations. The elements included in the mass estimate are the manifold braze can mass, manifold container wall mass, manifold braze mass, and for liquid cooled manifolds, the mass of the NaK inventory in the manifold. It is expected that it will usually be desirable to leave the manifold uninsulated. Armor mass for the
HEAT TRANSFER ($j$) AND PRESSURE DROP ($f$) FACTORS FOR MULTI-ROW TUBE BUNDLES

FRICCTION FACTOR ($i$) & HEAT TRANSFER ($j$)

$N_{re}$ - REYNOLDS NUMBER

Figure 10: MANIFOLD SHELL-SIDE HEAT TRANSFER AND PRESSURE DROP
manifold is not included in the above calculation since the manifold is assumed to be shielded from its environment by other components on the spacecraft.

3.7 Shear Flow Condenser/Manifold

The K-Rankine cycle requires a condenser to directly reject waste heat from the cycle. A shear flow device has been identified as being the most likely candidate for this application since its operation does not require the presence of a gravity field. A flow schematic for a heat pipe cooled shear flow condenser is given in Figure 11.

The approach to analyzing the performance of the shear flow condenser is similar to the one used for the convectively cooled manifolds. The code first estimates the proportion of the manifold that is required for subcooling and the portion required for condensing the wet or saturated inlet flow. The manifold routine cannot accommodate superheated flow, due to the fact that either large surface areas or flow dilution must be used to provide desuperheating. A separate piece of equipment is usually used in commercial or utility practice. The code then computes an average film temperature drop for condensing and for subcooling in a manner similar to that used for the convective manifolds. An average value for film temperature drop is then found by averaging the above values weighted by the number of heat pipes involved in each process. Condenser pressure drop is computed for the condensing region and for the subcooling region and then added.

The model used to estimate shear flow condensation is based on computing the condensation of pure vapors inside horizontal tubes. At high Reynolds numbers, the heat transfer rate is controlled by the vapor flow heat transfer coefficient to the continuously forming film on the duct wall. The thickness of this film increases with flow manifold length. Gas phase heat transfer coefficients are estimated by the use of common empirical relations. The model is assumed to be valid provided that the flow is in the shear flow regime. A test is provided in the calculations to determine if the flow is in the shear flow regime, however, the code only issues a warning that the manifold is operating in an invalid flow regime. If such an event occurs, the results of the condensing manifold performance estimating routine is invalid and the user must make a change to the design. This change will usually consist of increasing the local vapor flow velocity in the manifold.

Manifold mass is computed by simple density times part volume relations. The elements included in the mass estimate are the manifold wall mass, manifold to heat-pipe braze mass, the mass of any manifold insulation, and the mass of the NaK inventory in the subcooler portion of the manifold. Armor mass for the manifold is not included in the above calculation since the manifold is
Figure 11: SHEAR CONTROLLED FLOW CONDENSER AND HEAT PIPE RADIATOR FLOW SCHEMATIC
assumed to be shielded from its environment by other components on the spacecraft.

3.8 Gas Ducting

Cycle reject heat can be transferred to a heat pipe cooled gas manifold by a gas ducting system. The gas ducting system affects system mass by providing resistance to the Brayton compressor and by requiring a volume of metal to provide fluid containment. Aerospace gas ducting systems are usually designed not to exceed a certain maximum flow velocity. This velocity is usually less than about 30 to 40 meters/second in order to avoid excessive pressure drop. A usually satisfactory value for pipe wall thickness is given by assuming the duct will be fabricated from 1/16" sheet steel. The use of thinner sections should be carefully evaluated.

The pressure drop in the gas ducting system is estimated from input values of flowrate, pipe diameter, pipe length and number of 90 degree bends in the system. Pipe bend resistances are estimated by use of an empirical equation derived from a cross plot of bend resistance data published by Miller [3]. Pipe friction factors are estimated by means of equation 2. Masses are computed by simple density times part volume relations. The elements included in the mass estimate are the duct insulation and duct material.

3.9 Heat Pipe Radiator

Cycle waste heat is ultimately rejected by the heat pipe/fin radiator surface. The code determines the size of the heat pipe and fin assembly necessary to reject the specified amount of cycle waste heat. The heat pipe radiator subroutine is based on a detailed calculation of the amount of heat that can be radiated from the condenser section of a finned heat pipe. The code can be adapted to use any heat pipe working fluid for which the appropriate fluid physical properties are available. The calculations in the subroutine start with an initial estimate of the length of heat pipe required. The heat pipe length is sectioned into a prespecified number of segments which are treated as isothermal. The amount of heat radiated from a particular segment is computed and compared to the various heat pipe performance limits that apply at the particular length step. The saturation temperature is then adjusted and the heat rejection from the next step is computed. The overall length of heat pipe is adjusted to radiate the correct amount of heat by iterating on the amount of heat rejected. The subroutine uses the calculations for a single heat pipe to scale the results for the entire radiator. The evaporator inlet temperature for this single heat pipe is taken as the fourth power average temperature of the radiator.

The effect of temperature variation in the spanwise direction along the radiator surface is evaluated using the numerical results of Lieblein [6] for radiating fins of constant cross section. The
radiating efficiency presented by Lieblein was empirically represented by a relationship developed by Nervenga and Zarotti [7]. This expression yields an estimate of the fin efficiency directly, without iterations or table lookups, saving considerable computer run time.

The radiator is generally assumed to be radiating from both sides as in a flat plate configuration. However, cylindrical and conical geometries are available as options.

The use of heat pipes to dissipate waste heat from the cycle offers an opportunity to use redundant heat pipes to offset radiator armor. Using this approach, the code uses the binomial equation to estimate the required heat pipe reliability as a function of system reliability and redundancy. The value of heat pipe reliability is then used in the expression developed by Haller and Lieblein [8] to estimate the armor or heat pipe wall thickness required to provide sufficient meteorite protection to meet the heat pipe reliability requirement.

Masses are computed by simple density times part volume relations. The elements included in the mass estimate are the heat pipe container tube, the heat pipe wick, the heat pipe working fluid, the fins, the armor and an allowance for radiator structural support. This allowance is taken as 10% of the mass of the radiator components.
4.0 SUPPORTING SUBROUTINE/ALGORITHM DEVELOPMENT

4.1 Orbit/Environment

Subroutine HRENVR computes the values of the meteorite or debris flux constants and the solar flux constant for use in the armor sizing subroutine and the heat sink temperature estimating subroutine. The meteorite and debris information is based on the 1990 Kessler model. The solar constant is scaled from 1.0 AU by the inverse ratio of the AU's from the sun, squared.

Kessler gives the meteorite flux model for space not influenced by the earth's gravitational field as:

\[
N_t = \left[ \frac{1.0}{(2200 \cdot m^{0.306} + 15.0)^{4.38}} + \frac{1.3 \cdot 10^{-9}}{(m + (10^{11} \cdot m^{2.0}) + (10^{27} \cdot m^{4.0}))} \right] + \frac{1.3 \cdot 10^{-16}}{(m + (10^{6} \cdot m^{2.0}))^{0.85}} \right] \cdot \left( \frac{1.0}{R_{\text{sun}}^{1.5}} \right)
\]

where:

- \( N_t \) = Number of particles of mass, \( m \), or greater per square meter per second.
- \( m \) = Particle mass in grams.
- \( R_{\text{sun}} \) = Distance from sun (AU's)

The orbits that are influenced by the earth's gravitational field are taken to be those between LEO and GEO. For these orbits, the earth focusing factor and the earth shielding factor are applied as:

\[
\text{ShieldingFactor} = 0.5 \cdot (1.0 + \cos[\arcsin(\frac{R_e}{R_e + H})])
\]

and

\[
\text{FocusingFactor} = 1.0 \cdot (\frac{R_e}{I})
\]

and for the region influenced by the gravitational attraction of the earth:

\[
N_t = \frac{N_t}{0.565}
\]

... (5)
where:
\[ R_e = \text{Earth Radius} + 100 \text{ KM atmosphere (6478 KM)} \]
\[ H = \text{Height above Earth's atmosphere (Orbit altitude - 100 KM)} \]
\[ r = \text{Orbit Radius (from earth center) = Orbit Altitude + 6378 KM.} \]

The debris flux model is given by Kessler as:
\[ N_t = 3.168896 \times 10^{-8} \times [H + \phi] \times (F_1 g_1 + F_2 g_2) \]

where:
\[ g_1 = (1.0 + q)^{t-1988} \]

\[ q = 0.02, \text{ if } q < 2011. \]
\[ t = \text{Year Vehicle Launched} \]

or:
\[ g_1 = (1 + q)^{23} \times (1 + q')^{t-2011} \]

\[ q = q' = 0.04, \text{ if } q > 2011. \]

and:
\[ g_2 = 1.0 + (p \times (t-1988)) \]

where:
\[ p = \text{Assumed annual growth rate of mass in orbit} \]

Also:
\[ F_1 = \frac{1.22 \times 10^{-5}}{d^{2.5}} \]

and:
\[ F_2 = \frac{8.1 \times 10^{10}}{(d+700)^6} \]

where:
\[ d = \left( \frac{6.0 \times m}{(2.8 \times \pi)} \right)^{0.3623}, m > 0.3076 \text{ gram} \]

or:
\[ 24. \]
\[
d_j = \left(\frac{6.0 \times m}{4.7 \times \pi}\right)^{0.3333}, \text{if } m < 0.3076 \text{gram}
\]

and:
\[
\phi_j = 10.0 \left(\frac{H}{200} - \frac{S}{140} - 1.5\right)
\]

where:
\[S = 87.2\]

and:
\[
\phi = \frac{\phi_j}{(\phi_j + 1)}
\]

and:
\[
H = \left[10.0 \times \left(\frac{-\log_2(d) - 0.78}{0.637^2}\right)^2\right]^{0.5}
\]

and for: \(28.5 < i < 80.0\) degrees
\[
\psi = -0.313471 + (0.084327 \times i) - (0.00186 \times i^2) + (0.000014 \times i^3)
\]

where:
\[i = \text{Orbit inclination in degrees.}\]

The meteorite flux constants for use in the armor requirements equation evaluated in subroutine ARMOR are estimated from the meteorite model and from the debris model for orbits from LEO to GEO. The larger of the two values is used. For orbits beyond GEO, debris is not usually found, therefore only the meteorite flux is considered.

The solar flux is scaled as a function of distance from the sun in AU, as:
\[
Q_{\text{sun}} = 1353.0 \times \left(\frac{1.0}{R}\right)^2; \text{watts/meter}^2
\]

This flux is used in the HTSINK routine to estimate the effective sink temperature seen by the radiator.
4.2 Thermal Properties

The code makes extensive use of thermal properties in its many subroutines. The majority of the properties required to run the code are built in as curve-fit subroutines. There are several places in the code where the same thermal properties are used under different names and come from different subroutines. These cases developed from the fact that several existing subroutines/algorithms were used to describe some of the components in the system. The routines often used different systems of units and had their own property generating subroutines. These were preserved in order to take advantage of the calibration and development that the routines had at the time of their application. Making all of the subroutines in the code use the same property subroutines will be an area of ongoing code development.

4.3 Armor Thickness Estimates

Subroutine HRARMR computes the amount of armor required in order to provide a specific non-puncture probability in the specified orbit for the specified mission duration. Armor thickness is computed from a semi-empirical relationship developed by Haller and Leiblien [8]. The equation developed requires that specific functions of the armor material be input and that specific meteorite and orbital debris parameters be specified. The orbital parameters are computed in subroutine HRENVR, described above and the materials dependent parameters are given in Table 3. The empirical relationship used is:

\[
\delta = \gamma' a \left[ \frac{P_a}{\rho_p} \right]^{1/2} \left[ \frac{V_p}{C_s} \right]^{2/3} \left[ \frac{6}{\pi \rho_p} \right]^{1/3} \left[ \frac{E \alpha A_v \gamma}{-\ln(P_o)} \right]^{1/3} \left[ \frac{2}{2^\beta + 2} \right]^{1/3} \left[ \frac{T}{T_r} \right]^{1/6}
\]

where:
- \( \gamma' \) = Room temperature cratering coefficient (from Table 3)
- \( a' \) = Rear surface damage thickness factor (from Table)
- \( \rho_p \) = Impacting particle specific gravity (values are built in to the subroutine)
- \( P_a \) = Armor specific gravity - (Grams/cu-Cm)
- \( V_p \) = Impacting particle velocity (values are built in to subroutine)
- \( C_s \) = Armor sonic velocity
- \( A_v \) = Target area
- \( t' \) = Exposure time (mission duration)
- \( P_o \) = Probability of non-puncture (ie; for example 0.9, 0.99, 0.999)
- \( T \) = Average armor temperature
- \( \delta \) = Armor thickness (units depend on other units used)
TABLE 3
CRATERING COEFFICIENT VALUES AND DAMAGE THICKNESS FACTORS FOR SELECTED MATERIALS

<table>
<thead>
<tr>
<th>TARGET MATERIAL</th>
<th>CRATERING COEFFICIENT $y_r$</th>
</tr>
</thead>
<tbody>
<tr>
<td>356 - T51 Aluminum</td>
<td>2.15</td>
</tr>
<tr>
<td>7075 - T6 Aluminum</td>
<td>2.00</td>
</tr>
<tr>
<td>2024 - T6 Aluminum</td>
<td>1.70</td>
</tr>
<tr>
<td>Nb + 1% Zr</td>
<td>1.81</td>
</tr>
<tr>
<td>316 - Stainless Steel</td>
<td>2.19</td>
</tr>
<tr>
<td>A- 286</td>
<td>1.77</td>
</tr>
<tr>
<td>Inconel - 718</td>
<td>1.85</td>
</tr>
<tr>
<td>L - 605</td>
<td>2.00</td>
</tr>
<tr>
<td>Vanadium</td>
<td>1.71</td>
</tr>
<tr>
<td>Tantalam</td>
<td>1.77</td>
</tr>
<tr>
<td>TZM - Molybdenum</td>
<td>2.00</td>
</tr>
<tr>
<td>Carbon-Carbon</td>
<td>1.70</td>
</tr>
</tbody>
</table>

Damage Thickness Factors for Incipient Dimple, Spall and Perforation

<table>
<thead>
<tr>
<th>Material</th>
<th>Dimple</th>
<th>Spall</th>
<th>Perforation</th>
</tr>
</thead>
<tbody>
<tr>
<td>2024 - T6 Aluminum</td>
<td>2.5</td>
<td>2.3</td>
<td>1.7</td>
</tr>
<tr>
<td>316 - Stainless Steel</td>
<td>2.35</td>
<td>1.9</td>
<td>1.4</td>
</tr>
<tr>
<td>A - 286</td>
<td>2.80</td>
<td>2.0</td>
<td>1.65</td>
</tr>
<tr>
<td>Nb + 1% Zr</td>
<td>4.5</td>
<td>4.0</td>
<td>1.7</td>
</tr>
<tr>
<td>Inconel - 718</td>
<td>3.0</td>
<td>2.5</td>
<td>1.75</td>
</tr>
<tr>
<td>Cobalt Alloy L-605</td>
<td>2.5</td>
<td>2.1</td>
<td>1.7</td>
</tr>
<tr>
<td>Titanium</td>
<td>3.1</td>
<td>2.6</td>
<td>1.65</td>
</tr>
<tr>
<td>Vanadium</td>
<td>3.6</td>
<td>2.5</td>
<td>1.55</td>
</tr>
<tr>
<td>TZM - Molybdenum</td>
<td>3.25</td>
<td>3.0</td>
<td>1.85</td>
</tr>
<tr>
<td>Carbon/Carbon</td>
<td>2.5</td>
<td>2.3</td>
<td>1.70</td>
</tr>
</tbody>
</table>

Notes:
1. For heat pipe radiator "perforation" is usual design approach.
2. For pumped loop radiator "dimple" is preferred, but "spall" will usually be acceptable.
4.4 Sink Temperature Estimates

Subroutine HRTSNK computes the maximum sink temperature experienced by a body in a given orbit. The sink temperature is a function of the solar constant, which is determined by subroutine HRENVR. In earth orbit, the energy reflected from the earth and the energy radiated by the earth are significant. Values of the earth reflected and earth emitted radiation are built into the code and used to determine the environmental flux constant for LEO to GEO orbits.

4.5 Statistical Equation Solution Routines

An appropriate relationship with which to estimate the reliability of a heat pipe as a function of system reliability and redundancy is the binomial equation, which can be stated as:

\[ U = \sum_{H=J+1}^{K} \left( \frac{K^H}{(K-H)!} \right) (P)^H (1-P)^{K-H} \]

where:
- \( P \) = Probability of failure of a single heat pipe
- \( K \) = Number of heat pipes in the radiator
- \( J \) = Number of additional redundant heat pipes
- \( U \) = Probability of system failure

The binomial equation assumes that the probabilities of failure will be binomially distributed among the individual heat pipes. The values of \( U, K, \) and \( J \) are specified and the subroutine/function PNEW iteratetively solves equation 8 to determine \( P \), the probability of failure of an individual heat pipe which is then used in the armor thickness equation discussed above.
5.0 CONCLUSIONS/RECOMMENDATIONS

It is believed that the heat pipe cooled heat rejection subsystem model presented will yield performance and mass results of adequate accuracy for system analysis purposes. The code will accommodate designs for which relatively complete dimensional and operating data are available or it will use a minimum input data set to generate a relatively complete, but not optimized design to use as the basis for optimization studies.

Improvements in several areas of the model are suggested. The use of the various thermal properties routines should be made more consistent so as to eliminate redundant property generating routines; the code can be condensed considerably by eliminating many of the comments and output routines; and the code could probably be made to run considerably faster by the use of improved methods of obtaining numerical convergence. However, the implementation of these changes should be deferred until the code is used in a systems context, so that the actual need for some of the improvements can be better prioritized. A second area of interest may be to couple this code with one of the currently available general optimization codes to produce a relatively complete optimization for the minimum input data case.
REFERENCES


APPENDIX A

OPERATING INSTRUCTIONS FOR THE HREJEC CODE
The HREJEC subroutine is designed to estimate the performance and mass of heat rejection subsystems used on space based nuclear power systems. The subroutine offers six options which are selected by the use of the flags Iselec and Iprob.

The selection logic is as follows:

IF Iselec = 1, THEN THE CODE WILL SUPPLY MOST OF THE VARIABLE VALUES NEEDED. IF Iselec = 2, THEN THE USER MUST SUPPLY MOST OF THE VARIABLE VALUES NEEDED

IF Iprob = 1, CODE IS SET UP FOR A DIRECT COOLED Brayton configuration. (Figure A-1)
IF Iprob = 2, CODE IS SET UP FOR A LIQUID LOOP COOLED Brayton configuration. (Figure A-2)
IF Iprob = 3, CODE IS SET UP FOR A SHEAR FLOW CONDENSER IN A POTASSIUM RANKINE CYCLE. (Figure A-3)

The subroutine HREJEC is entered by use of the following call statement in the main or driver program:

CALL HREJEC(Iselec, Iprob, IENflg, Pin, Tin, Tout, Qred)

In addition to the flags Iselec and Iprob, a flag called IENflg is used to select the environment desired. IENflg is defined as follows:

IENflg = FLAG TO SET ENVIRONMENT DESIRED
  = 1, EARTH ORBIT, LED TO GEO USES GREATER OF DEBRIS OR METEORITE FLUX, NO DEBRIS ABOVE 2000 Km.
  = 2, BEYOND EARTH ORBIT, 0.25 TO 2.00 AU

The other variables in the call statement are defined as follows:

Pin = CYCLE WORKING FLUID INLET PRESSURE (Grams/sq-Cm)
Tin = CYCLE WORKING FLUID INLET TEMPERATURE (K)
Tout = CYCLE WORKING FLUID OUTLET TEMPERATURE (K)
Qred = CYCLE TOTAL HEAT REJECTION RATE REQUIRED (Kw)

In addition to the call statement the main program must provide for the opening of a data file called RADAT. The contents of RADAT provide the balance of the data needed to run HREJEC. For the cases that will use the minimum amount of input data to run HREJEC (Iselec = 1), the contents of RADAT are as follows:

IENflg, Halt, HINCL, Rsun
Yrlnch, Time
Pin, Tin, Xmw, Tout
Grad

If desired, IENflg, Halt, HINCL, Rsun, Yrlnch, and Time may be set equal to zero and the code will use built-in default values for these parameters. If IENflg is not equal zero, then the required parameters are defined as:

Halt = ORBIT ALTITUDE (km)
HINCL = ORBIT INCLINATION ANGLE (28.5 TO 80.0 degrees, ONLY)
Rsun = DISTANCE FROM SUN (AU)
Yrlnch = YEAR IN WHICH VEHICLE IS PLACED IN ORBIT
Time = MISSION DURATION (Secs)
Pin = CYCLE WORKING FLUID INLET PRESSURE (Grams/sq-Cm)
Tin = CYCLE WORKING FLUID INLET TEMPERATURE (K)
Xmw = MOLECULAR WEIGHT OF CYCLE WORKING FLUID
Tout = CYCLE WORKING FLUID OUTLET TEMPERATURE (K)
Qred = CYCLE TOTAL HEAT REJECTION RATE REQUIRED (Kw)
For normal cases where a reasonable definition of the design is available, then the contents of RADAT will vary depending on the case being considered. If Iprob = 1, then the contents of RADAT are as follows:

\[
\begin{align*}
IEnfig & , \text{Ha}lt, \text{HINCL}, \text{Rsun} \\
\text{YrInch}, \text{Time} \\
\text{GAM}, \text{ARSF}, \text{Earm}, \text{PRob} \\
\text{CONFIG, Xtubes, Xnexpip, Xfleat} \\
\text{Dpipe, Ifuid, Imatll, Theta} \\
D2rad, Thickm, Thickf, Thick \\
\text{Em, Alpha, Hap, HArad} \\
\text{Tkflin, Rhocoating, Rhofin, RHOarm} \\
Xladiab, Xnchmas \\
Iflg2, Hman, Gap, Pitch \\
Dcan, Dhp, Rc, Rb \\
Tf, Tkflin, Tkcan, Tkbraze \\
\text{TKhp, Xnf, Xnw, RHOcan} \\
\text{RHObraze, THICKman, Wman} \\
\text{Xnp, R9, Dp, SUMLEN} \\
\text{THICKP, RHOPIP, THICK1, RHOINS}
\end{align*}
\]

The required parameters are defined as:

**ORBIT DESCRIPTION**

- \text{Halt} = ORBIT ALTITUDE (km)
- \text{HINCL} = ORBIT INCLINATION ANGLE (28.5 TO 80.0 degrees, ONLY)
- \text{Rsun} = DISTANCE FROM SUN (AU)
- \text{Yrlinc} = YEAR IN WHICH VEHICLE IS PLACED IN ORBIT
- \text{Time} = MISSION DURATION (Secs)

**RADIATOR DESCRIPTION**

- \text{GAM, ARSF} = PENETRATION CONSTANTS - FUNCTIONS OF THE SPECIFIC MATERIAL (SEE Table 3)
- \text{Earm} = YOUNG'S MODULUS OF ARMOR Grams/sq-Cm
- \text{PRob} = NON-PUNCTURE PROBABILITY (0.9, 0.99, 0.999, ETC.)
- \text{CONFIG} = 1.0, THEN RADIATOR IS A FLAT PLATE, ELSE IS A CONE OR CYLINDER
- \text{Xntubes} = NUMBER OF PRIMARY HEAT PIPE IN RADIATOR
- \text{Xnexpip} = NUMBER OF REDUNDANT HEAT PIPES
- \text{Xfleat} = HEAT PIPE EVAPORATOR LENGTH (Cm)
- \text{Dpipe} = HEAT PIPE INSIDE DIAMETER (Cm)
- \text{Ifuid} = HEAT PIPE WORKING FLUID ID NUMBER (SEE Table 2 for recommendations)
- \text{Imatll} = HEAT PIPE LINER MATERIAL ID NUMBER (SEE Table 2 for recommendations)
- \text{Theta} = CONE ANGLE FOR CONICAL RADIATOR (DEGREES)
- \text{D2rad} = MANIFOLD DIAMETER FOR CONICAL RADIATOR OR MANIFOLD LENGTH DIVIDED BY 3.141593 FOR FLAT PLATE (Cm)
- \text{Thickm} = RADIATOR EMISSIVITY CONTROL COATING THICKNESS (Cm)
- \text{Thickf} = RADIATOR FIN THICKNESS (Cm)
- \text{Thick} = HEAT PIPE WALL or LINER THICKNESS (Cm)
- \text{Em} = RADIATOR SURFACE EMISSIVITY
- \text{Alpha} = RADIATOR SURFACE ABSORTIVITY
- \text{Hap} = RADIATOR PROJECTED AREA (TOWARD SUN) (FRACTION OF TOTAL)
- \text{HArad} = RADIATOR ACTUAL AREA (USUALLY = 1.0)
- \text{Tkflin} = THERMAL CONDUCTIVITY OF FIN MATERIAL (Watts/(Cm-K))
- \text{Rhocoating} = COATING MATERIAL DENSITY (Grams/CC)
- \text{Rhofin} = FIN MATERIAL DENSITY (Grams/CC)
- \text{RHOarm} = ARMOR DENSITY (Grams/CC)
- \text{Xladiab} = LENGTH OF ADIABATIC PORTION OF THE HEAT PIPE (Cm)
- \text{Xnchmas} = MASS OF RADIATOR DEPLOYMENT MECHANISM (KG)
HEAT PIPE COOLED MANIFOLD DESCRIPTION

1flg2 = FLAG TO SET MANIFOLD WORKING FLUID
   1 = He-Xe MIXTURE
   2 = NaK

Hman = MANIFOLD HEIGHT (Cm)

Gap = MANIFOLD WIDTH (Cm)

Pitch = DISTANCE BETWEEN CAN (HEAT PIPES) CENTERLINES (Cm)

Dcan = OUTSIDE DIAMETER OF MANIFOLD BRAZE CAMS (Cm)

Dhp = INSIDE DIAMETER OF HEAT PIPE (Cm)

Rc = MANIFOLD BRAZE CAN INSIDE RADIUS (Cm)

Rb = BRAZE JOINT INSIDE RADIUS (Cm)

Tf = FIN THICKNESS (Cm)

Tkfina = THERMAL CONDUCTIVITY OF FIN MATERIAL (Watts/(Cm-K))

Tkcan = THERMAL CONDUCTIVITY OF MANIFOLD CAN MATERIAL (*)

Tkbraze = THERMAL CONDUCTIVITY OF MANIFOLD BRAZE ALLOY (*)

Tkhp = THERMAL CONDUCTIVITY OF HEAT PIPE WALL MATERIAL (*)

Xmf = TOTAL NUMBER OF FINS FOR THE MANIFOLD HEIGHT

Xm = MOLECULAR WEIGHT OF MANIFOLD WORKING FLUID

Rohoncan = DENSITY OF MANIFOLD MATERIAL (Grams/CC)

Rhobraze = DENSITY OF BRAZE MATERIAL (Grams/CC)

THICKman = MANIFOLD MATERIAL THICKNESS (Cm)

RHO = MANIFOLD FLOWRATE (KG/HR)

DUCTING DESCRIPTION

Xn9 = NUMBER OF 90 DEGREE ELBOWS OR EQUIVALENT IN DUCT SYSTEM

R9 = AVERAGE RADIUS FOR 90 DEGREE ELBOWS (Cm)

Dp = INSIDE DUCT DIAMETER (Cm)

Sthlen = TOTAL LENGTH OF DUCT SYSTEM (Cm)

THICKP = DUCT WALL THICKNESS (Cm)

RHOPIP = DUCT WALL DENSITY (Grams/CC)

THICKI = DUCT INSULATION THICKNESS (Cm)

RHOINS = DUCT INSULATION DENSITY (Grams/CC)

If lprob = 2, then the contents of RADAT are as follows:

IE, flg, Halt, HINCL, Rsun

Yr, Inch, Time

GAM, ARSF, Earm, PROB

CONFIG, Xntubes, Xnexp, Xiflat

Dhpipe, ifluid, Imat, Theta

D2rad, Thick, Thckf, Thck

Em, Alp, Hap, HArad

Tkfin, Rhocoating, Rhofin, RHOarm

Xladiab, Xmchmas

IHXflg, UEST, TCIN, TCOUT

WDOTS, AMWS, TINS, DENINS

DENSSH, DTUBE, PR, Ttube

AMPLATES, WDOTT, ACTUBE

Ifflg2, Hman, Gap, Pitch

Dcan, Dhp, Rc, Rb

Tf, Tkfina, Tkcan, Tkbraze

Tkhp, Xmf, Xm, RhoCan

RHObraze, THICKman, Hman

Xn9, R9, Dp, SUMLEN

THICKP, RHOPIP, THICKI, RHOINS

A-4.
The required parameters are defined as:

**ORBIT DESCRIPTION**

- **Halt** = ORBIT ALTITUDE (km)
- **HIncl** = ORBIT INCLINATION ANGLE (28.5 TO 80.0 degrees, ONLY)
- **Rsun** = DISTANCE FROM SUN (AU)
- **YrLnch** = YEAR IN WHICH VEHICLE IS PLACED IN ORBIT
- **Time** = MISSION DURATION (Secs)

**RADIATOR DESCRIPTION**

- **GAM,ARSF** = PENETRATION CONSTANTS - FUNCTIONS OF THE SPECIFIC MATERIAL (SEE Table 3)
- **Earm** = YOUNGS MODULUS OF ARMOR Grams/sq-Cm
- **PROB** = NON-PUNCTURE PROBABILITY (0.9, 0.99, 0.999, ETC.)
- **CONFIG** = 1.0, THEN RADIATOR IS A FLAT PLATE, ELSE IS A CONE OR CYLINDER
- **Xntubes** = NUMBER OF PRIMARY HEAT PIPE IN RADIATOR
- **Xnexpip** = NUMBER OF REDUNDANT HEAT PIPES
- **Xlfflat** = HEAT PIPE EVAPORATOR LENGTH (Cm)
- **Dhpipe** = HEAT PIPE INSIDE DIAMETER (Cm)
- **Ifina** = HEAT PIPE WORKING FLUID ID NUMBER (SEE Table 2 for recommendations)
- **Imat** = HEAT PIPE LINER MATERIAL ID NUMBER (SEE Table 2 for recommendations)
- **Theta** = CONE ANGLE FOR CONICAL RADIATOR (DEGREES)
- **D2rad** = MANIFOLD DIAMETER FOR CONICAL RADIATOR OR MANIFOLD LENGTH DIVIDED BY 3.141593 FOR FLAT PLATE (Cm)
- **Thickena** = RADIATOR EMISSIVITY CONTROL COATING THICKNESS (Cm)
- **Thickf** = RADIATOR FIN THICKNESS (Cm)
- **Thick** = HEAT PIPE WALL or LINER THICKNESS (Cm)
- **Em** = RADIATOR SURFACE EMISSIVITY
- **Alpha** = RADIATOR SURFACE ABSORTIVITY
- **Hmap** = RADIATOR PROJECTED AREA (TOWARD SUN) (FRACTION OF TOTAL)
- **HArad** = RADIATOR ACTUAL AREA (USUALLY = 1.0)
- **Tkfin** = THERMAL CONDUCTIVITY OF FIN MATERIAL (Watts/(Cm-K))
- **Rhocone** = COATING MATERIAL DENSITY (Grams/CC)
- **Rhocon** = ARMOR DENSITY (Grams/CC)
- **Xladlab** = LENGTH OF ADIABATIC PORTION OF THE HEAT PIPE (Cm)
- **Xmchmas** = MASS OF RADIATOR DEPLOYMENT MECHANISM (KG)

**HEAT SINK HEAT EXCHANGER DESCRIPTION**

- **IXHxifl** = 1, THEN TUBE SIDE FLUID IS LITHIUM
- **IXHxifg** = 2, THEN TUBE SIDE FLUID IS NaK-78
- **UEST** = INITIAL VALUE OF Uoverall (Watts/sqCm-K)
- **TCIN** = COLD SIDE Inlet Temperature (K)
- **TCOUT** = COLD SIDE Outlet Temperature (K)
- **WDOTS** = SHELL SIDE FLUID Flourate (KG/Sec)
- **AMW** = MOLECULAR WEIGHT OF SHELL SIDE FLUID
- **TINS** = OD INSULATION THICKNESS (Cm)
- **DENINS** = OD INSULATION DENSITY (Grams/CC)
- **DENSSH** = SHELL MATERIAL Density (Grams/CC)
- **DTUBE** = Outside TUBE Diameter - (Cm)
- **PR** = TUBE PITCH RATIO
- **TUBE** = TUBE Wall Thickness (Cm)
- **ANPLATES** = NUMBER OF SHELL SIDE BAFFLES (ASSUMED EQUALLY SPACED)
- **WDOTT** = TUBE -SIDE FLUID Flourate (KG/SEC)
- **AKTUBE** = TUBE Wall Thermal Conductivity (Watts/Cm-K)
HEAT PIPE COOLED MANIFOLD DESCRIPTION

Iflgz = FLAG TO SET MANIFOLD WORKING FLUID
   1 = He-Xe MIXTURE
   2 = NaK

Hman = MANIFOLD HEIGHT (Cm)
Gap = MANIFOLD WIDTH (Cm)
Pitch = DISTANCE BETWEEN CAN (HEAT PIPES) CENTERLINES (Cm)
Dcan = OUTSIDE DIAMETER OF MANIFOLD BRAZE CANS (Cm)
Dhp = INSIDE DIAMETER OF HEAT PIPE (Cm)
Rc = MANIFOLD BRAZE CAN INSIDE RADIUS (Cm)
Rb = BRAZE JOINT INSIDE RADIUS (Cm)
Tf = FIN THICKNESS (Cm)
Tkfin = THERMAL CONDUCTIVITY OF FIN MATERIAL (Watts/(Cm-K))
Tkcan = THERMAL CONDUCTIVITY OF MANIFOLD CAN MATERIAL (W")
Tkbraze = THERMAL CONDUCTIVITY OF MANIFOLD BRAZE ALLOY (W")
Tkhp = THERMAL CONDUCTIVITY OF HEAT PIPE WALL MATERIAL (W")
Xnf = TOTAL NUMBER OF FINS FOR THE MANIFOLD HEIGHT
Xcan = MOLECULAR WEIGHT OF MANIFOLD WORKING FLUID
RhoCan = DENSITY OF MANIFOLD MATERIAL (Grams/CC)
RhoBraze = DENSITY OF BRAZE MATERIAL (Grams/CC)
Thickman = MANIFOLD MATERIAL THICKNESS (Cm)
Wman = MANIFOLD FLOWRATE (KG/HR)

NaK PIPING DESCRIPTION

XN9 = NUMBER OF 90 DEGREE ELBOWS OR EQUIVALENT IN DUCT SYSTEM
R9 = AVERAGE RADIUS FOR 90 DEGREE ELBOWS (Cm)
Dp = INSIDE DUCT DIAMETER (Cm)
Sumlen = TOTAL LENGTH OF DUCT SYSTEM (Cm)
Thickp = DUCT WALL THICKNESS (Cm)
RhoPip = DUCT WALL DENSITY (Grams/CC)
ThickI = DUCT INSULATION THICKNESS (Cm)
RHOINS = DUCT INSULATION DENSITY (Grams/CC)

If lprob = 3, then the contents of RADAT are as follows:

IENflg,Halt,HINCL,Rsun
Yrlinch,Time
GAM,ARSF,Earm,PROB
CONFIG,Xntubes,Xnexpip,Xlflat
Dhpipe,lfluid,imatl,theta
D2rad,thickm,thickf,thick
Em,Alpha,Hap,HArad
Tkfin,Rhocoating,Rhofin,RHOarm
Xlambda,b,xmcmaas

Cman,Hman,Gap,thickins
Rhoins,Tout,Tbraze,Tkcan
Tkbraze,Tkhp,Pin,Tin
Xin,Rhopip,Rhocan,Rhobraze
Thickman,Thtpip,Wman

The required parameters are defined as:

ORBIT DESCRIPTION
Halt = ORBIT ALTITUDE (km)
HINCL = ORBIT INCLINATION ANGLE (28.5 TO 80.0 degrees, ONLY)
Rsun = DISTANCE FROM SUN (AU)
Yrlinch = YEAR IN WHICH VEHICLE IS PLACED IN ORBIT
Time = MISSION DURATION (Secs)
RADIATOR DESCRIPTION

\[ \text{Gam,Arf} = \text{penetration constants - functions of the specific material (see Table 3)} \]
\[ \text{Earm} = \text{Young's modulus of armor Grams/sq-Cm} \]
\[ \text{Prob} = \text{non-puncture probability (0.9, 0.99, 0.999, etc.)} \]
\[ \text{Config} = 1.0, \text{then radiator is a flat plate, else is a cone or cylinder} \]
\[ \text{Xntubea} = \text{number of primary heat pipe in radiator} \]
\[ \text{Xnexpip} = \text{number of redundant heat pipes} \]
\[ \text{Xiflat} = \text{heat pipe evaporator length (Cm)} \]
\[ \text{Dpipe} = \text{heat pipe inside diameter (Cm)} \]
\[ \text{Ifluid} = \text{heat pipe working fluid ID number (see Table 2 for recommendations)} \]
\[ \text{Imatt} = \text{heat pipe liner material ID number (see Table 2 for recommendations)} \]
\[ \text{Theta} = \text{cone angle for conical radiator (degrees)} \]
\[ \text{D2rad} = \text{manifold diameter for conical radiator or manifold length divided by 3.141592 for flat plate (Cm)} \]
\[ \text{Thickm} = \text{radiator emissivity control coating thickness (Cm)} \]
\[ \text{Thickf} = \text{radiator fin thickness (Cm)} \]
\[ \text{Em} = \text{radiator surface emissivity} \]
\[ \text{Alpha} = \text{radiator surface absorptivity} \]
\[ \text{Halrad} = \text{radiator actual area (usually = 1.0)} \]
\[ \text{Tkin} = \text{thermal conductivity of fin material (Watts/(Cm-K))} \]
\[ \text{Rhocoating} = \text{coating material density (Grams/CC)} \]
\[ \text{Rhofin} = \text{fin material density (Grams/CC)} \]
\[ \text{RHOarm} = \text{armor density (Grams/CC)} \]
\[ \text{Xtadiab} = \text{length of adiabatic portion of the heat pipe (Cm)} \]
\[ \text{Xmchmas} = \text{mass of radiator deployment mechanism (Kg)} \]

CONDENSER/MANIFOLD DESCRIPTION

\[ \text{Cman} = \text{manifold flat length (Cm)} \]
\[ \text{Hman} = \text{manifold height (Cm)} \]
\[ \text{Gap} = \text{average manifold condenser surface space (Cm)} \]
\[ \text{THICKins} = \text{manifold insulation thickness (Cm)} \]
\[ \text{RHOins} = \text{manifold insulation density (Grams/CC)} \]
\[ \text{Tout} = \text{manifold outlet temperature (K)} \]
\[ \text{Tbraze} = \text{manifold-heat pipe braze material thickness (Cm)} \]
\[ \text{TKcan} = \text{manifold wall material thermal conductivity (W/CmK)} \]
\[ \text{TKbraze} = \text{braze material thermal conductivity (W/CmK)} \]
\[ \text{Pin} = \text{manifold inlet pressure (Grams/sqCm)} \]
\[ \text{Tin} = \text{manifold inlet temperature (K)} \]
\[ \text{Xin} = \text{manifold inlet vapor fraction (quality)} \]
\[ \text{RHOpip} = \text{heat pipe wall material density (Grams/CC)} \]
\[ \text{RHOcan} = \text{manifold wall material density (Grams/CC)} \]
\[ \text{Thtpip} = \text{heat pipe wall thickness (Cm)} \]
\[ \text{Wman} = \text{manifold flowrate (Kg/Hr)} \]

Sample input files are supplied on the disk that contains the source code for the HREJEC subroutine.
APPENDIX B
SAMPLE CASES
CASE 1: DIRECT COOLED BRAYTON CONFIGURATION - HEAT REJECTION SYSTEM PHYSICAL DATA AVAILABLE

******************************************************************************
CONTENTS OF CALL: HREJEC(2, 1, 1, 5624.56, 411.1, 388.89, 250.0)
******************************************************************************

CONTENTS OF DATA FILE 'RADAT'

1, 1000.0, 30.0, 1.0
2000.0, 0.315360E+09
1.7, 1.7, 0.703070E+09, 0.931693
1.0, 643.810, 64.381, 206.188
2.54, 2, 8, 0.0
1821.84, 0.0, 0.127, 0.762E-02
0.8, 0.5, 1.0, 2.0
0.849788, 0.0, 1.81009, 1.81009
0.0, 0.0
1, 206.188, 17.9933, 8.890
2.75335, 2.53999, 1.32588, 1.32079
0.253998E-01, 1.93842, 0.173073, 0.484604
3.91193, 811.766, 40.0, 0.08932
8.56988, 0.285537, 21.6435
12.0, 149.684, 37.6211, 41.9.053
0.299369, 8.0932, 10.16, 0.256295

******************************************************************************

OUTPUT FROM HREJEC

******************************************************************************

*** HEAT REJECTION SYSTEM FOR A BRAYTON CYCLE SYSTEM IN WHICH CYCLE WASTE HEAT IS REJECTED DIRECTLY FROM THE CYCLE WORKING FLUID IN A HEAT PIPE COOLED GAS MANIFOLD ***

RADIATOR DEFINITION INPUTS

GAMMA = 1.70000
ABSF = 1.70000
ARMOR DENSITY (Grams/CC) = 1.81009
YOUNG'S MODULUS OF ARMOR (Grams/CC) = 0.703070E+09
EXPOSURE TIME OR MISSION DURATION (Secs) = 0.315360E+09
NON-PUNCTURE PROBABILITY = 0.92386
RADIATOR HEAT REJECTION RATE (Kw) = 250.0
AVERAGE RADIATOR SURFACE TEMPERATURE (K) = 399.263
NUMBER OF PRIMARY HEAT PIPE IN RADIATOR = 643.810
NUMBER OF REDUNDANT HEAT PIPES= 64.3810
HEAT PIPE EVAPORATOR LENGTH (Cm)= 206.188
HEAT PIPE INSIDE DIAMETER (Cm)= 2.54000
HEAT PIPE WORKING FLUID ID NUMBER= 2
HEAT PIPE LINER MATERIAL ID NUMBER= 8
COME ANGLE FOR CONICAL RADIATOR (DEGREES) = 0.000000
MANIFOLD DIAMETER FOR CONICAL RADIATOR OR MANIFOLD LENGTH DIVIDED BY 3.141593 FOR FLAT PLATE (Cm) = 1821.84
HEAT PIPE MALL or LINER THICKNESS (Cm)= 0.000000
LENGTH OF ADIABATIC PORTION OF THE HEAT PIPE (Cm)= 0.000000
RADIATOR EMISIVIVITY CONTROL COATING THICK.(Cm)= 0.000000
RADIATOR FIN THICKNESS (Cm)= 0.127000
HEAT PIPE WALL or LINER THICKNESS (Cm)= 0.762000E-02
RADIATOR SURFACE EMISIVIVITY= 0.800000
RADIATOR SURFACE ABSOPTIVITY= 0.500000
RADIATOR PROJ. AREA (FRAC. OF TOT.)= 1.00000
RADIATOR ACTUAL AREA (FRACTION)= 2.00000
THERMAL COND. OF FIN MATERIAL (W/Cm-K) = 0.849773
COATING MATERIAL DENSITY (Grams/CC)= 0.000000
FIN MATERIAL DENSITY (Grams/CC)= 1.81009
MASS OF RADIATOR DEPLOYMENT MECHANISM (KG) = 0.000000
TOTAL HEAT AVERAGE Radiator Emissivity
REJECTED EVAPORATOR FIN Coating
(KWt) TEMP (K) Thick (Cm) Thick (Cm)
250.0000 399.2626 0.1270 0.0000

Actual Effective
Core-side Radiator
Area(sq-Me.) Area(sq-Me)
174.6257 349.2515

HEAT PIPE DESIGN DETAILS - DIME in Cm
Pipe ID Wick Thick #Arteries Art ID Art Wall Pipe wall
2.5400 0.0129 7.6200 0.6452 0.0129 0.0076
Evap Length Adi Length Cond Length Total Length
206.1880 0.0000 305.1339 511.3219

RADIATOR MASS BREAKDOWN - Mass in KG
Heat Pipes Fluids FINS Emiss. Cont.
624.6960 33.7311 315.4453 0.0000
O.D.ARMOR I.D.ARMOR Structure TOTAL RADIATOR
342.0656 342.0656 0.0000 1658.0040

IENfig (ORBIT SELECTION) = 1
  IENfig=1, EARTH ORBIT (LEO-GEO)
  IENfig=2, SOLAR ORBIT (0.5 to 2.0 AU)
ORBIT ALTITUDE (Km) = 1000.00
ORBIT INCLINATION ANGLE (Degrees) = 30.0000
DISTANCE FROM SUN (AU) = 1.00000
YEAR SATELLITE LAUNCHED = 2000.00

HEAT PIPE COOLED MANIFOLD DEFINITION VARIABLES

iflg2 = 1
MANIFOLD HEIGHT (Cm)= 206.188
MANIFOLD WIDTH (Cm)= 17.9933
DIST. BETWN CAN(HEAT PIPES)C-LINES (Cm)= 8.89000
NUMBER OF HEAT PIPES IN RADIATOR= 643.810
NUMB. OF REDUNDENT HEAT PIPES IN RADIATOR= 64.3810
INSIDE DIAMETER OF HEAT PIPE (Cm)= 2.54000
INSIDE DIAMETER OF HEAT PIPE (Cm)= 2.53999
MANIFOLD BRAZE CAN INSIDE RADIUS (Cm)= 1.32588
BRAZE JOIN INSIDE RADIUS (Cm)= 1.32079
FIN THICKNESS (Cm)= 0.253898E-01
THERM. COND. OF FIN MATERIAL (W/(Cm-K))= 1.93842
THERM. COND. OF MANIFOLD CAN MATERIAL (W/(Cm-K))= 0.173073
THERM. COND. OF MANIF. BRAZE ALLOY (W/(Cm-K))= 0.486604
THERM. COND. OF HEAT PIPE WALL MATL (W/(Cm-K))= 3.91193
TOTAL NUMBER OF FINS FOR THE MANIFOLD HEIGHT= 811.766
DENSITY OF MANIFOLD MATERIAL (Grms/CC)= 8.08932
DENSITY OF BRAZE MATERIAL (Grms/CC)= 8.56988
MANIFOLD MATERIAL THICKNESS (Cm)= 0.285357
MANIFOLD INLET PRESSURE (Grms/sq-Cm)= 5624.56
MANIFOLD INLET TEMPERATURE (K)= 250.000
MANIFOLD FLOW RATE (KG/HR)= 71.000
MANIFOLD AND RADIATOR HEAT LOAD (KWt)= 250.000
MOLECULAR WEIGHT OF MANIFOLD WORKING FLUID= 40.0000
MANIFOLD PRESSURE DROP (Grms/sq-Cm)= 955.366
MANIFOLD FILM TEMPERATURE DROP (K)= 0.475179
NAK INVENTORY MASS (KG) = 131.482
NET MASS OF HEAT PIPE MANIFOLD (KG) = 6491.51
DUCTING INPUT VARIABLES

NUMB. OF 90 DEG. ELBOWS OR EQUIV. = 12.0000
AVERAGE RADIUS FOR 90 DEGREE ELBOWS (Cm) = 149.684
INSIDE DUCT DIAMETER (Cm) = 37.4211
TOTAL LENGTH OF DUCT SYSTEM (Cm) = 449.053
GAS VELOCITY IN DUCTS (M/SEC) = 30.4785
GAS TEMPERATURE (K) = 411.100
GAS PRESSURE (Grams/sq-Cm) = 5624.56
DUCT WALL THICKNESS (Cm) = 0.299369
DUCT WALL DENSITY (Grams/CC) = 8.08932
DUCT INSULATION THICKNESS (Cm) = 10.1600
DUCT INSULATION DENSITY (Grams/CC) = 0.256288
GAS MOLECULAR WEIGHT = 0.000000
DUCT SYSTEM PRESSURE DROP (Grams/sq-Cm) = 57.9987
DUCT SYSTEM MASS (KG) = 1266.74

MASS SUMMARY FOR DIRECT BRAYTON SYSTEM

HEAT PIPE COOLED GAS MANIFOLD MASS (KG) = 131.482
MANIFOLD DUCTING MASS (KG) = 1266.74
RADIATOR MASS (KG) = 1658.00

DIRECT BRAYTON SYSTEM MASS (KG) = 3056.23
CASE 2: LIQUID LOOP COOLED BRAYTON CONFIGURATION - HEAT REJECTION SYSTEM PHYSICAL DATA AVAILABLE

CONTENTS OF CALL: HREJEC(2, 1, 5624.56, 466.7, 444.45, 250.0)

CONTENTS OF DATA FILE 'RADAT'

```
1, 1000.0, 30.0, 1.0
2000.0, 0.315360E+09
1.7, 1.7, 0.703070E+09, 0.944048
1.0, 259.676, 0.59676, 45.720
2.54, 2, 8, 0.0
734.826, 0.0, 0.127, 0.762E-02
0.8, 0.5, 1.0, 2.0
0.849788, 0.0, 1.81009, 1.81009
0.0, 0.0
2, 10.1950, 0, 1.0
200.0, 0.0, 0.127, 0.762E-02
0.8, 0.5, 1.0, 2.0
0.849788, 0.0, 1.81009, 1.81009
0.0, 0.0
2, 10.1950, 0, 1.0
200.0, 0.0, 0.127, 0.762E-02
0.8, 0.5, 1.0, 2.0
0.849788, 0.0, 1.81009, 1.81009
0.0, 0.0
2, 10.1950, 0, 1.0
200.0, 0.0, 0.127, 0.762E-02
0.8, 0.5, 1.0, 2.0
0.849788, 0.0, 1.81009, 1.81009
0.0, 0.0
2, 10.1950, 0, 1.0
200.0, 0.0, 0.127, 0.762E-02
0.8, 0.5, 1.0, 2.0
0.849788, 0.0, 1.81009, 1.81009
0.0, 0.0
2, 10.1950, 0, 1.0
200.0, 0.0, 0.127, 0.762E-02
0.8, 0.5, 1.0, 2.0
0.849788, 0.0, 1.81009, 1.81009
0.0, 0.0
```

OUTPUT FROM HREJEC

*** HEAT REJECTION SYSTEM FOR A BRAYTON CYCLE SYSTEM IN WHICH CYCLE WASTE HEAT IS REJECTED TO A PUMPED NaK LOOP FROM THE CYCLE WORKING FLUID TO A HEAT PIPE COOLED LIQUID MANIFOLD ***

RADIATOR DEFINITION INPUTS

```
GAMMA = 1.70000
ARSF = 1.70000
ARMOR DENSITY (Grams/CC) = 1.81009
YOUNG'S MODULUS OF ARMOR (Grams/CC) = 0.703070E+09
EXPOSURE TIME OR MISSION DURATION (Secs) = 0.315360E+09
NON-PUNCTURE PROBABILITY = 0.934292
RADIATOR HEAT REJECTION RATE (kW) = 250.0
AVERAGE RADIATOR SURFACE TEMPERATURE (K) = 419.225
NUMBER OF PRIMARY HEAT PIPE IN RADIATOR = 259.676
NUMBER OF REDUNDANT HEAT PIPES = 25.9676
HEAT PIPE EVAPORATOR LENGTH (Cm) = 45.720
HEAT PIPE INSIDE DIAMETER (Cm) = 2.5400
HEAT PIPE WORKING FLUID ID NUMBER = 2
HEAT PIPE LINER MATERIAL ID NUMBER = 8
CONE ANGLE FOR CONICAL RADIATOR (DEGREES) = 0.000000
MANIFOLD DIAMETER FOR CONICAL RADIATOR OR MANIFOLD LENGTH DIVIDED BY 3.141593 FOR FLAT PLATE (Cm) = 734.826
RADIATOR EMISSIVITY CONTROL COATING THICK. (Cm) = 0.000000
RADIATOR FIN THICKNESS (Cm) = 0.127000
HEAT PIPE WALL or LINER THICKNESS (Cm) = 0.762000E-02
RADIATOR SURFACE EMISSIVITY = 0.800000
RADIATOR SURFACE ABSORPTIVITY = 0.500000
RADIATOR PROJ. AREA (FRACT. OF TOT.) = 1.000000
RADIATOR ACTUAL AREA (FRACTION) = 2.000000
THERMAL COND. OF FIN MATERIAL (W/Cm-K) = 0.849773
COATING MATERIAL DENSITY (Grams/CC) = 0.000000
FIN MATERIAL DENSITY (Grams/CC) = 1.81009
LENGTH OF ADIABATIC PORTION OF THE HEAT PIPE (Cm) = 0.000000
MASS OF RADIATOR DEPLOYMENT MECHANISM (KG) = 0.000000
```
TOTAL HEAT AVERAGE Radiator Emissivity
REJECTED EVAPORATOR FIN Coating
(KWt) TEMP (K) Thick (Cm) Thick (Cm)
250.0000 419.2248 0.1270 0.0000

Actual Effective
(one-side) Radiator
Area(sq-Me.) Area(sq-Me.)
130.8736 261.7472

HEAT PIPE DESIGN DETAILS - DIMS in Cm
Pipe ID Wick Thick #Arties Art ID Art Wall Pipe wall
2.5400 0.0129 7.6200 0.6452 0.0129 0.0076
Evap Length Adj Length Cond Length Total Length
45.7200 0.0000 566.9699 612.6899

RADIATOR MASS BREAKDOWN - Mass in KG
Heat Pipes Fluids FINS Emiss. Cont.
301.8325 16.2465 236.4111 0.0000
O.D.ARMOR I.D.ARMOR Structure TOTAL RADIATOR
350.6339 350.6339 0.0000 1255.7580

IENf1g (ORBIT SELECTION) = 1
IENflg=l, EARTH ORBIT (LEO-GE0)
IENflg=2, SOLAR ORBIT (0.5 to 2.0 AU)
ORBIT ALTITUDE (KM) = 1000.00
ORBIT INCLINATION ANGLE (Degrees) = 30.0000
DISTANCE FROM SUN (AU) = 1.00000
YEAR SATELLITE LAUNCHED = 2000.00

HEAT PIPE COOLED MANIFOLD DEFINITION VARIABLES
Ifig2 = 2
MANIFOLD HEIGHT (Cm)= 36.1541
MANIFOLD WIDTH (Cm)= 15.2400
DIST. BETW CAN(HEAT PIPES)-C-LINES (Cm)= 8.89000
NUMBER OF HEAT PIPES IN RADIATOR= 259.676
NUMB. OF REDUNDANT HEAT PIPES IN RADIATOR= 25.9676
OUTSIDE DIAMETER OF BRAZE CAN(Cm)= 2.75335
INSIDE DIAMETER OF HEAT PIPE (Cm)= 2.53999
MANIFOLD BRAZE CAN INSIDE RADIUS (Cm)= 1.32588
BRAZE JOINT INSIDE RADIUS (Cm)= 1.32079
FIN THICKNESS (Cm)= 0.253898E-01
THERM. COND. OF FIN MATERIAL (W/(Cm-K))= 1.93842
THERM. COND. OF MANIFOLD CAN MATERIAL (W/CmK)= 0.173073
THERM. COND. OF MANIF. BRAZE ALLOY (W/CmK)= 0.484604
THERM. COND. OF HEAT PIPE WALL MATL (W/CmK)= 3.91193
TOTAL NUMBER OF FINS FOR THE MANIFOLD HEIGHT= 180.000
DENSITY OF MANIFOLD MATERIAL (Grams/CC)= 8.08932
DENSITY OF BRAZE MATERIAL (Grams/CC)= 8.56988
MANIFOLD MATERIAL THICKNESS (Cm)= 0.285537
MANIFOLD INLET PRESSURE (Grams/sq-Cm)= 562.456
MANIFOLD INLET TEMPERATURE (K)= 466.700
MANIFOLD FLOWRATE (KG/HR)= 8.16972
MANIFOLD AND RADIATOR HEAT LOAD (KWt)= 250.000
MOLECULAR WEIGTH OF MANIFOLD WORKING FLUID= 40.0000
MANIFOLD PRESSURE DROP (Grams/sq-Cm)= 27.7819
MANIFOLD FILM TEMPERATURE DROP (K)= 36.1043
MAX INVENTORY MASS (KG) = 1001.46
NET MASS OF HEAT PIPE MANIFOLD (KG) = 585.325
**PIPING DEFINITION VARIABLES**

- **NUMB. OF 90 DEG. ELBOWS OR EQUIV.** = 12.0000
- **AVERAGE RADIUS FOR 90 DEGREE ELBOWS (Cm)** = 14.8324
- **INSIDE PIPE DIAMETER (Cm)** = 3.70810
- **TOTAL LENGTH OF PIPE SYSTEM (Cm)** = 762.000
- **MAX VELOCITY IN PIPES (M/SEC)** = 9.14358
- **MAX TEMPERATURE (K)** = 466.700
- **MAX TEMPERATURE (K)** = 466.700
- **MAX PRESSURE (Grams/sq-Cm)** = 5624.56
- **PIPE WALL THICKNESS (Cm)** = 0.254000
- **PIPE WALL DENSITY (Grams/CC)** = 8.08932
- **PIPE INSULATION THICKNESS (Cm)** = 10.1600
- **PIPE INSULATION DENSITY (Grams/CC)** = 0.384444
- **PIPE SYSTEM PRESSURE DROP (Grams/sq-Cm)** = 1696.15
- **PIPE SYSTEM MASS (KG)** = 210.384
- **MAX TEMPERATURE (K)** = 466.700

**HEAT SOURCE/SINK HEAT EXCHANGER DEFINITION**

- **TUBE SIDE FLUID FLAG =** 2
- **Heat Rate or Duty (KWt)** = 250.000
- **HOT SIDE Inlet Temperature (K)** = 466.700
- **HOT SIDE Outlet Temperature (K)** = 444.450
- **COLD SIDE Inlet Temperature (K)** = 416.672
- **COLD SIDE Outlet Temperature (K)** = 450.053
- **SHELL SIDE FLUID Flowrate (KG/HR)** = 21.6045
- **SHELL MATERIAL Density (Grams/CC)** = 8.08934
- **INSIDE TUBE Diameter (Cm)** = 0.952500
- **TUBE Wall Thickness (Cm)** = 0.508000E-01
- **TUBE Side Fluid Flowrate (KG/Sec)** = 8.16972
- **TUBE Wall Thermal Conductivity (W/(Cm-K))** = 10.2137
- **INSULATION MASS (KG)** = 17.9806
- **HEAD MASS (KG)** = 0.348627
- **SHELL MASS (KG)** = 2.44039
- **PLATE MASS (KG)** = 0.128417
- **TUBE SHEETS MASS (KG)** = 0.348627
- **TUBE MASS (KG)** = 7.66617
- **STRUCTURE AND BRACKETS MASS (KG)** = 1.44564
- **MASS OF NaK IN H-X (KG)** = 4.99176
- **Net Mass of Shell and Tube Unit (DRY) (KG)** = 30.3585

**NaK PUMP DEFINITION**

- **NaK INLET TEMPERATURE (K)** = 466.700
- **NaK FLW RATE (KG/SEC)** = 8.16972
- **PIPING SYSTEM PRESSURE DROP (G/SC)** = 1696.15
- **NaK SID HEAT EXCHANGER PRESSURE DROP (G/SC)** = 79.1445
- **NaK MANIFOLD PRESSURE DROP (G/SC)** = 27.7819
- **NaK LOOP PRESSURE DROP (G/SC)** = 1803.08
- **NaK LOOP PUMP POWER REQUIRED (HYDRAULIC) (WATTS)** = 1738.59
- **E-M PUMP MASS (DRY) (KG)** = 271.508
NAK LOOP EXPANSION COMPENSATOR DEFINED

VOLUME ACCUMULATOR N\(\text{a}\)k MASS (KG) = 53.7542
VOLUME ACCUMULATOR MASS (WET) (KG) = 110.184

MASS SUMMARY FOR INDIRECT BRAYTON SYSTEM

HEAT SINK HEAT EXCHANGER MASS (KG)(DRY) = 30.3585
HEAT EXCHANGER N\(\text{a}\)k MASS (KG) = 4.99176
N\(\text{a}\)k PIPING SYSTEM MASS (KG)(DRY) = 210.384
MASS OF NaK IN PIPING SYSTEM (KG) = 9.30602
MASS OF EM PUMP (KG) (WET) = 271.508
HEAT PIPE/NaK MANIFOLD MASS (KG) (DRY) = 585.325
MASS OF NaK IN MANIFOLD (KG) = 1001.46
EXPANSION COMPENSATOR MASS (KG) (DRY) = 110.184
MASS OF NaK IN EXPANSION COMPENSATOR(KG) = 53.7542
RADIATOR MASS (KG) = 1255.76

INDIRECT BRAYTON SYSTEM MASS (KG) (WET) = 3533.03
CASE 3: SHEAR FLOW CONDENSER IN A POTASSIUM RANKINE CYCLE - HEAT REJECTION SYSTEM PHYSICAL DATA AVAILABLE

******************************************************************************
OUTPUT FROM HREJEC
******************************************************************************

*** HEAT REJECTION SYSTEM FOR A RANKINE CYCLE SYSTEM IN WHICH CYCLE WASTE HEAT IS REJECTED DIRECTLY FROM THE CYCLE WORKING FLUID IN A HEAT PIPE COOLED CONDENSER ***

RADIATOR DEFINITION INPUTS

GAMMA = 1.70000
ARSF = 1.70000
ARMOR DENSITY (Grams/CC) = 1.81009
YOUNG'S MODULUS OF ARMOR (Grams/CC) = 0.703070E+09
EXPOSURE TIME OR MISSION DURATION (Secs) = 0.315300E+09
NON-PUNCTURE PROBABILITY = 0.961311
RADIATOR HEAT REJECTION RATE (IG/t) = 250.0
AVERAGE RADIATOR SURFACE TEMPERATURE (K) = 827.144
NUMBER OF PRIMARY HEAT PIPE IN RADIATOR = 41.3705
NUMBER OF REDUNDANT HEAT PIPES = 2.54000
HEAT PIPE EVAPORATOR LENGTH (Cm) = 43.2394
HEAT PIPE INSIDE DIAMETER (Cm) = 2.54000
HEAT PIPE WORKING FLUID ID NUMBER = 5
HEAT PIPE LINER MATERIAL ID NUMBER = 7
CONE ANGLE FOR CONICAL RADIATOR (DEGREES) = 0.000000
MANIFOLD DIAMETER FOR CONICAL RADIATOR OR MANIFOLD LENGTH DIVIDED BY 3.141593 FOR FLAT PLATE (Cm) = 66.8968
RADIATOR EMISSIVITY CONTROL COATING THICK. (Cm) = 0.000000
RADIATOR FIN THICKNESS (Cm) = 0.127000
HEAT PIPE WALL or LINER THICKNESS (Cm) = 0.762000E-02
RADIATOR SURFACE EMISSIVITY = 0.849773
RADIATOR SURFACE ABSORTIVITY = 0.500000
RADIATOR PROJ. AREA (FRACT. OF TOT.) = 1.00000
RADIATOR ACTUAL AREA (FRACTION) = 2.00000
THERMAL COND. OF FIN MATERIAL (W/Cm-K) = 8.49773
COATING MATERIAL DENSITY (Grams/CC) = 0.000000
FIN MATERIAL DENSITY (Grams/CC) = 1.81009
LENGTH OF ADIABATIC PORTION OF THE HEAT PIPE (Cm) = 0.000000
MASS OF RADIATOR DEPLOYMENT MECHANISM (KG) = 0.000000
TOTAL HEAT AVERAGE Radiator Emissivity
REJECTED EVAPORATOR FIN Coating
(KWt) TEMP (K) Thick (Cm) Thick (Cm)
250.0000 827.1442 0.1270 0.0000

Actual Effective
(one-side) Radiator
Area(sq-Me) Area(sq-Me)
6.7057 13.4114

HEAT PIPE DESIGN DETAILS - DIMS in Cm
Pipe ID Wick Thick #Arteries Art ID Art Wall Pipe wall
2.5400 0.0129 7.6200 0.6452 0.0129 0.0076
Evap Length Adi Length Cond Length Total Length
43.2394 0.0000 319.1042 362.3436

RADIATOR MASS BREAKDOWN - Mass in KG
Heat Pipes Fluids FINS Emiss. Cont.
26.6852 1.3352 8.4793 0.0000
O.D.ARMOR I.D.ARMOR Structure TOTAL RADIATOR
34.6265 34.6265 0.0000 105.7527

IENfig (ORBIT SELECTION) = 1
IENfig=1, EARTH ORBIT (LEO-GEO)
IENfig=2, SOLAR ORBIT (0.5 to 2.0 AU)
ORBIT ALTITUDE (KM) = 1000.00
ORBIT INCLINATION ANGLE (Degrees) = 30.0000
DISTANCE FROM SUN (AU) = 1.00000
YEAR SATELLITE LAUNCHED = 2000.00

HEAT PIPE COOLED CONDENSER DESCRIPTION
MANIFOLD FLAT LENGTH (Cm) = 210.162
MANIFOLD HEIGHT (Cm) = 43.2394
AVERAGE MANIFOLD COND.SURF.SPACE(Gap)(Cm)= 1.05984
MANIFOLD INSULATION THICKNESS (Cm) = 10.1600
MANIFOLD INSULATION DENSITY (Grams/CC) = 0.00000
NUMBER OF PRIMARY HEAT PIPES ATTACHED TO COOL CONDENSER SURFACE = 41.3705
NUMBER OF REDUNDENT HEAT PIPES USED TO COOL CONDENSER SURFACE = 4.13705
MANIFOLD WALL MATERIAL THICKNESS(Cm)= 0.158750
MANIFOLD-HEAT PIPE BRAZE MATERIAL THICKNESS (Cm) = 0.508000E-02
HEAT PIPE WALL THICKNESS (Cm) = 0.508000E-01
MANIFOLD WALL MAT. THERMAL COND. (W/CmK) = 0.173073
BRAZE MAT. THERMAL COND. (W/CmK) = 0.605756
HEAT PIPE WALL MAT. THERMAL COND. (W/CmK) = 0.173073
MANIFOLD WALL MATERIAL DENSITY (Grams/CC)= 8.08932
BRAZE MATERIAL DENSITY (Grams/CC) = 8.40969
HEAT PIPE WALL MATERIAL DENSITY(Grams/CC)= 8.08932
HEAT PIPE WORKING FLUID NUMBER = 5

MANIFOLD OPERATING CONDITIONS
INLET PRESSURE (G/SC) = 140.616
INLET TEMPERATURE (K) = 855.559
MEAN CONDENSER QUALITY = 1.00000
OUTLET TEMPERATURE (K) = 849.999
MANIFOLD FLOWRATE (KG/Hr) = 442.541
MANIFOLD DUTY (KWt) = 250.000
COMPUTED RESULTS

MANIFOLD PRESSURE DROP (G/SC) = 6.96161
MANIFOLD FILL TEMPERATURE DROP (K) = 25.6274
CONDENSER CONDENSATE FLOW REGIME PARAMETER = 0.127759
CONDENSER IS OPERATING IN SHEAR FLOW REGIME

CONDENSATE FILM REYNOLDS NUMBER = 1901.94
MARTINELLI PARAMETER = 0.133079E-01
VAPOR REYNOLDS NUMBER = 3803.88
MANIFOLD MASS (KG) = 39.6255

MASS SUMMARY FOR CONDENSING RANKINE SYSTEM

HEAT PIPE COOLED CONDENSER MASS (KG) = 39.6255
RADIATOR MASS (KG) = 105.753

CONDENSING RANKINE SYSTEM MASS (KG) = 145.378
CASE 4: DIRECT COOLED BRAYTON CONFIGURATION - NO HEAT REJECTION SYSTEM PHYSICAL DATA AVAILABLE

CONTENTS OF CALL: HREJEC(1, 1, 5624.56, 411.1, 388.89, 250.0)

CONTENTS OF DATA FILE 'RADAT'

```
0, 0.0, 0.0, 0.0
0.0, 0.0
5624.56, 411.1, 40.0, 388.89, 250.0
```

OUTPUT FROM HREJEC

THE SIMPLIFIED DATA INPUT OPTION HAS BEEN SELECTED

*** HEAT REJECTION SYSTEM FOR A BRAYTON CYCLE SYSTEM IN WHICH CYCLE WASTE HEAT IS REJECTED DIRECTLY FROM THE CYCLE WORKING FLUID IN A HEAT PIPE COOLED GAS MANIFOLD ***

INPUT FOR OPTION NUMBER 1

INPUT FOLLOWING DATA INTO FILE *RADAT* TO RUN OPT #1

```
1 1000.00 30.0000 1.00000
2 2000.00 0.315360E+09 1.70000 1.70000 0.703070E+09 0.990000
2 54000 643.810 64.3810 250.0
1821.84 0.000000 0.127000 0.762000E-02 0.990000
2 849788 0.000000 1.81009 1.81009
0.000000
1 206.188 17.9933 8.89000 2.75335 2.53999 1.32588 1.32079
0.253898E-01 1.93842 0.173073 0.484604
3.91193 811.766 40.0000 8.08932
8.56988 0.158750 21.6435
12.0000 149.684 37.4211 449.053
0.299369 8.08932 10.1600 0.256295
```

C IENflg,Halt,HLNCL,Rsun
C Yrlnc,Time
C GAM,ARSF,Earm,PROB
C CONFIG,Xntubes,Xnexpip,Xfliat
C Dpipe,Ifliuid,Imatl,Theta
C D2rad,Thickm,Thickf,Thick
C Em,Alpha,Hap,HArad
C Tf,RhoCoating,RhOfin,RHOarm
C Xadiab,Xmchow
C Iflg2,Hman,Gap,Pitch
C Dcan,Dhp,Re,Rb
C Tf,Tkfin,Tkcan,Tkbraze
C Tkhp,Xhf,Xmx,RHOcan
C RHObraze,THICKman,Wman
C XW9,R9,Dp,SUMLEN
C THICKP,RHOPIP,THICKI,RHOINS
RADIATOR DEFINITION INPUTS

GAMMA = 1.70000
ARSF = 1.70000
ARMOR DENSITY (Grams/CC) = 1.81009
YOUNG'S MODULUS OF ARMOR (Grams/CC) = 0.703070E+09
EXPOSURE TIME OR MISSION DURATION (Secs) = 0.315360E+09
NON-PUNCTURE PROBABILITY = 0.931693
RADIATOR HEAT REJECTION RATE (KWh) = 250.
AVERAGE RADIATOR SURFACE TEMPERATURE (K) = 399.262
NUMBER OF PRIMARY HEAT PIPE IN RADIATOR = 643.810
NUMBER OF REDUNDANT HEAT PIPES = 64.3810
HEAT PIPE EVAPORATOR LENGTH (Cm) = 206.188
HEAT PIPE INSIDE DIAMETER (Cm) = 2.54000
HEAT PIPE WORKING FLUID ID NUMBER = 2
HEAT PIPE LINER MATERIAL ID NUMBER = 8
CONE ANGLE FOR CONICAL RADIATOR (DEGREES) = 0.00000
MANIFOLD DIAMETER FOR CONICAL RADIATOR OR MANIFOLD LENGTH DIVIDED BY 3.141593 FOR FLAT PLATE (Cm) = 1821.84
RADIATOR EMISSIVITY CONTROL COATING THICK.(Cm) = 0.00000
RADIATOR FIN THICKNESS (Cm) = 0.127000
HEAT PIPE WALL or LINER THICKNESS (Cm) = 0.762000E-02
RADIATOR SURFACE EMISSIVITY = 0.800000
RADIATOR SURFACE ABSORTIVITY = 0.500000
RADIATOR PROJ. AREA (FRACT. OF TOT.) = 1.00000
RADIATOR ACTUAL AREA (FRACTION) = 2.00000
THERMAL COND. OF FIN MATERIAL (W/Cm-K) = 0.849774
COATING MATERIAL DENSITY (Grams/CC) = 0.000000
FIN MATERIAL DENSITY (Grams/CC) = 1.81009
LENGTH OF ADIABATIC PORTION OF THE HEAT PIPE (Cm) = 0.000000
MASS OF RADIATOR DEPLOYMENT MECHANISM (KG) = 0.000000

TOTAL HEAT REJECTED EVAPORATOR FIN Coating
(Average (KWh) TEMP (K) Thick (Cm) Thick (Cm)
250.0000 399.2623 0.1270 0.0000

Actual Effective
(one-side) Radiator Area(sq-Me) Area(sq-Me)
174.6265 349.2531

HEAT PIPE DESIGN DETAILS - Dims in Cm
Pipe ID Wick Thick #Arteries Art ID Art Wall Pipe wall
2.5400 0.0129 7.6200 0.6452 0.0129 0.0076
Evap Length Adi Length Cond Length Total Length
206.1884 0.0000 305.1358 511.3242

RADIATOR MASS BREAKDOWN - Mass in KG
Heat Pipes Fluids FINS Emiss. Cont.
624.6988 35.7312 315.4457 0.0000
O.D.ARMOR 1.D.ARMOR Structure TOTAL RADIATOR
357.6603 357.6603 0.0000 1689.1960

IENflg (ORBIT SELECTION) = 1
IENflg=1, EARTH ORBIT (LEO-GEO)
IENflg=2, SOLAR ORBIT (0.5 to 2.0 AU)
ORBIT ALTITUDE (KM) = 1000.00
ORBIT INCLINATION ANGLE (Degrees) = 30.0000
DISTANCE FROM SUN (AU) = 1.00000
YEAR SATELLITE LAUNCHED = 2000.00
### Heat Pipe Cooled Manifold Definition Variables

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<th>Variable</th>
<th>Value</th>
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<td>Manifold Height (m)</td>
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<tr>
<td>Manifold Width (m)</td>
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<td>Distance between can(heat pipes) to C-lines</td>
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<tr>
<td>Number of heat pipes in radiator</td>
<td>643.810</td>
</tr>
<tr>
<td>Number of redundant heat pipes in radiator</td>
<td>64.3810</td>
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<tr>
<td>Inside diameter of braze cans (m)</td>
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<tr>
<td>Inside diameter of heat pipe (m)</td>
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<tr>
<td>Manifold braze can inside radius (m)</td>
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<td>Braze joint inside radius (m)</td>
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<tr>
<td>Fin thickness (m)</td>
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<td>Thermal conductivity of fin material (W/(m·K))</td>
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<tr>
<td>Thermal conductivity of manifold can material (W/(m·K))</td>
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<tr>
<td>Thermal conductivity of braze alloy (W/(m·K))</td>
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</tr>
<tr>
<td>Thermal conductivity of heat pipe wall material (W/(m·K))</td>
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<td>Total number of fins for the manifold height</td>
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<td>Density of manifold material (g/cc)</td>
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<td>Density of braze material (g/cc)</td>
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<tr>
<td>Manifold material thickness (m)</td>
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<td>Manifold inlet temperature (K)</td>
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<td>Manifold and radiator heat load (kWt)</td>
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<tr>
<td>Molecular weight of manifold working fluid</td>
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<td>Manifold pressure drop (g/(sq·m))</td>
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<tr>
<td>Manifold film temperature drop (K)</td>
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<td>NAX inventory mass (kg)</td>
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<td>Net mass of heat pipe manifold (kg)</td>
<td>3663.87</td>
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### Ducting Input Variables

<table>
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<tr>
<th>Variable</th>
<th>Value</th>
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<tr>
<td>Number of 90 deg. elbows or equiv.</td>
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<tr>
<td>Average radius for 90 degree elbows (m)</td>
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<tr>
<td>Inside duct diameter (m)</td>
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<td>Total length of duct system (m)</td>
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<td>Gas velocity in ducts (m/sec)</td>
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<td>Gas pressure (g/(sq·m))</td>
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<td>Duct wall density (g/cc)</td>
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<td>Mass summary for direct Brayton system</td>
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<td>Heat pipe cooled gas manifold mass (kg)</td>
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<tr>
<td>Manifold ducting mass (kg)</td>
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<td>Radiator mass (kg)</td>
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<tr>
<td>Direct Brayton system mass (kg)</td>
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CASE 5: LIQUID LOOP COOLED BRAYTON CONFIGURATION - NO HEAT REJECTION SYSTEM PHYSICAL DATA AVAILABLE

*****************************************************************************

CONTENTS OF CALL: HREJEC(1, 2, 1, 5624.56, 466.7, 444.45, 250.0)

*****************************************************************************

CONTENTS OF DATA FILE 'RADAT'
0.0, 0.0, 0.0, 0.0
5624.56, 466.7, 444.45, 250.0

*****************************************************************************

OUTPUT FROM HREJEC

*****************************************************************************

THE SIMPLIFIED DATA INPUT OPTION HAS BEEN SELECTED

*** HEAT REJECTION SYSTEM FOR A BRAYTON CYCLE SYSTEM IN WHICH CYCLE WASTE HEAT IS REJECTED TO A PUMPED NaK LOOP FROM THE CYCLE WORKING FLUID TO A HEAT PIPE COOLED NaK MANIFOLD ***

INPUT FOR OPTION NUMBER 2

INPUT FOLLOWING DATA INTO FILE *RADAT* TO RUN OPT #2

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C IEFlg, WaIt, HiNCl, Rsun
C Yrlnch, Time
C GAMS, ARSF, Earm, PROB
C CONFIG, Xntubes, Xnexpilp, Xiflat
C Dpipe, Ifluid, lmat, Theta
C D2red, Thiccm, Thicke, Thickf, Thick
C Em, Alpaha, Hap, Harad
C Tkfin, Rhocoeting, Rhofin, RHOarm
C Xlatlab, Xmchmas
C IXfIg, UEST, TCIN, TCOUT
C MDOTS, ARMS, TINS, DEMING
C DEnSsh, DTUBE, PR, TTUBE
C ANPLATES, MDOT, AKTUBE
C HfIg2, Hman, Gap, Pitch
C Dcan, Dhp, Rc, Rb
C Tt, Tkflne, Tkcan, Tkbraze
C Tkhp, Khf, Xmu, RHOcan
C RHObraze, THICKman, Hman
C XNP, R9, Dp, SUMLEN
C THICKP, RHOPIP, THICKI, RHOINS
Radiator Definition Inputs

Gamma = 1.70000
ARSF = 1.70000
Armor Density (Grams/CC) = 1.81009
Youngs Modulus of Armor (Grams/CC) = 0.703070E+09
Exposure Time or Mission Duration (Secs) = 0.315360E+09
Non-Puncture Probability = 0.944048
Radiator Heat Rejection Rate (Kw) = 250.
Average Radiator Surface Temperature (K) = 419.224
Number of Primary Heat Pipe in Radiator = 259.676
Number of Redundent Heat Pipes = 25.9676
Heat Pipe Evaporator Length (Cm) = 45.7200
Heat Pipe Inside Diameter (Cm) = 2.54000
Heat Pipe Working Fluid Id Number = 2
Heat Pipe Liner Material Id Number = 8
Cone Angle for Conical Radiator (Degrees) = 0.703070E + 09
Manifold Diameter for Conical Radiator or Manifold Length Divided by 3.141593 for Flat Plate (Cm) = 734.826
Radiator Emissivity Control Coating Thick (Cm) = 0.000000
Radiator Fin Thickness (Cm) = 0.127000
Heat Pipe Wall or Liner Thickness (Cm) = 0.762000E-02
Radiator Surface Emissivity = 0.800000
Radiator Surface Absorptivity = 0.500000
Radiator Proj. Area (Frac. of TOT.) = 1.000000
Radiator Actual Area (Fraction) = 2.000000
Thermal Cond. of Fin Material (W/Cm-K) = 0.849774
Coating Material Density (Grams/CC) = 0.000000
Fin Material Density (Grams/CC) = 1.81009
Length of Adiabatic Portion of the Heat Pipe (Cm) = 0.000000
Mass of Radiator Deployment Mechanism (Kg) = 0.000000

Total Heat Average Radiator Emissivity
Rejected Evaporator Fin Coating
(Kw) Temp (K) Thick (Cm) Thick (Cm)
250.0000 419.2245 0.1270 0.0000
Actual Effective
(one-side) Radiator
Area(sq-Me.) Area(sq-Me)
130.8741 261.7481

Heat Pipe Design Details - Dims in Cm
Pipe Id Wick Thick #Arties Art ID Art Wall Pipe Wall
2.5400 0.0129 7.6200 0.6452 0.0129 0.0076
Evap Length Adi Length Cond Length Total Length
45.7200 0.0000 566.9722 612.6923

Radiator Mass Breakdown - Mass in Kg
Heat Pipes Fluids FINS Emiss. Cont.
301.8342 16.2466 236.4112 0.0000
O.D. Armor I.D. Armor Structure Total Radiator
374.3636 374.3636 0.0000 1303.2190

IENfig (Orbit Selection) = 1
IENfig=1, Earth Orbit (LEO-GEO)
IENfig=2, Solar Orbit (0.5 to 2.0 AU)
Orbit Altitude (Km) = 5000.00
Orbit Inclination Angle (Degrees) = 30.0000
Distance From Sun (AU) = 1.00000
Year Satellite Launched = 2000.00
HEAT PIPE COOLED MANIFOLD DEFINITION VARIABLES

Iflg2 = 2
MANIFOLD HEIGHT (Cm)= 36.1541
MANIFOLD WIDTH (Cm)= 15.2400
DIST. BETWN CAN(HEAT PIPES)C-LINES (Cm)= 8.89000
NUMBER OF HEAT PIPES IN RADIATOR= 259.676
NUMB. OF REDUNDENT HEAT PIPES IN RADIATOR= 25.9676
OUTSIDE DIAMETER OF BRAZE CAN(SM)= 2.75335
INSIDE DIAMETER OF HEAT PIPE (Cm)= 2.53999
MANIFOLD BRAZE CAN INSIDE RADIUS (Cm)= 1.32588
BRAZE JOINT INSIDE RADIUS (Cm)= 1.32079
FIN THICKNESS (Cm)= 0.25389E-01
THERM. COND. OF FIN MATERIAL (W/(Cm-K))= 1.93842
THERM. COND. OF MANIFOLD CAN MATERIAL (W/CMK)= 0.173073
THERM. COND. OF MANIF. BRAZE ALLOY (W/CMK)= 0.484604
THERM. COND. OF HEAT PIPE WALL NATL (W/CMK)= 3.91193
TOTAL NUMBER OF FINS FOR THE MANIFOLD HEIGHT= 180.000
DENSITY OF MANIFOLD MATERIAL (Grams/CC)= 8.08932
DENSITY OF BRAZE MATERIAL (Grams/CC)= 8.56988
MANIFOLD MATERIAL THICKNESS (Cm)= 0.158750
MANIFOLD INLET PRESSURE (Grams/sq-Cm)= 5624.56
MANIFOLD INLET TEMPERATURE (K)= 466.700
MANIFOLD FLOWRATE (KG/HR)= 8.16972
MANIFOLD AND RADIATOR HEAT LOAD (KW)= 250.000
MOLECULAR WEIGHT OF MANIFOLD WORKING FLUID= 40.0000
MANIFOLD PRESSURE DROP (Grams/sq-Cm)= 27.7819
MANIFOLD FILM TEMPERATURE DROP (K)= 36.1043
NAK INVENTORY MASS (KG)= 1001.46
NET MASS OF HEAT PIPE MANIFOLD (KG)= 343.698

PIPING DEFINITION VARIABLES

NUMB. OF 90 DEG. ELBOWS OR EQUIV.= 12.0000
AVERAGE RADIUS FOR 90 DEGREE ELBOWS (Cm)= 14.8324
INSIDE PIPE DIAMETER (Cm)= 3.70810
TOTAL LENGTH OF PIPE SYSTEM (Cm)= 762.000
NAK VELOCITY IN PIPES (M/SEC)= 9.14355
NAK TEMPERATURE (K)= 466.700
NAK PRESSURE (Grams/sq-Cm)= 5624.56
PIPE WALL THICKNESS (Cm)= 0.254000
PIPE WALL DENSITY (Grams/CC)= 8.08932
PIPE INSULATION THICKNESS (Cm)= 10.1600
PIPE INSULATION DENSITY (Grams/CC)= 0.384444
PIPE SYSTEM PRESSURE DROP (Grams/sq-Cm)= 1696.14
PIPE SYSTEM MASS (KG)= 210.304
PIPE SYSTEM NAK MASS (KG)= 9.30602
HEAT SOURCE/SINK HEAT EXCHANGER DEFINITION

TUBE SIDE FLUID FLAG = 2
Heat Rate or Duty (KWh) = 250.000
HOT SIDE Inlet Temperature (K) = 466.700
HOT SIDE Outlet Temperature (K) = 444.450
COLD SIDE Inlet Temperature (K) = 416.672
COLD SIDE Outlet Temperature (K) = 450.033
SHELL SIDE FLUID Flowrate (KG/Hr) = 21.6045
SHELL MATERIAL Density (Grams/CC) = 8.08934
INSIDE TUBE Diameter (Cm) = 0.952500
TUBE Wall Thickness (Cm) = 0.508000E-01
TUBE SIDE Fluid Flowrate (KG/Kg) = 8.16972
TUBE Side Thermal Conductivity(W/(Cm-K)) = 0.173073
SHELLSIDE DP (Gsq-Cm) = 620.624
SHELLSIDE H (W/(sqCm-K)) = 21.5383
FRI-C-FACT = 0.265246
UNEW (W/(sqCm-K)) = 10.2136
NUMBER OF TUBES IN BUNDLE = 81.0944
Tube Side Reynolds Number = 46447.7
Tube Side Press. Drop(Gsq-Cm) = 79.1433
Tube Side Hg (W/(sqCm-K)) = 38.0457
TUBE WALL THICKNESS (Cm) = 0.508000E-01
DOTL2 (Cm) = 13.5269
LENGTH (Cm) = 81.2085

INSULATION MASS (KG) = 17.9807
HEAD MASS (KG) = 0.348632
SHELL MASS (KG) = 2.44042
PLATE MASS (KG) = 0.128418
TUBE SHEETS MASS (KG) = 0.348632
TUBE MASS (KG) = 7.66628
STRUCTURE AND BRACKETS MASS (KG) = 1.44566
MASS OF NaK IN H-X (KG) = 4.99182
Net Mass of Shell and Tube Unit(DRY)(KG) = 30.3588

NaK PUMP DEFINITION

NaK INLET TEMPERATURE (K) = 466.700
NaK FLOWRATE (KG/Kg) = 8.16972
Piping SYSTEM PRESSURE DROP (G/SC) = 1696.14
NaK SIDE HEAT EXCHANGER PRESSURE DROP (G/SC) = 79.1433
NaK MANIFOLD PRESSURE DROP (G/SC) = 27.7819
NaK LOOP PRESSURE DROP (G/SC) = 1803.07
NaK LOOP PUMP POWER REQUIRED (HYDRAULIC) (WATTS) = 1738.58
E-M PUMP MASS (DRI) (KG) = 271.506

NaK LOOP EXPANSION COMPENSATOR DEFINED

VOLUME ACCUMULATOR NaK MASS (KG) = 54.2511
VOLUME ACCUMULATOR MASS (WET) (KG) = 111.024
MASS SUMMARY FOR INDIRECT BRAYTON SYSTEM

HEAT SINK HEAT EXCHANGER MASS (KG)(DRY) = 30.3588
HEAT EXCHANGER NaK MASS (KG) = 4.99182
NaK PIPING SYSTEM MASS (KG)(DRY) = 210.384
MASS OF NaK IN PIPING SYSTEM (KG) = 9.30602
MASS OF EN PUMP (KG)(WET) = 271.506
HEAT PIPE/NaK MANIFOLD MASS (KG) (DRY) = 343.698
MASS OF NaK IN MANIFOLD (KG) = 1001.46
EXPANSION COMPENSATOR MASS (KG) (DRY) = 111.024
MASS OF NaK IN EXPANSION COMPENSATOR(KG) = 54.2511
RADIATOR MASS (KG) = 1303.22

INDIRECT BRAYTON SYSTEM MASS (KG)(WET) = 3340.20
CASE 6: SHEAR FLOW CONDENSER IN A POTASSIUM RANKINE CYCLE - NO HEAT REJECTION SYSTEM PHYSICAL DATA AVAILABLE

******************************************************************************************************************

CONTENTS OF CALL: HREJEC(1, 3, 1, 140.64, 855.56, 850.00, 250.0)
******************************************************************************************************************

CONTENTS OF DATA FILE 'RADAT'

0.0, 0.0, 0.0, 0.0, 0.0, 1.0
0.0, 0.0
133.6707, 850.0, 40.0, 754.5
2128.32

******************************************************************************************************************

OUTPUT FROM HREJEC

******************************************************************************************************************

THE SIMPLIFIED DATA INPUT OPTION HAS BEEN SELECTED

*** HEAT REJECTION SYSTEM FOR A RANKINE CYCLE SYSTEM IN WHICH CYCLE WASTE HEAT IS REJECTED DIRECTLY FROM THE CYCLE WORKING FLUID IN A HEAT PIPE COOLED CONDENSER ***

INPUT FOR OPTION NUMBER 3

INPUT FOLLOWING DATA INTO FILE 'RADAT' TO RUN OPT #3

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<thead>
<tr>
<th>1</th>
<th>1000.00</th>
<th>30.0000</th>
<th>1.0000</th>
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<tbody>
<tr>
<td>2000.00</td>
<td>0.315360E+09</td>
<td></td>
<td></td>
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<tr>
<td>1.70000</td>
<td>1.70000</td>
<td>0.703070E+09</td>
<td>0.990000</td>
</tr>
<tr>
<td>1.00000</td>
<td>41.3662</td>
<td>4.13662</td>
<td>43.2447</td>
</tr>
<tr>
<td>2.54000</td>
<td>5</td>
<td>7</td>
<td>0.000000</td>
</tr>
<tr>
<td>66.8897</td>
<td>0.000000</td>
<td>0.127000</td>
<td>0.762000E-02</td>
</tr>
<tr>
<td>0.800000</td>
<td>0.500000</td>
<td>1.000000</td>
<td>2.000000</td>
</tr>
<tr>
<td>0.849788</td>
<td>84978.8</td>
<td>0.000000</td>
<td>1.81009</td>
</tr>
<tr>
<td>0.000000</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>210.160</td>
<td>43.2447</td>
<td>1.05962</td>
<td>10.1600</td>
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<tr>
<td>0.605756</td>
<td>0.173073</td>
<td>140.614</td>
<td>855.600</td>
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<tr>
<td>1.000000</td>
<td>8.08932</td>
<td>8.08932</td>
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</tr>
<tr>
<td>0.158750</td>
<td>0.508000E-01</td>
<td>442.915</td>
<td></td>
</tr>
</tbody>
</table>

C IENfig,Halt,HINCL,Reun
C Yrinch,Time
C GAM,ARSF,Earm,PROB
C CONFIG,Xntubes,Xnexp,XIflat
C Dpipe,Ifluid,Imatl,Theta
C D2rad,Thickness,Thickness,Thickness
C Em,Alpha,Rea,HArad
C Tkfin,Rhocoating,Rhofin,RHOarm
C Xladlab,Xnchmas
C Cman,Hman,Gap,THICKins
C RHOins,Tout,Tbraze,TKcan
C TKbraze,TKhp,Pin,Tin
C Xin,RHOpipe,RHOcan,RHObraze
C THICKmen,THtpip,WMman
RADIATOR DEFINITION INPUTS

\[
\begin{align*}
\text{GAMMA} &= 1.70000 \\
\text{ARSF} &= 1.70000 \\
\text{ARMOR DENSITY (Grams/CC)} &= 1.81009 \\
\text{YOUNG'S MODULUS OF ARMOR (Grams/CC)} &= 0.703070E+09 \\
\text{EXPOSURE TIME OR MISSION DURATION (Secs)} &= 0.315360E+07 \\
\text{NON-PUNCTURE PROBABILITY} &= 0.970672 \\
\text{RADIATOR HEAT REJECTION RATE (KWh)} &= 853250. \\
\text{AVERAGE RADIATOR SURFACE TEMPERATURE (K)} &= 827.164 \\
\text{NUMBER OF PRIMARY HEAT Pipe IN RADIATOR} &= 41.3662 \\
\text{NUMBER OF REDUNDANT HEAT PIPES} &= 4.1362 \\
\text{HEAT PIPE EVAPORATOR LENGTH (Cm)} &= 43.2447 \\
\text{HEAT PIPE INSIDE DIAMETER (Cm)} &= 2.54000 \\
\text{HEAT PIPE WORKING FLUID ID NUMBER} &= 5 \\
\text{HEAT PIPE LINER MATERIAL ID NUMBER} &= 7 \\
\text{CONE ANGLE FOR CONICAL RADIATOR (DEGREES)} &= 0.00000 \\
\text{MANIFOLD DIAMETER FOR CONICAL RADIATOR OR MANIFOLD LENGTH DIVIDED BY } 3.141593 \text{ FOR FLAT PLATE (Cm)} &= 2038.80 \\
\text{RADIATOR EMISSIVITY CONTROL COATING THICK. (Cm)} &= 0.000000 \\
\text{RADIATOR FIN THICKNESS (Cm)} &= 3.87096 \\
\text{HEAT PIPE WALL or LINER THICKNESS (Cm)} &= 0.232258 \\
\text{RADIATOR SURFACE EMISSIVITY} &= 0.800000 \\
\text{RADIATOR SURFACE ABSORPTIVITY} &= 0.500000 \\
\text{RADIATOR PROJ. AREA (FRACT. OF TOT.)} &= 1.000000 \\
\text{RADIATOR ACTUAL AREA (FRACTION)} &= 2.000000 \\
\text{THERMAL COND. OF FIN MATERIAL (W/Cm-K)} &= 0.849774 \\
\text{COATING MATERIAL DENSITY (Grams/CC)} &= 1.181009 \\
\text{FIN MATERIAL DENSITY (Grams/CC)} &= 1.810000 \\
\text{LENGTH OF ADIABATIC PORTION OF THE HEAT PIPE (Cm)} &= 0.000000 \\
\text{MASS OF RADIATOR DEPLOYMENT MECHANISM (KG)} &= 0.000000 \\
\end{align*}
\]

TOTAL HEAT AVERAGE Radiator Emissivity
REJECTED EVAPORATOR FIN Coating
(KWh) TEMP (K) Thick (Cm) Thick (Cm)
250.0000 827.1643 0.1270 0.0000

Actual Effective
(one-side) Radiator
Area(sq-Me.) Area(sq-Me)
6.7048 13.4097

HEAT PIPE DESIGN DETAILS - DIMS in cm

<table>
<thead>
<tr>
<th>Pipe ID</th>
<th>Wick Thick</th>
<th>#Arteries</th>
<th>Art ID</th>
<th>Art Wall</th>
<th>Pipe wall</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.5400</td>
<td>0.0129</td>
<td>7.6200</td>
<td>0.6452</td>
<td>0.0129</td>
<td>0.0076</td>
</tr>
</tbody>
</table>

Evap Length | Adi Length | Cond Length | Total Length
43.2447 | 0.0000 | 319.0964 | 362.3411

RADIATOR MASS BREAKDOWN - Mass in kg

<table>
<thead>
<tr>
<th>Heat Pipes</th>
<th>Fluids</th>
<th>FINS</th>
<th>Emiss. Cont.</th>
</tr>
</thead>
<tbody>
<tr>
<td>26.6823</td>
<td>1.3351</td>
<td>8.4781</td>
<td>0.0000</td>
</tr>
</tbody>
</table>

D.D.ARMOR | I.D.ARMOR | Structure | TOTAL RADIATOR
38.6962 | 38.6962 | 0.0000 | 113.8878

IENfig (ORBIT SELECTION) = 1

\[
\begin{align*}
\text{IENfig=1, EARTH ORBIT (LEO-GEO)} \\
\text{IENfig=2, SOLAR ORBIT (0.5 to 2.0 AU)} \\
\text{ORBIT ALTITUDE (KM)} &= 1000.00 \\
\text{ORBIT INCLINATION ANGLE (Degrees)} &= 30.0000 \\
\text{DISTANCE FROM SUN (AU)} &= 1.00000 \\
\text{YEAR SATELLITE LAUNCHED} &= 2000.00
\end{align*}
\]
HEAT PIPE COOLED CONDENSER DESCRIPTION

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manifold flat length (cm)</td>
<td>210.140</td>
</tr>
<tr>
<td>Manifold height (cm)</td>
<td>43.2447</td>
</tr>
<tr>
<td>Average manifold condensation space (Gap)(cm)</td>
<td>1.05962</td>
</tr>
<tr>
<td>Manifold insulation thickness (cm)</td>
<td>10.1600</td>
</tr>
<tr>
<td>Manifold insulation density (g/cc)</td>
<td>0.000000</td>
</tr>
<tr>
<td>Number of primary heat pipes attached to cool condenser surface</td>
<td>41.3662</td>
</tr>
<tr>
<td>Number of redundant heat pipes used to cool condenser surface</td>
<td>4.13662</td>
</tr>
<tr>
<td>Manifold wall material thickness (cm)</td>
<td>0.158750</td>
</tr>
<tr>
<td>Manifold-heat pipe braze material thickness (cm)</td>
<td>0.508000E-02</td>
</tr>
<tr>
<td>Heat pipe wall thickness (cm)</td>
<td>0.508000E-01</td>
</tr>
<tr>
<td>Manifold wall material thermal conduction (W/cmK)</td>
<td>0.173073</td>
</tr>
<tr>
<td>Braze material thermal conduction (W/cmK)</td>
<td>0.605756</td>
</tr>
<tr>
<td>Heat pipe wall material thermal conduction (W/cmK)</td>
<td>0.173073</td>
</tr>
<tr>
<td>Manifold wall material density (g/cc)</td>
<td>8.08932</td>
</tr>
<tr>
<td>Braze material density (g/cc)</td>
<td>8.40969</td>
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<tr>
<td>Heat pipe wall material density (g/cc)</td>
<td>8.08932</td>
</tr>
<tr>
<td>Heat pipe working fluid number</td>
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MANIFOLD OPERATING CONDITIONS

<table>
<thead>
<tr>
<th>Condition</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>Inlet pressure (g/sc)</td>
<td>140.614</td>
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<tr>
<td>Inlet temperature (K)</td>
<td>855.599</td>
</tr>
<tr>
<td>Mean condenser quality</td>
<td>1.00000</td>
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<tr>
<td>Outlet temperature (K)</td>
<td>849.999</td>
</tr>
<tr>
<td>Manifold flowrate (kg/hr)</td>
<td>442.564</td>
</tr>
<tr>
<td>Manifold duty (kWt)</td>
<td>250.000</td>
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</tbody>
</table>

COMPUTED RESULTS

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manifold pressure drop (g/sc)</td>
<td>6.96164</td>
</tr>
<tr>
<td>Manifold film temperature drop (K)</td>
<td>25.6271</td>
</tr>
<tr>
<td>Condenser condensate flow regime parameter</td>
<td>0.127761</td>
</tr>
<tr>
<td>Condenser is operating in shear flow regime</td>
<td></td>
</tr>
<tr>
<td>Condensate film Reynolds number</td>
<td>1901.90</td>
</tr>
<tr>
<td>Martineilli parameter</td>
<td>0.133113E-01</td>
</tr>
<tr>
<td>Vapor Reynolds number</td>
<td>3803.80</td>
</tr>
<tr>
<td>Manifold mass (kg)</td>
<td>39.6261</td>
</tr>
</tbody>
</table>

MASS SUMMARY FOR CONDENSING RANKINE SYSTEM

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat pipe cooled condenser mass (kg)</td>
<td>39.6261</td>
</tr>
<tr>
<td>Radiator mass (kg)</td>
<td>113.888</td>
</tr>
<tr>
<td>Condensing Rankine system mass (kg)</td>
<td>153.514</td>
</tr>
</tbody>
</table>
APPENDIX C

CODE LISTING
PROGRAM HRCHEK
C DRIVER CODE TO CHECKOUT SUBROUTINE HRMAST
C
OPEN(5,FILE='CHKDAT')
READ (5,*) iselec,iprob,ienflg
READ (5,*) Pin,Tin,Tout,Grad
CALL HREJEC(iselec,iprob,ienflg,Pin,Tin,Tout,Grad)
STOP
END
SUBROUTINE NREJEC(lsetec, lprob, lENfig, Pin, Tin, Tout, Grad)

COMPUTATION OF THE PERFORMANCE AND MASS OF HEAT REJECTION SYSTEMS

CODE ESTIMATES THE MASS AND PERFORMANCE OF HEAT PIPE COOLED HEAT
REJECTION SYSTEMS THAT OPERATE AS THE MAIN HEAT REJECTION ELEMENTS
IN BRAYTON AND RANKINE CYCLE SPACE POWER SYSTEMS.

AN OPTION IS OFFERED WHEREBY THE CODE WILL SUPPLY MOST OF THE
INPUTS REQUIRED AND RETURN THE INPUTS FOR A DETAILED CASE WITH
WHICH THE USER CAN START HIS OPTIMIZATION STUDY.

*** CODE LOGIC AND COMPUTATION OUTLINE ***

THE FOLLOWING STEPS ARE FOLLOWED IN ESTIMATING THE MASS AND
PERFORMANCE OF HEAT PIPE COOLED HEAT REJECTION SYSTEMS IN EITHER
BRAYTON OR RANKINE CYCLE APPLICATIONS:

1. SELECT THE HEAT REJECTION EQUIPMENT TRAIN AND DEFINE THE
   EQUIPMENT ELEMENTS REQUIRED. THREE OPTIONS ARE SUPPLIED:
   A. DIRECT COOLED GAS MANIFOLD FOR BRAYTONS.
   B. WAX LIQUID METAL COOLED H-X LOOP FOR BRAYTONS.
   C. SHEAR FLOW CONDENSER WITH DIRECT HEAT PIPE COOLING

2. IF NECESSARY, AN AUXILIARY ROUTINE IS INCLUDED THAT
   SUPPLIES NON-OPTIMIZED, BUT WORKABLE, INPUT VALUES FOR MOST
   OF THE VARIABLES REQUIRED TO RUN THE VARIOUS SUBROUTINES.

3. ANALYZE THE HYDRAULIC LOOP REQUIRED FOR THE LIQUID
   USED BY SOME OF THE SYSTEMS. THE H-X, PIPING AND MANIFOLD DELTA-P
   IS DETERMINED IN THIS STEP.

4. DETERMINE THE WEIGHT OF THE PUMP REQUIRED.

5. ON PUMPED LOOP SYSTEMS, A HEAT PIPE TO FLUID HEAT
   EXCHANGER IS ANALYZED

6. ON DIRECT SYSTEMS, A GAS TO HEAT PIPE FLUID HEAT EXCHANGER
   IS ANALYZED.

7. A RADIATOR IS SIZED TO REJECT THE PROPER AMOUNT OF HEAT
   AND ITS MASS IS DETERMINED.

8. CODE OUTPUT CONSISTS OF COMPONENT SIZES AND MASSES.

OPEN(5,FILE='RADAT')

PI = 3.14159265

IF lsetec = 1, THEN THE CODE WILL SUPPLY MOST OF THE VARIABLE
VALUES NEEDED. IF lsetec = 2, THEN THE USER MUST SUPPLY MOST
OF THE VARIABLE VALUES NEEDED

IF lprob = 1, CODE IS SET UP FOR A DIRECT COOLED BRAYTON
CONFIGURATION.

IF lprob = 2, CODE IS SET UP FOR A LIQUID LOOP COOLED
BRAYTON CONFIGURATION.
IF IProb = 3, CODE IS SET UP FOR A SHEAR FLOW CONDENSER IN A POTASSIUM RANKINE CYCLE.

INPUTS TO DEFINE ORBITS

IENfig = FLAG TO SET ENVIRONMENT DESIRED
1 = EARTH ORBIT, LEO TO GEO USES GREATER OF DEBRIS OR METEORITE FLUX, NO DEBRIS ABOVE 2000 Km.
2 = BEYOND EARTH ORBIT, 0.25 TO 2.00 AU

.Height = ORBIT ALTITUDE (km)

Ninc = ORBIT INCLINATION ANGLE (28.5 TO 80.0 degrees, ONLY)

.Raun = DISTANCE FROM SUN (AU)

.Yrlnch = YEAR IN WHICH VEHICLE IS PLACED IN ORBIT

Time = MISSION DURATION (Secs)

INPUTS TO DEFINE RADIATOR

GAM,ARSF = PENETRATION CONSTANTS - FUNCTIONS OF THE SPECIFIC MAT'L

Rhoarm = ARMOR DENSITY (Lbs/cu-Ft)

Earm = YOUNG'S MODULUS OF ARMOR (Lbs/sq-in)

.Prob = NON-PUNCTURE PROBABILITY (0.9, 0.99, 0.999, ETC.)

Grad = RADIATOR HEAT REJECTION RATE (W/C)

.Trad = AVERAGE RADIATOR SURFACE TEMPERATURE (deg-R)

.Xntubes = NUMBER OF PRIMARY HEAT PIPE IN RADIATOR

.Xnexpip = NUMBER OF REDUNDANT HEAT PIPES

.Xflat = HEAT PIPE EVAPORATOR LENGTH (INCHES)

.Dpipe = HEAT PIPE INSIDE DIAMETER (INCHES)

.Ifluid = HEAT PIPE WORKING FLUID ID NUMBER

.Imatl = HEAT PIPE LINER MATERIAL ID NUMBER

.Theta = CONE ANGLE FOR CONICAL RADIATOR (DEGREES)

.D2rad = MANIFOLD DIAMETER FOR CONICAL RADIATOR OR MANIFOLD

.Leng = LENGTH DIVIDED BY 3.141593 FOR FLAT PLATE

.Thickr = RADIATOR ENHANCEMENT COATING THICKNESS (FEET)

.Thickf = RADIATOR FIN THICKNESS (FEET)

.Thickw = HEAT PIPE WALL or LINER THICKNESS (FEET)

.Eem = RADIATOR SURFACE ENHANCEMENT

.Alpha = RADIATOR SURFACE ABSORPTION

.Hap = RADIATOR PROJECTED AREA (TOWARD SUN) (FRACTION OF TOTAL)

.Nrad = RADIATOR ACTUAL AREA (USUALLY = 1.0)

.Tkfin = THERMAL CONDUCTIVITY OF FIN MATERIAL (BTU/HR-FT-R)

.Rhocoat = COATING MATERIAL DENSITY (LB/cu-cf)

.Rhomin = FIN MATERIAL DENSITY (LB/cu-ft)

.Xladab = LENGTH OF ADIABATIC PORTION OF THE HEAT PIPE (FEET)

.Xmehmas = MASS OF RADIATOR DEPLOYMENT MECHANISM (LBS)

INPUTS TO DEFINE HEAT PIPE COOLED MANIFOLD

Iflg2 = FLAG TO SET MANIFOLD WORKING FLUID

1 = He-Xe Mixture

2 = NaK

.Heman = MANIFOLD HEIGHT (Feet)

.Gap = MANIFOLD WIDTH (Feet)

.Pitch = DISTANCE BETWEEN CAN (HEAT PIPES) CENTERLINES (Feet)
XNpipes = NUMBER OF HEAT PIPES IN RADIATOR
XNRedpipes = NUMBER OF REDUNDENT HEAT PIPES IN RADIATOR
Dcan = OUTSIDE DIAMETER OF MANIFOLD BRAZE CANS (Feet)
Dhp = INSIDE DIAMETER OF HEAT PIPE (Feet)
Rec = MANIFOLD BRAZE CAN INSIDE RADIUS (Feet)
Rb = BRAZE JOINT INSIDE RADIUS (Feet)
TF = FIN THICKNESS (Feet)
Tkfin = THERMAL CONDUCTIVITY OF FIN MATERIAL (BTU/Hr-Ft-R)
Tkcan = THERMAL CONDUCTIVITY OF MANIFOLD CAN MATERIAL (BTU/Hr-Ft)
Tkbraze = THERMAL CONDUCTIVITY OF MANIFOLD BRAZE ALLOY (BTU/Hr-Ft)
Tkhp = THERMAL CONDUCTIVITY OF HEAT PIPE WALL MATERIAL (BTU/Hr-Ft)
XNf = TOTAL NUMBER OF FINS FOR THE MANIFOLD HEIGHT
RhoCan = DENSITY OF MANIFOLD MATERIAL (Lb/cu-Ft)
RhoBraze = DENSITY OF BRAZE MATERIAL (Lb/cu-Ft)
ThickCan = MANIFOLD MATERIAL THICKNESS (Feet)
Pcan = MANIFOLD INLET PRESSURE (PSIA)
Tcan = MANIFOLD INLET TEMPERATURE (deg-R)
Wcan = MANIFOLD FLOWRATE (LBS/HR)
Can = MANIFOLD AND RADIATOR HEAT LOAD (BTU/HR)
Cwm = MOLECULAR WEIGHT OF MANIFOLD WORKING FLUID
Rd90 = NUMBER OF 90 DEGREE ELBOUS OR EQUIVALENT IN DUCT SYSTEM
R9 = AVERAGE RADIUS FOR 90 DEGREE ELBOWS (INCHES)
Dp = INSIDE DUCT DIAMETER (INCHES)
Slen = TOTAL LENGTH OF DUCT SYSTEM (INCHES)
Vpipe = GAS VELOCITY IN DUCTS (FT/SEC)
Tgas = GAS TEMPERATURE (deg-R)
Pgas = GAS PRESSURE (psia)
ThickP = DUCT WALL THICKNESS (INCHES)
RhoP = DUCT WALL DENSITY (Lb/cu-Ft)
ThickIns = DUCT INSULATION THICKNESS (INCHES)
RhoIns = DUCT INSULATION DENSITY (Lb/cu-Ft)
Xmgas = GAS MOLECULAR WEIGHT
Dpdf = DUCT SYSTEM PRESSURE DROP (PSID)
Dus = DUCT SYSTEM MASS (LBS)
RhoPipe = DUCT WALL DENSITY (Lb/cu-Ft)
CpP = SHELL-SIDE FLUID Specific Heat (BTU/Lb-R)
Kx = INITIAL VALUE OF Uoverett (BTU/M²-Ft-R)
Thin = HOT SIDE Inlet Temperature (R)
Thout = HOT SIDE Outlet Temperature (R)
Tcin = COLD SIDE Inlet Temperature (R)
Tcout = COLD SIDE Outlet Temperature (R)
Wdts = SHELL SIDE FLUID Flowrate (Lbs/Sec)
DenSsh = SHELL MATERIAL Density (Lbs/ft³)
CpS = SHELL-SIDE FLUID Specific Heat (BTU/Lb-R)
RHOSF = SHELL-SIDE FLUID Density (Lbm/ft^3)
AKST = SHELL-SIDE FLUID Thermal Cond (Btu/hr-Ft-R)
VISCST = SHELL-SIDE FLUID Viscosity (cp)
DTUBE = Outside TUBE Diameter - (Inches)
TTUBE = TUBE Wall Thickness (Inches)
MDOTT = TUBE-SIDE Fluid Flow Rate (Lbs/Sec)
AKTUBE = TUBE Wall Thermal Conductivity (Btu/hr-Ft-R)
CPT = TUBE-SIDE FLUID Specific Heat (Btu/Lb-R)
RHOT = TUBE-SIDE FLUID Density (Lbm/ft^3)
AKT = TUBE-SIDE FLUID Thermal Cond (Btu/hr-Ft-R)
VISCT = TUBE-SIDE FLUID Viscosity (Lb/Sec)

INPUTS TO DEFINE THE Heat PIPING SYSTEM

INPUTS TO DEFINE THE Heat PUMP

INPUTS TO DEFINE THE CONDENSER FOR A K-RANKINE CYCLE

IF Cgt < 0.3, SHEAR-CONTROLLED LIQUID FILM HEAT TRANSFER COEFFICIENT

Rel = CONDENSATE FILM REYNOLDS NUMBER
VCF = VISCOUS CORRECTION FACTOR, (BULK /WALL)**0.14
NI = SHEAR-CONTROLLED LIQUID FILM HEAT TRANSFER COEFFICIENT
Xtt = MARTIMELLI PARAMETER, FORM FOR BOTH TURBULENT PHASES
Ceh = CORRELATION FUNCTION FOR SHEAR-CONTROLLED FLOW HT & DP
Ftp = SHEAR-CONTROLLED FLOW TWO PHASE HEAT TRANSFER FACTOR
SUBROUTINE HRI4AST CompiLing Options:INOINT/BINC/mlNFIHINI/NR/HLIPIMQIlNG21R/S/NT/V/NXINZ1

Source file Listing

```fortran
223 C      HS = SHEAR-CONTROLLED LIQUID FILM HEAT TRANSFER COEFFICIENT
224 C      DPM = MOMENTUM PRESSURE DROP (psia)
225 C      Rev = VAPOR REYNOLDS NUMBER
226 C      DPL = LIQUID PRESSURE DROP (psia)
227 C      DPv = VAPOR PRESSURE DROP (psia)
228 C      FLF = TWO PHASE FRICTION LOSS FACTORS
229 C      DPf = FRICTION PRESSURE DROP (psia)
230 C      FF = FRICTION FACTOR
231 C      ETA = SURFACE ROUGHNESS, ft
232 C      P = SATURATION PRESSURE (psia)
233 C      Dl = LIQUID DENSITY (lbm/cu ft)
234 C      VF = LIQUID SPECIFIC VOLUME (cu ft/lbm)
235 C      HFG = ENTHALPY OF VAPORIZATION (Btu/lbm)
236 C      HGO = REFERENCE ENTHALPY (Btu/lbm)
237 C      NG = ENTHALPY VAPOR STATE (Btu/lbm)
238 C      NF = ENTHALPY LIQUID STATE (Btu/lbm)
239 C      SFG = ENTHALPY OF VAPORIZATION (Btu/lbm)
240 C      SG = ENTHALPY VAPOR STATE (Btu/lbm)
241 C      SF = ENTHALPY LIQUID STATE (Btu/lbm)
242 C      CI = LIQUID HEAT CAPACITY (Btu/lbm)
243 C      VL = LIQUID VISCOSITY (lbm/cu ft)
244 C      XXL = LIQUID THERMAL CONDUCTIVITY (Btu/h-ft-R)
245 C      Pr = LIQUID PRANDTL NUMBER
246 C      WW = VAPOR VISCOSITY (lbm/cu ft)
247 C      XXV = VAPOR THERMAL CONDUCTIVITY (Btu/h-ft-R)
248 C      IF (Iselect.EQ.1) THEN
249 C      10 GO TO 1000
250 C      ELSE
251 C      ENDIF
252 C      IF (Iselect.EQ.1) THEN
253 C      10 GO TO 1000
254 C      ELSE
255 C      GO TO 10
256 C      ENDIF
257 C      10 GO TO (100,200,300), Iprob
258 C      INPUTS REQUIRED TO DEFINE ORBIT
259 C      100 READ (5,*) IENfig,Halt,HINCL,Rau
260 C      READ (5,*) Yrinch,Time
261 C      INPUTS REQUIRED TO DEFINE RADIATOR
262 C      READ (5,*) GAM,ARSF,EaRe,PROB
263 C      READ (5,*) CONFIG,Xntubes,Xnexpip,Xflate
264 C      READ (5,*) Dpipe,Ifluid,Instl,Theo
265 C      READ (5,*) DZrad,Thickm,Thickf,thick
266 C      READ (5,*) Em,Alpha,Hap,Harad
267 C      READ (5,*) Tkfin,Rhocoating,Rhofig,RHOfilm
268 C      READ (5,*) Xladiab,Xmachmms
269 C      INPUTS REQUIRED TO DEFINE HEAT PIPE MANIFOLD
270 C      READ (5,*) Ifig2,Hmmn,Gap,Pitch
```
SUBROUTINE HRNAST Calling Options:

INPUTS REQUIRED TO DEFINE DUCTING

1. READ (5,*) Dcan, Dhp, Rc, Rb
2. READ (5,*) Tf, TKfin, TKcan, THOcan
3. READ (5,*) THObraze, TThick, Dhp, Rc, Rb, Tf, TKfin
4. CALL HPMAM(Ifluid, Iflag, Dcan, Dhp, Rc, Rb, Tf, TKfin)
5. CALL WRRAD(Grad, Trad, Xntubes, Xnxpipex, Dhp, Rc, Rc, Tf, TKfin, TKcan, THOcan)
6. CALL THEAN(Dcan, Dhp, Rc, Rc, Tf, TKfin, TKcan, THOcan, Dhp, Rc, Rc, Tf, TKfin, TKcan, THOcan)
7. CALL HRDUCT(XN9o R9, Dp, SUNLEN, Vpipe, Trad, Xntubes, Xnxpipex, Dhp, Rc, Rc, Tf, TKfin, TKcan, THOcan)
8. CALL RADPRT(Qrsd, Trad, Xntubes, Xnxpipex, Dhp, Rc, Rc, Tf, TKfin, TKcan, THOcan)
9. CALL MN_T(Ifluid, Iflag, Dcan, Dhp, Rc, Rc, Tf, TKfin, TKcan, THOcan)
10. CALL ORBPRT(IEmag, Dcan, Dhp, Rc, Rc, Tf, TKfin, TKcan, THOcan, Dhp, Rc, Rc, Tf, TKfin, TKcan, THOcan)
SUBROUTINE HRAST

CALL DUCPRT(XN9,R9,Dp,SUNLEN,Vpipe,Tin,Pin,THICK,P,RHO,P)
&THICKI,RHOINS,XMIN,DPDUCT,DUCHAS)

WRITE (6,*) 'MASS SUMMARY FOR DIRECT BRAYTON SYSTEM'
WRITE (6,*)
WRITE (6,*) 'HEAT PIPE COOLED GAS MANIFOLD MASS (LBS) =',XMIN
WRITE (6,*) 'MANIFOLD DUCTING MASS (LBS) =',DUCHAS
WRITE (6,*) 'RADIATOR MASS (LBS) =',Xnetradmass2

XMSYST = XMIN + DUCHAS + Xnetradmass2

WRITE (6,*)
WRITE (6,*) 'DIRECT BRAYTON SYSTEM MASS (LBS) =',XMSYST

STOP

CASE WHERE A SECONDARY NAK LOOP IS USED TO TRANSFER HEAT BETWEEN THE CYCLE WORKING FLUID AND THE HEAT PIPE RADIATOR

INPUTS REQUIRED TO DEFINE ORBIT

200 READ (5,*) IEN,f,M,D
READ (5,*) Yrnch,Time

INPUTS REQUIRED TO DEFINE RADIATOR

READ (5,*) GAH,ARSF,Eom,PRO8
READ (5,*) CONFlO,Xntubes,Xnexptp,Xtftlt
READ (5,*) Dhpipe,lpw,imat,Theta
READ (5,*) D2rad,thick,thickf,thicki
READ (5,*) Em,Alpha,Harad
READ (5,*) Tkfin,Rhocoating,Rhomin,ROHosm
READ (5,*) Xladiab,Xmchmas

INPUTS REQUIRED TO DEFINE HEAT SINK HEAT EXCHANGER

READ (5,*) IHXfLo,UEET,TCIN,TCOUT
READ (5,*) DDOTS,AMUS,TINS,DENINS
READ (5,*) DENS,DTUBE,PR,TTUBE
READ (5,*) ANPLATES,LDOTT,AKTUBE

INPUTS REQUIRED TO DEFINE HEAT PIPE MANIFOLD

READ (5,*) Ifig2,Hasen,Gap,Pitch
READ (5,*) Dcan,Dhp,Rc,Rb
READ (5,*) Tt,Tkfin,Tkcan,TKbraze
READ (5,*) TCanp,XN9,Xw,RHOcan
READ (5,*) RHObraze,THICKcan,Umam

READ (5,*) X09,R9,Dp,SUNLEN
READ (5,*) THICK,P,RHO,P,THICKI,RHOINs

Cmam = PI*D2rad
SOURCE C

380 XNpipes = Xntubes
381 XNexpipes = Xnexpip
382 THIN = Tin
383 THOUT = Tout
384 PHOT = Pin
385 GDOT = Grad
386 AWAX = Xaw
387 C

388 CALL HRSHEL(INXflag,UEST,THIN,THOUT,PHOT,TCIN,TCOUT,WDOTS,AWAX
389 &INS,DENINS,DENSHE,DTUBE,PR,TTUBE,AMPLATES,WDOT,Y,AKTUBE,0
390 &DPSHELL,ANTUBES,DPTUBE,DOTL2,ALSHEL,AMSHELL,AMPLATES,
391 &SANTUBES,ANMKUL,ANNEADS,ANSTRY,ANETASS,XNNHEX,HSHHELL,AFRIC,UNERW,
392 &GRTUBE,INC,AMSHS)
393 C

394 CALL HPNAM(INfluid,IN2,Can,Man,Gap,Pitch,DCan,INh,Rb,TF,TKfi
395 EM,TCan,TDBrace,TDNP,XFPIpologies,XNpipes,INexpipes,Xaw,Pin,TIn,RNOconc,RF
396 &BRAzE,TINKMen,UNm,Grad,XNNMagas,DPmean,DTfilm,SNMAM)
397 C

398 Apipe = (PI*(DP**2.0))/(4.0*164.0)
399 CALL XNAXPR(TIn,INCONC,SP,VIS,TK)
400 Vpipe = UNm/(3600.0*RNOconc*Apipe)
401 Tnak = Tin
402 Pnak = Pin
403 CALL HRPIPE(XN9,9,Dp,SUBLN,Vpipe,Tnak,Pnak,THICK,THICK1,
404 &NINS,DPpipe,PIPnuck,PIPnmas)
405 C

406 UNak = UNm
407 DPHX = DPTUBE
408 DPMANIF = DPmean
409 CALL PUMP(Tnak,UNak,DPPIPE,DPHindhoven,DPMANIF,DLOOP,Phy,PUMP)
410 C

411 C

412 C

413 DTmnu = Tin-Tout
414 CALL NKAN(TIn,DTmnu,DTfilm,
415 &TRNAK,RDADQ,TRADD,Xntubes,XNexpip,XXflat,Dpipe,INfluid,INmtl,
416 &Ebeta,DRrad,THICM,THICKF,THICK,EM,IEHFLG,HAULT,NNICL,HEAUN,YRZH,
417 &Ebeta,KNAP,GRAD,TKFIN,RHOcoating,RFHOF,RNOenc,XXFLombine,CONFIG,
418 &XNMN,PROB,GRAN,ARSF,EN,TIME,OREJECTED,THICK2,THICK2,
419 &Radiator,Aradeffect,WWthick2,XXN2,ART2,ART12,
420 &ARTX2,THICK2,XXL2,XXL3,XXS2,XXS3,XXS4,XXS5,XXS6,XXS7,XXS8,XXS9,
421 &Radiator,Aradeffect,WWthick2,XXN2,ART2,ART12,
422 &XNTMANN,XXM2,XXM3

423 C

424 WRITE (6,'*') '*** HEAT REJECTION SYSTEM FOR A BRAYTON CYCLE SYSTEM
425 &WHICH CYCLE WATER HEAT IS REJECTED TO A PUMPED MAE LOOP FROM
426 &THE CYCLE WORKING FLUID TO A HEAT PIPE COOLED GAS MANIFOLD ***
427 WRITE (6,'*') '*

428 CALL RADPNTR(GRAD,TRAD,XTUBES,XNEXPIP,XXFLAT,DPIPE,INFLUID,INMTL,
429 &EThet,DRRAD,THICM,THICKF,THICK,EM,
430 &Ebeta,KNAP,GRAD,TKFIN,RHOcoating,RFHOF,RNOenc,XXFLombine,CONFIG,
431 &XNMN,PROB,GRAN,ARSF,EN,TIME,OREJECTED,THICK2,THICK2,
432 &Radiator,Aradeffect,WWthick2,XXN2,ART2,ART12,
SUBROUTINE HRHAST CouplInoOptiorm:INOIN7/BINC/IIDINF/H/NI/NrJNLIPINQ1/NQ2/NQ3/RIS/NT/WINX/NZ1

Source file Listing

CALL ORBPRT |ENfEg,HeLt,HINCL,Rsun,YrLnch)
CALL IgWPRT(lftg?.,llmn, Gap,Pttch,XNpipes,XnexpJpes,Dcan,
& Ho,p,Re,Rb,Tt,TKfin,TKcan,TKbraze,TKop,XHf,RHCan,RHDbraze,
&THICKman,Pin,Tin,Man,Grad,XW,XMANmass,DPman,DTfilm,XMANMAN)
WRITE (6,*)
CALL PIPPRCT(XN9,R9,Dp, SUMLEN,Vpipe,Trak,RhHOPIP,
&THICK,RHOINS,DPPIPE,PIPMAX,PIPMAS)
WRITE (6,*)
CALL NSXKPTCIMXfig,ODOT,THIN,THOUT,TCIN,TCOUT,WOODS,DESNH,
& DTUBE,TUBE,WDOTT,AKTUBE,DPHELL,ANTUBES,DTUBE2,ALSHL,
&AMPLATES,ANTUBES,ANETMSS,XXHNHEX,XXHBL,APRIC,UNEW,RETUBE,
& ANINSUL,ANHEADS,ANTSH,AMSTR)
WRITE (6,*)
CALL PMPPRT(Tin,UDOTT,DPPIPE,DPPIPE,DPLOOP,Phyd,
&_mpum)
CALL VAC_T(XNNvaC,XNVAC)
WRITE (6,*)
WRITE (6,*)
WRITE (6,*)
WRITE (6,*)
WRITE (6,*)
STOP
CASE WHERE A DIRECT CONDENSING SHEAR FLOW CONDENSER IS USED TO
REJECT HEAT FROM A RANKINE CYCLE
READ (5,*) IENfEg,HaLt,HINCL,Run
READ (5,*) YrLnch,Time
INPUTS REQUIRED TO DEFINE ORBIT
INPUTS REQUIRED TO DEFINE RADINATOR
READ (5,*) GAM,ARSF,Eam,PROB
IMSS SUNKARY FOR INDIRECT BRAYTON SYSTEM
HEAT SINK HEAT EXCHANGER NASS (LBS)(DRY) 8'.ANETHASS
HEAT EXCHANGER NASS (LBS) m',)O4NHEX
NalC PIPING SYSTEM (LBS)(DRY) s'.PIPNAIC
HASS OF NaK IN PIPING SYSTEM (LBS) =',)O4NPIP
HEAT PIPE/NaKNANIFOLD NASS (LbS) (DRY)
& + XHNNAN
HEAT PIPE/NaK IN MANIFOLD (LBS) =',)O4NPIP
EXPANSION COMPENSATOR MASS (LBS) (DRY) =',)O4NVAC
RADIATOR MASS (LBS) =',)XNETRADMA22
XHST = ANETMSS + XXHNHEX + PIPMAK + PIPMAK + XORPUMP + XMANmass
& + XHNNAN + XEXAC + XMOVA + XNHEX + Xnetradmass2
STOP
CASE WHERE A DIRECT CONDENSING SHEAR FLOW CONDENSER IS USED TO
REJECT HEAT FROM A RANKINE CYCLE
INPUTS REQUIRED TO DEFINE ORBIT
INPUTS REQUIRED TO DEFINE RADINATOR
READ (5,*) GAM,ARSF,Eam,PROB
Inputs required to define condenser

READ (5,*), CONFIG, Xntubes, Xnexpip, Xlflat
READ (5,*), Dpipe, Ifluid, Imatl, Theta
READ (5,*), D2rad, Thickm, Thickf, Thick
READ (5,*), Em, Alpha, Hap, Harad
READ (5,*), Tkfin, Rhcoating, Rhofin, RHarm
READ (5,*), Xlflab, Xnchannels

INPUTS REQUIRED TO DEFINE CONDENSER

READ (5,*) Cmn, Hmean, Gap, THICKins
READ (5,*) RHOfins, Tout, Tbreze, TKcan
READ (5,*) Tkbraze, Tkhp, Pin, Tin
READ (5,*) Xlflin, RHOpip, RHOfins, RHObraze
READ (5,*) THICKm, Thtpip, Iman

XHpipes = Xntubes
XHexpipes = Xnexpip
CALL COMM (Ifluid, Cmn, Hmean, Gap, THICKins, RHOfins, Tout,
& Tbraze, TKcan, Tbreze, TKhp, XHpipes, XHexpipes, Pin, Tin, Xlfin, RHOpip,
& RHOfins, RHObraze, THICKm, Thtpip, Iman, Grad, XHchannels, DPman, DTFsup,
& Ar, Gt, V, Dh, Cgt, Rel, ML, Xtt, Rev,
& DTFcon, DTFsub, DTFfilm)

DTm = Tin - Tout
CALL THEAM (Tin, DTm, DTFfilm, Trad)

CALL HRRAD (Grad, Trad, Xntubes, Xnexpip, Xlflat, Dpipe, Ifluid, Imatl,
& Theta, D2rad, Thickm, Thickf, Thick, Em, IEHFig, Halt, HINCL, Rmean, Yrinch,
& Alpha, Hap, Harad, Tkfin, Rhcoating, Rhofin, RHarm, Xlflab, CONFIG,
& Xchannels, PROB, GAN, ARSF, Eem, Tarime, arejected, Thickf2, Thickm2,
& ARadiator, ARadec1, Wthick2, Xh2arte2, ArtidZ,
& Artwall2, Thick2, Xlevap2, Xlad2, Xispec2, Xltot2, Xmpipes, Xamfluid,
& Xamfin, Xacoating, Xamarmor, Xamarmorid, Xstructure,
& Xnetradmasst2, Mx(2)

WRITE (6,*), '**** HEAT REJECTION SYSTEM FOR A RANKINE CYCLE SYSTEM
& IN WHICH CYCLE HEAT IS REJECTED DIRECTLY FROM THE CYCLE WORK
****
WRITE (6,*), '**** HEAT REJECTION SYSTEM FOR A RANKINE CYCLE SYSTEM
& IN WHICH CYCLE HEAT IS REJECTED DIRECTLY FROM THE CYCLE WORK
****
CALL RADPRT (Grad, Trad, Xntubes, Xnexpip, Xlflat, Dpipe, Ifluid, I
& matl, Theta, D2rad, Thickm, Thickf, Thick, Em,
& Alpha, Hap, Harad, Tkfin, Rhcoating, Rhofin, RHarm, Xlflab,
& Xchannels, PROB, GAN, ARSF, Eem, Tarime, arejected, Thickf2, Thickm2,
& ARadiator, ARadec1, Wthick2, Xh2arte2, ArtidZ,
& Artwall2, Thick2, Xlevap2, Xlad2, Xispec2, Xltot2, Xmpipes, Xamfluid,
& Xamfin, Xacoating, Xamarmor, Xamarmorid, Xstructure,
& Xnetradmasst2)
CALL CRBPIRT (IEHFig, Halt, HINCL, Rmean, Yrinch)

CALL COMPT (Ar, Gt, V, Dh, Cgt, Rel, ML, Xtt, Rev,
& Ifluid, Cmn, Hmean, Gap, THICKins, RHOfins, Tout,
& Tbraze, TKcan, Tbreze, TKhp, Xmpipes, Xexpipes, Pin, Tin, Xlfin, RHOpip,
& RHOfins, RHObraze, THICKm, Thtpip, Iman, Grad, XHchannels, DPman,
SUBROUTINE HRMAST

C

WRITE (6,*) 'MASS SUMMARY FOR CONDENSING RANKINE SYSTEM'
WRITE (6,*) 'HEAT PIPE COOLED CONDENSER MASS (Lbs) =',XMAWmas
WRITE (6,*) 'RADIATOR MASS (LBS) =',Xnetradmasst2
XNSYST = XOAImmas + Xnetradmasst2
WRITE (6,*) 'CONDENSING RANKINE SYSTEM MASS (LBS) =',XNSYST
WRITE (6,*) '
STOP

1000 WRITE (6,*) 'THE SIMPLIFIED DATA INPUT OPTION HAS BEEN SELECTED'

READ INPUTS TO DEFINE ORBITS
IF IENfilg .NE. 0, THEN USE DEFAULTS OF:
Halt = 1000.0 Km
HINCL = 30.0
Rsun = 1.0
Yrlnch = 2000.0
Time = 10.0*365.0*24.0*3600.0
READ (5,*) IENfilg,Halt,HINCL,Rsun
READ (5,*) Yrlnch,Time
IF (IENfilg.EQ.0) THEN
Halt = 1000.0
HINCL = 30.0
Rsun = 1.0
Yrlnch = 2000.0
Time = 10.0*365.0*24.0*3600.0
ELSE
ENDIF
READ IN DATA TO DEFINE PROBLEM
READ (5,*) Pin,Tin,Xm,w,Tout
READ (5,*) Grad
Pin = CYCLE WORKING FLUID INLET PRESSURE (PSIA)
Tin = CYCLE WORKING FLUID INLET TEMPERATURE (deg-R)
Xm,w = CYCLE WORKING FLUID MOLECULAR WEIGHT (MW)
Tout = CYCLE WORKING FLUID OUTLET TEMPERATURE (deg-R)
Grad = CYCLE TOTAL HEAT REJECTION RATE REQUIRED (KWt)
Time = MISSION TIME (SECONDS)
CODE WILL ATTEMPT TO ESTIMATE THE VALUES REQUIRED TO RUN THE FULL
CASE WHICH CAN BE USED AS THE STARTING POINT FOR A FULL ANALYSIS
IF (lprob.EQ.1) THEN
GO TO 1005
ELSE
GO TO 1200
ENDIF
C
C SET MANIFOLD GAS VELOCITY TO DESIGN MANIFOLD
C
1005 Vgasman = 35.0
105 iflg2 = 1
106 DTman = Tin-Tout
107 DTflim = 50.0
108 CALL THEAN(Tin,DTman,DTflim,Tbar)
109 CALL RADFLG(Tin,ifluid,Imat1)
600 Alpha = 0.5
601 Nap = 1.0
602 HArad = 2.0
603 C WRITE (6,*),Vgasman,iflg2,DTman,DTflim',Vgasman,iflg2,DTman,DTflim
604 C &lm
605 C WRITE (6,*),Tin,Tbar,ifluid,Imat1',Tin,Tbar,ifluid,Imat1
606 CALL HRTSNK(1,Enflg,Enalt,NINCL,Uninl,Trinch,Alpha,Nap,HArad,Tsink)
607 C WRITE (6,*),'Alpha,Nap,HArad,Tsink=',Alpha,Nap,HArad,Tsink
608 Em = 0.8
609 Efard = 0.65+(0.0002*Tsink)
610 ARadest = (3413.0*Grad)/(0.1713E’08*Em*Efard*((Tsink* &*4.0))
612 Aactual = 0.5*ARadest
613 C WRITE (6,*),Em,Efard,ARadest,Aactual=',Em,Efard,ARadest,Aactual
614 DUNLen = 20.0
615 Width = Aactual/DUNlen
616 Can = Width
617 Xntubes = (12.0*Width)/3.5
618 C WRITE (6,*),DUNlen,Width,Can,Xntubes=',DUNlen,Width,Can,Xntubes
619 Xnexpip = 0.1*Xntubes
620 Pitch = 3.5/12.0
621 Dcan = 0.090333
622 C WRITE (6,*),Xnexpip,Pitch,Dcan=',Xnexpip,Pitch,Dcan
623 Dhp = 0.083333
624 Rc = 0.043500
625 Rb = 0.043333
626 Tf = 0.0000533
627 C WRITE (6,*),Dhp,Rc,Rb,Tf=',Dhp,Rc,Rb,Tf
628 TKfin = 112.0
629 TKcan = 10.0
630 TKbraze = 28.0
631 TO = Tin*1.18273.2
632 C WRITE (6,*),TKfin,TKcan,TKbraze,TO=',TKfin,TKcan,TKbraze,TO
633 CALL Wallprop(Imat1,TO,Valden,Tcwall)
634 TKhp = 242.0*Tcwall
635 Xlnpipes = Xntubes
636 C WRITE (6,*),Valden,Tcwall,TKhp=',Valden,Tcwall,TKhp
637 Xnexpip = Xnexpip
638 XNW = Xnw
639 PWan = Pin
640 C WRITE (6,*),Xlnpipes,Xnexpip,Xnw,PWan=',Xlnpipes,Xnexpip,Xnw
641 C &en
642 Tman = Tin
RHOcan = 505.0
RHObraze = 535.0
THICKmmn = 0.005208 + (0.000052 * Pin)

644 C WRITE (6, *) 'Tmm, RHOcan, RHObraze, THICKmmn, Tmm, RHOcan, RHObraze,' 
645 C &THICKmmn
646 C CALL HEXEPR(XW, Tmm, RHOcan, RHObraze, Tcond, Pr)
647 C WRITE (6, *) 'Gma, C, Rho, Amu, Tcond, Pr
648 C WRITE (6, *) 'Gma, C, Rho, Amu, Tcond, Pr
649 C WRITE (6, *) 'Gma, C, Rho, Amu, Tcond, Pr
650 Vmm = (3413.0 * Grad) / (3600.0 * C * (Tin - Tout))
651 Gap = (6.0 + (12.0 * Dcan)) / 12.0
652 Vmm = 1.50
653 XF = Vmm / 12.0 / 10.0
654 C WRITE (6, *) 'Tcond, Pr, Vmm, Gap', Tcond, Pr, Vmm, Gap
655 1008 Amin = (Gap * Vmm) - (Dcan * Vmm)
656 Vmm = Vmm / (Rho * Amin)
657 ERROR3 = (Vgasman / Vmm) - 1.0
658 IF (ERROR3 .GT. 0.1) THEN
659 ERROR3 = 0.1
660 ELSE
661 ERROR3 = ERROR3
662 ENDIF
663 Vmm = Vmm * (1.0 + (0.8 * ABS(ERROR3)))
664 XF = Vmm / 12.0 / 10.0
665 C WRITE (6, *) 'ERRORS = ', ERROR3
666 C WRITE (6, *) 'ERROR = ', Vmm
667 IF (ABS(ERROR3) .GT. 0.0001) THEN
668 GO TO 1008
669 ELSE
670 GO TO 1009
671 ENDIF
672 1009 CONTINUE
673 C WRITE (6, *) 'INPUTS FOR HPMAN FROM LINE 598'
674 C WRITE (6, *) 'IfLuld, IfLg2, Camn, Hmm', IfLuld, IfLg2, Camn, Hmm
675 C WRITE (6, *) 'Gap, Pitch, Dcan, Dhp', Gap, Pitch, Dcan, Dhp
676 C WRITE (6, *) 'Rc, Rb, Tf, Tkfinw', Rc, Rb, Tf, Tkfin
677 C WRITE (6, *) 'Tkcan, Tkbraze, Tkhp, Xnf', Tkcan, Tkbraze, Tkhp, Xnf
678 C WRITE (6, *) 'Xnpipes, Xnpipes, Xn', Xn
679 C WRITE (6, *) 'Tin, RHOcan, RHObraze, THICKmmn, Tin, RHOcan, RHObraze, Tin
680 C &THICKmmn
681 C WRITE (6, *) 'Vmm, Grad', Vmm, Grad
682 CALL HPMAN(ifLuld, IfLg2, Camn, Hmm, Gap, Pitch, Dcan, Dhp, Rc, Rb, Tf, Tkfin
683 &\&, Tkcan, Tkbraze, Tkhp, Xnf, Xnpipes, Xnpipes, Xn, Tin, RHOcan, RH
684 &RHObraze, THICKmmn, Vmm, Grad, XNNAmm, DPmm, Diffilm, XMMAN)
685 Grad = Grad
686 Grad = Grad
687 Xntubes = (12.0 * Width) / 5.5
688 Xnpipes = 0.1 * Xntubes
689 Xflat = Vmm / 12.0
690 Dhpipes = 1.0
691 CALL RADFLG(Tbar, IfLuld, IfLg2)
692 1100 THETA = 0.0
693 D2rad = Width / PI
694 Thick = 0.0
SUBROUTINE HRNAST

Source file Listing

695  Thick = 0.050/12.0
696  Thick = 0.003/12.0
697    Em = 0.8
698  Tkfin = 49.1
699  Rhocoating = 0.0
700  Rhofin = 113.0
701  RHOfam = 113.0
702  Xladiab = 0.0
703    Xamchab = 0.0
704    PROB = 0.99
705    GAN = 1.70
706    ARSF = 1.70
707    Eam = 10000000.0
708    CONFIG = 1.0
709
710  CALL THEAK(Tin,D1man,DTfilm,Trad)
711  CALL HRRAD(Qrad,Trad,Xntubes,Xnexp,Xntubm,Xnexpm,Xtfin,Dhpipe,Ifuid,Imatl,
712    &Thea,D2rad,Thickb,Thickness,Em,Emtflg,Emt,NINCL,Rsun,Yrfinch,
713    &Alpha,Nap,NArad,Tkfin,Rhocoating,Rhofin,RHOfam,Xladiab,CONFIG,
714    &Xamcham,PROB,GAN,ARSF,Eam,Em,Tm,Projeted,Thick2,Thickm2,
715    &Aradlector,Aradefect,Whick2,Xntot2,Artid2,
716    &Aradwall2,Whick2,Xlevep2,Xladi2,Xlames2,Xltot2,Xnpipe3,Whick3,
717    &Xnfin,Xamcham,Xnexp,Xnexpm,Xamcham,PROB,GAH,ARSF,Em,Tm,Projeted,Whickf2,Whickm2,
718    &Xmcham,PROB,GAH,ARSF,Em,Tm,Projeted,Whickf2,Whickm2,
719     *XN9 = 12.0
720     Vpipe = 100.0
721     PGAS = Pm
722     TGAS = Tin
723     CALL HEPHRM(Pm,PGAS,TGAS,GNA,CP,RHOBIS,NI,J,AK,PR)
724     Dp = 12.0*3RT((1.27324*Vp)/Vpipe)
725 C WRITE (6,*) 'RHOgas = ',RHOgas
726 C WRITE (6,*) 'Dp = ',Dp
727 SUNLEN = 12.0*Dp
728 THICKP = PGAS*Dp/(2.0*SO00.O)
729 IF (THICKP.GT.0.03125) THEN
730 THICKP = THICKP
731 ELSE
732 THICKP = 0.03125
733 EMDF
734 THICKI = 4.0
735 RHOPIP = 505.0
736 RHOINS = 16.0
737 R9 = 4.0*Dp
738 CALL HRDUCT(XN9, R9,Dp,SUNLEN,Vpipe,TGAS,PGAS,THICKP,THICKI,RHOPIP,
739    &THICKI,RHOINS,Xin,DPDUCT,DUCHAS)
740 C
741 C
742 WRITE (6,*) ' **** HEAT REJECTION SYSTEM FOR A BRAYTON CYCLE SYSTEM
743 EIN WHICH CYCLE WASTE HEAT IS REJECTED DIRECTLY FROM THE CYCLE WORK
744 ENGING FLUID IN A HEAT PIPE COOLED GAS MANIFOLD ****
745 WRITE (6,*) ',
746 WRITE (6,*) 'INPUT FOR OPTION NUMBER 1'
SUBROUTINE HRKAST  

C define options
0NT/NO/BIN/C/NFH/NI/NL/P/NQ1/NG2/NG3/R/SINT/}

WRITE (6,*) INPUT FOLLOWING DATA INTO FILE *RADAT* TO RUN OPT 01

C DEFINE ORBIT
WRITE (6,*) GM, ARSF, Earm, PROB
WRITE (6,*) CONFIG, Xntubes, Xnexpip, Xi flat
WRITE (6,*) Dpipe, fluid, Imatl, Theta
WRITE (6,*) D2rad, Thick, Thickf, Thick
WRITE (6,*) Em, Alpha, N, NArad
WRITE (6,*) Tkfin, Rhocoating, Rhoftn, RHOarm
WRITE (6,*) Xladiab, Xachmas

C DEFINE RADATOR
WRITE (6,*) ifig2, Mean, Gap, Pitch
WRITE (6,*) Dcan, Dhp, Rc, Rb
WRITE (6,*) Tf, Tkfin, TKcan, TBraze
WRITE (6,*) TKhp, XHF, Xw, RHOcan
WRITE (6,*) RHObraze, THICKcan, Mean
WRITE (6,*) 

C DEFINE DUCTING
WRITE (6,*) XN9, R9, Dp, SUNLEN
WRITE (6,*) THICK, RHOPIP, THICKI, RHOINS
WRITE (6,*) 
WRITE (6,*) ifig2, Mean, Gap, Pitch
WRITE (6,*) Dcan, Dhp, Rc, Rb
WRITE (6,*) Tf, Tkfin, TKcan, TBraze
WRITE (6,*) TKhp, XHF, Xw, RHOcan
WRITE (6,*) RHObraze, THICKcan, Mean
WRITE (6,*) 

CALL RAPRTG, Grad, Trad, Xntubes, Xnexpip, Xi flat, Dpipe, fluid, I

C define structure,
SUBROUTINE HRMAST (Capitallng Options: NO, NT, B, NC, ND, NF, H, NI, NK, NL, P, ml, NQ2, NQ3, R, S, NT, V, NX, NZ)

Source file listing

800     &Xnetradmass2)
801     CALL ORBPRT(ENfig, Halt, HINCL, Rsun, Trinch)
802 C
803     CALL HNNPRT(Ifig2, Hmean, Gap, Pitch, XMpipes, Xcanpipes, Dcan,
804     &Dhp, Rc, Rb, Tf, TKfin, TKcan, TKbrazx, TXF, RHOCan, RHOBrazx,
805     &THICcan, Pin, Tin, Hmean, Grad, XMW, XHCan, DPMcan, DTfilm, XMNN)
806     WRITE (6,"(6,*)")
807 C
808     CALL DUCPRT(XN9, R9, Dp, SUNLEN, Vpipe, Tin, Pin, THICKP, RHOPIP,
809     &THICKl, RHOINS, XMW, DPOUCT, DUCNAS)
810 C
811     WRITE (6,"(6,*)") 'MASS SUMMARY FOR DIRECT Brayton SYSTEM'
812     WRITE (6,"(6,*)")
813     WRITE (6,"(6,*)") 'HEAT PIPE COOLED GAS MANIFOLD MASS (Lbs) = ', XHCan
814     WRITE (6,"(6,*)") 'MANIFOLD DUCTING MASS (Lbs) = ', DUCNAS
815     WRITE (6,"(6,*)") 'RADIATOR MASS (Lbs) = ', Xnetradmass2
816     WRITE (6,"(6,*)") 'XNETS YST = XHCan + DUCNAS + Xnetradmass2
817     WRITE (6,"(6,*)")
818     WRITE (6,"(6,*)") 'DIRECT Brayton SYSTEM MASS (LBS) = ', XHSTY
819     WRITE (6,"(6,*)")
820 C
821     STOP
822 C
823 1200 IF (Iprob.Eq.3) THEN
824     GO TO 1400
825 ELSE
826     GO TO 1205
827 ENDIF
828 1205 INXfig = 2
829 C
830 C DESIGN HEAT REJECTION HEAT EXCHANGER (HRHX)
831 C
832     UEST = 100.0
833     THIN = Tin
834     TCOUT = Tout
835     PHOT = Pin
836     TCOUT = THIN - 30.0
837     TCIN = THOUT - 50.0
838     CALL HEXTPR(XMW, PHOT, THIN, GHA, CP, RHO, ANU, TCOND, PR)
839     WRITE (6,"(6,*)")
840 C
841     WRITE (6,"(6,*)") 'INXfig, UEST, THIN, TCOUT, PHOT, TCIN = ', INXfig,
842 C &UEST, THIN, TCOUT, PHOT, TCIN
843 C
844     WRITE (6,"(6,*)") 'XMW, PHOT, THIN, GHA, CP, RHO, ANU, TCOND, PR = ', XMW, PHOT,
845 C &THIN, GHA, CP, RHO, ANU, TCOND, PR
846     LDOT = (3415.0*Grad)/(3600.0*CP*(THIN-TCOUT))
847     ANUS = XMW
848     TINS = 4.0
849     DENINS = 24.0
850     DENSNH = 505.0
851 DTUBE = 0.375
852 PR = 1.5
853 TUBE = 0.020
SUBROUTINE HRMAST C_ap|t|ng Optionm:/NOINT/BiNCIHK)/NOFININrJIILiPlNQ21NG31RISINTiV/NX/NZlSource file Listing

852 C AMPLATES = 5.0
853 C WRITE (6,*) 'WDOTS,AMWS,TIMS,DENINS,DENSSH,DTUBE,PR,TTUBE,AMPLATES
854 C & =',WDOTS,AMWS,TIMS,DENINS,DENSSH,DTUBE,PR,TTUBE,AMPLATES
855 CALL XNAKPR(TCIN,RHOnak,CPnak,VI3nak,TKnak)
856 C WRITE (6,*) 'TCIN,RHOnak,CPnak,VI3nak,TKnak =',TCIN,RHOnak,CPnak,
857 C &VI3nak,TKnak
858 UDOTT = (3413.0*Grad)/(3600.0*CPnak*(TCOUT-TCIN))
859 AXTUBE = 10.0
860 GDOT = 3413.0*Grad
861 C WRITE (6,*) 'UDOTT,AXTUBE,GDOT =',UDOTT,AXTUBE,GDOT
862 C WRITE (6,*) 'CALLING HRSHEL'
863 CALL HRSHEL(\HXf Lg,UEST, THIN, THOUT, PHOT, TCIN, TCOUT,MDQTS,ANU,
864 &S,TIMS,DENINS,DENSSH,DTUBE,PR,TTUBE,AMPLATES,UDOTT,AXTUBE,0
865 &GDOT,DP4EL,ANTUDES,DP4ane,DOL2,AL4HEL,APSHELL,AMPLATES,
866 &ANTUDES,ANxUL,ANHEADS,AMSTR,ANETMASS,AN44HEX,ANxHEL,AFRIC,UNE,
867 &ANTUDES,THC,ANxSHT)
868 C SET MANIFOLD LIQUID VELOCITY TO DESIGN MANIFOLD
869 C
870 C
871 Wllman = 30.0
872 ifl2 = 2
873 DTman = Tin-Tout
874 DTFilm = 50.0
875 C CALL THEAN(Tin,DTman,DTFilm,Tab)
876 C CALL RADFLG(Tin, Iftuld, lmtt)
877 Alpha = 0.5
878 Hap = 1.0
879 HArad = 2.0
880 C CALL HR4ELM(\ENfig,WEH,CNCL,RA,\lch,Alph,\ap,\Arad,Tsink)
881 Ec = 0.8
882 Eradst = 0.65+(0.0002*Tbmr)
883 Aradest = (3413.0*Grad)/(0.1713E-08*Ec*Eradst*((Tbmr**4.0)-(Tsink*
884 &4.0)))
885 Aactual = 0.5*Aradest
886 DUNLen = 20.0
887 Width = Aactual/DUNLen
888 Caen = Width
889 C WRITE (6,*) '******FROM LINE 81******
890 C WRITE (6,*) 'Eradst,Aradest,Aactual,Width,Cæn=','Eradst,Aradest,A
891 C 'actual,Width,Cæn
892 Caen = 1.5
893 Pitch = 3.5/12.0
894 Dcan = 0.090333
895 Dhp = 0.083333
896 Rc = 0.043500
897 Rb = 0.043333
898 Ty = 0.000033
899 TKfin = 112.0
900 TKcan = 10.0
901 TKbraze = 28.0
902 T0 = Trad/1.8-273.2
903 CALL Welplp(Imat, T0, Wallen, Tcwall)
SUBROUTINE HRIMST (Camp! I,
ing Options:iNO/N7/BINClmlNFIH/NIINK/NL/PINQ1/N2/NG_/RISINT/UINXINZ1
Source File Listing

TKhp = 242.0*Twall
XHF = 1.5*12.0*10
Xntubes = ((12.0*Width)/3.5
Xnexpip = 0.1*Xntubes
XNpipex = Xntubes
XNexpip = Xnexpip
XNW = Xnw
Pman = Pin
Tee = Tin
RHOcan = 505.0
RHoBraze = 535.0
THICKman = 0.005208 + (0.000052*Pin)
Uman = WDOtt
GAP = 0.5

DO 1209 I = 1,100,1
Vlmn = Idmr*(Rho*Nn|n)
ERROR4 = 1.0 - (Vlmn/Vman)
Amin = ERROR4(1.0+(0.8*ERROR4))
WRITE (6,*), 'Vman,ERROR4,Amin=', Vman, ERROR4, Amin
IF (ABS(ERROR4).GT.0.01) THEN
  GO TO 1209
ELSE
  GO TO 1210
ENDIF

CALL HPIMN(f luid, Hfig2, C_m, Nmn, Gap,PitcH,Dcan,Dl_d,Rc,Rb,Tf,Tf/TKfi
&n,TKcan,TKbraze,THP,XMf,XNpipex,XNexpipex,Xnw,Pin,Tin,RHOcan,RH
&Obraze,THICKman,Umam,Grd,DKAHrHs,DPnrn,Dft film,DKHRAM)

XNW = 12.0

SET PIPE VELOCITY AT 30.0 FT/SEC TO DESIGN MAK PLUMBING SYSTEM

CALL XNAKPR (Tram, RHO, CP,VIS,TK)

Vpipe = 30.0
UpiPe = Vpipe
Dp = SQRT((183.346*Vpipe)/(Rho*Vpipe))
SUMLEN = 60.0*(Grad/50.0)
THICKP = 0.10
RNPIP = 505.0
THICKI = 4.0
RNOINs = 24.0
R9 = 4.0*Dp
WRITE (6,*), 'INPUTS FOR HRPIPE'
WRITE (6,*), 'Vpipe,Upipe,Dp,SUMLEN=', Vpipe,Upipe,Dp,SUMLEN
CALL HRPIPE(Xhp,R,Dp,SUMLEN,Vpipe,Tin,Pin,THICKP,RNPIP,THICKI),
&RNIOIns,DlpIPe,PIPMak,PIPMAs)

Grad = Grad
Tread = Tbar
SUBROUTINE HRMAST
CowptLtrIOpttons:/NO/NT/B/NC/ND/NF/H/NI/NYJNL/P/NQ1/NQ2/NO3/R/S/NT/NL/NX/NZ1

Source file Listing

956  Xntubes = (12.0*Width)/3.5
957  Xnexpip = 0.1*Xntubes
958  Xflat = 18.00
959  Dpipe = 1.0
960  CALL RADFLGCT(Tbar,Ifuid,Imatl)
961  1300 TMETA = 0.0
962  D2rad = Width/P1
963  Thickm = 0.0
964  Thickf = 0.050/12.0
965  Thick = 0.003/12.0
966  Eam = 0.8
967  Tkfin = 49.1
968  Rhocoating = 0.0
969  Rhofin = 113.0
970  RH0arm = 113.0
971  Xladiab = 0.0
972  Xchmase = 0.0
973  PROB = 0.99
974  GAN = 1.70
975  ARSF = 1.70
976  Earm = 10000000.0
977  CONFIG = 1.0
978  CALL TNEAN(Tin,DTman,DTfilm,Trad)
979  CALL HRRAD(Grad,Trad,Xntubes,Xnexpip,Xf1at,Dpipe,Ifuid,Imatl,
980  &Theta,D2rad,Thickm,Thickf,Thick,Em,IEHfig,Halt,HINCL,Raun,Yrlnch,
981  &Alpe,Hap,Hrad,Tkfin,Rhocoating,Rhofin,ROOarm,Xladiab,CONFIG,
982  &Xchmase,PROB,GAM,ARSF,Earm,Time,Rejected,Thick2,Thickm2,
983  &RADiater,AREdect,UThick2,Xntot2,Ar1d2,
984  &ARail2,Trick2,Xlevap2,Xladi2,Xispec2,Xitot2,Xmpipe,Xmfluid,
985  Xh0fin,Rhocoat,Xarmor,Xarmworld,xtstructure,
986  &Xnetworkmass2,T2(2)
987  C
988  C
989  MDOTT = Wpipe
990  CALL PUMP(Tin,MDOTT,DPPIPE,DPTUBE,DPman,DPLOOP,Phyd,XPUMP)
991  C
992  CALL VACMS(Tin,PIPEAIC,GNNOMN,JOM(NHEX,BIVAC,IVAC)
993  C
994  C
995  C
996  C
997  C
998  C
999  C
1000  WRITE (6,*) '*** HEAT REJECTION SYSTEM FOR A BRAYTON CYCLE SYSTEM
1001  &IN WHICH CYCLE WASTE HEAT IS REJECTED TO A PUMPED NAIK LOOP FROM
1002  &THE CYCLE WORKING FLUID TO A HEAT PIPE COOLED NAIX MANIFOLD ***'
1003  WRITE (6,*)'*'
1004  WRITE (6,*)'*'
1005  WRITE (6,*)'*** INPUT FOLLOWING DATA INTO FILE *RADAT* TO RUN OPT #2 ***'
1006  DEFINE ORBIT
1007  WRITE (6,*) IENfig,Halt,HINCL,Raun
1008  WRITE (6,*) Yrlnch,Time
SUBROUTINE HRJ4AST

1008 WRITE (6, *) ', '
1009 C DEFINE RADIATOR
1010 WRITE (6, *) GAMS, ARSF, Ears, PROB
1011 WRITE (6, *) CONFIG, Xntubes, Xmaxpip, Xlif
1012 WRITE (6, *) Dhpipe, Ifluid, Imat, Theta
1013 WRITE (6, *) D2rad, Thck, Thick, Thick
1014 WRITE (6, *) Em, Alpha, Heps, HArad
1015 WRITE (6, *) Tkfl, Rhcoating, Rhofin, RHOarma
1016 WRITE (6, *) Xladiab, Xmachas
1017 WRITE (6, *) ', '
1018 C DEFINE HEAT SINK HEAT EXCHANGER
1019 WRITE (6, *) IINfig, UEST, TCIN, TCOUT
1020 WRITE (6, *) DOTS, ANNS, TINS, DENINS
1021 WRITE (6, *) DENSSH, DTUBE, PR, TTUBE
1022 WRITE (6, *) AMPLATES, WDOTT, AKTUBE
1023 WRITE (6, *) ', '
1024 C DEFINE HEAT PIPE MANIFOLD
1025 WRITE (6, *) TFlg2, Hman, Gap, Pitch
1026 WRITE (6, *) Dcan, Dhp, Rc, Rb
1027 WRITE (6, *) Tf, TKfin, TKcan, TKbraze
1028 WRITE (6, *) TKhp, XNf, Xw, RHOcan
1029 WRITE (6, *) RHObraze, THICKman, Xman
1030 WRITE (6, *) ', '
1031 C DEFINE PIPING
1032 WRITE (6, *) XN9, R9, Dp, SUNLEN
1033 WRITE (6, *) THICKP, RHOPIP, THICKI, RHOINS
1034 WRITE (6, *) ', '
1035 WRITE (6, *) 'C IEFlfig, Helt, HINCl, Ran\n
1036 WRITE (6, *) 'C Yrlnch, Time'
1037 WRITE (6, *) ', '
1038 WRITE (6, *) 'C GAMS, ARSF, Ears, PROB'
1039 WRITE (6, *) 'C CONFIG, Xntubes, Xmaxpip, Xlif'
1040 WRITE (6, *) 'C Dhpipe, Ifluid, Imat, Theta'
1041 WRITE (6, *) 'C D2rad, Thck, Thick, Thick'
1042 WRITE (6, *) 'C Em, Alpha, Heps, HArad'
1043 WRITE (6, *) 'C Tkfl, Rhcoating, Rhofin, RHOarma'
1044 WRITE (6, *) 'C Xladiab, Xmachas'
1045 WRITE (6, *) ', '
1046 WRITE (6, *) 'C IINfig, UEST, TCIN, TCOUT'
1047 WRITE (6, *) 'C DOTS, ANNS, TINS, DENINS'
1048 WRITE (6, *) 'C DENSSH, DTUBE, PR, TTUBE'
1049 WRITE (6, *) 'C AMPLATES, WDOTT, AKTUBE'
1050 WRITE (6, *) ', '
1051 WRITE (6, *) 'C TFfig2, Hman, Gap, Pitch'
1052 WRITE (6, *) 'C Dcan, Dhp, Rc, Rb'
1053 WRITE (6, *) 'C Tf, TKfin, TKcan, TKbraze'
1054 WRITE (6, *) 'C TKhp, XNf, Xw, RHOcan'
1055 WRITE (6, *) 'C RHObraze, THICKman, Xman'
1056 WRITE (6, *) ', '
1057 WRITE (6, *) 'C XN9, R9, Dp, SUNLEN'
1058 WRITE (6, *) 'C THICKP, RHOPIP, THICKI, RHOINS'
1059 WRITE (6, *) ', '
SUBROUTINE HRHAST

CALL UDPRT (arid, Trllci,Xntubes,Xnexpt p, X tfl,t,Dhptpe, 

! PUID,

knt

L,Thetl,O2rad,Th|clae,Th|ckf,Th|ck, Ea,

IA
tphm, Ilap, HArld, Tl(f in,Rhocolt ing, Rhofin, RHOam,X tllclilb, 

lXmchms,PRoR,GNI,ARSF ,Emm, Tim,Qrejected, Th|ckf2, Th icim2,

IAradi

mtor,ArKlef fect

Vtht

ck2,Xrmrt2,Art
d2,

IArtuat

t2, Th i ck2,X L evsp2,X tradiZ,Xtspec2, X t tot2, Xapi pes, Xaf tuid, 

lXafin,XEoet t no,Xmmor ,YJmmorid,Xst ructure,

&XnetrlM/mmlt2)

PALL

ORBPRT(IENfLII,Ha|

t,HIMCL,Rmm,Yrtnch)

C

CALL H411PItT (! f t

jR, Ilmm,

Gap, Pitch, Xllpt pes, Xne_l pes ,Dcan,

&l)hp,Ilc, lib, Tf, TICf

|n, TICclm, TICbrllze, TlOip, XMf, RHOclm, RHObl'llze,

&TH i ClCmn, P| n, T

|n, Wmln, Orld,)Nd,

Xl4ANIm,I)Pmn,DTf ! LII,XNII4AM)

WRITE

(6,*)

’!

C

CALL P I PPRT(XM9, R9,Dp, SUNLEM,VpIpe, T

|n, P| n, TH! CXP, RHOPIP,

&THIDCI, RHOi

MS,DPP

I PE, Pi PHAK, PIPHAS)

bEITE

(6,*)

+’

CALL HSHXPT( IHXfLg,OOOT,THIM,TIIOUT,TCIM,TCOUT,kOOTS,DEMSSH,

&DTUSE, TTUBE, UDOTT, AJ(TUBE,DPSHELL ,AMTUSES, DPTUB , DOTL2, ALSHEL,

/J_NSRELL, ANPLATES, N4TURES

)XNMHEX, HSHELL, AFR

C, UNEV, RE_E,

&THC,

NN

1MSUL,

N4HE.4DS,

AHTSIIT,

N4STRT

)XNMHEX, HSHELL, AFR

C, UNEV, RE_E,

&THC,

NN

1MSUL,

N4HE.4DS,

AHTSIIT,

N4STRT

)XNMHEX, HSHELL, AFR

C, UNEV, RE_E,

&THC,

NN

1MSUL,

N4HE.4DS,

AHTSIIT,

N4STRT

)XNMHEX, HSHELL, AFR

C, UNEV, RE_E,

&THC,

NN

1MSUL,

N4HE.4DS,

AHTSIIT,

N4STRT

)XNMHEX, HSHELL, AFR

C, UNEV, RE_E,

&THC,

NN

1MSUL,

N4HE.4DS,

AHTSIIT,

N4STRT

)XNMHEX, HSHELL, AFR

C, UNEV, RE_E,

&THC,

NN

1MSUL,

N4HE.4DS,

AHTSIIT,

N4STRT

)XNMHEX, HSHELL, AFR

C, UNEV, RE_E,

&THC,

NN

1MSUL,

N4HE.4DS,

AHTSIIT,

N4STRT

)XNMHEX, HSHELL, AFR

C, UNEV, RE_E,

&THC,

NN

1MSUL,

N4HE.4DS,

AHTSIIT,

N4STRT

)XNMHEX, HSHELL, AFR

C, UNEV, RE_E,

&THC,

NN

1MSUL,

N4HE.4DS,

AHTSIIT,

N4STRT

)XNMHEX, HSHELL, AFR

C, UNEV, RE_E,

&THC,

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AHTSIIT,

N4STRT

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C, UNEV, RE_E,

&THC,

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1MSUL,

N4HE.4DS,

AHTSIIT,

N4STRT

)XNMHEX, HSHELL, AFR

C, UNEV, RE_E,

&THC,

NN

1MSUL,

N4HE.4DS,

AHTSIIT,

N4STRT

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&THC,

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AHTSIIT,

N4STRT

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&THC,

NN

1MSUL,

N4HE.4DS,

AHTSIIT,

N4STRT

)XNMHEX, HSHELL, AFR

C, UNEV, RE_E,

&THC,

NN

1MSUL,

N4HE.4DS,

AHTSIIT,

N4STRT

)XNMHEX, HSHELL, AFR

C, UNEV, RE_E,

&THC,

NN

1MSUL,

N4HE.4DS,

AHTSIIT,

N4STRT

)XNMHEX, HSHELL, AFR

C, UNEV, RE_E,

&THC,

NN

1MSUL,

N4HE.4DS,

AHTSIIT,

N4STRT

)XNMHEX, HSHELL, AFR

C, UNEV, RE_E,

&THC,

NN

1MSUL,

N4HE.4DS,

AHTSIIT,

N4STRT

)XNMHEX, HSHELL, AFR

C, UNEV, RE_E,

&THC,

NN

1MSUL,

N4HE.4DS,

AHTSIIT,

N4STRT

)XNMHEX, HSHELL, AFR

C, UNEV, RE_E,

&THC,

NN

1MSUL,

N4HE.4DS,

AHTSIIT,

N4STRT

)XNMHEX, HSHELL, AFR

C, UNEV, RE_E,

&THC,

NN

1MSUL,

N4HE.4DS,

AHTSIIT,

N4STRT

)XNMHEX, HSHELL, AFR

C, UNEV, RE_E,
SUBROUTINE NRMAST  Compt Ling Optiorm:INOINT/B/NC/H)/NFIHINI/NR/NL/PINQIlNG./N(13/RISINT/U/NXINZ1

Source file Listing

1112 CALL Tuman(Tin,DTmn,DTftu, Ther)
1113 Alpha = 0.5
1114 Nmp = 1.0
1115 NArad = 2.0
1116 CALL HRTHSN(LHflng, Malt, NINCL, Reun, Yrlnc, Alpha, Nmp, NArad, Tsink)
1117 C WRITE (6,*), 'RESULTS FROM SIMPLIFIED OPTION #3'
1118 C WRITE (6,*), 'DTman,Tber, Tsink = ',DTman,Tber, Tsink
1119 Em = 0.8
1120 Etared = 0.65 + (0.0002*Tber)
1121 Aradet = (3413.0*Grad)/(0.1713E-08*Em*Etared*(Tber**4.0)-(Tsink**4.0))
1122 Aa = 0.5*Aradet
1123 Actual = 0.5*Actual
1124 DUNLEN = 10.0
1125 Width = Actual/DUNLEN
1126 C WRITE (6,*), 'ETREd, Aradet, Actual, Width = ',Etared, Aradet, Actual
1127 C &x, Width
1128 Grad = Grad
1129 Trad = Trad
1130 Xntubes = (12.0*Width)/2.0
1131 Xnexpip = 0.1*Xntubes
1132 Xflat = 18.00
1133 Dhpipes = 1.0
1134 CALL RADFLOG(Tber,fluid, Imat)
1135 C WRITE (6,*), 'Grad, Trad, Xntubes, Xnexpip, fluid, Imat = ',Grad, Trad,
1136 C &xntubes, &xexpip, fluid, Imat
1137 1500 THETA = 0.0
1138 Cmaw = Width
1139 THlckێme = 4.0/12.0
1140 Tbrcase = 0.002/12.0
1141 TCan = 10.0
1142 TCan = 35.0
1143 THnpipes = Xntubes
1144 Xnexpip = Xnexpip
1145 Xhnpipes = Xnexpip
1146 RH0pip = 505.0
1147 RH0Can = 505.0
1148 RH0Braz = 525.0
1149 THlckCan = 0.0625/12.0
1150 Thnpipes = 0.020/12.0
1151 Xin = 1.0
1152 C WRITE (6,*), 'INPUT TO 1ST CALL TO KPRP (Xin,Pin, Tin) = ',Xin,Pin, Tin
1153 C &x
1154 CALL KPRP(Xin, Pin, Tin, DL, DV, NF, HF, HFG, SF, SFG, VF, VG)
1155 C WRITE (6,*), 'OUTPUT FROM KPRP (DL, DV, NF, HF, HFG, SF, SFG, VF, VG) = ',
1156 C &x
1157 CALL KPRP(Xin, Pin, Tin, CL, CV, TK, TV, Pr, Prv, VL, VV)
1158 Test = (-7633.6)/(ALOG10(Pin)-5.279)
1159 IF (Test.GT.Test) DHNET=C*(Test-Test)+HFG+CL*(Test-Test)
1160 IF (Test.EQ.Test) DHNET=(Xin*HFG)+CL*(Test-Test)
1161 IF (Test.LT.Test) DHNET=CL*(Test-Test)
1162 Vmen = 3413.0*Grad/DHNET
1163 Gap = 3.0/12.0
SUBROUTINE HRNAST

C Calql)rg

Options:/NO/NT/B/NC/NDINF/H/N/KNL/NQ2/HG3/RISINT/W/NX/NZ1

C Source file Listing

NEN = 2.0

DPlimit = 0.05*Pin

DTlimit = D菲尔

C WRITE (6,*), 'Hnen,DPlimit =', Hnen,DPlimit

C WRITE (6,*), 'DTlimit =', DTlimit

1504 CONTINUE

1170 CALL COMMAN(IFluid,Can, Hnen, Gap, THICKins, RHOins, Tout,

&Thbraz,TKcan,TKbraze,TKhp,XNpipes,XNexpipes,Pin,Tin,Xin,RHOpip,

&RHcan,RHObraz,THICKman,THtpip,Hnen,Grad,XNANmes,DPman,DTsup,

&Ar,ST,V,Dh,Ctg,Rel,Nl,Xnt,Re,

&DTFcon,DTFeub,DTfilmx)

1175 DTEROR = 1.0 - (DTlimit/DTfilm)

1176 Hnen = Hnen*(1.0+(0.1*DTEROR))

1177 C WRITE (6,*), 'DTEROR,Hnen =', DTEROR,Hnen

1178 IF (ABS(DTEROR).GT.0.01) THEN

1179 GO TO 1504

1180 ELSE

1181 GO TO 1506

1182 ENDF

1183 1506 Hnen = Hnen

1184 C WRITE (6,*), '-----------------------------------------------------------,

1185

1186 1508 CONTINUE

1187 CALL COMMAN(IFluid,Can, Hnen, Gap, THICKins, RHOins, Tout,

&Thbraz,TKcan,TKbraze,TKhp,XNpipes,XNexpipes,Pin,Tin,Xin,RHOpip,

&RHcan,RHObraz,THICKman,THtpip,Hnen,Grad,XNANmes,DPman,DTsup,

&Ar,ST,V,Dh,Ctg,Rel,Nl,Xnt,Re,

&DTFcon,DTFeub,DTfilmx)

1192 DPEROR = 1.0 - (DPlimit/DPmn)

1193 Gap = Gap*(1.0+(0.002*DPEROR))

1194 C WRITE (6,*), 'DPEROR,GAP, Hnen =', DPEROR,GAP,Hnen

1195 IF (ABS(DPEROR).GT.0.01) THEN

1196 GO TO 1508

1197 ELSE

1198 GO TO 1510

1199 ENDF

1200 1510 Gap = Gap

1201 CALL COMMAN(IFluid,Can, Hnen, Gap, THICKins, RHOins, Tout,

&Thbraz,TKcan,TKbraze,TKhp,XNpipes,XNexpipes,Pin,Tin,Xin,RHOpip,

&RHcan,RHObraz,THICKman,THtpip,Hnen,Grad,XNANmes,DPman,DTsup,

&Ar,ST,V,Dh,Ctg,Rel,Nl,Xnt,Re,

&DTFcon,DTFeub,DTfilmx)

1206 Xfilat = 12.0*Hnen

1207 D2rad = Width/PI

1208 Thick = 0.0

1209 Thick = 0.050/12.0

1210 Thick = 0.003/12.0

1211 Em = 0.8

1212 Tkfin = 49.1

1213 Rhocoating = 0.0

1214 Rhofin = 113.0

1215 RHOarm = 113.0
SUBROUTINE HRNAST

Compiling Options: /NOINT/BINC/MINF/N/NINJNL/P/mullMQIWL31RISIMTiU/MXlMZ1

Source file Listing

1216  Xladiab = 0.0
1217  Xchmas = 0.0
1218  PROB = 0.99
1219  GAM = 1.70
1220  ARSF = 1.70
1221  Earn = 10000000.0
1222  CONFIG = 1.0
1223  CALL THEAN(Tin,DTman,DTfilm,Trad)
1224  CALL NRRAD(Grad,Tin,Dxntubes,Xnexpip,Xtflt,Dhpipe,Ifluid,Imatl)
1225  WRITE (6,*)’Grad,Tin,Dxntubes,Xnexpip,Xtflt,Dhpipe,Ifluid,Immati,
1226  &Theta,D2rad,Thickness,Thickf,Em,EHfilg,Malt,INCL,Run,Yrinch,
1227  &Alpha,Nap,NArad,Tkfin = = = = = = = Grad,Trad,Xntubes,Xnexpip,Xtflt,Dhpipe
1228  &Ifluid,Imatl,Theta,D2rad,Thickness,Thickf,Em,EHfilg,Malt,INCL,
1229  &Run,Yrinch,Alpha,Nap,NArad,Tkfin
1230  CALL NRRAD(Grad,Trad,Xntubes,Xnexpip,Xtflt,Dhpipe,Ifluid,Imatl,
1231  &Theta,D2rad,Thickness,Thickf,Em,EHfilg,Malt,INCL,Run,Yrinch,
1232  &Alpha,Nap,NArad,Tkfin,Rhocoating,Rhofin,RNOarm,Xladiab,CONFIG,
1233  &Xchmas,PROB,GAM,ARSF,Earn,Time,Projected,Thickf2,Thickness2,
1234  &ARodio,Aradffect,Whick2,Xntube2,Artit2
1235  &Artit2,Thickness2,Xladi2,Xladi2,Xltot2,Xpipe,Ifluid,
1236  &Xrfin,Xxcoating,Xxarmor,Xxarmor,Xstructure,
1237  &Xntotmasst2,Wx(2)
1238  C
1239  C
1240  WRITE (6,*)’*** HEAT REJECTION SYSTEM FOR A RAMSHNE CYCLE SYSTEM
1241  &IN WHICH CYCLE WASTE HEAT IS REJECTED DIRECTLY FROM THE CYCLE WORK
1242  ++FLUID IN A HEAT PIPE COOLED CONDENSER ***
1243  WRITE (6,*)’ ‘
1244  WRITE (6,*)’INPUT FOR OPTION NUMBER 3’
1245  WRITE (6,*)’ ‘
1246  WRITE (6,*)’INPUT FOLLOWING DATA INTO FILE *RADAT* TO RUN OPT #3’
1247  WRITE (6,*)’
1248  C
1249  DEFINE ORBIT
1250  WRITE (6,*) IEHflg,Malt,INCL,Run
1251  WRITE (6,*) Yrinch,Time
1252  WRITE (6,*)’
1253  C
1254  DEFINE RADIATOR
1255  WRITE (6,*) GAM,ARSF,Earn,PROB
1256  WRITE (6,*) CONFIG,Xntubes,Xnexpip,Xtflt
1257  WRITE (6,*) Dhpipe,Ifluid,Imatl,Theta
1258  WRITE (6,*) D2rad,Thickness,Thickf,Em
1259  WRITE (6,*) Em,Alpha,Nap,NArad
1260  WRITE (6,*) Tkfin,Rhocoating,Rhofin,RNOarm
1261  WRITE (6,*) Xladiab,Xchmas
1262  WRITE (6,*)’
1263  C
1264  DEFINE CONDENSER
1265  WRITE (6,*) Can,Man,Gap,THICKine
1266  WRITE (6,*) RHOfine,Yout,Tbraze,TCan
1267  WRITE (6,*) TKbraze,Tfip,Pin,Tin
1268  WRITE (6,*) Xf,ROHpip,RHCan,ROHbraze
1269  WRITE (6,*) THICke2,Thlp,Mean
1270  WRITE (6,*)’
SUBROUTINE HP_HAST

C Compiling Option: INOIMT/Ii/MCIILIO/HFH/HITNL/P/MOIlNG2/MO3/R/S/NT/W/NX/NZ1

Source file Listing

```fortran
1268 C
1269 WRITE (6,*) 'C IENFfg,Halt,HIMCL,Reun'
1270 WRITE (6,*) 'C Yrlnch,Time'
1271 WRITE (6,*) 'C GAM,ARSF,Earm,PROB'
1272 WRITE (6,*) 'C CONFIG,Xntubes,Xnexpip,Xflat'
1273 WRITE (6,*) 'C Dpipe,Ifuid,Imatl,Theta'
1274 WRITE (6,*) 'C D2rad,Thicka,Thucl,Thucl'
1275 WRITE (6,*) 'C Em,Alpha,Ham,Harad'
1276 WRITE (6,*) 'C Tkin,Rhocoating,Rhoin,RHOrarm'
1277 WRITE (6,*) 'C Xladiab,Xnchmas'
1278 WRITE (6,*) 'C Cnsm,Mean,Gap,THICKins'
1279 WRITE (6,*) 'C RHOins,Yout,Tbraze,TCan'
1280 WRITE (6,*) 'C TCan,Dpipe,BH0m,THICKf,THick'
1281 WRITE (6,*) 'C Xrdpipe,FLuid,ImatI,Theta'
1282 WRITE (6,*) 'C TCan,BH0m,THICKf,THick'
1283 WRITE (6,*) 'C Xn,HOPm,RHO0m,RHObraze'
1284 WRITE (6,*) 'C THICKman,Thalp,Mean'
1285 WRITE (6,*) 'C CALL RAPRT(qrad,Trocl,Xntubes,Xnexpip,XtfLat,Dpipe,Ifuid,1'
1286 & imatI,Theta,D2rad,Thicka,Thucl,Thucl,Em,
1287 & Alpha,Ham,Harad,Tkin,Rhocoating,Rhoin,RHOrarm,Xladiab,
1288 & Xnchmas,PROB,GAM,ARSF,Earm,Time,Inoimt,THickf2,Thucl2,
1289 & Tkin,Dpipe,BH0m,THICKf,THick,Em,
1290 & Xrdpipe,FLuid,ImatI,Theta'
1291 WRITE (6,*) 'C CALL ORBPRG(IENFfg,Halt,HIMCL,Reun,Yrlnch)
1292 CALL ORBPRG(IENFfg,Halt,HIMCL,Reun,Yrlnch)
1293 C
1294 CALL COMPRTR(Gt,V,Dr,Gt,Rel,HI,Xt,Rev,
1295 & Ifuid,Can,Earn,Gap,THICKins,RHOins,Yout,
1296 & TCan,BH0m,THICKf,THick,Tkin,RHOrpm,
1297 & RHO0m,THICKf,THick,Tkin,RHOrpm,
1298 & XxvEvap2,Xladi2,Xhpec2,Xhewp2,Fluid,ImatI,Theta',
1299 & XxvEvap2,Xladi2,Xhpec2,Xhewp2,Fluid,ImatI,Theta',
1300 & XxvEvap2,Xladi2,Xhpec2,Xhewp2,Fluid,ImatI,Theta',
1301 & XxvEvap2,Xladi2,Xhpec2,Xhewp2,Fluid,ImatI,Theta',
1302 C
1303 C
1304 WRITE (6,*) 'MASS SUMMARY FOR CONDENSING RANKINE SYSTEM'
1305 WRITE (6,*) 'HEAT PIPE COOLED CONDENSER MASS (Lbs) = ',XMAAb9mass
1306 WRITE (6,*) 'RADITATOR MASS (Lbs) = ',Xnetradmass2
1307 XNYSY = XMAAb9mass + Xnetradmass2
1308 WRITE (6,*) '
1309 WRITE (6,*) 'CONDENSING RANKINE SYSTEM MASS (Lbs) = ',XNYSY
1310 WRITE (6,*) '
1311 C
1312 STOP
1313 END
```
SUBROUTINE RADFLG

C
C SUBROUTINE RADFLG(Tbar, ifluid, lmatl)
C IF (Tbar.LT.450.0) THEN
C WRITE (6,*) 'RADIATOR TEMPERATURE TOO LOW TO CONTINUE CALCULATION'
C STOP
C ELSE
C GO TO 1410
C ENDIF
C 1410 IF (Tbar.LT.549.0) THEN
C ifluid = 9
C lmatl = 6
C GO TO 1500
C ELSE
C GO TO 1420
C ENDIF
C 1420 IF (Tbar.LT.1008.0) THEN
C ifluid = 2
C lmatl = 8
C GO TO 1500
C ELSE
C GO TO 1430
C ENDIF
C 1430 IF (Tbar.LT.1350.0) THEN
C ifluid = 8
C lmatl = 5
C GO TO 1500
C ELSE
C GO TO 1440
C ENDIF
C 1440 IF (Tbar.LT.1710.0) THEN
C ifluid = 5
C lmatl = 7
C GO TO 1500
C ELSE
C GO TO 1450
C ENDIF
C 1450 IF (Tbar.LT.2070.0) THEN
C ifluid = 3
C lmatl = 7
C GO TO 1500
C ELSE
C GO TO 1460
C ENDIF
C 1460 IF (Tbar.LT.3240.0) THEN
C ifluid = 4
C lmatl = 2
C GO TO 1500
C ELSE
C WRITE (6,*) 'TEMPERATURE ABOVE MAXIMUM HEAT PIPE OPERATING LIMIT'
C STOP

C
C
SUBROUTINE RADFLG

Source file Listing

1366   ENDF
1367   1500 RETURN
1368   END
SUBROUTINE RADPRT

WRITE (6,*), 'RADIATOR DEFINITION INPUTS'
WRITE (6,*), 'RADIATOR HEAT REJECTION RATE (KW) = ', Grad
WRITE (6,*), 'AVERAGE RADIATOR SURFACE TEMPERATURE (deg-R) = ', Trad
WRITE (6,*), 'NUMBER OF PRIMARY HEAT PIPE IN RADIATOR = ', Xntubes
WRITE (6,*), 'NUMBER OF REDUNDANT HEAT PIPES = ', Xnexpip
WRITE (6,*), 'HEAT PIPE EVAPORATOR LENGTH (INCHES) = ', Xiflat
WRITE (6,*), 'HEAT PIPE INSIDE DIAMETER (INCHES) = ', Dpipe
WRITE (6,*), 'HEAT PIPE WORKING FLUID ID NUMBER = ', ifluid
WRITE (6,*), 'HEAT PIPE LINER MATERIAL ID NUMBER = ', ilmat
WRITE (6,*), 'CORNER ANGLE FOR CONICAL RADIATOR (DEGREES) = ', Theta
WRITE (6,*), 'MANIFOLD DIAMETER FOR CONICAL RADIATOR OR MANIFOLD LENGTH = ', Xnchlms
WRITE (6,*), 'LENGTH DIVIDED BY 3.141593 FOR FLAT PLATE (FEET) = ', D2Rad
WRITE (6,*), 'RADIATOR EMISSIVITY CONTROL COATING THICKNESS (FEET) = ', Th Emcoat
WRITE (6,*), 'RADIATOR FIN THICKNESS (FEET) = ', Thick
WRITE (6,*), 'HEAT PIPE WALL or LINER THICKNESS (FEET) = ', Thick
WRITE (6,*), 'RADIATOR SURFACE ABSORPTIVITY = ', Alpha
WRITE (6,*), 'RADIATOR PROJ. AREA (FRACT. OF TOT.) = ', Hap
WRITE (6,*), 'RADIATOR ACTUAL AREA (FRACTION) = ', Warad
WRITE (6,*), 'THERMAL COND. OF FIN MATERIAL (BTU/HR-FT-R) = ', Tfin
WRITE (6,*), 'COATING MATERIAL DENSITY (LB/cu-FT) = ', Rhocoating
WRITE (6,*), 'FIN MATERIAL DENSITY (LB/cu-FT) = ', Rhoft
WRITE (6,*), 'LENGTH OF ADIABATIC PORTION OF THE HEAT PIPE (FEET) = ', LXladlab
WRITE (6,*), 'MASS OF RADIATOR DEPLOYMENT MECHANISM (LBS) = ', Xmachmas
WRITE (6,*), 'TOTAL HEAT AVERAGE Radiator Emissivity'
WRITE (*,*) 'REJECTED EVAPORATOR FIN Coating'
WRITE (*,*) 'TOTAL HEAT TEMPERATURE (R) Thick (In) Thick (In)'
SUBROUTINE RADPRT

WRITE (*,2555) Qrejected, Trad, Thick2, Thicmv2
WRITE (*,*) ' Actual Effective'
WRITE (*,*) '(one-side) Radiator'
WRITE (*,*) 'Area(sq-Ft.) Area(sq-Ft.)'
WRITE (*,*) A radiator, Radiator
RETURN
END
SUBROUTINE ORBPRT(IENfig,Halt,HINCL,Rsun,YrLnch)

WRITE (6,*) 'IENfig (ORBIT SELECTION) =', IENfig
WRITE (6,*) 'IENfig=1, EARTH ORBIT (LEO-GEO)'
WRITE (6,*) 'IENfig=2, SOLAR ORBIT (0.5 to 2.0 AU)'
WRITE (6,*) 'ORBIT ALTITUDE (km) =', Halt
WRITE (6,*) 'ORBIT INCLINATION ANGLE (Degrees) =', HINCL
WRITE (6,*) 'DISTANCE FROM SUN (AU) =', Rsun
WRITE (6,*) 'YEAR SATELLITE LAUNCHED =', YrLnch
RETURN
END
SUBROUTINE HNMPRT

HEAT PIPE COOLED MANIFOLD DEFINITION VARIABLES

WRITE (6,*), 'HEAT PIPE COOLED MANIFOLD DEFINITION VARIABLES'
WRITE (6,*), 1fisg2 = ', Ifisg2
WRITE (6,*), 'MANIFOLD HEADING (Feet) = ', Hman
WRITE (6,*), 'MANIFOLD WIDTH (Feet) = ', Gap
WRITE (6,*), 'DIST. BETWEEN CAN (HEAT PIPES) C-LINES (Feet) = ', Pitch
WRITE (6,*), 'NUMBER OF HEAT PIPES IN RADIATORS = ', XNpipes
WRITE (6,*), 'NUMBER OF REDUNDANT HEAT PIPES IN RADIATORS = ', Xnexpipes
WRITE (6,*), 'OUTSIDE DIAMETER OF MANIFOLD BRAZE CANS (Feet) = ', Dcan
WRITE (6,*), 'INSIDE DIAMETER OF HEAT PIPE (Feet) = ', Dhp
WRITE (6,*), 'MANIFOLD BRAZE CAN INSIDE RADIUS (Feet) = ', Rc
WRITE (6,*), 'BRAZE JOINT INSIDE RADIUS (Feet) = ', Rb
WRITE (6,*), 'FIN THICKNESS (Feet) = ', Tf
WRITE (6,*), 'THERM. COND. OF FIN MATERIAL (BTU/HR-Ft-R) = ', Tkfin
WRITE (6,*), 'THERM. COND. OF MANIFOLD CAN MATERIAL (BTU/HR-Ft-R) = ', Tkcan
WRITE (6,*), 'THERM. COND. OF MANIFOLD BRAZE ALLOY (BTU/HR-Ft-R) = ', Tkbraze
WRITE (6,*), 'TOTAL NUMBER OF FINS FOR THE MANIFOLD HEIGHT = ', XNf
WRITE (6,*), 'DENSITY OF MANIFOLD MATERIAL (Lb/cu-Ft) = ', RHOfcan
WRITE (6,*), 'DENSITY OF BRAZE MATERIAL (Lb/cu-Ft) = ', RHOfbraze
WRITE (6,*), 'MANIFOLD MATERIAL THICKNESS (Feet) = ', THICman
WRITE (6,*), 'MANIFOLD INLET PRESSURE (PSIA) = ', Pman
WRITE (6,*), 'MANIFOLD INLET TEMPERATURE (deg-R) = ', Tmin
WRITE (6,*), 'MANIFOLD FLOWRATE (LBS/HR) = ', Uman
WRITE (6,*), 'MANIFOLD AND RADIATOR HEAT LOAD (BTU/HR) = ', Grad
WRITE (6,*), 'MOLECULAR WEIGHT OF MANIFOLD WORKING FLUID = ', XNman
WRITE (6,*), 'MANIFOLD PRESSURE DROP (PSID) = ', DPman
WRITE (6,*), 'MANIFOLD FILM TEMPERATURE DROP (deg-R) = ', DTfilm
WRITE (6,*), 'MANIFOLD NET MASS OF HEAT PIPE MANIFOLD (Lbs) = ', XNmanmass
WRITE (6,*), 'NET MASS OF HEAT PIPE MANIFOLD (Lbs) = ', XNmanmass
RETURN
END
SUBROUTINE DUCPRT

SUBROUTINE DUCPRT(XHP,R9,Dp,SUMLEN,Vpipe,TGAS,PGAS,THICKP,RHOPIP,
&THICK1,RHOINS,WWW,DPDUCT,DUCMAS)

WRITE (6,*),'DUCTING INPUT VARIABLES'
WRITE (6,*),'NUMB. OF 90 DEG. ELBOWS OR EQUIV.=',XHP
WRITE (6,*),'AVERAGE RADIUS FOR 90 DEGREE ELBOWS (INCHES)=',R9
WRITE (6,*),'INSIDE DUCT DIAMETER (INCHES)=',Dp
WRITE (6,*),'TOTAL LENGTH OF DUCT SYSTEM (INCHES)=',SUMLEN
WRITE (6,*),'GAS VELOCITY IN DUCTS (FT/SEC)=',Vpipe
WRITE (6,*),'GAS TEMPERATURE (deg-R)=',TGAS
WRITE (6,*),'GAS PRESSURE (psia)=',PGAS
WRITE (6,*),'DUCT WALL THICKNESS (INCHES)=',THICKP
WRITE (6,*),'DUCT WALL DENSITY (LB/cu-FT)=',RHOPIP
WRITE (6,*),'DUCT INSULATION THICKNESS (INCHES)=',THICK1
WRITE (6,*),'DUCT INSULATION DENSITY (LB/cu-FT)=',RHOINS
WRITE (6,*),'GAS MOLECULAR WEIGHT=',WWW
WRITE (6,*),'DUCT SYSTEM PRESSURE DROP (PSID)=',DPDUCT
WRITE (6,*),'DUCT SYSTEM MASS (LBS)=',DUCMAS

RETURN
END
SUBROUTINE PIPPRT(XN9,R9,Dp,SUMLEN,Vpipe,Tnak,Pnak,THICKP,RHOPIP,
&THICKI,RHOINS,DPPipe,PIPMAS)

'PIPING DEFINITION VARIABLES'

WRITE (6,*) 'NUMB. OF 90 DEG. ELBOWS OR EQUIV.',XN9
WRITE (6,*) 'AVERAGE RADIUS FOR 90 DEGREE ELBOWS (INCHES)=',R9
WRITE (6,*) 'INSIDE PIPE DIAMETER (INCHES)=',Dp
WRITE (6,*) 'TOTAL LENGTH OF PIPE SYSTEM (INCHES)=',SUMLEN
WRITE (6,*) 'MAX VELOCITY IN PIPES (FT/SEC)=',Vpipe
WRITE (6,*) 'MAX TEMPERATURE (deg-R)=',Tnak
WRITE (6,*) 'MAX PRESSURE (psia)=',Pnak
WRITE (6,*) 'PIPE WALL THICKNESS (INCHES)=',THICKP
WRITE (6,*) 'PIPE WALL DENSITY (LB/cu-FT)=',RHOPIP
WRITE (6,*) 'PIPE INSULATION THICKNESS (INCHES)=',THICKI
WRITE (6,*) 'PIPE INSULATION DENSITY (LB/cu-FT)=',RHOINS
WRITE (6,*) 'PIPE SYSTEM PRESSURE DROP (PSID)=',DPPipe
WRITE (6,*) 'PIPE SYSTEM MASS (LBS)=',PIPMAS
WRITE (6,*) 'PIPE SYSTEM WtK MASS (LBS)=',PIPMAS

RETURN
END
SUBROUTINE NSD OPT(CHXFLgeQDOT,THIN,THOUT,TCIN,TCOUT,ADOT,DENSSH,
DPSHELL,DTUBE,TTUBE,AMTSHT,AMPLATES,AMHEADS,AMINSUL,AFRIC,
UYE,NETMASS,RETUBE,TNC,AHINSUL,AHTUBE,AHTUBE,AHTUBE)
WRITE (6,*) 'HEAT SOURCE/ Sink HEAT EXCHANGER DEFINITION'
WRITE (6,*) 'TUBE SIDE FLUID FLAG =',CHXFLg
WRITE (6,*) 'Heat Rate or Duty (BTU/hr) =',ADOT
WRITE (6,*) 'HOT SIDE Inlet Temperature (R) =',THIN
WRITE (6,*) 'HOT SIDE Outlet Temperature (R) =',THOUT
WRITE (6,*) 'COLD SIDE Inlet Temperature (R) =',TCIN
WRITE (6,*) 'COLD SIDE Outlet Temperature (R) =',TCOUT
WRITE (6,*) 'SHELL SIDE FLUID Flowrate (Lbs/Sec)=',ADOT/3600.0
WRITE (6,*) 'SHELL MATERIAL Density (Lbs/Ft^3) =',DENSSH
WRITE (6,*) 'INSIDE TUBE Diameter (Inches) =',DTUBE
WRITE (6,*) 'TUBE Wall Thickness (Inches) =',TTUBE
WRITE (6,*) 'TUBE -SIDE Fluid Flowrate (Lbs/Sec) =',ADOTT
WRITE (6,*) 'TUBE Wall Thermal Conductivity (BTU/hr-Ft-R) =',AKTUBE
WRITE (6,*) 'SHELLSIDE DP (PSID) =',DPSHELL
WRITE (6,*) 'SHELLSIDE H (BTU/hr-Ft-sq FT-R) =',HSHELL
WRITE (6,*) 'FRIC-FAC =',AFRIC
WRITE (6,*) 'UNEW (BTU/hr-sqFT-R) =',UNEW
WRITE (6,*) 'NUMBER OF TUBES IN BUNDLE =',AHTUBES
WRITE (6,*) 'Tube Side Reynolds Number =',RETUBE
WRITE (6,*) 'Tube Side Pressure Drop (PSID) =',DPTUBE
WRITE (6,*) 'Tube Side Kg (BTU/hr-sq.Ft-R) =',THC
WRITE (6,*) 'TUBE WALL THICKNESS (Inches) =',TTUBE
WRITE (6,*) 'DOTL2 (Inches) =',DOTL2
WRITE (6,*) 'LENGTH (Inches) =',ALSHEL
WRITE (6,*) 'STRUCTURE AND BRACING MTS MASS (Lbs) =',N4STRT
WRITE (6,*) 'MASS OF HEAT IN H-X (LBS) =',XMMHHEX
WRITE (6,*) 'Net Mass of Shell and Tube Unit(DRY)(Lbs)=',NETMASS
RETURN
END
SUBROUTINE PHPPRT

SUBROUTINE PHPPRT(Tnak,Unak,DPPIPE,DPHX,DPMANIF,DPLOOP,Phyd, XNMPUMP)

WRITE (6,*), 'NPPD PUMP DEFINITION'
WRITE (6,*), 'NAX INLET TEMPERATURE (deg-R)=',Tnak
WRITE (6,*), 'NAX FLOWRATE (LBS/SEC)=',Unak
WRITE (6,*), 'NIPING SYSTEM PRESSURE DROP (PSID)=',DPPIPE
WRITE (6,*), 'NAX SIDE HEAT EXCHANGER PRESSURE DROP (PSID)=',DPHX
WRITE (6,*), 'NAX MANIFOLD PRESSURE DROP (PSID)=',DPMANIF
WRITE (6,*), 'NAX LOOP PRESSURE DROP (PSID)=',DPLOOP
WRITE (6,*), 'NAX LOOP PUMP POWER REQUIRED (HYDRAULIC) (WATTS)=',
&Phyd
WRITE (6,*), 'N-E-M PUMP MASS (DRY) (LBS)=',XNMPUMP

RETURN
END
1617 C
1618 SUBROUTINE VACPRT(XNHvac,XHVAC)
1619 WRITE (6,*) 'MAK LOOP EXPANSION COMPENSATOR DEFINED'
1620 WRITE (6,*) 'VOLUME ACCUMULATOR Mank MASS (Lbs) =',XNHvac
1621 WRITE (6,*) 'VOLUME ACCUMULATOR MANK (WET) (Lbs) =',XHVAC
1624 C
1625 RETURN
1626 END
SUBROUTINE CONPRT

VWRITE (6,*) 'HEAT PIPE COOLED CONDENSER DESCRIPTION'

VWRITE (6,*) 'MANIFOLD FLAT LENGTH (Ft) =', Cman

VWRITE (6,*) 'MANIFOLD HEIGHT (Ft) =', Hman

VWRITE (6,*) 'AVERAGE MANIFOLD SURF. SPACE (Gap) (Ft) =', Gap

VWRITE (6,*) 'MANIFOLD INSULATION THICKNESS (Ft) =', THICKins

VWRITE (6,*) 'MANIFOLD INSULATION DENSITY (Lbs/cu-Ft) =', RHOins

VWRITE (6,*) 'NUMBER OF PRIMARY HEAT PIPES ATTACHED TO COOL CONDENSER & SURFACE =', XNpipes

VWRITE (6,*) 'NUMBER OF REDUNDANT HEAT PIPES USED TO COOL CONDENSER & SURFACE =', XNexpipes

VWRITE (6,*) 'MANIFOLD WALL MATERIAL THICKNESS (Ft) =', THICKman

VWRITE (6,*) 'MANIFOLD-HEAT PIPE BRAZE MATERIAL THICKNESS (Ft) =', Tbraze

VWRITE (6,*) 'HEAT PIPE WALL THICKNESS (Ft) =', Thtp

VWRITE (6,*) 'MANIFOLD WALL MAT. THERMAL COND. (B/HFR) =', TKcan

VWRITE (6,*) 'BRAZE MAT. THERMAL COND. (B/HFR) =', TKbraze

VWRITE (6,*) 'HEAT PIPE WALL MAT. THERMAL COND. (B/HFR) =', TKhp

VWRITE (6,*) 'MANIFOLD WALL MATERIAL DENSITY (Lb/cu-Ft) =', RHOcan

VWRITE (6,*) 'BRAZE MATERIAL DENSITY (Lb/cu-Ft) =', RHObraze

VWRITE (6,*) 'HEAT PIPE WALL MATERIAL DENSITY (Lb/cu-Ft) =', RHOexpipes

VWRITE (6,*) 'HEAT PIPE WORKING FLUID NUMBER =', lfluid

VWRITE (6,*) 'MANIFOLD OPERATING CONDITIONS'

VWRITE (6,*) 'INLET PRESSURE (psia) =', Pin

VWRITE (6,*) 'INLET TEMPERATURE (deg-R) =', Tin

VWRITE (6,*) 'MEAN CONDENSER QUALITY =', Xin

VWRITE (6,*) 'OUTLET TEMPERATURE (deg-R) =', Tout

VWRITE (6,*) 'MANIFOLD FLOW RATE (Lbs/Hr) =', Uman

VWRITE (6,*) 'MAXIFOLD DUTY (Kw) =', Grad

VWRITE (6,*) 'COMPUTED RESULTS'

VWRITE (6,*) 'MANIFOLD PRESSURE DROP (psid) =', Dpress

VWRITE (6,*) 'MANIFOLD FILM TEMPERATURE DROP (deg-R) =', DTfilm

VWRITE (6,*) 'FLOW CROSS-SECTIONAL AREA (sq ft) =', Ar

VWRITE (6,*) 'MASS FLUX (lbm/sq ft) =', Gt

VWRITE (6,*) 'VAPOR VELOCITY, ft/sec =', V

VWRITE (6,*) 'HYDRAULIC DIAMETER =', Dh

IF (Cgt.LT.0.3) THEN
  VWRITE (6,*) 'CONDENSER CONDENSATE FLOW REGIME PARAMETER =', Cgt
ELSE
  VWRITE (6,*) 'CONDENSER IS OPERATING IN SHEAR FLOW REGIME'
END
SUBROUTINE COMPRT

WRITE (6,*) 'CONDENSER IS NOT OPERATING IN SHEAR FLOW REGIME'
WRITE (6,*) 'CONDENSATE FILM REYNOLDS NUMBER =',ReL
WRITE (6,*) 'SHEAR-CONTROLLED LIQ. FILM HEAT TRANSFE. COEFF. =',Xt
WRITE (6,*) 'MARTINELLI PARAMETER = ',Xtt
WRITE (6,*) 'VAPOR REYNOLDS NUMBER = ',Rev
WRITE (6,*) 'MANIFOLD MASS (Lbs) = ',XOMAHmas
RETURN
END
SUBROUTINE HRENVR

*** VARIABLES DEFINITION ***

IENflag = FLAG TO SET ENVIRONMENT DESIRED

1 = EARTH ORBIT, LEO TO GEO USES GREATER OF DEBRIS OR METEORITE FLUX, NO DEBRIS ABOVE 2000 Km.

2 = BEYOND EARTH ORBIT, 0.25 TO 2.00 AU

Halt = ORBIT ALTITUDE (km)

HINCL = ORBIT INCLINATION ANGLE (28.5 TO 80.0 degrees, ONLY)

Rsun = DISTANCE FROM SUN (AU)

Yrlnch = YEAR IN WHICH VEHICLE IS PLACED IN ORBIT

Ealpha = PRODUCT OF EARTH SHIELDING FACTOR AND METEORITE/DEBRIS FLUX CONSTANT

To|ok = EFFECTIVE SINK TEMPERATURE (K)

GO TO (10,20),IENFLG

COMPUTE DATA FOR EARTH ORBIT (LEO TO GEO)

10 IF (HINCL.LT.28.5.OR.HINCL.GT.80.0) THEN

WRITE (6,'*') 'INVALID ORBIT INCLINATION ANGLE WAS INPUT'

WRITE (6,'*') 'INPUT ORBIT INCLINATION ANGLE WAS (deg) *',HINCL

WRITE (6,'*') 'INCLINATION ANGLE MUST BE BETWEEN 28.5 AND 80 deg.'

STOP

ELSE

CONTINUE

EMIF

DO 12 J=1,2

IF (J.EQ.1) THEN

 Xm1E-06

ELSE

Xm1.0

ENDIF

12 CONTINUE

Ealpha1 = AX2

beta1 = (AX1-AX2)/6.0

*** COMPUTE EARTH SHIELDING FACTOR, FOCUSING FACTOR ***

Rorb = 6378.0 + Halt
SUBROUTINE HRENVR

Source file Listing

1743  Eearth = 6378.0 + 100.0
1744  Ge = 1.0 + (Eearth/Rorb)
1745  ETA = ASIN(Rearth/(Rearth+Halt-100.0))
1746  SF = (1.0-COS(ETA))/2.0
1747  DUMP = Ge*SF/(10.0**Alpha)
1748  Ealpha = ALOG10(DUMP)
1749  C *** COMPUTE DEBRIS FLUX ***
1750  IF (Halt.GT.2000.0) THEN
1751    WRITE (6,*) 'EARTH ORBIT IS ABOVE DEBRIS REGION'
1752    Ealpha = 10.0**Ealpha
1753    Beta = Beta1
1754    Ge = 443.0
1755    GO TO 30
1756    ELSE
1757    ENDIF
1758  J=0
1759  DO 14 J=1,2
1760    IF (J.EQ.1) THEN
1761      Xm = 1E-06
1762      D = (6.0*Xm/(4.7*3.141593))**0.33333
1763    ELSE
1764      Xm = 1.0
1765      D = (6.0*Xm/(2.8*3.141593))**0.362319
1766  ENDIF
1767  DUMP = XO**DUMP
1768  IF (Yrtnch.LT.2011) THEN
1769    G1 = 0.02
1770    G1 = ((1.0+G1)**(Yrtnch-1988.0))
1771    ELSE
1772    G1 = 0.04
1773    G1 = ((1.0+G1)**(23.0))**((1.0+G1)**(Yrtnch-2011.0))
1774  ENDIF
1775  P = 0.05
1776  G2 = 1.0 + (P*(Yrtnch-1988.0))
1777  F1 = 1.22E-05/(D**2.5)
1778  F2 = 8.1E+10/(D+700.0)**6.0
1779  S = 87.2
1780  DUM1 = (Halt/200.0)+((S/140.0)-1.5)
1781  PHONE = 10.0**DUM1
1782  PHI = PHONE/(PHONE+1.0)
1783  DUM2 = ((ALOG10(D)+0.78)**2.0)/(0.637**2.0)
1784  DUMG = EXP(-DUMG)
1785  ND = -SRT(10.0**DUMG)
1786  PSI = -(0.313477)+(0.084327*HINCL)-(0.001896*(HINCL**2.0))
1787 & (0.000114*(HINCL**3.0))
1788  DUM4 = (F1*G1)+(F2*G2)
1789  ANt = 3.168896E-08*(ND*PHI*PSI*DUM4)
1790  IF (J.EQ.1) THEN
1791    AX1 = ALOG10(ANT)
1792    ELSE
1793    AX2 = ALOG10(ANT)
1794  ENDIF
1795 14 CONTINUE
1796   Alpha2 = AX2
1797   Beta2 = (AX1-AX2)/6.0
1798   Ealpha2 = 1.0*Alpha2
1799   IF (Ealpha2.GT.EalphaM) THEN
1800     Ealpha = 10.0**Ealpha2
1801     Beta = Beta2
1802     ELSE
1803     Ealpha = 10.0**EalphaM
1804     Beta = Beta1
1805     ENDIF
1806     Gaurx = 443.0
1807     C     WRITE (6,*) 'Ealpha =',ALOG10(Ealpha),'Beta =',Beta,'Gaur =',Gaurx
1808     GO TO 40
1809   20 CONTINUE
1810 C *** COMPUTES METEORITE FLUX AWAY FROM EARTH ORBIT ***
1811 C
1812   DO 22 J=1,2
1813     IF (J.EQ.1) THEN
1814       XM=1E-06
1815     ELSE
1816       XM=1.0
1817     ENDIF
1818   22 CONTINUE
1819   A1 = 1.0/((2200.0*(XM**0.306)+15)**4.38)
1820   A2 = 1.35E-09/(XM**((1E11)*(XM**2.0)+((1E27)*(XM**4.0))))
1821   A3 = 1.35E-16/(XM**((1E06)*(XM**2.0)))**0.85
1822   Ant = (A1+A2+A3)*(1.0/(Gaur**1.5))
1823     IF (J.EQ.1) THEN
1824       AX1 = ALOG10(Ant)
1825     ELSE
1826       AX2 = ALOG10(Ant)
1827     ENDIF
1828   22 CONTINUE
1829     Ealpha = 10.0**AX2
1830   30 CONTINUE
1831     Gaurx = 443.0**((1.0/Gaur)**2.0)
1833 C     WRITE (6,*) 'Ealpha =',ALOG10(Ealpha),'Beta =',Beta,'Gaur =',Gaurx
1834   40 RETURN
1835   END
**SUBROUTINE HRARMR**

This subroutine predicts the amount of armor required to provide a specified non-puncture probability in the interplanetary environment (Earth-Mars) (NASA SP-8038, 1970) or in Earth orbit (LEO-GEO) using Kessler's 1990 debris model. Armor thickness is computed from the empirical relationship presented by Haller and Lieblen (NASA-TH-D-411), 1968.

**Variables Defined**
- `IEHfLH` = Flag to set environment desired
  - 1, Earth orbit, LEO-GEO
  - 2, Beyond Earth orbit, 0.25 to 2.00 AU
- `HaLt` = Orbit altitude (km)
- `HINCL` = Orbit inclination angle (degrees)
- `Rsun` = Distance from Sun (AU)
- `YrLnch` = Year in which vehicle is placed in orbit
- `GAN,ARSF` = Penetration constants - functions of the specific material
- `Earn` = Armor density (Lbs/cu-ft)
- `YNgS 14(X)ULUS OF ARMOR (Lbs/sq-In)
- `Atarget` = Target exposed area (Sq-Fe)
- `Temp` = Radiator temperature (K)
- `EalpHa` = Meteorite flux constant from HRENV
- `Time` = Exposure time (Secs)
- `Prob` = Non-puncture probability (0.9, 0.99, 0.999, etc.)

**Calculations**

```fortran
IF (IEHfLH.EQ.2) THEN
    HHOp = 0.5
    Vp  = 20.0
ELSE
    RHOp = 4.7
    Vp  = 15.4
ENDIF
```

**Armor Thickness**

```
RETURN
THARM = THARM/2.54
```

RETURN THICKNESS IN INCHES

RETURN

END
SUBROUTINE NRTSNK (IENflg, Halt, HINCL, Rsun, Yrlnch, Alpha, Hap, HArad, Tsink)

*** ROUTINE TO ESTIMATE THE MAXIMUM SINK TEMPERATURE SEEN BY A BODY IN ORBIT. EARTH REFLECTION AND EARTH RE-EMISSION IS CONSIDERED FOR BODIES IN LEO TO GEO EARTH ORBIT.

INPUTS DEFINITION

IENflg = FLAG TO SET ENVIRONMENT DESIRED
= 1, LEO TO GEO
= 2, BEYOND EARTH ORBIT

Halt = ORBIT ALTITUDE (Km)
HINCL = ORBIT INCLINATION ANGLE
Rsun = DISTANCE FROM SUN (AU)
Yrlnch = YEAR IN WHICH VEHICLE IS PLACED IN ORBIT
Alpha = RADIATOR SURFACE ABSORPTIVITY
Hap = PROJECTED AREA (SQ-Feet)
HArad = TOTAL RADIATING AREA (SQ-Feet)

OUTPUT DEFINITION

Tsink = EFFECTIVE SINK TEMPERATURE (K)

ORBITAL CONSTANTS

Sc = SOLAR CONSTANT
Er = EARTH REFLECTION CONSTANT
Ee = EARTH EMISSION CONSTANT
R = EARTH RADIUS (MILES)

CALL HREMVR(IENflg, Halt, HINCL, Rsun, Yrlnch, Alpha, Beta, Qsuna)

IF (Rsun.EQ.1.0) THEN
Sc = 443.0
Er = 74.2
Ee = 65.9
ELSE
Sc = Qsuna
Er = 0.0
Ee = 0.0
ENDIF

R = 6378.0
AK = (R/(R+Halt))**2.0
Ge = Sc*Alpha*Hap
Gr = AK*Er*Hap
Ge = AK*Ee*Hap
Grad = Ge*Gr+Ge
Qflux = Grad/HArad
SIGMA = 1.71E-09
Tsink = ((Qflux/SIGMA)**0.25)
RETURN Tsink IN (deg-R)

RETURN
SUBROUTINE FLUIDPROP
          ! Fluid option
          ! NT/B/NC/W/L/P/WQ1/WQ2/WQ3/R/S/NT/W/WX/WZ
          Source file Listing

          COMMON /RAD3/ Roomden(10),Whsp(159)
          Roomden(2)=1.000
          Roomden(3)=0.971
          Roomden(4)=0.534
          Roomden(5)=0.862
          Roomden(8)=13.546
          Roomden(9)=0.6120
          Tk=TO+273.2
          IF (fluid.EQ.2) THEN
            GOTO 8020
          ELSE
            CONTINUE
          ENDIF
          IF (fluid.EQ.3) THEN
            GOTO 8030
          ELSE
            CONTINUE
          ENDIF
          IF (fluid.EQ.4) THEN
            GOTO 8040
          ELSE
            CONTINUE
          ENDIF
          IF (fluid.EQ.5) THEN
            GOTO 8050
          ELSE
            CONTINUE
          ENDIF
          IF (fluid.EQ.6) THEN
            GOTO 8060
          ELSE
            CONTINUE
          ENDIF
          IF (fluid.EQ.7) THEN
            GOTO 8070
          ELSE
            CONTINUE
          ENDIF
          IF (fluid.EQ.8) THEN
            GOTO 8080
          ELSE
            CONTINUE
          ENDIF
          IF (fluid.EQ.9) THEN
            GOTO 8090
          ELSE
            CONTINUE
          ENDIF
          WRITE (*,*),'TEMPERATURE OF ',TO,'OUT OF RANGE FOR ',fluid
          GOTO 9000
          END

          ! WATER
          8020 IF (TO.LE.5.0) THEN
            GOTO 8100
          ELSE
            GOTO 8020
          END
SUBROUTINE FLUIDPROP

1987 CONTINUE
1988 ENDIF
1989 IF (T0.GT.433.0) THEN
1990 GOTO 8100
1991 ELSE
1992 CONTINUE
1993 ENDIF
1994 Xlqvisc=0.0002414*10.0**(247.8/(Tk-140.0))
1995 Vapvisc=0.000001*10.0**(2.5989-(179.3/Tk))
1996 IF (T0.GT.200.0) THEN
1997 GOTO 8055
1998 ELSE
1999 CONTINUE
2000 ENDIF
2001 Xlqden = 0.01*10.0**(1.8079*(64.9/Tk))
2002 P0=10.0**(8.625109-(2152.49/Tk))
2003 Vapden=0.2193*(P0/760.0)/Tk
2004 Surflcm=10.0**(1.06335*(259.17/Tk))
2005 Xlhv=10.0**(2.46008*(100.7/Tk))
2006 GOTO 8057
2007 8055 Xlqden=0.609675+3.02832E-03*T0-8.982149E-06*T0**2.0
2008 P0=2.24732E-06*T0**4.22186
2009 Vapden=2.35726E-07*EXP(0.01767*T0)
2010 Surflcm=77.8092-0.2080*TK
2011 Xlhv=200.529+2.93522*T0-8.30692E-03*T0**2.0
2012 8057 Xk=1.324
2013 Xme=18.0
2014 Tclfluid=0.000918+1.572E-06*Tk
2015 RETURN
2016 C SODIUM
2017 8030 IF (T0.LE.450.0) THEN
2018 GOTO 8100
2019 ELSE
2020 CONTINUE
2021 ENDIF
2022 IF (T0.GT.1100.0) THEN
2023 GOTO 8100
2024 ELSE
2025 CONTINUE
2026 ENDIF
2027 Xlqden=1.0629-.0003167*Tk+7.244E-08*Tk**2.0
2028 Vapden=EXP(-36.89+.04218*Tk-1.507E-05*Tk**2.0)
2029 Xlqvisc=-.0006549-7.271E-06*Tk+2.52E-09*Tk**2.0
2030 Vapvisc=5.724E-05+1.749E-07*Tk-2.466E-11*Tk**2.0
2031 Xl=12.5847
2032 X2=.0354139
2033 X3=.153891E-05
2034 P0=EXP(X3*T0**2.0*X2*T0*X1)
2035 Surflcm=193.2-.06442*Tk-.7388E-06*Tk**2.0
2036 Xlhv=1215.0-.2569*Tk+5.976E-06*Tk**2.0
2037 Xk=1.68
2038 Xme=22.99
SUBROUTINE FLUIDPROP Computing Options: /NO/WT/B/NC/NO/H/WI/NI/WL/P/WO1/WO2/W03/R/S/NT/NI/WI/W2
Source file Listing

2039 TcfTuiul=0.2389*(1.0796-0.0007057*Tk+2.185E-07*Tk**2.0)
2040 RETURN
2041 C LITHIUM
2042 8040 IF (T0.LE.800.0) THEN
2043 GOTO 8100
2044 ELSE
2045 CONTINUE
2046 ENDIF
2047 IF (T0.GT.1800.0) THEN
2048 GOTO 8100
2049 ELSE
2050 CONTINUE
2051 ENDIF
2052 P9=1.333.2
2053 X1qdpem=5.512-9.99E-05*Tk+1.085E-08*Tk**2.0
2054 Vapdem=EXP(32.23+0.021356*Tk-4.5573E-06*Tk**2.0)
2055 Xliqisc=.0033036-7.5424E-07*Tk+3.0799E-12*Tk**2.0
2056 Vapvisc=2.2296+1.59486*0.7*Tk-3.2966-11*Tk**2.0
2057 PO = EXP(-8.347+0.2045*Tk-4.146-06*Tk**2.0)/P9
2058 Surfim=4.86-1.7573*Tk+1.1599E-05*Tk**2.0
2059 Xihv=6396.0-1.401*Tk+1.8947E-04*Tk**2.0
2060 Xk=1.34
2061 Xx=6.94
2062 TcfTuium=.000012*T0+.10688
2063 RETURN
2064 C POTASSIUM
2065 8060 IF (T0.LE.100.0) THEN
2066 GOTO 8100
2067 ELSE
2068 CONTINUE
2069 ENDIF
2070 IF (T0.GT.900.0) THEN
2071 GOTO 8100
2072 ELSE
2073 CONTINUE
2074 ENDIF
2075 X1qdpem=0.908358-2.2445E-04*Tk-1.2746E-08*Tk**2.0
2076 Vapdem=EXP(0.8135742-8241.151/Tk+426986.1/Tk**2.0)
2077 Xliqisc=4.3906E-04+2.0287/Tk-541.09/Tk**2.0+164680.0/Tk**3.0
2078 Vapvisc=3.8701E-05+1.9825E-07*Tk-4.5283E-11*Tk**2.0
2079 PO=750.06*EXP(9.191863-9030.992/Tk-433033.8/Tk**2.0)
2080 Surfim=141.48-0.07392*Tk
2081 Xihv=0.23590*(2269.1-0.13184*Tk-0.002003*Tk**2.0)
2082 Xk=1.63
2083 Xx=39.096
2084 T9=1.8*Tk-459.7
2085 TcfTuiul=1.6931*(0.9669-4.7904E-04*T9+1.3778E-07*T9**2.0-2.4884E-11*T9**3.0
2086 RETURN
2087 C NASA MERCURY AS USED BY THERMACORE
2088 8080 IF (T0.LE.10.0) THEN
2089 GOTO 8100
SUBROUTINE FLUIDPROP

C *** INSERT P-TABLE HERE ***

C PRESSURE TABLE FOR MERCURY

M_gp(1) = 0.05796
M_gp(2) = 0.08958
M_gp(3) = 0.1386
M_gp(4) = 0.2067
M_gp(5) = 0.3087
M_gp(6) = 0.4562
M_gp(7) = 0.6672
M_gp(8) = 0.9658
M_gp(9) = 1.384
M_gp(10) = 1.965
M_gp(11) = 2.763
M_gp(12) = 3.850
M_gp(13) = 5.317
M_gp(14) = 7.280
M_gp(15) = 9.885
M_gp(16) = 13.31
M_gp(17) = 17.79
M_gp(18) = 23.59
M_gp(19) = 31.05
M_gp(20) = 40.57
M_gp(21) = 52.64
M_gp(22) = 67.86
M_gp(23) = 86.85
M_gp(24) = 110.5
M_gp(25) = 139.7
M_gp(26) = 175.5
M_gp(27) = 219.3
M_gp(28) = 272.4
M_gp(29) = 336.5
M_gp(30) = 413.6
M_gp(31) = 505.7
M_gp(32) = 615.2
M_gp(33) = 744.9
M_gp(34) = 897.7
M_gp(35) = 1077.0
M_gp(36) = 1286.0
M_gp(37) = 1530.0
M_gp(38) = 1813.0
M_gp(39) = 2139.0
M_gp(40) = 2514.0
M_gp(41) = 2944.0
SUBROUTINE FLUIDPROP

Source file Listing

2143 Uhp(42) = 3426.0
2144 Uhp(43) = 3996.0
2145 Uhp(44) = 4432.0
2146 Uhp(45) = 5351.0
2147 Uhp(46) = 6164.0
2148 Uhp(47) = 7078.0
2149 Uhp(48) = 8104.0
2150 Uhp(49) = 9254.0
2151 Uhp(50) = 10540.0
2152 Uhp(51) = 11970.0
2153 Uhp(52) = 13560.0
2154 Uhp(53) = 15320.0
2155 Uhp(54) = 17280.0
2156 Uhp(55) = 19440.0
2157 Uhp(56) = 21820.0
2158 Uhp(57) = 24440.0
2159 Uhp(58) = 27310.0
2160 Uhp(59) = 30470.0
2161 Uhp(60) = 33930.0
2162 Uhp(61) = 37710.0
2163 Uhp(62) = 41840.0
2164 Uhp(63) = 46330.0
2165 Uhp(64) = 51230.0
2166 Uhp(65) = 56550.0
2167 Uhp(66) = 62320.0
2168 Uhp(67) = 68580.0
2169 Uhp(68) = 75360.0
2170 Uhp(69) = 82680.0
2171 Uhp(70) = 90600.0
2172 Uhp(71) = 99140.0
2173 Uhp(72) = 108300.0
2174 Uhp(73) = 118200.0
2175 Uhp(74) = 128900.0
2176 Uhp(75) = 140300.0
2177 Uhp(76) = 152600.0
2178 Uhp(77) = 165800.0
2179 Uhp(78) = 179900.0
2180 Uhp(79) = 194900.0
2181 Uhp(80) = 211000.0
2182 Uhp(81) = 228200.0
2183 Uhp(82) = 246600.0
2184 Uhp(83) = 266200.0
2185 Uhp(84) = 287000.0
2186 Uhp(85) = 309100.0
2187 Uhp(86) = 332700.0
2188 Uhp(87) = 357700.0
2189 Uhp(88) = 384200.0
2190 Uhp(89) = 412400.0
2191 Uhp(90) = 442200.0
2192 Uhp(91) = 473700.0
2193 Uhp(92) = 507000.0
2194 Uhp(93) = 542200.0
SUBROUTINE FLUIDPROP

\begin{align*}
2195 & \quad \text{Uhsp(94)} = 579300.0 \\
2196 & \quad \text{Uhsp(95)} = 618400.0 \\
2197 & \quad \text{Uhsp(96)} = 659700.0 \\
2198 & \quad \text{Uhsp(97)} = 703000.0 \\
2199 & \quad \text{Uhsp(98)} = 748700.0 \\
2200 & \quad \text{Uhsp(99)} = 796600.0 \\
2201 & \quad \text{Uhsp(100)} = 846800.0 \\
2202 & \quad \text{Uhsp(101)} = 899600.0 \\
2203 & \quad \text{Uhsp(102)} = 954800.0 \\
2204 & \quad \text{Uhsp(103)} = 1013000.0 \\
2205 & \quad \text{Uhsp(104)} = 1073000.0 \\
2206 & \quad \text{Uhsp(105)} = 1135000.0 \\
2207 & \quad \text{Uhsp(106)} = 1202000.0 \\
2208 & \quad \text{Uhsp(107)} = 1271000.0 \\
2209 & \quad \text{Uhsp(108)} = 1342000.0 \\
2210 & \quad \text{Uhsp(109)} = 1417000.0 \\
2211 & \quad \text{Uhsp(110)} = 1494000.0 \\
2212 & \quad \text{Uhsp(111)} = 1575000.0 \\
2213 & \quad \text{Uhsp(112)} = 1658000.0 \\
2214 & \quad \text{Uhsp(113)} = 1745000.0 \\
2215 & \quad \text{Uhsp(114)} = 1835000.0 \\
2216 & \quad \text{Uhsp(115)} = 1927000.0 \\
2217 & \quad \text{Uhsp(116)} = 2024000.0 \\
2218 & \quad \text{Uhsp(117)} = 2123000.0 \\
2219 & \quad \text{Uhsp(118)} = 2225000.0 \\
2220 & \quad \text{Uhsp(119)} = 2331000.0 \\
2221 & \quad \text{Uhsp(120)} = 2441000.0 \\
2222 & \quad \text{Uhsp(121)} = 2553000.0 \\
2223 & \quad \text{Uhsp(122)} = 2669000.0 \\
2224 & \quad \text{Uhsp(123)} = 2788000.0 \\
2225 & \quad \text{Uhsp(124)} = 2911000.0 \\
2226 & \quad \text{Uhsp(125)} = 3037000.0 \\
2227 & \quad \text{Uhsp(126)} = 3166000.0 \\
2228 & \quad \text{Uhsp(127)} = 3299000.0 \\
2229 & \quad \text{Uhsp(128)} = 3436000.0 \\
2230 & \quad \text{Uhsp(129)} = 3576000.0 \\
2231 & \quad \text{Uhsp(130)} = 3719000.0 \\
2232 & \quad \text{Uhsp(131)} = 3867000.0 \\
2233 & \quad \text{Uhsp(132)} = 4018000.0 \\
2234 & \quad \text{Uhsp(133)} = 4173000.0 \\
2235 & \quad \text{Uhsp(134)} = 4332000.0 \\
2236 & \quad \text{Uhsp(135)} = 4495000.0 \\
2237 & \quad \text{Uhsp(136)} = 4662000.0 \\
2238 & \quad \text{Uhsp(137)} = 4834000.0 \\
2239 & \quad \text{Uhsp(138)} = 5010000.0 \\
2240 & \quad \text{Uhsp(139)} = 5191000.0 \\
2241 & \quad \text{Uhsp(140)} = 5377000.0 \\
2242 & \quad \text{Uhsp(141)} = 5568000.0 \\
2243 & \quad \text{Uhsp(142)} = 5766000.0 \\
2244 & \quad \text{Uhsp(143)} = 5969000.0 \\
2245 & \quad \text{Uhsp(144)} = 6179000.0 \\
2246 & \quad \text{Uhsp(145)} = 6396000.0
\end{align*}
SUBROUTINE FLU|DPROP compltno Optic_:/MOiNTIBIMImiNFIH//MIINKiMLIP/ml/NQZ/NQSiR/S/NTiV/NXINZl

```
2247  Lhgp(146) = 6620000.0
2248  Lhgp(147) = 6855000.0
2249  Lhgp(148) = 7094000.0
2250  Lhgp(149) = 7345000.0
2251  Lhgp(150) = 7607000.0
2252  Lhgp(151) = 7880000.0
2253  Lhgp(152) = 8165000.0
2254  Lhgp(153) = 8465000.0
2255  Lhgp(154) = 8779000.0
2256  Lhgp(155) = 9110000.0
2257  Lhgp(156) = 9460000.0
2258  Lhgp(157) = 9830000.0
2259  Lhgp(158) = 10220000.0
2260  Lhgp(159) = 10640000.0
2261  A0 = 0.0060783
2262  A1 = -3.1546E-05
2263  A2 = 8.0436E-08
2264  A3 = -1.0536E-10
2265  A4 = 6.9127E-14
2266  A5 = -1.7981E-17
2267  Xlqvisc=A0*A1*Tk+A2*Tk**2.0+A3*Tk**3.0+A4*Tk**4.0+A5*Tk**5.0
2268  Xlqvisc=Xlqvisc*10.0
2269  A0 = -2.0271E05
2270  A1 = -3.0869E-07
2271  A2 = -7.6612E-10
2272  A3 = 1.2985E-12
2273  A4 = -9.7932E-16
2274  A5 = 2.7985E-19
2275  Vapvisc=A0*A1*Tk+A2*Tk**2.0+A3*Tk**3.0+A4*Tk**4.0+A5*Tk**5.0
2276  Vapvisc=Vapvisc*10.0
2277  A0 = 7787.0
2278  A1 = 55.864
2279  A2 = -0.19524
2280  A3 = 3.0795E-04
2281  A4 = -2.3092E-07
2282  A5 = 6.631E-11
2283  Xlqgden=A0*A1*Tk+A2*Tk**2.0+A3*Tk**3.0+A4*Tk**4.0+A5*Tk**5.0
2284  Xlqgden=Xlqgden*0.001
2285  A0 = -69.042
2286  A1 = 0.37673
2287  A2 = -8.7608E-04
2288  A3 = 1.0875E-06
2289  A4 = -6.8926E-10
2290  A5 = 1.7519E-13
2291  Vapgden=A0*A1*Tk+A2*Tk**2.0+A3*Tk**3.0+A4*Tk**4.0+A5*Tk**5.0
2292  Vapgden=EXP(Vapgden)*0.001
2293  A0 = -58.282
2294  A1 = 0.36094
2295  A2 = -8.1354E-04
2296  A3 = 9.8676E-07
2297  A4 = -6.1379E-10
2298  A5 = 1.5358E-13
```
SUBROUTINE FLUIDPROP Compiling Options: NO/NI/7/B/N/NC/NF/NI/NK/NL/P/NO1/NO2/NO3/R/S/NT/W/NI/NX/N1

Source file Listing

2299  P0=AO+A1*TK+A2*TK**2.0+A3*TK**3.0+A4*TK**4.0+A5*TK**5.0
2300  PO=10.0*EXP(P0)/1333.2
2301  AO = 0.67466
2302  A1 = -0.0015864
2303  A2 = 4.8201E-06
2304  A3 = -7.5378E-09
2305  A4 = 5.2245E-12
2306  A5 = -1.3472E-15
2307  SurfTem=AO+A1*TK+A2*TK**2.0+A3*TK**3.0+A4*TK**4.0+A5*TK**5.0
2308  SurfTem=SurfTem*1000.0
2309  AO = 316360.0
2310  A1 = -27.136
2311  A2 = -0.063935
2312  A3 = 1.7119E-04
2313  A4 = -1.6668E-07
2314  A5 = 4.4864E-11
2315  Xlhv=AO+A1*TK+A2*TK**2.0+A3*TK**3.0+A4*TK**4.0+A5*TK**5.0
2316  Xlhv=0.001*Xlhv/4.184139
2317  AO = 4.0347
2318  A1 = 0.16674
2319  A2 = -5.1079E-06
2320  A3 = -1.7922E-09
2321  A4 = 1.1886E-12
2322  A5 = -3.0063E-16
2323  Xlcv=AO+A1*TK+A2*TK**2.0+A3*TK**3.0+A4*TK**4.0+A5*TK**5.0
2324  Tcfluid=AO+A1*TK+A2*TK**2.0+A3*TK**3.0+A4*TK**4.0+A5*TK**5.0
2325  XK=1.663
2326  Xnm=200.59
2327  RETURN
2328  C AMMONIA
2329  8090 IF (TO.LE.-60.0) THEN
2330  GOTO 8100
2331  ELSE
2332  CONTINUE
2333  ENDIF
2334  IF (TO.GT.120.0) THEN
2335  GOTO 8100
2336  ELSE
2337  CONTINUE
2338  ENDIF
2339  XLiqden=1.887137-(1.165350E-02*TK)+(3.96285E-05*TK**2.0)-(5.02087E-08*TK**3.0)
2340  E0=9.08864E-9
2341  Vpden=16.0564123573-(0.34110173779*TK)+(2.9277645470E-03*TK**2.0)
2342  &60=1.12723174826E-05*TK**3.0)+(2.76697543450E-08*TK**4.0)-(2.003E-08*TK**5.0)
2343  &70=3.154734734E-01-(2.31634291110E-14*TK**6.0)+(3.544923473E-01*TK**7.0)
2344  &80=1.227975812E-03
2345  Xlqvsc=(8.162446E-02)-(9.845264E-04*TK)+(4.283905E-06*TK**2.0)-(9.472735E-09*TK**3.0)+(7.484892E-12*TK**4.0)
2346  &90=1.161381E-04-(2.789346E-06*TK)-(1.026799E-08*TK**2.0)+(1.432954E-11*TK**3.0)
2347  Tdummy=TK**1.8
2348  Pdumy=EXP(13.89430-(4618.37/(Tdummy-19)))
SUBROUTINE FLUIDPROP

PO = Pdummy*70.3077
Surften=94.9794*(1-((Tk/405.56)**1.15191))
Xlv=-2296.721959+(39.685263*Tk)-0.218296*Tk**2-(5.240955E-04)*Tk**3.0-(1.731599E-07)*Tk**4
Xk=1.33
Xma=17.03
Tcfluid=(2.441905E-04)+(1.284515E-05*Tk)-(2.651515E-08*Tk**2.0)
9000 RETURN
END
SUBROUTINE TSAT (Tsat, P, T)

CALCULATE TEMPERATURE FROM PRESSURE

COMMON /RAD3/ Roomden(10),Whsp(159)

IF (IFLUID.EQ.2) THEN
  GOTO 9110
ELSE
  CONTINUE
ENDIF

IF (IFLUID.EQ.3) THEN
  GOTO 9220
ELSE
  CONTINUE
ENDIF

IF (IFLUID.EQ.4) THEN
  GOTO 9230
ELSE
  CONTINUE
ENDIF

IF (IFLUID.EQ.5) THEN
  GOTO 9120
ELSE
  CONTINUE
ENDIF

IF (IFLUID.EQ.8) THEN
  GOTO 9170
ELSE
  CONTINUE
ENDIF

IF (IFLUID.EQ.9) THEN
  GOTO 9180
ELSE
  CONTINUE
ENDIF

C WATER

IF (PO.LE.12750.0) THEN
  GOTO 9110
ELSE
  CONTINUE
ENDIF

TO = (PO/2.24732E-06)**0.2368624
RETURN

9110 TO = -2152.69/(((ALOG(PO)/2.30259)-8.625109)-273.2
RETURN

9120 X = SORT((-9030.9923)**2-4*ALOG(PO/750.06)-9.191863)*433033.8
TO = (-9030.9923-X)*(2*(ALOG(PO/750.06)-9.191863))-273.2
RETURN
C NASA MERCURY
2410 Phasa=PO*133.32
2415 DO 9171 I=2,159,1
2419 IF (Phasa.GT.Whgp(I)) THEN
2421 CONTINUE
2423 WRITE (6,*)
2424 "NASA MERCURY PRESSURE TOO HIGH --- JOB ABORTED"
2426 RETURN
2430 CONTINUE
2435 RETURN

C AMMONIA
2470 Ps=0.0142232*PO
2475 Ts=(4618.37/(13.89*ALOG(Ps)))*19
2480 TO = Ts/1.8-273.2
2485 RETURN

C SODIUM
2510 X1=12.5847
2515 X2=.0354119
2520 X3=1.53891E-05
2525 TO=(-X2+2.4*X3*(X1-ALOG(PO)))/(2*X3)
2530 RETURN

C LITHIUM
2550 PO=0.020455*4.18205E-04-1.656E-05*(ALOG(PO+8.347))/8.28E-06-273.2
2560 RETURN
2565 END
SUBROUTINE Wallprop(lmatl, T0, Wallden, Tcwall)

DENSITY AND THERMAL CONDUCTIVITY OF HEAT PIPE WALL MATERIALS

IF (lmatL.EQ.1) THEN
    GOTO 9200
ELSE
    CONTINUE
ENDIF

IF (lmatL.EQ.2) THEN
    GOTO 9210
ELSE
    CONTINUE
ENDIF

IF (lmatL.EQ.3) THEN
    GOTO 9220
ELSE
    CONTINUE
ENDIF

IF (lmatL.EQ.4) THEN
    GOTO 9230
ELSE
    CONTINUE
ENDIF

IF (lmatL.EQ.5) THEN
    GOTO 9240
ELSE
    CONTINUE
ENDIF

IF (lmatL.EQ.6) THEN
    GOTO 9250
ELSE
    CONTINUE
ENDIF

IF (lmatL.EQ.7) THEN
    GOTO 9260
ELSE
    CONTINUE
ENDIF

IF (lmatL.EQ.8) THEN
    GOTO 9270
ELSE
    CONTINUE
ENDIF

TUNGSTEN

9200 Wallden=19.35
9210 Tcwall=0.298-0.000024*T0
RETURN
SUBROUTINE WALLPROP

C

2496 C NOLYDENUM
2497 9210 Vallden=10.22
2498 Tcwall=0.3488-0.0000617*(T0+273.2)
2499 RETURN
2500 C LOCKALLOY
2501 9220 Vallden=2.08
2502 Tcwall=0.5100611-4.19242E-04*T0
2503 RETURN
2504 C 230 ALUMINUM
2505 9230 Vallden=2.85
2506 Tcwall=0.376701+1.37458E-04*T0
2507 RETURN
2508 C 347-CRES
2509 9240 Vallden=8.03
2510 Tcwall=0.034393+3.2975E-05*T0
2511 RETURN
2512 C CARBON-CARBON
2513 9250 Vallden=1.86
2514 Tcwall=0.0562
2515 RETURN
2516 C NIOBIUM-0.1%ZIRCONIUM
2517 9260 Vallden=840.0*0.01
2518 Tcwall= 0.1075*T0/30000.0
2519 RETURN
2520 C COPPER
2521 9270 Vallden=8.96
2522 Tcwall=0.934
2523 RETURN
2524 END
SUBROUTINE XLITHP(T,RHO,CP,VIS,TK)

THERMAL PROPERTIES OF LITHIUM LIQUID
T = INPUT TEMPERATURE (deg-R)
RHO = DENSITY (Lbs/cu-Ft)
CP = SPECIFIC HEAT (BTU/LB'R)
VIS = DYNAMIC VISCOSITY (Lb/Ft-Sec)
TK = THERMAL CONDUCTIVITY (BTU/Hr-Ft-Sec)

RHO = 34.393537 - (0.003456*T) + (2.080291E-07*(T**2.0)) - (1.805873E-01*(T**3.0)) + (3.155296E-14*(T**4.0)) - (2.136471E-17*(T**5.0))

CP = 1.356357 - (0.00068’T) ÷ (5.006625E-07*(T**2.0)) - (1.805873E-01*(T**3.0)) + (3.155296E-14*(T**4.0)) - (2.136471E-17*(T**5.0))

VIS = 0.001085 - (t.32(A97E-O6*T) ÷ (7.245662E-10*(T**2.0)) - (1.7

TK = 25.25376 + (0.001588*T)

RETURN

END
SUBROUTINE XNAKPR(T,RHO, CP,VIS,TIC)
THE THERMAL PROPERTIES OF NaK LIQUID

T = INPUT TEMPERATURE (deg-R)
RHO = DENSITY (Lb/cu-Ft)
CP = SPECIFIC HEAT (BTU/Lb-R)
VIS = DYNAMIC VISCOSITY (Lb/Ft-sec)
TK = THERMAL CONDUCTIVITY (BTU/hr-Ft-R)

RHO = 58.54299*(0.00820rT)
CP = 0.26478 (O.000089rT) + (4.093060E-08*(T**2.0)) -
   (4.532164E-12*(T**3.0))
VIS = 0.000822 - (1.142435E-06*(T)) + (6.125737E-10*(T**2.0)) -
   (1.130181E-13*(T**3.0))
TK = 7.313351 * (0.013983*(T)) - (7.660423E-06*(T**2.0)) +
   (1.189370E-09*(T**3.0))

RETURN
END
SUBROUTINE HEXEPR(Amamix, Pmix, Tmix, Gme, Cpmix, Rhoix, Amamix, Akmix, &Pmix)

PROPERTIES OF HELIUM-XENON MIXTURES

WRITE (6,*) 'Amamix, Pmix, Tmix=', Amamix, Pmix, Tmix

Gme=1.667
Am1=4.0
Am2=131.3

X2=(Amamix-Am1)/(Am2-Am1)

X1=1.0-X2

Cpmix=4.97/Aamamix

Rhoix=144.0*Pmix*Aamamix/(1545.0*Tmix)

IF (Tmix.GT.1000.0) THEN
  GOTO 10
ELSE
  Amhve=5.7E-06+1.45E-08*Tmix
  GOTO 100
ENDIF

10 IF (Tmix.GT.1600.0) THEN
  GOTO 20
ELSE
  Amhve=8.867E-06+1.1333E-08*Tmix
  GOTO 100
ENDIF

20 Amhve=1.114E-05+9.930E-09*Tmix

100 IF (Tmix.GT.1100.0) THEN
  GOTO 30
ELSE
  Amhve=0.0403+8.471E-05*Tmix
  GOTO 200
ENDIF

30 IF (Tmix.GT.1800.0) THEN
  GOTO 40
ELSE
  Amhve=0.0504+6.786E-05*Tmix
  GOTO 200
ENDIF

40 Amhve=0.0625+6.583E-05*Tmix

200 IF (Tmix.GT.1200.0) THEN
  GOTO 50
ELSE
  Amhve=5.25E-06+2.1375E-08*Tmix
  GOTO 300
ENDIF

50 IF (Tmix.GT.2000.0) THEN
  GOTO 60
ELSE
  Amhve=1.0500E-05+1.7000E-08*Tmix
  GOTO 300
ENDIF
2616 ENDIF
2617 60 Axmx=1.5500E+05+1.45E-08*Tmix
2618 300 IF (Tmix.GT.1200.0) THEN
2619 GOTO 70
2620 ELSE
2621 Axmx=0.00115+4.375E-06*Tmix
2622 GOTO 400
2623 ENDIF
2624 70 IF (Tmix.GT.2500.0) THEN
2625 GOTO 80
2626 ELSE
2627 Axmx=0.00252+3.2308E-06*Tmix
2628 GOTO 400
2629 ENDIF
2630 80 Axmx=0.00342+1.8000E-06*Tmix
2631 400 Amu1=Amu-he
2632 Amu2=Amux
2633 Ak1=Akhe
2634 Ak2=Akxe
2635 Duml=2.82843*SORT(1.0+(Am1/Am2))
2636 Duml=1.0*SORT(Am1/Am2)*(Am2/Am1)**0.25
2637 Ps112=Duml**2.0/Duml
2638 Duml=Aml/Am2
2639 Ps121=Duml**2.0
2640 Duml=1.0+Ps112*(X2/X1)
2641 Duml=1.0+Ps121*(X1/X2)
2642 Amux=Amu1/Duml+Amu2/Duml
2643 Duml=2.82843*SORT(1.0+(Am1/Am2))
2644 Duml=1.0*SORT(Ak1/Ak2)*(Am2/Ak1)**0.25*2.0
2645 Duml=2.82843*SORT(1.0+(Am2/Ak2))
2646 Duml=1.0*SORT(Ak2/Ak1)*(Am2/Ak1)**0.25*2.0
2647 Aml=40*Duml/Duml
2648 Aml=40*Duml/Duml
2649 Duml=(Am1+Am2)**2.0
2650 Duml=2.41*(Am1-Am2)**(Am1-0.142*Am2)
2651 Duml=2.41*(Am2-Am1)**(Am2-0.142*Am1)
2652 For12=Aml2*(1.0+Duml/Duml)
2653 For21=Aml2*(1.0+Duml/Duml)
2654 Duml=1.0+For12*(X2/X1)
2655 Duml=1.0+For21*(X1/X2)
2656 Aml=1.0+Duml/1.0+Duml
2657 Prmx=36000*Amux*Ps121*Duml/X1
2658 C WRITE (6,*),' 'Thermodynamic Properties of Helium-Xenon Mixtures'
2659 C WRITE (6,*),' 'Thermodynamic Properties of Helium-Xenon Mixtures'
2660 C WRITE (6,*),' 'Thermodynamic Properties of Helium-Xenon Mixtures'
2661 C WRITE (6,*),' 'Thermodynamic Properties of Helium-Xenon Mixtures'
2662 C WRITE (6,*),' 'Thermodynamic Properties of Helium-Xenon Mixtures'
2663 C WRITE (6,*),' 'Thermodynamic Properties of Helium-Xenon Mixtures'
2664 C WRITE (6,*),' 'Thermodynamic Properties of Helium-Xenon Mixtures'
2665 C WRITE (6,*),' 'Thermodynamic Properties of Helium-Xenon Mixtures'
2666 C WRITE (6,*),' 'Thermodynamic Properties of Helium-Xenon Mixtures'
2667 C WRITE (6,*),' 'Thermodynamic Properties of Helium-Xenon Mixtures'
2668 C WRITE (6,*),' 'Thermodynamic Properties of Helium-Xenon Mixtures'
SUBROUTINE HEXEP

Compiling Options: /NO/N7/B/NC/ND/NF/NL/NL/P/NQ1/NQ2/NQ3/R/S/NT/V/NX/NZ1

Source file Listing

2669 C WRITE (6,*) 'Thermal Conductivity (BTU/Hr-Ft-R) ='&Akmix
2670 C WRITE (6,*) 'Prandtl Number (o) =',Pmix
2671 END
SUBROUTINE HRRAD(Grad, Trad, Xntubes, Xnexpip, Xlflap, Dhpipe, Tfluid,

&Imetl, Theta, D2rad, Thick, Thickf, Thick, Em, IEHfig, Halt, HINCL, Rsun,

&Yrlinc, Alpha, Hap, HArad, Tktfin, Rhocoating, Rhofin, RNdarm

2678 &, Xladiab, CONFIG, Xnhmms, PRO8, GAN, ARSF, Email, Time, Oreqected,

2679 &Thickf2, Thickm2, A Radiator, Aрадаеfect, Withick2, Xnart2, Artid2,

2680 &Artid2, Thick2, Xlexpvp2, Xladi2, Xlasep2, Xlto2, Xmpipes, Xmfluid,

2681 &Xmflin, Xmcoating, Xmmarm, Xmarmor, Xstructure,

2682 &Xntredmat2, Wx12)

2683 C

2684 C DIMENSION Dv(99), Space(99), T(99), Drod(99)

2685 C DIMENSION Qc(99), Qact(99), Eff(99)

2686 C COMMON /RAD3/ Roomden(10), Whsp(159)

2687 C

2688 C IF CONFIG = 1.0, RADIATOR IS A FLAT PLATE, ELSE IS A CONE OR CYL.

2689 C

2690 C Pdesi = 1.0 - PROB

2691 C Grad = 3413.0*Grad

2692 C

2693 C Angle2=Theta

2694 C Dhpipe=2.54*Dhpipe

2695 C CALL HRTSHN(JENFиг, Halt, HINCL, Rsun, Yrlnch, Alpha, Hap, HArad, Tsink)

2696 C Xlasep=6.0

2697 C Xnpunit = 1.0

2698 C lxincr=50

2699 C VOID=0.5

2700 C Wthick2=0.0020*Dhpipe

2701 C Artid2=0.0020*Dhpipe

2702 C Artid2=0.10*Dhpipe

2703 C Xnart2=ANINT(3.141593*Dhpipe/2.54)

2704 C

2705 C 810 Dp=Dhpipe

2706 T(t)=Trad

2707 840 DV7=Dp/2.54/12.0

2708 850 CONTINUE

2709 900 Gtot=0.0

2710 910 Atot=0.0

2711 920 D0=0.0

2712 9520 I=1,50,1

2713 9713 Xlv=FLOAT(I)

2714 9714 Xlincr=FLOAT(lixncr)

2715 9715 Dv(I)=D7

2716 Drod(I)=D2rad+2.0*Xlasep*SIN(Angle2/57.29578)*(Xlv/Xlincr)

2717 1060 Space(I)=3.141593*Drod(I)/Xntubes-Dv(I)

2718 1090 Xfrin=12.0*Space(I)/2.0

2719 1070 Deltax=Xlasep/Xlincr

2720 1090 IF (I.EQ.1) THEN

2721 1220 D3=D2rad

2722 ELSE

2723 1220 D3=Grad(I-1)
SUBROUTINE HRRAD CoopiLinoOptiorm=INOINTIBiNC/MDIHFIHIHIIHY_INLIPIMOIlHQ2/H(L_IR/S/HT/W/NXlNZlSource file Listing

2724 IF (I.EQ.1) THEN
2725 H2=Hnet
2726 ELSE
2727 H2=Hnet-(DeltaX*COS(Angle2/57.29578).*(XIV-1.0))
2728 ENDIF
2729 IF (I.EQ.1) THEN
2730 H1=H2+(2.0*Xspec*SIN(Angle2/57.29578))
2731 D1=0.2*rad(1)
2732 H1=H2-(DeltaX*COS(Angle2/57.29578))
2733 CALL View(D1,H1,H2,AA,AA,Vf)
2734 CALL HRHTPP(Imat,Ifuid,Xlevep,Xladi,Xlcond,Pipid,Wall,Tettrk,Gs
2735 tstart,Whick2,2wdz2,Artwall2,Artid2,Xnart2,T(I),Fluidcharge,Totalm
2736 2aza)
2737 T(I) = (T(I)+273.0)*1.8
2738 Taubr=Taink/(T(I)
2739 Ahfint=.Em*1.7212E-09*(T(I)**3.0)*(1.0+Taubr**2.0)**(1.0+Taubr)
2740 Xm1=((Ahfint/(T(kfin*Thickf)**0.5))*(Xlfrfin))/12.0
2741 Fin1=(EXP(Xm1)+EXP(-Xm1))/(EXP(Xm1)+EXP(-Xm1))
2742 Fin2=1.0-(1.58*(1.0-EXP(-0.2*Xm1))**0.5)**(1.0-Taubr))
2743 Eff1=1.0/(Xm1)**Fin1*Fin2
2744 Xm1=(1.0-2.8*(1.0-EXP(-1.0*Xm1))**0.5)**(1.0-Taubr))
2745 Xspec=Xipec*(1.0+Vfct)*(1.0+Eff1*Xspace(I))**Em*4.77E-13
2746 Qact(I)=Xlpec/Xinc*(1.0+Vfct)*(1.0+Eff1*Xspace(I))**Em*4.77E-13
2747 CONTINUE
2748 Qctbar=Vfbar/Aatot
2749 IF (ABS(ErrorT).GT.0.0001) THEN
2750 Aatot=0.0
2751 Vfbar=0.0
2752 I=1
2753 CONTINUE
2754 ENDIF
C  HEAT PIPE RADIATOR MASS ALGORITHM
C
2776 1720 Xradiator=Xlspec
2777 1730 Dv7 = 0.0
2778 1740 Space7 = 0.0
2780 DO 1780 lnl,SO, l
2781   Dv7 = Dv7 + Dv(l)
2782   Space7 = Space7 + Space(l)
2783 1780 CONTINUE
2784 Dv7=Dv7/Xinc
2785 Space7=Space7/Xinc
2786 1820 Aradiator=3.141593*(Drad(1)/2.0+Drad(lxincr)/2.0)*SORT(((Xlspec*  
2787   100(Theta/57.29578)**2.0)+((Drad(lxincr)/2.0)-(Drad(1)/2.0)**2.0)  
2788   )/20)
2789 1870 Xampipes=Xampipes*(Xntubes*Xnexpip)
2790 1880 Xampinf=Space7*Thickf*Xradiator*Rhofoil*(Xntubes*Xnexpip)
2791 1890 Xampbuf=Xampbuf*(Xntubes*Xnexpip)
2792 1900 Acetoat=3.141593/2.0*(Dv7+Thick+Thicke)/(2.0)*Thickf+Space7*Thickm
2793 1910 Xncasting=Acetoat*Xradiator*Rhoocasting*(Xntubes*Xnexpip)
2794 1930 Atube=Dv7*Xradiator
2795 1940 Jj=IFIX(Xnexpip*Xnpp units)
2796 1950 Kkkk=IFIX(Xntubes)+Jj
2797 1960 P7=Pnew(Pdes1,Jj,Kkkk)
2798 1970 Prob=1.0-P7
2799 Temp = T(49)
2800 ATarget = Atube/10.764961
2801 1980 CALL HRAWRH(ENFlg,Halt,HINCL,Raun,Yrlnch,GAM,ARSF,Eans,RHOa,At  
2802   &Target,Time,Prob,Temp,Tharm)
2803 WRITE (6,*) 'Tharm (Inches) = ',Tharm  
2804 Thickarm=Tharm/1.2
2805 2050 Xmassm=Thickarm*Dv7*Xradiator*Rhoarm*(Xntubes*Xnexpip)/3.141593/  
2806 * & 2.0
2807 2555 FORMAT (6F12.4)
2808 Thick2=12.0*Thickf
2809 Thickm2=12.0*Thickm
2810 Projlected=Grad/343.0
2811 C WRITE (*,*)
2812 C WRITE (*,*) 'TOTAL HEAT AVERAGE . Radiator Emissivity'  
2813 C WRITE (*,*) 'REJECTED EVAPORATOR FIN Coating'  
2814 C WRITE (*,*) 'K(kW) TEMP (R) Thick (In) Thick (In)'  
2815 C WRITE (*,*) 'Projected,Trad,Thickness'  
2816 Xltotal=Xlpecc+((Xlrad+Xlevap)/(2.54*12.0))
2817 Dv7=Dv7/2.54
2818 Thickarm2=Thickarm2*12.0
2819 Aradffect=1.0+VFctbar)*Aradiator
2820 C WRITE (*,*)
2821 C WRITE (*,*) 'Actual Effective'
2822 C WRITE (*,*) 'one-side' Radiator'
2823 C WRITE (*,*) 'Area(sq-Ft.) Area(sq-Ft)'  
2824 C WRITE (*,*) 'HEAT PIPE DESIGN DETAILS - DIMS in INCHES'
SUBROUTINE HRRAD

WRITE (*,2555) Dhpipe,Wall2,Wall12,Art2,Art12,Wall12,Wall2
WRITE (*,Xladi2*Xladi1/2.54)
WRITE (*,Xlevap2*Xlevap/2.54)
WRITE (*,Xspec2*Xspec+12.0)
WRITE (*,Xlotot2*Xlotot+12.0)
WRITE (*,Xarmorid*Xarmor)
Xl12=13.2142*((0.6072+0.1514*Aradiator)**0.5)-10.296525
Xstructure=0.0
WRITE (*,Xnetradmass=2*Xmpipes+Xmpfluid+Xmpfin+2.0*Xmcoating+Xmchimor+Xmarmor+
WRITE (*,1*Xmarmorid*Xstructure)
WRITE (*,2555) Xevap2,Xladi2,Xspec2,Xlotot2
WRITE (*,Xlotot2*Xlotot+12.0)
WRITE (*,Xarmorid*Xstructure)
WRITE (*,*),Evap,Length,Adi,Length,Cond,Length,Total,Length
WRITE (*,2555) Xlevap2,Xladi2,Xspec2,Xlotot2
WRITE (*,13.2142*((0.6072+0.1514*Aradiator)**0.5)-10.296525
WRITE (*,*),RAD,ATOR,M,ASS,BREAKDOWN,Mass,in,Lbs.
WRITE (*,*),Heat,Pipes,Fluids,FINS,Emiss.,Cont.
WRITE (*,2555) Xmpipes,Xmpfluid,Xmpfin,Xmcoating
WRITE (*,*),O.D.,ARMOR,1.D.,ARMOR,Structure,TOTAL,RA,DIATOR
WRITE (*,2555) Xmarmor,Xarmorid,Xstructure,Xnetradmass=2
1dmmass=2.2046,LENGTH(00)=',Xl12,12.0*2.54
WRITE (*,*),ETA=',2.825/Aradiator,' MASS/AREA(#/sq-ft.)=',(Xnetradmass=2)/Aradiator
WRITE (*,*),RADIATOR,AREA,REQUIRED,(1.129412*Acomp)'=',0.104916*A
RETURN
END
SUBROUTINE HRHTPP
Calpi||ng

Source file Listing

2858 C
2859 C
2860 C
2861 2960 SUBROUTINE HRHTPP(llmtt,lfLuid,Xte,Xta,Xt¢,P|pid,WetL,Tstrtk,kta
2862 3863
2864 2865
2866
2867
2868
2869
2870 2871
2872 2873
2874
2875
2876 C
2877 C5140 CHECK ARTERY SPACING AND VAPOR SPACE
2878 3879
2880 2881
2882 3883
2884 3885
2886 C
2887 3888
2889
2890
2891
2892
2893 C
2894 3895
2896
2897
2898
2899 C
2900 3899
2901
2902
2903 C
2904 3899
2905
2906
2907
2908
2909
2910 1)
SUBROUTINE HRHTPP

Source file Listing

CALL Fluidprop(Ifluid, TO, Xliqden, Vapden, Xliqvisc, Vapvisc, P0, Surfte, 1n, Xlhv, Xk, Xaw, Tcf_tufd)

C

3970 X=PO*P9
3980 Dtevap1=TO+273.2
3990 X9=60/((2.0*3.141593*Vaprad*Xnart*3.141593*Artod/2.0)*Xle)
4000 J+1
4010 IF (J.GT.200) THEN
4020 ENDIF
4021 IF (X8.GT.X9) THEN
4030 GO TO 3950
4031 ELSE
4032 GO TO 3950
4033 ENDIF
4034 ENDIF
4035 IF (X8.EQ.X9) THEN
4040 Axvapvel=0/(Vapden*Effarea*Xlhv)
4050 ENDIF
4060 Axvapvel=60/(Vapden*Effarea*Xlhv)
4070 Exaxreyn=Vapden*Axvapvel*Hydiasm/Vapvisc
4080 Ff=16.0/Exaxreyn
4090 C7=3.141593**2.0/8.0
4100 C4=C7**0.5*2.0/(Effarea**2.0*Xlhv**2.0*Vapden)
4110 IF (Pbev**2.0.LT.Pbev**2.0*C7*Xle*FF/Exaxreyn*Vapden*Axvapvel**2.0) THEN
4120 RETURN
4130 IF (4.0*C4**Pbev.LE.Pbev**2.0) THEN
4140 GOTO 4270
4150 ELSE
4160 GOTO 4270
4170 ENDIF
4180 END
ELSE
2964 4260 GOTO 5750
2965 ENDIF
2966 4270 Dpviscous=Pbev-SORT(Pbev**2.0-Pbev*2.0*Xle*Effdiam*Vapden*1.1)*EXP(2.0)
2967 4280 Dpviscous=(Pbev-SORT(Pbev**2.0-4.0*CA*Pbev))/2.0
2969 4290 Xd=Pbev-Dpviscous
2970 4300 IF (X0.GT.0.0) THEN
2971 GOTO 4400
2972 ELSE
2973 GOTO 5790
2974 ENDIF
2975 4400 Dpsear=Pb visc*(Xle/2.0)**(60/Xnart)/(Artper*Xliqden*XLh**3.1415
2976 193*Artid**2.0/4.0)
2977 4420 Xlengthflow=3.141593*(Pipid-Vthick)/(2.0*Xnart)
2978 4430 Dpvisc=Pb visc*Xlengthflow**0.8/(Piperm*Xliqden*XLh
2979 1*Xle*Vthick)
2980 4450 PO=(Pbev-Dpviscous*Dpvisc))/P9
2981 4460 Peav=PO**P9
2982 4470 CALL Test(lfuid,PO,PO,T0)
2983 4480 T0=10
2984 CALL Fluidprop(lfuid,T0,Xliqden,Vapden,Xliqvisc,Vapvisc,PO,Surft)
2985 1n,Xthv,Xk,Xmu,Tefliuid)
2986 4520 Axvapvel=60/(Vapden*Effdiam*XLh)
2987 4530 Velsound=SORT(Xk*8.3144E+07*(Temv*273.2)/Xm)
2988 4540 Examch=Axvapvel/Velsound
2989 4550 IF (Examch.LT.1.0) THEN
2990 GOTO 4570
2991 ELSE
2992 GOTO 5830
2993 ENDIF
2994 4570 Examch=Examch
2995 4580 IF (Xle.EQ.0.0) THEN
2996 GOTO 4950
2997 ELSE
2998 CONTINUE
2999 ENDIF
3000 4600 Adscapforce=2.0*Surftene*CDW(Retangle/S72.29578)/Wcaprad
3001 4620 Axvapvel=60/(Vapden*Effdiam*XLh)
3002 4630 Axvapvel=Vapden*Axvapvel*Hydiam/Vapvisc
3003 4640 Fr=16.0/Axvrayn
3004 4650 IF (Axvrayn.LE.2100.0) THEN
3005 GOTO 4710
3006 ELSE
3007 CONTINUE
3008 ELSE
3009 4660 IF (Axvrayn.GT.30000.0) THEN
3010 GOTO 4690
3011 ELSE
3012 CONTINUE
3013 ELSE
3014 4670 Fr=0.0791/Axvrayn**0.25
SUBROUTINE HRHTPP (CeilpitJng Optiorm:INOINTiD/HCIHDINFIH/NIIW_NLiPIMOIlN_NO31RISINTiV/NXINZ1Source file List|nO

3015 4680 GOTO 4710
3016 4690 F=f=0.066/Aaxreyn**0.2
3017 4710 P7=Pave
3018 4720 IF (EamKh.6T.O.15) THEN
3019 GOTO 4750
3020 ELSE CONTINUE
3021 ENDIF
3022 4730 Dpoveviscous=2.0*FF*Xla/Effdiam*Vapden*Axvapvel**2.0
3023 4740 GOTO 4790
3024 4750 Sonicflag=0.0
3025 4760 CALL Xmach(Eamach,P7,FF,Xla,Effdiam,Xk,XmB,Dpoveviscous,Sonicflag)
3026 4770 IF (Sonicflag.EQ.0.0) THEN
3027 GOTO 6790
3028 ELSE CONTINUE
3029 ENDIF
3030 4780 GOTO 5870
3031 ENDIF
3032 4790 CONTINUE
3033 4800 Dplart=Xliqvisc*Xla*(Q0/Xmart)/(Artperm*Xliqden*Xlhv=3.141593*Ar
3034 4810 ltid**2.0/4.0)
3035 4820 PO=(Pave-Dpoveviscous)/P9
3036 4830 Pacv=PO*P9
3037 4840 Acmach=XmB
3038 4850 CALL Test(Ifluid,P9,PO,TO)
3039 CALL Fluidprop(Ifluid,TO,Xliqden,Vapden,Xliqvisc,Vapvisc,PO,Surf)il
3040 In,xlhv,Xk,XmB,Tcfluid)
3041 4860 IF (Acmach.GT.0.15) THEN
3042 GOTO 5000
3043 ELSE CONTINUE
3044 ENDIF
3045 4870 CONTINUE
3046 4880 Axvapvel=Q0/(Vapden*Effarea*Xlhv)
3047 4890 Velsound=SQR(TK*8.3164E+07*(Teav+273.2)/Xmw)k
3048 4900 Acmach=Axvapvel/Velsound
3049 4910 GOTO 5000
3050 4920 Pacv=Pave
3051 4930 IF (Acmax=Emach)
3052 5000 CONTINUE
3053 5020 Condscforce=2.0*Surflen*PCOS(Vetangle/57.29578)/Acaprad
3054 5060 Axvapvel=Q0/(Vapden*Effarea*Xlhv)
3055 5070 Caxreyn=Vapden*Axvapvel*Hydiam/Vapvisc
3056 5080 FF=16.0/Caxreyn
3057 5090 IF (Caxreyn.LE.2100.0) THEN
3058 GOTO 5140
3059 ELSE CONTINUE
3060 5100 IF (Caxreyn.GT.30000.0) THEN
3061 ENDIF
3062 5110 GOTO 5130
3063 ELSE CONTINUE
3064 ENDIF
SUBROUTINE HRHTPP  

Source file Listing

3067  5110  F=0.0791/Caxreyen**2.0.25
3068  5120  GOTO 5140
3069  5130  F=0.064/Caxreyen**0.2
3070  5140  CONTINUE
3071  5150  Dpvcviscous=2.0*F*(Xl/2.0)/Effdime*Vapden*Axvapev**2.0
3072  5160  Dpvcinertial=0.5*Vapden*Axvapev**2.0
3073  5180  DpLcart*Xliqvisc*(Xl/2.0)*/(Q0/Xnart)/(Artpen*Xliqden*Xlhve=3.1415
3074  5193  (Ar)d**2.0/4.0)
3075  5200  Xlengthflow=3.141593*(Ppid-Vthick)/(2.0*Xnart)
3076  5210  DpLcick*Xliqvisc*Xlengthflow*(Q0/(2.0*Xnart))/(Upen*Xliqden*Xlhve
3077  5*kic*Xthick)
3078  5230  P0=(Pawv-Dpvcinertial*Dpvcviscous)/P9
3079  5240  Pfcv=P0*P9
3080  5260  IF (Pfcv.GT.0.0) THEN
3081  5270  GOTO 5290
3082  5280  ELSE
3083  5290  CONTINUE
3084  5300  ENDIF
3085  5320  X=PI/2.0
3086  5330  CALL Tstat(IfLuid,P9,P0,TO)
3087  5340  T=PI/2.0
3088  5350  Zot=FLOAT(I)
3089  5360  DpLcond=DtCevap*(Xl/Xl)*(Zot/50.0)
3090  5370  T9=Tfcv-DtCcond
3091  5380  CALL Fluidprop(Ifluid,T0,Xliqden,Vapden,Xliqvisc,Vapvisc,P0,Surfte
3092  5390  Xn,Xlve,Xn,TeLuid)
3093  5400  CALL Wallprop(Iwall,T0,Wallden,Twall)
3094  5410  TcLnick=Twall
3095  5420  TcLfilledLick=Lwick*(1.0-WoLd)*(1.0-TcLuid/Lwick)
3096  5430  DtcLwick=G0*ALOG(Ppid/2.0*Vaprad)/(2.0*3.141593*TeLfilledLick*Xl
3097  5440  )*Zot/50.0)
3098  5450  TcLick=LfYfct-DtLcond-LtcLwick
3099  5460  CALL Wallprop(Iwall,T0,Wallden,Twall)
3100  5470  DtcLwall=G0*ALOG(Ppid/Ppid)/(TcLwall*2.0*3.141593*Xl)*(Zot/50.0)
3101  5480  Textcond=fTfcv-DtCcond-LtcLwick-LtcLwall
3102  5490  Condenserdp=Dpvcviscous*Dpvcinertial*DpLcart*Dplcwick
3103  5500  IF (Condapforce.LT.-Condenserdp) THEN
3104  5510  GOTO 5950
3105  5520  ELSE
3106  5530  CONTINUE
3107  5540  ENDIF
3108  5550  X=Dpvcviscous*Dpvcinertial
3109  5560  IF (X.LT.0.0) THEN
3110  5570  X=0.0
3111  5580  ELSE
3112  5590  CONTINUE
3113  5600  ENDIF
3114  5610  XleftoversCondapforce-X-Dplcart-Dplcwick
3115  5620  IF (X.LT.0.0) THEN
3116  5630  Xleftovers=0.0
3117  5640  GOTO 5610
3118  5650  ELSE
SUBROUTINE HRHTPP
      CONTINUE
5570 ENDIF
5580 IF (Xleftoverc+Adbcapforce-Condcapforce.LT.Dpviscous+Dplearnt) THEN
162
5590 GOTO 5990
5600 ELSE
125
5610 CONTINUE
5620 ENDIF
5630 Xleftoverc=Xleftoverc+Adbcapforce-Condcapforce+Dpviscous-Dplearnt
5640 Evapcapforce=Opviscous+Opvleart+Opwisek
125
5650 IF (Xleftoverc+Evapcapforce-Adbcapforce.LT.Evmpforce) THEN
126
5660 GOTO 6030
5670 ELSE
125
5680 GOTO 6060
125
5690 ENDIF
5700 WRITE (*,*) 'TOO MUCH EVAPORATION DELTA-P'
5710 WRITE (*,*) 'SONIC LIMIT EXCEEDED AT BEGINNING OF EVAPORATOR'
5720 WRITE (*,*) 'SQRT IS NEGATIVE IN EVAP VISC DELTA-P EQN'
5730 WRITE (*,*) 'EVAP VAPOR DELTA-P IS TOO HIGH'
5740 WRITE (*,*) 'SONIC LIMIT EXCEEDED AT E-A INTERFACE'
5750 WRITE (*,*) 'SONIC LIMIT EXCEEDED IN ADIABATIC SECTION'
5760 WRITE (*,*) 'TOO MUCH CONDENSER VAPOR DELTA-P'
5770 WRITE (*,*) 'NOT ENOUGH CAPILLARY FORCE IN CONDENSER'
5780 WRITE (*,*) 'NOT ENOUGH CAPILLARY FORCE IN ADIABATIC SECTION'
5790 WRITE (*,*) 'NOT ENOUGH CAPILLARY FORCE IN THE EVAPORATOR'
5800 STOP
5810 Xlp=Xlp+Xvao+Xlco
5820 Pipovolume=3.141593*(Pipod**2.0-Pipid**2.0)/4.0*Xlp+2.0*3.141593*P
5830 nPipod**2.0/4.0*Wall
5840 Xlp=Xlp+Pipovolume-Wall
den
5850 Wickvolume=3.141593*(Pipid**2.0-Pipid**2.0)/4.0*Xlp+2.0*3.141593*P
5860 Xlp=Xlp+Pipovolume-Wall
den
5870 Arteryvolume=3.141593*(Artod**2.0-Artid**2.0)/4.0*Xlp
5880 Xlp=Xlp+Arteryvolume-Wall
den
5890 Fluidcharge=(Wickvolume+Arteryvolume+Fluidcharge)
5900 Vvold+Xnart*(3.141593*Artid**2.0/4.0)*Room
5910 1en(lfluid)
5920 Totalmass=Pipmass+ Wickmass+ Arterymass+ Fluidcharge
5930 160 RETURN
5940 END
SUBROUTINE XMACH(Eammach, P7, Ff, Xla, Efdiam, Xk, Xm8, Dpliascous, Sonic &flag)
  7200 Xm7=Eammach
  7210 X7=Xm7
  7220 X5=4.0**ff*Xla/Efdiam
  7260 X2=(1.0-Xm7**2.0)/(Xk*Xm7**2.0)+(Xk+1.0))/(2.0*Xk)*ALOG((Xk+1.0)*Xm
  7300 X4=X2-X5
  7310 IF (X1.GT.0.0) THEN
  7320 ELSE
  7330 ENDIF
  7340 Ya6-1.0
  7350 RETURN
  7360
  7400 X4=0.1
  7410 Xmb=X7+X4*X7
  7420 Xn=(1.0-Xm7**2.0)/(Xk*Xm7**2.0)+(Xk+1.0)/(2.0*Xk)*ALOG((Xk+1.0)*Xm8
  7450 IF (ABS((X1-X)/X1).LE.0.001) THEN
  7460 ELSE
  7470 ENDIF
  7480 X4_0.01
  7490 X4=X7-X4*X7
  7500 IF (Xm8.LE.1.0) THEN
  7510 ELSE
  7520 ENDIF
  7530 Sonic&flag=1.0
  7540 Dptaviacous=P7-P7*Xm7/Xm8*SQRT((1.0+(Xk-1.0)/2.0*Xm7**2.0)/(1.0+(X
  7550 1k-1.0)/2.0*Xm8**2.0))
  7560 RETURN
SUBROUTINE XNACH  Compiling Options:/NO/HT/BLMC/HD/MC/ML/P/MQ1/MQ2/MQ3/R/S/W/NX/NZ1
Source file Listing

3211      END
FUNCTION Pнев(U, J, K)

C FUNCTION TO CALCULATE HEAT PIPE FAILURE PROBABILITY

C
C VARIABLES DEFINITION

C U = Prob (0.1, 0.01, 0.001)
C
C INTEGER NUMBER OF REDUNDANT HEAT PIPES
C K = INTEGER NUMBER OF TOTAL HEAT PIPES (REQUIRED+REDUNDANT)

C
C

C INTEGER N
C REAL*8 Potd, Dudp, Dudpnew, F, U, A, Pnev
C Pold=0.03
C Dudpold=10.0

C
C

DO 9512 H=J+1,K,1
A=INLNC(K)-INLNC(K-H)+H*ALOG(Pold)+(K-H)*ALOG(1-Pold)
IF (A.GT.-50.0) THEN
A=A*A
F=F/A
Dudp=Dudp+A*(H/Pold-(K-H)/(1-Pold))
ELSE
CONTINUE
END IF
CONTINUE
Dudpold=Dudpnew
IF (Pm_.GT.0.99999) THEN
Pnev=0.1+0.9*Pold
ELSE
CONTINUE
ENDIF
CONTINUE
END IF

END FUNCTION Pнев(U, J, K)
FUNCTION PHEM  Compiling Options: /NO/NT/B/NC/NF/N1/NK/NL/P/NQ1/NQ2/NQ3/R/S/WT/W/NX/N21
Source file Listing

3264       RETURN
3265       END
FUNCTION XLNFAC

C REAL*8 F, Z, X, XLNFAC
C FUNCTION TO CALCULATE THE LOG OF FACTORIALS OF WHOLE NUMBERS
C
IF (N.EQ.0) THEN
  F = 0.0
ELSE
  CONTINUE
ENDIF
IF (N.EQ.1) THEN
  F = 0.0
ELSE
  CONTINUE
ENDIF
IF (N.EQ.2) THEN
  F = ALOG(2.0)
ELSE
  CONTINUE
ENDIF
IF (N.EQ.3) THEN
  F = ALOG(6.0)
ELSE
  CONTINUE
ENDIF
IF (N.EQ.4) THEN
  F = ALOG(24.0)
ELSE
  CONTINUE
ENDIF
IF (N.EQ.5) THEN
  F = ALOG(120.0)
ELSE
  CONTINUE
ENDIF
IF (N.GT.5) THEN
  Z = FLOAT(N+1)
  XI = 1.0/2
  F = (XI + 0.5) * ALOG(2) - 0.5 * ALOG(2 * PI) + 1.0 / (12 * XI) * (1 - XI * XI / 2) * (1 - XI * XI / 4)
ELSE
  CONTINUE
ENDIF
XLNFAC = F
RETURN
END
SUBROUTINE THEAN(Tin, DTmax, DTeff, Tbar)
  Tref = Tin - DTeff
  Z1 = (1.0-(DTmax/Tref))**3.0
  Z2 = 1.0/(1.0/Z1)-1.0
  Z3 = 3.0*(Z2*(DTmax/Tref))
  Tbar = (Z3*(Tref**4.0))**0.25
RETURN
END
SUBROUTINE ACONE

C
C

SUBROUTINE ACONE(Rs, RL, Ht, Areacone)
A = 3.141593*(Rs+RL)
B = SQRT((Ht**2.0)+(RL-Rs)**2.0)
Areacone = A*B
RETURN
END
SUBROUTINE AVIEW(Ds, Dl, Ht, Acone, Vfct)
  R1 = Ds/2.0
  R2 = Dl/2.0
  Acone = 3.141593*(R1+R2)*SQRT((Ht**2.0)+((R2-R1)**2.0))
  Aend = 3.141593*(R2**2.0)
  A1 = 3.141593*(R1**2.0)
  DUM1 = 1.0 + ((R2/R1)**2.0) + ((Ht/R1)**2.0)
  DUM2 = 4.0*((R2/R1)**2.0)
  DUM3 = SQRT((DUM1**2.0)-DUM2)
  Flto2 = 0.5*(DUM1-DUM3)
  Vfct = (Aend/Acone)*(1.0-((A1/Acone)*Flto2))
RETURN
END
SUBROUTINE VIEW(D1,D2,D3,H1,N2,Am,Vf)

CONICAL RADIATOR ID VIEW FACTOR - Cone ID to Space via

Large End Only

**** VARIABLES DEFINITION ****

D1 = DIAMETER OF EXIT DISC
D2 = LARGE DIAMETER OF CONICAL ELEMENT
D3 = SMALL DIAMETER OF CONICAL ELEMENT
H1 = DISTANCE FROM TOP OF CONE TO SMALL DIAMETER PLANE
H2 = DISTANCE FROM TOP OF CONE TO LARGE DIAMETER PLANE
Am = AREA OF ID OF CONICAL ELEMENT SURFACE
Vf = VIEW FACTOR OF CONICAL ELEMENT TO CONE END (LARGE DIA. END)

R1=01/2.0
R2=D2/2.0
R3=D3/2.0
X12=1.0+(R2/R1)**2.0+(H1/R1)**2.0
X13=1.0+(R3/R1)**2.0+(H2/R1)**2.0
Ft02=0.5*(X12-SQRT((X12**2.0)-(4.0*(R2/R1)**2.0)))
Ft03=0.5*(X13-SQRT((X13**2.0)-(4.0*(R3/R1)**2.0)))
Aix=3.141593*(D1**2.0)/4.0
Dab=3.141593*(D2+D3)/2.0
Aaa=Dab*Dab
Vf=(Aix/Aaa)*(Ft02-Ft03)
RETURN}

END
***** TUBE-SIDE FLUID PROPERTIES

CPT = TUBE-SIDE FLUID Specific Heat (BTU/Lb-R)
RHOT = TUBE-SIDE FLUID Density (Lbs/Ft^3)
AKTT = TUBE-SIDE FLUID Thermal Cond (BTU/Hr-Ft-R)
VISCT = TUBE-SIDE FLUID Viscosity (Lb/Ft-Sec)

SET FLUID THERMAL PROPERTIES

TBARR = (THIN+TCIN)/2.0

GO TO (5,6), IHX, I1N

CALL XLITHP(TBARR,RHOT,CPT,VISCT,AKTT)

CALL HEXEP(AWMS,PHOT,TBARR,GAMMA,CPSF,RHOSF,VISCST,AKTST,PRMIX)

GO TO 10

10 NDOTS = 3600.0*DLOTS

VISCT = VISCST/6.72E-4

WRITE (6,*) 'TBARR,RHOT,CPT,VISCT,AKTT',TBARR,RHOT,CPT,VISCT,AKTT

WRITE (6,*) 'N4WS,PHOT,TBARR,GAMMA,CPSF,RHOSF,VISCST,AKTST,PRMIX'

NWRITE (6,*) 'MOTS,VISCST -',MOTS,VISCST

AT = (THIN-TCOUT) - (THOUT-TCIN)

IF ((THIN-TCOUT).GE.(THOUT-TCIN)) THEN

ALNMTD = THIN-TCOUT

ELSE

A2 = ALOG((THIN-TCOUT)/(THOUT-TCIN))

ALNMTD = A1/A2

ENDIF

15 PR = PR

WRITE (6,*) 'A1, ALNMTD, PR = ', A1, ALNMTD, PR

GOTO 100

35 UEST = UNEV

100 AQ = -2.0*DTUBE

BG = (DTUBE**2.0)

CO1 = PE*DTUBE

CO2 = 144.0*DQOT*(CQ1**2.0)

CQ3 = UEST*ALNMTD*(9.869604)*DTUBE

CQ = CO2/CQ3

PQ = -(AQ**2.0)/3.0-BG

QQ = (2.0*(AQ**3.0)**5.0)-(AQ*BQ/3.0)+CO

CBIG = (((CO/3.0)**5.0)+(CO/2.0)**2.0)

AARG = -(QQ/2.0)+SQRT(QBIG)

ABIG = (ABS(AARG))**0.333333

BBIG = -(QQ/2.0)-SQRT(QBIG)

BBIG = (ABS(BBIG))**0.333333

DOIT = ABIG + BBIG - (AQ/3.0)

ALXHEL = (AMPLATES+1.0)*DOTL

AVAL = 0.867
**SUBROUTINE HRSHEL**

*HEAT EXCHANGER DESIGN SUBROUTINE*

*ROUTINE ASSUMES THAT LIQUID IS ON TUBE SIDE*

**GAS IS ON SHELL SIDE. BELL'S CORRELATION IS USED FOR GAS SIDE HEAT TRANSFER - LYNNS IS USED FOR TUBE SIDE**

**LIQUID METAL HEAT TRANSFER, McELLION, MCQEE AND LEPPERT**

**IS USED FOR OTHER FLUIDS (LIQUIDS AND GASES)**

***** OVERALL PARAMETERS *****

**INDXFL = 1, THEN TUBE SIDE FLUID IS LITHIUM**

**INDXFL = 2, THEN TUBE SIDE FLUID IS NAK-78**

**ALMTD = Heat Exchanger Log Mean Temperature Difference**

**GDOT = Heat Rate or Duty (BTU/HR)**

**UEST = INITIAL VALUE OF OVERALL (BTU/HR-Ft-R)**

**TTUBE = TUBE WALL Thickness (INCHES)**

**WDOTT = TUBE -SIDE Fluid Flowrate (Lb/SEC)**

**AKTUBE = TUBE Wall Thermal Conductivity (BTU/HR-Ft-R)**

***** SHELL SIDE DATA *****

**UDOTS = SHELL SIDE Fluid Flowrate (Lb/SEC)**

**DENSSH = SHELL MATERIAL Density (Lb/FT³)**

***** SHELL-SIDE FLUID PROPERTIES *****

**CPSF = SHELL-SIDE FLUID Specific Heat (BTU/Lb-R)**

**RHOSF = SHELL-SIDE FLUID Density (Lb/FT³)**

**NXST = SHELL-SIDE FLUID Thermal Cond (BTU/HR-Ft-R)**

**VISCST = SHELL-SIDE FLUID Viscosity (Cp)**

***** TUBE SIDE DATA *****

**DTUBE = Outside TUBE Diameter - (Inches)**

**TTUBE = TUBE Wall Thickness (Inches)**

**UDOTT = TUBE -SIDE Fluid Flowrate (Lb/SEC)**

**AKTUBE = TUBE Wall Thermal Conductivity (BTU/HR-Ft-R)**
SUBROUTINE HRSHEL

Source file listing:

3484  FFBH = 0.4307652 + (4.521962E-03*(DOTL)) - (6.335725E-05*(DOTL**2)
3485  1.0)) + (3.716571E-07*(DOTL**3.0))
3486  GXT = 1560.0*(WDOTS/(DOTL**2.0))
3487  REXT = (DTUBE*GXT)/(29.0*VISCST)
3488  RC = 1.0
3489  IF (REXT>1000.0) 200,150,150
3490  RC = 1.0
3491  GOTO 300
3492  200 RC = 0.4812508 + (7.826048E-03*(REXT)) - (7.359986E-06*(REXT**2.0))
3493  1) + (9.905931E-09*(REXT**3.0)) - (4.437588E-12*(REXT**4.0))
3494  300 FFBP = FFBH+0.125
3495  REXP = FFBP*REXT
3496  REXH = FFBP*REXT
3497  AREP = ALOG(REXP)/2.302585093
3498  AREH = ALOG(REXH)/2.302585093
3499  AFX = 1.397542 - (0.96108*(AREP)) + (0.064751*(AREP**2.0)) + (0.0
3500  106305*(AREP**3.0))
3501  AFRIC = 10.0**AFX
3502  AJX = 0.359018 - (0.259608*(AREH)) - (0.094385*(AREH**2.0)) + (0.0
3503  1.012556*(AREH**3.0))
3504  AJFAC = 10.0**AJX
3505  WRITE (6,*),FACTOR = AJFAC
3506  NS1 = 0.415*CPSF*GXT*FFBH*AJFAC
3507  NS2 = (ARTST/CCPSF*VISCST)**0.66667
3508  NSHELL = NS1*NS2
3509  DPSF = 0.00873*(((AJFAC*ALSHEL)/(AVALVq_R°DI1BE*0.0))
3510  DPSH = 0.00155191*((ALSHEL+1.0)/(0.4*DOTL))
3511  DPSHELL = (0.3*(DPSF+DPSH)/RHOSF)*/(GXT*FFBP)/10000.0
3512  PT = PR*TUBE
3513  ANTUBE = ((0.7854*(DOTL-DTUBE)**2.0)/(PT**2.0))
3514  W5UBE = WDOTT/ANTUBE
3515  AREAT = (0.7854*(DTUBE-(2.0*PTUBE))**2.0)/144.0
3516  VTUBE = WTVU/AREAT*RHO
3517  GTUBE = RHO*(VTUBE**2.0)/(2.0*52.174*144.0)
3518  RETUBE = VTUBE*RHO*TUBE/(12.0*VISCT)
3519  DTUBE = DTUBE-(2.0*PTUBE)
3520  PRTRUBE = (3600*VISCT*CPT)/AKTT
3521  IF (PRTRUBE<0.1) 350,350,340
3522  330 THC = 0.25*(12.0*AKT/DTUBE)**(1.0*(0.025*(RETUBE*PRTRUBE)**0.8))
3523  350RETUBE = 12.0*(AKT/DTUBE)**(1.0*(0.025*(RETUBE*PRTRUBE)**0.8))
3524  GOTO 440
3525  340 IF (RETUBE>2000.0) 350,350,400
3526  350 TFRIC=64.0/RETUBE
3527  TNC = 4.364*(12.0*AKT/DTUBE)**(1.0*(0.025*(RETUBE*PRTRUBE)**0.8))
3528  400 AK = 0.0001
3529  AXD = AK/DTUBE
3530  FRIC1 = ALOG((AXD/3.7)+(5.74*(RETUBE=0.9))**2.0
3531  TFRIC = 0.25*FRIC1
3532  TNC = 0.026*(12.0*AKT/DTUBE)**(RETUBE=0.8)*(PRTRUBE=0.4)
3533  440 GOTO 450
3534  440 IF (RETUBE>2000.0) 442,442,445


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Source file listing

```
3536  442  TFRIC=64.0/RETUBE
3537  GOTO 450
3538  455  AK = 0.0001
3539  456  TFRIC = ALOG10((AK/3.7)+(5.74/(RETUBE**0.9)))**2.0
3540  451  TFRIC = 0.25/FRIE1
3541  452  FCSTU = 0.0001
3542  453  COND2 = 12.0*A2K/TTUBE
3543  454  UNEW = 1.0/(1.0/THK)+(1.0/HSHELL)+(1.0/COND2)
3544  455  DPTUBE = (2.0*GTUBE) + ((TFRIC*(ALSHEL/DTUBE1))*QTUBE)
3545  456  Q03 = UNEW*PAINTD*(9.869604)*TTUBE
3546  457  Q0 = (2.0*((AQ/3.0)**3.0)-(AQ**3.0)/4)+C0
3547  458  QBIG = ((Q0/3.0)**3.0)+(Q0/2.0)**2.0
3548  459  AARG = -(Q0/2.0)+SORT(QBIG)
3550  460  ABIG = (ABS(AARG))**0.333333
3551  461  BBRG = -(Q0/2.0)-SORT(QBIG)
3552  462  BBIG = (ABS(BBRG))**0.333333
3553  463  DOT2 = ABIG + BBIG - (AQ/3.0)
3554  464  ERROR = ABS(DOTL-DOTL2)/DOTL
3555  465  IF (ERROR = 0.001) 600,600,35
3556  600  TMINPR = PHOT*DOTT/(2.0*10000.0)
3557  601  TMINSC = (0.005*DOTT) + (0.0001*(DOTT**2.0))
3558  602  IF (TMINPR.GT.TMINSC) THEN
3559  603  TMIN = TMINPR
3560  GOTO 650
3561  ELSE
3562  TMIN = TMINSC
3563  ENDIF
3564  650  MINSUL = (3.141593*DOTL*(DOTL+ALSHEL)*TINS*(DENINS/1728.0)) + (3.141593*DOTL2**2.0)*TINS*(DENINS/1728.0))
3566  651  WRITE (6,*) ' SHELL AND TUBE HEAT EXCHANGER DESIGN CODE'
3567  652  WRITE (6,*) ' SHELLSIDE DP =',DPSHELL
3568  653  WRITE (6,*) ' SHELLSIDE H =',HNAME
3569  654  WRITE (6,*) ' TUBE SIDE Reynolds Number =',RETUBE
3569  655  WRITE (6,*) ' Tube Conductance =',COND2
3566  656  WRITE (6,*) ' Tube Side Pressure Drop (PSID) =',DPTUBE
3567  657  WRITE (6,*) ' Number of Tubes in Bundle =',ANTUBES
3568  658  WRITE (6,*) ' Tube Side Reynolds Number =',RETUBE
3569  659  WRITE (6,*) ' Tube Side Heat Transfer Coefficient =',COH2
3570  650  WRITE (6,*) ' TUBE CONDUCTANCE =',COND2
```

3589 C WRITE (6,*) 'TUBE WALL THICKNESS (inches) = ', TTUBE
3590 C WRITE (6,*) 'DOTL2 (inches) = ', DOTL2
3591 C WRITE (6,*) 'LENGTH (inches) = ', ALSHEL
3592 C WRITE (6,*)
3593 C WRITE (6,*) 'INSULATION MASS (Lbs) = ', AIMINSUL
3594 C WRITE (6,*) 'HEAD MASS (Lbs) = ', AMHEADS
3595 C WRITE (6,*) 'SHELL MASS (Lbs) = ', AMSHELL
3596 C WRITE (6,*) 'PLATE MASS (Lbs) = ', AMPATES
3597 C WRITE (6,*) 'TUBE SHEETS MASS (Lbs) = ', AMTSHT
3598 C WRITE (6,*) 'TUBE MASS (Lbs) = ', AMTUBES
3599 C WRITE (6,*) 'STRUCTURE AND BRACKETS MASS (Lbs) = ', AMSTRT
3600 C WRITE (6,*) 'Net Mass of Shell and Tube Unit (Lbs) = ', AMETMASS
3601 VNAK1 = 0.785398*(DTUBE**2.0)*ALSHEL*AMTUBES
3602 VNAK2 = 0.523599*(DOTL**3.0)
3603 XTHEX = (VNAK1+VNAK2)**(RHOT/1728.0)
3604 RETURN
3605 END
SUBROUTINE HPMAN

SUBROUTINE HPMAN(ifluid,iflg2,Manan,Mann,Gap,Pitch,Dcan,Dhp,Rc, 
RhoCan,RhoBraze,ThickMan,Grad,ManMass,DInlet,DTfilm,Dtmesh)

SUBROUTINE TO DETERMINE THE MASS AND PERFORMANCE OF A MANIFOLD WHICH USES LIQUID OR GAS TO TRANSFER HEAT TO THE HEAT PIPES OF A HEAT PIPE RADIATOR. THE MANIFOLD CONFIGURATION CONSISTS OF A SINGLE ROW OF TUBE CANS (BRAZED TO HEAT PIPES) (FINS OPTIONAL)

INPUT VARIABLES REQUIRED
iflg2 = FLAG TO SET MANIFOLD WORKING FLUID
   1 = He-Xe MIXTURE
   2 = NeK
Manan = MANIFOLD HEIGHT (Feet)
Gap = MANIFOLD WIDTH (Feet)
Pitch = DISTANCE BETWEEN CAN (HEAT PIPES) CENTERLINES (Feet)
Xhpipes = NUMBER OF HEAT PIPES IN RADIATOR
Xhexpipes = NUMBER OF REDUNDANT HEAT PIPES IN RADIATOR
Dcan = OUTSIDE DIAMETER OF MANIFOLD BRAZE CANS (Feet)
Dhp = INSIDE DIAMETER OF HEAT PIPE (Feet)
Rc = MANIFOLD BRAZE CAN INSIDE RADIUS (Feet)
RhoCan = DENSITY OF MANIFOLD CAN MATERIAL (Lb/cu-Ft)
RhoBraze = DENSITY OF BRAZE MATERIAL (Lb/cu-Ft)
ThickMan = MANIFOLD MATERIAL THICKNESS (Feet)
Psman = MANIFOLD INLET PRESSURE (PSIA)
Tman = MANIFOLD INLET TEMPERATURE (deg-R)
ManMass = MANIFOLD MASSES (Lbs)
DInlet = MANIFOLD INLET PRESSURE DROP (PSIA)
DTfilm = MANIFOLD FILM TEMPERATURE DROP (deg-R)

OUTPUT VARIABLES
ManMass = MANIFOLD MASSES (Lbs)
DInlet = MANIFOLD PRESSURE DROP (PSIA)

PI = 3.14159265
A = (PI*Dcan*(1.0-(XNf*Tf)))^Manan + (2.0*Dcan*Manan*Pitch*Gap-
&((PI/4.0)*(Dcan^2.0)))
A0 = A - (PI*Dcan*Manan*(1.0-(XNf*Tf)))
X = 12.0*(Gap*Dcan)/2.0
Xe = X^((1.0-(12.0*Tf))/(2.0*X))*(1.0+(0.35*ALOG(X/(12.0*Dcan))))
SUBROUTINE HPHAM

Option:INO/NTiBINCINDMFIHMlMKiML/PlmllNG2iV,_/R/SINTiU/NXINZ1

Source file Listing

3658 C WRITE (6,*) '8888888888888888888888888888888'
3659 C WRITE (6,*) 'Ao, Afo, X, xe =', Ao, Afo, X, xe
3660 C
3661 C MANIFOLD CONVECTIVE HEAT TRANSFER COEFFICIENT
3662 C
3663 GOTO (10,20), I froli
3664 10 CALL HXEPH(Xepr, Pm, Tmn, GAMMA, CP, RHO, AMU, TK, Prmix)
3665 GOTO 30
3666 20 CALL XMAGPR(Tmn, RHO, CP, AMU, TK)
3667 30
3668 AMIN = ((Gap-Dcan)*Amu) - (Gap*Xf*Tf)
3669 Gmax = 3600.0*Wmean/Wmin
3670 REYman = Gmax*AMu/AMU
3671 C WRITE (6,*) 'AMIN, GMAX, REYMAN = ', AMIN, GMAX, REYMAN
3672 Fiso = 10.0**((1.714012) - (1.349954*(ALOG10(REYMAN))) + (0.216271*)
3673 &((ALOG10(REYMAN)**2.0) - (0.012421*((ALOG10(REYMAN)**3.0))))
3674 XJ = 10.0**((0.321848) - (0.640808*(ALOG10(REYMAN))) + (0.081598*)
3675 &((ALOG10(REYMAN)**2.0) - (0.004631*((ALOG10(REYMAN)**3.0))))
3676 C WRITE (6,*) 'Fiso, XJ = ', Fiso, XJ
3677 PR = AMU*CP/TK
3678 Hcman = XJ*CP/Gmax/(PR**0.6667)
3679 Gc = 4.16979E+08
3680 XMT = Xpipex*Xmaxpipes
3681 C WRITE (6,*) 'PR, Hcman, GC, XMT =', PR, Hcman, GC, XMT
3682 C MANIFOLD PRESSURE DROP
3683 Vmax = Gmax/(3600.0*RHO)
3684 Gmax = RHO*(Vmax**2.0)/(2.0*32.176*144.0)
3685 Dman = (4.0*Fiso*XMT**((Gmax**2.0)/(288.0*Gc*RHO))) + (0.9*Gmax)
3686 C HEAT PIPE EVAPORATOR HEAT TRANSFER COEFF (VERY VERY ROUGH)
3687 Qflux = Gmax/(PI*Dman*Hman*XH)
3688 TO = (Tmn/1.8) - 273.2
3689 C WRITE (6,*) 'VMAX, GMAX, DMAN, QFLUX, TO = ', VMAX, GMAX, DMAN, QFLUX,
3690 C ATO
3691 CALL Fluidprop(Tfluid, TO, Xlhg, Vapden, Xhqvsc, Vapvsc, PO, Surf
3692 &Tiqh, Xhqv, Xhqvsc, Tfluid)
3693 C WRITE (6,*) 'THERMAL COND OF HEAT PIPE FLUID IS (** =', Tfluid
3694 Hevap = (Tcfluid/0.00413656)/(0.010*Dhp)
3695 C FINISH UP FIN CALCULATION
3696 IF (TF.LE.0.0) THEN
3697 Hc = Hcman
3698 GOTO 50
3699 ELSE
3700 XM = SORT((2.0*Hcman)/(TKfin*Tf))
3701 Xe = Xe/12.0
3702 Efin = (1.0/(XMT*Xe))*TANH(XMT*Xe)
3703 Ecorr = 1.2*Efin - 0.2
3704 IF (Ecorr.LE.0.1) THEN
3705 Ecorr = Efin
3706 GO TO 45
3707 ELSE
3708 CONTINUE
3709 ENDIF
SUBROUTINE HPMAN

45 Ne = Ncman*(1.0-(1.0*Ecorr)*(Afo/Ao))
ENDF

WRITE (6,*) 'Hemvap, XN, Efin, Ecorr, Ne =',Hemvap,XN,Efin,Ecorr,Ne

C COMPUTE FILM TEMPERATURE DROP

50 Rhp = Dhp/2.0
Ro = Dcan/2.0

D1 = Qfmc/(2.0*PI*Rhp*Ncman)
D2 = 2.0*PI*Rhp*Ncman/(Ne*Ao)
D3 = Rhp*ALOG(Ro/Rc)/TKcan
D4 = Rhp*(ALOG(Rc/Rb)/TKbraze
D5 = Rhp*ALOG(Rb/Rhp)/TKhp
D6 = (1.0/Hevap)

DTfilm = D1*D2*D3*D4*D5*D6

WRITE (6,*) 'D1,D2,D3,D4,D5,D6 =',D1,D2,D3,D4,D5,D6

C MASS ESTIMATE

WRITE (6,*) 'Vcman,l_n =',Vcman,XNcan

C BRAZE MASS

Vbraze = (2.0*Pl*RC*Ncman*(Rc-Rb))

WRITE (6,*) 'Vbraze,XNbraze =',Vbraze,XNbraze

RETURN
END
SUBROUTINE HRPipe(X9, R9, Dp, SUNLEN, Vpipe, TnAk, PrAk, &THICKP, RHOPI, THICKI, RHOINS, DPPipe, PIPMAK, PIPPI)

******** VARIABLE DEFINED **********

X9 = NUMBER OF 90 DEGREE ELBOWS OR EQUIVALENT IN PIPE SYSTEM
R9 = AVERAGE RADIUS FOR 90 DEGREE ELBOWS (INCHES)
Dp = INSIDE PIPE DIAMETER (INCHES)
SUNLEN = TOTAL LENGTH OF PIPE SYSTEM (INCHES)
Vpipe = MAX VELOCITY IN PIPES (FT/SEC)
ThnAk = Weld TEMPERATURE (deg-R)
PrAk = Weld PRESSURE (psia)
THICKP = PIPE WALL THICKNESS (INCHES)
RHOPI = PIPE WALL DENSITY (LB/cu-FT)
THICKI = PIPE INSULATION THICKNESS (INCHES)
RHOINS = PIPE INSULATION DENSITY (LB/cu-FT)
DPPipe = PIPE SYSTEM PRESSURE DROP (PSID)
PIPMAs = PIPE SYSTEM MASS (LBS)
PIPMAs = MASS OF NaK IN PIPE SYSTEM (LBS)

IF (THICKP.EQ.0.0) THICKP = (PrAk*Dp)/15000.0
CALL XNAKP(TrA, Rho, CP, VIS, TnAk)
RmAk = Vpipe*Dp*Rho/(12.0*VIS)
OmAk = Rho*(Vpipe**2.0)/(2.0*32.174*144.0)
X1 = ALOG10(R9/Dp)
BETA = -0.589233-(1.334185*X1)+(2.424496*(X1**2.0))-(1.272074*(X1**3.0))-(0.148518*(X1**4.0))
AK9 = 10.0**BETA
X2 = ALOG10(RmAk)
Cfc = 6.723115-((1.517276*X2)+(0.093726*(X2**2.0)))
DPeibo = X9*Cfc*AK9*OmAk
ROUGH = 0.0001
FR1 = (ALOG10((ROUGH/(3.7*Dp))+(5.74/((RmAk**0.9)))))**2.0
Fric = 0.25/FR1
DPP = Fric*(SUNLEN/Dp)*RmAk
DPPipe = DPeibo*DPP

PIPING MASS ALGORITHM

DPP = Dp + (2.0*THICKP)
DPP = Dp
Axp = 0.785398*((DPP**2.0)-(DPP**2.0))
XMPipes = Axp*SUNLEN*(RHOPI/1728.0)
DOI = DPP + (2.0*THICKI)
AXPin = 0.785398*((DOI**2.0)-(DOI**2.0))
XMPINS = AXPin*SUNLEN*(RHOINS/1728.0)
Xavel = X9*0.785398*R9**2.0*Axp*(RHOPI/1728.0)
Source file Listing

3799 \[ x_{\text{meln}} = x_{\text{mep}} \cdot 0.785398 \cdot r^9 \cdot 2.0 \cdot a_\text{exp} \cdot (\rho_{\text{ins}}/1728.0) \]
3800 \[ p_{\text{pipas}} = x_{\text{mep}} + x_{\text{pins}} + x_{\text{meln}} + x_{\text{nelin}} \]
3801 \[ a_{\text{nk1}} = 0.785398 \cdot (d_\text{p}^2 \cdot 2.0) \]
3802 \[ x_{\text{nk1}} = a_{\text{nk1}} \cdot s_{\text{meln}} \cdot (\rho_{\text{n}}/1728.0) \]
3803 \[ x_{\text{nk2}} = a_{\text{nk1}} \cdot x_{\text{mep}} \cdot 0.785398 \cdot r^9 \cdot 2.0 \cdot (\rho_{\text{n}}/1728.0) \]
3804 \[ p_{\text{pipak}} = x_{\text{nk1}} + x_{\text{nk2}} \]
3805 \[ \text{return} \]
3806 \[ \text{end} \]
SUBROUTINE PUMP(Trvlk,Unak,DPPipe,DPHX,DPMANIF,DPLOOP,Phyd,XNPUMP)

****** VARIABLES DEFINED **********

Trvlk = MAX INLET TEMPERATURE (deg-R)
Unak = MAX FLOWRATE (LBS/SEC)
DPPipe = PIPING SYSTEM PRESSURE DROP (PSID)
DPHX = MAX SIDE HEAT EXCHANGER PRESSURE DROP (PSID)
DPMANIF = MAX MANIFOLD PRESSURE DROP
Phyd = HYDRAULIC POWER REQUIRED FROM PUMP (WATTS)
XNPUMP = E-N PUMP MASS (LBS)

CALL XNACPR(Trvlk,RHO,DP,CP,V[S,TIC)

GPM = 446.89*(Unak/RHO)
DPLOOP = DPPipe+DPHX+DPMANIF
Phyd = 0.435*DPLOOP**GPM
XNPUMP = 37.0 + 0.323*Phyd

WRITE (6,*), 'PUMP POWER REQUIRED (WATTS) (HYDRAULIC) =',Phyd
WRITE (6,*), 'PUMP MASS (Lbs) =',XNPUMP
RETURN
END
SUBROUTINE VACMAS (TrmK, XMAIP, XMAHM, XMXHEX, XMAVC, XMAVAC)

VOLUME ACCUMULATOR MASS ESTIMATE

VOLUME ACCUMULATOR NAC VOLUME IS ESTIMATED TO BE 1.20 TIMES THE CHANGE IN LOOP NAC VOLUME BETWEEN 560 R AND THE OPERATING TEMP.

********** VARIABLES DEFINED **********

Tnak = NaC TEMPERATURE (deg-R)
XMAIP = NAC MASS IN PIPING SYSTEM (Lbs)
XMAHM = NAC MASS IN RADIATOR MANIFOLD (Lbs)
XMXHEX = NAC MASS IN HEAT REJECTION HEAT EXCHANGER (Lbs)
XMAVC = NAC VOLUME IN VOLUME ACCUMULATOR (cu-in)
XMAVAC = VOLUME ACCUMULATOR NAC VOLUME (bET) (LBS)
All = 560.0
A12 = 0.66*ALOGIO(VOLACC) - 0.28
XAmet = 10.0**A12
XMAVAC = (VOLACC/1728.0)**XMAHAX
XMAVAC = XAmet*XMXHEX
XMAVAC = 0.0
RETURN

IF (VOLACC.LT.0.0) THEN
   XMAVAC = 0.0
   XMAVAC = 0.0
RETURN
ELSE

   VOLACC = (((XMAHEX*RHONAK)/(RHONAK)*(VOLTOT/RHONAK)**1728.0)**1.2)

   IF (VOLACC.LT.0.0) THEN
      XMAVAC = 0.0
      XMAVAC = 0.0
      RETURN
JECT (VOLACC-LT.0.0) THEN
   END IF

   VOLACC = 0.0
   XMAVAC = XAmet**XMXHEX
   XMAVAC = 0.0
   XMAVAC = 0.0
   RETURN

   WRITE (6,*), 'VOLUME ACCUMULATOR NAC VOLUME (Lbs) =', XMAVAC
   WRITE (6,*), 'VOLUME ACCUMULATOR NAC VOLUME (Lbs) =', XMAVAC
   RETURN
END
SUBROUTINE HDUCT(XNH,R9,Dp,SUMLEN,Vpipe,TGAS,PGAS,THICK,P,RHOPIP, &THICKI,RHOINS,XNH,DPODUCT,DUCHAS)

HE-XE DUCT MASS AND PRESSURE DROP FOR DIRECT CYCLE BRAYTON

************ VARIABLES DEFINED **************

XNH = NUMBER OF 90 DEGREE ELBOWS OR EQUIVALENT IN PIPE SYSTEM

R9 = AVERAGE RADIUS FOR 90 DEGREE ELBOWS (INCHES)

Dp = INSIDE DUCT DIAMETER (INCHES)

SUMLEN = TOTAL LENGTH OF DUCT SYSTEM (INCHES)

Vpipe = GAS VELOCITY IN DUCTS (FT/SEC)

TGAS = GAS TEMPERATURE (deg-R)

PGAS = GAS PRESSURE (psia)

THICK = DUCT WALL THICKNESS (INCHES)

RHOPIP = DUCT WALL DENSITY (LB/cu-FT)

THICKI = DUCT INSULATION THICKNESS (INCHES)

RHOINS = DUCT INSULATION DENSITY (LB/cu-FT)

XNH = GAS MOLECULAR WEIGHT

DPODUCT = DUCT SYSTEM PRESSURE DROP (PSID)

DUCHAS = DUCT SYSTEM MASS (LBS)

CALL HXEPR(CXNH,PGAS,TGAS,GNA,CP,RHO,VS,TI,M,PRGAS)

REnak = Vpipe*Dp*RHO/(12.0*VS)

X1 = ALOG10(R9/Dp)

BETA = -0.589233-(1.334185*X1)+(2.426996*(X1**2.0))-(1.272074*(X1**3.0))+(0.148518*(X1**4.0))

AK = 10.0**BETA

X2 = ALOG10(REnak)

Cfc = 6.725115-(1.517276*(X2)+(0.095726*(X2**2.0))

DPelbo = XNH*Cfc*AKg*Onak

ROUGH = 0.0001

FR1 = (ALOG10((ROUGH/(3.7*Dp))+(5.74/(REnak**0.9))))**2.0

FRIC = 0.25/FR1

DPP = FRIC*(SUMLEN/Dp)*Onak

DPODUCT = DPelbo+DPP

DOp = Dp + (2.0*THICKP)

Dnp = Dp

AXp = 0.785398*(DOp**2.0)-(Dnp**2.0)

XMPipeE = AXp*SUMLEN*(RHOPIP/1728.0)

DOi = DOp + (2.0*THICKI)

AXPin = 0.785398*(DOi**2.0)-(DOp**2.0)

XMPinE = AXpin*SUMLEN*(RHOINS/1728.0)

XNEL = XNH*0.785398*R9*AXpi*(RHOPIP/1728.0)

XNELin = XNH*0.785398*R9*AXPin*(RHOINS/1728.0)
SUBROUTINE PRODUCT

Source file Listing

3924   DUCMAS = XMPINES+XMPINS+XNEL+XNELIn
3925   RETURN
3926   END
SUBROUTINE CONHAR Cmlp|L|ng Optione:/NOINT/BINCIHDIHFIH/NIINK/NL/PINQIlNQ2/NO3iRIS/NT/N/NX/NZ1

Source file Listing

3927 C
3928 C
3929 C
3930 C  SUBROUTINE CONHAR(1fluid,Cman,Mman,Gap,THICKins,RHOins,Tout,
3931 C &Tbraz,Tcan,TKbraz,TKhp,XNpipes,XNexpipes,Pin,Tin,XHcan,RHOcan,
3932 C &RHOcan,RHObraz,THICKcan,Thtpip,Lman,Grad,XMLames,DPman,DTFsup,
3933 C &Ar,Gr,V,Dh,Cgt,Rel,HI,XXt,Rev,
3934 C &DTFcon,DTFsup,DTfilm)
3935 C WRITE(6,*),Tout,Tbraz,Tcan,TKbraz,TKhp
3936 C &Tcan,TKhp
3937 C WRITE(6,*) 'FROM CONHAR - Ifluid,Cman,Mman,Gap,THICKins,RHOins = '
3938 C C &fluid,Cman,Mman,Gap,THICKins,RHOins
3939 C WRITE(6,*) 'Tout,Tbraz,Tcan,TKbraz,TKhp = ',Tout,Tbraz,Tcan,
3940 C &Tcan,TKhp
3941 C WRITE(6,*) 'XNpipes,XNexpipes,Pin,Tin,XHcan,RHOcan,RHObraz,THICKcan,Thtpip = ',XNpipes,
3942 C &XNpipes,XNexpipes,Pin,Tin,XHcan,RHOcan,RHObraz,THICKcan,Thtpip
3943 C WRITE(6,*) 'Lman,Grad = ',Lman,Grad
3944 C COMMON /CNFL/ DL, DV, VF, WG, HG, HG, SF, SG,
3945 C & SFG, Cl, Cv, TKl, TKv, Pmy, Prv, VL, VV
3946 C & SUBROUTINE TO DETERMINE THE MASS AND PERFORMANCE OF A CONDENSING
3947 C & MANIFOLD FOR POTASSIUM WHICH TRANSFERS HEAT TO THE HEAT PIPES OF
3948 C & A HEAT PIPE RADIATOR. THE MANIFOLD CONFIGURATION CONSISTS OF
3949 C & A SQUARE PASSAGE WITH HEAT PIPES BRAZED TO ITS OD.
3950 C & VARIABLES
3951 C & Ifluid = FLAG TO IDENTIFY HEAT PIPE WORKING FLUID
3952 C & Cman = MANIFOLD CIRCUMFERENCE OR LENGTH (FEET)
3953 C & Mman = MANIFOLD HEIGHT (FEET)
3954 C & Gap = MANIFOLD WIDTH (FEET)
3955 C & XNpipes = NUMBER OF PRIMARY HEAT PIPES IN RADIATOR
3956 C & XNexpipes = NUMBER OF REDUNDANT HEAT PIPES IN RADIATOR
3957 C & Tbraz = BRAZE JOINT THICKNESS (Feet)
3958 C & TKcan = THERMAL CONDUCTIVITY OF MANIFOLD CAN MATERIAL (B/HFR)
3959 C & TKbraz = THERMAL CONDUCTIVITY OF MANIFOLD BRAZE ALLOY (""
3960 C & TKhp = THERMAL CONDUCTIVITY OF HEAT PIPE WALL MATERIAL ("
3961 C & RHOcan = DENSITY OF MANIFOLD MATERIAL (Lb/cu-Ft)
3962 C & RHObraz = DENSITY OF BRAZE MATERIAL (Lb/cu-Ft)
3963 C & THICKcan = MANIFOLD MATERIAL THICKNESS (Feet)
3964 C & Thtpip = HEAT PIPE WALL THICKNESS (FEET)
3965 C & Pin = MANIFOLD INLET PRESSURE (PSIA)
3966 C & Tin = MANIFOLD INLET TEMPERATURE (deg-R)
3967 C & Xin = MANIFOLD INLET QUALITY (LIQUID FRACTION)
3968 C & Lman = MANIFOLD FLOW RATE (LBS/HR)
3969 C & Grad = MANIFOLD AND RADIATOR HEAT LOAD (BTU/HR)
3970 C & XMLames = MANIFOLD WORKING FLUID
3971 C & OUTPUT VARIABLES
3972 C & XMLames = MANIFOLD MASS (Lbs)
3973 C & DPman = MANIFOLD PRESSURE DROP (PSIA)
3974 C & DTfilm = MANIFOLD FILM TEMPERATURE DROP (deg-R)
3975 C & Lman = 3413.0*Grad
3980 C MANIFOLD CONVECTIVE HEAT TRANSFER COEFFICIENT
3981 C
3982 C CALL KMP(Xin,Pin,Tin,DL,DV,H,NG,NSG,SG,SGF,VF,VG)
3983 C CALL KTRK(Xin,Pin,Tin,CL,CV,TK1,TKv,Prv,Vl,Vv)
3984 C WRITE (6,*),(Xin,Pin,Tin,DL,DV,H,NG,NSG,SG,SGF,VF,VG)
3985 C &Pin,Tin,DL,DV,H,NG,NSG,SG,SGF,VF,VG
3986 C WRITE (6,*),(CL,CV,TK1,TKv,Prv,Vl,Vv)
3987 C &Vl,Vv
3988 C
3989 C
3990 C
3991 C
3992 C Ax = Gap/Cmn
3993 C Dh = (4.0*Ax)/((2.0*Gap)**(2.0*Cmn))
3994 C
3995 C NOTE THAT CONDENSER HAS TWO SIDES - 1/2 THE HEAT PIPES ARE
3996 C ATTACHED TO ALTERNATING SIDES OF THE MANIFOLD BOX
3997 C
3998 C Ac = 2.0*(Cmn/Cmn)/(XNpipes*XNexpipes)
3999 C DX = Ac/Cmn
4000 Umn = Umn
4001 X = Xin
4002 C = Cmn
4003 CV = Gap
4004 ETA = 0.000005
4005 Gflux = Umn/((2.0*Cmn)**(2.0))
4006 JHP = JFJNK(XNpipes*XNexpipes)
4007 C WRITE (6,*),Ax,Dh,Ac,DX,Umn,C,CH,CU,ETA,Gflux,JHP
4008 C &Umn,X,CH,CU,ETA,Gflux,JHP
4009 C
4010 C COMPUTE SATURATION TEMP: EQUATION IS FOR POTASSIUM ONLY
4011 C
4012 C Test = (-7633.6)/(ALOG10(Pin)-5.279)
4013 C WRITE (6,*),(Test FROM 3650 (R))
4014 IF (Tin.GT.Test) THEN
4015 Gdesup = Umn**CV*(Tin - Test)
4016 Qcondn = Umn**HFG
4017 Qsubc = Umn - Qdesup - Qcondn
4018 C WRITE (6,*),(Qdesup,Qcondn,Qsubc FROM 3661 =',Qdesup,Qcondn,Qsubc
4019 JNSUP = (Qdesup/Umn)**JHP
4020 JNCNNJ = (Qcondn/Umn)**JHP
4021 JNSUB = (Qsubc/Umn)**JHP
4022 IF (JNSUP.EQ.0) JNSUP = 1
4023 IF (JNCNNJ.EQ.0) JNCNNJ = 1
4024 IF (JNSUB.EQ.0) JNSUB = 1
4025 C WRITE (6,*),(JNSUP, JNCNNJ, JNSUB =',JNSUP,JNCNNJ,JNSUB
4026 GO TO 70
4027 ELSE
4028 GO TO 20
4029 ENDIF
4030 20 IF (Tin.EQ.Test) THEN
4031 Gdesup = 0.0
SUBROUTINE CONI4A, N
Options: ININTIBIMDINFINIINIKINLiPINQIlNQ3iRISIHTIV/NXINZ1

C Source file Listing

4032 Qsubc = wmen*PCL*(Tsat - Tout)
4033 Qcondn = wmen - Qsubc
4034 C WRITE (6, *) 'Qdesup,Qcondn,Qsubc FROM 3674=',Qdesup,Qcondn,Qsubc
4035 JNSUP = 0
4036 JNCON = (Qcondn/wmen)*JHP
4037 JNSUB = JHP - JNCON
4038 IF (JNCON.EQ.0) JNCON = 1
4039 IF (JNSUB.EQ.0) JNSUB = 1
4040 C WRITE (6, *) 'JNSUP, JNCON, JNSUB=',JNSUP,JNCON,JNSUB
4041 GO TO 80
4042 ELSE
4043 GO TO 30
4044 ENDIF
4045 30 IF (Tin.LT.Tsat) THEN
4046 Qdesup = 0.0
4047 Qcondn = 0.0
4048 Qsubc = wmen
4049 C WRITE (6, *) 'Qdesup,Qcondn,Qsubc FROM 3687=',Qdesup,Qcondn,Qsubc
4050 JNSUP = 0
4051 JNCON = 0
4052 JNSUB = JHP
4053 IF (JNSUB.EQ.0) JNSUB = 1
4054 C WRITE (6, *) 'JNSUP, JNCON, JNSUB=',JNSUP,JNCON,JNSUB
4055 GO TO 90
4056 ELSE
4057 GO TO 70
4058 ENDIF
4059 70 CALL CVAP(wmen, CH, CW, DX, ETA, Hc, DPnet1,Ar,Gt,V,Dh,Rev, Ht)
4060 C WRITE (6, *) 'INFO FROM AFTER CVAP CALL IN CONI4A'
4061 C WRITE (6, *) 'Wmen,CH,CW,DX,ETA,Hc,DPnet1,Ar,Gt,V,Dh,Rev,Ht'
4062 C C \[TE (6,*) ,Odesup,Ocondn,Qsubc FROM 3687,'Odesup,Ocondn,Qsubc
4063 Nc = wmen
4064 Tmen = Tin
4065 T0 = (Tmen/1.8) - 273.2
4066 CALL Fluidprop(ifluid,T0,Xliqden,Vapden,Xliqvisc,Vapvisc,PO,Surf
4067 Xlum,Xlum,xm,xmfluid,Tcfluid)
4068 Hevap = (Tcfluid/0.00413656)/(0.0083)
4069 Ha = Ncman
4070 C COMPUTE FILM TEMPERATURE DROP FOR DESUPERHEATER
4071 D1 = 0flux
4072 D2 = 1.0/Na
4073 D3 = THICKman/Tcman
4074 D4 = Tbraze/Tcbraze
4075 D5 = Thpip/Tkhp
4076 D6 = 1.0/Hevap
4077 Usup = 1.0/(D2+D3+D4+D5+D6)
4078 DTFsup = D1*(D2+D3+D4+D5+D6)
4079 C WRITE (6, *) '0flux, Usup, DTFsup=',0flux,Usup,DTFsup
4080 C WRITE (6, *) 'Hevap,Na,D1,D2,D3,D4,D5,D6,DTFsup=',Hevap,Na,D1,D2,
4081 C 8D3,D4,D5,D6,DTFsup
4082 C
4083 80 X=Xlin/2.0
CALL COND(Uenm, X, CH, CX, DX, ETA, Nc, DNet2, Ar, Gt, V, Dh, Cgt, Rel,
& Ht, Xtt, Rev)
WRITE (6, *) 'INFO FROM AFTER COND CALL IN COMMAN'
4087 C WRITE (6, *) 'Uenm, X, CH, CX, DX, ETA, Nc, DNet2, Ar, Gt, V, Dh, Rev, Cgt, Rel,
& Ht, Xtt, Rev = ', Uenm, X, CH, CX, DX, ETA, Nc, DNet2, Ar, Gt, V, Dh, Rev, Cgt, Rel
4089 C & Ht, Xtt, Rev
4090 Hcmen = Nc
4091 Timen = Tin
4092 TO = (Tmen/1.8) - 273.2
4093 CALL fluidprop(lfluid, TO, Xiqden, Vapden, Xliqvisc, Vapvisc, PO, Surf
4094 &ten, Xthv, Xk, Xwfluid, Tcflud)
4095 Hevap = (Tcfluid/0.00413656)/(0.0083)
4096 Na = Hcmen
4097 C COMPUTE FILM TEMPERATURE DROP FOR CONDENSER
4098 D1 = oflux
4099 D2 = 1.0/Na
4100 D3 = THICKmen/TKcan
4101 D4 = Thbraze/TKbraze
4102 D5 = Thtpip/TKhp
4103 D6 = 1.0/Hevap
4104 Ucon = 1.0/(D2+D3+D4+D5+D6)
4105 DTFCOn = D1*(D2+D3+D4+D5+D6)
4106 C WRITE (6, *) 'Oflux, Ucon, DTFCOn = ', Oflux, Ucon, DTFCOn
4107 C WRITE (6, *) 'Hevap, Na, D1, D2, D3, D4, D5, D6, DTFCOn = ', Hevap, Na, D1, D2,
& D3, D4, D5, D6, DTFCOn
4108 C & D3, D4, D5, D6, DTFCOn
4109 C 90 CALL CLOID(Uenm, X, CH, CX, DX, ETA, Nc, DNet3, Ar, Gt, V, Dh, Rev, Ht)
4111 C WRITE (6, *) 'INFO FROM AFTER CLOID CALL IN COMMAN'
4112 C WRITE (6, *) 'Uenm, X, CH, CX, DX, ETA, Nc, DNet3, Ar, Gt, V, Dh, Rev, Ht = ',
& Uenm, X, CH, CX, DX, ETA, Nc, DNet3, Ar, Gt, V, Dh, Rev, Ht
4114 Hcmen = Nc
4115 Timen = Tin
4116 TO = (Tmen/1.8) - 273.2
4117 CALL fluidprop(lfluid, TO, Xiqden, Vapden, Xliqvisc, Vapvisc, PO, Surf
4118 &ten, Xthv, Xk, Xwfluid, Tcflud)
4119 Hevap = (Tcfluid/0.00413656)/(0.0083)
4120 Na = Hcmen
4121 C COMPUTE FILM TEMPERATURE DROP FOR SUBCOOLER
4122 D1 = oflux
4123 D2 = 1.0/Na
4124 D3 = THICKmen/TKcan
4125 D4 = Thbraze/TKbraze
4126 D5 = Thtpip/TKhp
4127 D6 = 1.0/Hevap
4128 Usb = 1.0/(D2+D3+D4+D5+D6)
4129 DTFsub = D1*(D2+D3+D4+D5+D6)
4130 C WRITE (6, *) 'Oflux, Usb, DTFsub = ', Oflux, Usb, DTFsub
4131 C WRITE (6, *) 'Hevap, Na, D1, D2, D3, D4, D5, D6, DTFsub = ', Hevap, Na, D1, D2,
& D3, D4, D5, D6, DTFsub
4132 C & D3, D4, D5, D6, DTFsub
4133 C COMPUTE AVERAGE FILM DROP TO BE USED FOR RADIATOR DESIGN
4135 C ANSUP = FLOAT(JNSUP)
4137  ANCON = FLOAT(JHCON)
4138  ANSUB = FLOAT(JNSUB)
4139  AMP = FLOAT(JHP)
4140  DTFilm = ((ANCON/AMP)*DTfcon)
4141  &&((ANSUB/AMP)*DTfsub)
4142  DPMann = DPFnet1+DPnet2+DPnet3
4143  C WRITE (6,*) 'DTfilm, DPMann = ', DTFilm, DPMann
4144  C MASS ESTIMATE
4145  C MANIFOLD METAL MASS
4146  Vmann = (((2.0*Mann)+(2.0*Gap))*Cmam*THCmam)
4147  Vmann = Vmann*RHOcan
4148  C MANIFOLD TO HEAT PIPE BRAZE MASS
4149  Vbraze = 2.0*Mann*Cmam*TBraze
4150  XMbraze = Vbraze*RHObraze
4151  C TOTAL FLAT HEAT PIPE EVAPORATOR MASS
4152  Vheattpip = 4.0*Mann*Cmam*THtppip
4153  XMhtpip = RHOtpip*Vheattpip
4154  C WRITE (6,*) 'Vmann,XMwall,VBraze,XMbraze,Vheattpip,XMhtpip = ', Vmann,
4155  C XMwall,Vbraze,XMbraze,Vheattpip,XMhtpip
4156  C INSULATION MASS
4157  Vins = (((2.0*Mins)+(2.0*Gap))*Cmam*THCmam)
4158  XMins = VIN&MINS
4159  C LIQUID INVENTORY IN MANIFOLD
4160  Vliq = FLOAT(JNSUB/JHP)*Hmam*Gap*Can
4161  XMliqin = DL*Vliq
4162  C TOTAL MASS OF RADIATOR MANIFOLD
4163  XMAMmass = XMwall+XMbraze+XMhtpip+XMins+XMliqin
4164  C WRITE (6,*) 'Vins,XMins,Vliq,XMliqin,XMAMmass = ',Vins,XMins,Vliq,
4165  C XMliqin,XMAMmass
4166  IF (JHCON.EQ.0) Cgt80.0
4167  IF (JNSUB.EQ.0) XttE=0.0
4168  RETURN
4169  END

WARNING - REAL VARIABLE (USUP) assigned a value, never used, line 4077.
WARNING - REAL VARIABLE (UCON) assigned a value, never used, line 4104.
WARNING - REAL VARIABLE (USUB) assigned a value, never used, line 4128.
WARNING - REAL VARIABLE (ANSUB) assigned a value, never used, line 4136.
SUBROUTINE CLIQ (Idmn, HN, lamDX, ETA, Hs, DPlnet3, Ar, Gt, V, Dh,
& REL, NL)

** Calculates Heat Transfer & Pressure Drop for Pure Vapor **

COMMON /CNFL/ DL, DV, VF, VG, NF, NG, HF, HG, HF, SF, SG,
& SFG, Cl, Cv, TKL, TKv, PrL, Prv, VL, Vv

WRITE (6,*) 'DATA FROM CLIQ'
WRITE (6,*) 'REVIEW CONTENTS OF COMMON'
WRITE (6,*) 'DL,DV,VF,VG,NF,NG,HF,HG,HFG,SG,SFG,CI,CV,TKL,TKV,PRL,PRV,VL,VV'
Gc = 32.1739

** Heat Transfer **

FLOW CROSS-SECTIONAL AREA (sq ft)

\[
Ar = WM * WM
\]

\[
Dh = (4.0*Ar)/(2.0*WM) + (2.0*WM)
\]

\[
M = FLOW RATE PER TUBE (lbm/h sq ft)
\]

** Liquid Velocity, ft/s **

\[
V = Gt/(DL * 3600.0)
\]

** Condensate Velocity Number **

\[
Re = WM*Dh/(Ar*V)
\]

\[
HL = SHEAR-CONTROLLED LIQUID FILM HEAT TRANSFER COEFFICIENT
\]

\[
HL = (7.0 + 0.025*(ReL)**0.8)*((TKl/Dh)
\]

** Pressure Drop **

** Momentum Pressure Drop (psia) **

\[
\text{DPl} = \text{FF}\text{I}(\text{DX/Dh})\text{Gt}**(2.0)*((1.0-Y)/(DL*Y+DV)) - ((1.0-Y)/(DL*Y+DV))
\]

** Liquid Pressure Drop (psia) **

\[
\text{DFI} = \text{DPl} - \text{DFN} = \text{DPl} / (144.0*3600.0*2.0)
\]

\[
\text{DDP} = \text{DPl} / (144.0*3600.0*2.0)
\]

** Friction Pressure Drop (psia) **

DFI = FFI*(DX/Dh)*Gt**(2.0)*((1.0/Y)/(DL*Y+DV)) - ((1.0-Y)/(DL*Y+DV))
4222 C       WRITE (6,*) 'DPl,DPf,DPnet3 =',DPl,DPf,DPnet3
4223       RETURN
4224       END
SUBROUTINE COND

C** CALCULATES HEAT TRANSFER & PRESSURE DROP FOR
A TWO-PHASE FLUID (GAS-LIQUID) ** ADJUSTED FOR LIQUID METALS

COMMON /CHF/ DL, DV, VF, VG, HF, HG, NFG, SF, SG,
& $FG, Cl, CV, TKL, TKv, Pri, Prv, VI, VV

C** HEAT TRANSFER

C** FLOW CROSS-SECTIONAL AREA (sq ft)

C** VAPOR VELOCITY, ft/s
C** Y - LOCAL VAPOR WEIGHT FRACTION FACTOR

C** Gt - GAS FLUX (lbm/h K ft)
C** N - FLOW RATE PER TUBE (LIQUID PLUS VAPOR), lbm/h
C** W

C** HEAT TIUUISFER

C** CROSS-SECTIONAL AREA (sq ft)

C** LOCAL VAPOR WEIGHT FRACTION FACTOR

C** 'WRITE (6,*) 'V' = Y*Gt/(DV*3600.0)

C** CONDENSATE FILM REYNOLDS NUMBER

C** ASSUMED EQUAL TO 1

C** VCF - 1.0

C** Xtt - MARTINELLI PARAMETER, FORM FOR BOTH TURBULENT PHASES

C** 'WRITE (6,*) 'Xtt = (((1.0-Y)/(1.0-Y))**0.9 * (DV/DL))**0.5 * (VL/VV)**0.1
SUBROUTINE COND

C WRITE (6, *) 'Xtt = ', Xtt
4277 C

C** Cah - CORRELATION FUNCTION FOR SHEAR-CONTROLLED FLOW HT & DP
Cah = 2.75 * (1.0 + 2.0 / Xtt**0.5) * (1.0 - DV/DT)**1.5
4280 C

C WRITE (6, *) 'Cah = ', Cah
4281 C

C** Ftp - SHEAR-CONTROLLED FLOW TWO PHASE HEAT TRANSFER FACTOR
Ftp = (1.0 + Cah / Xtt + 1.0 / Xtt**2.0)**0.5
4284 C

C WRITE (6, *) 'Ftp = ', Ftp
4285 C

C** Hs - SHEAR-CONTROLLED LIQUID FILM HEAT TRANSFER COEFFICIENT
Hs = Ftp * HL
4288 C

C WRITE (6, *) 'Hs = ', Hs
4289 C

C** PRESSURE DROP
4291 C

C** MOMENTUM PRESSURE DROP (psia)
4292 C

C** if = inlet, e = exit
4293 C

C DPs = Gt**2.0/Gc*( ((1.0-Y)/Dle+Y/DVe) - ((1.0-Y)/Dli+Y/DVl) )
4294 C

C VAPOR REYNOLDS NUMBER
4295 C

C Rev = Wm*T*Dh/(Ar*VV)
4296 C

C WRITE (6, *) 'Rev = ', Rev
4297 C

C** CALCULATE FRICTION FACTORS
4300 C

C FFL = FF(Dh, ETA, Rel)
4301 C

C FFV = FF(Dh, ETA, Rev)
4302 C

C LIQUID PRESSURE DROP (psia)
4303 C

C DPL = FFL*(DX/Dh)*Gt**2.0*(1.0-Y)**2.0*(1.0/(2.0*DL*Gc))
4305 C

C DPL = DPL/(144.0*3600.0**2.0)
4306 C

C VAPOR PRESSURE DROP (psia)
4307 C

C DPV = FFV*(DX/Dh)*Gt**2.0*(Y-Y**2.0)/(2.0*DV*Gc))
4309 C

C DPV = DPV/(144.0*3600.0**2.0)
4310 C

C WRITE (6, *) 'FFL,FFV,DPL,DPV = ', FFL, FFV, DPL, DPV
4312 C

C** FLF TWO PHASE FRICTION LOSS FACTORS
4313 C

C** DFL FRICTION PRESSURE DROP (psia)
4314 C

C IF (Rel.GT.2000.0) THEN
4315 C

C FLF = (1.0 + Cah / Xtt + 1.0 / Xtt**2.0)**0.5
4316 C

C DPF = FLF**2.0 * DPL
4317 C

C ELSE
4318 C

C FLF = (1.0 + Cah / Xtt + Xtt**2.0)**0.5
4319 C

C DPF = FLF**2.0 * DPV
4320 C

C ENDIF
4321 C

C DPFnet2 = DPf
4322 C

C RETURN
4323 C

C END
SUBROUTINE CVAP

SUBROUTINE CVAP (Umean, WM, LM, DX, ETA, Hs, DPnet1, Ar, Gt, V, Dh,
& Rev, Hl)

Gc = 32.1739

** CALCULATES VAPOR HEAT TRANSFER & PRESSURE DROP FOR

** COMMON /CHVL/
DL, DV, VF, VG, NF, Hg, HFG, SF, SG,
& SFG, Cl, Cv, TKl, TKv, Prl, Prv, VI, Vv

WRITE (6,*) 'DATA FROM CVAP'
WRITE (6,*) 'VIEW CONTENTS OF COMMON'
WRITE (6,*) 'DL,DV,VF,VG,NF,HG,HFG,SG,SFG,Cl,Cv,TKI,TKv,Prl,Prv,VI,Vv'

C** VAPOR VELOCITY, ft/s
V = Gt / (DV * 3600.0)

C** VAPOR REYNOLDS NUMBER
Rev = Umean * Dh / (Ar * VV)

C** HL - SHEAR-CONTROLLED VAPOR FILM HEAT TRANSFER COEFFICIENT
HL = 0.0222 * Rev ^ 0.8 * (Prv)^0.6 * (TKv/Dh)

Ftp = 1.0

Hs = Ftp * HL

C** PRESSURE DROP

C** VAPOR PRESSURE DROP (psia)
DPv = Gt * 2.0 / (Dh * (1.0 - Y) / (DL + Y / DVI) - (1.0 - Y) / (DL + Y / DVI))

C** CALCULATE FRICTION FACTORS
FFv = FF(Dh, ETA, Rev)

DPv = FFv * (DX / Dh) * Gt * 2.0 * (1.0 / (2.0 * DV * GC))

RETURN
END
FUNCTION FF(D, ETA, RE)
C** FF, FRICTION FACTOR
C** ETA, SURFACE ROUGHNESS, ft
FF = 0.25/(ALOG10(ETA/(3.7*D)) + 5.74/RE**0.9)**2.0
IF (RE.LE.2000.0) FF = 64.0/RE
IF (RE.GT.2000.0 .AND. RE.LT.4000.0)
END
SUBROUTINE ICPRP(X,P,T,DL,DV,NG,FG,FV,FG,FV)

C t-at|TE (6, e)

C REFERENCE: NAVAL RESEARCH LABORATORY (NRL REPORT 6233)

C** SATURATION PRESSURE (psia), page 14, equation 2
IF(X.EQ.1) Pv, 10.0**((6.12758 - 8128.77/T - 0.53299*ALOG10(T))

C** LIQUID DENSITY (lbm/cu ft), page 18, equation 9
DL = 52.768 - 7.4975E-3*(T-TR) - 0.5255E-6*(T-TR)**2.0
& + 0.0498E-9*(T-TR)**3.0

C** LIQUID SPECIFIC VOLUME (cu ft/lbm)
VF = 1.0/DL

C** CONSTANTS & DERIVATIVES OF VIRIAL EQUATION, page 29, equation 29
B = -T**10.0**((-3.8787 + 4890.7/T)
DB = B/T**((1.0 - 4890.7*ALOG10(T))
C = 10.0**((0.5873 + 6385.7/T)
DC = -6385.7*ALOG10(T) * C/T**2.0
D = -1.0**10.0**((1.4595 + 7865.8/T)
DD = -7865.8*ALOG10(T) * D/T**2.0

C** SOLVE FOR VOLUME VAPOR STATE BY VIRIAL EQUATION, 0.7302=GAS CONSTANT
V1 = 0.7302*T/Pv
DO 10 I=1,100
FUNC = Pv*V1/(0.7302*T) - (1.0 + B/V1 + C/V1**2 + D/V1**3)
SLOPE = Pv/(0.7302*T) + (B/V1**2 + 2.0*C/V1**3 + 3.0*D/V1**4)
V2 = V1 - FUNC/SLOPE
IF (ABS(FUNC) .LT. 1.0E-6) GO TO 20
V1 = V2
10 CONTINUE

C** ENTHALPY OF VAPORIZATION (Btu/lbm)
HFG = (R/0.7302)*Pv*(8128.77*ALOG10(T) - 0.53299)*(V0/XW-VF)

C** REFERENCE ENTHALPY (Btu/lbm), page 23, equation 10
HGO = 998.95 + 0.127*T + 24836.0*EXP(-39375.0/T)
DE = T/VG*(DD/B-T)+1.0/VG*(DD/2.0-C/T)+1.0/VG**2.0*(DD/3.0-D/T)

C** ENTHALPY VAPOR STATE (Btu/lbm), page 32, equation 26
NG = HGO - (R*T/XW)*DE

C** ENTHALPY LIQUID STATE (Btu/lbm), page 33
NG = HGO - (R*T/XW)*DE

C** ENTROPY OF VAPORIZATION (Btu/lbm R)
SFG = HFG/T
C** REFERENCE ENTROPY STATE (Btu/lbm R), page 23, equation 11
SGD = 0.18075 + 0.127*ALOG(T) + 0.7617*EXP(-31126.0/T)
DS = T/VG*(DB+B/T) + 1.0/(2.0*VG)*(DC+C/T) +
& 1.0/(3.0*VG**2.0)*(DB+B/T) - ALOG(PV*VG/(0.7302*T))

C** ENTROPY VAPOR STATE (Btu/lbm R), page 32, equation 27
SG = SGD - (R/354)*(ALOG(PV) + DS)

C** ENTROPY LIQUID STATE (Btu/lbm R), page 33
SF = SG - SFG

C** VAPOR SPECIFIC VOLUME (cu ft/lbm)
VG = VG/X0W

C** VAPOR DENSITY (lbm/cu ft)
DV = 1.0/VG

RETURN
END

WARNING - REAL VARIABLE (P), a dummy argument, is never used, line 4391.
SUBROUTINE KTRN(X, P, T, Cl, Ct, TKL, TVL, Prl, Prv, VL, Vv)

C** TRANSPORT PROPERTIES OF POTASSIUM

C** LIQUID HEAT CAPACITY (Btu/lbm)
CI = 0.22713 - 64.848E-6*T + 23.178E-9*T**2

C** LIQUID VISCOSITY (lbf/ft-h)
VL = EXP(1553.9/T - 1.9206)

C** LIQUID THERMAL CONDUCTIVITY (Btu/h-ft-R)
TKL = 32.2036 - 7.6789E-3*T

C** LIQUID PRANDTL NUMBER
PRL = CL*VL/TKL

C** VAPOR CAPACITY (Btu/lbm)
CALL KPRP(X, P, (T-0.01), DL, DV, NF, SF, SG, SFG, VF, VG)
CALL KPRP(X, P, (T-0.01), DL, DV, NF, SF, SG, SFG, VF, VG)

C** VAPOR VISCOSITY (lbf/ft-h)
VV = 1.0282E-2 + 2.5664E-5*T - 3.125E-9*T**2

C** VAPOR THERMAL CONDUCTIVITY (Btu/h-ft-R)
TVV = 1.8786E-3 + 4.3527E-6*T - 5.2198E-10*T**2

C** VAPOR PRANDTL NUMBER

RETURN
END
NASA LeRC is currently developing a FORTRAN based computer model of a complete nuclear electric propulsion (NEP) vehicle that can be used for piloted and cargo missions to the Moon or Mars. Proposed designs feature either a Brayton or a K-Rankine power conversion cycle to drive a turbine coupled with rotary alternators. Both ion and MPD thrusters will be considered in the model. In support of the NEP model, Rocketdyne is developing power conversion, heat rejection, and power management and distribution (PMAD) subroutines. The subroutines will be incorporated into the NEP vehicle model which will be written by NASA LeRC. The purpose of this report is to document the heat pipe cooled heat rejection subsystem model and its supporting subroutines.

The heat pipe cooled heat rejection subsystem model is designed to provide estimates of the mass and performance of the equipment used to reject heat from Brayton and Rankine cycle power conversion systems. The subroutine models the ductwork and heat pipe cooled manifold for a gas cooled Brayton; the heat sink heat exchanger, liquid loop piping, expansion compensator, pump and manifold for a liquid loop cooled Brayton; and a shear flow condenser for a K-Rankine system. In each case, the final heat rejection is made by way of a heat pipe radiator. The radiator is sized to reject the amount of heat necessary.