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APPROVALS

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AUTHOR

DEPT & GROUP NO

James E. Bickel

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DATE 9-18-63

GO NO 7562

TITLE

SNAP-2 R/C and PCS Component Temperatures
Prior to Injection

S/A NO 1230

TWR

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PROGRAM

SNAP-2

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Analysis

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STATEMENT OF PROBLEM

Determine the SNAP-2 secondary system component temperatures and the temperature distribution around the R/C (radiator-condenser) from the time of launch to mercury injection.

Also, investigate the various means of alleviating any preheat problem areas which are determined from the initial studies.

ABSTRACT

A digital program was written which describes the temperature distribution around the R/C and the temperature of the secondary system components as a function of time and orbital position. These results are based on the extremes of any actual orbit into which the flight system may be placed (constant sun-constant shade and sun-shade transients orbits).

For the present flight design, this investigation resulted in the following conclusions:

- Practically all of the PCS components and the R/C are below the freezing point of mercury prior to the primary system temperature ramp.
- All of the PCS components are above the freezing point of mercury at mercury injection; however, the mercury regulator tank is marginal.
- The gold-coated portions of the R/C can be well below the freezing point of mercury even at the end of the primary system preheat.

As a result of these initial studies, several methods of increasing the cold portions of the R/C at injection were investigated. The results of these individual effects were as follows: (on next page)

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NO. NAA-SR-TDR 9004DATE September 18, 1963PAGE 1a OF 114Abstract- ContinuedMinimum R/C Node-Temperature
at End of Preheat

Present flight design	-120°F
Removal of gold-coating	-39°F
Removal of gold-coating from NaK cold leg	-84°F
Half of preheat ramp rate	-105°F
Soak period after preheat prior to injection	-84°F

From these results, the best approach is to remove the gold-coating from the R/C and the next best method being the high temperature soak (about one hour). If both methods were employed, the coldest R/C node temperature would be -8°F.

Additional studies are needed to determine the penalties associated with these approaches.

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III RESULTS AND RECOMMENDATIONS

The analysis of this problem was made by utilizing a digital computer program written by J. Temple. The results discussed in this section are based on the results of this digital program.

Initial conditions for all cases

1. Sun-Shade Transient Orbit In order to evaluate the flight system under the most severe conditions (coldest system temperatures at mercury injection), the vehicle was launched toward the sun ($\phi = 0$ in Figure 3) and was in orbit at least 15 hours before the initiation of the startup sequence. Except when stated, mercury injection was assumed to occur immediately after the primary system temperature ramp. At injection, the coldest component and R/C temperature are experienced when the vehicle is in the orbital position $\phi = 270^\circ$ (Figure 3). This represents the case where the vehicle is in the shade for the longest period of time prior to injection.

The orientation of the bracketed components, boiler, and CRU at an orbital position $\phi = 90^\circ$ is shown by Figure 4.

2. Constant Sun-Constant Shade Orbit The initial conditions for this orbit were identical to the transient orbit's except the orbital position was constant at $\phi = 90^\circ$. The vehicle was again in orbit for at least 15 hours before the initiation of the startup sequence.

The results of the various cases are presented according to changes made in the emissivity of certain nodes, the slope of the primary system temperature ramp, and the time of injection after the end of the NaK ramp.

The description of each case is included with the results and the coldest R/C node temperature for all of these cases are summarized by Graphs 1 and 2. Graph 1 gives the coldest R/C node temperature from sensible heat for the various cases investigated which have a normal preheat ramp rate. Graph 2 gives the coldest R/C node temperature for the current vehicle configuration with a normal and half of the normal preheat ramp rate.

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COLDEST RC NODE TEMPERATURE VS TIME

GRAPH 1

B. J. Ham
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COLDEST PC NODE TEMPERATURE VS TIME

TEMPERATURE ~ °F

20
 0
 -20
 -40
 -60
 -80
 -100
 -120
 -140
 -160
 -180

0
 ↑
 SENSIBLE HEAT

TIME ~ HOURS

CASE 1

CASE 2

↑
 H₂ INJ

↑
 H₂ INJ

GRAPH 2

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Case 1 - Reference Case

The emissivities of the R/C nodes and the slope of the primary system temperature ramp for this case were the same as the current values which are being considered for the flight design. Two of the upper R/C nodes and all of the subcooler nodes were gold-coated. The primary system temperature ramp simulated the results obtained with a control drum stepping rate of one pulse per 100 seconds. All of the primary system nodes were gold-coated ($\epsilon = .05$).

A. Transient Orbit

The temperatures as a function of orbital position of the secondary system components listed in Table I are summarized by Graphs 9 through 13. From these results, the only PCS component which appeared to be marginal at injection from mercury freezing considerations was the mercury regulator tank. The temperature of this component at injection was -32°F . At injection, the mean R/C temperature was -38°F (Graph 3) and the coldest R/C node temperature was -100°F . The temperature distributions for the upper R/C and subcooler nodes for this orbit are given by Graphs 4 and 5.

B. Constant Sun-Constant Shade Orbit

The mean R/C temperature at injection was 11°F . The mercury regulator was the coldest PCS component for this orbit also and was 3°F at injection. Although the mean R/C and component temperatures are warmer in this orbit, the coldest individual R/C node temperature (-120°F) was experienced on the shade side of the R/C during the constant sun-constant shade orbit. (Graphs 7 and 8)

Therefore, the coldest node temperature for the constant sun-constant shade orbit, and the mean R/C temperature at injection during the transient case were the main source of concern on all future cases.

Case 2 - Reference Case Except Half of Preheat Ramp Rate

The system was given a longer period to respond to the primary system temperature changes by reducing the slope of the NaK ramp to half of the predetermined value which was used in Case I. (This represents a stepping rate of approximately one pulse per 200 seconds, compared to one pulse per 100 seconds for Case 1)

A. Transient Orbit

The mean R/C temperature at injection was -22°F which represents an increase of approximately 20° from the results obtained with the normal temperature ramp (Graph 3).

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B. Constant Sun-Constant Shade Orbit

The temperature distribution around the upper R/C and subcooler nodes are shown by Graphs 14 and 15. The coldest individual node temperature was -105°F .

Case 3 - Removal of R/C Coating

The gold-coating which was on two of the upper R/C nodes and all of the subcooler nodes during Cases 1 and 2 was removed by assigning these nodes an emissivity of 0.21. Again, all of the primary system components were gold-coated and a normal NaK ramp was programmed into the analysis.

A. Transient Orbit

The temperatures of the secondary components were about 15°F less for this case. This decrease was due to the removal of the gold-coating from the R/C and subcooler nodes since these nodes represent an additional heat sink on the system with any increase in emissivity. The mean R/C temperature as a function of orbital position is shown by Graph 16.

B. Constant Sun-Constant Shade Orbit

The coldest R/C node temperature at injection was -45°F . The temperature distribution around the upper R/C and subcooler nodes are summarized in Graphs 17 and 18.

Case 4 - Removal of R/C Coating and Half of Preheat Ramp Rate

This case is identical to Case 3, except the primary system temperature ramp was half of the normal ramp.

A. Transient Orbit

From graph 19, the mean R/C temperature at injection was found to be -12°F .

B. Constant Sun-Constant Shade

The temperature distributions around the two sets of R/C nodes at injection are given by Graphs 20 and 21. The coldest R/C node temperature at injection was -28°F .

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Case 5 - Removal of Coating on NaK Cold Leg

In order to allow more heat to be radiated to the system during the primary system temperature ramp, the coating on the cold NaK leg was removed for this case. The upper R/C and subcooler nodes were gold-coated in the manner described by Case 1. The slope of the NaK temperature ramp was for the current stepping rate.

A. Transient Orbit

A mean R/C temperature at mercury injection of 8°F was obtained for this case (Graph 22). Again, the mercury regulator was the coldest component, and was -22°F at injection.

B. Constant Sun-Constant Shade Orbit

Graphs 23 and 24 give the temperature distribution of the upper R/C and subcooler nodes, respectively. The coldest R/C node at injection was -96°F.

Case 6 - Removal of Coating on NaK Cold Leg and Half of Preheat Ramp Rate

With the exception of the slope of the NaK ramp, this case was identical to the previous case. The primary system temperature ramp was half of the normal slope.

A. Transient Orbit

The mean R/C temperature as a function of orbital position is given by Graph 25. The temperature of this parameter at injection was 26°F.

B. Constant Sun-Constant Shade Orbit

The coldest R/C node temperature was -77°F. The temperature distribution around the upper R/C nodes at injection is given by Graph 26 and the distribution around the subcooler by Graph 27.

Case 7 - Removal of Coating From R/C and NaK Cold Leg

This and the preceding case represent the extremes as far as the amount of gold-coating which was removed. Gold-coating was removed from the two upper R/C subcooler, and gold NaK leg nodes. A normal stepping rate was used in this analysis.

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A. Transient Orbit

A mean R/C temperature of 19°F was experienced at injection as shown by Graph 28.

B. Constant Sun-Constant Shade

Only one of the R/C nodes was below 0°F for this case (-9°). The distribution around the R/C nodes is summarized by Graphs 29 and 30.

Case 8 - Removal of Coating from R/C and NaK Cold Leg; Also, Half Preheat Ramp Rate

This was a repeat of the previous case, except that the slope of the primary system temperature ramp was half of the normal ramp.

A. Transient Orbit

The mean R/C temperature at injection was 36°F (Graph 31). The coldest secondary system temperature was -20°F and was the mercury regulator tank.

B. Constant Sun-Constant Shade Orbit

The upper R/C and subcooler temperature distribution at mercury injection are given by Graphs 32 and 33, respectively. The coldest R/C node temperature was 11°F.

Case 9 - Reference Case with Temperature Soak at End of NaK Ramp

This case was identical to the reference case (1), except the system was allowed to "soak" for three hours at the end of the primary system temperature ramp.

A. Transient Orbit

Graph 34 gives the mean R/C temperature for a three hour "soak". From this graph, the R/C approached its equilibrium temperature during the first hour of the soak and very little change occurred during the remaining two hours.

B. Constant Sun-Constant Shade

The coldest individual R/C node temperatures were again experienced in this orbit. The coldest temperature was -83°F. The temperature distribution around the R/C is summarized by Graphs 35 and 36.

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Case 10 - Removal of Coating from NaK Cold Leg with Temperature Soak

For this case, the gold coating was removed from the cold NaK leg while the R/C was coated in the manner described by Case 1. The system was again allowed to soak for three hours at the end of the NaK ramp.

A. Transient Orbit

The mean R/C temperature at the end of the three hour "soak" was 63°F as shown by Graph 37. The mercury regulator was the coldest component at the end of the temperature soak and was at 4°F.

B. Constant Sun-Constant Shade

The coldest individual R/C node temperature at the end of the ramp was -54°F. The mean R/C temperature again had nearly reached its equilibrium temperature at the end of the first hour of the soak and, therefore, no advantage would be gained by extending the length of the soak.

The temperature distributions for both sets of R/C nodes are summarized by Graphs 38 and 39.

B. Recommendations

The results which are included in this report are based on an emissivity for gold of .05. However, this value is only valid if the coating is applied in an impeccable manner so that there is contact between the coating and surface being coated at all points. The minimum value this parameter can assume was determined by assuming there was no contact between surfaces. For this case, the emissivity of the gold-coating would approach half of the former value. This would represent a significant difference in the results contained herein. Therefore, as soon as this value is obtained experimentally, all of the candidate cases contained herein should be re-evaluated.

A weight study of all candidate cases should be made in order to determine the optimum case for mercury weight savings versus added copper weight resulting from gold removal.

Since the mercury regulator is the only marginal PCS component from mercury freezing considerations at injection, a higher emissivity coating or no coating at all should be considered for this component.

IV DISCUSSION OF THERMAL MODEL AND ANALYSIS

A. Division of R/C and PCS Components into Nodes

1. Radiator-Condenser In order to arrive at a realistic temperature distribution around the R/C while in orbit, the R/C

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FIGURE 1
DIVISION OF RC INTO NODES

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FIGURE 2
PROJECTED AREAS

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FIGURE 3

MODEL NO.

PREPARED BY:	ATOMICS INTERNATIONAL A DIVISION OF NORTH AMERICAN AVIATION, INC.	PAGE NO. 16 OF 114
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ORIENTATION OF COMPONENTS AT $\beta = 30^\circ$

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was divided into 20 nodes as shown in Figure 1. This division was made by first dividing the R/C vertically into 10 equal nodes. A further subdivision at a distance of 15 inches from the bottom of the R/C was necessary since the current design of the R/C designates that the inside surface of the lower 15 inches shall be gold-coated. These lower R/C nodes are called subcooler nodes and the upper nodes are referred to as upper R/C nodes throughout the remainder of this report.

In addition to the gold-coating on the interior of the subcooler nodes, eight of the forty R/C tubes which are located directly behind the boiler and NaK lines are presently specified to be gold-coated along their entire length. Therefore, the choice of 10 vertically equal nodes adheres to the actual geometry by assuming two of the upper R/C nodes are gold-coated. The radiation shield and the thermal barrier constitute two additional nodes at the top and bottom of the R/C respectively.

2. Internal Nodes A total of 15 internal nodes, each of which represents some component in the system, were included in this analysis. The criteria which dictated what components should be included were based on:

- a) A possible problem area at injection because of mercury freezing.
- b) The addition of heat that this component contributes to the system.
- c) The similarity of the component (with respect to location) to others in the system.
- d) Components which require a more detailed study of the effects of internal radiation and conduction to the R/C

This analysis utilized the current R/C-12 and component designs. The corresponding node number for each component and the properties of each are listed in Table I.

B. External Heat Inputs

Two different orbits were considered in this study. Each of these represents the extremes of any orbit into which the actual flight system might be placed. These two orbits are shown in Figure 3 and are:

- a) Sun-Shade transient orbit - the sun's rays and the plane of the orbit are parallel.
- b) Constant Sun-Constant Shade Orbit - the plane of the orbit is perpendicular to the sun's rays.

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The orbit was assumed to be circular and at a distance of 700 miles above the earth. Another assumption was that the vehicle axis was normal to the surface of the earth.

The two major sources of external heat input to the vehicle while in orbit are:

1. Direct Sunlight
2. Thermal Radiation from the Earth.

From reference (1), the heat input due to reflected sunlight from the earth was found to be negligible in comparison to the two sources listed above; therefore, this input was not included in the analysis.

1. Sun Shade Transient Orbit

a) Direct Sun

The heat input to any node i of the radiator condenser is given by:

$$q_{DS} = q_s \alpha_s A_i(\beta) \text{ BTU/HR} \quad (1)$$

where: q_s - solar constant = 443 BTU/hr ft²

α_s - absorptivity to solar radiation = 0.30

$A_i(\beta)$ - projected area of node i which is perpendicular to the sun's rays as a function of orbital position.

The projected area $A_i(\beta)$ may be related to the orbital position from Figures 2 and 3. From these figures the projected area is represented by:

$A_i(\beta) = \left\{ \begin{array}{l} \text{for} \\ \text{Node } i = \end{array} \right.$	1,11	A_i	$\left. \begin{array}{l} \cos \beta \\ \cos \alpha \\ \cos \alpha \\ \cos \beta \\ \cos \alpha \\ \cos \beta \\ \cos \beta \\ \cos \alpha \end{array} \right\} \begin{array}{l} x \sin(\beta + \delta) \text{ for } 0 < \beta < 90^\circ + \theta \\ x \sin(\delta - \beta) \text{ for } 0 < \beta < \delta \\ x \quad 0 \text{ for } \delta < \beta < 90^\circ + \theta \end{array}$
	2,12	$A_i \cos \beta$	
	3,13	$A_i \cos \alpha$	
	9,19	$A_i \cos \alpha$	
	10,20	$A_i \cos \beta$	
	4,14	$A_i \cos \alpha$	
	5,15	$A_i \cos \beta$	
	6,16	$A_i \cos \beta$	
7,17	$A_i \cos \alpha$		
8,18	$A_i \cos \alpha$		

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$A_i(\theta) = 0$ for all nodes

for $90^\circ + \theta < \theta < 270^\circ - \theta$

$$A_i(\theta) = \left\{ \begin{array}{ll} \text{for Node } i = 1,11 & A_i \\ 2,12 & A_i \cos \\ 3,13 & A_i \cos \\ 9,19 & A_i \cos \\ 10,20 & A_i \cos \\ 4,14 & A_i \cos \\ 5,15 & A_i \cos \\ 6,16 & A_i \\ 7,17 & A_i \cos \\ 8,18 & A_i \cos \end{array} \right\} \begin{array}{l} x \sin(\theta - \theta) \text{ for } 360^\circ - \theta < \theta < 360^\circ \\ x 0 \text{ for } 270^\circ - \theta < \theta < 360^\circ \\ x \sin(\theta + \theta) \text{ for } 270^\circ - \theta < \theta < 360^\circ \end{array}$$

where A_i - maximum projected area of any node i
for $1 \leq i \leq 10$ $A_i = 9.90 \text{ ft}^2$
for $11 \leq i \leq 20$ $A_i = 1.81 \text{ ft}^2$

θ - half apex angle of R/C = $7^\circ 5'$

$$\theta = \cos^{-1} \left(\frac{R}{R+h} \right) = 31^\circ 47'$$

R - radius of earth = 3,960 miles

h - orbital height = 700 miles

ρ - see Figure 3 = 36°

α - see Figure 3 = 72°

θ - orbital position (Figure 2)

The total heat input due to direct sunlight may be written as

$$Q_{DS} = q_s \alpha_s \sum_{i=1}^{20} A_i(\theta) \text{ BTU/HR}$$

or per node

$$q_{DS} = 133.0 A_i(\theta) \text{ BTU/HR} \quad (2)$$

b) Thermal Earth The total heat input to the R/C due to thermal radiation from the earth is given by:

$$Q_{TE} = F_{s-e} \alpha_T \epsilon_E q_{BE} \sum_{i=1}^{20} A'_i \quad (3)$$

or per node

$$q_{TE} = F_{s-e} \alpha_T \epsilon_E q_{BE} A'_i \text{ BTU/HR} \quad (4)$$

where: A'_i - surface area of each node

$A'_i = 10.1 \text{ ft}^2$ for $1 \leq i \leq 10$

$A'_i = 1.9 \text{ ft}^2$ for $10 < i \leq 20$

F_{s-e} - view factor from satellite to earth = 0.118
(Reference 2)

α_T - absorptivity to thermal radiation = 0.91

ϵ_E - emissivity of earth = 1

q_{BE} - black body radiation of the earth = σT_E^4

σ - Stefan-Boltzmann constant = 0.1713×10^{-8}

$\frac{\text{BTU}}{\text{hr-ft}^2-\text{R}^4}$

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$$Q_{TE} = 6.9 \sum_{i=1}^{20} A_i' \quad (5)$$

or per node $q_{TE} = 6.7 \text{ A}_c^2 \text{ STD/NR}$

$$Q_r = 133.0 \sum_{i=1}^{20} A_i(s) + 6.9 \sum_{i=1}^{20} A'_i \quad (6)$$
$$q_T = 133.0 A_c (3) + 6.9 A_c' \quad \text{Btu/HR-Node} \quad (7)$$
$$g_{(rad)}^2 = A' \epsilon_2 \sigma \epsilon_1^4 \quad (8)$$

2. Constant Sun-Constant Shade Orbit

C. Internal Heat Inputs

A. Upper R/C Nodes

$$(q_{in} - q_{out})_i = \left(\frac{KA}{\Delta X} \right)_1 [t_{i+1} - 2t_i + t_{i-1}] + \left(\frac{KA}{\Delta X} \right)_2 [t_{i+1} - t_i] \text{ BTU/HR} \quad (9)$$

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where: $\left(\frac{KA}{\Delta x}\right)_1$ - thermal conductance between upper R/C nodes =
1.045 $\frac{\text{BTU}}{\text{hr}^\circ\text{F}}$

$\left(\frac{KA}{\Delta x}\right)_2$ - thermal conductance between any upper R/C node i
and the corresponding subcooler node $i + 10$ =
.0476 $\frac{\text{BTU}}{\text{hr}^\circ\text{F}}$

b) Subcooler Nodes

The net gain or loss in heat due to conduction for the subcooler is

$$(q_{in} - q_{out})_{i+10} = \left(\frac{KA}{\Delta x}\right)_3 [t_{i+10+1} - 2t_{i+10} + t_{i+10-1}] + \left(\frac{KA}{\Delta x}\right)_2 [t_i - t_{i+10}] \quad (10)$$

where: $\left(\frac{KA}{\Delta x}\right)_3$ is the thermal conductance between the lower R/C nodes and equals 0.117 $\frac{\text{BTU}}{\text{hr}^\circ\text{R}}$

The manner in which the thermal conductance between R/C nodes was determined is included in the calculations.

2. Transfer of Heat Between Nodes by Radiation

The interchange of heat due to the internally reflected and radiated heat from the R/C nodes and internal components is expressed as:

$$q_i(\text{rad}) = A_i'' \sum_j F_{ij} (t_j^4 - t_i^4) \quad \text{BTU/HR} \quad (11)$$

where: F_{ij} - interchange factor which is used in determining the amount of heat interchanged between some node i and node j by reflection, emission, and reradiation. (A more detailed explanation is included in the Appendix)

A_i'' - total surface area of the node or component i , ft^2
 t_i - instantaneous temperature of any node i .

D. Resulting Heat Balance

The change in temperature as a function of time of any node can be determined from

$$(mc)_i \frac{dt_i}{d\tau} = q_{in} - q_{out} \quad (12)$$

where: $(mc)_i$ - mass time specific heat of any node or component i ,
 $\frac{\text{BTU}}{^\circ\text{R}}$

τ - unit of time, hr

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1. R/C Nodes

Substituting the change in heat ($\dot{q}_{in} - \dot{q}_{out}$) due to:

- a) direct sunlight
- b) thermal earth radiation
- c) conduction
- d) radiation to space
- e) internal radiation

into equation (12), the time rate of change, in temperature for the R/C nodes can be obtained, or for the

a) Upper R/C Nodes

$$(mc)_i \frac{dT_i}{dt} = \left(\frac{KA}{\Delta X} \right)_1 [T_{i+1} - 2T_i + T_{i-1}] + \left(\frac{KA}{\Delta X} \right)_2 [T_{i+10} - T_i] + q_{solar} A_i (\beta) + F_{5-8} \epsilon \epsilon_{eff} A_i' - A_i' \sigma \epsilon_{eff} T_i^4 - A_i'' \sigma \sum_{j=1}^4 F_{ij} (T_i^4 - T_j^4) \quad (13)$$

for $1 \leq i \leq 10$

b) Subcooler Nodes

$$(mc)_{i+10} \frac{dT_{i+10}}{dt} = \left(\frac{KA}{\Delta X} \right)_3 [T_{i+10+1} - 2T_{i+10} + T_{i+10-1}] + \left(\frac{KA}{\Delta X} \right)_2 [T_i - T_{i+10}] + q_{solar} A_{i+10} + F_{5-8} \epsilon \epsilon_{eff} A_{i+10}' - A_{i+10}' \sigma \epsilon_{eff} T_{i+10}^4 - A_{i+10}'' \sigma \sum_{j=1}^4 F_{i+10,j} (T_{i+10}^4 - T_j^4) \quad (14)$$

for $1 \leq i \leq 10$

In order to correlate the heat input with real time, it was necessary to express the orbital position angle β in terms of the angular velocity, or $\beta = \omega \tau$

An approximate relationship for obtaining angular velocity of an object h miles above the earth is:

$$\omega = \frac{R_0}{R_0 + h} \left[\frac{g}{R_0 + h} \right]^{\frac{1}{2}} \quad (\text{Reference 1})$$

where: g - gravity constant = 32.2 ft/sec²
 R_0 - radius of earth = 3960 miles
 h - 700 mile orbit
 ω - .00097 rad/sec or 200 degrees per hour

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2. Internal Components

Initially, all of the internal components were assumed to have no conduction losses through the brackets, pipes, etc. From this assumption, the time rate of change in temperature was simply written as

$$(mc)_i \frac{dt_i}{dt} = A_i \sigma \sum_j F_{ij} [t_j^4 - t_i^4] \quad \text{for } 22 \leq i \leq 37 \quad (15)$$

The capability to simulate a heater on all of the internal components was included in this analysis by the addition of a constant to equation (15). This term represents a constant number of BTU/hr which can be added to the component in order to maintain a higher component temperature or

$$(mc)_i \frac{dt_i}{dt} = A_i \sigma \sum_j F_{ij} [t_j^4 - t_i^4] + Q \quad (16)$$

Some of the internal components which are included in this analysis and their time rate of change in temperature are not adequately described by Equation (15). These components fall into at least one of the following three categories:

- a) A one node model for the entire component is not sufficient.
- b) Conduction through the brackets which support the component is significant.
- c) Due to the NaK circulating through the component or gamma heating from the reactor, the components temperature change is not described by equation (15). The modifications which were made on these components are as follows:

1) Multi-Node Component

CRU At mercury injection, one of suspected mercury freezing problem areas was the CRU. In order to obtain a more realistic temperature distribution of the CRU, this component was divided into three sub-nodes according to Figure 5.

FIGURE 5

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TABLE I
COMPONENT PARAMETERS

COMPONENT	NODE NO.	m_c BTU/°F	EMISSIVITY	TOTAL RADIATING AREA, FT ²	REMARKS
Radiation Shield	21	- -	.200	4.90	Rate of change in temperature was programmed in according to graph.
Thermal Barrier	22	4.00	.050	19.60	Bottom of the R/C
N ₂ Tank	23	1.44	.210	2.09	
Injection Tank (Full of Hg)	24	3.70	.210	2.05	Temperature can be held constant if desired. This node is subdivided into two nodes with conduction losses from the outer node through the brackets included.
Hg Regulator Tank	25	2.34	.050	3.57	Conduction losses due to brackets is included.
Injection Line	26	.0065	.210	.065	The value for m_c represents a typical one foot section.
Hg Regulator Line	27	.0152	.050	.131	This value of m_c represents a typical six-inch section.
CRU Hg Line	28	.007	.050	.052	This value of m_c represents a six-inch section
CRU Dram Line (Typical)	29	.021	.050	.122	The value of m_c is for a six-inch section.
Upper Hg Riser	30	.420	.210	2.75	This node represents the Hg vapor riser from the "T" up.
Lower Hg Riser	31	.353	.210	2.45	This represents the Hg vapor riser from the "T" down.

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TABLE I
COMPONENT PARAMETERS
(Continued)

COMPONENT	NODE NO.	mc BTU/°F	EMISSIVITY	TOTAL RADIATING AREA, FT ²	REMARKS
Turbine Feed	32	.1792	.017	1.30	Line parallel to the boiler
CRU	33-1	3.00	.210	2.35	This component was subdivided into three Nodes. Conduction through brackets was also taken into account
	33-2	2.00	.200	2.08	
	33-3	.5	.200	.42	
Boiler	34	- -	.050	5.50	Rate of change in temperature was programmed into the analysis.
NaK Compensator	35	- -	.050	.68	Same as boiler.
Hot NaK Leg	36	- -	.050	3.12	Same as boiler.
Cold NaK Leg	37	- -	.050	2.82	Same as boiler.

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Because of the complexity of adequately determining the thermal conductance between nodes, the only source of heat transfer considered was by radiation. A detailed thermal analysis of the CRU is currently being made, thus, the results in this report should be considered only as a first order approximation. Writing the equation of heat exchange for node 1,

$$(mc)_1 \frac{dt_1}{dt} = \sigma A_1 \sum_j F_{1-j} (t_j^4 - t_1^4) + \sigma A_1 F_{1-2} (t_2^4 - t_1^4) \quad (17)$$

The first term on the right hand side of this equation is the same as equation (15) and represents the net interchange of heat between node 1 and all the other external nodes which are included in the analysis however, the product (), now pertains to the outer can of the CRU and not the entire component.

Since conduction between nodes was not considered with this model, the interchange of heat due to radiation between nodes was assumed to be a maximum by setting the view factors between nodes equal to one and neglecting reflection and reradiation.

$$(mc)_1 \frac{dt_1}{dt} = \sigma A_1 \sum_j F_{1-j} (t_j^4 - t_1^4) + \sigma (EA)_{1-2} (t_2^4 - t_1^4) \quad (18)$$

The equations of heat transfer nodes 2 and 3 may be written as

$$(mc)_2 \frac{dt_2}{dt} = \sigma (EA)_{1-2} [t_1^4 - t_2^4] + \sigma (EA)_{2-3} [t_3^4 - t_2^4] \quad (19)$$

$$(mc)_3 \frac{dt_3}{dt} = \sigma (EA)_{2-3} (t_2^4 - t_3^4) \quad (20)$$

Table II lists the values of the parameter used in the solution of these equations.

Injection Tank From the results of this study, it may be required that the injection tank(s) be continuously heated from the time of launch until mercury injection. Therefore, this program was given added flexibility for future studies by building a more detailed two node model of the injection tank as shown by Figure 6.

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Node 1 (storage tank) was given the capability of being maintained at a constant temperature if so desired.

FIGURE 6

By making the same assumptions as were made for the model of the CRU, the equations of heat transfer may be written as:

$$(mc)_0 \frac{dt_0}{dt} = \sigma A_0 \sum F_{0j} (t_j^4 - t_0^4) + \sigma (\epsilon A)_{0-1} (t_1^4 - t_0^4) \quad (21)$$

$$(mc)_1 \frac{dt_1}{dt} = \sigma (\epsilon A)_{0-1} (t_0^4 - t_1^4) \quad (22)$$

Table III lists the values for the parameters used in the solution of these equations.

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TABLE II

CRU PARAMETERS USED FOR THREE NODE MODEL

NODE	1	2	3
$m, BTU/^\circ R$	3.0	2.0	0.5
EA, ft^2	.40	.40	.08

TABLE III

INJECTION TANK TWO NODE MODEL

NODE	1	0
$m, BTU/^\circ R$	1.0	2.7
EA, ft^2	.40	.40

2. Conduction Through the Supporting Brackets

Injection Tank, CRU, and Mercury Regulator Tank Another purpose of this program was to determine the feasibility of eliminating all external heat sources on the components prior to mercury injection. A more stringent model was made of three components to better analyze potential pre-heating requirements by including the conduction losses to the R/C through the supporting component brackets.

These losses were determined by combining the eight supporting brackets on each component into an equivalent bracket as shown in Figure 7.

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FIGURE 7

Point 1 represents the point of contact between the component and the equivalent bracket. Nodes 2, 3, and 4 were obtained by dividing the bracket into three equal nodes. Node 5 is the total surface area of the brackets which is attached to the supporting ring. The area of the conduction path through the honeycomb to the R/C copper fins was assumed to be the same as the cross-sectional area of node 5. This is probably conservative, however, based on this assumption, this resistance represents only a small percentage of the total resistance from the component to the R/C nodes. After passing through the honeycomb, the conduction path divides with part of the heat flow going to the center of the upper R/C node i and the remainder to the center of the corresponding subcooler node $i + 10$. The time rate of change in temperature of the component is expressed as:

$$(mc)_1 \frac{dt_1}{dt} = E_1 A_1 + \left(\frac{KA}{\Delta x} \right)_{1-2} [t_2 - t_1] \quad (23)$$

where $\left(\frac{KA}{\Delta x} \right)_{1-2}$ is the thermal conductance between nodes 1 and 2 in Figure 6. The time rate of change for node 2 is

$$(mc)_2 \frac{dt_2}{dt} = E_2 A_2 \sigma (t_{RC}^4 - t_2^4) + \left(\frac{KA}{\Delta x} \right)_{1-2} (t_1 - t_2) + \left(\frac{KA}{\Delta x} \right)_{2-3} (t_3 - t_2) \quad (24)$$

The first term on the right hand side of this equation represents the interchange of heat between this node and the mean radiating temperature of the R/C. The determination of this temperature is given in the appendix.

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Similarly, the equations of heat transfer for the remaining nodes are written as:

$$(mc)_3 \frac{dt_3}{dt} = \epsilon_3 A_3 \sigma (T_{RC}^4 - T_3^4) + \left(\frac{KA}{\Delta X} \right)_{2-3} (T_2 - 2T_3 + T_4) \quad (25)$$

$$(mc)_4 \frac{dt_4}{dt} = \epsilon_4 A_4 \sigma (T_{RC}^4 - T_4^4) + \left(\frac{KA}{\Delta X} \right)_{2-3} (T_3 - T_4) + \left(\frac{KA}{\Delta X} \right)_{4-5} (T_5 - T_4) \quad (26)$$

$$(mc)_5 \frac{dt_5}{dt} = \epsilon_5 A_5 \sigma (T_{RC}^4 - T_5^4) + \left(\frac{KA}{\Delta X} \right)_{5-6} (T_6 - T_5) + \left(\frac{KA}{\Delta X} \right)_{5-7} (T_7 - T_5) + \left(\frac{KA}{\Delta X} \right)_{4-5} (T_4 - T_5) \quad (27)$$

$$(mc)_6 \frac{dt_6}{dt} = E q_{13} + \left(\frac{KA}{\Delta X} \right)_{5-6} (T_5 - T_6) \quad (28)$$

$$(mc)_7 \frac{dt_7}{dt} = E q_{14} + \left(\frac{KA}{\Delta X} \right)_{5-7} (T_5 - T_7) \quad (29)$$

Nodes 6 and 7 correspond to the upper R/C node i and subcooler node $i + 1$ respectively.

Table IV lists the values of the heat transfer properties of the brackets which were used in the solution of these equations.

3. Constant or Programmed Temperature Changes

NaK Components Due to the circulation of heated NaK through the primary system, the NaK components remain at a nearly constant temperature until the initiation of startup. At startup, the primary system and corresponding components heat up in a manner which was determined by Reference 3.

Nuclear Radiation Shield The shield (node) has a large mass which gives this node a slow response to temperature changes. At startup, this components's

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time rate of change is dictated by gamma heating and radiation from the reactor. This rate of change was determined by reference 4 and these results were simulated in the program as shown by Graph 40. Prior to startup, this component was held constant at 25°F

TABLE IV
PARAMETERS USED IN DETERMINATION OF
HEAT LOSSES THROUGH BRACKETS

PARAMETER	INJECTION TANK	Hg REGULATOR TANK	CRU
$\left(\frac{KA}{\Delta X}\right)_{1-2}$	0.212 $\frac{\text{BTU}}{\text{hr}^\circ\text{R}}$	0.350 $\frac{\text{BTU}}{\text{hr}^\circ\text{R}}$	1.08 $\frac{\text{BTU}}{\text{hr}^\circ\text{R}}$
$\left(\frac{KA}{\Delta X}\right)_{2-3}$	0.106 $\frac{\text{BTU}}{\text{hr}^\circ\text{R}}$	0.175 $\frac{\text{BTU}}{\text{hr}^\circ\text{R}}$	0.54 $\frac{\text{BTU}}{\text{hr}^\circ\text{R}}$
$\left(\frac{KA}{\Delta X}\right)_{3-4}$	0.106 $\frac{\text{BTU}}{\text{hr}^\circ\text{R}}$	0.175 $\frac{\text{BTU}}{\text{hr}^\circ\text{R}}$	0.54 $\frac{\text{BTU}}{\text{hr}^\circ\text{R}}$
$\left(\frac{KA}{\Delta X}\right)_{4-5}$	0.065 $\frac{\text{BTU}}{\text{hr}^\circ\text{R}}$	0.074 $\frac{\text{BTU}}{\text{hr}^\circ\text{R}}$	0.150 $\frac{\text{BTU}}{\text{hr}^\circ\text{R}}$
$\left(\frac{KA}{\Delta X}\right)_{5-6}$	0.0567 $\frac{\text{BTU}}{\text{hr}^\circ\text{R}}$	0.0567 $\frac{\text{BTU}}{\text{hr}^\circ\text{R}}$	0.0554 $\frac{\text{BTU}}{\text{hr}^\circ\text{R}}$
$\left(\frac{KA}{\Delta X}\right)_{5-7}$	0.523 $\frac{\text{BTU}}{\text{hr}^\circ\text{R}}$	0.523 $\frac{\text{BTU}}{\text{hr}^\circ\text{R}}$	0.512 $\frac{\text{BTU}}{\text{hr}^\circ\text{R}}$
A_1	0.383 ft ²	0.383 ft ²	0.41 ft ²
A_2	0.383 ft ²	0.383 ft ²	0.41 ft ²
A_3	0.383 ft ²	0.383 ft ²	0.41 ft ²
A_4	0.098 ft ²	0.098 ft ²	0.063 ft ²
ϵ_1	.21	.21	.21
ϵ_2	.21	.21	.21
ϵ_3	.21	.21	.21
ϵ_4	.21	.21	.21

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PARAMETER	INJECTION TANK	Hg REGULATOR TANK	CRU
(mc) ₁	.021	.064	.084
(mc) ₂	.021	.064	.084
(mc) ₃	.021	.064	.084
(mc) ₄	.0136	.0136	.016

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CASE I TRANSIENT ORBIT
PRE-START UP MEAN TEMPERATURE VERSUS REVOLUTION

7129-01
008 000

TEMPERATURE - DEGREES FAHRENHEIT

REVOLUTIONS

GRAPH 3

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CASE I TRANSIENT ORBIT
TEMPERATURE DISTRIBUTION OF R/C NODES

2423-OR L
500 100

CIRCUMFERENCE REVOLUTIONS = 11.68

GRAPH 4

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CASE I TRANSIENT ORBIT
TEMPERATURE DISTRIBUTION OF SUB-COOLER NODES

GRAPH 5

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CASE I

CONSTANT SUN - CONSTANT SHADE ORBIT

PRE-START UP MEAN TEMPERATURE VERSUS REVOLUTION

7429-04 L
048 1963

TEMPERATURE - DEGREES FAHRENHEIT

REVOLUTIONS

GRAPH 6

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CASE I CONSTANT SUN-CONSTANT SHADE
TEMPERATURE DISTRIBUTION OF R/C NODES

7429-54
541 55

GRAPH 7

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CASE I : CONSTANT SUN-CONSTANT SHADE
TEMPERATURE DISTRIBUTION OF SUB-COOLER NODES

7429-04 L
942 000

GRAPH 8

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CASE I TRANSIENT ORBIT
COMPONENT TEMPERATURE VERSUS REVOLUTIONS
PLOT 1

7429-04 1
036 036

GRAPH 9

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CASE I TRANSIENT ORBIT
COMPONENT TEMPERATURE VERSUS REVOLUTIONS
PLOT 2

7429-04
039 05

GRAPH 10

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CASE I TRANSIENT ORBIT
COMPONENT TEMPERATURE VERSUS REVOLUTIONS
PLOT 3 937 99

GRAPH 11

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CASE I TRANSIENT ORBIT
COMPONENT TEMPERATURE VERSUS REVOLUTIONS

PLOT 4

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7429-54 L
535 500

GRAPH 12

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CASE I TRANSIENT ORBIT
COMPONENT TEMPERATURE VERSUS REVOLUTIONS
PLOT 5

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CASE 2 CONSTANT SUN-CONSTANT SHADE
TEMPERATURE DISTRIBUTION OF R/C NODES

7429-03
001

GRAPH 14

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CASE 2 CONSTANT SUN-CONSTANT SHADE
TEMPERATURE DISTRIBUTION OF SUB-COOLER NODES

7429-55
102 01

GRAPH 15

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CASE 3 SUN-SHADE TRANSIENT ORBIT
PRE-START UP MEAN TEMPERATURE VERSUS REVOLUTION

7129-12
GDR

GRAPH 16

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CASE 3 CONSTANT SUN-CONSTANT SHADE
TEMPERATURE DISTRIBUTION OF R/C NODES

7129-102
009

GRAPH 17

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CASE 3 CONSTANT SUN-CONSTANT SHADE
TEMPERATURE DISTRIBUTION OF SUB-COOLER NODES.

GRAPH 18

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CASE 4 SUN-SHADE TRANSIENT ORBIT
PRE-START UP MEAN TEMPERATURE VERSUS REVOLUTION

7429-05
416

GRAPH 19

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CASE 4 CONSTANT SUN-CONSTANT SHADE
TEMPERATURE DISTRIBUTION OF R/C NODES

7429-1.5
G17 00

GRAPH 20

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CASE 4 CONSTANT SUN-CONSTANT SHADE
TEMPERATURE DISTRIBUTION OF SUB-COOLER NODES

7429-15
G1R

GRAPH 21

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CASE-5 SUN-SHADE TRANSIENT ORBIT
PRE-START UP MEAN TEMPERATURE VERSUS REVOLUTION

7429-1-5
648

GRAPH 22

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RO 114-1-128 001
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CASE 5. CONSTANT SUN- CONSTANT SHADE
TEMPERATURE DISTRIBUTION OF R/C NODES

7429-55
549

GRAPH 23

~~CONFIDENTIAL~~

037122A.030

~~CONFIDENTIAL~~

NO. 9004
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CASE 5 CONSTANT SUN-CONSTANT SHADE
TEMPERATURE DISTRIBUTION OF SUB-COOLER NODES

7423-75
050 000

GRAPH 24

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0371229.030

~~CONFIDENTIAL~~

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CASE 6 SUN-SHADE TRANSIENT ORBIT
PRE-START UP MEAN TEMPERATURE VERSUS REVOLUTION

7429-105
132

GRAPH 25

~~CONFIDENTIAL~~

0371229.030

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NO. RAA-OR-LAR 9007
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7 CASE 61 CONSTANT SUN-CONSTANT SHADE ORBIT
TEMPERATURE DISTRIBUTION OF R/C NODES

7429-15
033 00

GRAPH 26

~~CONFIDENTIAL~~

0371291030

~~CONFIDENTIAL~~

NO. 1007
DATE: September 18, 1963
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CASE 6 CONSTANT SUN-CONSTANT SHADE ORBIT
TEMPERATURE DISTRIBUTION OF SUB-COOLER NODES

7429-05
934 00

GRAPH 27

~~CONFIDENTIAL~~

0371229.030

~~CONFIDENTIAL~~

DATE: September 18, 1963
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CASE 7 TRANSIENT ORBIT

7429-1/4
924 00

PRE-START UP MEAN TEMPERATURE VERSUS REVOLUTION

TEMPERATURE - DEGREES FAHRENHEIT

REVOLUTIONS
GRAPH 28

~~CONFIDENTIAL~~

0371220.030

~~CONFIDENTIAL~~

CASE 7 CONSTANT SUN- CONSTANT SHADE
TEMPERATURE DISTRIBUTION OF R/C NODES

7429-04
025 05

GRAPH 29

~~CONFIDENTIAL~~

03712201030

~~CONFIDENTIAL~~

NO NAA-SR-TDR 9004
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CASE 7 CONSTANT SUN - CONSTANT SHADE
TEMPERATURE DISTRIBUTION OF SUB-COOLER NODES

7429-04
026 00

GRAPH 30

~~CONFIDENTIAL~~

0371270.0000

~~CONFIDENTIAL~~

NO. 7429-104
DATE September 18, 1963
PAGE 61 OF 114

CASE 87 TRANSIENT ORBIT

7429-104
016 500

PRE-START UP MEAN TEMPERATURE VERSUS REVOLUTION

TEMPERATURE - DEGREES FAHRENHEIT

REVOLUTIONS

GRAPH 31

~~CONFIDENTIAL~~

CONFIDENTIAL

~~CONFIDENTIAL~~

NO. NAA-SR-TDR 9004
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CASE 8 CONSTANT SUN - CONSTANT SHADE
TEMPERATURE DISTRIBUTION OF R/C NODES

7429-04 L
551 555

GRAPH 32

~~CONFIDENTIAL~~

03782A1030

~~CONFIDENTIAL~~

DATE: September 18, 1963
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CASE 8 CONSTANT SUN-CONSTANT SHADE
TEMPERATURE DISTRIBUTION OF SUB-COOLER NODES

7429-04
002 00

TEMPERATURE - DEGREES FAHRENHEIT

CIRCUMFERENCE REVOLUTIONS = 12.67

GRAPH 33

~~CONFIDENTIAL~~

0370201030

~~CONFIDENTIAL~~

NO. NAA-SR-TDM 9004.
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CASE 9 TRANSIENT ORBIT - 5 HOUR SOAK
PRE-START UP MEAN TEMPERATURE VERSUS REVOLUTION

GRAPH 34

~~CONFIDENTIAL~~

037201030

~~CONFIDENTIAL~~

CASE 3 HOUR TEMPERATURE CASE
TEMPERATURE DISTRIBUTION OF
UPPER RC NODES CONSTANT SUN
CONSTANT SHADE GPBIT

GRAPH 35

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~~CONFIDENTIAL~~

CASE 31 3 HOUR TEMPERATURE SOAK
TEMPERATURE DISTRIBUTION OF
SUB-COOLER NODES CONSTANT SUN
CONSTANT SHADE ORBIT

TEMPERATURE, °F

CIRCUMFERENCE, °

GRAPH 36

~~CONFIDENTIAL~~

~~CONFIDENTIAL~~

K&K
20 X 20 TO THE INCH 359-101/25
KEUFFEL & ESSER CO. WASHINGTON, D.C.

CASE ID TRANSIENT ORBIT-3 HOUR TEMPERATURE
PRE-START UP MEAN TEMPERATURE VERSUS REVOLUTION

REVOLUTIONS
GRAPH 37

CONFIDENTIAL

0372281030

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~~CONFIDENTIAL~~

0000000000

GRAPH 39

K&W
20 X 20 TO THE INCH 359-10 1/2 G
KEUFFEL & ESSER CO
MADE IN U.S.A.

V CALCULATION OF R/C HEAT TRANSFER PROPERTIES

A. Effective Fin Thickness for Conduction Around R/C

In order to determine the thermal conductance between nodes on the R/C, it was necessary to calculate a mean thickness for the R/C fin. Writing the equation for heat conduction (neglecting radiation) from points 1 to 2 in the Figure above

$$q = K A(x) \frac{dT}{dx} = K A_{eff} \frac{\Delta T}{l} \quad (30)$$

where $A(x)$ represents the conduction area as a function of x . Using the linear relationship between area and x this may be re-written as:

$$q = K(a-bx) \frac{dT}{dx} \quad (31)$$

or

$$T_1 - T_2 = \frac{q}{K} \int_0^l \frac{dx}{a-bx} = -\frac{q}{Kb} \ln(a-bx) \Big|_{x=0}^{x=l} = -\frac{q}{Kb} \ln\left(\frac{A_1}{A_2}\right) \quad (32)$$

From Equation (30), this may also be expressed as

$$T_1 - T_2 = \frac{ql}{A_{eff} K} \quad (33)$$

Therefore

$$A_{eff} = \frac{lb}{\ln \frac{A_1}{A_2}} = \frac{A_1 - A_2}{\ln A_1 / A_2}$$

or

$$L_{eff} = \frac{L - t_2}{\ln t_1 / t_2} = .011 \text{ inches}$$

B. Thermal Conductance of R/C Nodes

1. Between Upper R/C Nodes Thermal conductance between the upper R/C nodes was assumed to be through the copper fins whenever possible once the thermal conductivity of copper is large in comparison to the other materials used for the construction of the R/C. However, because of machine limitations,

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there is a nominal gap of 0.03 inches between 36 of the copper fins. The remaining four gaps are equally spaced 0.25 inches apart at the R/C panel joints. Since the choice of ten nodes does not adhere to a convenient location of these four larger gaps, it was necessary to use a mean value for all 40 gaps for the thermal resistance between fins.

$$l_2 = \frac{(36)(.03) + (.25)(4)}{40} = .052$$

or gap per node = $(0.52)(4) = .21''$

Referring to the above figure, the resistivity may be determined from

$$\left(\frac{Kt}{\Delta x}\right)_{eff} = \frac{1}{\frac{l_1}{K_1 t_1} + \frac{l_2}{K_2 t_2}} = 0.117 Btu/ft-hr-^{\circ}F$$

Finally,

$$\left(\frac{KA}{\Delta x}\right)_{eff} = \left(\frac{KA}{\Delta x}\right) = \frac{(0.117)(107)}{12} = 1.045 Btu/m-^{\circ}F$$

where l is the vertical length of the upper R/C nodes.

2. Between Subcooler Nodes Following the same procedure for determining the resistance between the subcooler nodes as was done for the upper R/C nodes

$$\left(\frac{Kt}{\Delta x}\right) = \frac{1}{\frac{2.27}{192(.011)} + \frac{.0266}{10(.016)}} = 0.094 Btu/ft-hr-^{\circ}F$$

$$\left(\frac{KA}{\Delta x}\right) = (0.094)\left(\frac{15}{12}\right) = 0.117 Btu/hr-^{\circ}F$$

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3. Between Subcooler and Upper R/C Nodes Conduction between the subcooler and upper R/C nodes was considered to be through the copper fins only. The effective fin thickness which was used for this calculation was .012 therefore,

$$\left(\frac{KA}{\Delta X} \right) = \frac{(192)(1.375) \left(\frac{.012}{12} \right)}{\frac{61}{12}} = .0476 \text{ Btu/hr}^\circ\text{F}$$

C. Product of Mass and Specific Heat of R/C Nodes

The mc of the upper R/C nodes were obtained by first referring to Reference 5. The results of this reference gives the heat capacity per tube per unit length for R/C-12. The mc of any upper R/C node i was found to be $1.68 \frac{\text{BTU}}{^\circ\text{F}}$ and the subcooler nodes $0.306 \frac{\text{BTU}}{^\circ\text{F}}$.

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HEAT CAPACITY PER TUBE
PER UNIT LENGTH R-C 12
COPPER ARMOUR, TUBE,
HONEYCOMB, FIN, AND
FACE SHEETS

HEAT CAPACITY, BTU/IN-²F X 10⁻³

5.0

4.0

3.0

2.0

0

0 10 20 30 40 50 60 70 80 90 100 110 120

DISTANCE FROM CONDENSER INLET, INCHES

GRAPH 41

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TABLE V

MODEL NO.

i ↓ Fi →

NODE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	0	.04544	.07846	.12055	.08239	.07703	.09239	.09055	.06846	.03160	0	.00082	.00252	.00759	.00925	.00957	.00925	.00759	.00505	.00164
2	.04544	0	.04544	.09846	.10055	.06590	.06878	.10590	.09055	.05500	.00164	0	.00082	.00505	.00759	.00925	.00957	.00925	.00759	.00605
3	.07846	.04544	0	.05544	.09846	.06508	.05508	.10703	.09590	.07070	.00505	.00082	0	.00164	.00505	.00759	.00925	.00957	.00925	.00759
4	.12055	.09846	.05544	0	.05544	.02846	.05171	.07590	.09703	.08030	.00759	.00252	.00082	0	.00164	.00505	.00759	.00925	.00957	.00925
5	.08239	.10055	.09846	.05544	0	.04544	.02846	.03711	.06500	.08170	.00925	.00380	.00252	.00164	0	.00164	.00505	.00759	.00925	.00957
6	.07703	.06590	.05055	.02846	.04544	0	.05544	.08000	.09055	.08200	.00492	.00240	.00380	.00377	.00164	0	.00164	.00505	.00759	.00925
7	.09239	.06878	.06508	.05171	.02846	.05544	0	.04044	.06846	.07070	.00925	.00478	.00240	.00660	.00505	.00164	0	.00164	.00505	.00759
8	.09055	.10590	.10703	.07590	.03711	.08000	.05044	0	.05044	.05470	.00759	.00462	.00478	.00925	.00759	.00505	.00164	0	.00164	.00505
9	.06846	.09055	.09590	.09703	.06590	.09055	.06846	.05044	0	.03160	.00505	.00375	.00465	.00957	0	0	.00505	.00164	0	.00164
10	.04544	.07846	.10155	.11590	.11703	.04597	.05055	.07846	.02920	0	.00164	.00252	.00375	.00925	.00957	.00925	.00759	.00505	.00164	0
11	.01346	.00907	.02789	.04192	.05055	.02600	.05055	.04192	.02789	.00907	0	.01800	.01500	.02509	.02527	.02000	.02000	.02509	.02000	0
12	.00453	.00623	.00453	.01395	.02096	.02500	.02669	.02527	.02096	.01394	.01800	0	.02000	.02000	.02000	.02000	.02000	.02000	.02000	.02000
13	.01394	.00453	.00673	.00453	.01394	.02000	.02500	.02669	.02527	.02096	.01500	.01000	0	.02000	.02000	.02000	.02000	.02000	.02000	.02000
14	.04192	.02789	.00907	.01346	.00907	.02000	.03300	.05055	.05338	.05055	.02509	.02000	.01000	0	.02777	.02000	.02509	.02527	.02000	.02000
15	.05055	.04192	.02789	.00907	.01346	.00907	.02789	.04192	0	.05338	.02727	.02000	.02000	.02777	0	.02777	.02532	.02509	.02000	.02470
16	.05338	.05055	.04192	.02789	.00907	.01346	.00907	.02789	0	.05055	.02470	.02000	.02000	.02000	.02777	0	.02777	.02532	.02000	.02527
17	.05055	.05338	.05055	.04192	.02789	.00907	.01346	.00907	.02789	.04192	.02000	.02000	.02000	.02509	.02532	.02777	0	.02777	.02000	.02509
18	.04192	.05055	.05338	.05055	.04192	.02789	.00907	.01346	.00907	.02789	.02509	.02000	.02000	.02727	.02509	.02532	.02777	0	.02000	.02532
19	.01394	.02096	.02524	.02669	.02527	.02091	.01394	.00453	.00673	.00453	.02000	.02000	.02000	.02000	.02000	.02000	.02000	.02000	0	0
20	.00636	.01950	.02930	.03535	.03750	.03535	.02930	.01950	.00636	.00940	0	.02000	.02000	.02000	.02470	.02727	.02509	.02532	0	0
21	.09320	.09320	.09320	.09320	.09320	.09320	.09320	.09320	.09320	.09320	.00057	.00057	.00057	.00057	.00057	.00057	.00057	.00057	.00057	.00057
22	.05150	.05150	.05150	.05150	.05150	.05150	.05150	.05150	.05150	.05150	.03880	.03420	.03600	.03300	.02920	.02920	.02920	.02920	.02920	.02920
23	.03000	.00700	.02000	.00100	.00200	.00700	.03000	.04000	.06000	.04000	.03000	.02000	.01000	.00500	.01000	.02000	.03000	.05000	.20000	.05000
24	.03000	.00700	.02000	.00100	.00200	.00700	.03000	.04000	.06000	.04000	.03000	.02000	.01000	.00500	.01000	.02000	.03000	.05000	.05560	.20000
25	.05000	.07500	.07500	.05000	.02200	.01200	.00600	.00600	.01200	.02200	.03500	.10650	.10650	.03500	.01800	.00900	.00900	.00300	.00300	.01800
26	.02500	.01500	.00600	.00600	.01500	.02500	.05000	.10000	.10000	.05000	.02500	.01500	.00600	.00600	.01500	.02500	.05000	.10000	.10000	.05000
27	.07300	.16500	.16500	.07300	.05000	.02000	.01000	.01000	.02000	.05000	0	0	0	0	0	0	0	0	0	0
28	.01000	.02000	.05000	.07000	.10000	.13000	.10000	.07000	.05000	.02000	.00100	.00200	.00350	.00500	.02000	.04000	.02000	.00500	.00350	.00200
29	0	0	0	0	0	0	0	0	0	0	.00500	.01000	.02000	.04000	.10000	.15000	.10000	.01000	.02000	.01000
30	.08495	.08495	.08495	.08495	.08495	.08495	.08495	.08495	.08495	.08495	0	0	0	0	0	0	0	0	0	0
31	.04400	.04400	.04400	.04400	.04400	.04400	.04400	.04400	.04400	.04400	.05000	.05000	.05000	.05000	.05000	.05000	.05000	.05000	.05000	.05000
32	.08500	.08500	.08500	.08500	.08500	.08500	.08500	.08500	.08500	.08500	0	0	0	0	0	0	0	0	0	0
33	.00500	.01000	.02000	.05000	.10000	.14500	.10000	.05000	.02000	.01000	.00250	.00500	.01000	.02000	.05000	.07000	.05000	.02000	.01000	.00500
34	.00500	.00750	.01500	.03000	.08000	.25000	.08000	.03000	.01500	.00750	.01000	.01000	.01000	.01000	.00500	0	.00500	.01000	.01000	.01000
35	.02000	.04000	.02000	.02000	.01000	.05000	.20000	.10770	.08000	.04000	.01000	.02000	.02000	.04000	.06400	.00500	0	0	.01000	.01000
36	.04000	.08000	.10000	.15000	.20000	.20000	.01000	.01000	.03000	.03000	0	0	0	0	0	0	0	0	0	0
37	.08000	.04000	.03000	.03000	.01000	.01000	.20000	.20000	.15000	.10000	0	0	0	0	0	0	0	0	0	0

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TABLE 5 (CONTINUED)

MODEL NO.

FL-3

NODE	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	Σ FL-3
1	.04393	.10000	.00620	.00620	.00228	.00016	.00095	.00005	0	.02314	.01200	.01100	.00116	.00272	.00577	.01240	.02230	.9904
2	.04393	.10000	.00145	.00145	.00342	.00010	.00214	.00010	0	.02314	.01200	.01100	.00232	.00408	.01150	.02480	.01110	.9844
3	.04393	.10000	.00041	.00041	.00342	.00004	.00214	.00026	0	.02314	.01200	.01100	.00465	.00510	.00577	.03110	.00838	.9821
4	.04393	.10000	.00021	.00021	.00228	.00004	.00095	.00036	0	.02314	.01200	.01100	.01160	.01630	.00577	.04160	.00838	.9993
5	.04393	.10000	.00041	.00041	.00100	.00010	.00065	.00051	0	.02314	.01200	.01100	.02320	.04350	.00288	.06220	.00279	.9726
6	.04393	.10000	.00145	.00145	.00055	.00016	.00026	.00067	0	.02314	.01200	.01100	.03370	.08160	.01440	.06220	.00279	1.0000
7	.04393	.10000	.00620	.00620	.00027	.00032	.00013	.00051	0	.02314	.01200	.01100	.02320	.04350	.05770	.00311	.05580	.9725
8	.04393	.10000	.00830	.00830	.00027	.00065	.00013	.00036	0	.02314	.01200	.01100	.01160	.01630	.03110	.00311	.05580	1.025
9	.04393	.10000	.01240	.01240	.00055	.00065	.00026	.00026	0	.02314	.01200	.01100	.00465	.00810	.02311	.00932	.04120	.9939
10	.04393	.10000	.00830	.00830	.00100	.00032	.00065	.00010	0	.02314	.01200	.01100	.00232	.00408	.01150	.00932	.02790	.9767
11	.00146	.40000	.03300	.03300	.00850	.00081	0	.00003	.00032	0	.02000	0	.00310	.02890	.01530	0	0	1.0110
12	.00146	.35121	.02200	.01460	.20000	.00051	0	.00005	.00064	0	.02000	0	.00617	.02890	.03060	0	0	1.0160
13	.00146	.37121	.01100	.01100	.20000	.00021	0	.00009	.00128	0	.02000	0	.01230	.02890	.03060	0	0	1.0150
14	.00146	.34121	.00550	.00550	.00850	.00021	0	.00014	.00256	0	.02000	0	.02470	.02890	.06120	0	0	1.0000
15	.00146	.30000	.01100	.01100	.00437	.00051	0	.00054	.00642	0	.02000	0	.06180	.01440	.09800	0	0	1.0230
16	.00146	.30000	.02200	.02200	.00220	.00081	0	.00109	.00963	0	.02000	0	.08650	0	.00765	0	0	.9679
17	.00146	.30000	.03300	.03300	.00073	.00172	0	.00054	.00642	0	.02000	0	.06180	.01440	0	0	0	1.0100
18	.00146	.30000	.05500	.05500	.00073	.00345	0	.00014	.00256	0	.02000	0	.02470	.02890	0	0	0	1.0280
19	.00146	.30000	.22600	.06000	.00220	.00345	0	.00009	.00128	0	.02000	0	.01230	.02890	.01530	0	0	.9877
20	.00146	.30000	.05000	.22000	.00437	.00172	0	.00005	.00064	0	.02000	0	.00617	.02890	.01530	0	0	1.0390
21	0	.03341	.00091	.00076	.00992	.00016	.00035	.00011	0	.00586	.00085	0	.00730	.03200	.00790	0	0	1.0370
22	.00835	0	.03200	.03200	.05620	.00067	0	0	.00155	.00562	.00055	0	.01650	.02890	.02970	0	0	1.0440
23	.00216	.35000	0	0	.076	0	0	0	0	0	0	0	0	.02050	0	0	0	1.0170
24	.00216	.35000	0	0	0	0	0	0	0	0	0	0	0	.02050	0	0	0	1.0220
25	.01325	.29210	0	0	0	0	.01100	0	0	0	0	0	0	.00566	0	0	0	.9950
26	.01200	.20000	0	0	0	0	0	0	0	0	0	0	0	.00600	0	0	0	1.0020
27	.01320	0	0	0	.30000	0	0	0	0	0	0	0	0	.05000	0	0	0	.9992
28	.00100	0	0	0	0	0	0	0	0	0	0	0	.25000	.01000	0	0	0	.9830
29	0	.25000	0	0	0	0	0	0	0	0	0	0	.25000	0	0	0	0	.9950
30	.01045	.04000	0	0	0	0	0	0	0	0	0	0	0	.10005	0	0	0	1.0000
31	.00171	.00444	0	0	0	0	0	0	0	0	0	0	0	.06060	0	0	0	1.0070
32	0	0	0	0	0	0	0	0	0	0	0	0	0	.15000	0	0	0	1.0000
33	.01320	.25500	0	0	0	0	0	.00550	.01300	0	0	0	0	.00669	0	0	0	.9959
34	.03100	.07620	.00772	.00772	.00374	.00006	.00119	.00009	0	.05000	.02700	.01940	.00276	0	.01050	.08560	.07670	.9997
35	.01330	.20000	0	0	0	0	0	0	0	0	0	0	0	.02000	0	0	0	1.0000
36	0	0	0	0	0	0	0	0	0	0	0	0	0	.15000	0	0	0	1.0000
37	0	0	0	0	0	0	0	0	0	0	0	0	0	.15000	0	0	0	1.0000

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CHECKED BY:	INTERCHANGE FACTORS	NAA-SR-TDR 9004 REPORT NO.
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Fig 1

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	.01611	.01772	.01873	.02040	.01853	.00472	.00460	.01965	.01837	.01527	.00435	.00393	.00401	.00465	.00467	.00419	.00456	.00456	.00483	.00482
2	.01763	.01590	.01749	.01957	.01917	.00460	.00432	.01994	.01889	.01593	.00438	.00386	.00340	.00450	.00456	.00413	.00453	.00458	.00486	.00489
3	.01868	.01754	.01573	.01804	.01915	.00461	.00418	.01991	.01896	.01687	.00451	.00387	.00384	.00432	.00441	.00404	.00450	.00458	.00491	.00497
4	.02029	.01956	.01798	.01630	.01798	.00437	.00421	.01904	.01918	.01678	.00465	.00398	.00391	.00428	.00431	.00397	.00449	.00462	.00497	.00508
5	.01850	.01923	.01916	.01806	.01581	.00433	.00392	.01729	.01770	.01658	.00466	.00397	.00393	.00427	.00416	.00374	.00433	.00450	.00490	.00503
6	.00471	.00463	.00449	.00439	.00450	.00108	.00169	.00484	.00478	.00426	.00115	.00162	.00104	.00114	.00111	.00094	.00107	.00112	.00124	.00130
7	.00476	.00451	.00456	.00442	.00041	.00114	.00096	.00494	.00455	.00410	.00119	.00164	.00101	.00118	.00161	.00095	.00103	.00106	.00120	.00127
8	.01987	.02025	.02015	.01936	.01752	.00491	.00446	.01723	.01841	.01658	.00485	.00426	.00427	.00494	.00485	.00412	.00436	.00480	.00484	.00516
9	.01866	.01930	.01931	.01961	.01807	.00487	.00446	.01851	.01601	.01534	.00459	.00408	.00411	.00477	.00426	.00372	.00437	.00430	.00465	.00488
10	.01741	.01852	.01918	.01988	.01934	.00432	.00412	.01891	.01656	.01372	.00433	.00392	.00397	.00463	.00461	.00411	.00441	.00437	.00459	.00465
11	.00083	.00082	.00084	.00087	.00087	.00022	.00021	.00089	.00084	.00073	.00028	.00031	.00030	.00033	.00033	.00029	.00031	.00033	.00035	.00031
12	.00083	.00084	.00083	.00084	.00083	.00022	.00021	.00087	.00083	.00075	.00035	.00032	.00037	.00035	.00033	.00030	.00032	.00032	.00035	.00037
13	.00846	.00084	.00083	.00083	.00082	.00022	.00026	.00087	.00084	.00476	.00034	.00034	.00032	.00035	.00034	.00030	.00032	.00032	.00035	.00036
14	.00087	.00084	.00081	.00082	.00079	.00021	.00021	.00091	.00087	.00079	.00033	.00030	.00028	.00027	.00031	.00028	.00032	.00032	.00033	.00034
15	.00089	.00088	.00085	.00083	.00082	.00021	.00021	.00091	.00080	.00081	.00034	.00031	.00031	.00035	.00029	.00031	.00033	.00033	.00034	.00036
16	.00085	.00084	.00083	.00082	.00077	.00020	.00019	.00083	.00074	.00076	.00032	.00029	.00029	.00031	.00033	.00023	.00033	.00032	.00033	.00035
17	.00087	.00088	.00087	.00087	.00083	.00021	.00019	.00082	.00082	.00077	.00032	.00030	.00030	.00032	.00033	.00031	.00026	.00033	.00034	.00036
18	.00088	.00089	.00088	.00089	.00086	.00022	.00019	.00085	.00081	.00075	.00034	.00031	.00030	.00033	.00033	.00030	.00033	.00027	.00036	.00038
19	.00079	.00079	.00079	.00080	.00079	.00020	.00019	.00079	.00078	.00069	.00033	.00031	.00031	.00031	.00031	.00029	.00032	.00033	.00037	.00033
20	.00084	.00086	.00086	.00088	.00087	.00026	.00021	.00089	.00084	.00076	.00030	.00033	.00032	.00033	.00034	.00033	.00035	.00036	.00034	.00041
21	.00962	.00960	.00955	.00967	.00945	.00243	.00227	.00976	.00948	.00859	.00203	.00182	.00182	.00203	.00199	.00174	.00194	.00197	.00213	.00220
22	.00918	.00916	.00910	.00918	.00896	.00232	.00220	.00936	.00902	.00818	.00358	.00336	.00339	.00342	.00332	.00299	.00322	.00328	.00356	.00368
23	.00395	.00377	.00372	.00375	.00365	.00096	.00095	.00410	.00410	.00359	.00168	.00148	.00137	.00137	.00141	.00139	.00161	.00186	.00370	.00199
24	.00094	.00090	.00089	.00090	.00088	.00023	.00023	.00098	.00098	.00086	.00039	.00035	.00033	.00033	.00034	.00034	.00039	.00045	.00048	.00089
25	.00163	.00171	.00170	.00164	.00152	.00038	.00035	.00153	.00149	.00137	.00067	.00097	.00097	.00066	.00057	.00048	.00052	.00050	.00053	.00062
26	.00012	.00012	.00012	.00012	.00011	.00003	.00003	.00014	.00014	.00011	.00005	.00004	.00003	.00004	.00004	.00004	.00005	.00007	.00007	.00006
27	.00006	.00007	.00007	.00006	.00006	.00001	.00001	.00005	.00005	.00005	.00005	.00002	.00002	.00002	.000015	.000014	.00001	.00001	.00001	.000015
28	.00002	.00002	.00002	.00002	.00003	.000007	.000006	.00002	.00002	.00002	.000006	.000005	.000005	.000006	.000007	.000008	.000007	.000006	.000006	.000006
29	.00005	.00005	.00005	.00005	.00005	.00001	.00001	.00005	.00005	.00005	.00002	.00002	.00002	.000026	.00004	.00004	.000036	.000025	.000023	.00002
30	.00542	.00541	.00538	.00546	.00538	.00141	.00129	.00551	.00535	.00484	.00151	.00102	.00102	.00114	.00112	.00098	.00109	.00112	.00121	.00125
31	.00463	.00462	.00459	.00464	.00456	.00119	.00110	.00472	.00452	.00413	.00202	.00193	.00192	.00202	.00201	.00186	.00198	.00201	.00210	.00215
32	.00021	.00021	.00021	.00021	.00021	.00005	.00005	.00021	.00021	.00019	.00004	.00004	.00004	.00004	.00004	.000036	.00004	.00004	.000046	.00005
33	.00100	.00100	.00103	.00107	.00116	.00033	.00028	.00110	.00100	.00090	.00032	.00030	.00031	.00036	.00045	.00033	.00041	.00036	.00035	.00035
34	.00231	.00231	.00233	.00242	.00266	.00092	.00065	.00250	.00236	.00208	.00069	.00063	.00063	.00068	.00064	.00052	.00061	.00067	.00073	.00075
35	.00126	.00131	.00124	.00125	.00118	.00034	.00042	.00152	.00140	.00117	.00041	.00041	.00041	.00052	.00060	.00033	.00034	.00035	.00041	.00043
36	.00134	.00145	.00149	.00161	.00181	.00047	.00029	.00127	.00130	.00116	.00031	.00027	.00027	.00030	.00029	.00026	.00029	.00030	.00033	.00034
37	.00132	.00121	.00119	.00120	.00110	.00031	.00040	.00165	.00148	.00122	.00028	.00025	.00025	.00028	.00027	.00023	.00026	.00027	.00029	.00030

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CHECKED BY:	VIEW FACTORS	NAA-SR-TDR 9004
DATE: 7/11/63	TABLE VI (CONTINUED)	REPORT NO.
		MODEL NO.

Fig 1

	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37			
1	.01895	.00458	.01835	.00443	.00255	.01832	.00403	.00400	.00411	.01952	.01374	.00148	.00331	.00390	.00430	.00430	.00458			
2	.01880	.00454	.01740	.00420	.00256	.01794	.00487	.00404	.00407	.01935	.01363	.00147	.00391	.00388	.00442	.00464	.00416			
3	.01874	.00452	.01724	.00417	.00255	.01757	.00486	.00432	.00404	.01931	.01359	.00147	.00396	.00393	.00418	.00481	.00407			
4	.01870	.00456	.01740	.00422	.00255	.01767	.00408	.00452	.00409	.01950	.01372	.00148	.00419	.00408	.00420	.00528	.00411			
5	.01855	.00449	.01704	.00413	.00249	.01748	.00384	.00483	.00410	.01929	.01355	.00147	.00460	.00455	.00397	.00583	.00379			
6	.00477	.00162	.00446	.00108	.00064	.00462	.00089	.00134	.00108	.00500	.00351	.00038	.00129	.00135	.00115	.00149	.00103			
7	.00464	.00115	.00458	.00111	.00063	.00474	.00084	.00121	.00104	.00481	.00339	.00037	.00116	.00114	.00148	.00097	.00143			
8	.01942	.00475	.01918	.00467	.00262	.02161	.00361	.00469	.00426	.02000	.01412	.00152	.00437	.00428	.00543	.00412	.00582			
9	.01900	.00460	.01934	.00470	.00254	.02104	.00358	.00436	.00400	.01958	.01373	.00149	.00398	.00404	.00483	.00425	.00521			
10	.01854	.00449	.01817	.00439	.00248	.01866	.00380	.00396	.00402	.01908	.01344	.00145	.00383	.00380	.00431	.00414	.00459			
11	.00074	.00033	.00145	.00034	.00019	.00131	.00017	.00020	.00029	.00077	.00078	.00005	.00023	.00022	.00026	.00018	.00018			
12	.00075	.00034	.00138	.00032	.00045	.00125	.00025	.00021	.00031	.00077	.00079	.00005	.00023	.00022	.00029	.00018	.00018			
13	.00075	.00034	.00127	.00031	.00045	.00116	.00025	.00021	.00034	.00077	.00079	.00006	.00025	.00022	.00029	.00018	.00018			
14	.00074	.00032	.00116	.00028	.00018	.00120	.00017	.00022	.00033	.00077	.00078	.00006	.00026	.00022	.00033	.00018	.00018			
15	.00075	.00032	.00123	.00030	.00018	.00122	.00017	.00028	.00056	.00077	.00079	.00006	.00034	.00021	.00039	.00018	.00018			
16	.00070	.00030	.00129	.00031	.00017	.00127	.00016	.00033	.00068	.00072	.00075	.00005	.00038	.00018	.00023	.00017	.00017			
17	.00073	.00031	.00142	.00035	.00017	.00157	.00017	.00027	.00055	.00075	.00077	.00005	.00034	.00020	.00022	.00018	.00017			
18	.00074	.00032	.00166	.00040	.00017	.00201	.00017	.00022	.00039	.00077	.00079	.000056	.00027	.00022	.00023	.00019	.00018			
19	.00069	.00032	.00324	.00041	.00018	.00210	.00016	.00020	.00033	.00072	.00076	.000053	.00023	.00021	.00024	.00017	.00017			
20	.00076	.00034	.00165	.00080	.00019	.00164	.00018	.00021	.00032	.00078	.00081	.000057	.00024	.00023	.00026	.00019	.00018			
21	.00790	.00206	.00800	.00193	.00127	.00861	.00184	.00204	.00185	.00867	.00592	.00062	.00198	.00211	.00211	.00201	.00196			
22	.00810	.00255	.01398	.00339	.00239	.01262	.00200	.00214	.00334	.00817	.00662	.00060	.00252	.00222	.00276	.00195	.00191			
23	.00340	.00157	.00719	.00150	.00083	.00611	.00078	.00091	.00136	.00351	.00303	.00026	.00103	.00099	.00108	.00082	.00083			
24	.00081	.00037	.00147	.00042	.00020	.00138	.00019	.00022	.00032	.00084	.00072	.00006	.00025	.00024	.00026	.00020	.00020			
25	.00144	.00058	.00199	.00049	.00041	.00187	.00110	.00035	.00049	.00140	.00117	.00010	.00039	.00036	.00043	.00033	.00032			
26	.00011	.00004	.00019	.00004	.00002	.00017	.00002	.00003	.00004	.00011	.00009	.00008	.00003	.00003	.00003	.000025	.000026			
27	.00005	.000014	.00005	.000005	.000036	.00005	.00002	.00001	.000013	.000051	.000038	.000004	.00001	.000014	.000012	.000013	.00001			
28	.00002	.000006	.00002	.000005	.000003	.00002	.000004	.000009	.000009	.00002	.000016	.000002	.00002	.000005	.000006	.000006	.000005			
29	.000046	.00002	.00008	.00002	.00001	.000076	.00001	.00002	.000033	.000047	.00004	.000003	.00005	.00001	.000016	.00001	.00001			
30	.00477	.00118	.00452	.00110	.00065	.00461	.00096	.00108	.00103	.00482	.00340	.00096	.00104	.00157	.00113	.00120	.00116			
31	.00398	.00134	.00605	.00147	.00088	.00584	.00091	.00109	.00152	.00415	.00355	.00031	.00118	.00130	.00121	.00101	.00099			
32	.00017	.00004	.00017	.00004	.000024	.00017	.000037	.00004	.00004	.00019	.00013	.000014	.00004	.00007	.00004	.00005	.000046			
33	.00098	.00035	.00124	.00030	.00019	.00122	.00020	.00088	.00096	.00096	.00075	.00007	.00028	.00025	.00028	.00024	.00022			
34	.00231	.00064	.00267	.00065	.00038	.00250	.00058	.00059	.00058	.00331	.00231	.00024	.00058	.00063	.00063	.00096	.00090			
35	.00123	.00041	.00147	.00036	.00023	.00144	.00025	.00030	.00037	.00120	.00093	.00009	.00032	.00031	.00036	.00027	.00030			
36	.00124	.00030	.00118	.00029	.00017	.001197	.00027	.00031	.00027	.00134	.00094	.00010	.00029	.00051	.00029	.00037	.00030			
37	.00112	.00028	.00112	.00027	.00015	.00116	.00023	.00027	.00025	.00121	.00085	.00009	.00025	.00045	.00030	.00028	.00032			

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VII. APPENDIX

A. Interchange Factors

For black bodies,

$$q_{a-b} = A_a F_{a-b} (t_a^4 - t_b^4)$$

where F_{a-b} represents the direct viewfactor from node a to node b. For gray body interchange, the inter-reflections within the system must be considered as well as the direct radiation. This is accomplished by writing an analogous gray body equation of the form

$$q_{a-b} = A_a \mathcal{F}_{a-b} (t_a^4 - t_b^4)$$

where the factor $\mathcal{F}_{a-b}$, called the overall interchange factor, is introduced to account for the grayness of the source-sink temperatures. This factor is a function of the geometry (viewfactors) and emissivity or grayness of the surfaces.

Before the solution of this method could be accomplished, it was necessary to determine the viewfactors between all the components included in this analysis. The viewfactors between the R/C nodes, radiation shield, and thermal barrier for the geometry shown in Figure 2 were obtained by utilizing a computer program written for determining the direct viewfactors (Reference 5). This program only applies to flat surfaces and could not be used to obtain the viewfactors for the components. These viewfactors were calculated whenever possible; however, in most cases, estimations based on the results obtained from the above computer program were made. After determining the viewfactor between a R/C node and a component, the reciprocal law

$$A_1 F_{1-2} = A_2 F_{2-1}$$

was used to obtain this viewfactor in the opposite direction.

From the resulting viewfactors and by knowing the emissivity of each node, the overall interchange factors between nodes were obtained by utilizing an existing interchange factor code (Reference 6). This program in addition to calculating the interchange factors gives the $\sum F_{i-}$ and $\sum F_{-j}$, so that the results may be easily checked. The values of the interchange factors for Case I are listed in Table 6. These values were included since they provide a means by which the validity of the results contained herein may be checked.

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Although estimations were used in many cases for determining the viewfactors, two checks were used to minimize errors. These were $\sum F_i = 1$ and $\sum F_{ij} = \epsilon_i$. The values of each viewfactor used in this analysis are given in Table 5.

B. Mean R/C Radiating Temperature

The mean radiating temperature of the R/C was calculated by writing the heat balance between some node i and the R/C nodes j, or

$$\sigma \epsilon_i A_i [t_i^4 - t_{RC}^4] = \sigma A_i \sum_j F_{i-j} (t_i^4 - t_j^4)$$

where t_{RC} is the mean radiating R/C temperature. Therefore,

$$\epsilon_i t_i^4 - \epsilon_i t_{RC}^4 = t_i^4 \sum_j F_{i-j} - \sum_j F_{i-j} t_j^4$$

Making the approximation that

$$\epsilon_i = \sum_j F_{i-j}$$

$$t_{RC} = \left[\frac{t_i^4 \sum_j F_{i-j}}{\sum_j F_{i-j}} \right]^{1/4}$$

where j represents only the R/C nodes.

The utility of this calculation is that it gives the capability to compute the radiation heat transfer rates between the R/C (sink) and an enclosed object (source). The only assumption made in this calculation is the same which was made in the derivation of the mean temperature, namely, $\epsilon_i = \sum_j F_{i-j}$.

Mean R/C Temperature

The mean temperature of the R/C was determined by

$$t_{\text{mean}} (RC) = \frac{\sum_{i=1}^{25} (mc)_i t_i}{\sum_{i=1}^{25} (mc)_i}$$

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and represents the true average temperature. This number is used (at injection) to compute the required amount of mercury inventory for R/C preheat.

C. Program Description

A program to solve equations defined herein has been written for the IBM 7094 in the Fortran System.

With an increment of one minute, it operates at a rate of approximately three revolutions or five hours per minute of machine time. Words output is ≤ 15 per revolution or ≤ 10 per hour depending on the number of nodes being taken into account.

Following is a description of pre-data input information necessary, the input data itself, sample data sheets, printed output, and CRT plots.

Data Preparation

It is essential to the correct running of the program that the node data be entered in proper sequence. It is, therefore, suggested that the user write out his sequence according to the format below before attempting to prepare the data sheets. A sample node sequence follows the format.

<u>Node</u>	<u>Component</u>
1-10	R/C nodes
11-20	Sub-cooler nodes
21	Top
22	Bottom
.	Internal components
.	.
.	.
XX	NaK nodes
.	.
.	.
XX	Injection tank storage
	CRU housing
	CRU shaft
	Bracket 1 - first component bracketed

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Node

Component

(cont'd)

Bracket 2 - first component
bracketed

" 3 "

" 4 "

" 1 - second component
bracketed

.
. .

Nodes 1-22 are always in the same order. The number of radiating internal nodes may be added to, rearranged, etc., but must always follow the bottom (22) node. All internal components classified as NaK nodes must be together and be the last of the internal components listed. This order also applies when preparing data sheets for the interchange factor code by M. P. Berhold. Punched output from the program is used as input to this code. The number of nodes at this point is the total which requires the interchange factor data.

Immediately below the NaK nodes are the injection storage tank, CRU housing, and CRU shaft followed by the bracket nodes (4) for each component attached to the wall.

Sample Case*

1-10	R/C nodes
11-20	Sub-cooler nodes
21	Radiation shield (top)
22	Bottom node (top of thermal barrier)
23	N ₂ tank
24	Hg injection storage tank
25	Hg regulator tank
26	Injection line
27	Hg regulator line

*Node sequence defined here applies to sample data sheets attached.

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Sample Case (cont'd)

28	CRU exposed bearing line (directly exposed to NaK loop nodes)
29	CRU unexposed bearing line
30	Upper vapor riser
31	Lower vapor riser
32	Hg turbine feed line
33	CRU outer shell
34	Boiler
35	NaK expansion compensator
36	Hot NaK line
37	Cold NaK line
38	Hg injection storage tank
39	CRU housing
40	CRU shaft
41	Hg regulator bracket
42	" " "
43	" " "
44	" " "
45	CRU bracket
46	" "
47	" "
48	" "
49	Hg injection tank bracket
50	" " " "
51	" " " "
52	" " " "

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Secondly, and prior to filling out the data sheets, if plotting is desired, the user should decide which nodes (by number) are to put on each graph. A maximum of 14 nodes may be plotted in any manner, i.e., all one graph, one per graph, two, three, etc. A sample plot setup is shown below and applies to the case used which is attached.

Plot #1	Node 24
	38
#2	33
	39
	40
#3	25
	27
#4	28
	29
	23
	26
	32
#5	30
	31

In preparing the data in the IP array, enter a zero for nodes not to be plotted and enter the plot number for those to be plotted. A single node may be placed on one graph only.

For each case, the input data consists of two parts:

1. A title card containing up to 72 alphanumeric characters describing the case.
2. The decimal case data. The program uses the FORTRAN DECRD routine. Each piece of data has an index assigned to it from an array (defined on following pages). The index of the first piece of data on a card is entered to the far right of the first field (using FORTRAN FIXED 10 DIGIT DECIMAL DATA SHEETS). Data are then entered in numerical order by index filling the card. The last card of data in each case must contain a minus in column one.

If the user wishes to run more than one case at a time, it is necessary to have the title card and at least one data card. The user needs only to enter the data that is changing from the previous case.

Sample data sheets are attached.

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<u>Numerical Data Index</u>	<u>Equation Symbol</u> (eq #)	<u>Program Symbol</u>	<u>Description</u>
1		IDORT	=0, data entered, printed, and plotted as a function of time; =1, data as a function of revolution
2		ISORCS	=0, sun-shade orbit; =1, constant sun-constant shade orbit
3		NPASS	if IDORT=0, enter time in even number of hours at end of case; if IDORT=1, enter even number of revolutions at end of case
4		NIN	number of internal components which have radiation term requiring interchange factor code data plus top and bottom
5		NAKN	number of NaK components (≤ 10)
6		IPLOT	=0, no CRT plotting will be done (all data below applicable to plotting need not be entered); =1, CRT plotting is desired
7		NAVGT	node number assigned to component being used as reference node in computing R.C average temperature
8		INIT	=0, initial temperatures of components are all equal except top; =1, initial temperatures vary for some or all components; =2, program will pick up last values of previous case (this option allows the user to split the CRT plots of the nodes if desired, this is the only purpose of the option and

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<u>Numerical Data Sheet</u>	<u>Equation Symbol</u> (eq #)	<u>Program Symbol</u>	<u>Description</u>
19		IBRAC(1,2)	same as IBRAC(1,1) for second bracketed node
.		.	
.		.	
.		.	
.		.	
30		IBRAC(3,5)	
31		IP(1)	=0, do not plot node 1; =X, plot on graph X
32		IP(2)	=0, do not plot node 2; =X, plot on graph X
.		.	
.		.	
.		.	
.		.	
90		IP(60)	(note: a limit of 14 nodes plus the mean temperature will be plotted for each case, thus there should be entered ≤ 14 values of IP array ≥ 1)
91		DTIME	time increment for calcu- lations in minutes
92	$(mc)_i^{(15)}$	AMCRC(1)	product of mass and specific heat for R/C nodes

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<u>Numerical Data Index</u>	<u>Equation Symbol</u> (eq #)	<u>Program Symbol</u>	<u>Description</u>
93	$(mc)_i^{(16)} + 10$	AMCRC(2)	product of mass and specific heat for sub- cooler nodes
94	$*KA_1^{(15)}$	AK(1)	product of heat transfer coefficient and cross- sectional area for R/C nodes
95	$*KA_3^{(16)}$	AK(2)	sub-cooler nodes
96	$*KA_2^{(15,16)}$	AK(3)	R/C and sub-cooler nodes vertically
97	$\alpha_s^{(15,16)}$	ALPHAS(1)	absorptivity to solar radiation: for R/C nodes
98	$\alpha_s^{(15,16)}$	ALPHAS(2)	for subcooler nodes
99	$\epsilon_T^{(15,16)}$ (ϵ_T)	EPSI	absorptivity to thermal radiation (emissivity of outside area)
100		ANGI	angle of launch in rela- tion to sun if the sun- shade orbit is being considered (0° is directly into sun, 0°+ to 180° is moving away from the sun, and 180°+ to 360° is approaching sun)
101		TOR	frequency of R/C and sub- cooler profile plots (enter in minutes or frac- tions of revolutions depending on IDORT)

*the X shown in equations is constant
and therefore built into the code

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<u>Numerical</u> <u>Data Index</u>	<u>Equation</u> <u>Symbol</u>	<u>(eq #)</u> <u>Program</u> <u>Symbol</u>	<u>Description</u>
			note: plot will be done every TOR minutes or revolutions - value has been set on test case such that one set of profiles before temperature ramp is given and in second case following the ramp (second case is continuation of first, see data sheets
102		TRAM1	time in minutes at which the NaK nodes temperatures are raised by constant specified in array below*
103		TRAM2	time at which temperature ramp of NaK nodes begins - enter in minutes*
104		TRAM3	time in minutes when temperature ramp of NaK nodes ends and temperatures become constant again*
105		TRAM4	startup time of temperature ramp for the top of the R/C given in minutes*
106		TRAM5	termination time for ramp of top in minutes*
107		TSLOPE	rate of increase of top during ramp period - enter in btu/hour
108		CUT	time in minutes to stop plotting (time at end of case)
.		.	
.		.	

*in figuring time, use 107 minutes
(see sample data case)

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<u>Numerical Data Index</u>	<u>Equation^(eq #) Symbol</u>	<u>Program Symbol</u>	<u>Description</u>
111	$(mc)_i^{(18)}$	AMC(1)	product of mass and specific heat for bottom node (node 22)
112	$(mc)_i^{(18)}$	AMC(2)	product of mass and specific heat for first internal node specified (node 23)
			Enter in order of nodes user has specified, the mc of each internal node except NaK nodes. Then immediately following the mc of the last internal node, in the same array, enter data as follows:
	$(mc)_i^{(24)}$	AMC(XX)	product of mass and specific heat for injec- tion storage tank
	$(mc)_i^{(21)}$	AMC(XX+1)	product of mass and specific heat: for CRU housing
	$(mc)_i^{(22)}$	AMC(XX+2)	for CRU shaft
	$(mc)_i^{(26)}$	AMC(XX+3)	for first node of bracket of first component which is attached to R/C (see Figure 6)
	$(mc)_i^{(27)}$	AMC(XX+4)	for second node of bracket of first component which is attached to R/C
	$(mc)_i^{(28)}$	.	for third. . .
	$(mc)_i^{(29)}$	.	for fourth. . . .
	.	.	for first node of bracket of second component which is attached to R/C

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<u>Numerical Data Index</u>	<u>Equation Symbol</u> (eq #)	<u>Program Symbol</u>	<u>Description</u>
	.	.	.
	.	.	.
	.	.	.
140	$(mc)_i$	AMC(30)	(see sample data case)
141	$A_i^{(18)}$	AREA(1)	area of bottom in ft ² (node 22)
142	$A_i^{(18)}$	AREA(2)	area of first internal component specified (node 23)
			Enter in same order as the mc's the area of each internal component. Then again in the same order for the remainder of the AREA array, enter values equal to the product of the emissivity and area for that particular component.
	$(\epsilon A)_{12}^{(23,24)}$	AREA(XX)	product of emissivity and area for injection tank storage
	$(\epsilon A)_{12}^{(20,21)}$	.	product of emissivity and area for CRU housing
	$(\epsilon A)_{23}^{(21,22)}$	.	product of emissivity and area for CRU shaft
170		AREA(30)	.
			.
			.
171	$Q^{(18)}$	QCON(1)	blank

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<u>Numerical Data Index</u>	<u>Equation Symbol</u> (eq #)	<u>Program Symbol</u>	<u>Description</u>
172		QCON(2)	heat being added to first internal component in btu/hr if necessary to prevent freezing
173		QCON(3)	heat being added to second. . .
		.	.
		.	.
		.	.
		.	heat being added to last internal component exclusive of NaK nodes
200		QCON(30)	
201-2701	F_{ij} (15,16,18)	FSCRIP	these values are punched directly from interchange factor code in proper format (see deck setup)
2701		TI(1)	if INIT=0, TI(1) equals initial temperature of all components except the top; if INIT=1, TI(1) equals initial temperature of first node; if INIT=2, the TI array need not be entered at all
		TI(2)	if INIT=0, TI(2) equals initial temperature of the top; if INIT=1, TI(2) equals initial temperature of node 2.
			remainder of array needs to be entered only if INIT=1

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<u>Numerical</u> <u>Data Index</u>	<u>Equation</u> <u>Symbol</u>	<u>(eq #)</u> <u>Program</u> <u>Symbol</u>	<u>Description</u>
		TI(3)	initial temperature of node 3
.		.	must have initial temperature specified for all components, brackets, etc.
.		.	.
.		.	.
2760		TI(60)	
2761		SLOPE(1)	rate of increase of first NaK node during ramp period - enter in btu/hr
2762		SLOPE(2)	rate of increase of second. . .
.		.	
.		.	
2770		SLOPE(10)	
2771		CONT(1)	instantaneous change in temperature of first NaK node at time TRAM1 - enter in degrees Rankine
.		.	
.		.	
2780		CONT(10)	
2781	$\left(\frac{KA}{\Delta X}\right)$ 1-2	(25,26) AKX(1,1)	thermal conductance in btu/hr-°R for first component attached to R/C between the internal component and first 1/3 of equivalent bracket

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<u>Numerical Data Index</u>	<u>Equation Symbol</u> (eq #)	<u>Program Symbol</u>	<u>Description</u>
2782	$\left(\frac{KA}{\Delta X}\right)_{2-3}$ (26,27,28)	AKX(2,1)	thermal conductance for first component between first 1/3 and second; also, equal to thermal conductance between second 1/3 and third
2783	$\left(\frac{KA}{\Delta X}\right)_{4-5}$ (28,29)	AKX(3,1)	thermal conductance term of third 1/3 of equivalent bracket through total surface area of bracket attached to supporting wall
2784	$\left(\frac{KA}{\Delta X}\right)_{5-6}$ (29,30)	AKX(4,1)	thermal conductance through total surface area of bracket attached to supporting wall to: the upper R/C node
2785	$\left(\frac{KA}{\Delta X}\right)_{5-7}$ (29,31)	AKX(5,1)	the lower R/C or sub-cooler node
2786		AKX(6,1)	blank
2789		AKX(9,1)	
2790		AKX(1,2)	same as AKX(1,1) for second node bracketed to wall
.		.	
.		.	
.		.	
.		.	
2825		AKX(9,5)	

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Desk Setup

*The script f data has a minus in column one of the last card. Therefore, the user does not need one for the first case and must allow for the script f data deck to follow his decimal data.

FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO. CASE 1 PROGRAMMER _____ DATE _____ PAGE 1 of 10 JOB NO. _____

NUMBER	IDENTIFICATION	DESCRIPTION DO NOT KEY PUNCH
1 P 0.5T TEST CH		title card
13 SE NUMBER 0N		
25 E FOR TDR		
37		
49		
61		
1		
13 1.		IDRT
25 0.		ISRC5
37 12.		NPASS
49 17.		NIN
61 4.		NAKN
13 1.		IPLDT
25 1.		NAVGT
37 0.		INIT
49 0.		NPLDT
61 3.		NCON2
13 24.		LNJ
25 33.		ICRU
37 3.		ICDN
49		
61		

FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO. CASE1 PROGRAMMER _____ DATE _____ PAGE 2 of 10 JOB NO. _____

NUMBER	IDENTIFICATION	DESCRIPTION DO NOT KEY PUNCH
1	16	
13	25.	IBRAC (1,1)
25	3.	(2,1)
37	13.	(3,1)
49	33.	(1,2)
61	6.	(2,2)
1	21	
13	16.	(3,2)
25	24.	(1,3)
37	10.	(2,3)
49	20.	(3,3)
61	1.	60
1	31	
13	0.	IP (1)
25	0.	(2)
37	0.	(3)
49	0.	(4)
61	0.	(5)
1	36	
13	0.	(6)
25	0.	(7)
37	0.	(8)
49	0.	(9)
61	0.	(10)
	1.	80

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FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO. CASE1 PROGRAMMER _____ DATE _____ PAGE 3 of 10 JOB NO. _____

NUMBER	IDENTIFICATION	DESCRIPTION	DO NOT KEY PUNCH
1	41		
13	0.	(11)	
25	0.	(12)	
37	0.	(13)	
49	0.	(14)	
61	0.	(15)	
1	46		
13	0.	(16)	
25	0.	(17)	
37	0.	(18)	
49	0.	(19)	
61	0.	(20)	
1	51		
13	0.	(21)	
25	0.	(22)	
37	4.	(23)	
49	1.	(24)	
61	3.	(25)	
1	56		
13	4.	(26)	
25	3.	(27)	
37	4.	(28)	
49	4.	(29)	
61	5.	(30)	

FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO. CASE 1 PROGRAMMER _____ DATE _____ PAGE 4 of 10 JOB NO. _____

NUMBER	IDENTIFICATION	DESCRIPTION DO NOT KEY PUNCH
1	61	
13	5.	(31)
25	4.	(32)
37	2.	(33)
49	0.	(34)
61	0.	(35)
1	66	
13	0.	(36)
25	0.	(37)
37	1.	(38)
49	2.	(39)
61	2.	(40)
1	71	
13	0.	(41)
25	0.	(42)
37	0.	(43)
49	0.	(44)
61	0.	(45)
1	76	
13	0.	(46)
25	0.	(47)
37	0.	(48)
49	0.	(49)
61	0.	(50)

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FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO. CASE 1 PROGRAMMER _____ DATE _____ PAGE 5 of 10 JOB NO. _____

NUMBER	IDENTIFICATION	DESCRIPTION	DO NOT KEY PUNCH
1	81		
13	0.	(51)	
25	0.	(52)	
37			
49	73 80		
61	1. 170		
1	91		
13	1.	DTIME	
25	1.68	AMERE (1)	
37	.306	(2)	
49	1.32	AK (1)	
61	.044	1 1.80 (2)	
1	96		
13	.242	(3)	
25	.3	ALPHAS (1)	
37	.3	(2)	
49	.91	73 80 EPSI	
61	0.0	1 1.90 ANGI	
1	101		
13	11.7	TOR	
25	1107.7	TRAM1	
37	1132.7	TRAM2	
49	1247.7	73 80 TRAM3	
61	1185.7	1 200 TRAM4	

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FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO. CASE1 PROGRAMMER _____ DATE _____ PAGE 6 of 10 JOB NO. _____

NUMBER	IDENTIFICATION	DESCRIPTION	DO NOT KEY PUNCH
106			
1800.		TRANS	
24.8		TSLDPE	
1249.		CUT	
	73 80		
1	210		
111			
4.		AME (1)	internal nodes (mode 22)
1.44		(2)	
1.		(3)	
2.34		(4)	
.00656	1 220	(5)	
116			
.0152		(6)	
.00715		(7)	
.0207		(8)	
.415		(9)	
.353	1 230	(10)	
121			
1.792		(11)	
3.0		(12)	internal nodes (mode 33)
2.7		(13)	injection tank storage (38)
2.		(14)	CRU housing (39)
.5	1 240	(15)	CRU shaft (40)

FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO. CASE1 PROGRAMMER _____ DATE _____ PAGE 7 of 10 JOB NO. _____

NUMBER	IDENTIFICATION	DESCRIPTION	DO NOT KEY PUNCH
1.26			
.064		(16)	node 1 as per figure 6 - 1st node bracketed (4)
.064		(17)	" 2 " " " " "
.064		(18)	" 3 " " " " "
.0136		(19)	" 4 " " " " "
.084	1 250	(20)	" 1 " " " " 2nd node bracketed
131			
.084		(21)	" 2 " " " " "
.084		(22)	" 3 " " " " "
.0136		(23)	" 4 " " " " "
.0216		(24)	" 1 " " " " 3rd node bracketed
.0216	1 260	(25)	" 2 " " " " "
136			
.0216		(26)	" 3 " " " " "
.0136		(27)	" 4 " " " " "
141			
4.9		AREA (1)	internal nodes (area)
2.09		(2)	
2.06		(3)	
3.57		(4)	
.0655	1 280	(5)	

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FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO. CASE 1 PROGRAMMER _____ DATE _____ PAGE 8 of 10 JOB NO. _____

NUMBER	IDENTIFICATION	DESCRIPTION	DO NOT KEY PUNCH
1	146		
13	. 1305	(6)	
25	. 0517	(7)	
37	. 122	(8)	
49	2.75	(9)	
61	2.46	(10)	
1	151		
13	1.305	(11)	
25	2.35	(12)	internal nodes
37	.4	(13)	injection tank storage (E * area)
49	.4	(14)	same arrangement
61	.08	(15)	as AME array
1	156		
13	.08	(16)	
25	.08	(17)	
37	.08	(18)	
49	.0191	(19)	
61	.0853	(20)	
1	161		
13	.0853	(21)	
25	.0853	(22)	
37	.0139	(23)	
49	.08	(24)	
61	.08	(25)	

FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO. CASE1 PROGRAMMER _____ DATE _____ PAGE 9 of 10 JOB NO. _____

NUMBER	IDENTIFICATION	DESCRIPTION	DO NOT KEY PUNCH
1	166		
13	.08	(26)	
25	.02	(27)	
37			
49			
61	1 330		
1	2701		
13	40.	TI(1)	
25	25.	(2)	
37			
49			
61	1 340		
1	2761		
13	486.	SLOPE(1)	
25	486.	(2)	
37	486.	(3)	
49	486.	(4)	
61	1 350		
1	2771		
13	155.	CNT(1)	
25	155.	(2)	
37	155.	(3)	
49	155.	(4)	
61	1 360		

FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO. CASE 1 PROGRAMMER _____ DATE _____ PAGE 10 of 10 JOB NO. _____

NUMBER	IDENTIFICATION	DESCRIPTION	DO NOT KEY PUNCH
1	2781		
13	.35	AKX(1,1)	
25	.175	(2,1)	
37	.074	(3,1)	
49	.0567	(4,1)	
61	.523	(5,1)	
1	2790		
13	1.08	(1,2)	
25	.54	(2,2)	
37	.15	(3,2)	
49	.0554	(4,2)	
61	.512	(5,2)	
1	2799		
13	212	(1,3)	
25	106	(2,3)	
37	065	(3,3)	
49	.0567	(4,3)	
61	.523	(5,3)	
1			
13			
25			
37			
49			
61			

note: no - sign as script of data
will follow this card and
it contains a minus sign in
column one of last card.
successing cards must however
have the minus punch in
last card of data.

TEST CASE OF POST INCLUDING RAD. AND COND. TERMS FOR INTERNAL NODES

SUN-SHADE ORBIT FOR 10 REVOLUTIONS

TOTAL NUMBER OF NODES 47

NUMBER OF INTERNAL COMPONENTS
(INCLUDING TOP, BOTTOM, AND NAK NODES) 17

NUMBER OF NAK NODES 4

TIME INCREMENT 0.1000E 01 MINUTES

ABSORBTIVITY TO THERMAL RADIATION
= EMISSIVITY OF OUTSIDE AREA 0.9100E 00

ABSORBTIVITY TO SOLAR RADIATION
R/C NODES 0.3000E-00
SUB-COOLER NODES 0.3000E-00

PRODUCT OF MASS AND SPECIFIC HEAT
PER R/C NODE 0.1680E 01
PER SUB-COOLER NODE 0.3060E-00

PRODUCT OF HEAT TRANSFER COEFFICIENT
AND CROSS-SECTIONAL AREA
R/C NODES HORIZONTALLY 0.1320E 01
SUB-COOLER NODES HORIZONTALLY 0.1440E-00
R/C TO SUB-COOLER NODES VERTICALLY 0.2420E-00

ORBITAL POSITION AT TIME = 0.0 0. DEGREES

INITIAL TEMPERATURE OF TOP 0.2500E 02 DEGREES

TEMPERATURE OF TOP INCREASES AT 0.2480E 02 BTU/HR
FROM 0.1198E 04 TO 0.1800E 04 MINUTES

TEST CASE OF POST INCLUDING RAD. AND COND. TERMS FOR INTERNAL NODES

INTERIOR NODE DATA

MASS TIMES
SPECIFIC HEAT

AREA

HEATER

22	0.4000E 01	0.4900E 01	0.
23	0.1440E 01	0.2090E 01	0.
24	0.3700E 01	0.2060E 01	0.
25	0.2340E 01	0.3570E 01	0.
26	0.6560E-02	0.6550E-01	0.
27	0.1520E-01	0.1305E-00	0.
28	0.7150E-02	0.5170E-01	0.
29	0.2070E-01	0.1220E-00	0.
30	0.4150E-00	0.2750E 01	0.
31	0.3530E-00	0.2460E 01	0.
32	0.1792E 01	0.1305E 01	0.
33	0.3000E 01	0.2350E 01	0.

NAK NODE DATA

TEMPERATURE INCREASES BY CONSTANT AT 0.1120E 04

RAMP BEGINS AT 0.1145E 04

AND BECOMES CONSTANT AGAIN AT 0.1260E 04

NODE	CONSTANT	RATE OF INCREASE
34	0.1550E 03	0.4860E 03
35	0.1550E 03	0.4860E 03
36	0.1550E 03	0.4860E 03
37	0.1550E 03	0.4860E 03

TEST CASE POST INCLUDING RAD. AND COND. TERMS FOR INTERNAL NODES
SUN-SHADE ORBIT

MIN	REV	ANG	AVG RAD MEAN	TEMPERATURE OF NODES IN DEGREES FAHRENHEIT										
				I	I+1	I+2	I+3	I+4	I+5	I+6	I+7	I+8	I+9	I+10
0.	0.	0.	40.0	0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
			40.0	10	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
				20	25.0	40.0	40.0	400.0	40.0	40.0	40.0	40.0	40.0	40.0
				30	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
				40	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
1.00	0.009	3.37	31.9	0	33.4	32.9	31.7	31.3	31.7	31.8	31.6	31.3	31.7	32.9
			32.0	10	33.0	32.5	31.4	30.9	31.3	31.5	31.3	30.9	31.4	32.5
				20	25.0	40.0	40.0	400.0	40.0	40.2	40.0	40.0	40.0	40.1
				30	40.1	40.0	40.0	40.0	40.0	40.0	40.0	39.6	40.0	40.0
				40	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
2.00	0.019	6.73	24.6	0	28.0	27.0	24.4	23.0	23.4	23.5	23.3	23.0	24.4	27.0
			24.6	10	27.4	26.1	23.9	22.3	22.7	23.2	22.7	22.3	23.6	26.2
				20	25.0	40.0	40.0	400.0	40.0	40.1	40.0	40.0	40.0	40.0
				30	40.0	40.0	40.0	40.0	40.0	40.0	40.0	39.3	40.0	38.9
				40	38.9	38.9	33.7	39.9	39.9	39.9	34.9			
3.00	0.028	10.10	18.1	0	23.7	22.1	17.8	15.3	15.7	15.6	15.5	15.4	17.8	22.1
			18.0	10	22.9	20.8	17.2	14.4	14.7	15.5	14.7	14.4	16.7	20.9
				20	25.0	40.0	40.0	400.0	40.0	40.0	40.0	40.0	40.0	39.8
				30	39.9	40.0	40.0	40.0	40.0	40.0	40.0	38.9	40.0	37.8
				40	36.9	36.0	27.2	39.7	39.7	39.5	28.6			
4.00	0.037	13.47	12.3	0	20.5	18.1	11.9	8.3	8.6	8.4	8.2	8.3	11.9	18.1
			12.1	10	19.4	16.4	11.2	7.0	7.3	8.3	7.3	7.0	10.6	16.6
				20	25.0	40.0	40.0	400.0	40.0	39.6	39.9	39.9	40.0	39.6
				30	39.7	40.0	40.0	40.0	40.0	40.0	40.0	38.6	40.0	36.5
				40	34.4	32.3	20.9	39.5	39.4	38.9	22.4			
5.00	0.047	16.83	7.2	0	18.1	14.9	6.7	1.7	1.9	1.6	1.5	1.8	6.7	14.9
			6.8	10	16.9	12.9	5.9	0.1	0.4	1.7	0.4	0.2	5.0	13.1
				20	25.0	40.0	39.9	400.0	40.0	39.2	39.8	39.8	39.9	39.2
				30	39.5	40.0	40.0	40.0	40.0	40.0	40.0	38.2	40.0	35.1
				40	31.5	28.3	15.2	39.2	39.0	38.1	16.6			

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D. Method of Predicting the Temperature Extremes of any Component

The computer results obtained from the foregoing analysis were used to derive a method of predicting the temperature as a function of time of any component, valve, section of pipe, etc., contained in the PCS. Since this method is based on computer results, the only mode of heat transfer considered was by internal radiation.

The heat loss by radiation from a body of Area A, emissivity E, and surface temperature T_s to the surroundings at a temperature T_a is given by

$$q_r = \sigma A E (T_s^4 - T_a^4)$$

Even though this heat loss of radiant energy is proportional to the 4th power of the temperatures, a radiation coefficient (h_r) may be defined on the basis of the linear temperature difference, or

$$q_r = A h_r (T_s - T_a)$$

From this definition, a time constant $\frac{mc}{h_r EA}$ is obtained. Also, by equating the above equations

$$h_r = \frac{\sigma E (T_s + T_a) (T_s^2 + T_a^2)}{1}$$

Obviously h_r is a function of the source and sink temperature as well as the surface emissivity. The sink temperature for any PCS component is effectively the mean R/C temperature since the sink and source temperatures both vary and an analytic determination of the radiation coefficient is difficult.

For this reason, a pseudo time constant defined as $\tau = \frac{mc}{EA}$ was introduced and the relationship between this constant and the real time constant was determined from the results of the foregoing analysis. This relationship is shown by Graph 42 which is a plot of the real time constant versus the pseudo time constant.

By calculating the value of the pseudo time constant for any component in question, the real time constant can be obtained by referring to this graph. Once the real time constant is known, the temperature change of any component as a function of time may be determined from

$$t = t_0 - (t_0 - t_m)(1 - e^{-T/\tau})$$

prior to sensible heat.

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where: t_0 - initial component temperature at launch = 40°F
 t_m - mean temperature at which a component reaches thermal equilibrium with surroundings (-65°F)
 T - time from launch to point at which the temperature (t) of the component is derived prior to startup
 γ - real time constant

A second plot was made from the results of this program which gives the change in temperature from the period between sensible heat generation and mercury injection as a function of $\epsilon A/mc (\frac{1}{T})$.

This plot had a maximum deviation of $\pm 20^\circ\text{F}$ and this large of a variation was only experienced with $\epsilon A/mc$ greater than 1.2.

EX: This method is best illustrated by an example. Assume a component has the following properties:

mass = 10 lbs
specific heat = $.10 \frac{\text{BTU}}{\text{lb}^\circ\text{F}}$
emissivity = .05
surface area = 2 ft^2

The pseudo time constant is

$$\gamma' = \frac{mc}{\epsilon A} = \frac{(10)(.095)}{(.05)(2)} = 9.5$$

Referring to Graph 42, the real time constant is 18.8 hours. If the time from vehicle launch to startup is 20 hours (≈ 9 hours minimum) the temperature of the component at the initiation of the startup sequence is

$$\begin{aligned} t &= t_0 - (t_0 - t_m)(1 - e^{-T/\gamma}) \\ t &= 40 - 105(1 - e^{-20/18.8}) \\ t &= -28.6^\circ\text{F} \end{aligned}$$

Taking the reciprocal of the pseudo time constant (γ') and referring to graph 43, the component's change in temperature from sensible heat to injection is 26°F , or the temperature of the component at injection is -2.6°F .

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REAL TIME CONSTANT FROM
PROGRAM RESULTS
VERSUS
PSEUDO TIME CONSTANT

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X, PSEUDO TIME CONSTANT = tmc

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GRAPH 42

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K&M
20 X 20 TO THE INCH 359-10 1/4 G
KEUFFEL & ESSER CO
MADE IN U.S.A.

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CHANGE IN TEMPERATURE FROM
 SENSIBLE HEAT TO INJECTION
 VERSUS
 RECIPROCAL OF PSEUDO TIME CONSTANT

GRAPH 43

KE
 20 X 20 TO THE INCH 359-10 1/2 G
 KEUFFEL & ESSER CO
 MAINTENANCE

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REFERENCES

1. Berman, D., TDR 6747, "SNAP-2 Prestartup System Temperature Analysis."
2. Treuenfels, E., TDR 3961, "Radiator-Condenser Analysis."
3. James, L., TDR 8302, "SNAP-2 Orbital Startup with a Thermo-electric NaK pump."
4. Treuenfels, E., TDR 8306, "SNAP-2/10A Shield Temperatures."
5. Toupo, K., NAA-SID 62-393, "A General Computer Program for the Determination of Radiant-Interchange Configuration Factors."
6. Berhold, P., and Gresho, P., "Interchange Factor Code."
(Not Published)

UNCLASSIFIED