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THERMAL RESPONSE MODEL: MBALL,(U)
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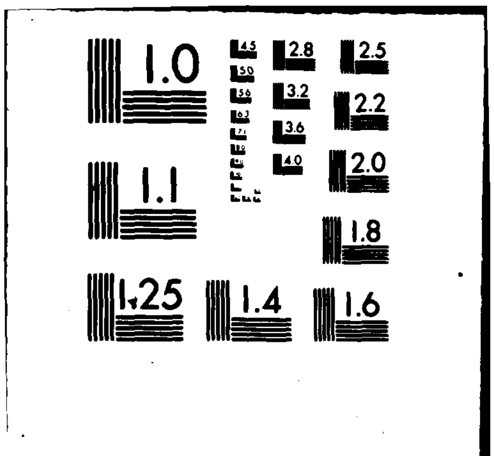

MICROCOPY RESOLUTION TEST CHART

MN-SD-9-79-893

MN-SD-9-79-893

THERMAL RESPONSE MODEL: MBALL

September 1979

TELEDYNE
BROWN ENGINEERING
Cummings Research Park • Huntsville, Alabama 35807

LETTER OF TRANSMITTAL MSE79-BMDATC-4735

TELEDYNE BROWN ENGINEERING

TO: Director
Ballistic Missile Defense
Advanced Technology Center
P. O. Box 1500
Huntsville, Alabama 35807

Attn: Max Hardwick, ATC-D

FROM: Optical Systems Department
Systems Division
Teledyne Brown Engineering
Cummings Research Park
Huntsville, Alabama 35807

SUBJECT: Transmittal of MBALL

DATE: 7 November 1979

To enable more faithful signature calculations of decoy target concepts applicable to the Optical Discrimination Program, TBE has developed a modification (MBALL) to the Optical Signatures Code (OSC). This modification supercedes all previous versions.

The following is a list of materials to be distributed as specified on the attached page:

- MBALL manual
- OSC Listing (including MBALL in EXOHEAT)
- A short description of the new 6-degree-of-freedom modification to the trajectory program BALLIS
- Update decks of MBALL and the 6-degree-of-freedom option for the OSC VI cycle.

If you have any questions concerning the above, contact the undersigned at 205-532-1355.

Warren Smith

LETTER OF TRANSMITTAL MSE79-BMDATC-4735

	Enclosures:
Director Ballistic Missile Defense Advanced Technology Center P. O. Box 1500 Huntsville, Alabama 35807 Attn: Max Hardwick, ATC-D	Letter of Transmittal Manual
Ballistic Missile Defense System Command P. O. Box 1500 Huntsville, Alabama 35807 Attn: BMDSC-C	Letter of Transmittal
Defense Technical Information Center Cameron Station Alexandria, Virginia 22314	Letter of Transmittal Manual (2)
McDonnell Douglas Corporation 5301 Bolsa Avenue Huntington Beach, California 92647 Attn: H. Herdman H. Ginell	Letter of Transmittal
MIT Lincoln Laboratory P. O. Box 73 Lexington, Massachusetts 02173 Attn: Wade Kornegay	Letter of Transmittal Manual Listing Card Decks
Nichols Research Corporation 7910 South Memorial Parkway Suite A Huntsville, Alabama 35802 Attn: C. Horgen	Letter of Transmittal Manual Listing Card Decks
Sandia Laboratories P. O. Box 5800 Albuquerque, New Mexico 87185 Attn: Bruce Bulmer	Letter of Transmittal Manual Listing Card Decks

BALLIS EXO 6DOF ANALYTIC SOLUTION

Insert into OSC VII Basic Manual:

BALLIS 6DOF ADDITION: IKIND = 4

In order to save computer time for exoatmospheric 6 degree of freedom trajectories where two moments of inertia are equal, an analytic solution to Euler's equations with no external torques has been developed. Such a solution is valid for axi-symmetric bodies above the top of BALLIS's atmosphere ($\sim 10^6$ feet). The rationale for this modification is to reduce the computer time required by BALLIS. The same input is required for this option as for option: IKIND = 3, IKIND6 = 0. The option is accessed by inputting IKIND as 4 on Card 4A. Cards 4B, 5 and 6 are also required.

Insert into Table 4-11 Basic Manual:

IKIND	.....
	=4 Exo-axisymmetric 6DOF Analytic Solution Cards 5 and 6 required.

MN-SD-9-79-893

THERMAL RESPONSE MODEL: MBALL

By

W. E. Smith

September 1979

Sponsored By

BALLISTIC MISSILE DEFENSE ADVANCED TECHNOLOGY CENTER
DEPARTMENT OF THE ARMY
HUNTSVILLE, ALABAMA

Prepared By

OPTICAL SYSTEMS DEPARTMENT
SYSTEMS DIVISION
TELEDYNE BROWN ENGINEERING
HUNTSVILLE, ALABAMA

409 177

ABSTRACT

MBALL is a subroutine of EXOHEAT for surface temperature calculations for convex objects of light to intermediate thermal mass (in-depth heat conduction is not important). It includes surface conduction and internal radiative coupling between stations, using the natural fluxes (Sun, albedo, earthshine) calculated in EXOHEAT. MBALL must be used with the OSC VI BASIC option.

APPROVED BY:

J. V. Beaupre
Manager
Optical Signature Analysis Section

N. A. Passino
Deputy Manager
Optical Systems Department

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1. INTRODUCTION

1.1 MBALL OVERVIEW

Subroutine MBALL was developed to provide target surface temperatures in an exoatmospheric environment for balloon and replica shapes of light to intermediate thermal mass. These temperatures are used by the Optical Signatures Code (OSC) (Ref. 1) to generate long wavelength infrared (LWIR) signatures for threat discrimination analysis. It is necessary that vehicle geometry, deployment, and external flux information be supplied by the OSC VI to MBALL, which performs temperature calculations for thermally light objects.

The OSC execution sequence is shown in Figure 1-1. MBALL is located in the EXO/ENDO thermal response block as a subroutine of EXOHEAT.

1.2 MBALL CAPABILITIES

Table 1-1 is a summary of MBALL's capabilities. For each point of the vehicle surface at which temperatures are calculated, MBALL uses averages of in-depth material properties (assuming a layered skin of different materials) and computes an average temperature as if the skin were made up of one homogeneous material. This temperature is then assigned to the surface of the vehicle for signature generation.

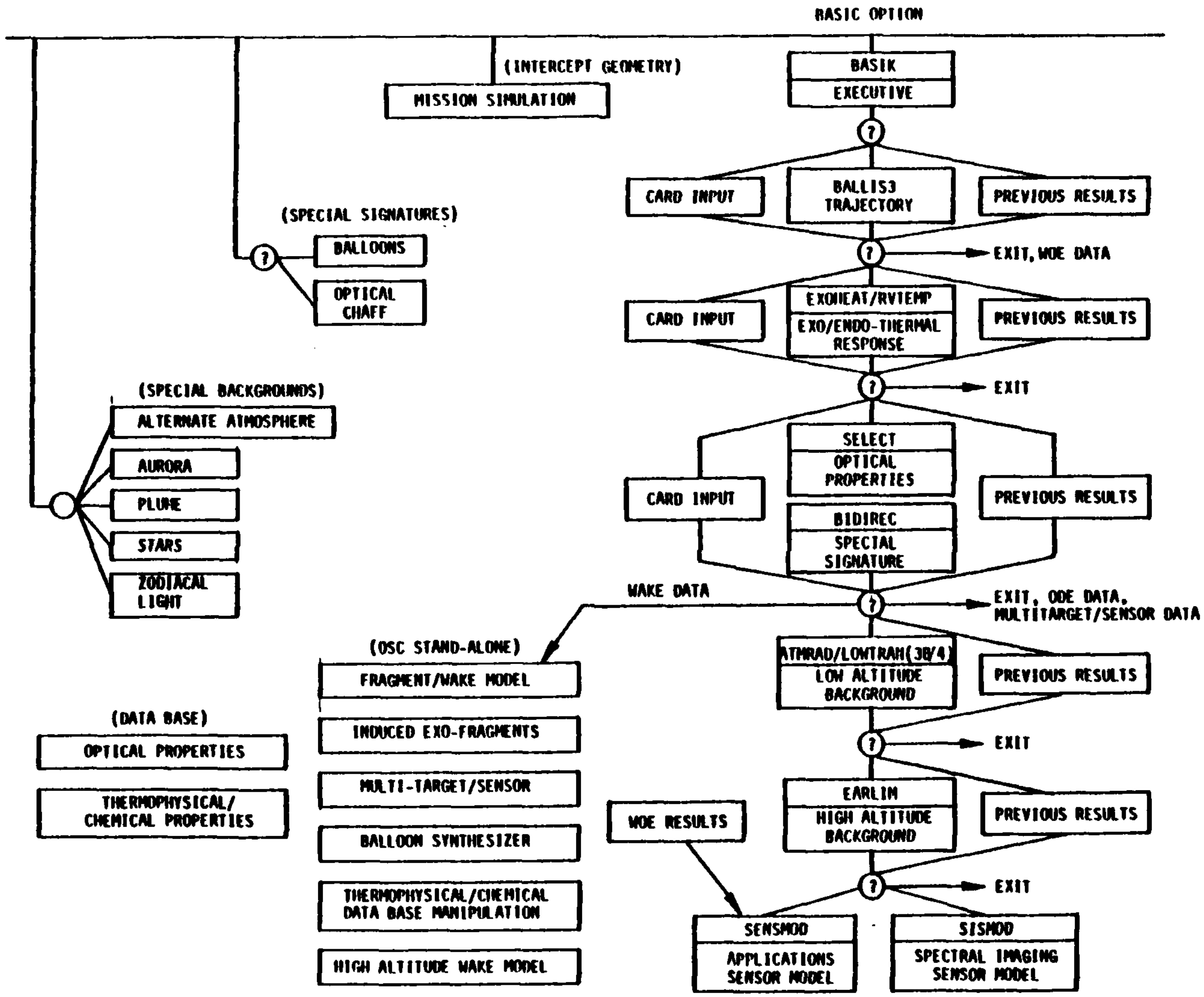


FIGURE 1-1. OSC VI PROGRAM STRUCTURE

TABLE 1-1. MBALL CAPABILITIES

Targets	• Thin to Intermediate Thermal Mass • Replica or Balloon Shapes
Thermal Fluxes	• Solar • Albedo — From EXOHEAT Subroutine (EXOENV) • Earthshine • Molecular
Station Coupling	• Internal Radiation • Thermal Conduction: Longitudinal and Transverse
Thermal Response	• Phase Change Capability • Thermal Properties Updated with Temperature
Data Base	• Earthshine Data: Models Based on NIMBUS Observations (Ref. 2)/LOWTRAN4 Calculations • Thermophysical Properties: OSC • Thermophysical/Chemical Data Base: OSC
Options	• Radiative Equilibrium (Thermal Mass = 0) • Open Surfaces

2. FUNCTIONAL ANALYSIS

Target surface temperatures are determined in the OSC by EXOHEAT for exoatmospheric conditions (greater than 400 kft) or by RVTEMP for endoatmospheric conditions (less than 400 kft). These programs need target position, velocity, and deployment information as a function of trajectory time to compute the temperatures. This information is supplied by BALLIS or by the user. The temperatures are then used by BIDIREC to generate radiometric signatures, with material optical properties supplied by SELECT. BALLIS, EXOHEAT, RVTEMP, SELECT, and BIDIREC are all contained in the OSC and are called by the OSC program BASIC$, depending on the user input.

MBALL is a subroutine of EXOHEAT and replaces EXOHEAT in-depth temperature calculations (i.e., replaces Subroutine EXOTMP) for objects of light to intermediate thermal mass. Heat flux calculations are performed in EXOHEAT (Subroutine EXOENV) for a given ballistic trajectory and vehicle geometry to determine external heating rates (from Sun, albedo, and Earth emission) and these are passed to MBALL, bypassing EXOHEAT's temperature subprograms. The vehicle geometry required by MBALL is computed in RVSNTH, a subroutine of BASIC$. Previously, RVSNTH was used only with the endoatmospheric heating routine, RVTEMP, but has been modified to supply MBALL with the necessary parameters. RVSNTH does not calculate SELECT or BIDIREC data when MBALL is called, however, so the inputs to SELECT and BIDIREC must be supplied by the user. The calculations that determine the external heating fluxes are described in the EXOHEAT manual (Ref. 3) (written before the MBALL option existed). Reference 1 contains the input to SELECT and BIDIREC. Figure 2-1 shows the EXOHEAT program flow. A description of how MBALL is called in the BASIC option is in Section 4.

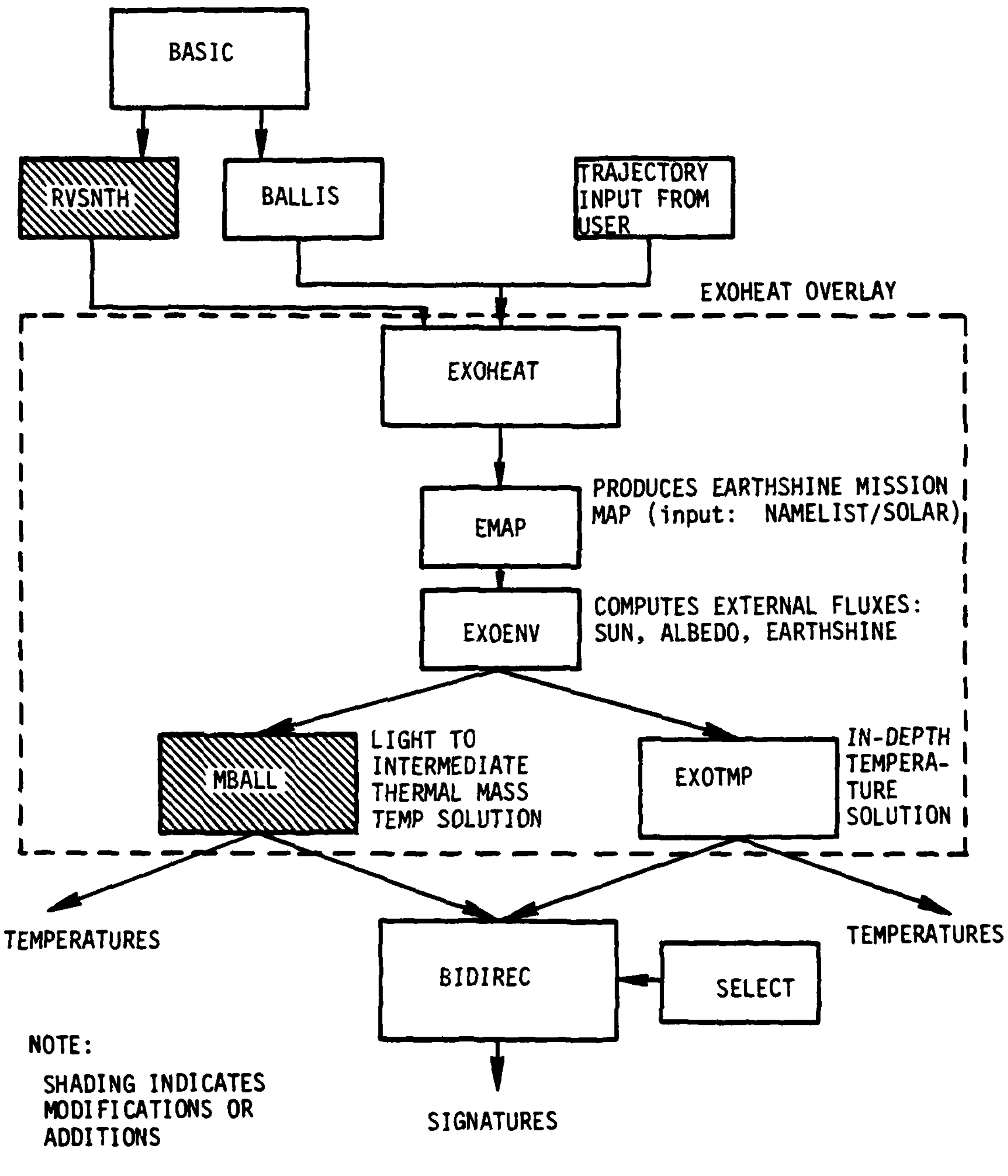


FIGURE 2-1. EXOHEAT PROGRAM STRUCTURE

3. THEORY

3.1 HEAT EQUATION

The heat equation expressing the time rate of change of temperature T at any point in a material of density ρ, thermal conductivity k, and specific heat c_p, with an internal energy source density S, can be written:

$$\rho\ c_p\ \frac{\partial T}{\partial t} = \nabla \cdot (k\ \vec{\nabla T}) + S \qquad (3\text{-}1)$$

where the term $k\vec{\nabla}T$ can be thought of as an energy density, whose divergence gives an energy source density. The term $\vec{\nabla}T$ is the spatial gradient of the temperature.

In MBALL, the thermally light skin of a replica or balloon shape is modeled by dividing it into N pieces defined by the user, where each piece has associated with it an outer surface, an inner surface, and up to four surfaces that adjoin adjacent pieces. The outer surface communicates with the external environment via radiative coupling, the inner surface communicates with the other interior surfaces in the same manner, and the adjoining surfaces communicate through heat conduction. Each piece also has an associated density, specific heat, and thermal conductivity. The values chosen for these quantities for a given piece, say the jth piece, are an appropriate average of the exact values taken over the volume of the piece. By integrating Equation 3-1 over the jth piece with this point in mind (the subscript j refers to average values), one obtains:

$$\int_{V_j} \rho_j\ c_{pj}\ \frac{\partial T_j}{\partial t}\ dV_j = \int_{\substack{\text{Areas}\\ \text{Bounding } V_j}} (k\ \vec{\nabla T}) \cdot \hat{n}_j\ dA_j \qquad (3\text{-}2)$$

where $\hat{n}_j$ is a unit normal pointing out of surface dA_j of piece j, and $S = 0$; i.e., the assumption is made that no independent sources of energy (batteries and wires) exist in the skin of our model. Because the material quantities are averages, they can be taken as constant over the volume of integration. The area integral can be resolved into its component parts:

$$\rho_j \, c_{pj} \, V_j \, \frac{\partial T_j}{\partial t} = \int_{A_j \text{ outer surface}} (k\vec{\nabla}T) \cdot \hat{n}_j \, dA_j + \int_{A_j \text{ inner surface}} (k\vec{\nabla}T) \cdot \hat{n}_j \, dA_j$$

$$+ \int_{A_j \text{ adjoining surfaces}} (k\vec{\nabla}T) \cdot \hat{n}_j \, dA_j \quad . \qquad (3\text{-}3)$$

The boundary conditions for the outside and inside surfaces of the jth piece can be written as follows, where the jth piece is assumed to radiate as a greybody with temperature T_j and emissivity ε_j:

$$\hat{n}_j \cdot k\vec{\nabla}T = -\varepsilon_j \, \sigma T_j{}^4 + Q_{ext,j} \text{ (outside)} \qquad (3\text{-}4)$$

$$\hat{n}_j' \cdot k\vec{\nabla}T = -\varepsilon_j' \, \sigma T_j{}^4 + Q_{int,j} \text{ (inside)} \qquad (3\text{-}5)$$

where prime marks denote internal normals and emissivities, and σ is the Stefan-Boltzmann constant. $Q_{ext,j}$ is the average power/area incident on the exterior of piece j and is due to the external environment. $Q_{int,j}$ is the average power/area striking the interior of piece j and is due to the other radiating pieces.

Substituting Equations 3-4 and 3-5 into Equation 3-3 for the appropriate surface integrals yields:

$$\rho_j \, c_{pj} \, V_j \, \frac{\partial T_j}{\partial t} = \int_{A_j \text{ outer}} (Q_{ext,j} - \varepsilon_j \, \sigma T_j{}^4) \, dA_j$$

$$+ \int_{A_j \text{ inner}} (Q_{int,j} - \varepsilon_j' \, \sigma T_j{}^4) \, dA_j + \int_{A_j\text{: adjoining}} (k\vec{\nabla}T) \cdot \hat{n}_j \, dA_j \quad . \qquad (3\text{-}6)$$

Because these are averages, and assuming $A_{outer} = A_{inner}$ (thin skin):

$$\rho_j c_{pj} V_j \frac{\partial T_j}{\partial t} = Q_{ext,j} A_j + Q_{int,j} A_j - (\varepsilon_j + \varepsilon_j') \sigma T_j^4 A_j$$

$$+ \sum_{\substack{\text{ajoining} \\ \text{areas}}} A_{adjoining} k_{eff} \frac{T_{adjoining} - T_j}{\Delta X_{j:adjoining}} \qquad (3\text{-}7)$$

where the conduction integral of Equation 3-6 has been approximated by a sum over all adjoining surfaces of the piece j. The terms $A_{adjoining}$, k_{eff}, $T_{adjoining}$, and $\Delta X_{j:adjoining}$ refer to the contact area between piece j and its neighbor, a properly averaged thermal conductivity between piece j and its neighbor (discussed below), the average temperature of the adjoining piece, and the distance between the centers of j and its neighbor, respectively.

It is convenient to rewrite Equation 3-7 in the following way to simplify the bookkeeping:

$$\rho_j c_{pj} V_j \frac{\partial T_j}{\partial t} = Q_{ext,j} A_j + \sum_i M_{ij} T_i^4 + \sum_i K_{ij} T_i \qquad (3\text{-}8)$$

where the matrices M_{ij} and K_{ij} contain the radiation and conduction terms, respectively, which are discussed in detail below. The sums are over all pieces, including the jth.

Because of the need to model materials that have rapidly changing specific heats as a function of temperature (i.e., water near 0°C), it is necessary to generalize the left-hand side of Equation 3-8:

$$\rho_j c_{pj} V_j \frac{\partial T_j}{\partial t} \longrightarrow \rho_j V_j \frac{\partial}{\partial t} \int_{T_{oj}}^{T_j} c_{pj} (T_j'') \, dT_j'' \qquad (3\text{-}9)$$

where T_{oj} is the initial temperature of piece j, and T_j is the temperature after some time t. Thus, the equation solved for T_j by MBALL can be written:

$$\rho_j V_j \frac{\partial}{\partial T} \int_{T_{oj}}^{T_j} c_{pj} (T_j'') \, dT_j'' = Q_{ext,j} A_j + \sum_i M_{ij} T_i^4 + \sum_i K_{ij} T_i \quad . \qquad (3\text{-}10)$$

The linearization of the left- and right -hand sides necessary for an iterative solution for T_j is described in detail in Section 3.

3.1.1 External Sources

There are four natural external sources of radiation considered: sunshine, albedo, earthshine, and molecular collisional heating. These parameters are calculated in EXOHEAT and are passed to MBALL. Reference 3 contains a complete discussion of these quantities.

- Sunshine - A solar exoatmospheric irradiance of 1353 W/m^2 is assumed. The Sun position is input in one of three ways:
  - ▲ Subsolar point input: latitude and longitude
  - ▲ Subsolar point calculated from month, day, GMT
  - ▲ Subsolar point calculated from month, day, local (24-hour) time at a given longitude
- Albedo - The reflectivity (α) of the sunlit Earth is assumed to be 0.4. The albedo radiance of a sunlit element of the Earth is

$$N_a = \frac{\alpha S \cos \theta}{\pi} \qquad (3\text{-}11)$$

  where S is the solar constant and θ is the angle between the Earth normal and the direction to the Sun.

- Earthshine - Six Earth radiance maps are available to EXOHEAT, corresponding to day/night conditions for winter, summer, and equinox. Each map corresponds to a 5- by 5-deg latitude, longitude grid. The seasons are determined by the month, and Sun position determines the time of day. Reference 2 contains a magnetic tape appendix containing earthshine data. The earthshine map may be modified with NAMELIST/SOLAR input (Ref. 3, p. 6)

- Molecular - At altitudes below 10^6 ft, a molecular collisional heating flux is used of the value

$$Q_{air} = \frac{1}{2} \rho_{air} V^3 (\hat{n} \cdot \hat{v}) \qquad (3\text{-}12)$$

  where ρ_{air} is the air density and V is the velocity of the target.

The effect that the above contributions have on the energy incident on a given area element of the target depends on the geometry of the Sun, Earth, and target configuration, and where the area element is located on the target. Only the flux component normal to the area element is considered. Reference 3 contains a detailed description of how this problem is treated. Figure 3-1 shows the geometry.

EXOHEAT has the option of calculating three different flux averaging methods (Table 3-1):

- Instantaneous - Energy incident on a given target element is that which is determined by the instantaneous geometry (i.e., position of the Sun and Earth, and location of the element on the target)

- Roll-Averaged - Energy incident on a given target element is the normalized average of the energy the element would see through a full revolution about the target longitudinal axis; therefore, all elements lying in a ring centered on the body axis experience the same incident energy.

- 4π Average - Incident energy is the normalized average of the energy that the element would see through a "tumble" over 4π steradians. All elements on the target receive the same incident energy.

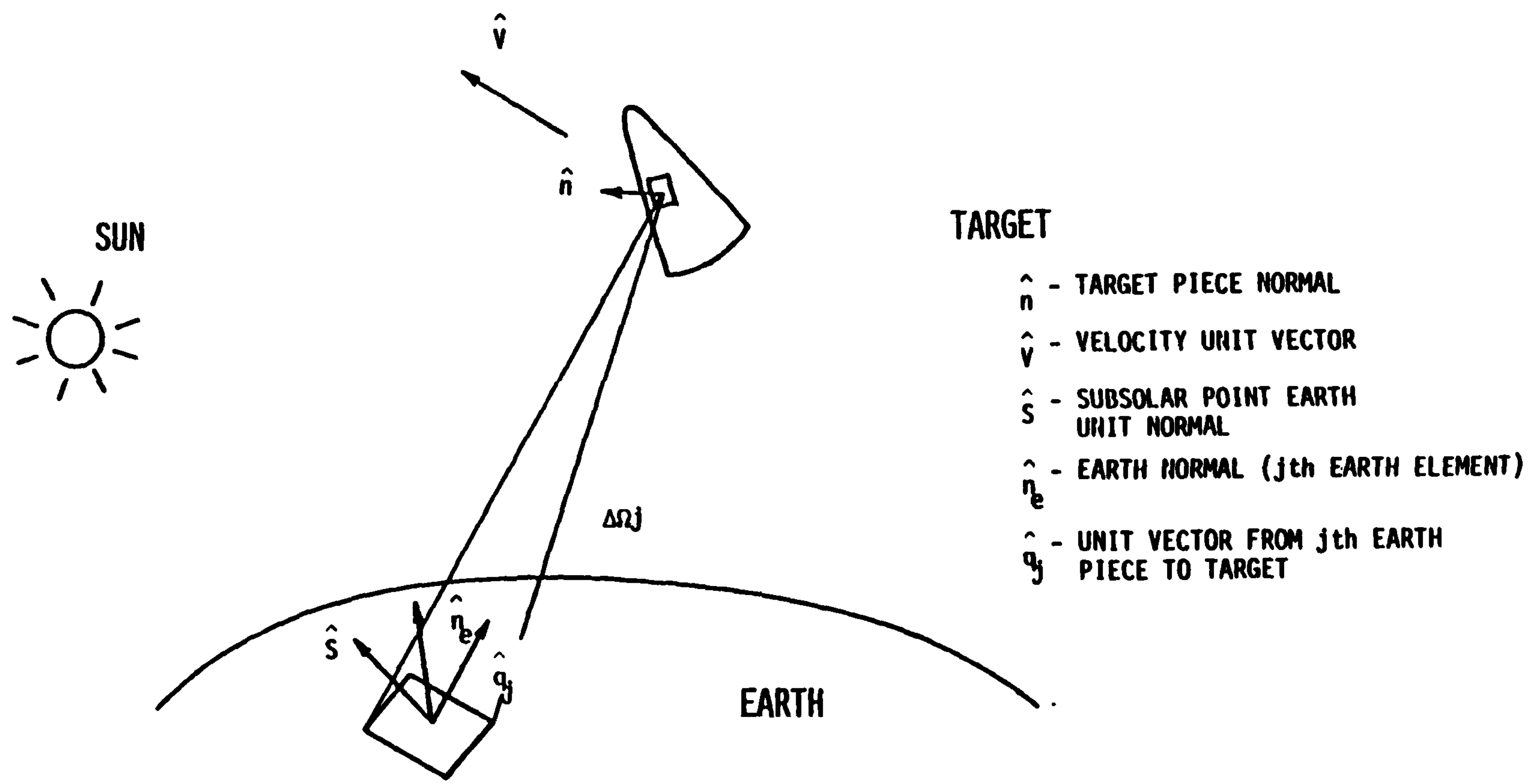


FIGURE 3-1. TARGET, SOLAR, EARTH GEOMETRY

TABLE 3-1. ATTITUDE AVERAGES FOR INCIDENCE FACTORS: $G(\hat{n},\hat{s}) = \hat{n}\cdot s\ \theta(\hat{n}\cdot\hat{s})$

MODE*	< G >	COMMENT
1	G	Not averaged. Instantaneous heat flux calculation
2	$\frac{1}{2\pi}\int_0^{2\pi} d\beta G$	Roll averaged
3	$\frac{1}{4\pi}\int d\Omega(\hat{s})\ G = \frac{1}{4}$	4π average: fast random tumbling

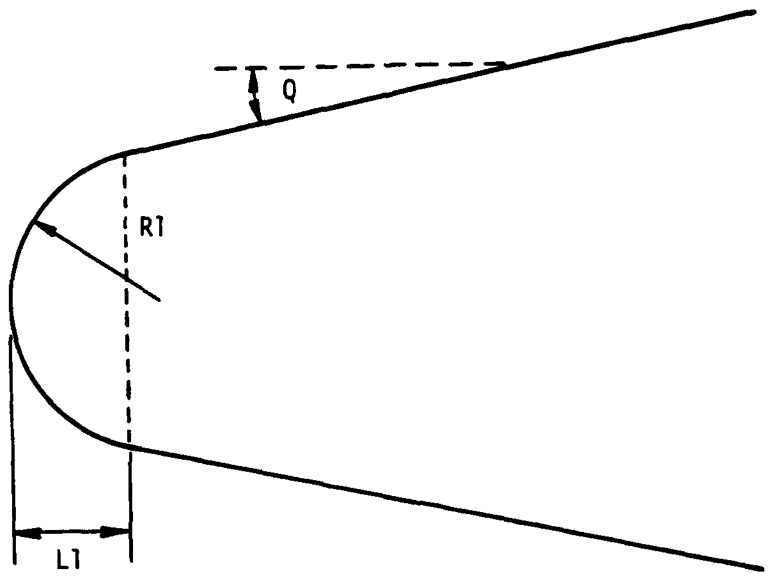
*Input parameter

MBALL has the capability of treating transverse as well as longitudinal heat conduction as described below, so mode 1, instantaneous heating rate, is necessary to make use of this ability.

3.1.2 Internal Sources, Vehicle Geometry, Radiation Matrix

MBALL considers radiative coupling between the inner surfaces of a replica or balloon shape. It is possible to model a completely closed structure, or one in which the baseplate has been removed (see Section 3.3). No internal source of energy, such as batteries or wires, are included.

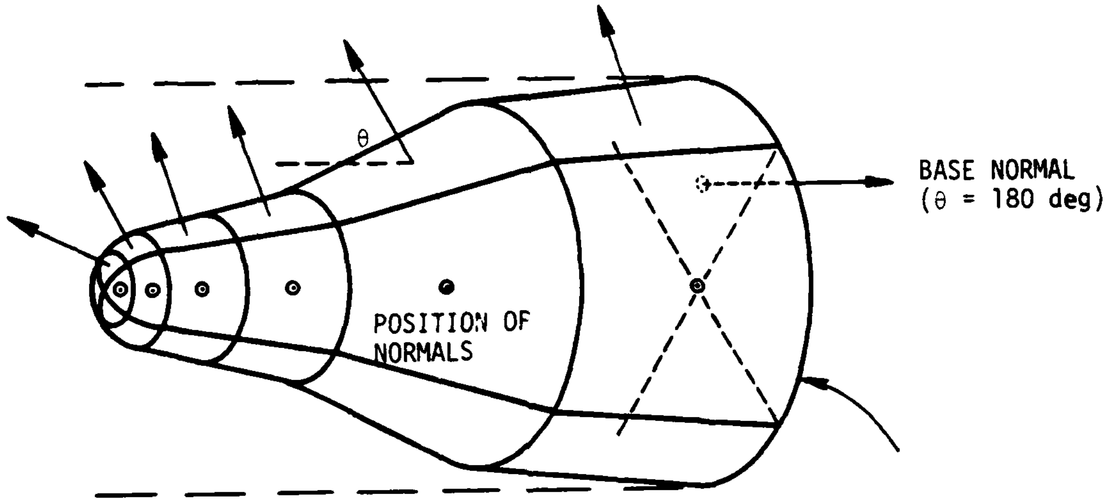
The user has the choice of modeling either a balloon (sphere) or an axially symmetric replica that can have a spherical nosecap, up to three frusta, and a flat baseplate. It is necessary to input the length of the nosecap such that it meets the first frustum tangentially (Figure 3-2). The surface area of the vehicle can be divided into as many as 50 pieces, called stations, where each station has an outer and inner surface normal, an initial temperature, an average thickness,



R1 = RADIUS OF NOSECAP
L1 = LENGTH OF NOSECAP
Q = CONE ANGLE OF FIRST FRUSTUM
L1 = R1 (1-sin Q)

FIGURE 3-2. NOSECAP GEOMETRY

specific heat, thermal conductivity, solar absorptance, outside emissivity, inside emissivity, and density defined by the user. All stations on the nose section (nose, frustum, and base are sections) have the same areas, which are calculated by the program RVSNTH. The orientation of the outer normal of each station is defined by the angle it makes with the z axis (looking toward the nose) and the roll angle ϕ (Figure 3-3). The running length, RL, distance from the nose along the axis z, and the distance from the axis, r, of the center of the station are calculated in RVSNTH (Figure 3-4). The polar and azimuthal angles are input by the user to EXOHEAT to determine the external heating rates. The polar angles for the normals on the frusta and base are chosen to agree with their respective slopes, but the choice for the polar angles on the spherical nose stations should be done such that all nose stations have equal areas (Figure 3-5). This ensures a consistent treatment of external and internal radiation in EXOHEAT and MBALL. The roll angle ϕ is measured counterclockwise from the vehicle x axis, looking from the nose to the base (Figure 3-3).

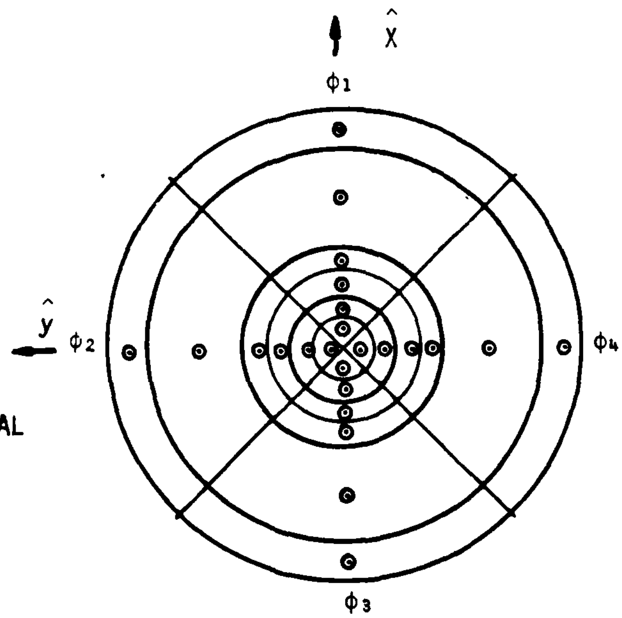


θ_i = POLAR ANGLE (THET(I))
ϕ_i = AZIMUTHAL ANGLE (ROLL(I))

THIS EXAMPLE HAS 7 LONGITUDINAL BY 4 AZIMUTHAL = 28 STATIONS TOTAL

NUMBERING OF STATIONS
INCREASES LONGITUDINALLY:

ϕ_1: STATION 1-7
ϕ_2 8-14
ϕ_3 15-21
ϕ_4 22-28

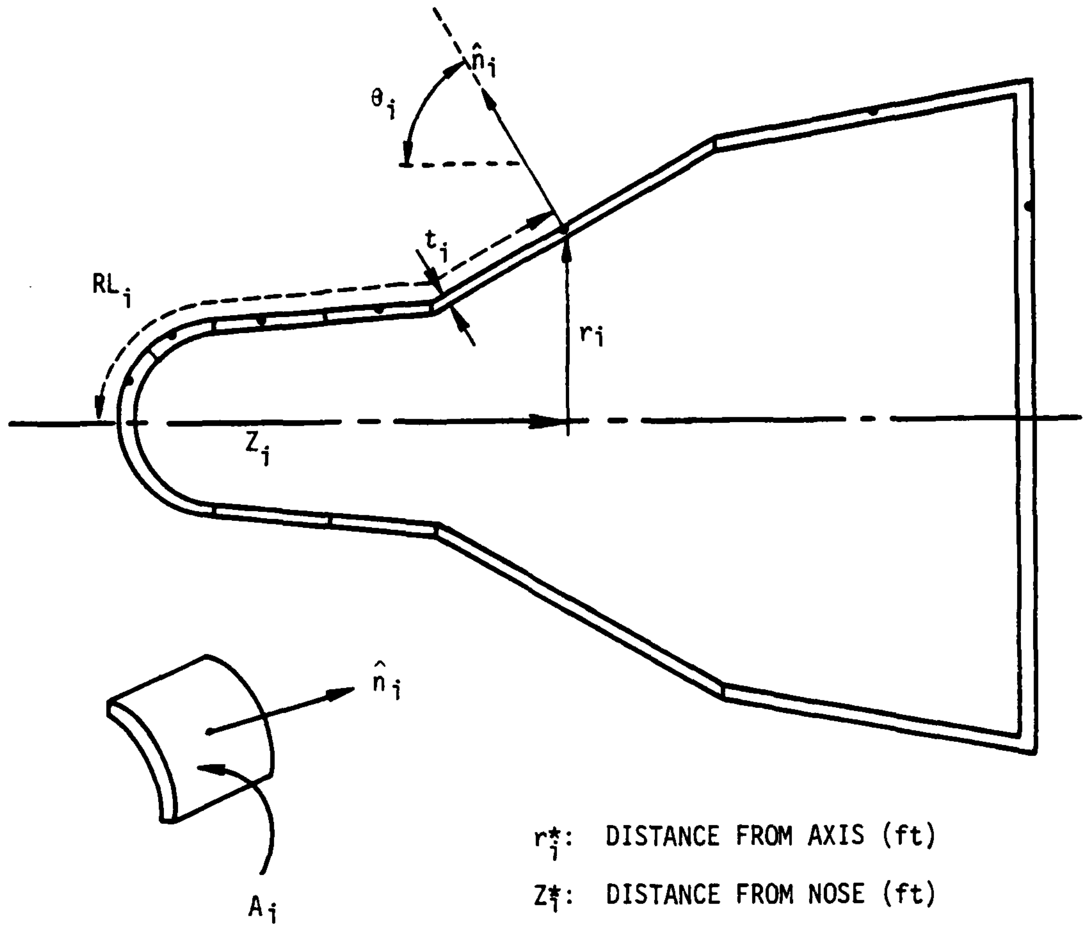


⊙ = POSITION OF SURFACE NORMAL
(BASE NORMALS ARE NOT
VISIBLE)

$\hat{Z}$ IS ALONG AXIS, OUT OF
PAGE

VEHICLE AS VIEWED FROM THE FRONT

FIGURE 3-3. STATION NORMALS (EXTERIOR)



r_i^*: DISTANCE FROM AXIS (ft)

Z_i^*: DISTANCE FROM NOSE (ft)

RL_i^*: RUNNING LENGTH (ft)

A_i^*: STATION AREA (ft^2)

t_i: THICKNESS (THK) (ft)

*CALCULATED IN RVSNTH

NOTE: θ_i IS NOT PASSED TO EXOHEAT BY RVSNTH, AND MUST BE CALCULATED BY THE USER FOR EXOHEAT INPUT, SEE FIGURE 3-5.

FIGURE 3-4. TARGET GEOMETRY

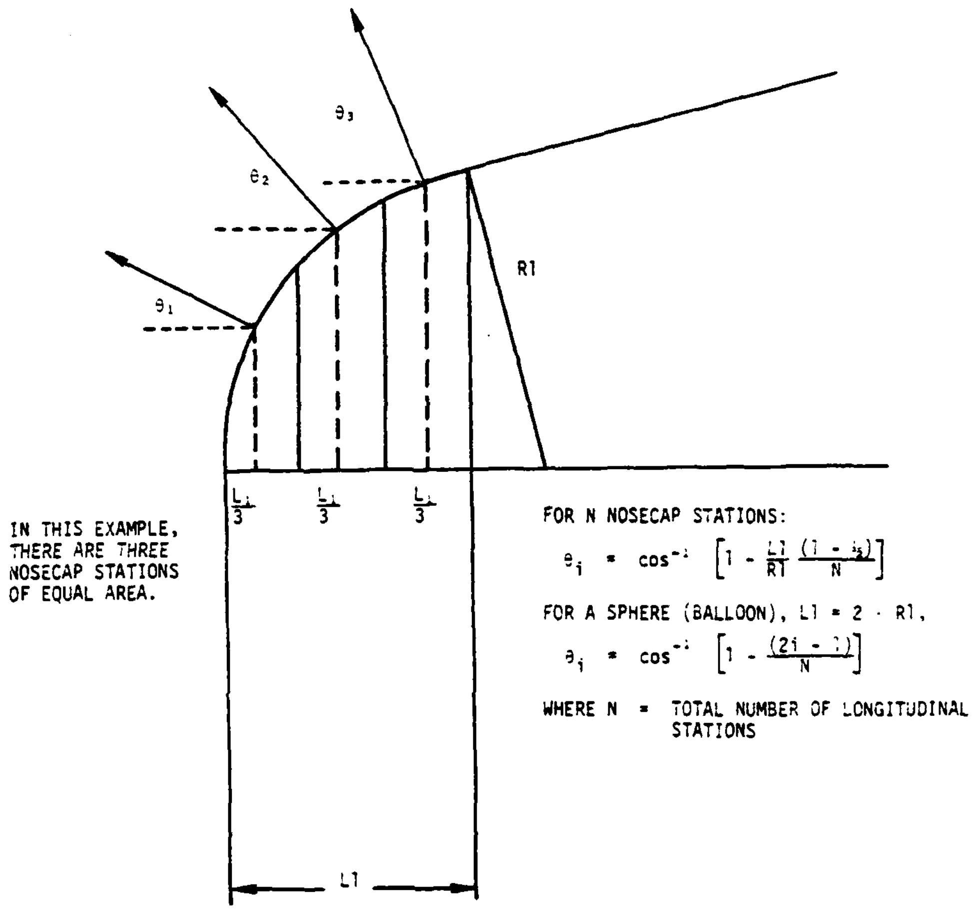


FIGURE 3-5. NOSECAP POLAR ANGLES

The stations can be distributed over the sections as desired, with the only restriction being that the number of roll angles times the number of polar angles be less than or equal to 50. Thus, it is possible to have 50 longitudinal stations along a single ϕ, or 50 azimuthal stations at a single longitudinal position.

There is a small ambiguity in the term "station" as used in the RVSNTH input. There, it means the number of stations on a given section, assuming only a single roll angle. The program automatically multiplies this by the number of roll angles to get the correct number of stations on the section.

The balloon is handled similarly to the replica, keeping in mind the criteria of equal areas for the determination of the polar angles.

Section 4 describes the input to RVSNTH and EXOHEAT.

The radiation matrix, M_{ij}, will now be derived. The power, d^4P, incident on an area dA_j from a blackbody source of area dA_i can be written as (see Figure 3-6):

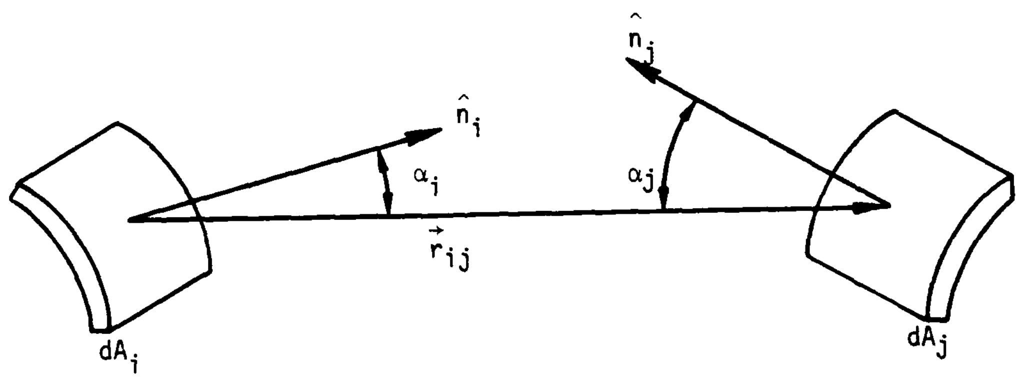


FIGURE 3-6. RADIATION EXCHANGE GEOMETRY

$$d^4P_j = \frac{\varepsilon_j \, \sigma \, T_i^4}{\pi} \; \frac{\cos \alpha_i \, \cos \alpha_j}{|\vec{r}_{ij}|^2} \; dA_i \, dA_j \qquad (3\text{-}13)$$

where

α_i, α_j - the angles the normals to dA_i, dA_j make with $\hat{r}_{ij}$, the vector pointing from dA_i to dA_j

ε_j - the emissivity of the piece j

T_i - the temperature of the source

σ - the Stefan-Boltzmann constant.

The source surface over which Equation 3-13 is integrated is the interior surface of the replica or balloon model, which has been divided into N stations as described previously. Because the temperature and internal emissivity, ε', of each station are average values over the station, the integral of Equation 3-13 over the entire inner surface (excluding $\vec{r}_{ij} = 0$) can be written as a sum over each station surface with ε', T outside the integral, which results in:

$$\frac{d^2 P_j}{dA_j} = \varepsilon_j' \sigma \sum_i g_{ij}^{BB} \; T_i^4 \qquad (3\text{-}14)$$

where g^{BB}, the blackbody radiation exchange matrix, is given by

$$g_{ij}^{BB} = \frac{1}{\pi} \int dA_i \; \cos\alpha_i \; \cos\alpha_j / |\vec{r}_{ij}|^2 \; . \qquad (3\text{-}15)$$

To take into account the fact that the sources on the interior are not blackbodies, one replaces g^{BB} in Equation 3-14 by

$$g^T = [g^{BB^T} (1 - \rho' \; g^{BB^T}) \; \varepsilon'] \qquad (3\text{-}16)$$

where g is the true radiation exchange matrix and superscript T stands for "transposed". The reflectivity ρ' is given by $\rho' = 1 - \varepsilon'$.

For a closed surface, one has

$$\sum_i g_{ij} = \sum_i g_{ij}^{BB} = 1. \qquad (3\text{-}17)$$

Holes/open surfaces are correctly treated by setting $\varepsilon_i' = \rho_i' = 0$ for the surfaces transparent to radiation in the calculation of g. Equation 3-17 no longer applies to g if some surfaces are transparent.

The total power incident on A_j is approximated by

$$p_j = \varepsilon_j' A_j \sigma \sum_i g_{ij} T_i^4 . \qquad (3\text{-}18)$$

The key to the calculation of g is, by Equation 3-16, the calculation of g^{BB}. The calculation of g_{ji}^{BB} is accomplished by the subdivision of A_j into η longitudinal strips with center positions $\vec{r}_m$, and a numerical integration is performed:

$$g_{ji}^{BB} = \frac{A_j}{\pi\eta} \sum_{m=1}^{\eta} \cos\alpha\,(j,m)\,\cos\alpha\,(i,m)/|\vec{r}_{mj}|^2 . \qquad (3\text{-}19)$$

To ensure that no serious errors result from this numerical procedure, Equation 3-17 is imposed on g^{BB}.

Excluding external sources for the moment, the total radiation flux into A_j is the amount incident from the interior minus the internal and external emission of A_j:

$$P_{j\ TOTAL} = \left[-\sigma(\varepsilon_j + \varepsilon_j')\, T_j^4 + \sigma \sum_i \varepsilon_j' T_i^4 g_{ij} \right] \cdot A_j$$

(3-20)

which can be written as:

$$P_{j\ TOTAL} = \sum_i M_{ij} T_i^4 \qquad (3\text{-}21)$$

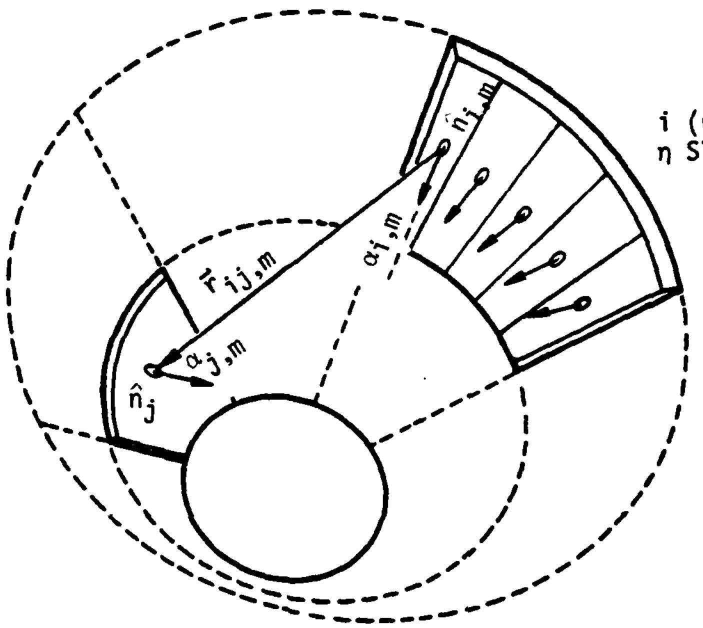


FIGURE 3-7. INTERNAL RADIATION GEOMETRY

where

$$M_{ij} = \left[-\sigma(\varepsilon_j + \varepsilon_j') \, \delta_{ij} + \sigma \sum_i \varepsilon_j' \, g_{ij} \right] \cdot A_j \qquad (3\text{-}22)$$

with $\delta_{ij} = \begin{Bmatrix} 1 & i=j \\ 0 & i \neq j \end{Bmatrix}$.

The term g_{ii}, the "self contribution", can be understood as a correction to the energy radiated away internally by a curved piece. One edge of the piece radiates back toward the opposite edge, thus reducing the total outward energy flow.

3.1.3 Conduction Matrix

Equation 3-7 expressed the conduction integral of Equation 3-6 as a sum over adjoining areas of the jth piece:

$$\int_{A_j:\text{adjoining}} (k\vec{\nabla}T) \cdot \hat{\eta}_j \, dA_j \rightarrow \sum_{\text{adjoining}} A_{\text{adjoining}} \cdot k_{\text{eff}} \frac{T_{\text{adjoining}} - T_j}{\Delta X_{j:\text{adjoining}}} \tag{3-23}$$

where all terms are defined below Equation 3-7. This sum can be expanded into its component terms by keeping in mind how the target surface has been divided:

$$\begin{aligned} \sum_{\text{adjoining}} A_{\text{adjoining}} \, k_{\text{eff}} \frac{T_{\text{adjoining}} - T_j}{\Delta X_{j:\text{adjoining}}} = & \frac{A_{(\ell-)} k_{\text{eff}(j-\theta,j)} (T_{j-\theta} - T_j)}{\Delta X_{j-\theta,j}} \\ & + \frac{A_{(\ell+)} \, k_{\text{eff}(j+\theta,j)} (T_{j+\theta} - T_j)}{\Delta X_{j+\theta,j}} \\ & + \frac{A_{(T-)} \, k_{\text{eff}(j-\phi,j)} (T_{j-\phi} - T_j)}{\Delta X_{j-\phi,j}} \\ & + \frac{A_{(T+)} \, k_{\text{eff}(j+\phi,j)} (T_{j+\phi} - T_j)}{\Delta X_{j+\phi,j}} \end{aligned} \tag{3-24}$$

where $j\pm\theta$, $j\pm\phi$ label the pieces adjacent to the jth piece, in the longitudinal and azimuthal directions, respectively (see Figure 3-8). The remaining terms are defined as:

$$A_{(\ell\pm)} = \Delta\phi \left(\frac{r_j + r_{j\pm\theta}}{2}\right) \left(\frac{t_j + t_{j\pm\theta}}{2}\right) \tag{3-25a}$$

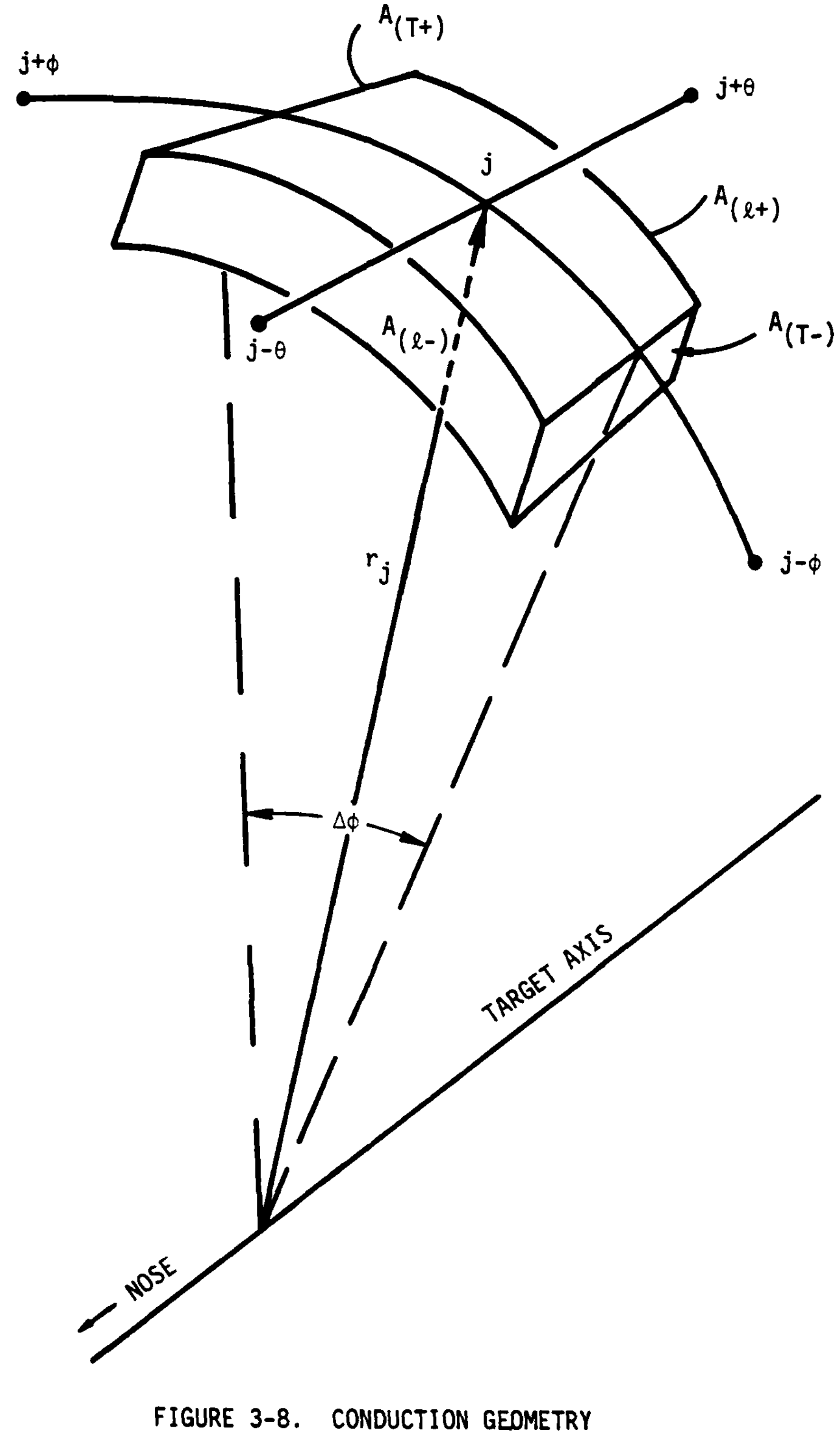


FIGURE 3-8. CONDUCTION GEOMETRY

where

$$\Delta\phi = \frac{1}{2}\ (\phi_j + \phi_{j+\phi}) - \frac{1}{2}\ (\phi_j + \phi_{j-\phi}) \tag{3-25b}$$

$$A_{(T\mp)} = \left[\left(\frac{RL_{j+\theta} + RL_j}{2}\right) - \left(\frac{RL_j + RL_{j-\theta}}{2}\right)\right] \left(\frac{t_j + t_{j\mp\phi}}{2}\right) \tag{3-25c}$$

$$\Delta X_{j\pm\theta,j} = \pm\ (RL_{j\pm\theta} - RL_j) \tag{3-25d}$$

$$\Delta X_{j\pm\phi,j} = |\phi_{j\pm\phi} - \phi_j| \left(\frac{r_j + r_{j\pm\phi}}{2}\right) \tag{3-25e}$$

$$k_{eff(\eta,\xi)} = \frac{2}{\frac{1}{k_\eta} + \frac{1}{k_\xi}} \qquad \text{where } \eta,\ \xi = j,\ j\pm\theta,\ j\pm\phi \tag{3-25f}$$

and where r, ϕ, t, RL are defined in Figure 3-4.

By defining longitudinal and transverse conduction coefficients of the form:

$$\alpha_{j\pm\theta} = \frac{A_{(\ell\pm)}\ k_{eff(j\pm\theta,j)}}{\Delta X_{j\pm\theta,j}} \tag{3-26a}$$

$$\beta_{j\pm\phi} = \frac{A_{(T\pm)}\ k_{eff(j\pm\phi,j)}}{\Delta X_{j\pm\phi,j}}\ . \tag{3-26b}$$

Equation 3-24 can be written as:

$$\sum_{adjoining} A_{adjoining}\ k_{eff}\ \frac{T_{adjoining} - T_j}{\Delta X_{j:adjoining}} = \alpha_{j-\theta}\ T_{j-\theta} + \alpha_{j+\theta}\ T_{j+\theta} + \beta_{j-\phi}\ T_{j-\phi} + \beta_{j+\phi}\ T_{j+\phi} - T_j\ (\alpha_{j-\theta} + \alpha_{j+\theta} + \beta_{j-\phi} + \beta_{j+\phi}). \tag{3-27}$$

Thus, by defining a conduction matrix of the form

$$K_{ij} = \begin{bmatrix} -(\alpha_{1+\theta} + \beta_{1+\phi} + \beta_{1-\phi}) & \alpha_{1+\theta} & 0 & \cdots & \beta_{1+\phi} & 0 & 0 & 0 \cdots & \beta_{1-\phi} & 0 & 0 & 0 \cdots \\ \alpha_{1+\theta} & -(\alpha_{1+\theta} + \alpha_{2+\theta} + \beta_{2+\phi} + \beta_{2-\phi}) & \alpha_{2+\theta} & \cdots & 0 & \beta_{2+\phi} & 0 & 0 \cdots & 0 & \beta_{2-\phi} & 0 & 0 \cdots \\ 0 & \alpha_{2+\theta} & -(\alpha_{2+\theta} + \alpha_{3+\theta} + \beta_{3+\phi} + \beta_{3-\phi}) & \cdots & 0 & 0 & \beta_{3+\phi} & 0 \cdots & 0 & 0 & \beta_{3-\phi} & 0 \cdots \\ \vdots & \vdots & \vdots & & & & \vdots & & & & \vdots & \end{bmatrix} \tag{3-28}$$

The sum (including $i = j$) $\sum_i k_{ij}\, T_i$ will contain all conduction terms associated with the jth piece, so that Equation 3-27 can be written as:

$$\sum_{\text{adjoining}} A_{\text{adjoining}}\, k_{\text{eff}}\, \frac{T_{\text{adjoining}} - T_j}{\Delta X_{j:\text{adjoining}}} = \sum_i K_{ij}\, T_i . \tag{3-29}$$

MBALL updates the K_{ij} with the changing temperatures of the stations through the thermal conductivity k_{eff}, which is, in general, a function of the temperature.

Because the end pieces, i.e., the first nose piece or the last baseplate piece, have only one longitudinal conduction contribution, the appropriate elements of the matrix K_{ij} are set to zero.

3.1.4 Thermal Mass

The left side of Equation 3-10 can be written as:

$$\rho_j\, V_j\, \frac{d}{dt} \int_{T_{oj}}^{T_j} c_{pj}(T'')\, dT'' = \int_{T_{oj}}^{T_j} m_j\, dT_j'' \tag{3-30}$$

where $m_j = \rho_j\, V_j\, c_{pj}$ is defined as the thermal mass of the jth piece, and is, in general, a function of the temperature because it contains the specific heat. If the vehicle being modeled has a skin structure, i.e., if it is built up of layers of materials with different densities and thermal properties, an appropriate average of these quantities must be made over all of the layers, because only a lumped thermal mass is treated in MBALL for each station. Equations 3-31 through 3-33 give the average density, specific heat, and thermal conductivity that are necessary:

$$\overline{\rho_j} = \sum_k \frac{\rho_{j,k} \, \Delta X_{j,k}}{\sum_k \Delta X_{j,k}} \tag{3-31}$$

$$\overline{c}_{p,j} = \frac{\sum_k \rho_{j,k} \, \Delta X_{j,k} \, c_{pj,k}}{\sum_k \rho_{j,k} \, \Delta X_{j,k}} \tag{3-32}$$

$$\overline{k}_j = \frac{\sum_k \Delta X_{j,k} \, k_{j,k}}{\sum_k \Delta X_{j,k}} \tag{3-33}$$

where $\Delta X_{j,k}$, $\rho_{j,k}$, $c_{pj,k}$, and $k_{j,k}$ are the thickness, density, specific heat, and thermal conductivity, respectively, of the kth layer of piece j. Because the specific heat and thermal conductivity are input by the user for different temperatures, an appropriate $\overline{c}_{pj}$ and $\overline{k}_j$ should be input for each temperature. The temperature calculated for the jth piece by MBALL is the average temperature over the thickness of the skin. Rapidly varying specific heats are accounted for in the solution of the heat equation described in the next section.

The option exists to set the thermal mass to zero (BALL = 2) for thin skins, in which case the temperature of each station is solved for assuming radiative equilibrium:

$$(\varepsilon_j + \varepsilon_j') \, \sigma \, T_j^4 = Q_{ext,j} + Q_{int,j} \tag{3-34}$$

where $Q_{ext,j}$, $Q_{int,j}$ are the external and internal power per unit area, respectively, incident on the jth piece.

3.2 SOLUTION OF THE HEAT EQUATION

3.2.1 Linearization

For numerical calculations, it is necessary to linearize both the left- and right-hand side of Equation 3-10. Proceeding with the left-hand side first:

$$\frac{\partial}{\partial t}\int_{T_{oj}}^{T_j} m_j(T_j'') \, dT_j'' \rightarrow \frac{m_j(T_j')(T_j - T_j')}{\Delta t} + \frac{1}{\Delta t}\int_{T_{oj}}^{T_j'} m_j(T'') \, dT''$$

(3-35)

where Δt is the time step, T_{oj} is the initial temperature of piece j, and T_j' is an estimated value for the new temperature T_j after the time Δt. The determination of Δt and T' is discussed below. Because the temperature change is being sought over a finite interval Δt, it is appropriate to replace the instantaneous value of the right-hand side of Equation 3-10 by a value averaged over the interval:

$$Q_{ext,j}(t)\, A_j + \sum_i (M_{ij}\, T_i^4 + K_{ij}\, T_i) \rightarrow Q_{ext,j}(t + \frac{\Delta t}{2})\, A_j$$

$$+ \sum_i (M_{ij}\, \overline{T}_i^4 + K_{ij}\, \overline{T}_i) \qquad (3\text{-}36)$$

where $\overline{T}_i$, the average temperature, is given by $\overline{T}_i = 1/2\ (T_{oi} + T_i)$, with T_{oi}, T_i the old and new temperature of the ith piece, respectively, and the external flux $Q_{ext,j}$ is interpolated to the midpoint of the time interval. The $\overline{T}_i^4$ term can be linearized in the following way: expanding T_i^4 in a Taylor's expansion about an estimated final temperature T_i':

$$T_i^4 = T_i'^4 + 4\, T_i'^3\, (T_i - T_i') \qquad (3\text{-}37)$$

and substituting this expression for T_i in $\overline{T}_i^4$ yields (after a further approximation):

$$\overline{T}_i^4 \rightarrow \left[\frac{1}{2}(T_i' + T_{oi})\right]^4 + 2\left[\frac{1}{2}(T_i' + T_{oi})\right]^3 \cdot (T_i - T_i') \, . \tag{3-38}$$

Defining the term $\overline{T}_i' = \frac{1}{2}(T_i' + T_{oi})$ for convenience, the full linearized heat equation can be written:

$$\frac{m_j\,(T_j')(T_j - T_j')}{\Delta t} + \frac{1}{\Delta t}\int_{T_{oj}}^{T_j'} m_j(T'')\,dT'' = Q_{ext,j}\left(t + \frac{\Delta t}{2}\right) A_j + \sum_i \left\{ M_{ij}\left[\overline{T}_i'^4 + 2\,\overline{T}_i'^3\,(T_i - T_i')\right] + \frac{K_{ij}}{2}\,(T_{oi} + T_i)\right\} \tag{3-39}$$

If the terms in Equation 3-39 are grouped to isolate T_j, the following equation results:

$$\sum_i c_{ij}\,T_i = B_j \tag{3-40}$$

where

$$c_{ij} = \begin{cases} \dfrac{m_j(T_j')}{\Delta t} - 2\,M_{jj}\,\overline{T}_j'^3 - \dfrac{1}{2}K_{jj} & \text{for } i = j \\ -\left(2\,M_{ij}\,\overline{T}_i'^3 + \dfrac{1}{2}K_{ij}\right) & \text{for } i \neq j \end{cases} \tag{3-41}$$

and

$$B_j = Q_{ext,j}\left(t + \frac{\Delta t}{2}\right) A_j + \frac{m_j(T_j') \, T_j'}{\Delta t} - \frac{1}{\Delta t}\int_{T_{oj}}^{T_j'} m_j \, dT$$

$$+ \sum_i \left[M_{ij} \left(\overline{T}_i'^4 - 2\overline{T}_i'^3 \cdot T_i'\right) + \frac{K_{ij}}{2} T_{oi} \right] .$$

Equation 3-40 is solved for the T_j by matrix inversion, and if the T_j are within one-half of one percent of the estimated T_j', the T_j are the new temperatures. Otherwise, the T_j become the estimated temperatures T_j' and Equation 3-40 is evaluated again for T_j. This process is repeated until the T_j are found.

3.2.2 Estimation of Δt, T'

It is important that the diagonals of the matrix c_{ij} be greater than zero, so that the time development is stable. Choosing the time step, Δt, such that

$$\Delta t < \frac{m_j \, (T_{oj})}{2M_{jj} \, T_{oj}^3 + 1/2 \, K_{jj}} \tag{3-43}$$

guarantees that the c_{ii} are all positive.

The estimated temperature, T_j', is found by solving the heat equation with the right-hand side approximated by an expansion about the initial temperature T_o:

$$\int_{T_{oj}}^{T_j'} m_j \, dT = \Delta t \left\{ \sum_i \left[M_{ij} \, T_{oi}^4 + K_{ij} \, T_{oi} + Q\left(t + \frac{\Delta t}{2}\right) A_j \right] \right.$$

$$\left. + \left(4 \, M_{jj} \, T_{oj}^3 + K_{jj}\right) \left(T_j' - T_{oj}\right) \right\} . \tag{3-44}$$

T_j' is then used to compute the specific heat at T_j', $c_{pj}(T_j')$, and the time step is checked to ensure that

$$\Delta t < \frac{m_j(T_j')}{4 M_{jj} T_{oj}^3 + K_{jj}} \quad . \tag{3-45}$$

If the time step does not satisfy Equation 3-45, a smaller step is chosen, and a new value for T_j' is found from Equation 3-44. This process is repeated until Δt is found to satisfy Equation 3-45. The time between trajectory points at which the temperatures are desired is used as the time step if this time is smaller than that defined by Equation 3-45.

3.3 OPEN SURFACE OPTION

It is possible to remove any station (more than one station may be removed) from the replica or balloon shape to simulate an open surface (hole) at that station. This is accomplished by setting the initial temperature of the station equal to 0°R on material property card 6.1 (Table 4-3). The conductivity and radiative coupling of any open station to the rest of the vehicle is set equal to zero. Any external fluxes entering the vehicle through the open station are neglected, however, so the percentage of open surface to total vehicle surface should be small to minimize the error in determining the true flux on an interior surface. Thus the total number of removed stations should be small.

An average temperature is assigned to an open surface for signature calculations in BIDIREC. This average temperature is representative of the internal energy that is passing through the hole from the interior. The average temperature of the missing station, $\overline{T}_{open}$, is found by evaluating:

$$\overline{\varepsilon}\, \overline{T}^4_{open} = \sum_i \varepsilon_i' \, g_{i,open} \, T_i^4 \tag{3-46}$$

Because this is an approximation, the internal emissivities, ε_i', are assumed to be about the same, and they cancel with the average emissivity, $\overline{\varepsilon}$. The $g_{i,open}$ term is the geometric factor for the ith surface as seen by the open surface.

4. INPUT SPECIFICATIONS

4.1 DISC UTILIZATION

MBALL requires the disc files used in EXOHEAT for its operation. Table 4-1 summarizes the necessary tapes and their utilization.

The thermophysical data (15) may be input by the user. The trajectory data (7) and earthshine data (4) must be input in the BASIC option. Note, however, that the user can supply trajectory data to tape 7 by using the trajectory card input option (Ref. 1).

TABLE 4-1. EXOHEAT (WITH MBALL) DISC FILES

DEVICE/ TAPE	UTILIZATION	ORIGIN
4	Earthshine Data	OSC Data Base
7	Trajectory Data	BALLIS/BASIC
15	Thermophysical Data	OSC Data Base
16	Temperature	MBALL
23	Vehicle Geometry	RVSNTH/BASIC

4.2 CARD INPUT

The MBALL card input consists of two parts: RVSNTH input and EXOHEAT input.

RVSNTH calculates the necessary geometrical parameters for MBALL from a modest user input (for both replica and balloon shapes). The user must be careful, however, to enter the nosecap polar angles [THET(I)] in the EXOHEAT input that are calculated by RVSNTH (see Figure 3-5) because RVSNTH does not pass them to EXOHEAT. RVSNTH input is displayed in Table 4-2.

TABLE 4-2. RVSNTH INPUT SUMMARY

CARD COLUMN	VARIABLE	FORMAT	UNITS	DESCRIPTION
FIRST CARD: TITLE (FORMAT 3A4)				
1-12	(NTI(I), I = 1,3)	3A4		RV title
SECOND CARD: UNIT DESIGNATOR (FORMAT I3)				
1-3	FLAG	I3		Designates what units of length the input is in: = 1, ft = 3, cm = 2, in. = 4, m
THIRD CARD: NOSECAP (FORMAT I5, 5X, 2F10.4, I5)				
1-5	N	I5		Number of stations on nosecap
11-20	R1	F10.4	(FLAG)	Nosecap radius (or balloon radius)
21-30	L1	F10.4	(FLAG)	Length of nosecap*† (or balloon diameter)
31-35	KROL	I5		Number of azimuthal divisions
FOURTH CARD: FRUSTA CONTROL (FORMAT I5, 5X, F10.4)				
1-5	MN	I5		Number of frusta (3 maximum)
11-20	Q	F10.4	deg	Cone angle of first frustum
FRUSTRA CARDS: (ONE PER FRUSTUM) (FORMAT I5, 5X, 2F10.4)				
1-5	N	I5		Number of stations on frustum
11-20	Q	F10.4	deg	Cone angle
21-30	L1	F10.4	(FLAG)	Length of frustum
BASE CARD (FORMAT F5.0)				
1-5	AN	F5.0		Number of stations on base

*See Figure 3-2 for replica.

†If balloon shape is desired, L1 = 2 × R1 and the third card is the last RVSNTH card.

The first card contains the user's title (up to 12 letters). The second card defines the units in which the target dimensions are input (these are changed internally to feet for MBALL). The nosecap information is input on the third card: N, the number of stations refers to the number of longitudinal stations along a single running length of the nosecap. The total number of nosecap stations is KROL X N. For a replica shape, the nosecap must fit tangentially to the first frustum, so that L1 is computed by the user according to Figure 3-2. If a balloon shape is desired (i.e., sphere), the user should set L1 equal to twice R1. RVSNTH bypasses the frustum calculations when L1 = 2 × R1, so the nosecap card is the last RVSNTH card when a balloon shape is desired. For the replica shape, the next card sets the number of frusta and defines the first cone angle, and this card is followed by a card for each frustum. Again, the total number of stations on each frustum is N × KROL. Finally, the base card contains the number of longitudinal stations on the base (in F format), to be multipled by KROL to get the total number of base stations.

EXOHEAT input is shown in Table 4-3. The first card is the NAMELIST/SOLAR data. This defines the earthshine mission map. The format for this card is (note the leading blank denoted by the b):

b$SOLAR ITYP = ..., $

with the variables separated by commas. A $ ends the namelist.

The next card set defines all station normals by their azimuthal and polar angles. The polar angles, THET(I), should agree with those calculated by RVSNTH (see Figure 3-5).

Card 3.1 determines the external flux averaging mode (see Table 3-1). MODE = 1 allows the full use of MBALL's capability for azimuthal, as well as longitudinal, heat conduction. In MODE = 2 (roll average), all azimuthal stations experience the same roll averaged external fluxes. Azimuthal conduction can still be important in this case, however, if adjacent stations have different thermal masses or thermal properties.

TABLE 4-3. EXOHEAT (WITH MBALL) CARD INPUT SUMMARY

NATURAL ENVIRONMENT SPECIFICATION	
	NAMELIST/SOLAR
VARIABLE	DESCRIPTION
ITYPE	Sun position option = 1 - Subsolar latitude and longitude (SLAT, SLON) input = 2 - Subsolar point calculated from MONTH, IDAY, HOUR, where HOUR is GMT time = 3 - Subsolar point calculated from MONTH, IDAY, HOUR, ELG, where HOUR is local Sun time at longitude ELG
SLAT	Sun latitude (deg)
SLON	Sun longitude
MONTH	Month of year - 1 to 12
IDAY	Day of month - 1 to 30
HOUR	24 hr time (1:15 p.m. ~ 13.25)
ELG	Reference longitude for local time (deg)
IPRINT	Earthshine map printing option = 0 - Do not print earthshine radiances ≠ 0 - Print earthshine map
ICLD	Cloud cover option = 0,1 - Average seasonal geographic earthshine = 2 - Cloudy radiance reduction = 3 - Clear radiance enhancement = 4 - Statistical - random geographical variation between clear and cloudy = 5* - Clear and cloudy sections are positioned over the Earth = 6* - Same as ICLD = 5, but different albedos are used for water, land, vegetation, snow, and ice on the Earth's surface.

*See Table 4-20, Reference 1.

TABLE 4-3 - Continued

BODY SHAPE			
CARD	PARAMETER	FORMAT	DESCRIPTION
2.1	KROL	I5	Numbers of azimuthal divisions
2.2	(ROLL(I), I=1, KROL)	8F10.5	Azimuthal angle (deg)
2.3	KTHET	I5	Number of polar angles
2.4	(THET(I), I=1, KTHET)	8F10.5	Polar angles (deg)*
FLUX AVERAGING MODE			
3.1	MODE	I5	= 1 - Instantaneous = 2 - Roll averaged fluxes = 3 - Spherical averaged fluxes

BALLOON OPTION	
NAMELIST/IBALL	
VARIABLE	DESCRIPTION
BALL†	= 2 - Radiative equilibrium = 3 - Thermal mass used

CONDUCTION SPECIFICATION			
CARD	PARAMETER	FORMAT	DESCRIPTION
5.1	COND FLAG	(5X,L5, F5.2)	T = Conduction F = No conduction 0 = Thermal prop. updated with time 1 = Thermal prop. not updated

*Nosecap THET(I) should agree with polar angles calculated in RVSNTH (see Figure 3-5).

†BALL must equal 2 or 3 for MBALL to be called.

TABLE 4-3 - Concluded

MATERIAL PROPERTY SPECIFICATION

(One card for each station) — The station index for the Mth roll angle and Nth polar angle is I = (M-1) · KTHET + N

CARD	PARAMETER	FORMAT	DESCRIPTION
6.1	JMAT	(I10, 2F10.5)	Material identification code word >200 - data taken from OSC data base <200 data taken from card sets composed of card types 7.1 and 7.2
	THK		Material thickness (ft)
	TOLD		Initial temperature* (°R)
If some of JMATS are less than 200 material property data will be input on these cards			
7.1	NCP	(I5, 7F10.2)	Number of temperatures and number of 7.2 cards
	DENS		Density (lb/ft^2)
	EO		Outside emissivity
	EI		Inside emissivity
	AL		Absorptance
7.2	TEMP	(3E12.5)	Temperature (°R)
	CP		Specific heat (Btu/lb/°R)
	TCON		Thermal conductivity (Btu/ft/°R/sec)

*TOLD = 0 for an open surface

The next card is NAMELIST/IBALL input. If BALL = 2, a zero thermal mass is assumed for all of the stations, and Equation 3-34 is solved for the temperatures. BALL = 3 uses the complete thermal mass solution of Section 3. BALL must equal two or three for MBALL to be called. The format for this namelist is:

```
b$IBALL   BALL = 2(or 3)     $
```

Card 5.1 chooses the two options: conduction on/off, and thermal properties updated/not updated with time.

Card set 6 defines the material, thickness, and initial temperature of each station (one card per station). An open station is flagged by setting its initial temperature equal to 0. If JMAT is greater than 200, the thermophysical properties are taken from the OSC data base. Table 4-4 contains the OSC thermophysical property code words. If JMAT is less than or equal to 200, the thermophysical properties must follow card set 6. If a station is built up of layers of different materials, an appropriate average of their thermophysical properties over the thickness of the skin should be input in card set 7 (see Equations 3-31 through 3-33). Card set 7 is read whenever a JMAT less than or equal to 200 is encountered that is different from the previous station's JMAT.

To model a phase change, the specific heat can be thought of as a spiked function of the temperature, as is shown in Figure 4-1(a). The enthalpy, or energy content per unit mass of the station material, is the area under curve (a), and is shown in (b). The area of the shaded spike of curve (a) corresponds to the heat of fusion or heat of vaporization of a unit mass of material. In the case of water, this area would correspond to about 144 Btu/lb for the heat of fusion. Table 4-5 is a tabulation of the curve of Figure 4-1(a). Note that the width of the spike was chosen to be 1°R, but a smaller width may be chosen if the c_p is increased so that the area under the spike remains 144 Btu/lb.

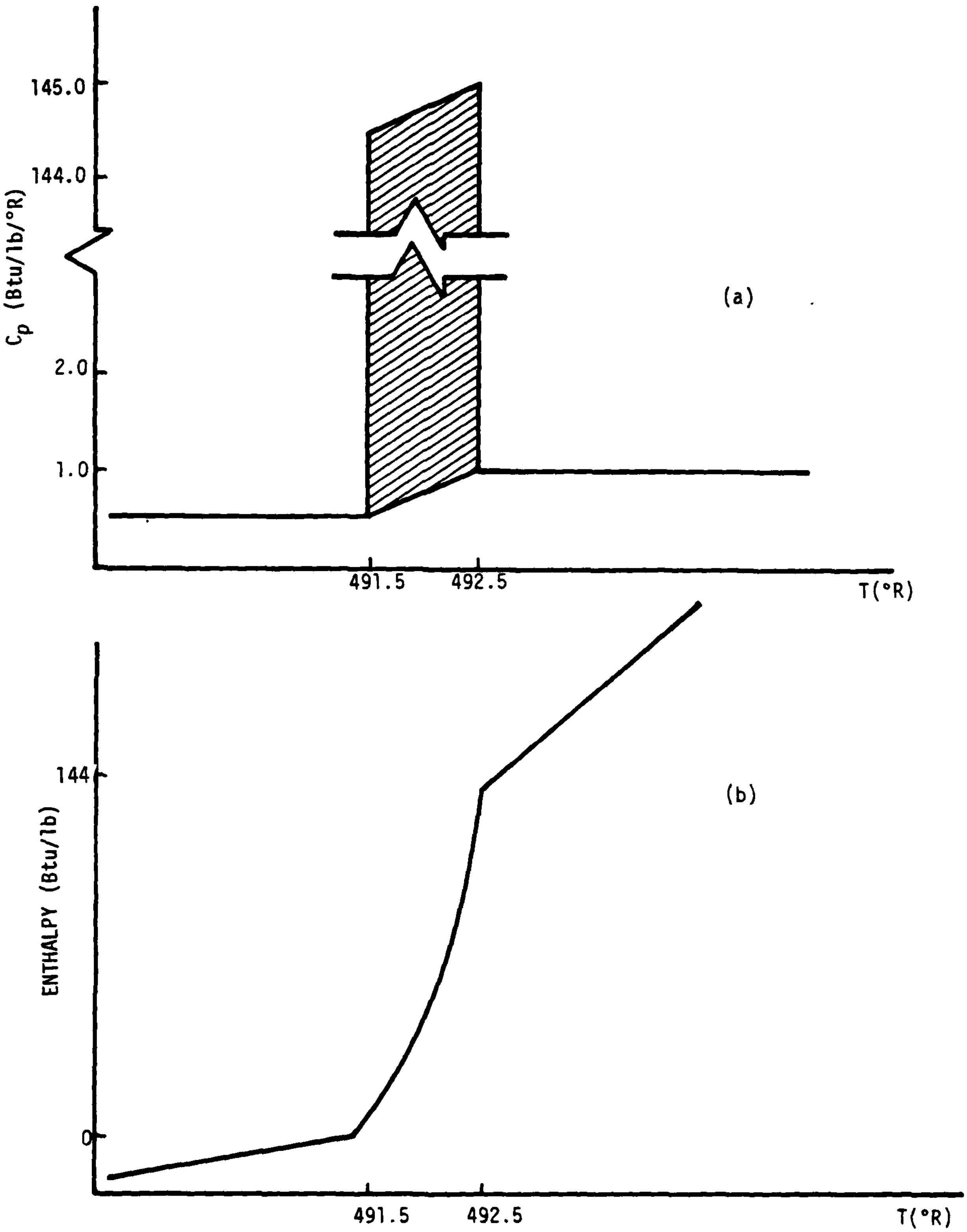


FIGURE 4-1. SPECIFIC HEAT AND ENTHALPY OF WATER

TABLE 4-4. OSC THERMOPHYSICAL PROPERTY CODE WORDS

CODE WORD	MATERIAL
201	Carbon phenolic
202	Graphite
203	Silica phenolic, asbestos phenolic
204	Fused silica
205	Teflon
206	Porous stainless steel
207	Aluminum
208	Beryllium

TABLE 4-5. MODELING THE HEAT OF FUSION OF WATER

TEMPERATURE (°R)	c_p(Btu/lb/°R)
480.00	0.5 (approx.)
491.49	0.5 (approx.)
491.50	144.5
492.50	145.0
492.51	1.0 (approx.)
500.00	1.0 (approx.)

4.3 ACCESSING MBALL IN THE BASIC OPTION

MBALL is accessed in the BASIC option (note that Reference 1 and 3 do not contain MBALL) if the BASIC parameters HEATRV = EXOHEAT and TARGSYN = YES (this calls RVSNTH). References 1 and 3 state that RVSNTH should not be used with EXOHEAT, but this has been changed with the addition of MBALL. To compute signatures from the MBALL temperatures, input is necessary for SELECT and BIDIREC, because the modified RVSNTH program does not compute the necessary parameters to these programs. Reference 1 describes SELECT and BIDIREC input.

5. EXAMPLES

5.1 WATER-JACKETED BALLOON

The first example (Figure 5-1) demonstrates the modeling of a water-jacketed balloon 1 m in radius consisting of an outer and inner skin of 1/32-in. teflon, supporting a 1/8-in. layer of water. It is necessary to average the density, specific heats, and thermal conductivities of the water and teflon over the layers of the balloon. The balloon's surface is divided into 36 stations of equal area. Table 5-1 shows the values chosen to represent the specific heat of water to model the phase change at 492 °R, and the specific heat of teflon. Also shown are the respective thermal conductivities. The averages used in the inputs were determined from Equations 3-31 through 3-33.

Trajectory cards have been input to place the balloon over the north pole with the axis of the balloon parallel to the axis of the Earth. The Sun is at 0° longitude and 0° latitude. The initial temperature of the entire balloon is 500 °R. Even though SELECT and BIDIREC input is present, the output from these programs is suppressed.

The MBALL output (Figure 5-2), following the average fluxes from the Sun, Earth, and molecular heating from EXOHEAT, is as follows for each station (units are in feet): the station area, perpendicular and parallel components of the station normal with respect to the vehicle axis, distance from the axis (r), distance along the axis (z), running length, and thermal mass (Btu/°R). The terms RAD and COND give an estimate of the initial radiation and conduction flow, respectively, involving the particular station. TMTP is the estimated time step Δt given by dividing the thermal mass TMASS by the sum of RAD and COND (this is one-half the Δt of Equation 3-43). ALF, EOUT, and EIN are the solar absorptivity and outside and inside emissivities, respectively. The temperatures (°R) are then output for each station.

```
       1         11        21        31        41        51        61        71
CARD   +.........+.........+.........+.........+.........+.........+.........+.........
  1    BASIC
  2    TRAJ      CARDS     HLATE     SHOREAT   MATER     CALC      SIGNA     CALT
  3    TIFGLVN   VIS
  4       7
  5    5.        9.
  6    11.       15.
  7    15.       24.
  8
  9      37
 10    60.       3261.771  3038.021  3280.8    200..     90.
 11    120.      3261.771  3038.021  3280.8    20000.    90.
 12    180.      3261.771  3038.021  3280.8    20000.    90.
 13    240.      3261.771  3038.021  3280.8    20000.    90.
 14    300.      3261.771  3038.021  3280.8    20000.    90.
 15    360.      3261.771  3 38.021  3280.8    20000.    90.
 16    420.      3261.771  3038.021  3280.8    20000.    90.
 17    480.      3261.771  3038.021  3280.8    20000.    90.
 18    540.      3261.771  3038.021  3280.8    20000.    90.
 19    600.      3261.771  3038.021  3281.8    20000.    90.
 20    660.      3261.771  3038.021  3281.8    20000.    90.
 21    720.      3261.771  3038.021  3280.8    20000.    90.
 22    780.      3261.771  3038.021  3281.8    21000.    90.
 23    84 .      3261.771  3 38.021  3280.8    20000.    90.
 24    900.      3261.771  3038.021  3280.8    20000.    90.
 25    960.      3261.771  3038.021  3281.8    20000.    90.
 26    1020.     3261.771  3038.021  3280.8    20000.    90.
 27    1 80.     3261.771  3 38.021  328 .8    20000.    90.
 28    1140.     3261.771  3038.021  328..8    20000.    90.
 29    1200.     3261.771  3038.021  3280.8    20000.    90.
 30    1260.     3261.771  3038.021  3280.8    20000.    90.
 31    1320.     3261.771  3038.021  328 .8    20000.    90.
 32    1380.     3261.771  3038.021  3280.8    20000.    90.
 33    1440.     3261.771  3038.021  3280.8    20000.    90.
 34    1500.     3261.771  3038.021  3280.8    20000.    90.
 35    1560.     3261.771  3038.021  328 .8    20000.    90.
 36    1620.     3261.771  3038.021  3280.8    20000.    90.
 37    1680.     3261.771  3038.021  3280.8    20000.    90.
 38    1740.     3261.771  3038.021  3280.8    20000.    90.
 39    18..      3261.771  3 38.021  328 .8    20...     90.
 40    MBALL
 41      3
 42         6    100.      200.          6
 43     $SOLAR ITYPE=1,SLAT= ..SLON= ..MONTH=9,IDAY=15,IPRINT=.,ICLD=3 $
 44         5
 45    0.        60.       120.      180.      240.      300.
 46        .5
 47    37.56     60.       8 .41     99.39     120.      146.44
 48         1
 49     $IBALL BALL=3. $
 50         F    T

       1         11        21        31        41        51        61        71
CARD   +.........+.........+.........+.........+.........+.........+.........+.........
```

FIGURE 5-1. BALLOON EXAMPLE INPUT

CARD	1	11	21	31	41	51	61	71
51		190 .0156	500.					
52		190 .0156	500.					
53		190 .0156	500.					
54		190 .0156	500.					
55		190 .0156	500.					
56		190 .0156	500.					
57		190 .0156	500.					
58		190 .0156	500.					
59		190 .0156	500.					
60		190 .0156	500.					
61		190 .0156	500.					
62		190 .0156	500.					
63		190 .0156	500.					
64		190 .0156	500.					
65		190 .0156	500.					
66		190 .0156	500.					
67		190 .0156	500.					
68		190 .0156	500.					
69		190 .0156	500.					
70		190 .0156	500.					
71		190 .0156	500.					
72		190 .0156	500.					
73		190 .0156	500.					
74		190 .0156	500.					
75		190 .0156	500.					
76		190 .0156	500.					
77		190 .0156	500.					
78		190 .0156	500.					
79		190 .0156	500.					
80		190 .0156	500.					
81		190 .0156	500.					
82		190 .0156	500.					
83		190 .0156	500.					
84		190 .0156	500.					
85		190 .0156	500.					
86		190 .0156	500.					
87	6	86.6	.9	.9	.2			
88		491.00	.359	.152				
89		491.49	.362	.165				
90		491.50	38.790	.165				
91		492.50	39.030	.165				
92		492.51	.630	.165				
93		500.00	.610	.167				
94		1	1	1	0			
95	F03096	11						
96	F030340	11						
97		0	1	1	1	2	1	
98			3	1	4	1	5	
99			1	5	1	7	1	
100			8	1	9	1	10	
CARD	1	11	21	31	41	51	61	71

FIGURE 5-1 - Continued

CARD	1	11	21	31	41	51	61	71
101			1	11	1	12	1	
102			13	1	14	1	15	
103			1	16	1	17	1	
104			18	1	19	1	20	
105			1	21	1	22	1	
106			23	1	24	1	25	
107			1	26	1	27	1	
108			28	1	29	1	30	
109			1	31	1	32	1	
110			33	1	34	1	35	
111			1	36				
112		5	.349	24.09	0.	48.19	60.	
113		5	.349	59.35	0.	22.34	60.	
114		5	.349	80.25	0.	19.47	60.	
115		5	.349	99.74	0.	19.47	60.	
116		5	.349	120.64	0.	22.34	60.	
117		5	.349	155.91	0.	48.19	60.	
118		5	.349	24.09	60.	48.19	60.	
119		5	.349	59.35	60.	22.34	60.	
120		5	.349	80.25	60.	19.47	60.	
121		5	.349	99.74	60.	19.47	60.	
122		5	.349	120.64	60.	22.34	60.	
123		5	.349	155.91	60.	48.19	60.	
124		5	.349	24.09	120.	48.19	60.	
125		5	.349	59.35	120.	22.34	60.	
126		5	.349	80.25	120.	19.47	60.	
127		5	.349	99.74	120.	19.47	60.	
128		5	.349	120.64	120.	22.34	60.	
129		5	.349	155.91	120.	48.19	60.	
130		5	.349	24.09	180.	48.19	60.	
131		5	.349	59.35	180.	22.34	60.	
132		5	.349	80.25	180.	19.47	60.	
133		5	.349	99.74	180.	19.47	60.	
134		5	.349	120.64	180.	22.34	60.	
135		5	.349	155.91	180.	48.19	60.	
136		5	.349	24.09	240.	48.19	60.	
137		5	.349	59.35	240.	22.34	60.	
138		5	.349	80.25	240.	19.47	60.	
139		5	.349	99.74	240.	19.47	60.	
140		5	.349	120.64	240.	22.34	60.	
141		5	.349	155.91	240.	48.19	60.	
142		5	.349	24.09	300.	48.19	60.	
143		5	.349	59.35	300.	22.34	60.	
144		5	.349	80.25	300.	19.47	60.	
145		5	.349	99.74	300.	19.47	60.	
146		5	.349	120.64	300.	22.34	60.	
147		5	.349	155.91	300.	48.19	60.	
148	IDAS? REFLET=1.,WT=0.,1.,0.,NR=10,NC=10 $							

FIGURE 5-1 - Concluded

TABLE 5-1. ρ, c_p, k FOR WATER AND TEFLON

	ρ (lb/ft^3)	c_p Btu/lb/°R)	k Btu/ft/°R/sec)	T(°R)
Water (1/8-in. Thick)	62.4	0.5	0.323	480.00
	62.4	0.5	0.329	491.49
	62.4	144.5	0.329	491.50
	62.4	145.0	0.329	492.50
	62.4	1.0	0.329	492.51
	62.4	1.0	0.334	500.00
Teflon (1/16-in. Thick Total)	135.0	0.229	0.414×10^{-4}	480.00
	135.0	0.234	0.414×10^{-4}	491.49
	135.0	0.234	0.414×10^{-4}	491.50
	135.0	0.234	0.414×10^{-4}	492.50
	135.0	0.234	0.414×10^{-4}	492.51
	135.0	0.238	0.415×10^{-4}	500.00

PROGRAM BASIK

TRAJECTORY DATA WILL BE INPUT VIA CARDS

EXOHEAT WILL CALCULATE THERMAL DATA

SELECT WILL PROVIDE BIDIREC WITH OPTICAL PROPERTIES DATA

BIDIREC WILL CALCULATE TARGET SIGNATURE DATA

NO NATURAL,PLUME,OR NUCLEAR BACKGROUND DATA WILL BE INPUT OR CALCULATED

NO OFFAXIS CALCULATIONS WILL BE MADE

NO SENSOR MODEL CALCULATIONS WILL BE MADE

TARGET SYNTHESIS PERFORMED

NOBAND = 3

LAMBDA INCREMENT WAS NOT INPUT, DEFAULTED TO 0.1

LWAVE = 191 LAMINC = .100E+00

.500000E+01	.510000E+01	.520000E+01	.530000E+01	.540000E+01	.550000E+01	.560000E+01	.570000E+01
.580000E+01	.590000E+01	.600000E+01	.610000E+01	.620000E+01	.630000E+01	.640000E+01	.650000E+01
.660000E+01	.670000E+01	.680000E+01	.690000E+01	.700000E+01	.710000E+01	.720000E+01	.730000E+01
.740000E+01	.750000E+01	.760000E+01	.770000E+01	.780000E+01	.790000E+01	.800000E+01	.810000E+01
.820000E+01	.830000E+01	.840000E+01	.850000E+01	.860000E+01	.870000E+01	.880000E+01	.890000E+01
.900000E+01	.910000E+01	.920000E+01	.930000E+01	.940000E+01	.950000E+01	.960000E+01	.970000E+01
.980000E+01	.990000E+01	.100000E+02	.101000E+02	.102000E+02	.103000E+02	.104000E+02	.105000E+02
.106000E+02	.107000E+02	.108000E+02	.109000E+02	.110000E+02	.111000E+02	.112000E+02	.113000E+02
.114000E+02	.115000E+02	.116000E+02	.117000E+02	.118000E+02	.119000E+02	.120000E+02	.121000E+02
.122000E+02	.123000E+02	.124000E+02	.125000E+02	.126000E+02	.127000E+02	.128000E+02	.129000E+02
.130000E+02	.131000E+02	.132000E+02	.133000E+02	.134000E+02	.135000E+02	.136000E+02	.137000E+02
.138000E+02	.139000E+02	.140000E+02	.141000E+02	.142000E+02	.143000E+02	.144000E+02	.145000E+02
.146000E+02	.147000E+02	.148000E+02	.149000E+02	.150000E+02	.151000E+02	.152000E+02	.153000E+02
.154000E+02	.155000E+02	.156000E+02	.157000E+02	.158000E+02	.159000E+02	.160000E+02	.161000E+02
.162000E+02	.163000E+02	.164000E+02	.165000E+02	.166000E+02	.167000E+02	.168000E+02	.169000E+02
.170000E+02	.171000E+02	.172000E+02	.173000E+02	.174000E+02	.175000E+02	.176000E+02	.177000E+02
.178000E+02	.179000E+02	.180000E+02	.181000E+02	.182000E+02	.183000E+02	.184000E+02	.185000E+02
.186000E+02	.187000E+02	.188000E+02	.189000E+02	.190000E+02	.191000E+02	.192000E+02	.193000E+02
.194000E+02	.195000E+02	.196000E+02	.197000E+02	.198000E+02	.199000E+02	.200000E+02	.201000E+02
.202000E+02	.203000E+02	.204000E+02	.205000E+02	.206000E+02	.207000E+02	.208000E+02	.209000E+02
.210000E+02	.211000E+02	.212000E+02	.213000E+02	.214000E+02	.215000E+02	.216000E+02	.217000E+02
.218000E+02	.219000E+02	.220000E+02	.221000E+02	.222000E+02	.223000E+02	.224000E+02	.225000E+02
.226000E+02	.227000E+02	.228000E+02	.229000E+02	.230000E+02	.231000E+02	.232000E+02	.233000E+02
.234000E+02	.235000E+02	.236000E+02	.237000E+02	.238000E+02	.239000E+02	.240000E+02	

FIGURE 5-2. BALLOON EXAMPLE OUTPUT

36 PIECES EXOHEAT
6 AZIM. DIVISIONS
6 LONG. DIVISIONS

AZIM. ANGLES 0.00 60.00 120.00 180.00 240.00 300.00

POLAR ANGLES 33.56 60.00 80.41 99.59 120.00 146.44

MODE 1 (1=INST.FLUX, 2=ROLL-AVGED FLUX)
MONTH 9
DAY 5
GMT 0.00
SUN-LAT,LNG 0.00 0.00

TIME	CONDITION	AVERAGE FLUXES -- W/(M**2) SUN/ALBEDO	EARTH	MOLECULAR
60.00000	SUNLIT	344.9600	54.42691	0.
120.0000	SUNLIT	344.9600	54.42691	0.
180.0000	SUNLIT	344.9600	54.42691	0.
240.0000	SUNLIT	344.9600	54.42691	0.
300.0000	SUNLIT	344.9600	54.42691	0.
360.0000	SUNLIT	344.9600	54.42691	0.
420.0000	SUNLIT	344.9600	54.42691	0.
480.0000	SUNLIT	344.9600	54.42691	0.
540.0000	SUNLIT	344.9600	54.42691	0.
600.0000	SUNLIT	344.9600	54.42691	0.
660.0000	SUNLIT	344.9600	54.42691	0.
720.0000	SUNLIT	344.9600	54.42691	0.
780.0000	SUNLIT	344.9600	54.42691	0.
840.0000	SUNLIT	344.9600	54.42691	0.
900.0000	SUNLIT	344.9600	54.42691	0.
960.0000	SUNLIT	344.9600	54.42691	0.
1020.000	SUNLIT	344.9600	54.42691	0.
1080.000	SUNLIT	344.9600	54.42691	0.
1140.000	SUNLIT	344.9600	54.42691	0.
1200.000	SUNLIT	344.9600	54.42691	0.
1260.000	SUNLIT	344.9600	54.42691	0.
1320.000	SUNLIT	344.9600	54.42691	0.
1380.000	SUNLIT	344.9600	54.42691	0.
1440.000	SUNLIT	344.9600	54.42691	0.
1500.000	SUNLIT	344.9600	54.42691	0.
1560.000	SUNLIT	344.9600	54.42691	0.
1620.000	SUNLIT	344.9600	54.42691	0.
1680.000	SUNLIT	344.9600	54.42691	0.
1740.000	SUNLIT	344.9600	54.42691	0.
1800.000	SUNLIT	344.9600	54.42691	0.

FIGURE 5-2 - Continued

STAT	AREA	PERP	PAR	RADIUS	ZED	RUNLTH	TMASS	RAD	COND	TMTP	ALF	EOUT	EIN
1	3.76	.553	.833	1.81	.547	1.92	3.05	.159E-02	.115E-01	232.	.200	.900	.900
2	3.76	.866	.500	2.84	1.64	3.44	3.05	.159E-02	.136E-01	200.	.200	.900	.900
3	3.76	.986	.167	3.23	2.73	4.61	3.05	.159E-02	.159E-01	165.	.200	.900	.900
4	3.76	.986	-.167	3.23	3.83	5.70	3.05	.159E-02	.159E-01	165.	.200	.900	.900
5	3.76	.866	-.500	2.84	4.92	6.87	3.05	.159E-02	.136E-01	200.	.200	.900	.900
6	3.76	.553	-.833	1.81	6.01	8.39	3.05	.159E-02	.112E-01	237.	.200	.900	.900
7	3.76	.553	.833	1.81	.547	1.92	3.05	.159E-02	.115E-01	232.	.200	.900	.900
8	3.76	.866	.500	2.84	1.64	3.44	3.05	.159E-02	.136E-01	200.	.200	.900	.900
9	3.76	.986	.167	3.23	2.73	4.61	3.05	.159E-02	.159E-01	165.	.200	.900	.900
10	3.76	.986	-.167	3.23	3.83	5.70	3.05	.159E-02	.159E-01	165.	.200	.900	.900
11	3.76	.866	-.500	2.84	4.92	6.87	3.05	.159E-02	.136E-01	200.	.200	.900	.900
12	3.76	.553	-.833	1.81	6.01	8.39	3.05	.159E-02	.112E-01	237.	.200	.900	.900
13	3.76	.553	.833	1.81	.547	1.92	3.05	.159E-02	.115E-01	232.	.200	.900	.900
14	3.76	.866	.500	2.84	1.64	3.44	3.05	.159E-02	.136E-01	200.	.200	.900	.900
15	3.76	.986	.167	3.23	2.73	4.61	3.05	.159E-02	.159E-01	165.	.200	.900	.900
16	3.76	.986	-.167	3.23	3.83	5.70	3.05	.159E-02	.159E-01	165.	.200	.900	.900
17	3.76	.866	-.500	2.84	4.92	6.87	3.05	.159E-02	.136E-01	200.	.200	.900	.900
18	3.76	.553	-.833	1.81	6.01	8.39	3.05	.159E-02	.112E-01	237.	.200	.900	.900
19	3.76	.553	.833	1.81	.547	1.92	3.05	.159E-02	.115E-01	232.	.200	.900	.900
20	3.76	.866	.500	2.84	1.64	3.44	3.05	.159E-02	.136E-01	200.	.200	.900	.900
21	3.76	.986	.167	3.23	2.73	4.61	3.05	.159E-02	.159E-01	165.	.200	.900	.900
22	3.76	.986	-.167	3.23	3.83	5.70	3.05	.159E-02	.159E-01	165.	.200	.900	.900
23	3.76	.866	-.500	2.84	4.92	6.87	3.05	.159E-02	.136E-01	200.	.200	.900	.900
24	3.76	.553	-.833	1.81	6.01	8.39	3.05	.159E-02	.112E-01	237.	.200	.900	.900
25	3.76	.553	.833	1.81	.547	1.92	3.05	.159E-02	.115E-01	232.	.200	.900	.900
26	3.76	.866	.500	2.84	1.64	3.44	3.05	.159E-02	.136E-01	200.	.200	.900	.900
27	3.76	.986	.167	3.23	2.73	4.61	3.05	.159E-02	.159E-01	165.	.200	.900	.900
28	3.76	.986	-.167	3.23	3.83	5.70	3.05	.159E-02	.159E-01	165.	.200	.900	.900
29	3.76	.866	-.500	2.84	4.92	6.87	3.05	.159E-02	.136E-01	200.	.200	.900	.900
30	3.76	.553	-.833	1.81	6.01	8.39	3.05	.159E-02	.112E-01	237.	.200	.900	.900
31	3.76	.553	.833	1.81	.547	1.92	3.05	.159E-02	.115E-01	232.	.200	.900	.900
32	3.76	.866	.500	2.84	1.64	3.44	3.05	.159E-02	.136E-01	200.	.200	.900	.900
33	3.76	.986	.167	3.23	2.73	4.61	3.05	.159E-02	.159E-01	165.	.200	.900	.900
34	3.76	.986	-.167	3.23	3.83	5.70	3.05	.159E-02	.159E-01	165.	.200	.900	.900
35	3.76	.866	-.500	2.84	4.92	6.87	3.05	.159E-02	.136E-01	200.	.200	.900	.900
36	3.76	.553	-.833	1.81	6.01	8.39	3.05	.159E-02	.112E-01	237.	.200	.900	.900

TIME DEVELOPMENT OF TEMPERATURES

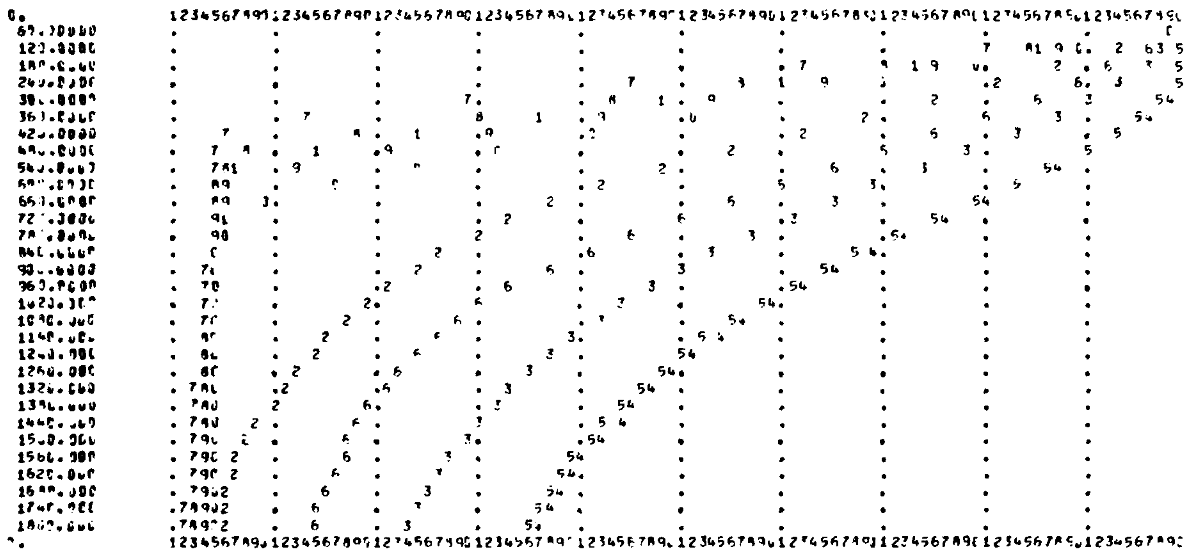
LONGITUDINAL CONDUCTION TREATED -- T

OPEN REAR SURFACE -- F

NR MTX INV-- 58

FIGURE 5-2 - Continued

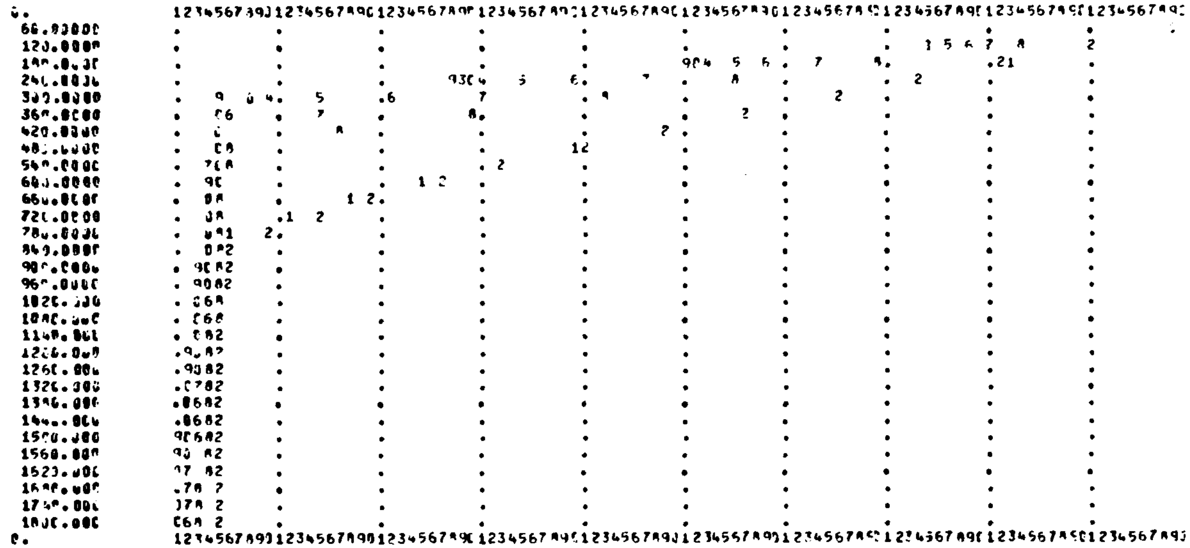
1
TE #S
MAX 500.122
MIN 492.895



TIME/STAT	1	2	3	4	5	6	7	8	9	11
60.000	500.000	500.001	500.001	500.000	500.000	500.000	500.000	500.000	500.000	500.000
120.000	498.994	499.597	499.972	500.098	501.092	499.814	499.535	499.862	499.187	499.250
180.000	497.997	499.154	499.811	500.122	500.1[illegible]9	499.559	497.121	497.745	499.179	499.494
240.000	496.984	498.675	499.613	500.078	500.059	499.268	495.753	496.649	497.276	497.732
300.000	495.985	498.165	499.374	499.973	499.948	498.939	494.425	495.572	496.378	496.966
360.000	494.999	497.629	499.091	499.814	499.794	498.579	493.184	494.539	495.494	496.261
420.000	494.356	497.073	498.774	499.612	499.5[illegible]	498.295	492.5[illegible]1	493.557	494.645	495.454
480.000	493.250	496.528	498.431	499.375	499.341	497.794	492.49[illegible]	492.7[illegible]1	493.94[illegible]	494.739
540.000	492.592	495.993	498.070	499.112	499.076	497.383	492.479	492.581	493.115	494.056
600.000	492.540	495.531	497.703	498.826	498.790	496.969	492.467	492.492	492.565	493.415
660.000	492.495	495.135	497.348	498.525	498.488	496.561	492.456	492.484	492.499	492.856
720.000	492.499	494.798	497.017	498.219	498.176	496.161	492.444	492.475	492.493	492.516
780.000	492.453	494.505	496.718	497.922	497.8[illegible]	495.773	492.432	492.467	492.487	492.501
840.000	492.477	494.252	496.422	497.639	497.553	495.461	492.420	492.459	492.486	492.495
900.000	492.47[illegible]	494.[illegible]29	496.157	497.3[illegible]	497.267	495.07[illegible]	492.409	492.459	492.474	492.491
960.000	492.463	493.831	495.914	497.117	497.0[illegible]2	494.8[illegible]	492.397	492.441	492.468	492.486
1020.000	492.457	493.654	495.689	496.879	496.755	494.567	492.385	492.433	492.461	492.481
1080.000	492.45[illegible]	493.496	495.482	496.657	496.530	494.367	492.374	492.424	492.455	492.476
1140.000	492.443	493.353	495.291	496.456	496.323	494.195	492.362	492.416	492.449	492.472
1200.000	492.436	493.223	495.115	496.259	496.1[illegible]	494.046	492.350	492.417	492.442	492.467
1260.000	492.429	493.1[illegible]5	494.954	496.0[illegible]2	495.96[illegible]	493.915	492.338	492.399	492.436	492.462
1320.000	492.421	492.999	494.816	495.918	495.8[illegible]2	493.801	492.327	492.389	492.429	492.457
1380.000	492.414	492.90[illegible]	494.669	495.757	495.658	493.716	492.315	492.381	492.423	492.452
1440.000	492.4[illegible]7	492.812	494.543	495.628	495.527	493.611	492.303	492.372	492.416	492.447
1500.000	492.399	492.728	494.427	495.5[illegible]1	495.4[illegible]6	493.521	492.292	492.363	492.41[illegible]	492.442
1560.000	492.392	492.652	494.321	495.393	495.297	493.46[illegible]	492.280	492.354	492.40[illegible]	492.437
1620.000	492.394	492.582	494.223	495.276	495.197	493.396	492.258	492.345	492.396	492.432
1680.000	492.376	492.519	494.133	495.177	495.1[illegible]5	493.339	492.256	492.337	492.391	492.427
1740.000	492.369	492.527	494.052	495.[illegible]86	495.[illegible]22	493.287	492.245	492.329	492.383	492.422
1800.000	492.361	492.595	493.984	495.[illegible]	494.945	493.243	492.233	492.31[illegible]	492.376	492.417

FIGURE 5-2 - Continued

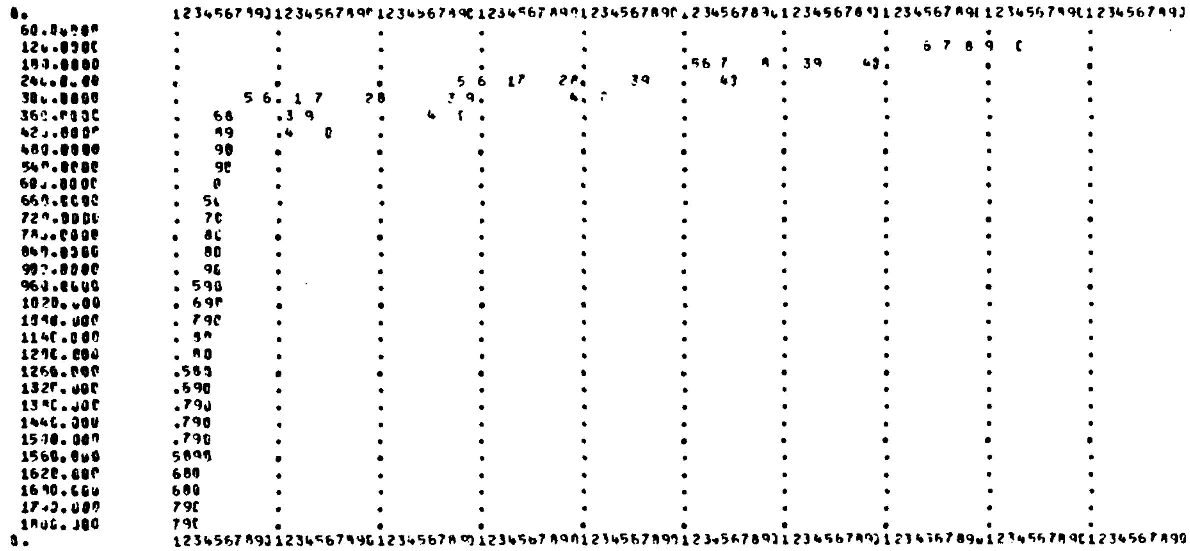
11
TEMPS
MAX 500.122
MIN 492.095



TIME/STAT	11	12	13	14	15	16	17	18	19	20
60.000	500.010	500.023	500.100	500.100	500.020	500.000	500.020	500.000	500.000	500.000
120.000	499.347	499.336	498.861	498.114	498.227	498.380	498.576	499.835	498.046	499.163
180.000	498.643	498.672	496.199	496.295	496.513	496.849	497.188	497.700	496.142	496.258
240.000	498.909	498.307	494.446	494.539	494.854	495.284	495.836	496.579	494.291	494.461
300.000	497.325	497.339	492.677	492.942	493.246	493.863	494.517	495.499	492.491	492.713
360.000	496.638	496.669	492.492	492.493	492.498	492.566	493.237	494.431	492.476	492.492
420.000	495.955	496.024	492.476	492.479	492.484	492.492	492.427	493.398	492.460	492.476
480.000	495.298	495.343	492.460	492.463	492.470	492.479	492.417	492.569	492.444	492.461
540.000	494.672	494.739	492.444	492.448	492.455	492.466	492.416	492.497	492.429	492.446
600.000	494.079	494.193	492.428	492.432	492.441	492.454	492.395	492.493	492.413	492.430
660.000	493.520	493.694	492.413	492.417	492.427	492.441	492.385	492.481	492.397	492.415
720.000	493.015	493.241	492.397	492.402	492.412	492.427	492.374	492.473	492.381	492.399
780.000	492.569	492.929	492.381	492.386	492.398	492.414	492.363	492.464	492.365	492.384
840.000	492.512	492.507	492.365	492.371	492.384	492.401	492.351	492.455	492.349	492.369
900.000	492.439	492.502	492.349	492.355	492.369	492.388	492.343	492.446	492.333	492.353
960.000	492.495	492.499	492.333	492.340	492.355	492.375	492.329	492.436	492.317	492.338
1020.000	492.491	492.495	492.317	492.325	492.340	492.362	492.318	492.427	492.311	492.322
1080.000	492.497	492.491	492.301	492.309	492.326	492.349	492.307	492.419	492.286	492.307
1140.000	492.494	492.489	492.285	492.294	492.312	492.336	492.296	492.403	492.270	492.291
1200.000	492.480	492.484	492.269	492.278	492.297	492.322	492.284	492.401	492.254	492.276
1260.000	492.476	492.483	492.254	492.263	492.283	492.309	492.273	492.391	492.238	492.260
1320.000	492.472	492.476	492.239	492.248	492.268	492.296	492.252	492.382	492.222	492.245
1380.000	492.468	492.472	492.222	492.232	492.254	492.283	492.251	492.373	492.206	492.230
1440.000	492.464	492.469	492.206	492.217	492.240	492.270	492.241	492.363	492.190	492.214
1500.000	492.463	492.464	492.199	492.201	492.225	492.257	492.229	492.354	492.174	492.199
1560.000	492.456	492.463	492.174	492.186	492.211	492.244	492.219	492.345	492.158	492.183
1620.000	492.452	492.456	492.158	492.171	492.196	492.230	492.216	492.335	492.142	492.168
1680.000	492.449	492.451	492.142	492.155	492.182	492.217	492.195	492.327	492.127	492.152
1740.000	492.444	492.447	492.126	492.140	492.168	492.204	492.184	492.318	492.111	492.137
1800.000	492.443	492.443	492.111	492.125	492.153	492.191	492.173	492.303	492.095	492.121

FIGURE 5-2 - Continued

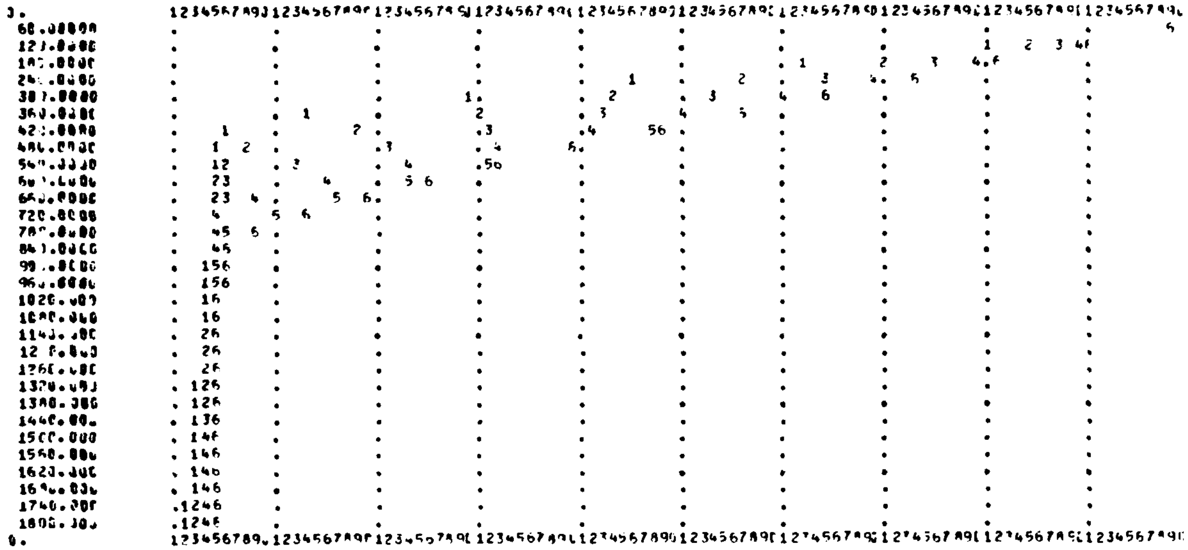
21
TEMPS
MAX 500.122
MIN 492.095



TIME/STAT	21	22	23	24	25	26	27	28	29	30
60.000	500.000	500.000	500.000	503.000	504.090	510.000	513.016	509.003	516.000	503.020
120.000	498.212	498.359	498.547	499.804	498.751	498.112	498.222	498.371	499.565	499.928
180.000	496.470	496.754	497.117	497.613	496.198	495.294	496.502	496.792	497.168	497.694
240.000	494.771	495.185	495.711	496.424	494.475	494.532	494.837	495.253	495.867	496.565
360.000	493.115	493.649	494.336	495.259	492.676	492.932	493.225	493.771	494.490	495.468
360.000	492.496	492.503	492.983	494.174	492.492	492.493	492.497	492.505	493.192	494.395
420.000	492.482	492.489	492.498	492.997	492.476	492.478	492.493	492.492	492.501	493.363
480.000	492.457	492.476	492.487	492.510	492.460	492.463	492.459	492.479	492.490	492.527
540.000	492.453	492.463	492.475	492.491	492.444	492.449	492.455	492.466	492.479	492.497
600.000	492.439	492.453	492.464	492.482	492.428	492.432	492.441	492.453	492.468	492.489
660.000	492.424	492.437	492.452	492.473	492.413	492.417	492.426	492.440	492.457	492.481
720.000	492.410	492.424	492.441	492.464	492.397	492.401	492.412	492.427	492.446	492.472
780.000	492.395	492.411	492.429	492.454	492.391	492.386	492.397	492.414	492.434	492.463
840.000	492.381	492.397	492.418	492.445	492.365	492.371	492.383	492.401	492.423	492.454
900.000	492.366	492.384	492.406	492.436	492.349	492.355	492.369	492.388	492.412	492.445
960.000	492.352	492.371	492.395	492.427	492.333	492.340	492.354	492.375	492.400	492.436
1020.000	492.337	492.358	492.383	492.417	492.317	492.324	492.340	492.361	492.389	492.427
1080.000	492.323	492.345	492.372	492.408	492.301	492.309	492.325	492.348	492.377	492.418
1140.000	492.308	492.332	492.360	492.399	492.285	492.294	492.311	492.335	492.366	492.408
1200.000	492.294	492.318	492.349	492.390	492.269	492.278	492.296	492.322	492.354	492.399
1260.000	492.279	492.305	492.337	492.380	492.254	492.263	492.282	492.309	492.343	492.390
1320.000	492.265	492.292	492.325	492.371	492.238	492.247	492.267	492.296	492.332	492.381
1380.000	492.250	492.279	492.314	492.362	492.222	492.232	492.253	492.283	492.320	492.372
1440.000	492.236	492.266	492.302	492.353	492.206	492.216	492.239	492.269	492.309	492.363
1500.000	492.221	492.252	492.291	492.343	492.190	492.201	492.224	492.256	492.297	492.354
1560.000	492.207	492.239	492.279	492.334	492.174	492.186	492.210	492.243	492.286	492.344
1620.000	492.192	492.226	492.268	492.325	492.158	492.170	492.195	492.230	492.274	492.335
1680.000	492.178	492.213	492.256	492.315	492.142	492.155	492.181	492.217	492.263	492.326
1740.000	492.163	492.200	492.245	492.306	492.126	492.139	492.166	492.204	492.252	492.317
1800.000	492.149	492.186	492.233	492.297	492.111	492.124	492.152	492.191	492.241	492.308

FIGURE 5-2 - Continued

31
TEMPS
MAX 5[illegible].120
MIN 492.095



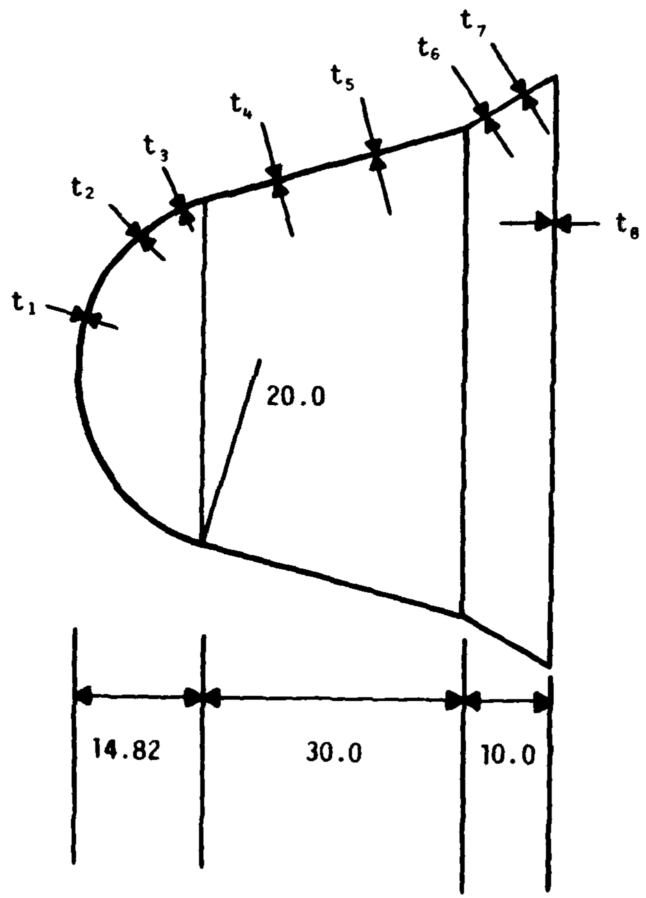
TIME/STAT	31	32	33	34	35	36
60.000	500.000	500.000	500.000	500.000	500.000	500.000
120.000	498.535	499.860	499.881	499.741	499.337	499.328
180.000	497.121	497.740	498.168	498.476	498.652	498.656
240.000	495.752	496.641	497.259	497.727	497.979	497.984
300.000	494.424	495.562	496.357	496.934	497.288	497.379
360.000	493.182	494.518	495.468	496.182	496.593	496.634
420.000	492.531	493.542	494.615	495.410	495.9[illegible]5	495.963
480.000	492.496	492.684	493.906	494.690	495.244	495.304
540.000	492.479	492.493	493.079	494.[illegible]	494.614	494.691
600.000	492.467	492.492	492.517	493.359	494.[illegible]18	494.142
660.000	492.456	492.483	492.499	492.862	493.457	493.644
720.000	492.444	492.475	492.493	492.475	492.940	493.190
780.000	492.432	492.457	492.487	492.471	492.504	492.776
840.000	492.420	492.459	492.481	492.466	492.5[illegible]	492.516
900.000	492.409	492.450	492.474	492.462	492.496	492.501
960.000	492.397	492.441	492.468	492.457	492.492	492.498
1020.000	492.395	492.433	492.461	492.452	492.4[illegible]9	492.494
1080.000	492.374	492.424	492.455	492.447	492.485	492.491
1140.000	492.362	492.415	492.448	492.443	492.481	492.487
1200.000	492.350	492.407	492.442	492.438	492.477	492.483
1260.000	492.338	492.398	492.435	492.433	492.473	492.479
1320.000	492.327	492.389	492.429	492.428	492.469	492.475
1380.000	492.315	492.380	492.422	492.423	492.465	492.471
1440.000	492.303	492.371	492.416	492.418	492.461	492.467
1500.000	492.292	492.363	492.409	492.413	492.457	492.463
1560.000	492.280	492.354	492.402	492.408	492.452	492.459
1620.000	492.268	492.345	492.396	492.403	492.448	492.454
1680.000	492.256	492.336	492.389	492.398	492.444	492.450
1740.000	492.245	492.327	492.382	492.393	492.440	492.446
1800.000	492.233	492.318	492.375	492.388	492.436	492.441

FIGURE 5-2 - Concluded

5.2 REPLICA

This example consists of a biconic shape with a tangentially fitting spherical nosecap that is divided into 24 stations, eight longitudinal by three azimuthal. The nose is made of silicon phenolic that tapers from 0.3 in. for the first two nose stations (along a single longitudinal ray) to 0.2 in. for the third nose station. The first frustum has two stations, each consisting of a 0.1-in. aluminum structure covered by a 0.1-in. thickness of silicon phenolic. The second frustum contains two stations with the a 0.1-in.-thick aluminum structure covered by 0.05 in. of silicon phenolic. The base has one station of material structured similar to that of the first frustum. The dimensions of the replica are shown in Figure 5-3. Note that whenever the material identification code word JMAT of card 6.1 changes, card set 7 must be input. The nose is completely silicon phenolic (JMAT = 203), and the numbers JMAT = 180 and JMAT = 190 have been arbitrarily assigned to the aluminum and silicon phenolic combinations. Equations 3-31 through 3-33 were used to compute the average values of ρ, c_p, and k that are input. Figure 5-4 and 5-5 show the input and output, respectively, for this example.

NOTE: ALL DIMENSIONS IN cm



SKIN STRUCTURE	JMAT
t_1 0.3 in. SILICON PHENOLIC (SP)	203
t_2 0.3 in. SP	203
t_3 0.2 in SP	203
t_4 0.1 in. SP, 0.1 in. ALUMINUM	190
t_5 0.1 in. SP, 0.1 in. ALUMINUM	190
t_6 0.05 in. SP, 0.1 in. ALUMINUM	180
t_7 0.05 in. SP, 0.1 in. ALUMINUM	180
t_8 0.1 in. SP, 0.1 in. ALUMINUM	190

FIGURE 5-3. REPLICA GEOMETRY

```
        1         11        21        31        41        51        61        71
CARD    +.........+.........+.........+.........+.........+.........+.........+.........
   1    BASIC
   2    TRAJ      CALC      WATR      EXOMLAT   WATR      CALC      SIGMA     CALC
   3    TARGSYM   YES
   4        3
   5    5.        9.
   6    11.       15.
   7    18.       24.
   8
   9    MBALL
  10      3
  11        3         20.0      14.82     3
  12        2         15.0
  13        2         15.0      30.
  14        2         30.0      1..0
  15    1.
  16
  17     RV EXAMPLE                  110    2    1.      15.0
  18     RV-USC4    300.         1    0
  19      2.       1500.     1161.115   59.804    84.597   216.4.   22.       -2.137
  20     GR-USC4
  21                          539..91   54.957    -98.481
  22     END
  23
  24    EXIT
  25     $SULAR .TYPE=1,SLAT=?.,SLON=0.,MONTH=8,IDAY=1.,TCLO=3    $
  26        3
  27    0.        120.      240.
  28        8
  29       28.78     50.99     67.51     76.0      75.0      66.0      56.       14..6
  30        1
  31     $TBALL DALL=3.  $
  32        F    T
  33            233 .250      540.
  34            203 .250      540.
  35            203 .167      540.
  36            197 .167      540.
  37            193 .167      540.
  38            183 .125      540.
  39            183 .125      540.
  40            193 .167      540.
  41            203 .250      540.
  42            233 .250      540.
  43            203 .167      540.
  44            197 .167      540.
  45            193 .167      540.
  46            183 .125      540.
  47            193 .125      540.
  48            193 .167      540.
  49            203 .250      540.
  50            233 .250      540.

        1         11        21        31        41        51        61        71
CARD    +.........+.........+.........+.........+.........+.........+.........+.........
```

FIGURE 5-4. REPLICA EXAMPLE INPUT

```
       1         11        21        31        41        51        61        71
CARD   +.........+.........+.........+.........+.........+.........+.........+.........
  51            200 .167   540.
  52            190 .167   540.
  53            190 .167   540.
  54            180 .125   540.
  55            180 .125   540.
  56            190 .167   540.
  57      4       139.0     .75      .2         .5
  58              400.     .178     .0135
  59              510.     .206     .0095
  60              610.     .221     .0105
  61              710.     .233     .0120
  62      4       151.3     .75      .2         .5
  63              400.     .193     .0113
  64              510.     .205     .0127
  65              610.     .216     .0140
  66              700.     .226     .0160
  67      4       139.0     .75      .2         .5
  68              410.     .179     .0095
  69              510.     .206     .0095
  70              610.     .221     .0105
  71              710.     .233     .0120
  72      4       139.0     .75      .2         .5
  73              400.     .178     .0085
  74              530.     .206     .0095
  75              630.     .221     .0105
  76              710.     .233     .0120
  77      4       150.3     .75      .2         .5
  78              400.     .193     .0113
  79              530.     .205     .0127
  80              630.     .216     .0140
  81              710.     .226     .0160
  82      4       139.0     .75      .2         .5
  83              490.     .179     .0085
  84              530.     .206     .0095
  85              630.     .221     .0105
  86              700.     .233     .0120
  87      4       139.0     .75      .2         .5
  88              400.     .178     .0085
  89              500.     .216     .0095
  90              600.     .221     .0105
  91              700.     .233     .0120
  92      4       150.3     .75      .2         .5
  93              400.     .183     .0113
  94              500.     .205     .0127
  95              510.     .216     .0140
  96              700.     .226     .0160
  97      4       139.0     .75      .2         .5
  98              400.     .178     .0085
  99              500.     .216     .0095
 100              610.     .221     .0105

       1         11        21        31        41        51        61        71
CARD   +.........+.........+.........+.........+.........+.........+.........+.........
```

FIGURE 5-4 - Continued

```
IMAGE OF DATA-CARDS...

          1         11        21        31        41        51        61        71
CARD      +.........+.........+.........+.........+.........+.........+.........+.........
 1^1                7..       .2??      .J12(

          1         11        21        31        41        51        61        71
CARD      +.........+.........+.........+.........+.........+.........+.........+.........
```

FIGURE 5-4 - Concluded

```
PROGRAM BASIK

          BALLIS WILL CALCULATE TRAJECTORY DATA
          EXOHEAT WILL CALCULATE THERMAL DATA
          SELECT WILL PROVIDE BIDIREC WITH OPTICAL PROPERTIES DATA
          BIDIREC WILL CALCULATE TARGET SIGNATURE DATA
          NO NATURAL,PLUME,OR NUCLEAR BACKGROUND DATA WILL BE INPUT OR CALCULATED
          NO OFFAXIS CALCULATIONS WILL BE MADE
          NO SENSOR MODEL CALCULATIONS WILL BE MADE
          TARGET SYNTHESIS PERFORMED

NORANO =      3
LAMBDA INCREMENT WAS NOT INPUT, DEFAULTED TO 0.1

   LWAVE =   191          LAMINC =   .100E+00
```

.500000E+01	.510000E+01	.520000E+01	.530000E+01	.540000E+01	.550000E+01	.560000E+01	.570000E+01
.580000E+01	.590000E+01	.600000E+01	.610000E+01	.620000E+01	.630000E+01	.640000E+01	.650000E+01
.660000E+01	.670000E+01	.680000E+01	.690000E+01	.700000E+01	.710000E+01	.720000E+01	.730000E+01
.740000E+01	.750000E+01	.760000E+01	.770000E+01	.780000E+01	.790000E+01	.800000E+01	.810000E+01
.820000E+01	.830000E+01	.840000E+01	.850000E+01	.860000E+01	.870000E+01	.880000E+01	.890000E+01
.900000E+01	.910000E+01	.920000E+01	.930000E+01	.940000E+01	.950000E+01	.960000E+01	.970000E+01
.980000E+01	.990000E+01	.100000E+02	.101000E+02	.102000E+02	.103000E+02	.104000E+02	.105000E+02
.106000E+02	.107000E+02	.108000E+02	.109000E+02	.110000E+02	.111000E+02	.112000E+02	.113000E+02
.114000E+02	.115000E+02	.116000E+02	.117000E+02	.118000E+02	.119000E+02	.120000E+02	.121000E+02
.122000E+02	.123000E+02	.124000E+02	.125000E+02	.126000E+02	.127000E+02	.128000E+02	.129000E+02
.130000E+02	.131000E+02	.132000E+02	.133000E+02	.134000E+02	.135000E+02	.136000E+02	.137000E+02
.138000E+02	.139000E+02	.140000E+02	.141000E+02	.142000E+02	.143000E+02	.144000E+02	.145000E+02
.146000E+02	.147000E+02	.148000E+02	.149000E+02	.150000E+02	.151000E+02	.152000E+02	.153000E+02
.154000E+02	.155000E+02	.156000E+02	.157000E+02	.158000E+02	.159000E+02	.160000E+02	.161000E+02
.162000E+02	.163000E+02	.164000E+02	.165000E+02	.166000E+02	.167000E+02	.168000E+02	.169000E+02
.170000E+02	.171000E+02	.172000E+02	.173000E+02	.174000E+02	.175000E+02	.176000E+02	.177000E+02
.178000E+02	.179000E+02	.180000E+02	.181000E+02	.182000E+02	.183000E+02	.184000E+02	.185000E+02
.186000E+02	.187000E+02	.188000E+02	.189000E+02	.190000E+02	.191000E+02	.192000E+02	.193000E+02
.194000E+02	.195000E+02	.196000E+02	.197000E+02	.198000E+02	.199000E+02	.200000E+02	.201000E+02
.202000E+02	.203000E+02	.204000E+02	.205000E+02	.206000E+02	.207000E+02	.208000E+02	.209000E+02
.210000E+02	.211000E+02	.212000E+02	.213000E+02	.214000E+02	.215000E+02	.216000E+02	.217000E+02
.218000E+02	.219000E+02	.220000E+02	.221000E+02	.222000E+02	.223000E+02	.224000E+02	.225000E+02
.226000E+02	.227000E+02	.228000E+02	.229000E+02	.230000E+02	.231000E+02	.232000E+02	.233000E+02
.234000E+02	.235000E+02	.236000E+02	.237000E+02	.238000E+02	.239000E+02	.240000E+02	

```
   WAVEBAND FROM    5.000 MICRONS TO    [illegible] MICRONS
```

FIGURE 5-5. REPLICA EXAMPLE OUTPUT

```
RV EXAMPLE
FLIGHT STARTS AT       0.00 SECONDS AND PROCEEDS IN   130 STEPS OF      15.00 SECONDS, PRINTING EACH  2TH STEP
.........................................................................................
RV-OSC4       300.00    1    0
     0.00   1500.00   1166.12     59.80     84.66  21644.00     22.00     -2.14
.........................................................................................
GB-OSC4         0.00    0    0
     0.00      0.00   5980.91     54.86    -98.48      0.00      0.00      0.00
.........................................................................................
END             0.00    0    1
     0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
  2   TARGETS  INITIALIZED
 ID TAG    TIME     ALT-KFT      LAT     LONG   VEL-FT/S  ENT.ANG  COURSE  RANGE-KFT     ELEV     AZIM    ASP1    ASP2    ASP3

GB-OSC4    0.00    5980.910   54.857  -98.481      0.000    0.010    0.000
RV-OSC4    0.00    1160.115   59.804   84.597  21604.000   22.000  357.863  26720.973  -41.393  358.297   46.99   86.21   44.16 INVISIBLE

GB-OSC4   30.00    5980.910   54.857  -98.481      0.000    0.000    0.000
RV-OSC4   30.00    1398.099   61.347   84.482  21296.138   21.417  357.932  26270.267  -40.465  358.417   44.95   86.31   45.29 INVISIBLE

GB-OSC4   60.00    5980.910   54.857  -98.481      0.000    0.000    0.000
RV-OSC4   60.00    1626.495   62.958   84.367  20982.951   20.998  358.007  25817.131  -39.433  358.532   43.80   86.41   46.43 INVISIBLE

GB-OSC4   90.00    5980.910   54.857  -98.481      0.000    0.000    0.000
RV-OSC4   90.00    1845.339   64.339   84.253  20694.258   20.172  358.088  25361.588  -38.479  358.644   42.63   86.51   47.58

GB-OSC4  120.00    5980.910   54.857  -98.481      0.000    0.000    0.000
RV-OSC4  120.00    2054.660   65.792   84.141  20419.113   19.510  358.175  24903.651  -37.541  358.750   41.45   86.63   48.75

GB-OSC4  150.00    5980.910   54.857  -98.481      0.000    0.000    0.000
RV-OSC4  150.00    2254.522   67.220   84.030  20157.802   18.825  358.268  24443.323  -36.620  358.853   40.25   86.75   49.93

GB-OSC4  180.00    5980.910   54.857  -98.481      0.000    0.000    0.000
RV-OSC4  180.00    2444.941   68.624   83.920  19919.842   18.115  358.367  23982.595  -35.716  358.951   39.04   86.87   51.14

GB-OSC4  210.00    5980.910   54.857  -98.481      0.000    0.000    0.000
RV-OSC4  210.00    2625.964   70.006   83.812  19674.977   17.383  358.472  23519.454  -34.829  359.045   37.91   87.01   52.36

GB-OSC4  240.00    5980.910   54.857  -98.481      0.000    0.000    0.000
RV-OSC4  240.00    2797.632   71.367   83.706  19452.977   16.628  358.583  23047.877  -33.959  359.134   36.55   87.15   53.60

GB-OSC4  270.00    5980.910   54.857  -98.481      0.000    0.000    0.000
RV-OSC4  270.00    2959.982   72.709   83.6.3  19243.637   15.853  358.701  22577.839  -33.107  359.219   35.28   87.29   54.86

GB-OSC4  300.00    5980.910   54.857  -98.481      0.000    0.000    0.000
RV-OSC4  300.00    3113.052   74.034   83.503  19046.771   15.057  358.825  22105.307  -32.273  359.299   33.99   87.45   56.14

GB-OSC4  330.00    5980.910   54.857  -98.481      0.000    0.000    0.000
RV-OSC4  330.00    3256.880   75.342   83.407  18862.217   14.243  358.957  21636.248  -31.457  359.375   32.67   87.61   57.44

GB-OSC4  360.00    5980.910   54.857  -98.481      0.000    0.010    0.000
```

FIGURE 5-5 - Continued

RV-OSC4 360.00	3391.566	76.635	83.316	18680.424	13.419	359.097	21152.623	-30.663	359.445	31.33	87.74	58.76
GB-OSC4 390.00	5980.910	54.857	-98.481	0.000	0.000	0.000						
RV-OSC4 390.00	3516.946	77.915	83.272	19529.475	12.559	359.247	21672.394	-29.882	359.511	29.97	87.95	60.11
GB-OSC4 420.00	5980.910	54.857	-98.481	0.000	0.000	0.000						
RV-OSC4 420.00	3633.249	79.182	83.157	18781.845	11.691	359.418	20189.521	-29.125	359.572	28.59	88.14	61.49
GB-OSC4 450.00	5980.910	54.857	-98.481	0.000	0.000	0.000						
RV-OSC4 450.00	3746.440	80.437	83.095	18244.440	10.819	359.585	19733.965	-28.388	359.628	27.18	88.33	62.88
GB-OSC4 480.00	5980.910	54.857	-98.481	0.000	0.000	0.000						
RV-OSC4 480.00	3838.547	81.682	83.056	18119.572	9.912	359.782	19215.698	-27.674	359.678	25.74	88.52	64.31
GB-OSC4 510.00	5980.910	54.857	-98.481	0.000	0.000	0.000						
RV-OSC4 510.00	3927.594	82.917	83.033	18016.361	9.002	.667	18724.656	-26.983	359.722	24.28	88.73	65.76
GB-OSC4 540.00	5980.910	54.857	-98.481	0.000	0.000	0.000						
RV-OSC4 540.00	4007.606	84.144	83.361	17904.747	8.080	.279	18232.433	-26.317	359.763	22.78	88.94	67.24
GB-OSC4 570.00	5980.910	54.857	-98.481	0.000	0.000	0.000						
RV-OSC4 570.00	4078.605	85.364	83.167	17814.677	7.148	.631	17734.190	-25.678	359.792	21.26	89.16	68.75
GB-OSC4 600.00	5980.910	54.857	-98.481	0.000	0.000	0.000						
RV-OSC4 600.00	4140.608	86.577	83.434	17736.092	6.205	1.147	17234.712	-25.067	359.817	19.71	89.38	70.30
GB-OSC4 630.00	5980.910	54.857	-98.481	0.000	0.000	0.000						
RV-OSC4 630.00	4193.633	87.784	84.127	17668.963	5.254	2.088	16732.383	-24.486	359.834	18.13	89.62	71.88
GB-OSC4 660.00	5980.910	54.857	-98.481	0.000	0.000	0.000						
RV-OSC4 660.00	4237.694	88.985	86.751	17613.254	4.296	4.961	16227.202	-23.938	359.843	16.51	89.86	73.49
GB-OSC4 690.00	5980.910	54.857	-98.481	0.000	0.000	0.000						
RV-OSC4 690.00	4272.804	89.791	236.132	17568.937	3.332	154.592	15719.177	-23.427	359.844	14.86	90.11	75.14
GB-OSC4 720.00	5980.910	54.857	-98.481	0.000	0.000	0.000						
RV-OSC4 720.00	4298.971	90.612	257.734	17535.991	2.364	176.443	15208.336	-22.956	359.835	13.17	90.36	76.93
GB-OSC4 750.00	5980.910	54.857	-98.481	0.000	0.000	0.000						
RV-OSC4 750.00	4316.204	91.419	259.721	17514.402	1.392	178.281	14694.773	-22.525	359.816	11.45	90.63	78.57
GB-OSC4 780.00	5980.910	54.857	-98.481	0.000	0.000	0.000						
RV-OSC4 780.00	4324.506	92.227	259.825	17504.157	.419	179.035	14178.409	-22.144	359.786	9.69	90.91	80.35
GB-OSC4 810.00	5980.910	54.857	-98.481	0.000	0.000	0.000						
RV-OSC4 810.00	4323.880	93.034	260.029	17505.252	-.555	179.486	13659.493	-21.816	359.743	7.90	91.19	82.19
GB-OSC4 840.00	5980.910	54.857	-98.481	0.000	0.000	0.000						
RV-OSC4 840.00	4314.325	93.841	260.1[illegible]3	17517.683	-1.529	179.816	13138.1[illegible]9	-21.548	359.687	6.09	91.49	84.09

FIGURE 5-5 - Continued

```
EXOHEAT

 24  PIECES
  3  AZIM. DIVISIONS
  8  LONG. DIVISIONS

AZIM. ANGLES
                         0.00     120.00     240.00
POLAR ANGLES
                         28.78    50.99      67.51     75.00     75.00     69.00     60.00     18.00

MODE        1  (1=INST.FLUX, 2=ROLL-AVGED FLUX)
MONTH       8
DAY        10
GMT         0.00
SUN-LAT,LNG      0.00      0.00
```

TIME	CONDITION	AVERAGE FLUXES -- W/(M**2) SUN/ALBEDO	EARTH	MOLECULAR
0.	SUNLIT	348.6558	128.7528	0.
30.0000	SUNLIT	348.5368	120.6860	0.
60.0000	SUNLIT	348.4320	114.1127	0.
90.0000	SUNLIT	348.3308	108.1425	0.
120.0000	SUNLIT	348.2346	102.9933	0.
150.0000	SUNLIT	348.1297	98.10172	0.
180.0000	SUNLIT	348.0234	93.69156	0.
210.0000	SUNLIT	347.9122	89.48573	0.
240.0000	SUNLIT	347.7941	85.84116	0.
270.0000	SUNLIT	347.6683	83.56494	0.
300.0000	SUNLIT	347.5425	80.59827	0.
330.0000	SUNLIT	347.4137	78.28134	0.
360.0000	SUNLIT	347.2815	76.16543	0.
390.0000	SUNLIT	347.1512	74.53495	0.
420.0000	SUNLIT	347.0161	72.93921	0.
450.0000	SUNLIT	346.8767	71.10149	0.
480.0000	SUNLIT	346.7342	69.97856	0.
510.0000	SUNLIT	346.5906	69.09332	0.
540.0000	SUNLIT	346.4458	67.93349	0.
570.0000	SUNLIT	346.2975	67.18211	0.
600.0000	SUNLIT	346.1483	66.66748	0.
630.0000	SUNLIT	346.0013	66.16748	0.
660.0000	SUNLIT	345.8664	65.78464	0.
690.0000	SUNLIT	345.7052	64.71902	0.
720.0000	SUNLIT	345.3639	65.26889	0.
750.0000	SUNLIT	345.2271	65.11285	0.
780.0000	SUNLIT	345.0555	64.90722	0.
810.0000	SUNLIT	344.8723	64.75410	0.
840.0000	SUNLIT	344.6819	65.07951	0.
870.0000	SUNLIT	344.4868	65.31422	0.
900.0000	SUNLIT	344.2884	65.68816	0.
930.0000	SUNLIT	344.0838	66.16785	0.
960.0000	SUNLIT	343.8754	66.69854	0.
990.0000	SUNLIT	343.6620	67.59173	0.
1020.000	SUNLIT	343.4480	68.42413	0.
1050.000	SUNLIT	343.2294	69.33975	0.
1080.000	SUNLIT	343.0042	70.37536	0.
1110.000	SUNLIT	342.7763	71.85812	0.
1140.000	SUNLIT	342.5274	73.15459	0.
1170.000	SUNLIT	342.2778	74.72723	0.
1200.000	SUNLIT	342.0177	76.39032	0.
1230.000	SUNLIT	341.7588	78.76298	0.
1260.000	SUNLIT	341.4791	81.32219	0.
1290.000	SUNLIT	341.1988	84.11873	0.
1320.000	SUNLIT	340.9063	86.14510	0.
1350.000	SUNLIT	340.6124	89.66132	0.
1380.000	SUNLIT	340.3091	92.03871	0.
1410.000	SUNLIT	340.0108	95.26317	0.
1440.000	SUNLIT	339.7077	99.08869	0.
1470.000	SUNLIT	339.4169	102.2723	0.

```
BASELINE SILICA PHENOLIC (QUARTZ PHENOLIC) (30 PERCENT PHENOLIC RESIN)
BASELINE SILICA PHENOLIC (QUARTZ PHENOLIC) (30 PERCENT PHENOLIC RESIN)
BASELINE SILICA PHENOLIC (QUARTZ PHENOLIC) (30 PERCENT PHENOLIC RESIN)
BASELINE SILICA PHENOLIC (QUARTZ PHENOLIC) (30 PERCENT PHENOLIC RESIN)
BASELINE SILICA PHENOLIC (QUARTZ PHENOLIC) (30 PERCENT PHENOLIC RESIN)
BASELINE SILICA PHENOLIC (QUARTZ PHENOLIC) (30 PERCENT PHENOLIC RESIN)
BASELINE SILICA PHENOLIC (QUARTZ PHENOLIC) (30 PERCENT PHENOLIC RESIN)
BASELINE SILICA PHENOLIC (QUARTZ PHENOLIC) (30 PERCENT PHENOLIC RESIN)
BASELINE SILICA PHENOLIC (QUARTZ PHENOLIC) (30 PERCENT PHENOLIC RESIN)
```

FIGURE 5-5 - Continued

STAT	AREA	PERP	PAR	RADIUS	ZED	RUNLTH	THASS	RAD	COND	THTP	ALF	EOUT	EIN
1	.223	.481	.876	.316	.810E-01	.330	.130	.981E-04	.580E-05	.125E+04	.500	.750	.750
2	.223	.777	.629	.510	.243	.584	.130	.981E-04	.109E-04	.119E+04	.500	.750	.750
3	.223	.924	.382	.606	.405	.773	.867E-01	.981E-04	.131E-04	780.	.500	.750	.750
4	.747	.966	.259	.700	.732	1.11	.367	.208E-03	.623E-03	442.	.500	.750	.200
5	.887	.966	.259	.832	1.22	1.62	.437	.248E-03	.148E-02	252.	.500	.750	.200
6	.375	.866	.500	.945	1.55	1.97	.147	.106E-03	.274E-02	51.9	.500	.750	.200
7	.412	.866	.500	1.04	1.72	2.16	.162	.116E-03	.231E-02	67.0	.500	.750	.200
8	1.24	-.308E-09	-1.00	.543	1.80	2.80	.609	.352E-03	.680E-03	590.	.500	.750	.200
9	.223	.481	.876	.316	.810E-01	.330	.130	.981E-04	.580E-05	.125E+04	.500	.750	.750
10	.223	.777	.629	.510	.243	.584	.130	.981E-04	.109E-04	.119E+04	.500	.750	.750
11	.223	.924	.382	.606	.405	.773	.867E-01	.981E-04	.131E-04	780.	.500	.750	.750
12	.747	.966	.259	.700	.732	1.11	.367	.208E-03	.623E-03	442.	.500	.750	.200
13	.887	.966	.259	.832	1.22	1.62	.437	.248E-03	.148E-02	252.	.500	.750	.200
14	.375	.866	.500	.945	1.55	1.97	.147	.106E-03	.274E-02	51.9	.500	.750	.200
15	.412	.966	.500	1.04	1.72	2.16	.162	.116E-03	.231E-02	67.0	.500	.750	.200
16	1.24	-.308E-09	-1.00	.543	1.80	2.80	.609	.352E-03	.680E-03	590.	.500	.750	.200
17	.223	.481	.876	.316	.810E-01	.330	.130	.981E-04	.580E-05	.125E+04	.500	.750	.750
18	.223	.777	.629	.510	.243	.584	.130	.981E-04	.109E-04	.119E+04	.500	.750	.750
19	.223	.924	.382	.606	.405	.773	.867E-01	.981E-04	.131E-04	780.	.500	.750	.750
20	.747	.966	.259	.700	.732	1.11	.367	.208E-03	.623E-03	442.	.500	.750	.200
21	.887	.966	.259	.832	1.22	1.62	.437	.248E-03	.148E-02	252.	.500	.750	.200
22	.375	.866	.500	.945	1.55	1.97	.147	.106E-03	.274E-02	51.9	.500	.750	.200
23	.412	.966	.500	1.04	1.72	2.16	.162	.116E-03	.231E-02	67.0	.500	.750	.200
24	1.24	-.308E-09	-1.00	.543	1.80	2.80	.609	.352E-03	.680E-03	590.	.500	.750	.200

TIME DEVELOPMENT OF TEMPERATURES

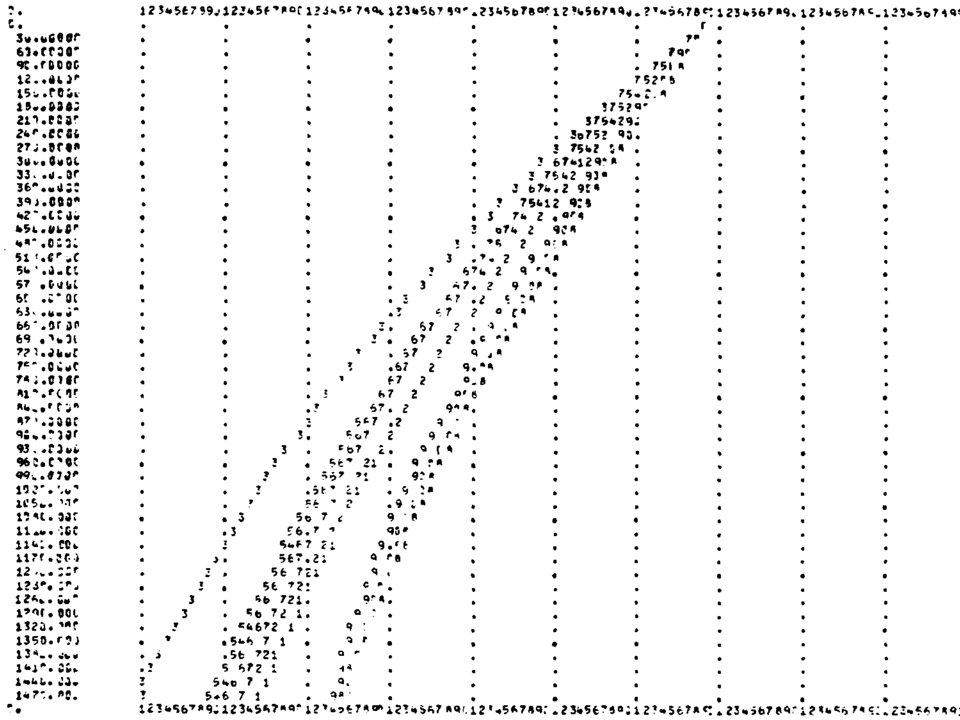
LONGITUDINAL CONDUCTION TREATED -- T

OPEN REAR SURFACE -- F

NR MTX INV-- 147

FIGURE 5-5 - Continued

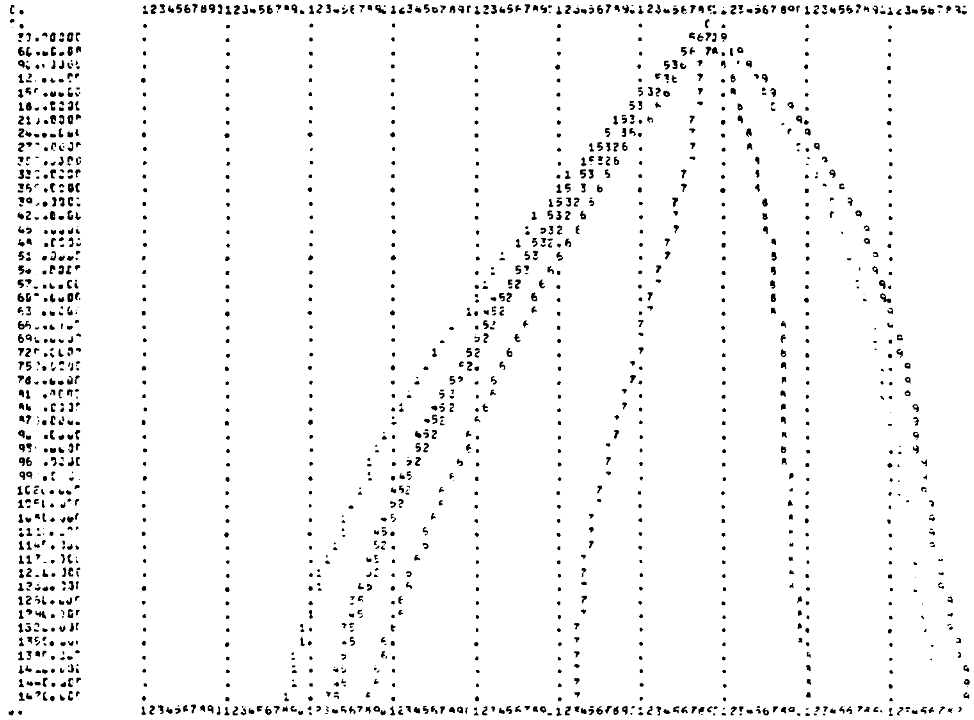
TEMPS 1
MAX 571.271
MIN 472.653



TIME/STAT	1	2	3	4	5	6	7	8	9	10
[illegible]	540.010	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
30.[illegible]	538.496	529.545	527.915	538.338	538.324	537.934	537.942	538.23[illegible]	538.759	539.451
60.[illegible]	536.999	537.1[illegible]	535.86[illegible]	536.717	536.657	535.379	536.[illegible]	537.099	537.515	537.751
90.[illegible]	535.516	535.675	532.862	535.173	535.102	534.1[illegible]8	534.177	535.956	536.272	536.015
120.[illegible]	534.154	534.257	531.987	533.525	533.365	532.335	532.431	535.895	535.[illegible]	535.477
150.[illegible]	532.614	532.849	529.992	532.97[illegible]	531.745	53[illegible]	53[illegible]	534.[illegible]	533.[illegible]	[illegible]
180.[illegible]	531.195	52[illegible].451	528.125	53[illegible].435	530.144	528.961	529.141	533.731	532.581	533.[illegible]5
210.[illegible]	529.736	530.[illegible]	526.273	529.924	528.567	527.351	527.577	532.637	531.367	532.[illegible]
240.[illegible]	528.418	528.674	524.462	527.423	527.0[illegible]1	525.782	52[illegible].56	531.542	53[illegible].143	53[illegible]
270.[illegible]	527.360	527.299	522.681	525.941	525.458	524.249	52[illegible].571	53[illegible].451	529.972	52[illegible]
300.[illegible]	525.721	525.941	520.926	524.474	523.972	522.748	523.117	529.362	527.708	529.[illegible]
330.[illegible]	524.432	524.6[illegible]2	519.195	523.[illegible]	522.424	521.272	521.541	529.26[illegible]	525.63[illegible]	527.[illegible]
360.[illegible]	523.131	523.25[illegible]	517.487	522.579	520.931	519.826	52[illegible].29[illegible]	527.215	525.460	526.573
390.[illegible]	521.918	521.979	515.798	52[illegible].148	519.454	518.4[illegible]	519.929	526.139	524.354	525.459
420.[illegible]	520.554	520.694	514.108	519.776	517.992	517.[illegible]	517.613	525.087	523.278	524.[illegible]99
450.[illegible]	519.338	519.427	512.465	517.748	516.546	515.69[illegible]	516.3[illegible]	524.441	522.137	523.349
480.[illegible]	518.098	518.[illegible]77	51[illegible].865	515.933	515.13[illegible]	514.378	515.[illegible]	523.[illegible]12	521.151	522.712
510.[illegible]	516.859	516.943	5[illegible]9.287	514.572	513.75[illegible]	513.491	513.817	522.[illegible]	519.981	521.2[illegible]
540.[illegible]	515.675	515.723	5[illegible]7.744	513.237	5[illegible]2.396	511.834	51[illegible].511	52[illegible]	518.908	520.241
570.[illegible]	514.499	514.525	506.2[illegible]5	5[illegible].926	511.070	510.6[illegible]5	511.432	52[illegible]20	517.401	519.2[illegible]7
600.[illegible]	513.339	513.33[illegible]	504.759	51[illegible].629	509.772	509.462	51[illegible].277	519.155	516.971	51[illegible]
630.[illegible]	512.197	512.169	5[illegible]3.315	5[illegible]9.375	5[illegible]8.5[illegible]1	508.224	509.146	519.108	515.968	517.3[illegible]
660.[illegible]	51[illegible]	51[illegible]	5[illegible]1.9[illegible]2	[illegible].134	507.256	5[illegible]7.[illegible]	51[illegible].038	517.179	514.[illegible]	[illegible].796
690.[illegible]	509.962	509.874	5[illegible]0.5[illegible]8	5[illegible]6.915	5[illegible]6.[illegible]36	505.941	51[illegible].95[illegible]	516.263	513.9[illegible]	515.[illegible]
720.[illegible]	508.876	508.749	499.163	5[illegible]5.718	5[illegible]4.841	504.924	5[illegible].89[illegible]	515.304	512.966	51[illegible].541
750.[illegible]	507.796	507.678	497.875	5[illegible]4.543	5[illegible]3.676	503.749	51[illegible].947	514.[illegible]	512.[illegible]35	513.642
780.[illegible]	506.737	506.542	496.532	5[illegible]3.349	5[illegible]2.522	502.645	51[illegible].925	513.6[illegible]	511.122	512.759
810.[illegible]	505.696	505.46[illegible]	495.255	5[illegible].255	5[illegible]1.396	501.643	51[illegible].922	512.753	510.227	511.891
840.[illegible]	504.671	504.292	494.[illegible]2	5[illegible]1.142	5[illegible]0.292	5[illegible]	5[illegible]1.939	511.933	510.351	[illegible]
870.[illegible]	503.664	503.339	492.773	5[illegible]	499.2[illegible]9	499.614	5[illegible].975	511.[illegible]	510.495	51[illegible]
900.[illegible]	502.676	502.37[illegible]	491.568	498.97[illegible]	499.[illegible]47	498.634	499.929	51[illegible].281	5[illegible]7.659	51[illegible]
930.[illegible]	501.731	501.275	49[illegible].385	497.919	497.1[illegible]	497.869	493.[illegible]	509.4[illegible]	515.847	514.592
960.[illegible]	500.765	50[illegible].263	489.225	49[illegible].881	496.[illegible]	4[illegible].72[illegible]	49[illegible]	5[illegible]	5[illegible]	5[illegible].412
990.[illegible]	499.847	499.266	498.[illegible]	495.061	495.[illegible]76	4[illegible]5.792	497.136	5[illegible]7.935	515.27[illegible]	5[illegible]
1020.[illegible]	498.996	498.282	486.969	49[illegible].859	49[illegible]	45[illegible].88[illegible]	495.319	5[illegible]7.1[illegible]	5[illegible].517	[illegible]
1050.[illegible]	497.992	497.311	485.877	4[illegible]7.975	493.122	453.985	495.458	5[illegible]	5[illegible].744	[illegible]
1080.[illegible]	497.095	496.35[illegible]	484.798	492.9[illegible]	492.171	4[illegible]3.1[illegible]8	494.614	505.698	5[illegible]3.[illegible]	5[illegible].895
1110.[illegible]	496.226	495.413	483.743	491.957	491.239	492.24[illegible]	493.795	504.972	5[illegible]2.393	5[illegible]
1140.[illegible]	495.775	494.483	482.7[illegible]7	491.[illegible]23	490.323	[illegible]1.464	492.973	5[illegible].25[illegible]	501.71[illegible]	5[illegible]3.545
1170.[illegible]	494.563	493.565	481.692	49[illegible].106	489.425	490.577	492.177	5[illegible]3.549	51[illegible]	5[illegible]2.[illegible]
1200.[illegible]	493.729	492.664	480.696	4[illegible].706	488.543	489.766	491.335	[illegible]2.[illegible]	5[illegible]	[illegible]
1230.[illegible]	492.934	491.777	479.720	48[illegible].322	487.679	488.972	49[illegible]	5[illegible].14[illegible]	[illegible]	[illegible]
1260.[illegible]	492.158	490.9[illegible]6	478.763	487.455	486.832	4[illegible]8.194	489.88[illegible]	5[illegible].444	[illegible].292	5[illegible].131
1290.[illegible]	491.403	490.052	477.927	486.816	486.[illegible]3	487.4[illegible]	489.165	5[illegible].763	498.751	5[illegible].591
1320.[illegible]	490.668	489.214	476.911	485.774	485.190	486.689	488.425	50[illegible].281	4[illegible].237	[illegible]
1350.[illegible]	489.955	488.391	476.116	484.959	484.396	485.962	487.722	495.[illegible]2	497.745	499.583
1380.[illegible]	489.263	487.591	475.142	484.183	483.67[illegible]	485.252	487.[illegible]	498.720	497.25[illegible]	49[illegible].115
1410.[illegible]	488.594	486.577	474.290	4[illegible]2.385	482.862	484.561	486.264	49[illegible]59	496.[illegible]	49[illegible]
1440.[illegible]	487.952	486.044	473.450	4[illegible].076	482.123	483.899	485.711	497.393	496.42[illegible]	49[illegible].2[illegible]
1470.98[illegible]	487.334	485.382	472.653	481.887	481.413	483.236	485.177	49[illegible].73[illegible]	496.[illegible]	497.97[illegible]

FIGURE 5-5 - Continued

11
TEMPS
MAX 571.271
MIN 472.652



TIME/STAT	11	12	13	14	15	16	17	18	19	20
0.000	540.010	540.[illegible]	540.00?	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	541.[illegible]	[illegible]
30.000	538.496	538.799	538.788	535.466	538.46?	539.422	539.973	541.43?	541.985	541.579
60.000	536.965	537.585	537.546	535.973	536.962	538.42?	539.814	541.6?1	543.421	543.?59
90.000	535.445	536.367	536.245	535.519	535.5?7	537.?61	539.646	542.378	545.524	544.449
120.000	533.970	535.144	535.?12	534.?1?	534.?41	535.971	539.495	542.359	547.1?7	545.?5?
150.000	532.465	533.923	533.736	532.715	532.7??	534.921	539.237	543.659	548.569	546.444
180.000	531.932	532.7??	532.458	531.560	531.368	533.882	538.991	544.132	549.929	549.1??
210.000	529.452	531.457	531.187	531.?3?	529.?53	532.832	538.717	544.62?	551.169	549.226
240.000	527.986	530.275	529.917	529.725	528.765	531.782	538.42?	545.084	552.355	551.?45
270.000	526.542	529.174	528.655	527.469	527.5?7	530.739	538.1?2	545.511	553.429	551.??4
300.000	525.128	527.895	527.412	526.2??	526.279	529.7??	537.7?5	545.9?4	554.448	552.??7
330.000	523.721	526.7?9	526.187	524.977	525.?76	528.674	537.413	546.254	555.354	552.957
360.000	522.346	525.545	524.974	523.778	523.849	527.654	537.445	546.545	555.255	553.756
390.000	520.997	524.397	523.777	522.676	522.749	526.644	536.657	546.898	557.?65	554.??8
420.000	519.674	523.265	522.6?3	521.459	521.625	525.644	536.268	547.176	557.82?	555.216
450.000	518.774	522.147	521.446	520.??4	520.521	524.665	535.951	547.429	558.521	555.8??
480.000	517.?38	521.445	520.7?8	519.231	519.44?	523.697	535.467	547.658	559.173	556.??4
510.000	515.849	519.959	519.19?	518.152	518.382	522.745	535.215	547.865	559.78?	557.???
540.000	514.626	518.692	518.?93	517.?96	517.349	521.914	534.579	548.?55	559.346	557.???
570.000	513.429	517.54?	517.117	516.461	516.334	520.889	534.127	548.228	5??.476	558.157
600.000	512.259	516.813	515.963	515.?51	515.35?	519.987	533.688	548.383	551.?6?	554.64?
630.000	511.115	515.795	514.929	514.?63	514.?44	519.1?3	533.234	548.524	551.?27	559.?4?
660.000	509.999	514.5?2	513.917	513.?99	513.441	518.236	532.779	548.052	552.259	559.570
690.000	508.925	513.925	512.925	512.156	512.527	517.385	532.32?	548.763	552.664	559.31?
720.000	507.837	512.866	511.954	511.235	511.620	516.549	531.861	548.475	563.?46	56?.31?
750.000	506.798	511.928	511.3?6	51?.?77	510.743	515.728	531.4?5	548.972	553.4?9	56?.479
780.000	505.794	511.?63	510.379	509.460	509.896	514.921	530.351	549.163	553.753	561.?22
810.000	504.793	510.1?7	509.171	508.6?3	509.?4?	514.?3?	530.?93	549.149	554.?8?	561.?4?
840.000	503.828	509.224	508.2?5	507.707	508.271	513.35?	530.?54	549.229	554.?93	561.???
870.000	502.889	508.362	507.461	506.953	507.435	512.595	529.514	549.316	554.695	561.956
900.000	501.977	507.5?3	506.670	506.162	506.66?	511.852	529.143	549.398	554.987	562.24?
930.000	501.031	506.639	505.759	505.292	505.9?8	511.122	528.761	549.46?	555.272	562.512
960.000	500.271	505.894	504.96?	504.643	505.136	[illegible]	528.35?	549.537	555.551	562.7??
990.000	499.398	505.118	504.164	503.917	504.465	509.7?4	527.951	549.62?	555.827	563.?56
1020.000	498.592	504.361	503.431	503.213	503.776	509.?14	527.566	549.737	555.?12	563.?1?
1050.000	497.813	503.624	502.7?1	502.532	503.1?4	508.336	527.135	549.759	556.376	563.673
1080.000	497.060	502.9?9	501.994	501.873	502.4??	507.669	526.84?	549.895	556.652	563.920
1110.000	496.336	502.219	501.3?1	501.237	501.837	507.012	525.5?4	550.???	556.932	564.?4?
1140.000	495.641	501.551	500.65?	50?.626	501.275	506.363	526.193	550.1??	557.22?	564.3?7
1170.000	494.975	500.?07	500.?19	[illegible]	500.694	505.727	525.996	550.25?	557.514	564.5??
1200.000	494.339	500.287	499.6?4	499.4?3	500.?98	505.?9?	525.62?	55?.?91	557.?17	564.8??
1230.000	493.735	499.694	498.826	498.037	499.56?	504.465	525.37?	551.?47	558.133	565.1??
1260.000	493.166	499.124	498.273	498.?21	499.?51	503.849	525.148	551.72?	558.4??	565.4??
1290.000	492.634	498.59?	497.749	497.934	498.56?	503.2?8	524.956	551.914	558.??6	565.7??
1320.000	492.135	498.086	497.257	497.481	498.1?9	502.63?	524.732	551.125	559.182	565.?77
1350.000	491.667	497.6?3	496.?42	497.?45	497.668	502.?34	524.65?	551.?52	559.561	566.???
1380.000	491.236	497.164	496.74?	496.636	497.252	501.441	524.5?7	551.590	[illegible]	[illegible]
1410.000	490.837	496.72?	495.927	496.253	496.86?	[illegible]	524.671	551.967	57?.376	567.1??
1440.000	490.477	496.32?	495.549	495.898	496.493	500.275	524.427	552.155	57?.914	567.4??
1470.000	490.154	495.960	495.192	495.571	496.15?	499.7??	524.417	552.467	571.2??	567.8??

FIGURE 5-5 - Continued

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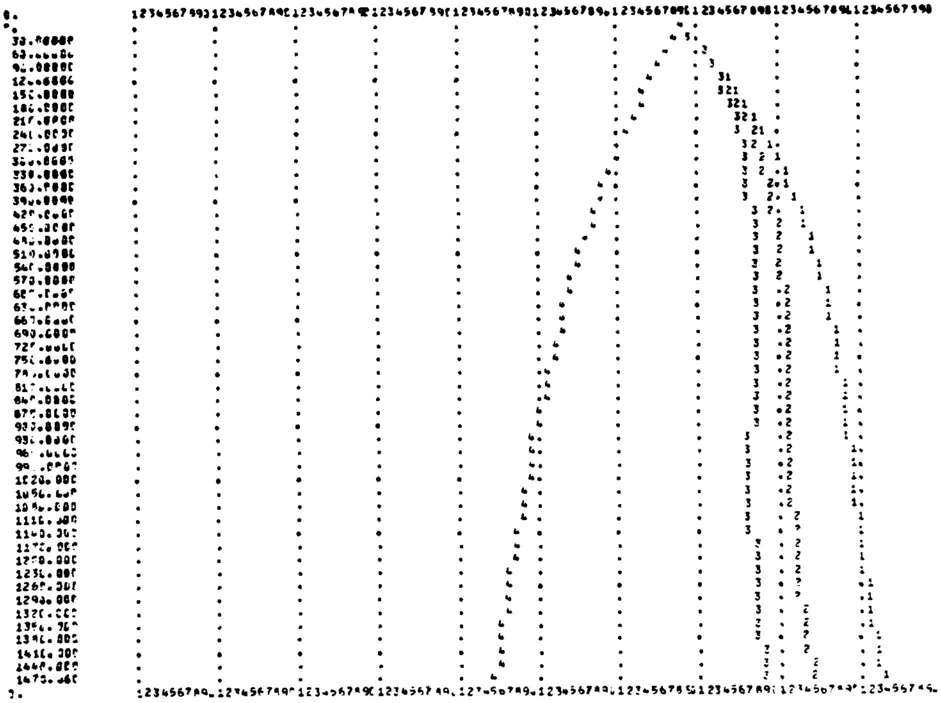
TEMPS
MAX 571.271
MIN 472.653



TIME/STAT	21	22	23	24
0.000	540.036	[illegible]	540.2[illegible]	[illegible]
30.000	541.595	541.648	541.574	539.057
60.000	543.076	543.115	542.866	538.152
90.000	544.478	544.412	543.958	537.205
120.000	545.793	545.549	544.801	536.431
150.000	547.022	546.549	545.628	535.646
180.000	548.169	547.424	546.274	534.857
210.000	549.235	548.189	546.815	534.113
240.000	550.222	548.857	547.264	533.385
270.000	551.179	549.442	547.678	532.684
300.000	551.989	549.957	547.954	532.086
330.000	552.776	550.406	548.264	531.350
360.000	553.593	550.793	548.411	530.715
390.000	554.175	551.144	548.577	530.108
420.000	554.797	551.445	548.748	529.516
450.000	555.369	551.705	548.846	528.931
480.000	555.895	551.929	548.876	528.376
510.000	556.379	552.123	548.923	527.841
540.000	556.826	552.296	548.951	527.324
570.000	557.237	552.433	548.962	526.826
600.000	557.616	552.555	548.959	526.342
630.000	557.965	552.659	548.944	525.877
660.000	558.287	552.748	548.921	525.429
690.000	558.595	552.825	548.889	524.996
720.000	558.861	552.890	548.853	524.578
750.000	559.126	552.949	548.814	524.166
780.000	559.362	552.999	548.772	523.765
810.000	559.599	553.044	548.728	523.379
840.000	559.863	553.085	548.685	523.005
870.000	560.097	553.127	548.645	522.646
900.000	560.232	553.167	548.608	522.294
930.000	560.391	553.213	548.576	521.953
960.000	560.575	553.255	548.549	521.622
990.000	560.757	553.324	548.538	[illegible]
1020.000	560.939	553.363	548.519	520.986
1050.000	561.120	553.428	548.518	520.688
1080.000	561.344	553.499	548.525	520.370
1110.000	561.492	553.584	548.544	520.086
1140.000	561.647	553.674	548.577	519.794
1170.000	561.889	553.783	548.622	519.517
1200.000	562.138	553.893	548.686	519.224
1230.000	562.327	554.034	548.754	518.944
1260.000	562.561	554.189	548.848	518.669
1290.000	562.816	554.365	548.964	518.395
1320.000	563.097	554.554	549.095	518.123
1350.000	563.378	554.766	549.240	517.854
1380.000	563.677	554.992	549.443	517.586
1410.000	563.998	555.243	549.586	517.322
1440.000	564.330	555.508	549.789	517.062
1470.000	564.688	555.795	550.069	516.806

END EXOHEAT

FIGURE 5-5 - Concluded

6. HINTS AND DIAGNOSTICS

1. To call MBALL, it is necessary that: HEATRV = EXOHEAT
   TARGSYN = YES
   BALL = 2 or 3 (in NAMELIST/IBALL)

2. If the removal of a piece (creation of a hole) is desired:

   a. The initial temperature of the piece is input as 0.

   b. The external flux entering the interior is neglected, so the number of stations removed should be small.

3. For a skin that consists of layers of different materials, the appropriate averages of the material properties should be input (see Equations 3-31 through 3-33) in card set 7 (Table 4-3).

4. If, for any reason, it is necessary to model a station with an outside emissivity equal to zero (this piece thus has no radiative communication with the external environment) the outside emissivity on card 7.1 (Table 4-3) should be set to a small number, but not zero. This is because the external emissivity is set equal to zero internally for an open station (when TOLD = 0) and is used as the flag for that open station in the calculations, so that any outside emissivity equal to zero would be interpreted as an open station.

7. REFERENCES

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3. J. V. Beaupre, "Optical Signatures Code, Volume II - Exoatmospheric Thermal Response Model: EXOHEAT", Fifth Distribution, Teledyne Brown Engineering, December 1977