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THERMAL RESPONSE MODEL: MBALL.(U)

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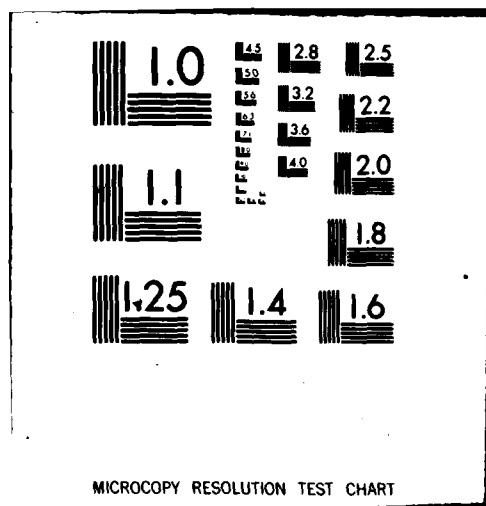
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THERMAL RESPONSE MODEL: MBALL

September 1979

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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

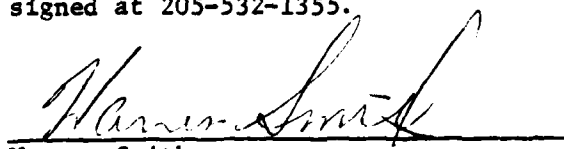
DATE: 7 November 1979

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

Letter of Transmittal
Manual

Attn: Max Hardwick, ATC-D

Ballistic Missile Defense System
Command
P. O. Box 1500
Huntsville, Alabama 35807

Letter of Transmittal

Attn: BMDSC-C

Defense Technical Information
Center
Cameron Station
Alexandria, Virginia 22314

Letter of Transmittal
Manual (2)

McDonnell Douglas Corporation
5301 Bolsa Avenue
Huntington Beach, California 92647

Letter of Transmittal

Attn: ^{H.} Herdman
H. Ginell

MIT Lincoln Laboratory
P. O. Box 73
Lexington, Massachusetts 02173

Letter of Transmittal
Manual
Listing
Card Decks

Attn: Wade Kornegay

Nichols Research Corporation
7910 South Memorial Parkway
Suite A
Huntsville, Alabama 35802

Letter of Transmittal
Manual
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Attn: C. Horgen

Sandia Laboratories
P. O. Box 5800
Albuquerque, New Mexico 87185

Letter of Transmittal
Manual
Listing
Card Decks

Attn: Bruce Bulmer

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.

14 MN-SD-9-79-893

6 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

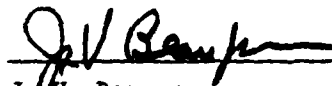
OPTICAL SYSTEMS DEPARTMENT
SYSTEMS DIVISION
TELEDYNE BROWN ENGINEERING
HUNTSVILLE, ALABAMA

408 877

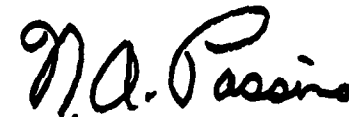
ABSTRACT

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.

TABLE 1-1. MBALL CAPABILITIES

Targets	• Thin to Intermediate Thermal Mass • Replica or Balloon Shapes
Thermal Fluxes	• Solar • Albedo From EXOHEAT Subroutine • Earthshine (EXOENV) • 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 RVSNTN, a subroutine of BASIC\$. Previously, RVSNTN was used only with the endoatmospheric heating routine, RVTEMP, but has been modified to supply MBALL with the necessary parameters. RVSNTN 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.

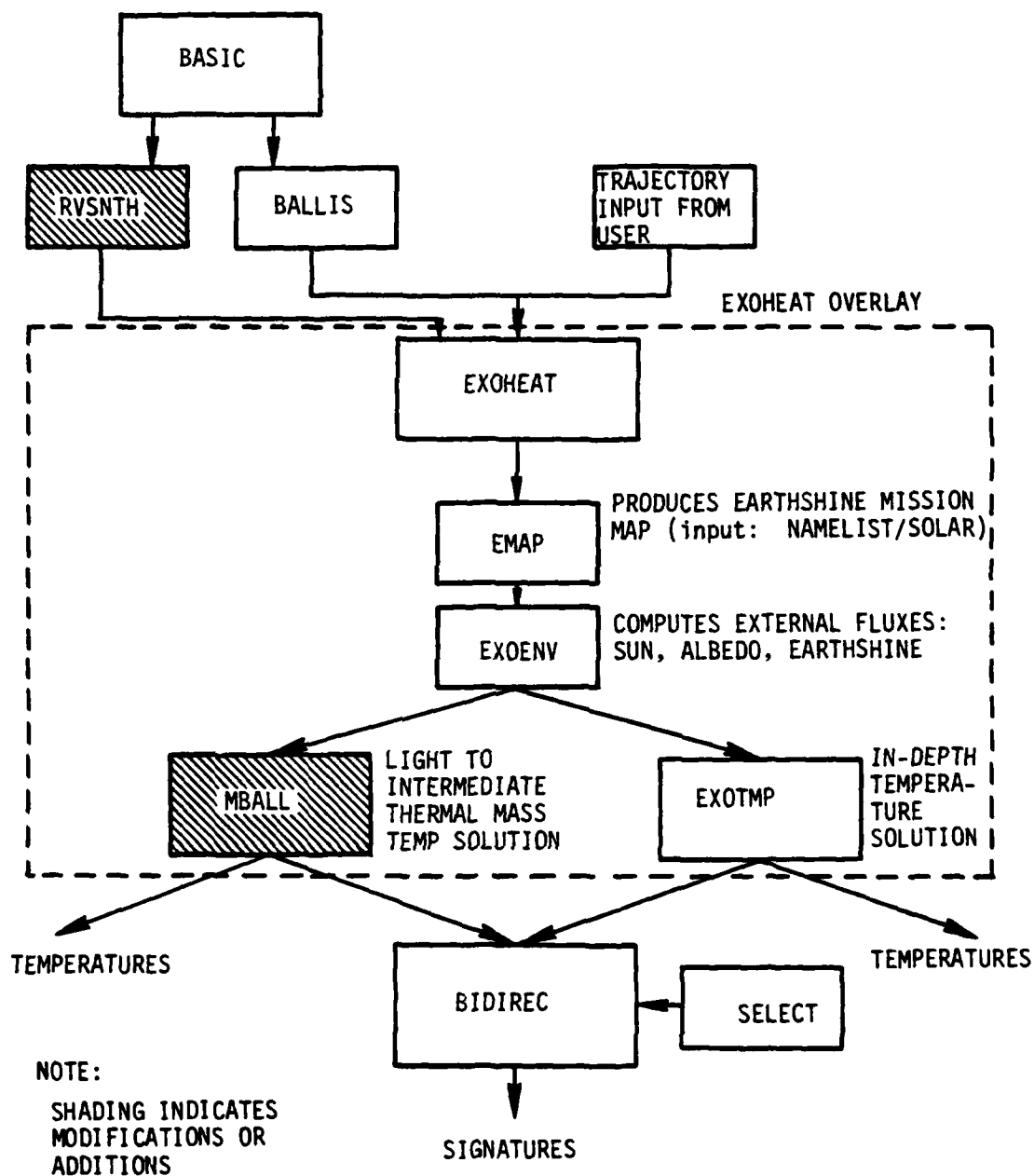


FIGURE 2-1. EXOHEAT PROGRAM STRUCTURE

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:

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

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 j th piece, are an appropriate average of the exact values taken over the volume of the piece. By integrating Equation 3-1 over the j th piece with this point in mind (the subscript j refers to average values), one obtains:

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

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:

$$\begin{aligned} \rho_j c_{pj} V_j \frac{\partial T_j}{\partial t} = & \int_{A_j \text{ outer surface}} (\vec{kVT}) \cdot \hat{n}_j dA_j + \int_{A_j \text{ inner surface}} (\vec{kVT}) \cdot \hat{n}_j dA_j \\ & + \int_{A_j \text{ adjoining surfaces}} (\vec{kVT}) \cdot \hat{n}_j dA_j . \end{aligned} \quad (3-3)$$

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

$$\hat{n}_j \cdot \vec{kVT} = -\epsilon_j \sigma T_j^4 + Q_{\text{ext},j} \text{ (outside)} \quad (3-4)$$

$$\hat{n}_j' \cdot \vec{kVT} = -\epsilon_j' \sigma T_j^4 + Q_{\text{int},j} \text{ (inside)} \quad (3-5)$$

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

$$\begin{aligned} \rho_j c_{pj} V_j \frac{\partial T_j}{\partial t} = & \int_{A_j \text{ outer}} (Q_{\text{ext},j} - \epsilon_j \sigma T_j^4) dA_j \\ & + \int_{A_j \text{ inner}} (Q_{\text{int},j} - \epsilon_j' \sigma T_j^4) dA_j + \int_{A_j \text{ adjoining}} (\vec{kVT}) \cdot \hat{n}_j dA_j . \end{aligned} \quad (3-6)$$

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

$$\rho_j c_{pj} V_j \frac{\partial T_j}{\partial t} = Q_{\text{ext},j} A_j + Q_{\text{int},j} A_j - (\epsilon_j + \epsilon'_j) \sigma T_j^4 A_j + \sum_{\substack{\text{adjoining} \\ \text{areas}}} A_{\text{adjoining}} k_{\text{eff}} \frac{T_{\text{adjoining}} - T_j}{\Delta X_{j:\text{adjoining}}} \quad (3-7)$$

where the conduction integral of Equation 3-6 has been approximated by a sum over all adjoining surfaces of the piece j . The terms $A_{\text{adjoining}}$, k_{eff} , $T_{\text{adjoining}}$, and $\Delta X_{j:\text{adjoining}}$ 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:

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

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 j th.

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:

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

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:

$$\rho_j V_j \frac{\partial}{\partial T} \int_{T_{oj}}^{T_j} c_{pj}(T_j') dT_j' = Q_{ext,j} A_j + \sum_i M_{1j} T_i^4 + \sum_i K_{1j} T_i \quad (3-10)$$

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/m² 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

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

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

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

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.

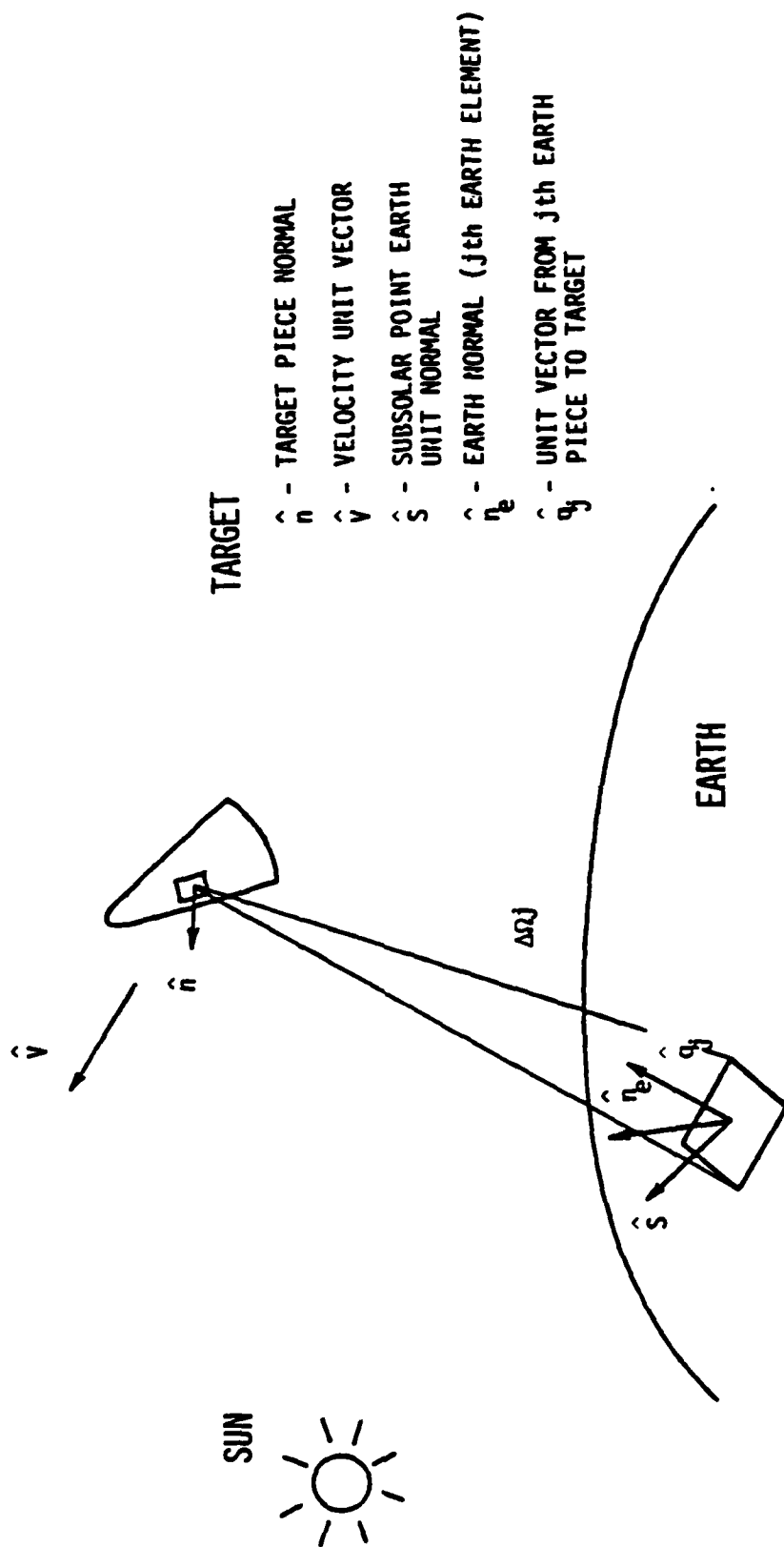


FIGURE 3-1. TARGET, SOLAR, EARTH GEOMETRY

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

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	$\frac{1}{4\pi} \int d\Omega(\hat{s}) G = \frac{1}{4}$	4 π average: fast random tumbling

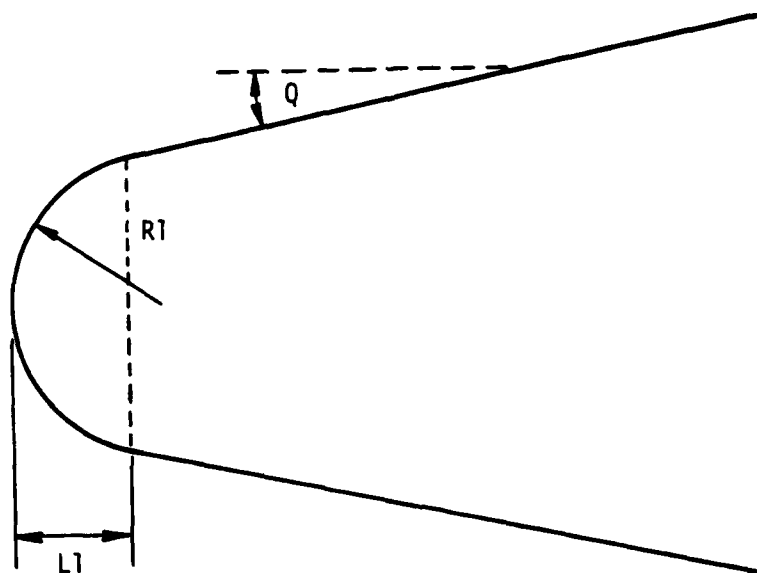
*Input parameter

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.

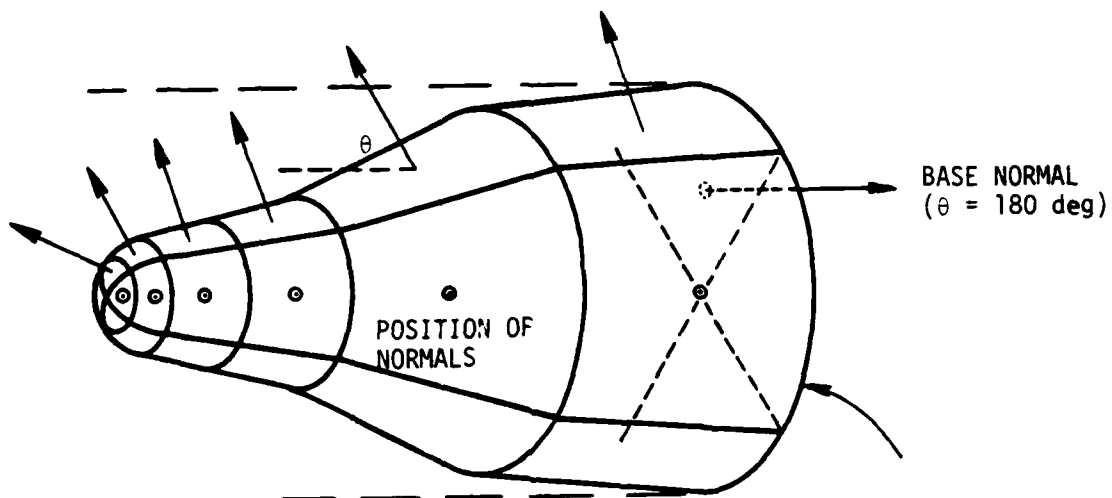
The user has the choice of modeling either a balloon (sphere) or an axially symmetric replica that can have a spherical nose cap, up to three frusta, and a flat baseplate. It is necessary to input the length of the nose cap such that it meets the first frustum tangentially (Figure 3-2). The surface area 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 RVSNTN. 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 RVSNTN (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

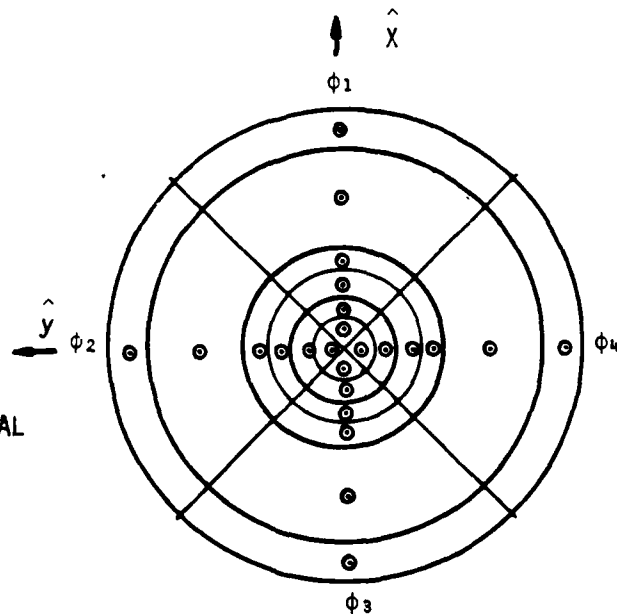
ϕ_2 8-14

ϕ_3 15-21

ϕ_4 22-28

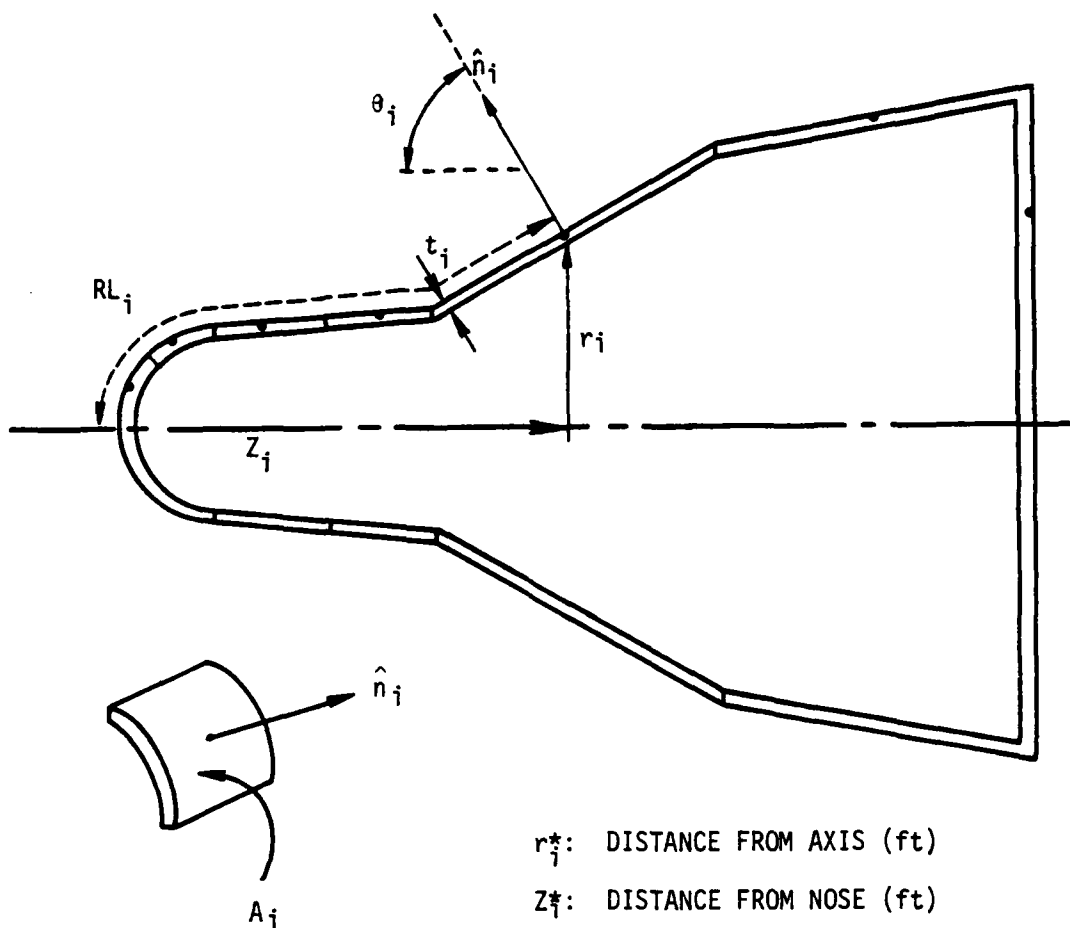
⊙ = POSITION OF SURFACE NORMAL
(BASE NORMALS ARE NOT
VISIBLE)

$\hat{z}$ 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 (ft²)

t_i : THICKNESS (THK) (ft)

*CALCULATED IN RVSNTN

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

FIGURE 3-4. TARGET GEOMETRY

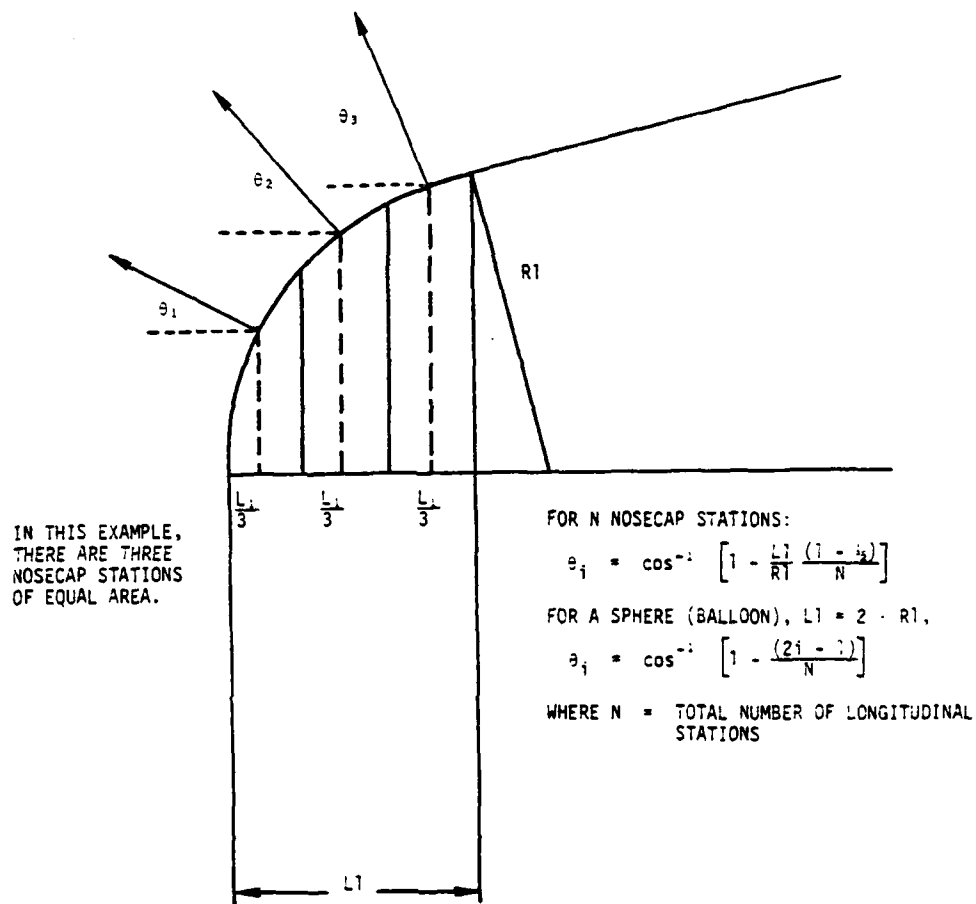


FIGURE 3-5. NOSECAP POLAR ANGLES

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 RVSNTN 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 RVSNTN 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):

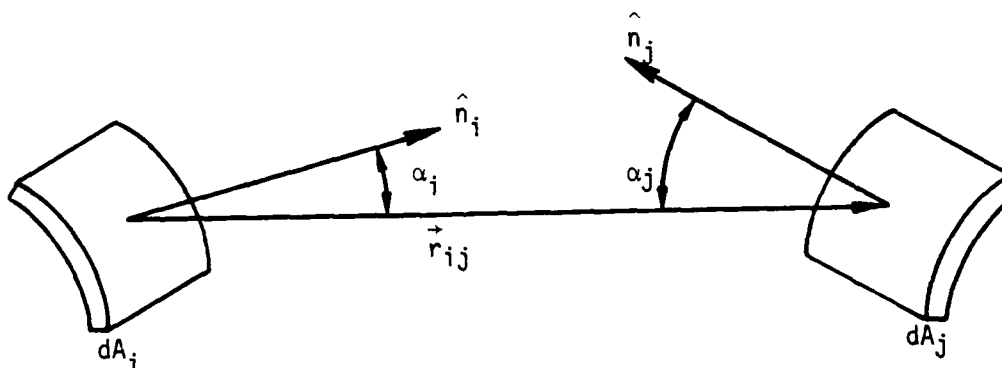


FIGURE 3-6. RADIATION EXCHANGE GEOMETRY

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

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:

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

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

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

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

$$g^T = [g^{BBT} (1 - \rho' g^{BBT}) \epsilon'] \quad (3-16)$$

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

For a closed surface, one has

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

Holes/open surfaces are correctly treated by setting $\epsilon_i' = \rho_i' = 0$ 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

$$P_j = \epsilon_j' A_j \sigma \sum_i g_{ij} T_i^4 \quad (3-18)$$

The key to the calculation of g is, by Equation 3-16, the calculation of g_{ji}^{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:

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

To ensure that no serious errors result from this numerical procedure, Equation 3-17 is imposed on g_{ji}^{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 :

$$P_j \text{ TOTAL} = \left[-\sigma(\epsilon_j + \epsilon_j') T_j^4 + \sigma \sum_i \epsilon_j' T_i^4 g_{ij} \right] \cdot A_j \quad (3-20)$$

which can be written as:

$$P_j \text{ TOTAL} = \sum_i M_{ij} T_i^4 \quad (3-21)$$

INSIDE SURFACE
OF A TYPICAL
FRUSTUM

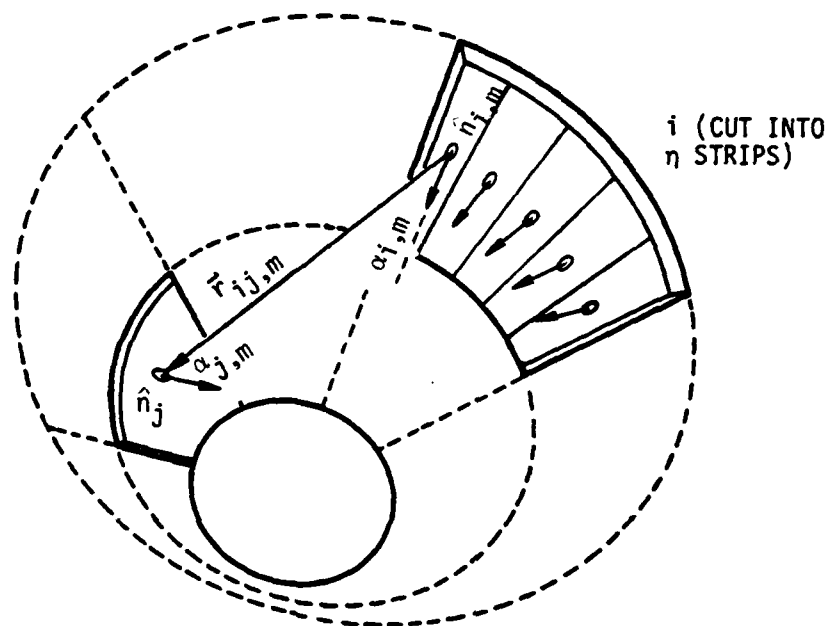


FIGURE 3-7. INTERNAL RADIATION GEOMETRY

where

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

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

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 j th piece:

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

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:

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

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

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

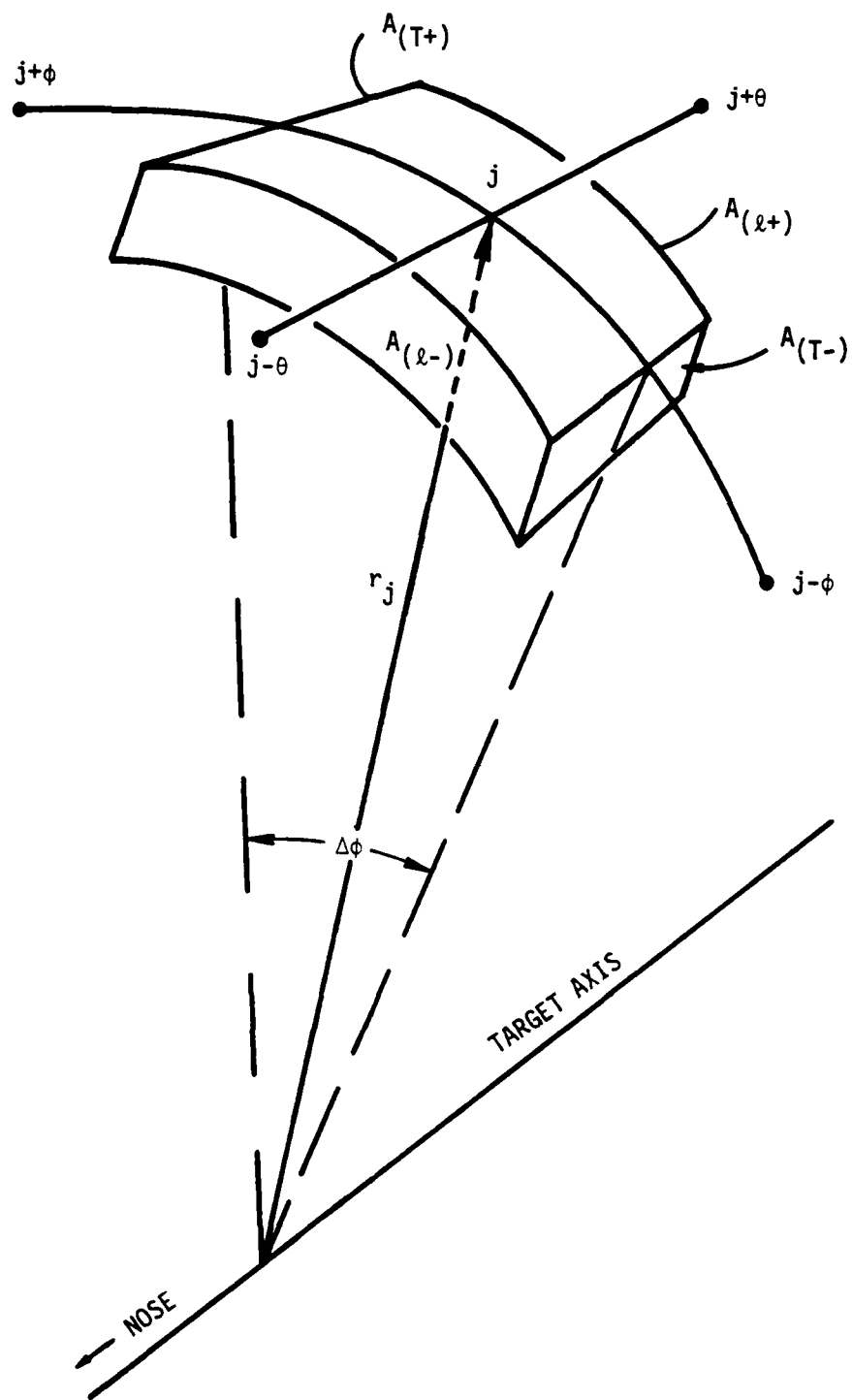


FIGURE 3-8. CONDUCTION GEOMETRY

where

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

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

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

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

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

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

By defining longitudinal and transverse conduction coefficients of the form:

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

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

Equation 3-24 can be written as:

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

Thus, by defining a conduction matrix of the form

$$K_{ij} = \begin{bmatrix} -(a_{1,0} + b_{1,0} + b_{1,-1}) & a_{1,0} & 0 & \dots & b_{1,0} & 0 & 0 & \dots & b_{1,-1} & 0 & 0 & \dots \\ a_{1,0} & -(a_{1,0} + a_{2,0} + b_{2,0} + b_{2,-1}) & a_{2,0} & \dots & 0 & b_{2,0} & 0 & \dots & 0 & b_{2,-1} & 0 & \dots \\ 0 & a_{2,0} & -(a_{2,0} + a_{3,0} + b_{3,0} + b_{3,-1}) & \dots & 0 & 0 & b_{3,0} & \dots & 0 & 0 & b_{3,-1} & \dots \\ \vdots & \vdots & \vdots & \ddots & \vdots & \vdots & \vdots & \ddots & \vdots & \vdots & \vdots & \ddots \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \end{bmatrix}$$

(3-28)

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

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

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:

$$\rho_j V_j \frac{d}{dt} \int_{T_{0j}}^{T_j} c_{pj}(T'') dT'' = \int_{T_{0j}}^{T_j} m_j dT_j'' \quad (3-30)$$

where $m_j = \rho_j V_j c_{pj}$ is defined as the thermal mass of the j th 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:

$$\bar{\rho}_j = \frac{\sum_k \rho_{j,k} \Delta X_{j,k}}{\sum_k \Delta X_{j,k}} \quad (3-31)$$

$$\bar{c}_{p,j} = \frac{\sum_k \rho_{j,k} \Delta X_{j,k} c_{p,j,k}}{\sum_k \rho_{j,k} \Delta X_{j,k}} \quad (3-32)$$

$$\bar{k}_j = \frac{\sum_k \Delta X_{j,k} k_{j,k}}{\sum_k \Delta X_{j,k}} \quad (3-33)$$

where $\Delta X_{j,k}$, $\rho_{j,k}$, $c_{p,j,k}$, and $k_{j,k}$ are the thickness, density, specific heat, and thermal conductivity, respectively, of the k th layer of piece j . Because the specific heat and thermal conductivity are input by the user for different temperatures, an appropriate $\bar{c}_{p,j}$ and $\bar{k}_j$ should be input for each temperature. The temperature calculated for the j th 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:

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

where $Q_{\text{ext},j}$, $Q_{\text{int},j}$ are the external and internal power per unit area, respectively, incident on the j th 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:

$$\frac{\partial}{\partial t} \int_{T_{0j}}^{T_j} m_j(T_j'') dT_j'' \rightarrow \frac{m_j(T_j') (T_j - T_j')}{\Delta t} + \frac{1}{\Delta t} \int_{T_{0j}}^{T_j'} m_j(T'') dT'' \quad (3-35)$$

where Δt is the time step, T_{0j} 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:

$$Q_{\text{ext},j}(t) A_j + \sum_i (M_{ij} T_i^4 + K_{ij} T_i) \rightarrow Q_{\text{ext},j}(t + \frac{\Delta t}{2}) A_j + \sum_i (M_{ij} \bar{T}_i^4 + K_{ij} \bar{T}_i) \quad (3-36)$$

where $\bar{T}_i$, the average temperature, is given by $\bar{T}_i = 1/2 (T_{0i} + T_i)$, with T_{0i} , T_i the old and new temperature of the i th piece, respectively, and the external flux $Q_{\text{ext},j}$ is interpolated to the midpoint of the time interval. The $\bar{T}_i^4$ term can be linearized in the following way: expanding T_i^4 in a Taylor's expansion about an estimated final temperature T_i' :

$$T_i^4 = T_i'^4 + 4 T_i'^3 (T_i - T_i') \quad (3-37)$$

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

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

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

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

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

$$\sum_i c_{ij} T_i = B_j \quad (3-40)$$

where

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

and

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

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

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

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 :

$$\int_{T_{oj}}^{T_j'} m_j dT = \Delta t \left\{ \sum_i \left[M_{ij} T_{oi}^4 + K_{ij} T_{oi} + Q \left(t + \frac{\Delta t}{2} \right) A_j \right] \right. \\ \left. + (4 M_{jj} T_{oj}^3 + K_{jj}) (T_j' - T_{oj}) \right\}. \quad (3-44)$$

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

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

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, $\bar{T}_{open}$, is found by evaluating:

$$\bar{\epsilon} \bar{T}_{open}^4 = \sum_i \epsilon_i' g_{i,open} T_i^4 \quad (3-46)$$

Because this is an approximation, the internal emissivities, ϵ_i' , are assumed to be about the same, and they cancel with the average emissivity, $\bar{\epsilon}$. The $g_{i,open}$ term is the geometric factor for the i th 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	RVSNTN/BASIC

4.2 CARD INPUT

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

RVSNTN 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 nose cap polar angles [THET(I)] in the EXOHEAT input that are calculated by RVSNTN (see Figure 3-5) because RVSNTN does not pass them to EXOHEAT. RVSNTN input is displayed in Table 4-2.

TABLE 4-2. RVSNTN 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, $L1 = 2 \times R1$ and the third card is the last RVSNTN 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 nose cap 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 nose cap. The total number of nose cap stations is $KROL \times N$. For a replica shape, the nose cap 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 $R1$. RVSNTN bypasses the frustum calculations when $L1 = 2 \times R1$, so the nose cap card is the last RVSNTN 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 $N \times KROL$. Finally, the base card contains the number of longitudinal stations on the base (in F format), to be multiplied 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 RVSNTN (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 RVSNTN (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 $I = (M-1) \cdot KTHET + N$	
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 TOLD		Material thickness (ft) 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/ft²)
	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.

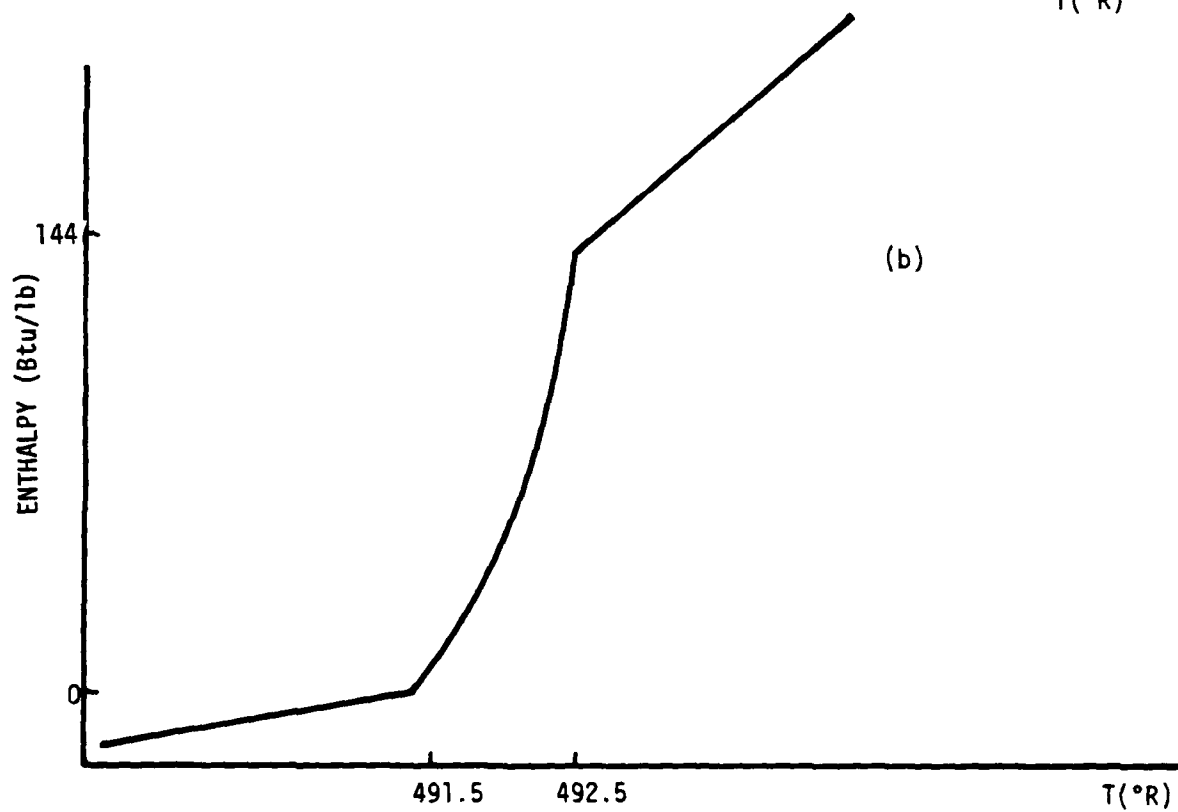
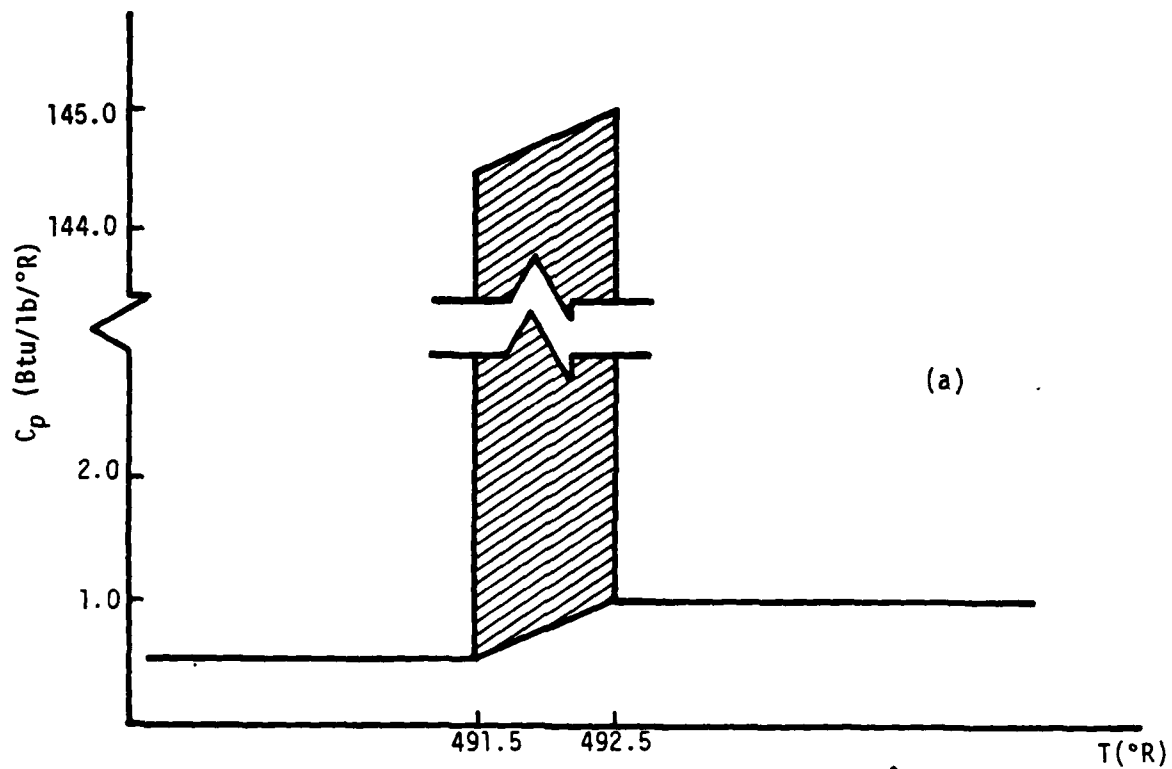


FIGURE 4-1. SPECIFIC HEAT AND ENTHALPY OF WATER

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 RVSNTN). References 1 and 3 state that RVSNTN 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 RVSNTN 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.

CARD	1	11	21	31	41	51	61	71
1	JADIT							
2	TRAJ	CAPES	HATF	ENDIENT	HATF	CALC	SIGNA	CALC
3	TRFGLVN	VCS						
4								
5	5.	9.						
6	11.	15.						
7	19.	24.						
8								
9	37							
10	61.	3261.771	3239.021	3280.8	20000.	90.		
11	10.	3261.771	3239.021	3280.8	20000.	90.		
12	150.	3261.771	3239.021	3280.8	20000.	90.		
13	240.	3261.771	3239.021	3280.8	20000.	90.		
14	300.	3261.771	3239.021	3280.8	20000.	90.		
15	360.	3261.771	3239.021	3280.8	20000.	90.		
16	420.	3261.771	3239.021	3280.8	20000.	90.		
17	480.	3261.771	3239.021	3280.8	20000.	90.		
18	540.	3261.771	3239.021	3280.8	20000.	90.		
19	600.	3261.771	3239.021	3280.8	20000.	90.		
20	660.	3261.771	3239.021	3280.8	20000.	90.		
21	720.	3261.771	3239.021	3280.8	20000.	90.		
22	780.	3261.771	3239.021	3280.8	20000.	90.		
23	840.	3261.771	3239.021	3280.8	20000.	90.		
24	900.	3261.771	3239.021	3280.8	20000.	90.		
25	960.	3261.771	3239.021	3280.8	20000.	90.		
26	1020.	3261.771	3239.021	3280.8	20000.	90.		
27	1080.	3261.771	3239.021	3280.8	20000.	90.		
28	1140.	3261.771	3239.021	3280.8	20000.	90.		
29	1200.	3261.771	3239.021	3280.8	20000.	90.		
30	1260.	3261.771	3239.021	3280.8	20000.	90.		
31	1320.	3261.771	3239.021	3280.8	20000.	90.		
32	1380.	3261.771	3239.021	3280.8	20000.	90.		
33	1440.	3261.771	3239.021	3280.8	20000.	90.		
34	1500.	3261.771	3239.021	3280.8	20000.	90.		
35	1560.	3261.771	3239.021	3280.8	20000.	90.		
36	1620.	3261.771	3239.021	3280.8	20000.	90.		
37	1680.	3261.771	3239.021	3280.8	20000.	90.		
38	1740.	3261.771	3239.021	3280.8	20000.	90.		
39	1800.	3261.771	3239.021	3280.8	20000.	90.		
40	MEALL							
41	3							
42	6	100.	200.	6				
43	ICOLAF ITYPE=1,SLAT=..SLON=..MONTH=9,IDA=15,IPRINT=4,ICLD=3 \$							
44	5							
45	5.	60.	120.	180.	240.	300.		
46	5							
47	37.50	60.	0.41	99.99	120.	146.64		
48	1							
49	SIBALL BALL=3. ?							
50	F	1						

CARD	1	11	21	31	41	51	61	71
1								

FIGURE 5-1. BALLOON EXAMPLE INPUT

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CAFD	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	86.5	.9	.9	.2			
88	491.00		.153		.152			
89	491.49		.162		.165			
90	491.50		38.720		.165			
91	492.50		39.030		.165			
92	492.51		.630		.165			
93	500.20		.610		.167			
94	1		1	1	0			
95	FQ3096	11						
96	FQ3096	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	
CAFD	1	11	21	31	41	51	61	71

FIGURE 5-1 - Continued

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	1	11	21	31	41	51	61	71
CASE	1	11	21	31	41	51	61	71
101			1	11	1	12	1	
102			13	1	14	1	15	
103			1	13	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	35				
112	5	.349	24.03	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	24.03	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	24.03	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	24.03	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	24.03	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	24.03	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	TCASE REFLET=1.,WT=0.1.,VR=10,NC=10 \$							

	1	11	21	31	41	51	51	71
CASE	1	11	21	31	41	51	51	71

FIGURE 5-1 - Concluded

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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

FYOMAT WILL CALCULATE THERMAL DATA

SELECT WILL PROVIDE BIRDREC WITH OPTICAL PROPERTIES DATA

BIRDREC 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

NO RAND = 2

LAH9DA INCREMENT WAS NOT INPUT, DEFAULTED TO .01

LWAVE = 191 LAHINC = .15E+00

.50000E+01	.51000E+01	.52000E+01	.53000E+01	.54000E+01	.55000E+01	.56000E+01	.57000E+01
.58000E+01	.59000E+01	.60000E+01	.61000E+01	.62000E+01	.63000E+01	.64000E+01	.65000E+01
.66000E+01	.67000E+01	.68000E+01	.69000E+01	.70000E+01	.71000E+01	.72000E+01	.73000E+01
.74000E+01	.75000E+01	.76000E+01	.77000E+01	.78000E+01	.79000E+01	.80000E+01	.81000E+01
.82000E+01	.83000E+01	.84000E+01	.85000E+01	.86000E+01	.87000E+01	.88000E+01	.89000E+01
.90000E+01	.91000E+01	.92000E+01	.93000E+01	.94000E+01	.95000E+01	.96000E+01	.97000E+01
.98000E+01	.99000E+01	.10000E+02	.10100E+02	.10200E+02	.10300E+02	.10400E+02	.10500E+02
.10600E+02	.10700E+02	.10800E+02	.10900E+02	.11000E+02	.11100E+02	.11200E+02	.11300E+02
.11400E+02	.11500E+02	.11600E+02	.11700E+02	.11800E+02	.11900E+02	.12000E+02	.12100E+02
.12200E+02	.12300E+02	.12400E+02	.12500E+02	.12600E+02	.12700E+02	.12800E+02	.12900E+02
.13000E+02	.13100E+02	.13200E+02	.13300E+02	.13400E+02	.13500E+02	.13600E+02	.13700E+02
.13800E+02	.13900E+02	.14000E+02	.14100E+02	.14200E+02	.14300E+02	.14400E+02	.14500E+02
.14600E+02	.14700E+02	.14800E+02	.14900E+02	.15000E+02	.15100E+02	.15200E+02	.15300E+02
.15400E+02	.15500E+02	.15600E+02	.15700E+02	.15800E+02	.15900E+02	.16000E+02	.16100E+02
.16200E+02	.16300E+02	.16400E+02	.16500E+02	.16600E+02	.16700E+02	.16800E+02	.16900E+02
.17000E+02	.17100E+02	.17200E+02	.17300E+02	.17400E+02	.17500E+02	.17600E+02	.17700E+02
.17800E+02	.17900E+02	.18000E+02	.18100E+02	.18200E+02	.18300E+02	.18400E+02	.18500E+02
.18600E+02	.18700E+02	.18800E+02	.18900E+02	.19000E+02	.19100E+02	.19200E+02	.19300E+02
.19400E+02	.19500E+02	.19600E+02	.19700E+02	.19800E+02	.19900E+02	.20000E+02	.20100E+02
.20200E+02	.20300E+02	.20400E+02	.20500E+02	.20600E+02	.20700E+02	.20800E+02	.20900E+02
.21000E+02	.21100E+02	.21200E+02	.21300E+02	.21400E+02	.21500E+02	.21600E+02	.21700E+02
.21800E+02	.21900E+02	.22000E+02	.22100E+02	.22200E+02	.22300E+02	.22400E+02	.22500E+02
.22600E+02	.22700E+02	.22800E+02	.22900E+02	.23000E+02	.23100E+02	.23200E+02	.23300E+02
.23400E+02	.23500E+02	.23600E+02	.23700E+02	.23800E+02	.23900E+02	.24000E+02	.24100E+02
.24200E+02	.24300E+02	.24400E+02	.24500E+02	.24600E+02	.24700E+02	.24800E+02	.24900E+02

FIGURE 5-2. BALLOON EXAMPLE OUTPUT

EXCHEAT

36 PIECES
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 99.59 120.00 145.44

MODE 1 (1=INST.FLUX, 2=ROLL-AVGED FLUX)

MONTH 9
DAY 5
GMT 3.00 J.00
SUN-LAT.LNG J.00 0.00

TIME	CONDITION	AVERAGE FLUXES -- W/(M ²)		MOLECULAR
		SUN/AL ⁹⁰⁰	EARTH	
60.0000	SUNLIT	344.9600	54.42691	C.
120.0000	SUNLIT	344.9600	54.42691	C.
180.0000	SUNLIT	344.9600	54.42691	C.
240.0000	SUNLIT	344.9600	54.42691	C.
300.0000	SUNLIT	344.9600	54.42691	C.
360.0000	SUNLIT	344.9600	54.42691	C.
420.0000	SUNLIT	344.9600	54.42691	C.
480.0000	SUNLIT	344.9600	54.42691	C.
540.0000	SUNLIT	344.9600	54.42691	C.
600.0000	SUNLIT	344.9600	54.42691	C.
660.0000	SUNLIT	344.9600	54.42691	C.
720.0000	SUNLIT	344.9600	54.42691	C.
780.0000	SUNLIT	344.9600	54.42691	C.
840.0000	SUNLIT	344.9600	54.42691	C.
900.0000	SUNLIT	344.9600	54.42691	C.
960.0000	SUNLIT	344.9600	54.42691	C.
1020.0000	SUNLIT	344.9600	54.42691	C.
1080.0000	SUNLIT	344.9600	54.42691	C.
1140.0000	SUNLIT	344.9600	54.42691	C.
1200.0000	SUNLIT	344.9600	54.42691	C.
1260.0000	SUNLIT	344.9600	54.42691	C.
1320.0000	SUNLIT	344.9600	54.42691	C.
1380.0000	SUNLIT	344.9600	54.42691	C.
1440.0000	SUNLIT	344.9600	54.42691	C.
1500.0000	SUNLIT	344.9600	54.42691	C.
1560.0000	SUNLIT	344.9600	54.42691	C.
1620.0000	SUNLIT	344.9600	54.42691	C.
1680.0000	SUNLIT	344.9600	54.42691	C.
1740.0000	SUNLIT	344.9600	54.42691	C.
1800.0000	SUNLIT	344.9600	54.42691	C.

FIGURE 5-2 - Continued

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STAT AREA	DEFP	PAK	RADIUS	7ED	PUNLTH	THASS	QAD	CONJ	TPTP	ALF	EQUT	FIN
1 3.76	.553	.033	1.01	.547	1.92	3.05	.159E-02	.115F-01	232.	.200	.900	.900
2 3.76	.966	.500	2.04	1.04	3.44	3.05	.159E-02	.136F-01	200.	.200	.900	.900
3 3.76	.906	.167	3.23	2.73	4.61	3.05	.159E-02	.159E-01	165.	.200	.900	.900
4 3.76	.906	.167	3.23	3.03	5.70	3.05	.159E-02	.159E-01	165.	.200	.900	.900
5 3.76	.906	.167	3.23	4.92	6.87	3.05	.159E-02	.136F-01	200.	.200	.900	.900
6 3.76	.553	.033	1.01	6.01	8.39	3.05	.159E-02	.112F-01	237.	.200	.900	.900
7 3.76	.553	.033	1.01	.547	1.92	3.05	.159E-02	.115F-01	232.	.200	.900	.900
8 3.76	.966	.500	2.04	1.64	3.44	3.05	.159E-02	.136F-01	200.	.200	.900	.900
9 3.76	.906	.167	3.23	2.73	4.61	3.05	.159E-02	.159E-01	165.	.200	.900	.900
10 3.76	.906	.167	3.23	3.03	5.70	3.05	.159E-02	.159E-01	165.	.200	.900	.900
11 3.76	.906	.167	3.23	4.92	6.87	3.05	.159E-02	.136F-01	200.	.200	.900	.900
12 3.76	.553	.033	1.01	6.01	8.39	3.05	.159E-02	.112F-01	237.	.200	.900	.900
13 3.76	.553	.033	1.01	.547	1.92	3.05	.159E-02	.115F-01	232.	.200	.900	.900
14 3.76	.966	.500	2.04	1.64	3.44	3.05	.159E-02	.136F-01	200.	.200	.900	.900
15 3.76	.906	.167	3.23	2.73	4.61	3.05	.159E-02	.159E-01	165.	.200	.900	.900
16 3.76	.906	.167	3.23	3.03	5.70	3.05	.159E-02	.159E-01	165.	.200	.900	.900
17 3.76	.906	.167	3.23	4.92	6.87	3.05	.159E-02	.136F-01	200.	.200	.900	.900
18 3.76	.553	.033	1.01	6.01	8.39	3.05	.159E-02	.112F-01	237.	.200	.900	.900
19 3.76	.553	.033	1.01	.547	1.92	3.05	.159E-02	.115F-01	232.	.200	.900	.900
20 3.76	.966	.500	2.04	1.64	3.44	3.05	.159E-02	.136F-01	200.	.200	.900	.900
21 3.76	.906	.167	3.23	2.73	4.61	3.05	.159E-02	.159E-01	165.	.200	.900	.900
22 3.76	.906	.167	3.23	3.03	5.70	3.05	.159E-02	.159E-01	165.	.200	.900	.900
23 3.76	.906	.167	3.23	4.92	6.87	3.05	.159E-02	.136F-01	200.	.200	.900	.900
24 3.76	.553	.033	1.01	6.01	8.39	3.05	.159E-02	.112F-01	237.	.200	.900	.900
25 3.76	.553	.033	1.01	.547	1.92	3.05	.159E-02	.115F-01	232.	.200	.900	.900
26 3.76	.966	.500	2.04	1.64	3.44	3.05	.159E-02	.136F-01	200.	.200	.900	.900
27 3.76	.906	.167	3.23	2.73	4.61	3.05	.159E-02	.159E-01	165.	.200	.900	.900
28 3.76	.906	.167	3.23	3.03	5.70	3.05	.159E-02	.159E-01	165.	.200	.900	.900
29 3.76	.906	.167	3.23	4.92	6.87	3.05	.159E-02	.136F-01	200.	.200	.900	.900
30 3.76	.553	.033	1.01	6.01	8.39	3.05	.159E-02	.112F-01	237.	.200	.900	.900
31 3.76	.553	.033	1.01	.547	1.92	3.05	.159E-02	.115F-01	232.	.200	.900	.900
32 3.76	.966	.500	2.04	1.64	3.44	3.05	.159E-02	.136F-01	200.	.200	.900	.900
33 3.76	.906	.167	3.23	2.73	4.61	3.05	.159E-02	.159E-01	165.	.200	.900	.900
34 3.76	.906	.167	3.23	3.03	5.70	3.05	.159E-02	.159E-01	165.	.200	.900	.900
35 3.76	.906	.167	3.23	4.92	6.87	3.05	.159E-02	.136F-01	200.	.200	.900	.900
36 3.76	.553	.033	1.01	6.01	8.39	3.05	.159E-02	.112F-01	237.	.200	.900	.900

TIME DEVELOPMENT OF TEMPERATURES

LONGITUDINAL CONDUCTION TREATED -- T

OPEN REAR SURFACE -- F

NR MY INV-- 5A

FIGURE 5-2 - Continued

501.122
492.095

5-10

[illegible]

FIGURE 5-2 - Continued

500.122
692.095

[illegible]

FIGURE 5-2 - Continued

[illegible][illegible]

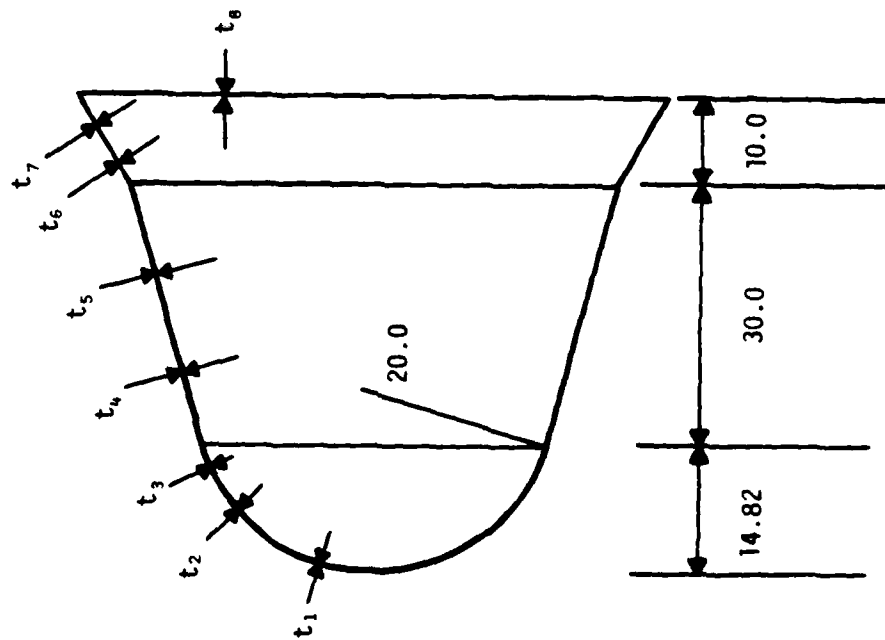
FIGURE 5-2 - Concluded

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5.2 REPLICA

This example consists of a biconic shape with a tangentially fitting spherical nose cap 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



<u>SKIN STRUCTURE</u>		<u>JMAT</u>
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
1	1000						
2	1000						
3	1000						
4	1000						
5	1000						
6	1000						
7	1000						
8	1000						
9	1000						
10	1000						
11	1000						
12	1000						
13	1000						
14	1000						
15	1000						
16	1000						
17	1000						
18	1000						
19	1000						
20	1000						
21	1000						
22	1000						
23	1000						
24	1000						
25	1000						
26	1000						
27	1000						
28	1000						
29	1000						
30	1000						
31	1000						
32	1000						
33	1000						
34	1000						
35	1000						
36	1000						
37	1000						
38	1000						
39	1000						
40	1000						
41	1000						
42	1000						
43	1000						
44	1000						
45	1000						
46	1000						
47	1000						
48	1000						
49	1000						
50	1000						

FIGURE 5-4. REPLICA EXAMPLE INPUT

CARD	1	11	21	31	41	51	61	71
51								
52		23.16	50.	.....	.....	.....	.....	.....
53		19.167	54.	.....	.....	.....	.....	.....
54		19.167	54.	.....	.....	.....	.....	.....
55		18.125	54.	.....	.....	.....	.....	.....
56		19.167	54.	.....	.....	.....	.....	.....
57		139.7	.75	.2	.5	.....	.....	.....
58		47.	.178	.145	.....	.....	.....	.....
59		51.	.26	.195	.....	.....	.....	.....
60		50.	.221	.115	.....	.....	.....	.....
61		71.	.23	.125	.....	.....	.....	.....
62		151.3	.75	.2	.5	.....	.....	.....
63		47.	.143	.213	.....	.....	.....	.....
64		50.	.205	.127	.....	.....	.....	.....
65		51.	.216	.160	.....	.....	.....	.....
66		71.	.226	.147	.....	.....	.....	.....
67		139.6	.75	.2	.5	.....	.....	.....
68		47.	.174	.195	.....	.....	.....	.....
69		51.	.26	.195	.....	.....	.....	.....
70		61.	.241	.155	.....	.....	.....	.....
71		71.	.233	.121	.....	.....	.....	.....
72		139.6	.75	.2	.5	.....	.....	.....
73		47.	.178	.185	.....	.....	.....	.....
74		50.	.26	.195	.....	.....	.....	.....
75		61.	.221	.155	.....	.....	.....	.....
76		71.	.233	.121	.....	.....	.....	.....
77		150.3	.75	.2	.5	.....	.....	.....
78		47.	.193	.213	.....	.....	.....	.....
79		51.	.26	.195	.....	.....	.....	.....
80		50.	.216	.160	.....	.....	.....	.....
81		71.	.226	.160	.....	.....	.....	.....
82		139.6	.75	.2	.5	.....	.....	.....
83		47.	.174	.195	.....	.....	.....	.....
84		51.	.26	.195	.....	.....	.....	.....
85		61.	.221	.155	.....	.....	.....	.....
86		70.	.233	.121	.....	.....	.....	.....
87		139.6	.75	.2	.5	.....	.....	.....
88		47.	.178	.195	.....	.....	.....	.....
89		50.	.26	.195	.....	.....	.....	.....
90		60.	.221	.155	.....	.....	.....	.....
91		71.	.233	.121	.....	.....	.....	.....
92		150.3	.75	.2	.5	.....	.....	.....
93		47.	.193	.213	.....	.....	.....	.....
94		50.	.26	.195	.....	.....	.....	.....
95		51.	.216	.160	.....	.....	.....	.....
96		70.	.226	.160	.....	.....	.....	.....
97		139.6	.75	.2	.5	.....	.....	.....
98		47.	.178	.195	.....	.....	.....	.....
99		50.	.26	.195	.....	.....	.....	.....
100		60.	.221	.155	.....	.....	.....	.....

FIGURE 5-4 - Continued

IMAGE OF DATA-CARDS...

1 11 21 31 41 51 61 71
 CARD 1
 101 700 .233 .1121

1 11 21 31 41 51 61 71
 CARD 1

FIGURE 5-4 - Concluded

PROGRAM BASIC

BALLS WILL CALCULATE TRAJECTORY DATA

EXOMET WILL CALCULATE THERMAL DATA

SELECT WILL PROVIDE BIDIRECT WITH OPTICAL PROPERTIES DATA

REMIPEC 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

MORAND = 3

LAMBDA INCREMENT WAS NOT INPUT, DEFAULTED TO 0.1

LWAVE = 191 LAMINC = .1E+00

.50000E+01	.51000E+01	.52000E+01	.53000E+01	.54000E+01	.55000E+01	.56000E+01	.57000E+01
.58000E+01	.59000E+01	.60000E+01	.61000E+01	.62000E+01	.63000E+01	.64000E+01	.65000E+01
.66000E+01	.67000E+01	.68000E+01	.69000E+01	.70000E+01	.71000E+01	.72000E+01	.73000E+01
.74000E+01	.75000E+01	.76000E+01	.77000E+01	.78000E+01	.79000E+01	.80000E+01	.81000E+01
.82000E+01	.83000E+01	.84000E+01	.85000E+01	.86000E+01	.87000E+01	.88000E+01	.89000E+01
.90000E+01	.91000E+01	.92000E+01	.93000E+01	.94000E+01	.95000E+01	.96000E+01	.97000E+01
.98000E+01	.99000E+01	.10000E+02	.10100E+02	.10200E+02	.10300E+02	.10400E+02	.10500E+02
.10600E+02	.10700E+02	.10800E+02	.10900E+02	.11000E+02	.11100E+02	.11200E+02	.11300E+02
.11400E+02	.11500E+02	.11600E+02	.11700E+02	.11800E+02	.11900E+02	.12000E+02	.12100E+02
.12200E+02	.12300E+02	.12400E+02	.12500E+02	.12600E+02	.12700E+02	.12800E+02	.12900E+02
.13000E+02	.13100E+02	.13200E+02	.13300E+02	.13400E+02	.13500E+02	.13600E+02	.13700E+02
.13800E+02	.13900E+02	.14000E+02	.14100E+02	.14200E+02	.14300E+02	.14400E+02	.14500E+02
.14600E+02	.14700E+02	.14800E+02	.14900E+02	.15000E+02	.15100E+02	.15200E+02	.15300E+02
.15400E+02	.15500E+02	.15600E+02	.15700E+02	.15800E+02	.15900E+02	.16000E+02	.16100E+02
.16200E+02	.16300E+02	.16400E+02	.16500E+02	.16600E+02	.16700E+02	.16800E+02	.16900E+02
.17000E+02	.17100E+02	.17200E+02	.17300E+02	.17400E+02	.17500E+02	.17600E+02	.17700E+02
.17800E+02	.17900E+02	.18000E+02	.18100E+02	.18200E+02	.18300E+02	.18400E+02	.18500E+02
.18600E+02	.18700E+02	.18800E+02	.18900E+02	.19000E+02	.19100E+02	.19200E+02	.19300E+02
.19400E+02	.19500E+02	.19600E+02	.19700E+02	.19800E+02	.19900E+02	.20000E+02	.20100E+02
.20200E+02	.20300E+02	.20400E+02	.20500E+02	.20600E+02	.20700E+02	.20800E+02	.20900E+02
.21000E+02	.21100E+02	.21200E+02	.21300E+02	.21400E+02	.21500E+02	.21600E+02	.21700E+02
.21800E+02	.21900E+02	.22000E+02	.22100E+02	.22200E+02	.22300E+02	.22400E+02	.22500E+02
.22600E+02	.22700E+02	.22800E+02	.22900E+02	.23000E+02	.23100E+02	.23200E+02	.23300E+02
.23400E+02	.23500E+02	.23600E+02	.23700E+02	.23800E+02	.23900E+02	.24000E+02	.24100E+02

MAVERAND FROM 5.4E8 MICRONS TO 9.0E8 MICRONS

FIGURE 5-5. REPLICA EXAMPLE OUTPUT

RV-0SC4 360.00	3391.566	76.635	83.316	14680.824	13.449	359.007	21152.623	-37.663	359.445	31.33	87.74	54.76
GV-0SC4 390.00	5986.910	54.057	-98.481	11.000	12.059	359.247	231672.244	-29.882	359.411	24.07	87.95	63.11
RV-0SC4 390.00	3516.946	77.915	83.272	14529.475	12.059	359.247	231672.244	-29.882	359.411	24.07	87.95	63.11
GV-0SC4 420.00	5980.910	54.057	-98.481	11.000	12.059	359.247	231672.244	-29.882	359.411	24.07	87.95	63.11
RV-0SC4 420.00	3633.249	79.182	83.157	18741.546	11.691	359.411	231672.244	-29.882	359.411	24.07	87.95	63.11
GV-0SC4 450.00	5980.910	54.057	-98.481	11.000	12.059	359.247	231672.244	-29.882	359.411	24.07	87.95	63.11
RV-0SC4 450.00	3746.440	80.437	83.705	18244.440	10.819	359.585	13713.965	-27.348	359.429	27.10	89.33	62.00
GV-0SC4 480.00	5980.910	54.057	-98.481	11.000	12.059	359.247	231672.244	-29.882	359.411	24.07	87.95	63.11
RV-0SC4 480.00	7030.547	91.682	82.751	18119.571	9.012	359.782	12215.444	-27.674	359.474	25.74	88.52	64.31
GV-0SC4 510.00	5980.910	54.057	-98.481	11.000	12.059	359.247	231672.244	-29.882	359.411	24.07	87.95	63.11
RV-0SC4 510.00	3927.504	92.917	83.033	18016.161	9.012	359.782	12215.444	-27.674	359.474	25.74	88.52	64.31
GV-0SC4 540.00	5980.910	54.057	-98.481	11.000	12.059	359.247	231672.244	-29.882	359.411	24.07	87.95	63.11
RV-0SC4 540.00	4077.666	94.144	83.361	17904.747	8.040	359.782	12215.444	-27.674	359.474	25.74	88.52	64.31
GV-0SC4 570.00	5980.910	54.057	-98.481	11.000	12.059	359.247	231672.244	-29.882	359.411	24.07	87.95	63.11
RV-0SC4 570.00	4278.605	95.364	83.167	17814.677	7.114	359.782	12215.444	-27.674	359.474	25.74	88.52	64.31
GV-0SC4 600.00	5980.910	54.057	-98.481	11.000	12.059	359.247	231672.244	-29.882	359.411	24.07	87.95	63.11
RV-0SC4 600.00	4140.610	96.577	83.474	17736.092	6.205	359.782	12215.444	-27.674	359.474	25.74	88.52	64.31
GV-0SC4 630.00	5980.910	54.057	-98.481	11.000	12.059	359.247	231672.244	-29.882	359.411	24.07	87.95	63.11
RV-0SC4 630.00	4193.672	97.784	84.127	17668.963	5.254	359.782	12215.444	-27.674	359.474	25.74	88.52	64.31
GV-0SC4 660.00	5980.910	54.057	-98.481	11.000	12.059	359.247	231672.244	-29.882	359.411	24.07	87.95	63.11
RV-0SC4 660.00	4237.694	98.945	86.751	17514.402	4.296	359.782	12215.444	-27.674	359.474	25.74	88.52	64.31
GV-0SC4 690.00	5980.910	54.057	-98.481	11.000	12.059	359.247	231672.244	-29.882	359.411	24.07	87.95	63.11
RV-0SC4 690.00	4272.844	99.791	236.172	17568.937	3.332	359.782	12215.444	-27.674	359.474	25.74	88.52	64.31
GV-0SC4 720.00	5980.910	54.057	-98.481	11.000	12.059	359.247	231672.244	-29.882	359.411	24.07	87.95	63.11
RV-0SC4 720.00	4298.971	98.612	257.774	17535.991	2.364	359.782	12215.444	-27.674	359.474	25.74	88.52	64.31
GV-0SC4 750.00	5980.910	54.057	-98.481	11.000	12.059	359.247	231672.244	-29.882	359.411	24.07	87.95	63.11
RV-0SC4 750.00	4316.204	97.419	259.721	17514.402	1.392	359.782	12215.444	-27.674	359.474	25.74	88.52	64.31
GV-0SC4 780.00	5980.910	54.057	-98.481	11.000	12.059	359.247	231672.244	-29.882	359.411	24.07	87.95	63.11
RV-0SC4 780.00	4324.566	96.227	259.825	17506.157	0.419	359.782	12215.444	-27.674	359.474	25.74	88.52	64.31
GV-0SC4 810.00	5980.910	54.057	-98.481	11.000	12.059	359.247	231672.244	-29.882	359.411	24.07	87.95	63.11
RV-0SC4 810.00	4325.800	95.34	260.024	17506.262	-0.555	359.782	12215.444	-27.674	359.474	25.74	88.52	64.31
GV-0SC4 840.00	5980.910	54.057	-98.481	11.000	12.059	359.247	231672.244	-29.882	359.411	24.07	87.95	63.11
RV-0SC4 840.00	4314.325	93.841	260.113	17517.687	-1.529	359.782	12215.444	-27.674	359.474	25.74	88.52	64.31

FIGURE 5-5 - Continued

EXHIBIT

24 SECTORS
3 4TH DIVISIONS
8 LONG DIVISIONS

AZIMUTH ANGLES

0.00 120.00 240.00

POLAR ANGLES

29.74 50.94 67.51 75.00 75.00 67.00 67.00 19.00

MODE 1 (1=INST. FLUX, 2=POLY-AVERAGED FLUX)

MONTH 5

DAY 1

GMT

0.00

SUN-LAT, LNC

0.00

0.00

TIME	CONDITION	AVERAGE FLUXES -- W/ (M ²)		MOLECULAR
		SUN/ALBEDO	EAPT4	
30.0000	SUNLIT	346.6558	128.7528	0.
30.0000	SUNLIT	348.5368	126.6460	0.
30.0000	SUNLIT	348.4320	114.1127	0.
30.0000	SUNLIT	348.3308	108.1425	0.
30.0000	SUNLIT	348.2344	102.9933	0.
30.0000	SUNLIT	348.1297	98.17172	0.
30.0000	SUNLIT	348.1234	93.69156	0.
30.0000	SUNLIT	347.9122	89.48573	0.
30.0000	SUNLIT	347.7941	85.84116	0.
30.0000	SUNLIT	347.6683	81.56494	0.
30.0000	SUNLIT	347.5425	76.59427	0.
30.0000	SUNLIT	347.4117	74.24104	0.
30.0000	SUNLIT	347.2815	74.16543	0.
30.0000	SUNLIT	347.1512	74.53495	0.
30.0000	SUNLIT	347.1161	72.93901	0.
30.0000	SUNLIT	346.8767	71.17169	0.
30.0000	SUNLIT	346.7362	69.97456	0.
30.0000	SUNLIT	346.5976	69.04332	0.
30.0000	SUNLIT	346.4458	67.93349	0.
30.0000	SUNLIT	346.2975	67.18211	0.
30.0000	SUNLIT	346.1493	66.66744	0.
30.0000	SUNLIT	346.1013	66.16748	0.
30.0000	SUNLIT	345.8664	65.78464	0.
30.0000	SUNLIT	345.7652	64.71902	0.
30.0000	SUNLIT	345.3639	65.26889	0.
30.0000	SUNLIT	345.2271	65.11285	0.
30.0000	SUNLIT	345.0555	64.97222	0.
30.0000	SUNLIT	344.8723	64.75417	0.
30.0000	SUNLIT	344.6819	65.07251	0.
30.0000	SUNLIT	344.4868	65.37422	0.
30.0000	SUNLIT	344.2884	65.68816	0.
30.0000	SUNLIT	344.1878	66.16786	0.
30.0000	SUNLIT	343.8754	66.64854	0.
30.0000	SUNLIT	343.6621	67.59173	0.
30.0000	SUNLIT	343.4481	68.42413	0.
30.0000	SUNLIT	343.2294	69.33975	0.
30.0000	SUNLIT	343.1142	71.37506	0.
30.0000	SUNLIT	342.7723	72.88412	0.
30.0000	SUNLIT	342.5274	73.15449	0.
30.0000	SUNLIT	342.2778	74.72723	0.
30.0000	SUNLIT	342.1177	75.39032	0.
30.0000	SUNLIT	341.7548	74.76294	0.
30.0000	SUNLIT	341.4791	71.32214	0.
30.0000	SUNLIT	341.1988	70.11873	0.
30.0000	SUNLIT	340.9463	66.14510	0.
30.0000	SUNLIT	340.6124	63.66132	0.
30.0000	SUNLIT	340.3491	62.07471	0.
30.0000	SUNLIT	340.1178	60.24317	0.
30.0000	SUNLIT	339.7877	59.04459	0.
30.0000	SUNLIT	339.4169	112.2723	0.
BASELINE SILICA PHENOLIC (QUARTZ PHENOLIC) (31 PERCENT PHENOLIC RESIN)				
BASELINE SILICA PHENOLIC (QUARTZ PHENOLIC) (32 PERCENT PHENOLIC RESIN)				
BASELINE SILICA PHENOLIC (QUARTZ PHENOLIC) (33 PERCENT PHENOLIC RESIN)				
BASELINE SILICA PHENOLIC (QUARTZ PHENOLIC) (34 PERCENT PHENOLIC RESIN)				
BASELINE SILICA PHENOLIC (QUARTZ PHENOLIC) (35 PERCENT PHENOLIC RESIN)				
BASELINE SILICA PHENOLIC (QUARTZ PHENOLIC) (36 PERCENT PHENOLIC RESIN)				
BASELINE SILICA PHENOLIC (QUARTZ PHENOLIC) (37 PERCENT PHENOLIC RESIN)				
BASELINE SILICA PHENOLIC (QUARTZ PHENOLIC) (38 PERCENT PHENOLIC RESIN)				
BASELINE SILICA PHENOLIC (QUARTZ PHENOLIC) (39 PERCENT PHENOLIC RESIN)				
BASELINE SILICA PHENOLIC (QUARTZ PHENOLIC) (40 PERCENT PHENOLIC RESIN)				
BASELINE SILICA PHENOLIC (QUARTZ PHENOLIC) (41 PERCENT PHENOLIC RESIN)				
BASELINE SILICA PHENOLIC (QUARTZ PHENOLIC) (42 PERCENT PHENOLIC RESIN)				
BASELINE SILICA PHENOLIC (QUARTZ PHENOLIC) (43 PERCENT PHENOLIC RESIN)				
BASELINE SILICA PHENOLIC (QUARTZ PHENOLIC) (44 PERCENT PHENOLIC RESIN)				
BASELINE SILICA PHENOLIC (QUARTZ PHENOLIC) (45 PERCENT PHENOLIC RESIN)				
BASELINE SILICA PHENOLIC (QUARTZ PHENOLIC) (46 PERCENT PHENOLIC RESIN)				
BASELINE SILICA PHENOLIC (QUARTZ PHENOLIC) (47 PERCENT PHENOLIC RESIN)				
BASELINE SILICA PHENOLIC (QUARTZ PHENOLIC) (48 PERCENT PHENOLIC RESIN)				
BASELINE SILICA PHENOLIC (QUARTZ PHENOLIC) (49 PERCENT PHENOLIC RESIN)				
BASELINE SILICA PHENOLIC (QUARTZ PHENOLIC) (50 PERCENT PHENOLIC RESIN)				

FIGURE 5-5 - Continued

STAT AREA	PERP	PAR	RAOINS	7ED	HUNLTH	THASS	RAD	CCND	THTP	ALF	EOUT	EIN
1 .223	.441	.876	.316	.411C-01	.334	.130	.981E-04	.580E-05	.125E+04	.500	.750	.750
2 .223	.777	.629	.510	.243	.584	.130	.981E-04	.103F-04	.119E+04	.500	.750	.750
3 .223	.924	.382	.606	.485	.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	.134E-02	.252	.500	.750	.200
6 .375	.866	.500	.945	1.55	1.97	.147	.116E-03	.274E-02	51.9	.500	.750	.200
7 .412	.866	.511	1.04	1.72	2.16	.152	.116E-03	.231E-02	67.0	.500	.750	.200
8 .124	-.308E-09	-1.00	.543	1.86	2.84	.649	.352E-03	.630E-03	590.	.500	.750	.200
9 .223	.481	.876	.316	.410F-01	.330	.130	.981E-04	.580E-05	.125E+04	.500	.750	.750
10 .223	.777	.629	.510	.243	.584	.130	.981E-04	.103F-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	.134E-02	.252	.500	.750	.200
14 .375	.866	.500	.945	1.55	1.97	.147	.116E-03	.274E-02	51.9	.500	.750	.200
15 .412	.866	.511	1.04	1.72	2.16	.152	.116E-03	.231E-02	67.0	.500	.750	.200
16 .124	-.308E-09	-1.00	.543	1.86	2.80	.649	.352E-03	.630E-03	590.	.500	.750	.200
17 .223	.481	.876	.316	.410E-01	.330	.130	.981E-04	.580E-05	.125E+04	.500	.750	.750
18 .223	.777	.629	.510	.243	.584	.130	.981E-04	.103F-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	.134E-02	.252	.500	.750	.200
22 .375	.866	.500	.945	1.55	1.97	.147	.116E-03	.274E-02	51.9	.500	.750	.200
23 .412	.866	.500	1.04	1.72	2.16	.152	.116E-03	.231E-02	67.0	.500	.750	.200
24 .124	-.308E-09	-1.00	.543	1.86	2.80	.649	.352E-03	.630E-03	590.	.500	.750	.200

TIME DEVELOPMENT OF TEMPERATURES

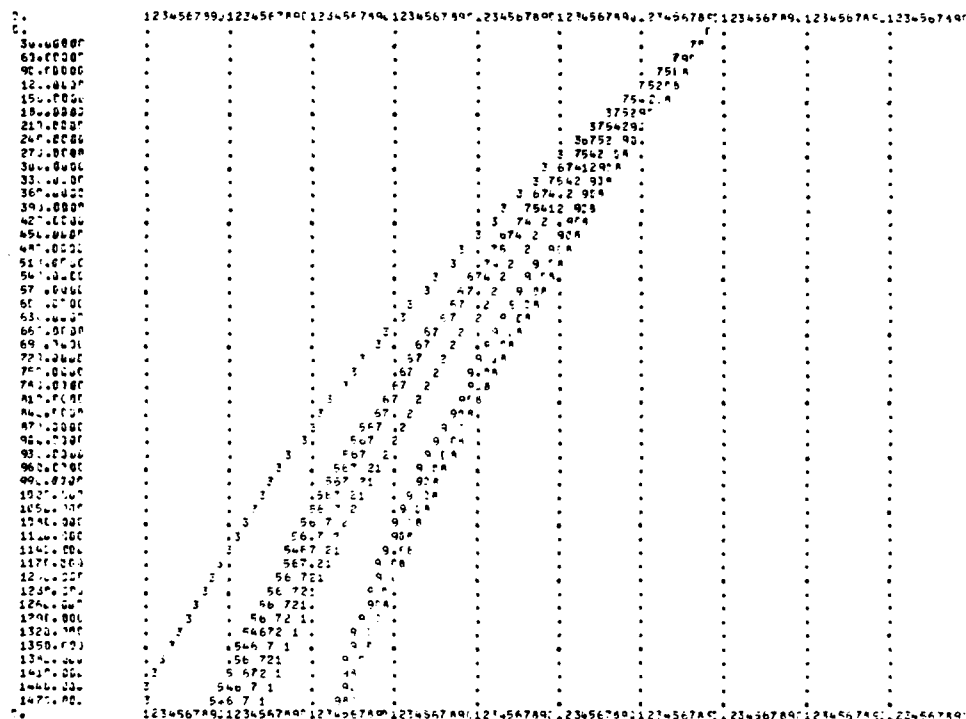
LONGITUDINAL CONDUCTION TREATED -- T

OPEN REAR SURFACE -- F

NR MYX INV-- 147

FIGURE 5-5 - Continued

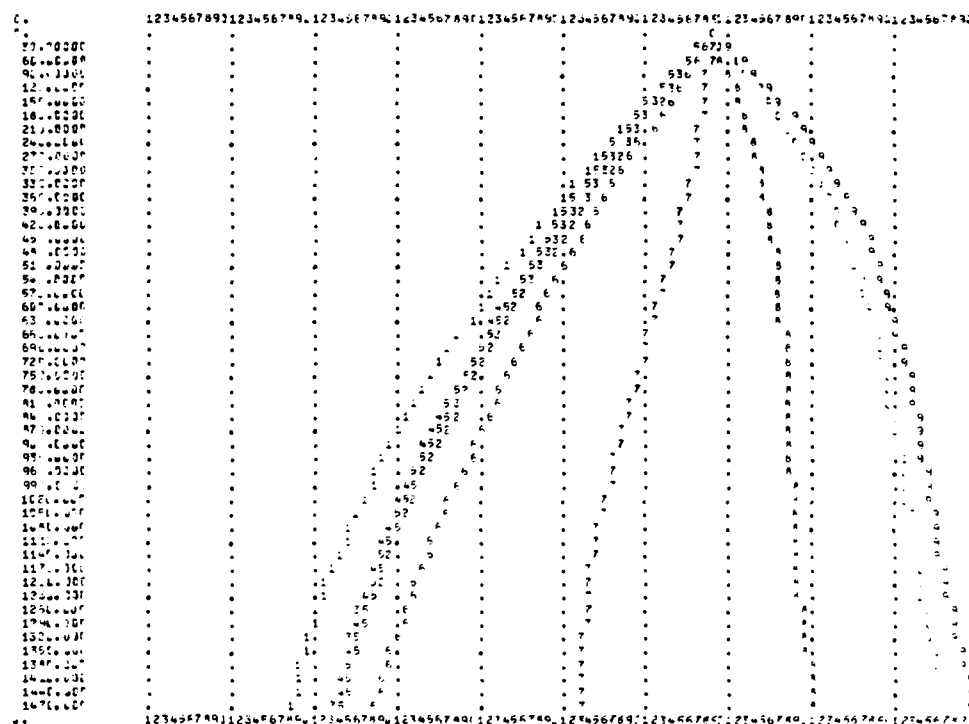
1
TEMES
MAY 571.271
MTW 472.692



TIME/STAI	540.610	541.610	542.610	543.610	544.610	545.610	546.610	547.610	548.610	549.610	550.610	551.610	552.610	553.610	554.610	555.610	556.610	557.610	558.610	559.610	560.610	561.610	562.610	563.610	564.610	565.610	566.610	567.610	568.610	569.610	570.610	571.610	572.610	573.610	574.610	575.610	576.610	577.610	578.610	579.610	580.610	581.610	582.610	583.610	584.610	585.610	586.610	587.610	588.610	589.610	590.610	591.610	592.610	593.610	594.610	595.610	596.610	597.610	598.610	599.610	600.610	601.610	602.610	603.610	604.610	605.610	606.610	607.610	608.610	609.610	610.610	611.610	612.610	613.610	614.610	615.610	616.610	617.610	618.610	619.610	620.610	621.610	622.610	623.610	624.610	625.610	626.610	627.610	628.610	629.610	630.610	631.610	632.610	633.610	634.610	635.610	636.610	637.610	638.610	639.610	640.610	641.610	642.610	643.610	644.610	645.610	646.610	647.610	648.610	649.610	650.610	651.610	652.610	653.610	654.610	655.610	656.610	657.610	658.610	659.610	660.610	661.610	662.610	663.610	664.610	665.610	666.610	667.610	668.610	669.610	670.610	671.610	672.610	673.610	674.610	675.610	676.610	677.610	678.610	679.610	680.610	681.610	682.610	683.610	684.610	685.610	686.610	687.610	688.610	689.610	690.610	691.610	692.610	693.610	694.610	695.610	696.610	697.610	698.610	699.610	700.610	701.610	702.610	703.610	704.610	705.610	706.610	707.610	708.610	709.610	710.610	711.610	712.610	713.610	714.610	715.610	716.610	717.610	718.610	719.610	720.610	721.610	722.610	723.610	724.610	725.610	726.610	727.610	728.610	729.610	730.610	731.610	732.610	733.610	734.610	735.610	736.610	737.610	738.610	739.610	740.610	741.610	742.610	743.610	744.610	745.610	746.610	747.610	748.610	749.610	750.610	751.610	752.610	753.610	754.610	755.610	756.610	757.610	758.610	759.610	760.610	761.610	762.610	763.610	764.610	765.610	766.610	767.610	768.610	769.610	770.610	771.610	772.610	773.610	774.610	775.610	776.610	777.610	778.610	779.610	780.610	781.610	782.610	783.610	784.610	785.610	786.610	787.610	788.610	789.610	790.610	791.610	792.610	793.610	794.610	795.610	796.610	797.610	798.610	799.610	800.610	801.610	802.610	803.610	804.610	805.610	806.610	807.610	808.610	809.610	810.610	811.610	812.610	813.610	814.610	815.610	816.610	817.610	818.610	819.610	820.610	821.610	822.610	823.610	824.610	825.610	826.610	827.610	828.610	829.610	830.610	831.610	832.610	833.610	834.610	835.610	836.610	837.610	838.610	839.610	840.610	841.610	842.610	843.610	844.610	845.610	846.610	847.610	848.610	849.610	850.610	851.610	852.610	853.610	854.610	855.610	856.610	857.610	858.610	859.610	860.610	861.610	862.610	863.610	864.610	865.610	866.610	867.610	868.610	869.610	870.610	871.610	872.610	873.610	874.610	875.610	876.610	877.610	878.610	879.610	880.610	881.610	882.610	883.610	884.610	885.610	886.610	887.610	888.610	889.610	890.610	891.610	892.610	893.610	894.610	895.610	896.610	897.610	898.610	899.610	900.610	901.610	902.610	903.610	904.610	905.610	906.610	907.610	908.610	909.610	910.610	911.610	912.610	913.610	914.610	915.610	916.610	917.610	918.610	919.610	920.610	921.610	922.610	923.610	924.610	925.610	926.610	927.610	928.610	929.610	930.610	931.610	932.610	933.610	934.610	935.610	936.610	937.610	938.610	939.610	940.610	941.610	942.610	943.610	944.610	945.610	946.610	947.610	948.610	949.610	950.610	951.610	952.610	953.610	954.610	955.610	956.610	957.610	958.610	959.610	960.610	961.610	962.610	963.610	964.610	965.610	966.610	967.610	968.610	969.610	970.610	971.610	972.610	973.610	974.610	975.610	976.610	977.610	978.610	979.610	980.610	981.610	982.610	983.610	984.610	985.610	986.610	987.610	988.610	989.610	990.610	991.610	992.610	993.610	994.610	995.610	996.610	997.610	998.610	999.610	1000.610
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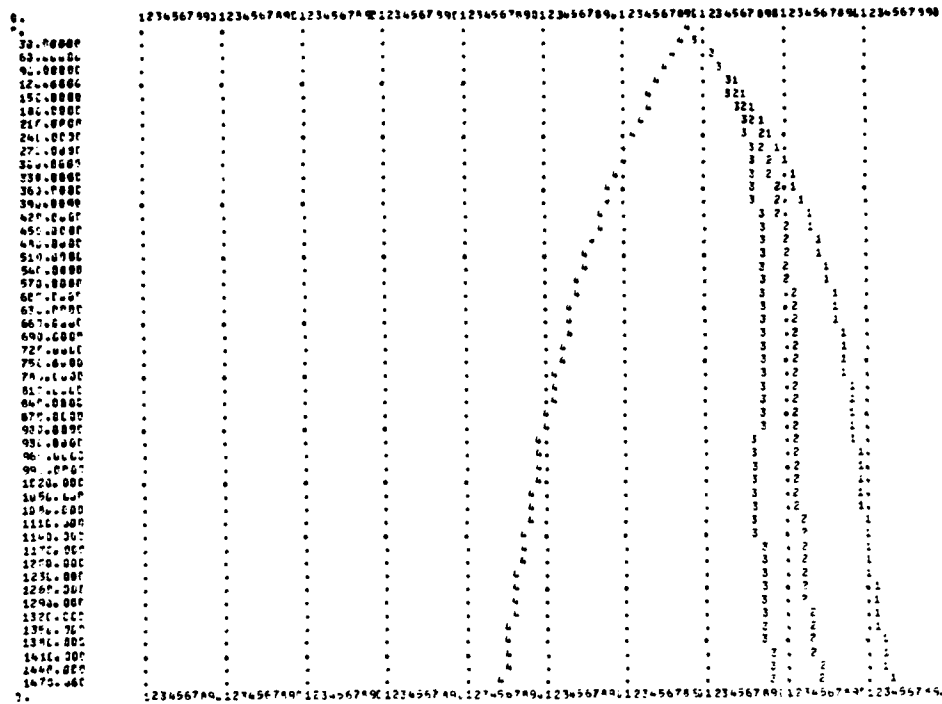
FIGURE 5-5 - Continued

11
TEWES
571.271
472.652



21
TECHS
404
412

571.271
472.653



TIME/STAT	21	22	23	24
6.0000	543.036	544.122	545.208	546.294
7.0000	541.595	542.681	543.767	544.853
8.0000	540.154	541.240	542.326	543.412
9.0000	538.713	539.799	540.885	541.971
10.0000	537.272	538.358	539.444	540.530
11.0000	535.831	536.917	537.993	539.089
12.0000	534.390	535.476	536.552	537.641
13.0000	532.949	534.035	535.111	536.193
14.0000	531.508	532.594	533.670	534.745
15.0000	530.067	531.153	532.229	533.297
16.0000	528.626	529.712	530.788	531.849
17.0000	527.185	528.271	529.347	530.401
18.0000	525.744	526.830	527.906	528.953
19.0000	524.303	525.389	526.465	527.505
20.0000	522.862	523.948	525.024	526.057
21.0000	521.421	522.507	523.583	524.609
22.0000	520.000	521.086	522.162	523.188
23.0000	518.579	519.665	520.741	521.767
24.0000	517.158	518.244	519.320	520.346
25.0000	515.737	516.823	517.899	518.925
26.0000	514.316	515.402	516.478	517.504
27.0000	512.895	513.981	515.057	516.083
28.0000	511.474	512.560	513.636	514.662
29.0000	510.053	511.139	512.215	513.241
30.0000	508.632	509.718	510.794	511.820
31.0000	507.211	508.297	509.373	510.399
32.0000	505.790	506.876	507.952	508.978
33.0000	504.369	505.455	506.531	507.557
34.0000	502.948	504.034	505.110	506.136
35.0000	501.527	502.613	503.689	504.715
36.0000	500.106	501.192	502.268	503.294
37.0000	498.685	499.771	500.847	501.873
38.0000	497.264	498.350	500.426	500.452
39.0000	495.843	496.929	498.995	499.031
40.0000	494.422	495.508	497.574	497.610
41.0000	493.001	494.087	496.153	496.189
42.0000	491.580	492.666	494.732	494.768
43.0000	490.159	491.245	493.311	493.347
44.0000	488.738	489.824	491.890	491.926
45.0000	487.317	488.403	490.469	490.505
46.0000	485.896	486.982	489.048	489.084
47.0000	484.475	485.561	487.627	487.663
48.0000	483.054	484.140	486.206	486.242
49.0000	481.633	482.719	484.785	484.821
50.0000	480.212	481.298	483.364	483.400
51.0000	478.791	479.877	481.943	481.979
52.0000	477.370	478.456	480.522	480.558
53.0000	475.949	477.035	479.101	479.137
54.0000	474.528	475.614	477.680	477.716
55.0000	473.107	474.193	476.259	476.295
56.0000	471.686	472.772	474.838	474.874
57.0000	470.265	471.351	473.417	473.453
58.0000	468.844	469.930	471.996	472.032
59.0000	467.423	468.509	470.575	470.611
60.0000	466.002	467.088	469.154	469.190
61.0000	464.581	465.667	467.733	467.769
62.0000	463.160	464.246	466.312	466.348
63.0000	461.739	462.825	464.891	464.927
64.0000	460.318	461.404	463.470	463.506
65.0000	458.897	459.983	462.049	462.085
66.0000	457.476	458.562	460.628	460.664
67.0000	456.055	457.141	459.207	459.243
68.0000	454.634	455.720	457.786	457.822
69.0000	453.213	454.299	456.365	456.401
70.0000	451.792	452.878	454.944	454.980
71.0000	450.371	451.457	453.523	453.559
72.0000	448.950	449.036	452.102	452.138
73.0000	447.529	447.615	450.681	450.717
74.0000	446.108	446.194	449.260	449.296
75.0000	444.687	444.773	447.839	447.875
76.0000	443.266	443.352	446.418	446.454
77.0000	441.845	441.931	444.997	445.033
78.0000	440.424	440.510	443.576	443.612
79.0000	438.003	438.089	442.155	442.191
80.0000	436.582	436.668	440.734	440.770
81.0000	435.161	435.247	439.313	439.349
82.0000	433.740	433.826	437.892	437.928
83.0000	432.319	432.405	436.471	436.507
84.0000	430.898	430.984	435.050	435.086
85.0000	429.477	429.563	433.629	433.665
86.0000	428.056	428.142	432.208	432.244
87.0000	426.635	426.721	430.787	430.823
88.0000	425.214	425.300	429.366	429.402
89.0000	423.793	423.879	427.945	427.981
90.0000	422.372	422.458	426.524	426.560
91.0000	420.951	421.037	425.103	425.139
92.0000	419.530	419.616	423.682	423.718
93.0000	418.109	418.195	422.261	422.297
94.0000	416.688	416.774	420.840	420.876
95.0000	415.267	415.353	419.419	419.455
96.0000	413.846	413.932	418.000	418.036
97.0000	412.425	412.511	416.579	416.615
98.0000	411.004	411.090	415.158	415.194
99.0000	409.583	409.669	413.737	413.773
100.0000	408.162	408.248	412.316	412.352

END EXOMET

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

1. E. K. Stewart, "Optical Signatures Code, Volume I - Basic Option", Sixth Distribution, Teledyne Brown Engineering, March 1979
2. H. Rose, D. Anding, R. R. Kauth, and J. Walker, "Handbook of Albedo and Earthshine", Environmental Research Institute of Michigan, University of Michigan, Ann Arbor, Michigan, June 1973, 190201-1-T
3. J. V. Beaupre, "Optical Signatures Code, Volume II - Exoatmospheric Thermal Response Model: EXOHEAT", Fifth Distribution, Teledyne Brown Engineering, December 1977