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# ANALYSIS OF PERIODIC THERMAL LOADS IMPOSED ON ENVIRONMENTAL CONTROL SYSTEMS: A COMPUTER PROGRAM

Frederick H. Green

SS-3028

February 1964

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AIRESEARCH MANUFACTURING DIVISION
Los Angeles, California

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# ANALYSIS OF PERIODIC THERMAL LOADS IMPOSED ON ENVIRONMENTAL CONTROL SYSTEMS: A COMPUTER PROGRAM


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A Division of The Garrett Corporation
Los Angeles, California



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GARRETT AIRESEARCH MANUFACTURING DIVISION
Los Angeles, California

## FOREWORD

This report was prepared by the AiResearch Manufacturing Division of The Garrett Corporation, Los Angeles, under contract to the NASA Manned Spacecraft Center. The documentation presented here was performed under Contract No. NAS 9-2044.

The computer program is sponsored by the Crew Systems Division of the NASA Manned Spacecraft Center, and is under the technical direction of W. W. Guy. F. H. Green is the principal investigator at AiResearch.

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# SECTION I

## INTRODUCTION

This document describes a digital computer program for the analysis of periodic thermal loads imposed on space vehicle environmental control systems. In an orbiting vehicle, for example, the external heat load will vary extensively as a function of time. The walls of the vehicle will be composed of several layers of material, each with different heat transfer characteristics. The resulting influence upon the interior atmosphere of the vehicle will lag (in time) behind the outside changes and be of far different magnitude.

The purpose of the computer program is to predict the resulting influence by simple means and to predict the performance of different types of vehicle walls under different imposed thermal loads. Basic performance equations and logic for thirty different system loads are included in the program. Adaptation to different loads is made by simple input adjustments. Usually, more than one type of load is considered at one time.

The assumptions used and the equations solved are presented, together with the program listings, written in FORTRAN II language, usable on the IBM 7074, 7090, and 7094. Examples of program input, program output, and program usage are included.

## SECTION 2

## NOMENCLATURE

ANRO(I)

Program Dimension ANRO(101)
Input Dimension DATA (LBN ≤ 201)
Input - Fixed point - F10.5 - Decimal percent

Over-all transmissivity of first, outside, material layer for infrared radiation at time I. LBD = 21.

ANRP(I)

Program Dimension ANRP(101)
Input Dimension DATA (LBN ≤ 201)
Input - Fixed Point - F10.5 - Decimal percent

Over-all transmissivity of second material layer for infrared radiation at time I. LBD = 26.

ANSO(I)

Program Dimension ANSO(101)
Input Dimension DATA (LBN ≤ 201)
Input - Fixed point - F10.5 - Decimal percent

Over-all transmissivity of first, outside, material layer for visible (solar) radiation at time I. LBD = 24.

ANSP(I)

Program Dimension ANSP(101)
Input Dimension DATA (LBN ≤ 201)
Input - Fixed point - F10.5 - Decimal percent

Over-all transmissivity of second material layer for visible (solar) radiation at time I. LBD = 29.

AR12(I)

Program Dimension AR12(101)
Input Dimension DATA (LBN ≤ 201)
Input - Fixed point - F10.5 - Decimal percent

Reflectivity of surface of first material layer for infrared radiation at time I. LBD = 22.

AR23(I)

Program Dimension AR23(101)
Input Dimension DATA (LBN ≤ 201)
Input - Fixed point - F10.5 - Decimal percent

Reflectivity of surface of second material layer for infrared radiation at time I. LBD = 27.

ARSI(I)

Program Dimension ARSI(101)
Input Dimension DATA (LBN ≤ 201)
Input - Fixed point - F10.5 - Decimal percent

Inside radiant source - inside wall surface absorptivity factor at time I. LBD = 18.

ARSO(I)

Program Dimension ARSO(101)
Input Dimension DATA (LBN ≤ 201)
Input - Fixed point - F10.5 - Decimal percent

Outside - first radiant source - outside wall surface absorptivity factor at time I. LBD = 10. If the outside layer of the wall is transparent, this is the surface absorptivity for infrared radiation.

ARSSO(I)

Program Dimension ARSSO(101)
Input Dimension DATA (LBN ≤ 201)
Input - Fixed point - F10.5 - Decimal percent

Outside - second radiant source - outside wall surface absorptivity factor at time I. LBD = 12. If the outside layer of the wall is transparent this is the surface absorptivity for visible (solar) radiation.

ARSTO(I)

Program Dimension ARSTO(101)
Input Dimension DATA (LBN ≤ 201)
Input - Fixed point - F10.5 - Decimal percent

Outside - third radiant source - outside wall surface absorptivity factor at time I. LBD = 14.

AS12(I)

Program Dimension AS12(101)
Input Dimension DATA (LBN ≤ 201)
Input - Fixed point - F10.5 - Decimal percent

Reflectivity of surface of first material layer for visible (solar) radiation at time I. LBD = 25.

AS23(I)

Program Dimension AS23(101)
Input Dimension DATA (LBN $\leq$ 201)
Input - Fixed point - F10.5 - Decimal percent

Reflectivity of surface of second material layer for visible (solar) radiation at time I. LBD = 30.

AVACI

Input - Fixed point - F10.5 - Decimal percent

Absorptivity of insideward wall surface facing vacuum layer.

AVACO

Input - Fixed point - F10.5 - Decimal percent

Absorptivity of outsideward wall surface facing vacuum layer.

COND(I)

Dimension COND(5)
Input - Fixed point - F10.5 - Btu/hr/sq ft per $^{o}$F/ft

Conductivity of material in layer I.

CSUBP(I)

Dimension CSUBP(5)
Input - Fixed point - F10.5 - Btu/lb/$^{o}$F

Specific heat of material in layer I.

CUE(I)

Dimension CUE(10)
Generated - Btu/hr/sq ft

Heat flow rate, situation I

I = 1. Convection to outside surface.
2. Convection to inside surface.
3. Input (given) heat flow to outside surface.
4. Input (given) heat flow to inside surface.
5. Heat flow represented by given outside surface temperature.
6. Heat flow represented by given inside surface temperature.
7. Heat flow from third radiant source to outside surface.
8. Heat flow from second radiant source to outside surface.
9. Heat flow from first radiant source to outside surface minus heat flow from outside surface to outside sink.
10. Heat flow from inside radiant source to inside surface minus heat flow from inside surface to inside sink.

CUEI(I)

Program Dimension CUEI(101)
Input Dimension DATA (LBN ≥ 201)
Input - Fixed point - F10.5 - Btu/hr/sq ft

Quantity of heat flowing to inside surface from inside sources at time I. LBD = 6.

CUEO(I)

Program Dimension CUEO(101)
Input Dimension DATA (LBN ≥ 201)
Input - Fixed point - F10.5 - Btu/hr/sq ft

Quantity of heat flowing to outside surface from outside sources at time I. LBD = 5.

CUESI

Output - Fixed point - F7.2 - Btu/hr/sq ft

Rate of heat flow to inside wall surface from internal sources at a particular time in the orbit or cycle.

CUESIS

Output - Fixed point - F7.2 - Btu/hr/sq ft

Rate of heat flow to inside wall surface from internal sources, sum of all computed values of CUESI for one orbit or cycle.

CUESO

Output - Fixed point - F7.2 - Btu/hr/sq ft

Rate of heat flow to outside wall surface from external sources at a particular time in the orbit or cycle.

CUESOS

Output - Fixed point - F7.2 - Btu/hr/sq ft

Rate of heat flow to outside wall surface from external sources, sum of all computed values of CUESO for one orbit or cycle.

DATA(I)

Dimension DATA(201)
Input - Fixed point - F10.5 - Units as defined under specific type of data.

Periodic input data, identified by heading card (see under "LBD"), with points arranged in chronological sequence. The total number of points, "LBN," will be one more than the number of time divisions of data per orbit since the last point must be a repeat of the first point. The card format is: Heading card, containing LBD, LBN, and KL, followed by as many data cards as needed in 7F10.5 format. This is repeated for each type of data.

DD(I,J)

Dimension DD(102,2)

Generated

Proportionality factor for construction lines for slice I. J identifies const. line. J = 1 for const. line 2. J = 2 for const. line 4.

DELT

Input - Fixed point - F10.5 - $^{0}F$

Temperature difference used in test for convergence.

DTHN(I)

Dimension DTHN(5)
Output - Fixed point - F10.5 - Hours

Time increment associated with material layer I.

DX(I)

Dimension DX(5)
Output - Fixed point - F10.5 - Feet

Equivalent thickness of material layer I.

DXN(I)

Dimension DXN(5)
Output - Fixed point - F10.5 - Feet

Equivalent thickness, for k = 1, of each slice of material layer I.

DXNA

Generated

One-half of equivalent thickness of first slice of outside layer of wall = 0.5 * DXN(1).

DXNB

Generated

Thickness factor = DXNA + 1.

DXNC

Generated

One-half of equivalent thickness of first slice of inside layer of wall = 0.5 * DXN(IW).

DXND

Generated

Thickness factor = DXNC + 1.

ER12(I)

Program Dimension ER12(101)
Input Dimension DATA (LBN ≦201)
Input - Fixed point - F10.5 - Decimal percent

Proportion of incident radiant energy which is infrared. LBD = 23

ER23(I)

Program Dimension ER23(101)
Input Dimension DATA (LBN ≦ 201)
Input - Fixed point - F10.5 - Decimal percent

ERKI(I)

Program Dimension ERKI(101)
Input Dimension DATA (LBN ≦ 201)
Input - Fixed point - F10.5 - Decimal percent

Inside radiant sink - inside wall surface emissivity factor at time I. LBD = 20.

ERKO(I)

Program Dimension ERKO(101)
Input Dimension DATA (LBN ≦ 201)
Input - Fixed point - F10.5 - Decimal percent

Outside radiant sink - outside wall surface emissivity factor at time I. LBD = 16.

FCI(I)

Program Dimension FCI(101)
Input Dimension DATA (LBN ≤ 201)
Input - Fixed point - F10.5 - Btu/hr/sq ft/$^{0}$F

Inside air film heat transfer coefficient at time I. LBD = 4.

FCO(I)

Program Dimension FCO(101)
Input Dimension DATA (LBN ≤ 201)
Input - Fixed point - F10.5 - Btu/hr/sq ft/$^{0}$F

Outside air film heat transfer coefficient at time I. LBD = 2.

HRSOBT

Input - Fixed point - F10.5 - Hours

Time required for one orbit or cycle.

IDATA

Input - Integer constant

Number of time-dependent input variables for which data sets are provided. See also DATA(I).

IL(I)

Dimension IL(5)
Output - Integer

Number of slices in material layer I. Maximum 20.

IND(I)

Dimension IND(20)
Generated-Integer

Integer used to identify and call equations in S/R TEMPER

INDX

Number of equations used in TEMPER

ITPMAX

Input - Integer constant

Maximum number of time intervals per orbit to be used in solution. Maximum is 100.

ITPMIN

Input - Integer constant

Minimum number of time intervals per orbit to be used in solution.

ITRN

Input - Integer constant

Constant indicating whether material layers are transparent to incoming radiation, either infrared or visible or both.

ITRN = 0 No layer transparent
ITRN = 1 First, outside, layer transparent
ITRN = 2 First and second layers transparent
ITRN = 3 First and third layers transparent; second layer vacuum.

IVAC

Input - Integer constant

Constant indicating that one material layer of wall is a vacuum space.

IVAC = 1 No vacuum space
IVAC = 2 Second layer is vacuum
IVAC = 3 Third layer is vacuum
IVAC = 4 Fourth layer is vacuum

IW

Input - Integer constant

Number of material layers in wall. Maximum 5.

IWALL

Input - Integer constant

Wall number used to identify separate complete walls.

IWC

Generated - Integer constant

Total number of slices in all material layers in wall, plus 2 to allow identification of outside conditions (1) and inside conditions (IWC).

IWD

Generated - Integer constant

Control integer for DISTX and TEMCAL loops. IWD = IWC -1.

JDI

Input - Integer constant

Constant controlling print-out of intermediate diagnostic outputs.

JDI = 0 No intermediate print-out
JDI = 1 Intermediate print-out

JTPR

Output - Integer

Tests per orbit needed to satisfy basic equation. Number of time intervals into which orbit is divided for computation and output.

KL

Input - Integer constant

Integer determining the number of points used in the interpolation. Recommended value, 3.

LBD

Input - Integer constant

Identity number of a set of data. Values of this constant and corresponding data symbols are:

| LBD | DATA | LBD | DATA | LBD | DATA | LBD | DATA |
|---|---|---|---|---|---|---|---|
| 1 | TO(I) | 9 | TRSO(I) | 17 | TRSI(I) | 25 | AS12(I) |
| 2 | FCO(I) | 10 | ARSO(I) | 18 | ARSI(I) | 26 | ANRP(I) |
| 3 | TI(I) | 11 | TRSSO(I) | 19 | TRKI(I) | 27 | AR23(I) |
| 4 | FCI(I) | 12 | ARSSO(I) | 20 | ERKI(I) | 28 | ER23(I) |
| 5 | CUEO(I) | 13 | TRSTO(I) | 21 | ANRO(I) | 29 | ANSP(I) |
| 6 | CUEI(I) | 14 | ARSTO(I) | 22 | AR12(I) | 30 | AS23(I) |
| 7 | TWLO(I) | 15 | TRKO(I) | 23 | ER12(I) | | |
| 8 | TWLI(I) | 16 | ERKO(I) | 24 | ANSO(I) | | |

LBK(I)

Dimension LBK(30)

Generated

Input data identification number for set I.

LBN

Input - Integer constant

Number of points in the immediately following set of data. Numerically LBN is one more than the number of time period subdivisions for one orbit of input data since the last point must be a repeat of the first point.

LT1

Integer constant. Change Step 1 of subroutine TAPL before compiling.

Fortran number of read/write tape unit used for input data.

LT2

Integer constant. Change Step 2 of subroutine TAPL before compiling.

Fortran number of read/write tape unit used for output data.

MA

Output - Integer

Integer denoting time interval number in orbit.

MR

Output - Integer

Integer denoting number of orbits or cycles used to arrive at solution.

NDAT

Generated

Output message identification for incorrect inputs.

NSET

Input - Integer constant

Minimum number of slices per material layer to be used in calculations.

NSETR

Input - Integer constant

Maximum number of orbits or cycles used in program to check convergence.

NSETS

Input - Integer constant

Number of divergent cycles permitted before abandoning calculation.

NWALL

Input - Integer constant

Number of complete walls for which solution is desired. Maximum 20.

PROP(I)

Dimension PROP(5)
Output - Fixed point - F10.5

Thermal property parameter for material in layer I.

RHO(I)

Dimension RHO(5)
Input - Fixed point - F10.5 - lb/cu ft.

Density of material in layer I.

SUMA

Generated

X - argument for interpolation routine

TAB(I)

Dimension TAB(402)

Generated

One-dimensional array for interpolation of input values.

THCK(I)

Dimension THCK(5)
Input - Fixed point - F10.5 - inches

Thickness of material in layer I.

TI(I)

Program Dimension TI(101)
Input Dimension DATA (LBN ≤ 201)
Input - Fixed point - F10.5 - $^{0}$F

Inside air temperature at time I. LBD = 3.

TM(I,J)

Dimension TM(102, 4)

Generated

Temperature at line J, slice I.

TO(I)

Program Dimension TO(101)
Input Dimension DATA (LBN ≤ 201)
Input - Fixed point - F10.5 - $^{0}$F

Outside air temperature at time I. LBD = 1.

TRKI(I)

Program Dimension TRKI(101)
Input Dimension DATA (LBN ≤ 201)
Input - Fixed point - F10.5 - $^{0}$F

Inside radiant sink temperature at time I. LBD = 19.

TRKO(I)

Program Dimension TRKO(101)
Input Dimension DATA (LBN ≤ 201)
Input - Fixed point - F10.5 - $^{0}$F

Outside radiant sink temperature at time I. LBD = 15.

TRSI(I)

Program Dimension TRSI(101
Input Dimension DATA (LBN ≤ 201)
Input - Fixed point - F10.5 - $^{o}$F

Inside radiant source temperature at time I. LBD = 17.

TRSO(I)

Program Dimension TRSO(101)
Input Dimension DATA (LBN ≤ 201)
Input - Fixed point - F10.5 - $^{o}$F

Outside - first radiant source temperature at time I. LBD = 9.

TRSSO(I)

Program Dimension TRSSO(101)
Input Dimension DATA (LBN ≤ 201)
Input - Fixed point - F10.5 - $^{o}$F

Outside - second radiant source temperature at time I. LBD = 11.

TRSTO(I)

Program Dimension TRSTO(101)
Input Dimension DATA (LBN ≤ 201)
Input - Fixed point - F10.5 - $^{o}$F

Outside - third radiant source temperature at time I. LBD = 13.

TSUM(I)

Dimension TSUM(20)

Average DELT for orbit I.

TTEM(I)

Dimension TTEM(100)

Generated

Temperature, from previous cycle, for slice - time parameter I.

TWLI(I)

Program Dimension TWLI(101)
Input Dimension DATA (LBN ≤ 201)
Input - Fixed point - F10.5 - $^{o}$F
Output - Fixed point - F7.2 - $^{o}$F

Inside wall surface temperature at time I. LBD = 8.

TWLO(I)

Program Dimension TWLO(101)
Input Dimension DATA (LBN ≤ 201)
Input - Fixed point - F10.5 - $^{o}$F
Output - Fixed point - F7.2 - $^{o}$F

Outside wall surface temperature at time I. LBD = 7.

X(I,J)

Dimension X(102,4)

Generated

X-axis location of line J of slice I, with slices sequentially numbered from outside. Outside conditions are slice 1. First slice of first material layer is slice 2.

XD(I,J,K)

Dimension XD(5,20,5)
Output - Fixed point - F10.5 - Feet

X-axis location of line K of slice J of material layer I.

XDD12

Generated

Proportionality factor used in determining temperature at interface between material layers 1 and 2, with 1 outside.

XDD23

Generated

Proportionality factor used in determining temperature at interface between material layers 2 and 3.

XDD34

Generated

Proportionality factor used in determining temperature at interface between material layers 3 and 4.

XDD45

Proportionality factor used in determining temperature at interface between material layers 4 and 5.

XKDX(I)

Dimension XKDX(5)
Output - Fixed point - F10.5 - Feet

Offset distance for construction lines 2 and 4 for each slice of material layer I.

XWI

Generated

Constructed X-axis location of inside wall surface.

XWO

Generated

Constructed X-axis location of outside wall surface.

Y

Generated

The interpolant in the interpolation subroutine.

## SECTION 3

## ANALYSIS AND LOGIC

### THEORETICAL BACKGROUND

The general differential equation expressing the rate of change of temperature with respect to time at any point is, for unidirectional heat flow,

$$\frac{\partial t}{\partial \theta} = \frac{k}{\rho c} \frac{\partial^2 t}{\partial x^2} \tag{1}$$

where t is temperature; $\theta$, time; x, distance; k, thermal conductivity; $\rho$, density; and c, specific heat at constant pressure.

To avoid the complexity inherent in analytical solutions of this equation for many different boundary conditions, the computer program is based on the graphical method of finite differences. The solution of this problem by means of the method of finite differences is based upon work by E. Schmidt (Reference 1), which has been extended by Nessi and Nisolle (Reference 2), and reduced to practical application by Raber and Hutchinson (References 3, 4, and 5). Consider a finite section of homogeneous wall, $\Delta x$ of Figure 1, across which the temperature gradient at a particular time is given by the dashed line. At that time, the gradient at each boundary is the tangent to the dashed line at that point. Draw the tangent lines, establish a pair of construction lines, Figure 2, at distance $p = K\Delta x$ on either side of the midplane of the $\Delta x$ section, and label the intersections a, b, and c. Extend ab to intersect the right construction line at e, erect perpendicular bb', and connect a and c with a straight line which intersects the midplane of the finite area at point d.

The instantaneous rate of heat flow into the finite element from the left is

$$q = \frac{\Delta Q_\ell}{\Delta \theta} = -kA \frac{\Delta t}{\Delta x} = -kA \text{ (slope ab)} = + kA \frac{b'e}{p} \tag{2}$$

and the corresponding rate of heat flow in from the right is

$$q = \frac{\Delta Q_r}{\Delta \theta} = -kA \frac{\Delta t}{\Delta x} = + kA \text{ (slope bc)} = + kA \frac{b'c}{p} \tag{3}$$

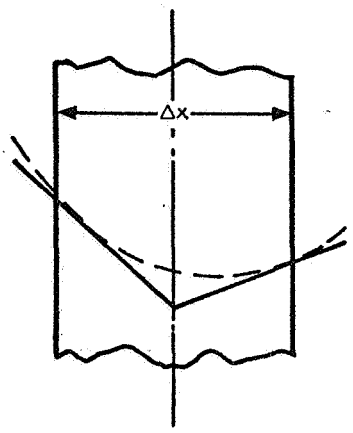



Figure 1. Finite Wall Section

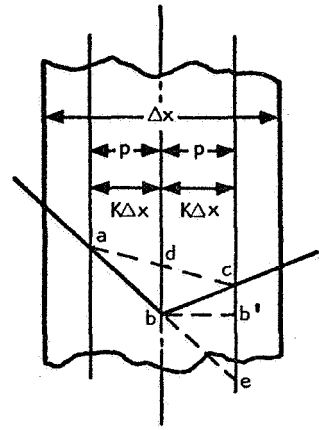



Figure 2. Temperature Gradients in Wall Section

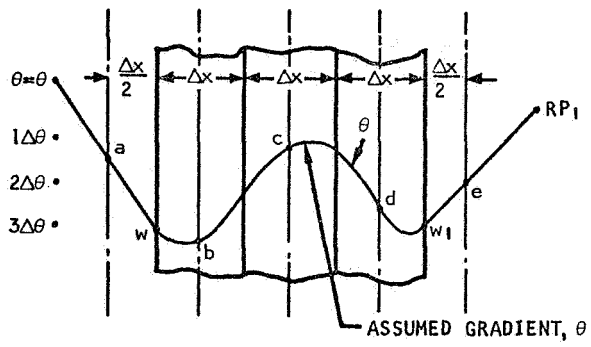



Figure 3. Original Assumed Gradient

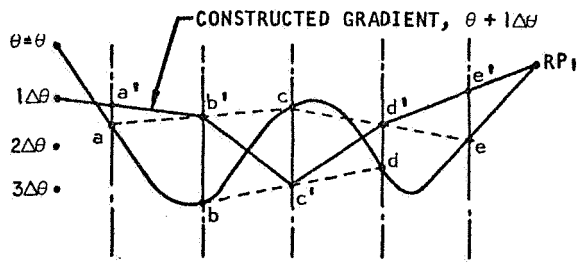



Figure 4. Gradient at End of First Time Increment

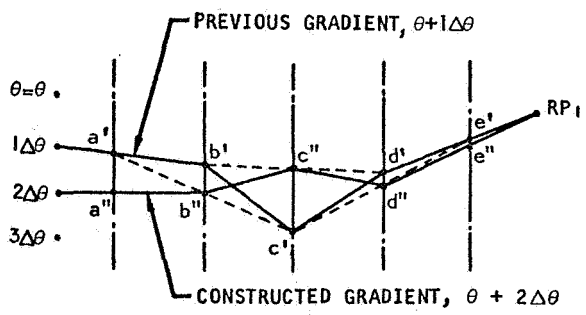



Figure 5. Gradient at End of Second Time Increment

A-3517

The net heat gain of the element during the finite time interval, $\Delta\theta$, is equal to the sum of the heat entering from left and right. It also can be expressed in terms of the change in mean temperature, $\Delta t$, which must occur during the same time interval:

$$\Delta Q_{\ell} + \Delta Q_r = kA\ (\Delta\theta) \left(\frac{b'e}{p} + \frac{b'c}{p}\right) = \rho c\ (\Delta t)(\Delta x)\ A \tag{4}$$

or

$$\frac{b'e}{p} + \frac{b'c}{p} = \frac{\rho c\ (\Delta t)(\Delta x)}{k\ (\Delta\theta)} = \frac{b'e + b'c}{p} = \frac{ce}{p} \tag{5}$$

By similar triangles, bd = 1/2 ce or ce/p = 2(bd)/p and, by definition, p = K $(\Delta x)$; thus,

$$\frac{\rho c\ (\Delta t)(\Delta x)}{k\ (\Delta\theta)} = \frac{2(bd)}{K\ (\Delta x)} \tag{6}$$

or, if $\rho c/k = a$,

$$bd = 1/2\ \frac{\rho c}{k}\ (\Delta t) \left(\frac{(\Delta x)^2}{\Delta\theta}\right) K = \Delta t\ \frac{1}{2a}\ \frac{K\ (\Delta x)^2}{(\Delta\theta)} \tag{7}$$

Now, if a relationship is established among $\Delta x$, $\Delta\theta$, and K so that

$$\frac{1}{2a} \cdot \frac{K\ (\Delta x)^2}{\Delta\theta} = 1 \tag{8}$$

then the mean temperature change of the element during the time interval, $\Delta\theta$, is represented by the distance bd. If the temperature gradient abc is known at a particular time, the temperature at the midplane of the element $\Delta\theta$ hours later is directly determined by drawing line ac and finding the intersection at point d on the midplane. Point d is the midplane temperature at the end of the $\Delta\theta$ interval.

## PRACTICAL APPLICATION TO HOMOGENEOUS WALLS

In practice, there are certain restrictions on the use of Equation (8):

1. The element of wall width, $\Delta x$, must be an aliquot of the actual wall width.

2. The time interval, $\Delta\theta$, must be an aliquot of the complete cycle time.

3. The value of K must not exceed 1, to avoid extrapolation of the temperature gradient.

To simplify the graphical work, one may set K = 1, select a value of $\Delta x$ small enough so that the second derivative of temperature across an element will not be great, and calculate the required value of $\Delta\theta$ needed to satisfy Equation (8).

Since p now is equal to $\Delta x$, construction lines are eliminated, and a solution is obtained utilizing only the finite section center lines. Thus, an original problem, Figure 3, is actually solved by use of the lines shown in Figure 4. The temperature at the midplane of a finite section, $\Delta\theta$ hours after a known temperature gradient abc (Figure 4), is determined by drawing a straight line connecting the intersections of the original temperature gradient at the midplanes of the sections to the right and left of the one for which the temperature is to be determined. Thus, temperature b becomes b' after $\Delta\theta$ hours.

By similar means, temperatures c' and d' are found. By using a fictitious location for the outside and inside temperature points, the points a' and e' are determined. The wall surface temperatures are determined from a-b and d-e, respectively. The fictitious locations of the outside temperature points are determined from the fractions $k_w/h_i$ and $k_w/h_o$, in which $k_w$ is wall conductivity and $h_o$ and $h_i$ are the outside and inside film coefficients. The fraction has the dimensions of feet and therefore represents a specific distance from the outside or inside wall surface.

Figure 5 shows the same wall as Figure 4, after another $\Delta\theta$ time interval. If the outside temperature is varying, as with a typical satellite heating or cooling problem, then the construction can be carried on for a complete orbit or cycle. This first cycle will be crude, but succeeding cycles will more closely approach the true condition so that after three or four cycles an approximation will be reached that will be acceptable for most engineering purposes.

## APPLICATION TO COMPOSITE WALLS

A more complex analysis is required for solution of periodic thermal loads in composite walls. A composite wall is defined here as one composed of up to five different materials, each with its own dimensions and physical properties. One material may be an air space or a vacuum space. Provision is made for radiant heat interchange in the air space, in the vacuum space, and to and/or from each external surface. To avoid abrupt changes in the slope of the temperature gradient at interfaces between sections of different materials, an equivalent wall is set up having uniform conductivity throughout. This requires modification of Equation (8); thus,

$$\Delta\theta = \frac{K\,(\Delta x)^2}{2a} \qquad (9)$$

The total equivalent width of each homogeneous section of the composite wall will be $k_e\, w_a/k_a$, where $k_e$ is the uniform conductivity of the fictitious wall,

$k_a$ the true conductivity of section a, which has width $w_a$. If the arbitrary term, $k_e$, is taken as unity, the equivalent total width of section a becomes $w_a/k_a$, and the equivalent width, $\Delta x'$, of the finite element $\Delta x$ of section a is

$$\Delta x' = \frac{\Delta x}{k_a} \quad \text{or} \quad \Delta x = k_a \, \Delta x' \tag{10}$$

If a and $\Delta x$ are substituted for in Equation (9),

$$\Delta\theta = \frac{K \, (k_a \, \Delta x')^2}{\dfrac{2 \, k_a}{\rho c}} = 1/2 \, \rho c \, k_a \, K \, (\Delta x')^2 \tag{11}$$

Equation (11) is the basis of the analysis of composite walls.

The graphical solutions of References 1, 2, 3, 4, and 5 were originally applicable to ordinary house construction. However, if applied to metal walls exposed to sunlight, where the wall may be hotter than the air, graphical solution becomes more difficult since the slopes of the lines are so great. The steep slopes are not a problem with a digital computer program because of its ability to handle numbers of widely varying magnitudes.

Computer Program for Composite Walls

The computer program can be logically divided into two parts. The first part, based on Equation (11), starts with the known physical characteristics of the wall, including the thickness, density, specific heat, and conductivity of each material, and (1) designs an equivalent wall of k = 1, and (2) determines appropriate values of $\Delta x$ for each material, and of $\Delta\theta$ for the wall solution.

The second part of the program utilizes the external temperature conditions applicable to each side of the wall, varied as a function of time, and the radiation, conduction, and convection (or total Q) applicable to each wall surface, together with the results of the first part of the program. Successive solutions are obtained, for each reference line at each $\theta$, with the entire orbital cycle being repeated as often as needed to secure the desired repeatability, within a specified $\Delta T$.

The flow chart for the computer program logic is shown in Figure 6, Page 4-2. The first portion of the program reads in constants and dimensions applying to the first wall to be analyzed. If one layer is a vacuum, artificial dimensions are set up for that layer. The program then solves Equation (11) for each layer in the wall. This equation, written in terms of the nomenclature used in the FORTRAN program, will be, with K = 1

```
DTHN  =  0.5*RHO*CSUBP*COND*(THCK/(12*COND))**2          (12)
```

To simplify,

let

$$PROP = 0.5*RHO*CSUBP*COND \quad (13)$$

$$DXN = ((THCK/(12.*COND))**2)/AI27 \quad (14)$$

where AI27 = the number of slices into which the wall material is to be divided for purposes of analysis. The minimum value of AI27 is the input constant, NSET, and the maximum value is 20.

The program equation then is

$$DTHN = PROP*DXN**2 \quad (15)$$

Equation (15) is applied to each of the wall materials separately, with the number of slices in each wall being separately increased until the value of DTHN for each wall is such as to keep the number of time intervals per orbit within the limits ITPMAX and ITPMIN. In some cases, the solution may ride the limit. The number of tests or time intervals per orbit, JTPR, will be the highest integer applicable to any one layer and it will be used for all layers and for the output data. This is essentially equivalent to saying that the value of K, Equation (11), will be 1 for at least one material and less than 1 for all other materials. This procedure lends validity to the original assumption of a conductivity of 1.0 in all walls.

Further correlation between walls of different materials is obtained by use of the construction line offset distance, XKDX, in accordance with the equation

$$XKDX = DTHM/(PROP*DXN)$$

where DTHM = minimum value of DTHN for any layer.

The program next goes to subroutine DATAA, which reads in all imposed thermal conditions, including air temperatures, film transfer coefficients, quantity values in Btu, absorptivities and emissivities, transmissivities and reflectivities, radiant source and sink temperature, and wall temperatures, as required. Each set of input data, with respect to each item, must represent values evenly spaced, in time, for one complete orbit or cycle, with the first point repeated as the last point. The numbers of points in the different types of data need not be the same. The program uses a Lagrangian interpolation process to translate the data from the given number of values per orbit to JTPR number of values per orbit. It also performs other operations; for example, all radiant temperatures are transformed into $10^{-8}$ times the 4th power of the absolute temperature before the values are stored in the core.

Subroutine DISTX computes all the dimensions in the x direction to correspond with the values of DXN and XKDX set up earlier for each slice of each

material. The outside surface of the first material is assigned a value of 10.0 feet, to avoid negative numbers. An example wall is shown in Figure 7, Page 4-3, which gives the original physical characteristics of each of the three materials forming the wall. Using the assumption that the conductivity of the entire wall is to be 1.0 Btu per hour per sq ft per deg F per ft, the program determines the following values for use in the theoretical wall:

STARTING NEW PROBLEM,WALL NO = 1

TESTS PER ORBIT SET= 29

| LAYER | SLICES | DXN | DX | DTHN | PROP | XKDX |
|---|---|---|---|---|---|---|
| 1 | 3 | 0.54012 | 1.62037 | 0.09977 | 0.34200 | 0.45230 |
| 2 | 2 | 1.04167 | 2.08333 | 0.08355 | 0.07700 | 1.04167 |
| 3 | 2 | 0.60000 | 1.20000 | 0.08775 | 0.24375 | 0.57128 |

For the given orbit period of 2.4 hours, the program divides the first material layer into 3 slices and the second and third layers into 2 slices each. Since the smallest time interval computed, DTHN, is that corresponding to layer 2, for which it is 0.08355 hours, there will be 2.4/0.08355 or 29 time intervals per orbit. All input data will be interpolated to 29 time intervals and the output will show 29 intervals per orbit. The actual distances set up by the program will be:

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| LAYER | 1 | SLICE NUMBER | 1 | | | | | | | | |
| OUTSIDE = | 10.00000 | LEFT CONST = | 9.81776 | MIDPOINT = | 10.27006 | RIGHT CONST = | 10.72236 | INSIDE = | 10.54012 | | |
| LAYER | 1 | SLICE NUMBER | 2 | | | | | | | | |
| OUTSIDE = | 10.54012 | LEFT CONST = | 10.35788 | MIDPOINT = | 10.81018 | RIGHT CONST = | 11.26249 | INSIDE = | 11.08025 | | |
| LAYER | 1 | SLICE NUMBER | 3 | | | | | | | | |
| OUTSIDE = | 11.08025 | LEFT CONST = | 10.89800 | MIDPOINT = | 11.35031 | RIGHT CONST = | 11.80261 | INSIDE = | 11.62037 | | |
| LAYER | 2 | SLICE NUMBER | 1 | | | | | | | | |
| OUTSIDE = | 11.62037 | LEFT CONST = | 11.09954 | MIDPOINT = | 12.14120 | RIGHT CONST = | 13.18287 | INSIDE = | 12.66204 | | |
| LAYER | 2 | SLICE NUMBER | 2 | | | | | | | | |
| OUTSIDE = | 12.66204 | LEFT CONST = | 12.14120 | MIDPOINT = | 13.18287 | RIGHT CONST = | 14.22453 | INSIDE = | 13.70370 | | |
| LAYER | 3 | SLICE NUMBER | 1 | | | | | | | | |
| OUTSIDE = | 13.70370 | LEFT CONST = | 13.43242 | MIDPOINT = | 14.00370 | RIGHT CONST = | 14.57499 | INSIDE = | 14.30370 | | |
| LAYER | 3 | SLICE NUMBER | 2 | | | | | | | | |
| OUTSIDE = | 14.30370 | LEFT CONST = | 14.03242 | MIDPOINT = | 14.60370 | RIGHT CONST = | 15.17499 | INSIDE = | 14.90370 | | |

All of these lines, and their program identifications, are shown in Figure 8, Page 4-4. This figure also shows an Outside Source line, X(1,3), one foot from the outside surface, and an Inside Source line, X(9,3), located one foot from the inside surface. Since the assumption of unity for the conductivity is applied beyond the wall as well as within the wall, the use of these "source" lines allows the temperature scale, shown as the Y dimension in Figure 8, to be used also as a Btu scale. Thus all inputs, whether in the form of an air temperature and film coefficient, a wall surface temperature,

a gross Btu input, or a radiant heat input, are first converted by the program to equivalent Btu acting at the respective "source" line. They are then added, algebraically, and the resulting departure from the wall surface temperature acts, for the purposes of computation, exactly as a source at numerically the same temperature.

This is more clearly shown in Figure 9, Page 4-5, where various types of loads and the mathematical procedure used in their computation are shown on the two sides of the wall. At the extreme left of this figure is shown a scale of Radiant Source or Sink Temperature, $^{0}$F which indicates the relative effect of source and sink and wall temperature for radiative interchange, assuming an absorptivity and an emissivity of 1.

Figure 9 also shows the complete geometric construction for three steps of an example problem. The computer equations produce the same results as the graphical procedure. The assumed original distribution of temperature is that of line 1, running from an outside source temperature of 250$^{0}$F to an inside source temperature of 50$^{0}$F (an exaggerated situation has been used to keep the lines separated). After the passage of a time interval DTHN, it is assumed that the new source temperatures will be 300$^{0}$F and 30$^{0}$F, respectively. By use of the construction lines 4 and these new source temperatures, a new temperature distribution line 2 is obtained. Note that the construction lines connect intersections of the previous temperature distribution line with the pairs of verticals X(n,2) and X(n,4). The intersections of the construction lines with the respective verticals X(n,3) determine the inflection points of the new-temperature distribution line. The process is repeated, using source temperatures of 350$^{0}$F and 10$^{0}$F, together with construction lines 5 to determine the temperature distribution line 3 after a second DTHN time interval. Note that it is sometimes necessary to extrapolate certain segments of lines 1 and 2 to obtain correct starting points for the construction lines 4 and 5.

The procedure described in the previous paragraph is repeated until all time intervals for the first orbit have been computed. At the same time, a matrix of answers, consisting of up to 10 time intervals and up to 10 slices, is stored in the core for comparison on the next orbit. The program then computes all the temperatures for a second, repeat, orbit. For each temperature which was stored on the previous orbit, comparison is made and the difference is added to a "sum of the differences." The stored temperature is replaced by the new temperature and the computation proceeds. At the end of the orbit or cycle the average absolute difference is determined from the sum of the differences and compared with the input value DELT. If the average is greater than DELT, another cycle and another comparison are made. If the average is less than or equal to DELT, the program goes through one more cycle, without comparison, and prints out the answers for each time period and for all surfaces and interfaces. This portion of the program also contains a check for diverging answers. If the "average" defined above, increases more than NSETS times, a "failure to converge" message will be printed, together with pertinent results. Also if the average does not become less than or equal to DELT in NSETR cycles, a similar procedure is followed.

VACUUM LAYER

If one layer of material is a vacuum, the program makes allowance for this by subroutine DISVAC, which computes DXN, the theoretical thickness of the vacuum slice, for each time period in each orbit. The value of DXN is the thickness of a wall of unit conductivity which passes the number of Btu per sq ft which flows across the vacuum layer under the influence of the existing surface temperatures facing that layer. Due allowance is made for the absorptivity and emissivity of each of the boundary surfaces.

TRANSPARENT LAYERS

The computation of transparent layers is carried on in subroutine TEMTRN as follows:

Total radiant input from outside.
CUE(3)

Total infrared heat input.
QR = CUE(3)*ERI2(M)

Infrared reflected at first surface of first layer. Subtracted from total.
QR*ARI2(M)

Infrared absorbed at first surface of first layer. Subtracted from total. This was computed as part of load CUE(9) in subroutine TEMPER.
QR*ARSO(M)/.173

Net infrared entering first transparent layer.
QR*FRI
where FRI = 1.-ARI2(M)-ARSO(M)/.173

Infrared absorbed within the first layer. Proportion added to the input temperature to the first slice of the first layer.
QR*(FRI-FRI2)
where FRI2 = $(FRI*FR2)^{0.5}$
CUE(9) = CUE(9)+QR*(FRI-FRI2)

Infrared absorbed within the first layer. Proportion added to the centerline temperature of the last slice of the first layer.

CRI2 = QR*(FRI2-FR2)
TM(LWI2,3) = TM(LWI2,3)+.5(DXN(1)+DXN(2))*CRI2

Net infrared energy leaving first layer.

QRT = QR*FR2

By definition of FR2

At this point there are four possibilities, only one of which will apply to a single case:

1. If the wall consists of only one transparent layer, then the infrared energy leaving that layer (wall) will be
   QRT = QR*FR2

2. If the second layer is transparent to infrared then the infrared energy entering the second layer will be reduced by reflection at the interface between layers 1 and 2.
   QR*FR21
   where FR21 = FR2*(1.-AR23(M))

3. If the <u>second</u> layer is a vacuum, the infrared energy entering the <u>third</u> layer will be
   QR*FR2*AVACI

4. If the second layer is opaque to infrared, the centerline temperature of the first slice of the second layer is adjusted to account for absorption of this energy
   TM(LWI2+1,3) = TM(LWI2+1,3)+QR*FR2

Infrared absorbed within the second layer. Proportion added to the centerline temperature of the first slice of the second layer. Proportion added to the centerline temperature of the last slice of the second layer.

Calculations analogous to those for the first layer. If second layer is a vacuum, these are applied to the third layer.

Net infrared leaving second layer (or third layer)

QRT = QR*FR3*FR2

By definition of FR3 and FR2

If the next layer is opaque to infrared, the centerline temperature of the first slice of that layer is adjusted to account for absorption of this energy as before.

Total solar (visible) energy input

QS = CUE(3)*(1.-ERI2(M))

Solar (visible) reflected at first surface of first layer. Subtracted from total.

QS*ASI2(M)

Solar (visible) absorbed at first surface of first layer. Subtracted from total. This was computed as part of load CUE(8) in subroutine TEMPER

QS*ARSSO(M)/.173

Net solar (visible) entering first transparent layer.

QS*FS1

where FS1 = 1.-AS12(M)-ARSSO(M)/.173

Solar (visible) absorbed within the first layer. Proportion added to the input temperature to the first slice of the first layer.

QS*(FS1-FS12)

where FS12 = $(FS1*FS2)^{0.5}$

CUE(8) = CUE(8)+QS*(FS1-FS12)

Solar (visible) absorbed within the first layer. Proportion added to the centerline temperature of the last slice of the first layer.

CS12 = QS*(FS12-FS2)

TM(LW12,3) = TM(LW12,3)+.5*(DXN(1)+DXN(2))*CS12

Net solar (visible) energy leaving first layer.

QST = QS*FS2

By definition of FS2

At this point there are four possibilities, only one of which will apply to a single case.

1. If the wall consists of only one transparent layer, then the solar (visible) energy leaving that layer (wall) will be

   QST = QS*FS2

2. If the second layer is transparent to solar (visible) then the solar (visible) energy entering the second layer will be reduced by reflection at the interface between layers 1 and 2.

   QS*FS21

   where FS21 = FS2*(.1-AS23(M))

3. If the <u>second</u> layer is a vacuum, the solar (visible) energy entering the <u>third</u> layer will be

   QS*FS21

4. If the second layer is opaque to solar (visible), the centerline temperature of the first slice of the second layer is adjusted to account for absorption of this energy.

   TM(LW12+1,3) = TM(LW12+1,3)+QS*FS2

Solar (visible) absorbed within the second layer. Proportions added to the centerline temperature of the first slice of the second layer. Proportion added to the centerline temperature of the last slice of the second layer.

Calculations analogous to those for the first layer. If second layer is a vacuum, these are applied to the third layer.

Net solar (visible) leaving second layer (or third layer).

QST = QS*FS3*FS2

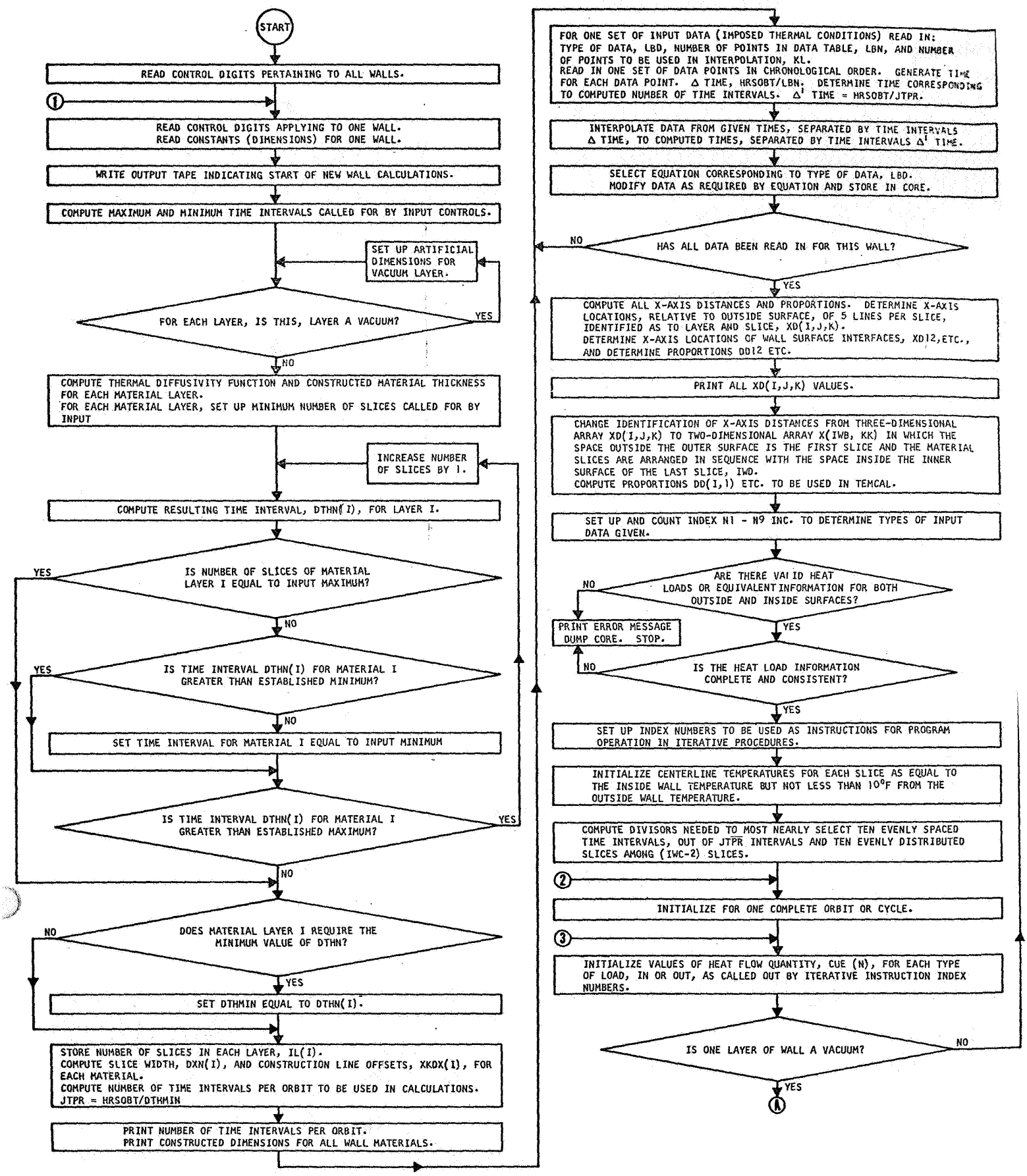
By definition of FS3 and FS2

If the next layer is opaque to solar (visible) the centerline temperature of the first slice of that layer is adjusted to account for absorption of this energy as before.

# SECTION 4

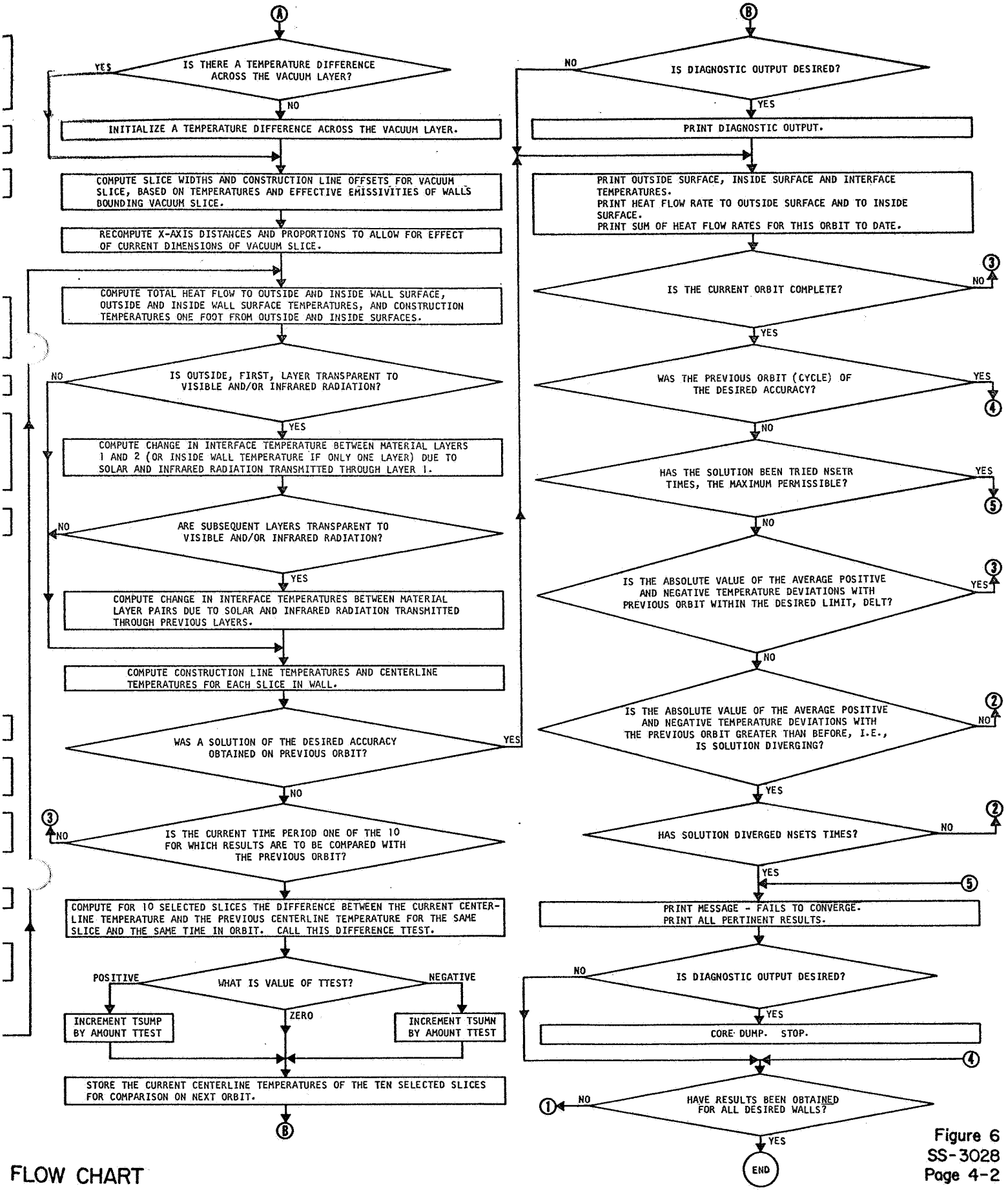
## FLOW DIAGRAMS AND GEOMETRIC-THERMODYNAMIC CORRELATIONS


| | Page |
|---|---|
| Flow Chart | 4-2 |
| Given Wall Dimensions | 4-3 |
| Computed Wall Dimensions and Dimensions Used in Sample Problem | 4-4 |
| Graphical Presentation of Analysis Procedure Used for Solid Opaque Walls with Corrective and/or Radiative Thermal Walls | 4-5 |




PROGRAM FL

GARRETT AIRESEARCH MANUFACTURING DIVISION
Los Angeles, California




FLOW CHART

Figure 6
SS-3028
Page 4-2

C-66

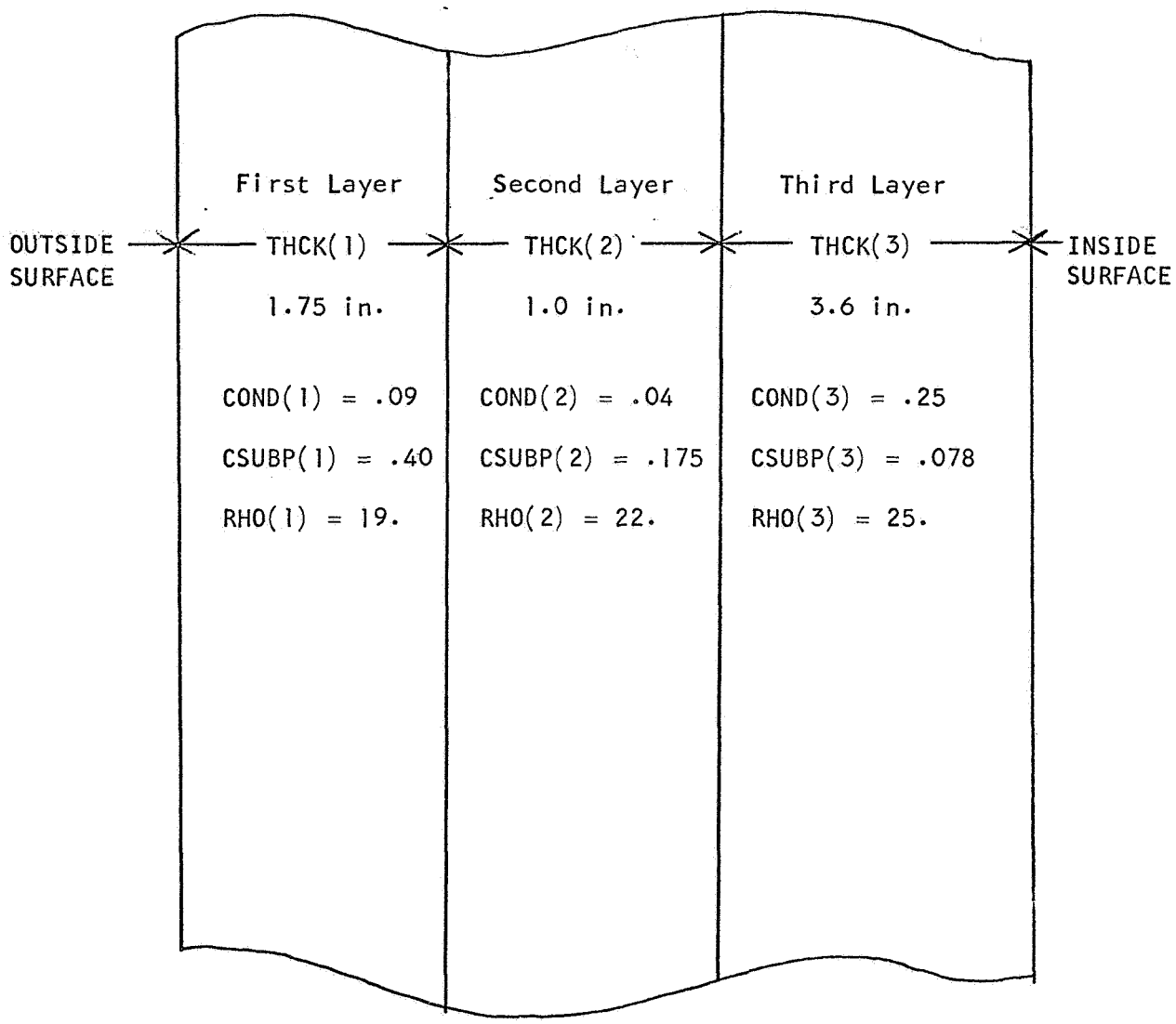
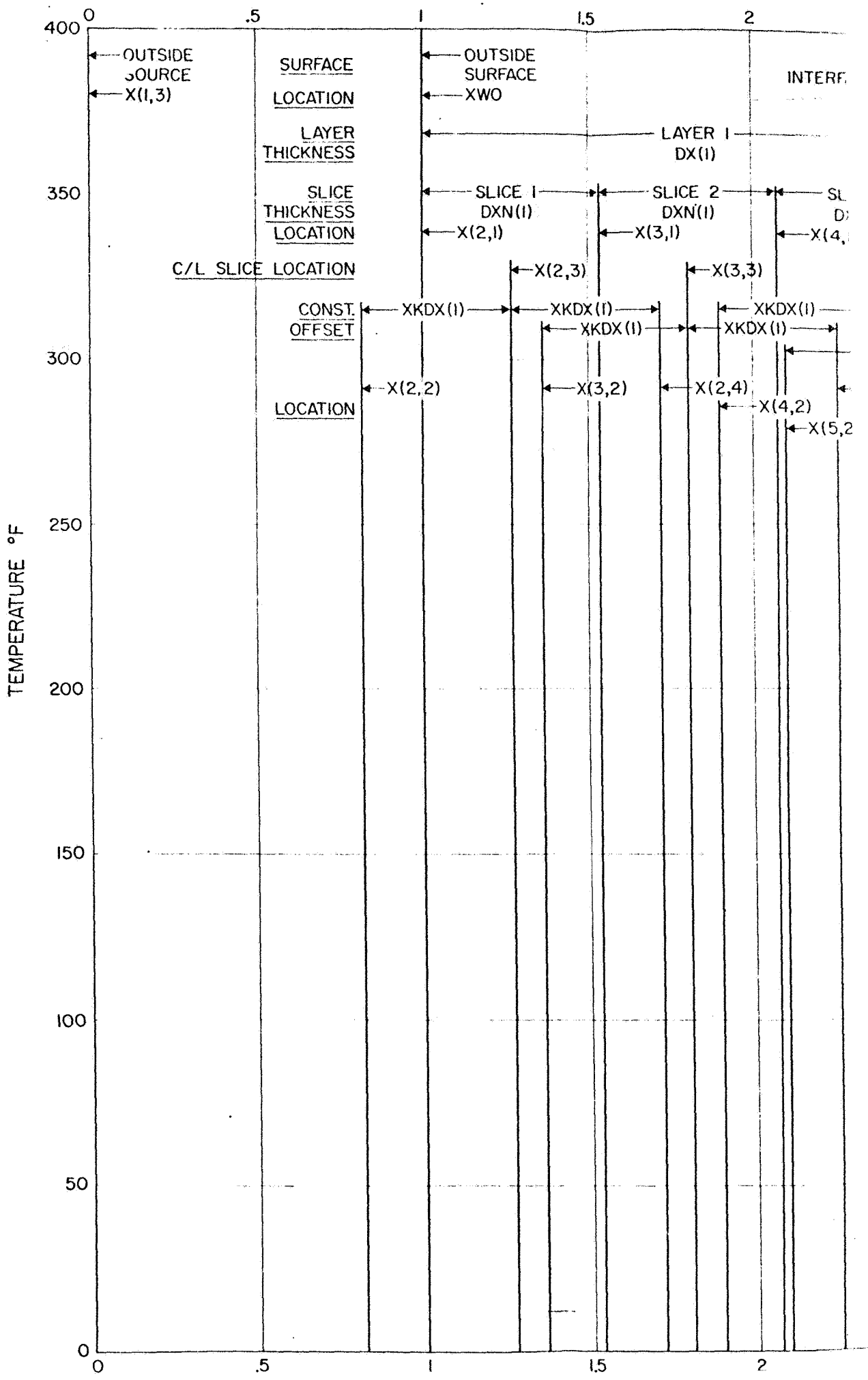
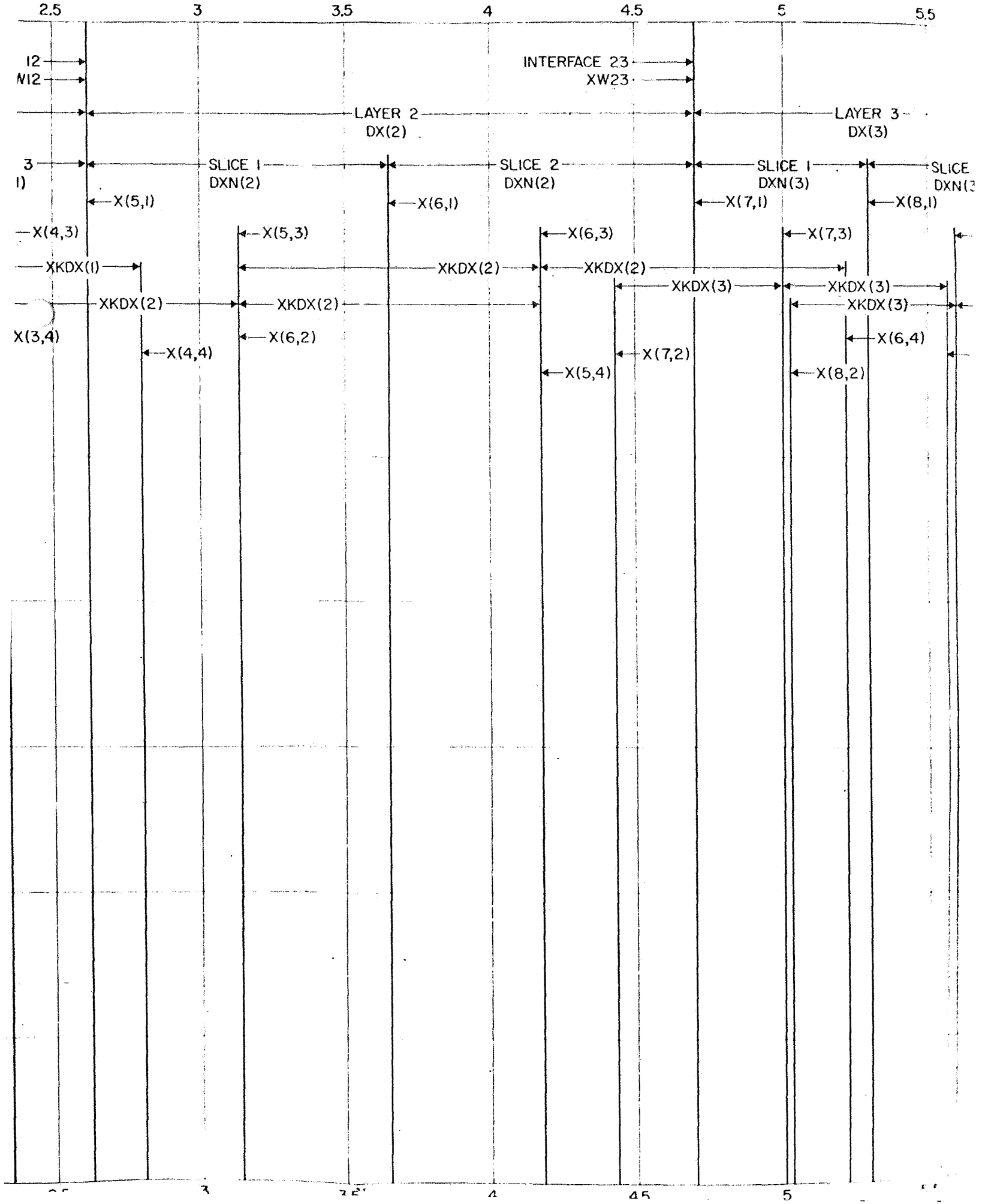



Figure 7. Given Wall Dimensions and Thermal Characteristics Used in Sample Problem




UFACTURING DIVISION
Los Angeles, California


2.5
3
3.5
4
4.5
5
5.5
12
M12
INTERFACE 23
XW23
LAYER 2
DX(2)
LAYER 3
DX(3)
3
1)
SLICE 1
DXN(2)
SLICE 2
DXN(2)
SLICE 1
DXN(3)
SLICE
DXN(3
X(5,1)
X(6,1)
X(7,1)
X(8,1)
X(4,3)
X(5,3)
X(6,3)
X(7,3)
XKDX(1)
XKDX(2)
XKDX(2)
XKDX(3)
XKDX(3)
XKDX(2)
XKDX(2)
XKDX(3)
X(3,4)
X(6,2)
X(6,4)
X(4,4)
X(7,2)
X(5,4)
X(8,2)

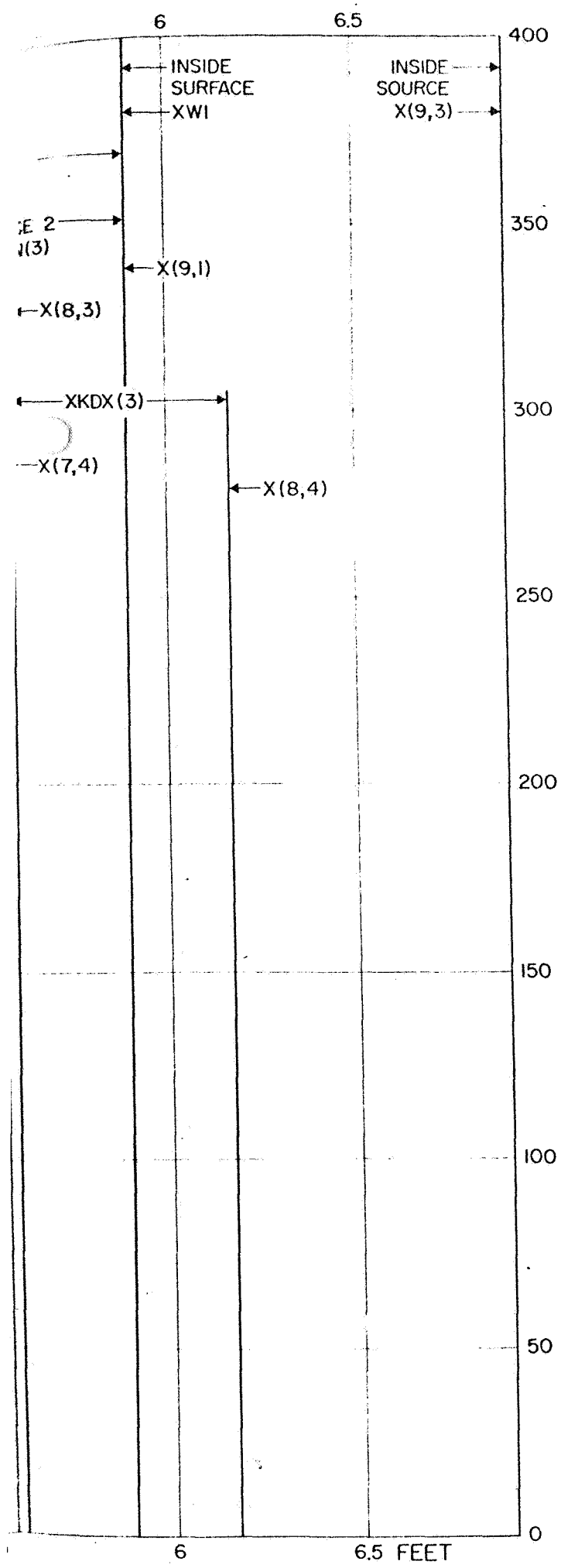
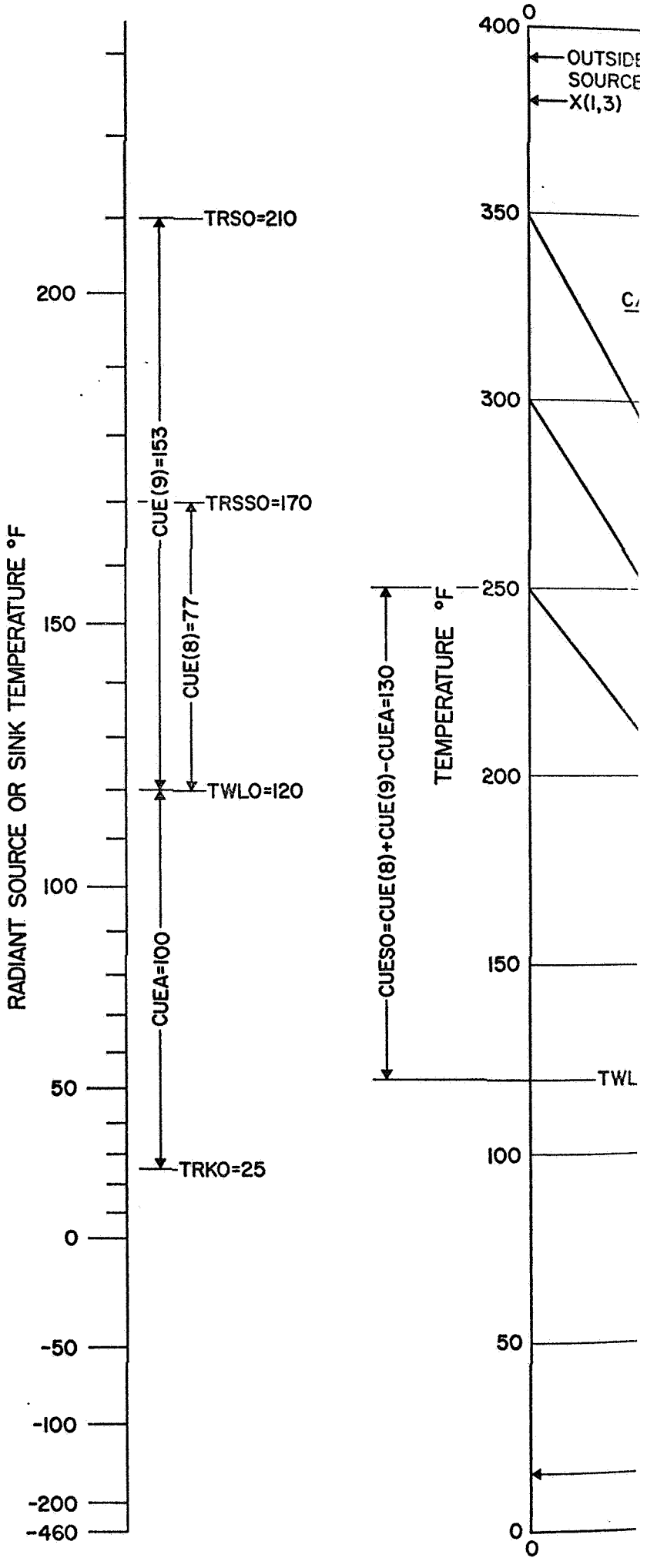
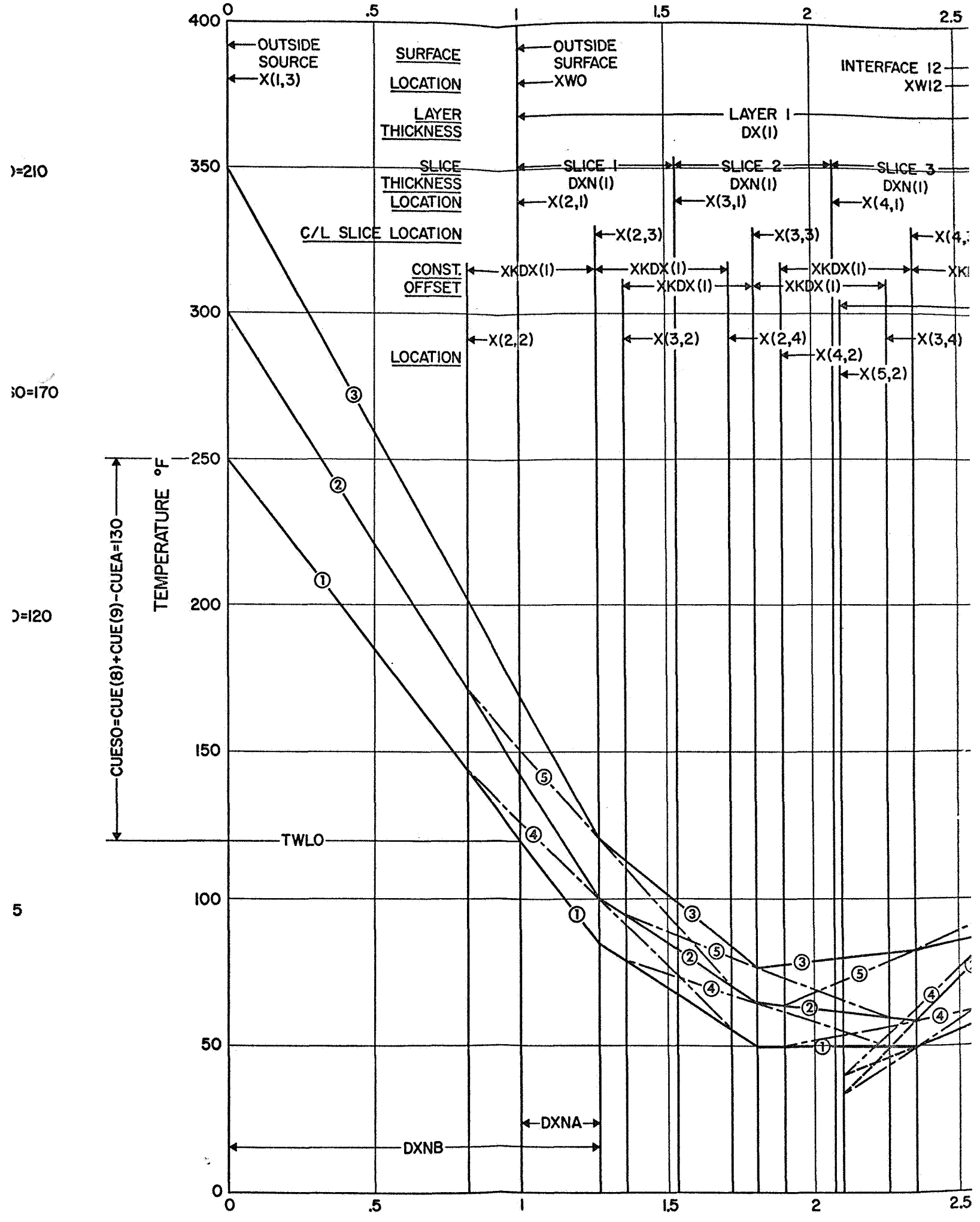
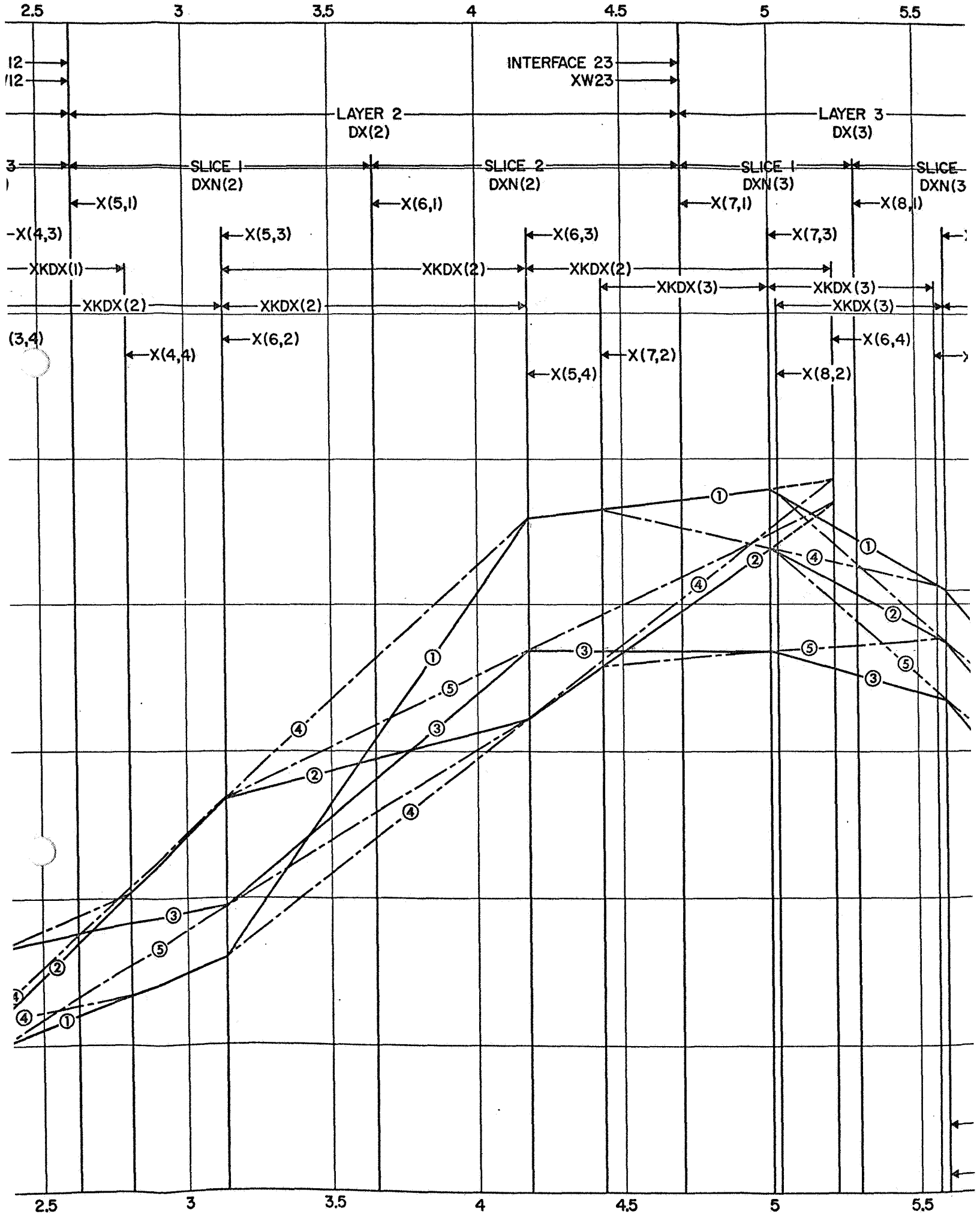



Figure 8 COMPUTED WALL DIVISIONS AND DIMENSIONS USED IN SAMPLE PROBLEM


RADIANT SOURCE OR SINK TEMPERATURE °F
200
150
100
50
0
-50
-100
-200
-460
TRSO=210
TRSSO=170
TWLO=120
TRKO=25
CUE(9)=153
CUE(8)=77
CUEA=100
CUESO=CUE(8)+CUE(9)-CUEA=130
TEMPERATURE °F
400
350
300
250
200
150
100
50
0
0
0
OUTSIDE
SOURCE
X(1,3)
TWL


OUTSIDE SOURCE
X(1,3)
SURFACE LOCATION
LAYER THICKNESS
SLICE THICKNESS LOCATION
C/L SLICE LOCATION
CONST. OFFSET
LOCATION
OUTSIDE SURFACE
XWO
INTERFACE 12
XW12
LAYER 1
DX(1)
SLICE 1
DXN(1)
SLICE 2
DXN(1)
SLICE 3
DXN(1)
X(2,1)
X(3,1)
X(4,1)
X(2,3)
X(3,3)
XKDX(1)
X(2,2)
X(3,2)
X(2,4)
X(4,2)
X(5,2)
X(3,4)
TEMPERATURE °F
CUESO=CUE(8)+CUE(9)-CUEA=130
TWLO
DXNA
DXNB
400
350
300
250
200
150
100
50
0
.5
1
1.5
2
2.5


2.5
3
3.5
4
4.5
5
5.5
INTERFACE 23
XW23
LAYER 2
DX(2)
LAYER 3
DX(3)
SLICE 1
DXN(2)
SLICE 2
DXN(2)
SLICE 1
DXN(3)
X(5,1)
X(6,1)
X(7,1)
X(8,1)
X(4,3)
X(5,3)
X(6,3)
X(7,3)
XKDX(1)
XKDX(2)
XKDX(2)
XKDX(3)
XKDX(3)
XKDX(2)
XKDX(2)
XKDX(3)
X(6,2)
X(6,4)
X(4,4)
X(7,2)
X(5,4)
X(8,2)

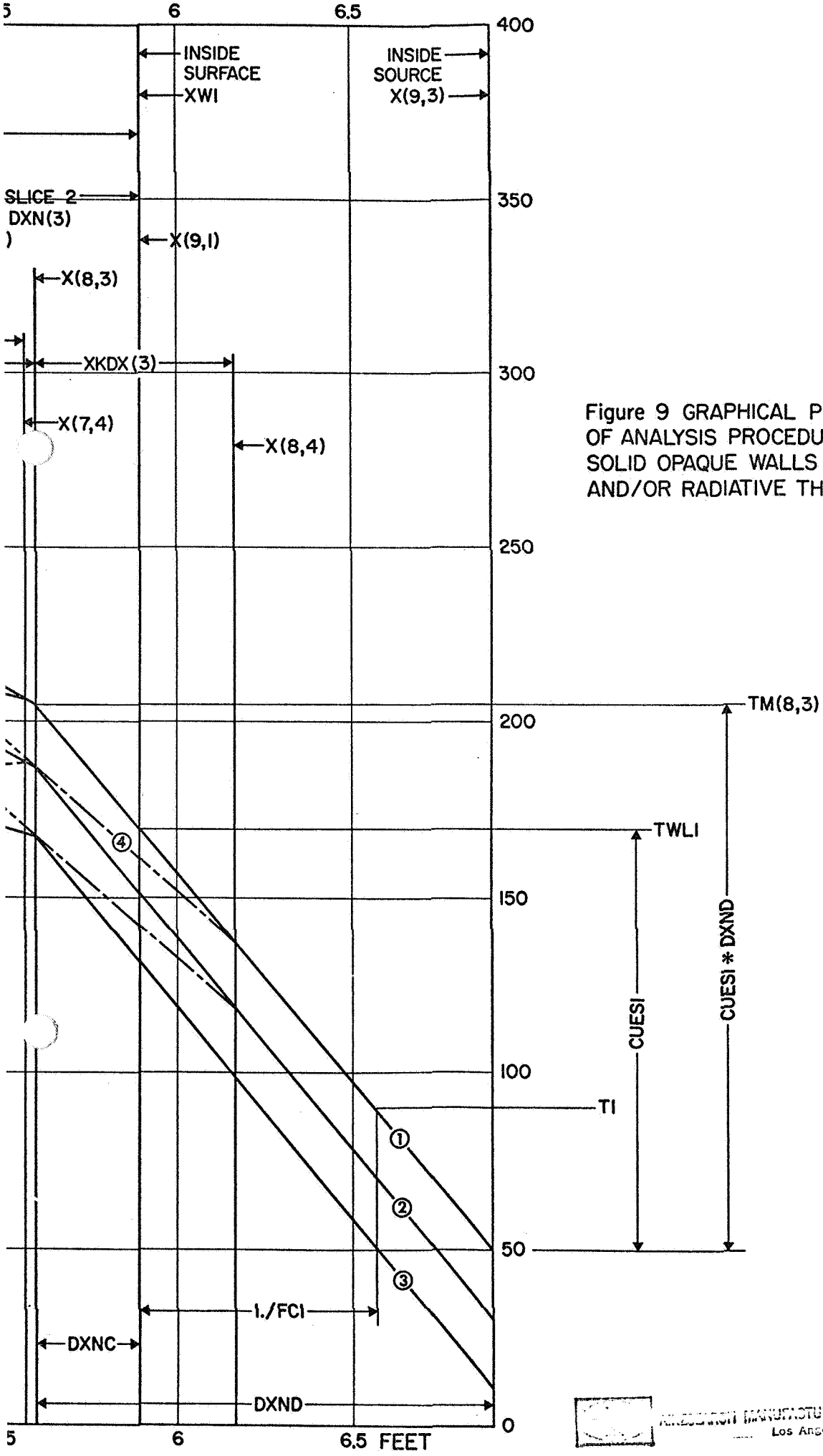



Figure 9 GRAPHICAL PRESENTATION OF ANALYSIS PROCEDURE USED FOR SOLID OPAQUE WALLS WITH CONVECTIVE AND/OR RADIATIVE THERMAL LOADS

# SECTION 5

## FORMATS FOR INPUT AND OUTPUT

### INPUT DATA

CARD NO. 1 FORMAT 2I5

NWALL, JDI

NWALL

Number of walls, maximum 20.

JDI

0 = No diagnostic output
1 = Diagnostic output

CARD NO. 2 FORMAT 14I5

IWALL, IDATA, IW, ITPMAX, ITPMIN, NSET, NSETR, NSETS, ITRN, IVAC

IWALL

Identifying number for each wall. Must start with 1 and go in sequence to NWALL.

IDATA

Input - Integer constant

Number of time-dependent input variables for which data sets are provided. See also DATA(I).

IW

Input - Integer constant

Number of material layers in wall. Maximum 5.

ITPMAX

Input - Integer constant

Maximum number of time intervals per orbit to be used in solution. Maximum is 100.

ITPMIN

Input - Integer constant

Minimum number of time intervals per orbit to be used in solution.

NSET

Input - Integer constant

Minimum number of slices per material layer to be used in calculations.

NSETR

Input - Integer constant

Maximum number of orbits or cycles used in program to check convergence.

NSETS

Input - Integer constant

Integer identifying wall for which solution is desired.

ITRN

Input - Integer constant

Constant indicating whether material layers are transparent to incoming radiation, either infrared or visible or both.

ITRN = 0 No layer transparent
ITRN = 1 First, outside, layer transparent
ITRN = 2 First and second layers transparent
ITRN = 3 First and third layers transparent; second layer vacuum.

IVAC

Input - Integer constant

Constant indicating that one material layer of wall is a vacuum space.

IVAC = 1 No vacuum space
IVAC = 2 Second layer is vacuum
IVAC = 3 Third layer is vacuum
IVAC = 4 Fourth layer is vacuum

There will be NWALL No. 2 cards, each placed at the head of the set of data for its wall.

CARD NO. 3 FORMAT 7F10.5

HRSOBT, DELT, AVACI, AVACO

HRSOBT

Input - Fixed point - F10.5 - Hours

Time required for one orbit or cycle.

DELT

Input - Fixed point - F10.5 - $^{0}F$

Temperature difference used in test for convergence.

AVACI

Input - Fixed point - F10.5 - Decimal percent

Absorptivity of insideward wall surface facing vacuum layer.

AVACO

Input - Fixed point - F10.5 - Decimal percent

Absorptivity of outsideward wall surface facing vacuum layer.

There will be one card No. 3 for each wall, following the card No. 2 for that wall.

CARD NO. 4 FORMAT 10X, 4F10.5

COND(I), CSUBP(I), RHO(I), THCK(I)

COND(I)

Dimension COND(5)
Input - Fixed point - F10.5 - Btu/hr/sq ft per $^{o}$F/ft

Conductivity of material in layer I.

CSUBP(I)

Dimension CSUBP(5)
Input - Fixed point - F10.5 - Btu/lb/$^{o}$F

Specific heat of material in layer I.

RHO(I)

Dimension RHO(5)
Input - Fixed point - F10.5 - lb/cu ft.

Density of material in layer I.

THCK(I)

Dimension THCK(5)
Input - Fixed point - F10.5 - inches

Thickness of material in layer I.

There will be one card No. 4 for each layer I of each wall. The cards must be in the same order as the layers, with the card for the "outside" layer first. If one layer is a vacuum, a blank card must be included at the proper location.

CARD NO. 5 FORMAT 3I5

LBD, LBN, KL

LBD

Input - Integer constant

Identity number of a set of data. Values of this constant and corresponding data symbols are:

| LBD | DATA | LBD | DATA | LBD | DATA | LBD | DATA |
|---|---|---|---|---|---|---|---|
| 1 | TO(I) | 9 | TRSO(I) | 17 | TRSI(I) | 25 | AS12(I) |
| 2 | FCO(I) | 10 | ARSO(I) | 18 | ARSI(I) | 26 | ANRP(I) |
| 3 | TI(I) | 11 | TRSSO(I) | 19 | TRKI(I) | 27 | AR23(I) |
| 4 | FCI(I) | 12 | ARSSO(I) | 20 | ERKI(I) | 28 | ER23(I) |
| 5 | CUEO(I) | 13 | TRSTO(I) | 21 | ANRO(I) | 29 | ANSP(I) |
| 6 | CUEI(I) | 14 | ARSTO(I) | 22 | AR12(I) | 30 | AS23(I) |
| 7 | TWLO(I) | 15 | TRKO(I) | 23 | ER12(I) | | |
| 8 | TWLI(I) | 16 | ERKO(I) | 24 | ANSO(I) | | |

LBN

Input - Integer constant

Number of points in the immediately following set of data. Numerically LBN is one more than the number of time period subdivisions for one orbit of input data since the last point must be a repeat of the first point.

KL

Input - Integer constant

Integer determining the number of points used in the interpolation. Recommended value, 3.

Card No. 5 defines the next succeeding set of thermodynamic data. There will be IDATA No. 5 cards, each placed at the head of a set of thermodynamic data.

| CARD NO. 6 | FORMAT 7F10.5 |
|---|---|

DATA(I), I = 1, LBN

DATA(I) is the input thermodynamic data for one cycle, at each time interval I. The type of data is defined by the No. 5 card preceding a set of one or more No. 6 cards. Up to 201 data points may be used, seven to each card.

INPUT DATA LISTING

A typical input data listing for four different cases, with inserted notes, is as follows.

```
*      DATA
     4     1
     1     6     3    90    20     2    20     3     0     1 CCase 1
2.4         1.0        0.         0.
     1      .09        .40        19.        1.75
     2      .04        .175       22.        1.        Wall
     3      .25        .078       25.        3.6       Properties
     1     7     3     Outside Air Temperature
150.        200.       250.       300.       250.       200.       150.
     2     7     3     Outside Air Film Coefficient
1.          1.         1.         1.         1.         1.         1.
     3     7     3     Inside Air Temperature
70.         50.        30.        10.        30.        50.        70.
     4     7     3     Inside Air Film Coefficient
1.          1.         1.         1.         1.         1.         1.
    15     7     3     Outside Radiant Sink Temperature
-50.        -40.       -30.       -20.       -30.       -40.       -50.
    16     7     3     Outside Wall Emissivity Times Shape Factor of Sink
.6          .7         .8         .9         .8         .7         .6
     2     4     3    50    20     2    10     3     0     1  Case 2
2.4         1.0        0.         0.
     1      .09        .40        19.        1.75
     2      .04        .175       22.        1.        Wall
     3      .25        .078       25.        3.6       Properties
     1    49     3     Outside Air Temperature
170.0       169.8      169.3      168.5      167.3      165.9      164.1
162.2       160.0      157.7      155.2      152.6      150.0      147.4
144.8       142.4      140.0      137.8      135.9      134.1      132.7
131.5       130.7      130.2      130.0      130.2      130.7      131.5
132.7       134.1      135.9      137.8      140.0      142.4      144.8
147.4       150.0      152.6      155.2      157.7      160.0      162.2
164.1       165.9      167.3      168.5      169.3      169.8      170.0
     2     7     3     Outside Air Film Coefficient
1.          1.         1.         1.         1.         1.         1.
     3     7     3     Inside Air Temperature
70.         50.        30.        10.        30.        50.        70.
     4     7     3     Inside Air Film Coefficient
1.          1.         1.         1.         1.         1.         1.
```

```
    3     3     3    90    20     2    20     3     0     1  Case 3
2.4        1.0        0.         0.
    1     .09        .40        19.        1.75
    2     .04        .175       22.        1.        Wall
    3     .25        .078       25.        3.6       Properties
    3     7     3     Inside Air Temperature
70.        50.        30.        10.        30.        50.        70.
    4     7     3     Inside Air Film Coefficient
1.         1.         1.         1.         1.         1.         1.
    5    49     3     Rate of Heat Flow to Outside Surface
170.0      169.8      169.3      168.5      167.3      165.9      164.1
162.2      160.0      157.7      155.2      152.6      150.0      147.4
144.8      142.4      140.0      137.8      135.9      134.1      132.7
131.5      130.7      130.2      130.0      130.2      130.7      131.5
132.7      134.1      135.9      137.8      140.0      142.4      144.8
147.4      150.0      152.6      155.2      157.7      160.0      162.2
164.1      165.9      167.3      168.5      169.3      169.8      170.0
    4     3     3    90    20     2    20     3     0     1  Case 4
2.4        1.0        0.         0.


    1     .09        .40        19.        1.75
    2     .04        .175       22.        1.        Wall
    3     .25        .078       25.        3.6       Properties
    3     7     3     Inside Air Temperature
70.        50.        30.        10.        30.        50.        70.
    4     7     3     Inside Air Film Coefficient
1.         1.         1.         1.         1.         1.         1.
    7    49     3     Outside Wall Surface Temperature
170.0      169.8      169.3      168.5      167.3      165.9      164.1
162.2      160.0      157.7      155.2      152.6      150.0      147.4
144.8      142.4      140.0      137.8      135.9      134.1      132.7
131.5      130.7      130.2      130.0      130.2      130.7      131.5
132.7      134.1      135.9      137.8      140.0      142.4      144.8
147.4      150.0      152.6      155.2      157.7      160.0      162.2
164.1      165.9      167.3      168.5      169.3      169.8      170.0
```

## OUTPUT AND SAMPLE PROBLEMS

The output form can be most easily shown by presenting solutions to two sample problems.

For the first problem, the second layer of a three-layer wall is a vacuum. The input data must include values for the absorptivities of the surfaces facing the vacuum layer; in this sample, a value of 0.474 is used for each surface. Physical properties of the second layer may be omitted. The pertinent input data will be:

```
*      DATA
    2     0
    1     4     3    90    20     2    20     3     0     2
2.4         2.0        0.474      0.474   Problem I - Second Layer Vacuum
    1      .09         .40        19.        1.75
    2                                                Wall
    3      .25         .078       25.        3.6     Properties
    1    49     3      Outside Air Temperature
170.0      169.8      169.3      168.5      167.3      165.9      164.1
162.2      160.0      157.7      155.2      152.6      150.0      147.4
144.8      142.4      140.0      137.8      135.9      134.1      132.7
131.5      130.7      130.2      130.0      130.2      130.7      131.5
132.7      134.1      135.9      137.8      140.0      142.4      144.8
147.4      150.0      152.6      155.2      157.7      160.0      162.2
164.1      165.9      167.3      168.5      169.3      169.8      170.0
    2     7     3      Outside Air Film Coefficient
1.          1.         1.         1.         1.         1.         1.
    3     7     3      Inside Air Temperature
70.        50.        30.        10.        30.        50.        70.
    4     7     3      Inside Air Film Coefficient
1.          1.         1.         1.         1.         1.         1.
```

The output listing will show wall number and tests per orbit. This will be followed by a list of the layers, number of slices per layer and pertinent properties of each layer. In this example, the second layer is a vacuum so it is shown as having only one slice, with an initial thickness of 10.0 feet.

```
STARTING NEW PROBLEM,WALL NO =     1

TESTS PER ORBIT SET=    27
```

| LAYER | SLICES | DXN | DX | DTHN | PROP | XKDX |
|---|---|---|---|---|---|---|
| 1 | 3 | 0.54012 | 1.62037 | 0.09977 | 0.34200 | 0.47504 |
| 2 | 1 | 10.00000 | 0.00000 | 0.00000 | 0.00000 | 5.00000 |
| 3 | 2 | 0.60000 | 1.20000 | 0.08775 | 0.24375 | 0.60000 |

The listing next gives the detail dimensions for each slice, using 10.0 feet for layer 2, slice 1 on the first trial and then correcting this thickness to 16.70949-11.62037 = 5.08912 before performing the first calculation. The results of the first calculation then follow with the identification of Wall No. 1, Orbit No. 0, Time Period No. 1.

```
LAYER    1     SLICE NUMBER    1
OUTSIDE =  10.00000   LEFT CONST =   9.79502   MIDPOINT =  10.27006   RIGHT CONST =  10.74510   INSIDE =  10.54012

LAYER    1     SLICE NUMBER    2
OUTSIDE =  10.54012   LEFT CONST =  10.33515   MIDPOINT =  10.81018   RIGHT CONST =  11.28522   INSIDE =  11.08025

LAYER    1     SLICE NUMBER    3
OUTSIDE =  11.08025   LEFT CONST =  10.87527   MIDPOINT =  11.35031   RIGHT CONST =  11.82534   INSIDE =  11.62037

LAYER    2     SLICE NUMBER    1
OUTSIDE =  11.62037   LEFT CONST =  11.62037   MIDPOINT =  16.62037   RIGHT CONST =  21.62037   INSIDE =  21.62037

LAYER    3     SLICE NUMBER    1
OUTSIDE =  21.62037   LEFT CONST =  21.32037   MIDPOINT =  21.92037   RIGHT CONST =  22.52037   INSIDE =  22.22037

LAYER    3     SLICE NUMBER    2
OUTSIDE =  22.22037   LEFT CONST =  21.92037   MIDPOINT =  22.52037   RIGHT CONST =  23.12037   INSIDE =  22.82037

LAYER    1     SLICE NUMBER    1
OUTSIDE =  10.00000   LEFT CONST =   9.79502   MIDPOINT =  10.27006   RIGHT CONST =  10.74510   INSIDE =  10.54012

LAYER    1     SLICE NUMBER    2
OUTSIDE =  10.54012   LEFT CONST =  10.33515   MIDPOINT =  10.81018   RIGHT CONST =  11.28522   INSIDE =  11.08025

LAYER    1     SLICE NUMBER    3
OUTSIDE =  11.08025   LEFT CONST =  10.87527   MIDPOINT =  11.35031   RIGHT CONST =  11.82534   INSIDE =  11.62037

LAYER    2     SLICE NUMBER    1
OUTSIDE =  11.62037   LEFT CONST =  11.62037   MIDPOINT =  14.16493   RIGHT CONST =  16.70949   INSIDE =  16.70949

LAYER    3     SLICE NUMBER    1
OUTSIDE =  16.70949   LEFT CONST =  16.40949   MIDPOINT =  17.00949   RIGHT CONST =  17.60949   INSIDE =  17.30949

LAYER    3     SLICE NUMBER    2
OUTSIDE =  17.30949   LEFT CONST =  17.00949   MIDPOINT =  17.60949   RIGHT CONST =  18.20949   INSIDE =  17.90949

      WALL NO    1     ORBIT NO    0     TIME PERIOD NO    1
      TEMPERATURES  OUTSIDE SURFACE  INSIDE SURFACE  INTERFACES    26.03   5.13  -4.19  -9.45   0.00   0.00
      OUTSIDE AND INSIDE HEAT FLOW RATES AND TOTALS BTU/HR

        133.41          50.43          133.41          50.43          0.00          0.00
```

The immediately following answers are printed for every third time period, to give ten answers per orbit until the system has reached a balance. The next three answers are:

```
WALL NO    1     ORBIT NO    0     TIME PERIOD NO    4
TEMPERATURES  OUTSIDE SURFACE  INSIDE SURFACE  INTERFACES    71.85  26.57  21.34  14.37   0.00   0.00
OUTSIDE AND INSIDE HEAT FLOW RATES AND TOTALS BTU/HR
  76.71          21.95          210.12          72.37          0.00          0.00

WALL NO    1     ORBIT NO    0     TIME PERIOD NO    7
TEMPERATURES  OUTSIDE SURFACE  INSIDE SURFACE  INTERFACES    83.45  30.98  42.60  28.60   0.00   0.00
OUTSIDE AND INSIDE HEAT FLOW RATES AND TOTALS BTU/HR
  53.74           6.71          263.87          79.09          0.00          0.00

WALL NO    1     ORBIT NO    0     TIME PERIOD NO   10
TEMPERATURES  OUTSIDE SURFACE  INSIDE SURFACE  INTERFACES    89.19  30.35  56.93  35.44   0.00   0.00
OUTSIDE AND INSIDE HEAT FLOW RATES AND TOTALS BTU/HR
  38.36          -4.19          302.22          74.90          0.00          0.00
```

On the fourth orbit, the $\Delta T$ between orbits has become less than the specified $2^{0}F$, so the program permits the complete answer for each time period. Note that the Btu totals in the two right-hand columns start with this printout The output for the first four time periods is:

```
LAYER    1     SLICE NUMBER    1
OUTSIDE =  10.00000   LEFT CONST =   9.79502   MIDPOINT =  10.27006   RIGHT CONST =  10.74510   INSIDE =  10.54012

LAYER    1     SLICE NUMBER    2
OUTSIDE =  10.54012   LEFT CONST =  10.33515   MIDPOINT =  10.81018   RIGHT CONST =  11.28522   INSIDE =  11.08025

LAYER    1     SLICE NUMBER    3
OUTSIDE =  11.08025   LEFT CONST =  10.87527   MIDPOINT =  11.35031   RIGHT CONST =  11.82534   INSIDE =  11.62037

LAYER    2     SLICE NUMBER    1
OUTSIDE =  11.62037   LEFT CONST =  11.62037   MIDPOINT =  12.98304   RIGHT CONST =  14.34572   INSIDE =  14.34572

LAYER    3     SLICE NUMBER    1
OUTSIDE =  14.34572   LEFT CONST =  14.04572   MIDPOINT =  14.64572   RIGHT CONST =  15.24572   INSIDE =  14.94572

LAYER    3     SLICE NUMBER    2
OUTSIDE =  14.94572   LEFT CONST =  14.64572   MIDPOINT =  15.24572   RIGHT CONST =  15.84572   INSIDE =  15.54572

         WALL NO    1     ORBIT NO    4     TIME PERIOD NO    1
         TEMPERATURES  OUTSIDE SURFACE  INSIDE SURFACE  INTERFACES   140.81  71.61 112.73  80.50   0.00   0.00
         OUTSIDE AND INSIDE HEAT FLOW RATES AND TOTALS BTU/HR
           23.16            -3.59            888.69           -270.92            23.16            -3.59

LAYER    1     SLICE NUMBER    1
OUTSIDE =  10.00000   LEFT CONST =   9.79502   MIDPOINT =  10.27006   RIGHT CONST =  10.74510   INSIDE =  10.54012

LAYER    1     SLICE NUMBER    2
OUTSIDE =  10.54012   LEFT CONST =  10.33515   MIDPOINT =  10.81018   RIGHT CONST =  11.28522   INSIDE =  11.08025

LAYER    1     SLICE NUMBER    3
OUTSIDE =  11.08025   LEFT CONST =  10.87527   MIDPOINT =  11.35031   RIGHT CONST =  11.82534   INSIDE =  11.62037

LAYER    2     SLICE NUMBER    1
OUTSIDE =  11.62037   LEFT CONST =  11.62037   MIDPOINT =  12.96829   RIGHT CONST =  14.31620   INSIDE =  14.31620

LAYER    3     SLICE NUMBER    1
OUTSIDE =  14.31620   LEFT CONST =  14.01620   MIDPOINT =  14.61620   RIGHT CONST =  15.21620   INSIDE =  14.91620

LAYER    3     SLICE NUMBER    2
OUTSIDE =  14.91620   LEFT CONST =  14.61620   MIDPOINT =  15.21620   RIGHT CONST =  15.81620   INSIDE =  15.51620

         WALL NO    1     ORBIT NO    4     TIME PERIOD NO    2
         TEMPERATURES  OUTSIDE SURFACE  INSIDE SURFACE  INTERFACES   141.15  71.49 114.01  82.46   0.00   0.00
         OUTSIDE AND INSIDE HEAT FLOW RATES AND TOTALS BTU/HR

           21.30            -8.07            909.99           -279.00            44.45            -11.66

LAYER    1     SLICE NUMBER    1
OUTSIDE =  10.00000   LEFT CONST =   9.79502   MIDPOINT =  10.27006   RIGHT CONST =  10.74510   INSIDE =  10.54012

LAYER    1     SLICE NUMBER    2
OUTSIDE =  10.54012   LEFT CONST =  10.33515   MIDPOINT =  10.81018   RIGHT CONST =  11.28522   INSIDE =  11.08025

LAYER    1     SLICE NUMBER    3
OUTSIDE =  11.08025   LEFT CONST =  10.87527   MIDPOINT =  11.35031   RIGHT CONST =  11.82534   INSIDE =  11.62037

LAYER    2     SLICE NUMBER    1
OUTSIDE =  11.62037   LEFT CONST =  11.62037   MIDPOINT =  12.95664   RIGHT CONST =  14.29291   INSIDE =  14.29291

LAYER    3     SLICE NUMBER    1
OUTSIDE =  14.29291   LEFT CONST =  13.99291   MIDPOINT =  14.59291   RIGHT CONST =  15.19291   INSIDE =  14.89291

LAYER    3     SLICE NUMBER    2
OUTSIDE =  14.89291   LEFT CONST =  14.59291   MIDPOINT =  15.19291   RIGHT CONST =  15.79291   INSIDE =  15.49291

         WALL NO    1     ORBIT NO    4     TIME PERIOD NO    3
         TEMPERATURES  OUTSIDE SURFACE  INSIDE SURFACE  INTERFACES   141.05  70.71 115.13  83.62   0.00   0.00
         OUTSIDE AND INSIDE HEAT FLOW RATES AND TOTALS BTU/HR
           19.05            -11.40           929.04           -290.39            63.50            -23.06

LAYER    1     SLICE NUMBER    1
OUTSIDE =  10.00000   LEFT CONST =   9.79502   MIDPOINT =  10.27006   RIGHT CONST =  10.74510   INSIDE =  10.54012

LAYER    1     SLICE NUMBER    2
OUTSIDE =  10.54012   LEFT CONST =  10.33515   MIDPOINT =  10.81018   RIGHT CONST =  11.28522   INSIDE =  11.08025

LAYER    1     SLICE NUMBER    3
OUTSIDE =  11.08025   LEFT CONST =  10.87527   MIDPOINT =  11.35031   RIGHT CONST =  11.82534   INSIDE =  11.62037

LAYER    2     SLICE NUMBER    1
OUTSIDE =  11.62037   LEFT CONST =  11.62037   MIDPOINT =  12.94850   RIGHT CONST =  14.27664   INSIDE =  14.27664

LAYER    3     SLICE NUMBER    1
OUTSIDE =  14.27664   LEFT CONST =  13.97664   MIDPOINT =  14.57664   RIGHT CONST =  15.17664   INSIDE =  14.87664

LAYER    3     SLICE NUMBER    2
OUTSIDE =  14.87664   LEFT CONST =  14.57664   MIDPOINT =  15.17664   RIGHT CONST =  15.77664   INSIDE =  15.47664

         WALL NO    1     ORBIT NO    4     TIME PERIOD NO    4
         TEMPERATURES  OUTSIDE SURFACE  INSIDE SURFACE  INTERFACES   140.50  69.50 116.00  84.12   0.00   0.00
         OUTSIDE AND INSIDE HEAT FLOW RATES AND TOTALS BTU/HR
           16.47            -14.22           945.51           -304.62            79.98            -37.29
```

It will be observed that the change in theoretical thickness of layer 2 has now become quite moderate. In the four time periods above the thicknesses are: 2.72535, 2.69583, 2.67254 and 2.65627 feet. The final temperatures and heat flow rates for this orbit, time period No. 27, are

```
WALL NO    1     ORBIT NO    4     TIME PERIOD NO   27
TEMPERATURES  OUTSIDE SURFACE  INSIDE SURFACE  INTERFACES   140.04  70.23 111.41  77.78   0.00   0.00
OUTSIDE AND INSIDE HEAT FLOW RATES AND TOTALS BTU/HR
  24.52            2.40          1231.14          -632.74          365.60          -365.41
```

It will be noted that the total of heat flow into the outside surface, 365.60 Btu, and of heat flow from the inside surface to the inside air (required cooling load) 365.41 are very nearly equal, indicating that the solution is near to the real conditions.

For the second problem, the first two layers of a three-layer wall are transparent, in part, to infrared and visible radiation. The input data is:

```
    2   12    3   90   20    2   20    3    2    1
2.4        1.0        0.        0.        Problem 2 - First and Second Layers
    1      .09        .40       19.       1.75  Wall          Transparent
    2      .04        .175      22.       1.    Properties
    3      .25        .078      25.       3.6
    5   73    3      Rate of Heat Flow to Outside Surface
80.        69.        92.       129.      167.      204.      65.
65.        65.        65.       65.       65.       65.       65.
65.        65.        65.       65.       65.       65.       65.
65.        65.        65.       65.       65.       65.       65.
65.        65.        65.       65.       65.       65.       189.
152.       115.       77.       73.       84.       96.       107.
118.       128.       138.      147.      156.      164.      171.
178.       183.       188.      192.      194.      196.      197.
197.       195.       193.      190.      186.      181.      148.
142.       137.       131.      124.      117.      109.      101.
94.        85.        76.
   21    7    3       Infrared Transmissivity of Outside Layer
.4         .4         .4        .4        .4        .4        .4
   22    7    3       Infrared Reflectivity of Outside Surface
.04        .04        .04       .04       .04       .04       .04
   23   73    3       Proportion of Infrared in Incident Heat Flow
.950       .985       .925      .875      .850      .830      1.
1.         1.         1.        1.        1.        1.        1.
1.         1.         1.        1.        1.        1.        1.
1.         1.         1.        1.        1.        1.        1.
1.         1.         1.        1.        1.        1.        .835
.855       .895       .960      .975      .940      .915      .905
.890       .875       .870      .855      .855      .845      .850
.845       .835       .835      .830      .830      .830      .830
.830       .835       .835      .835      .835      .835      .845
.845       .850       .855      .855      .870      .880      .890
.915       .935       .950
```

```
   24      7      3      Visible Transmissivity of Outside Layer
.9          .9          .9          .9          .9          .9          .9
   25      7      3      Visible Reflectivity of Outside Surface
.05         .05         .05         .05         .05         .05         .05
   26      7      3      Infrared Transmissivity of Second Layer
.5          .5          .5          .5          .5          .5          .5
   27      7      3      Infrared Reflectivity of Layer 1-2 Interface
.05         .05         .05         .05         .05         .05         .05
   29      7      3      Visible Transmissivity of Second Layer
.8          .8          .8          .8          .8          .8          .8
   30      7      3      Visible Transmissivity of Layer 1-2 Intefface
.04         .04         .04         .04         .04         .04         .04
    3      7      3      Inside Air Temperature
70.         50.         30.         10.         30.         50.         70.
    4      7      3      Inside Air Film Coefficient
1.          1.          1.          1.          1.          1.          1.
```

This time, the number of tests per orbit is set, by the program, at 29 and the wall is divided into three slices for the first layer and two slices each for the second and third layers. The first portion of the output is:

```
STARTING NEW PROBLEM,WALL NO =    2

TESTS PER ORBIT SET=   29

LAYER    SLICES     DXN        DX         DTHN       PROP       XKDX

  1        3      0.54012    1.62037    0.09977    0.34200    0.45230

  2        2      1.04167    2.08333    0.08355    0.07700    1.04167

  3        2      0.60000    1.20000    0.08775    0.24375    0.57128

LAYER    1     SLICE NUMBER    1
OUTSIDE =  10.00000   LEFT CONST =  9.81776   MIDPOINT =  10.27006   RIGHT CONST =  10.72236   INSIDE =  10.54012

LAYER    1     SLICE NUMBER    2
OUTSIDE =  10.54012   LEFT CONST =  10.35788   MIDPOINT =  10.81018   RIGHT CONST =  11.26249   INSIDE =  11.08025

LAYER    1     SLICE NUMBER    3
OUTSIDE =  11.08025   LEFT CONST =  10.89800   MIDPOINT =  11.35031   RIGHT CONST =  11.80261   INSIDE =  11.62037

LAYER    2     SLICE NUMBER    1
OUTSIDE =  11.62037   LEFT CONST =  11.09954   MIDPOINT =  12.14120   RIGHT CONST =  13.18287   INSIDE =  12.66204

LAYER    2     SLICE NUMBER    2
OUTSIDE =  12.66204   LEFT CONST =  12.14120   MIDPOINT =  13.18287   RIGHT CONST =  14.22453   INSIDE =  13.70370

LAYER    3     SLICE NUMBER    1
OUTSIDE =  13.70370   LEFT CONST =  13.43242   MIDPOINT =  14.00370   RIGHT CONST =  14.57499   INSIDE =  14.30370

LAYER    3     SLICE NUMBER    2
OUTSIDE =  14.30370   LEFT CONST =  14.03242   MIDPOINT =  14.60370   RIGHT CONST =  15.17499   INSIDE =  14.90370
```

In this case, ten complete orbits are required for an answer. The heat flow totals are 4318.61 and 4306.57, which agree within 0.3 percent. The complete output, for 29 time periods in one orbit, is:

WALL NO 2 ORBIT NO 10 TIME PERIOD NO 1
TEMPERATURES OUTSIDE SURFACE INSIDE SURFACE INTERFACES 980.74 248.63 738.42 425.28 0.00 0.00
OUTSIDE AND INSIDE HEAT FLOW RATES AND TOTALS BTU/HR
141.49 -139.88 14101.56 -12560.18 141.49 -139.88

WALL NO 2 ORBIT NO 10 TIME PERIOD NO 2
TEMPERATURES OUTSIDE SURFACE INSIDE SURFACE INTERFACES 1012.36 250.24 749.35 438.18 0.00 0.00
OUTSIDE AND INSIDE HEAT FLOW RATES AND TOTALS BTU/HR
264.47 -143.77 14366.03 -12703.95 405.96 -283.65

WALL NO 2 ORBIT NO 10 TIME PERIOD NO 3
TEMPERATURES OUTSIDE SURFACE INSIDE SURFACE INTERFACES 991.32 254.32 740.63 420.36 0.00 0.00
OUTSIDE AND INSIDE HEAT FLOW RATES AND TOTALS BTU/HR
87.12 -148.19 14453.15 -12852.14 493.08 -431.85

WALL NO 2 ORBIT NO 10 TIME PERIOD NO 4
TEMPERATURES OUTSIDE SURFACE INSIDE SURFACE INTERFACES 973.28 247.80 737.04 424.68 0.00 0.00
OUTSIDE AND INSIDE HEAT FLOW RATES AND TOTALS BTU/HR
87.12 -154.51 14540.27 -13006.66 580.20 -586.36

WALL NO 2 ORBIT NO 10 TIME PERIOD NO 5
TEMPERATURES OUTSIDE SURFACE INSIDE SURFACE INTERFACES 956.90 245.47 733.90 425.09 0.00 0.00
OUTSIDE AND INSIDE HEAT FLOW RATES AND TOTALS BTU/HR
87.12 -152.69 14627.39 -13159.34 667.32 -739.05

WALL NO 2 ORBIT NO 10 TIME PERIOD NO 6
TEMPERATURES OUTSIDE SURFACE INSIDE SURFACE INTERFACES 944.86 243.93 730.36 423.82 0.00 0.00
OUTSIDE AND INSIDE HEAT FLOW RATES AND TOTALS BTU/HR
87.12 -154.08 14714.51 -13313.42 754.44 -893.13

WALL NO 2 ORBIT NO 10 TIME PERIOD NO 7
TEMPERATURES OUTSIDE SURFACE INSIDE SURFACE INTERFACES 935.38 241.81 726.14 421.93 0.00 0.00
OUTSIDE AND INSIDE HEAT FLOW RATES AND TOTALS BTU/HR
87.12 -156.07 14801.63 -13469.49 841.56 -1049.20

WALL NO 2 ORBIT NO 10 TIME PERIOD NO 8
TEMPERATURES OUTSIDE SURFACE INSIDE SURFACE INTERFACES 926.84 239.17 721.56 419.50 0.00 0.00
OUTSIDE AND INSIDE HEAT FLOW RATES AND TOTALS BTU/HR
87.12 -157.62 14888.75 -13627.12 928.69 -1206.82

WALL NO 2 ORBIT NO 10 TIME PERIOD NO 9
TEMPERATURES OUTSIDE SURFACE INSIDE SURFACE INTERFACES 919.13 236.16 716.81 416.61 0.00 0.00
OUTSIDE AND INSIDE HEAT FLOW RATES AND TOTALS BTU/HR
87.12 -158.78 14975.87 -13785.89 1015.81 -1365.60

WALL NO 2 ORBIT NO 10 TIME PERIOD NO 10
TEMPERATURES OUTSIDE SURFACE INSIDE SURFACE INTERFACES 912.05 232.86 711.95 413.35 0.00 0.00
OUTSIDE AND INSIDE HEAT FLOW RATES AND TOTALS BTU/HR
87.12 -159.64 15062.99 -13945.54 1102.93 -1525.24

WALL NO 2 ORBIT NO 10 TIME PERIOD NO 11
TEMPERATURES OUTSIDE SURFACE INSIDE SURFACE INTERFACES 905.40 229.33 707.03 409.79 0.00 0.00
OUTSIDE AND INSIDE HEAT FLOW RATES AND TOTALS BTU/HR
87.12 -160.29 15150.11 -14105.83 1190.05 -1685.54

WALL NO 2 ORBIT NO 10 TIME PERIOD NO 12
TEMPERATURES OUTSIDE SURFACE INSIDE SURFACE INTERFACES 899.06 225.62 702.06 406.00 0.00 0.00
OUTSIDE AND INSIDE HEAT FLOW RATES AND TOTALS BTU/HR
87.12 -160.76 15237.23 -14266.59 1277.17 -1846.29

```
WALL NO    2     ORBIT NO   10     TIME PERIOD NO   13
TEMPERATURES  OUTSIDE SURFACE  INSIDE SURFACE  INTERFACES   892.96 220.77 697.07 402.02   0.00   0.00
OUTSIDE AND INSIDE HEAT FLOW RATES AND TOTALS BTU/HR
  87.12          -164.38        15324.35        -14430.97          1364.29          -2010.67

WALL NO    2     ORBIT NO   10     TIME PERIOD NO   14
TEMPERATURES  OUTSIDE SURFACE  INSIDE SURFACE  INTERFACES   919.70 216.64 702.91 409.21   0.00   0.00
OUTSIDE AND INSIDE HEAT FLOW RATES AND TOTALS BTU/HR
 208.01          -161.97        15532.37        -14592.93          1572.30          -2172.64

WALL NO    2     ORBIT NO   10     TIME PERIOD NO   15
TEMPERATURES  OUTSIDE SURFACE  INSIDE SURFACE  INTERFACES   911.30 217.88 695.34 392.41   0.00   0.00
OUTSIDE AND INSIDE HEAT FLOW RATES AND TOTALS BTU/HR
  97.01          -158.79        15629.37        -14751.73          1669.31          -2331.43
WALL NO    2     ORBIT NO   10     TIME PERIOD NO   16
TEMPERATURES  OUTSIDE SURFACE  INSIDE SURFACE  INTERFACES   910.26 212.67 693.24 393.60   0.00   0.00
OUTSIDE AND INSIDE HEAT FLOW RATES AND TOTALS BTU/HR
 122.04          -158.43        15751.41        -14910.15          1791.35          -2489.86

WALL NO    2     ORBIT NO   10     TIME PERIOD NO   17
TEMPERATURES  OUTSIDE SURFACE  INSIDE SURFACE  INTERFACES   917.01 213.13 694.08 393.98   0.00   0.00
OUTSIDE AND INSIDE HEAT FLOW RATES AND TOTALS BTU/HR
 156.76          -147.94        15908.17        -15058.10          1948.11          -2637.81

WALL NO    2     ORBIT NO   10     TIME PERIOD NO   18
TEMPERATURES  OUTSIDE SURFACE  INSIDE SURFACE  INTERFACES   931.19 215.37 696.59 394.61   0.00   0.00
OUTSIDE AND INSIDE HEAT FLOW RATES AND TOTALS BTU/HR
 186.84          -145.12        16095.01        -15203.21          2134.95          -2782.92

WALL NO    2     ORBIT NO   10     TIME PERIOD NO   19
TEMPERATURES  OUTSIDE SURFACE  INSIDE SURFACE  INTERFACES   950.18 217.68 700.70 395.92   0.00   0.00
OUTSIDE AND INSIDE HEAT FLOW RATES AND TOTALS BTU/HR
 213.45          -143.65        16308.46        -15346.86          2348.39          -2926.57

WALL NO    2     ORBIT NO   10     TIME PERIOD NO   20
TEMPERATURES  OUTSIDE SURFACE  INSIDE SURFACE  INTERFACES   970.66 220.13 706.20 397.82   0.00   0.00
OUTSIDE AND INSIDE HEAT FLOW RATES AND TOTALS BTU/HR
 233.68          -142.25        16542.13        -15489.11          2582.07          -3068.82

WALL NO    2     ORBIT NO   10     TIME PERIOD NO   21
TEMPERATURES  OUTSIDE SURFACE  INSIDE SURFACE  INTERFACES   991.12 222.82 712.83 400.37   0.00   0.00
OUTSIDE AND INSIDE HEAT FLOW RATES AND TOTALS BTU/HR
 247.55          -140.95        16789.68        -15630.05          2829.62          -3209.76

WALL NO    2     ORBIT NO   10     TIME PERIOD NO   22
TEMPERATURES  OUTSIDE SURFACE  INSIDE SURFACE  INTERFACES  1009.68 225.82 720.13 403.01   0.00   0.00
OUTSIDE AND INSIDE HEAT FLOW RATES AND TOTALS BTU/HR
 253.16          -139.83        17042.84        -15769.88          3082.78          -3349.60

WALL NO    2     ORBIT NO   10     TIME PERIOD NO   23
TEMPERATURES  OUTSIDE SURFACE  INSIDE SURFACE  INTERFACES  1024.88 228.97 727.48 405.89   0.00   0.00
OUTSIDE AND INSIDE HEAT FLOW RATES AND TOTALS BTU/HR
 250.98          -138.96        17293.82        -15908.85          3333.76          -3488.56

WALL NO    2     ORBIT NO   10     TIME PERIOD NO   24
TEMPERATURES  OUTSIDE SURFACE  INSIDE SURFACE  INTERFACES  1035.80 232.23 734.33 409.23   0.00   0.00
OUTSIDE AND INSIDE HEAT FLOW RATES AND TOTALS BTU/HR
 241.92          -138.20        17535.74        -16047.04          3575.68          -3626.75

WALL NO    2     ORBIT NO   10     TIME PERIOD NO   25
TEMPERATURES  OUTSIDE SURFACE  INSIDE SURFACE  INTERFACES  1031.74 235.72 736.96 409.18   0.00   0.00
```

```
OUTSIDE AND INSIDE HEAT FLOW RATES AND TOTALS BTU/HR
 189.50          -137.52          17725.24          -16184.56          3765.18          -3764.28

WALL NO    2     ORBIT NO   10     TIME PERIOD NO   26
TEMPERATURES  OUTSIDE SURFACE  INSIDE SURFACE  INTERFACES  1025.08 238.07 739.86 413.06   0.00   0.00
OUTSIDE AND INSIDE HEAT FLOW RATES AND TOTALS BTU/HR
 173.17          -137.03          17898.41          -16321.59          3938.35          -3901.30

WALL NO    2     ORBIT NO   10     TIME PERIOD NO   27
TEMPERATURES  OUTSIDE SURFACE  INSIDE SURFACE  INTERFACES  1014.98 241.48 741.17 415.60   0.00   0.00
OUTSIDE AND INSIDE HEAT FLOW RATES AND TOTALS BTU/HR
 151.71          -135.65          18050.12          -16457.24          4090.06          -4036.95

WALL NO    2     ORBIT NO   10     TIME PERIOD NO   28
TEMPERATURES  OUTSIDE SURFACE  INSIDE SURFACE  INTERFACES  1001.74 244.88 740.63 417.44   0.00   0.00
OUTSIDE AND INSIDE HEAT FLOW RATES AND TOTALS BTU/HR
 127.89          -135.09          18178.01          -16592.33          4217.95          -4172.04

WALL NO    2     ORBIT NO   10     TIME PERIOD NO   29
TEMPERATURES  OUTSIDE SURFACE  INSIDE SURFACE  INTERFACES   984.47 248.00 737.89 418.73   0.00   0.00
OUTSIDE AND INSIDE HEAT FLOW RATES AND TOTALS BTU/HR
 100.67          -134.53          18278.67          -16726.85          4318.61          -4306.57
```

## SECTION 6

## FORTRAN LISTINGS

This section presents the listings of the source program elements.

| | Element | Function |
|---|---|---|
| 1. | Main Program MP | Used only to call the controlling subroutine TAPL, which permits use of the entire program as a subroutine. |
| 2. | Subroutine TAPL | When program is to be used as a subroutine, start at this point. Subroutine provides input and control for all factors except thermodynamic data. |
| 3. | Subroutine DISTX | Computes appropriate x-axis dimensions for each slice and layer. |
| 4. | Subroutine DATAA | Reads in all thermodynamic data, converts and calls for interpolation where needed, and stores in core. |
| 5. | Subroutine TEMPER | Examines data for completeness and consistency. Sets up control digits for subsequent iterative processes. Handles basic computation on a Btu basis and checks solutions for convergence. |
| 6. | Subroutine TEMSET | Sets up initial wall temperatures. |
| 7. | Subroutine INTLA | Performs Lagrangian interpolation for input data. |
| 8. | Subroutine TEMCAL | Performs stepwise calculation of temperature, simulating the graphical process. |
| 9. | Subroutine DOPT | Controls writing of all output and error messages. |
| 10. | Subroutine TEMTRN | Handles special calculations required if any material layer is transparent to incident radiation. |
| 11. | Subroutine DISVAC | Performs calculations needed if any material layer is a vacuum. |

```
C     ANALYSIS OF PERIODIC THERMAL LOADS
C     IMPOSED ON ENVIRONMENTAL CONTROL SYSTEMS
C
C     FORTRAN II DIGITAL COMPUTER PROGRAM PREPARED FOR
C     NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
C     BY   AIRESEARCH MANUFACTURING DIVISION
C          THE GARRETT CORPORATION
C     NASA CONTRACT  NAS 9-2044
C
      COMMON ANRO,ANRP,ANSO,ANSP,AR12,AR23,ARSI,ARSO,ARSSO,ARSTO,AS12,AS
     123,AVACI,AVACO,COND,CSUBP,CUE,CUEI,CUEO,CUESI,CUESO,
     2DATA,DD,DELT,DTHN,DX,DXN,DXNA,DXNB,DXNC,DXND,ER12,ER23
      COMMON ERKI,ERKO,FCI,FCO,HRSOBT,IDATA,IL,IND,INDX,ITPMAX,ITPMIN,IT
     1RN,IVAC,IW,IWALL,IWC,IWD,JDI,JTPR,KL,LBD,LBK,LBN,LT1,LT2,MA,MR,NDA
     2T,NSET,NSETR,NSETS,NWALL,PROP,RBIT,RHO
      COMMON SUMA,TAB,THCK,TI,TM,TO,TRKI,TRKO,TRSI,TRSO,TRSSO,TRSTO,TSUM
     1,TTEM,TWLI,TWLO,X,XD,XDD12,XDD23,XDD34,XDD45,XKDX,XWI,XWO,Y
      COMMON QO,QI,QRT,QST
      DIMENSION ANRO(101),ANRP(101),ANSO(101),ANSP(101),AR12(101),AR23(1
     101),ARSI(101),ARSO(101),ARSSO(101),ARSTO(101),AS12(101),AS23(101),
     2COND(5),CSUBP(5),CUE(10),CUEI(101),CUEO(101),DATA(201),DD(102,2)
      DIMENSION DTHN(5),DX(5),DXN(5),ER12(101),ER23(101),ERKI(101),ERKO(
     1101),FCI(101),FCO(101),IL(5),IND(20),LBK(30),PROP(5),RHO(5),TAB(40
     22),THCK(5),TI(101),TM(102,4),TO(101),TRKI(101),TRKO(101),TRSI(101)
      DIMENSION TRSO(101),TRSSO(101),TRSTO(101),TSUM(20),TTEM(100),TWLI(
     1101),TWLO(101),X(102,4),XD(5,20,5),XKDX(5)
C
      CALL TAPL
      END
```

```
C
      SUBROUTINE TAPL
C
C     ANALYSIS OF PERIODIC THERMAL LOADS
C     IMPOSED ON ENVIRONMENTAL CONTROL SYSTEMS
C
C     FORTRAN II DIGITAL COMPUTER PROGRAM PREPARED FOR
C     NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
C     BY   AIRESEARCH MANUFACTURING DIVISION
C          THE GARRETT CORPORATION
C     NASA CONTRACT  NAS 9-2044
C
      COMMON ANRO,ANRP,ANSO,ANSP,AR12,AR23,ARSI,ARSO,ARSSO,ARSTO,AS12,AS
     123,AVACI,AVACO,COND,CSUBP,CUE,CUEI,CUEO,CUESI,CUESO,
     2DATA,DD,DELT,DTHN,DX,DXN,DXNA,DXNB,DXNC,DXND,ER12,ER23
      COMMON ERKI,ERKO,FCI,FCO,HRSOBT,IDATA,IL,IND,INDX,ITPMAX,ITPMIN,IT
     1RN,IVAC,IW,IWALL,IWC,IWD,JDI,JTPR,KL,LBD,LBK,LBN,LT1,LT2,MA,MR,NDA
     2T,NSET,NSETR,NSETS,NWALL,PROP,RBIT,RHO
      COMMON SUMA,TAB,THCK,TI,TM,TO,TRKI,TRKO,TRSI,TRSO,TRSSO,TRSTO,TSUM
     1,TTEM,TWLI,TWLO,X,XD,XDD12,XDD23,XDD34,XDD45,XKDX,XWI,XWO,Y
      COMMON QO,QI,QRT,QST
      DIMENSION ANRO(101),ANRP(101),ANSO(101),ANSP(101),AR12(101),AR23(1
     101),ARSI(101),ARSO(101),ARSSO(101),ARSTO(101),AS12(101),AS23(101),
     2COND(5),CSUBP(5),CUE(10),CUEI(101),CUEO(101),DATA(201),DD(102,2)
      DIMENSION DTHN(5),DX(5),DXN(5),ER12(101),ER23(101),ERKI(101),ERKO(
     1101),FCI(101),FCO(101),IL(5),IND(20),LBK(30),PROP(5),RHO(5),TAB(40
     22),THCK(5),TI(101),TM(102,4),TO(101),TRKI(101),TRKO(101),TRSI(101)
      DIMENSION TRSO(101),TRSSO(101),TRSTO(101),TSUM(20),TTEM(100),TWLI(
     1101),TWLO(101),X(102,4),XD(5,20,5),XKDX(5)
C
C     SET READ/WRITE TAPE UNIT TO FORTRAN NUMBERS FOR INSTALLATION
C                   LT1  =   INPUT DATA
C                   LT2  =   OUTPUT DATA
C
    1 LT1=41
    2 LT2=42
C
 9998 READ INPUT TAPE LT1,99,NWALL,JDI
   99 FORMAT(2I5)
 9999 READ INPUT TAPE LT1,100,IWALL,IDATA,IW,ITPMAX,ITPMIN,NSET,NSETR,NS
     1ETS,ITRN,IVAC
  100 FORMAT(14I5)
      QI=0.
      QO=0.
      READ INPUT TAPE LT1,103,HRSOBT,DELT,AVACI,AVACO
  103 FORMAT(7F10.5)
      CALL DOPT(9)
      READ INPUT TAPE LT1,102,(COND(L),CSUBP(L),RHO(L),THCK(L),L=1,IW)
  102 FORMAT(10X,4F10.5)
      TPRMIN=ITPMIN
      TPRMAX=ITPMAX
      DTHMAX=HRSOBT/TPRMIN
      DTHMIN=HRSOBT/TPRMAX
      DTHM=DTHMAX
      DO 300 I=1,IW
      IF(IVAC-1)205,205,204
  204 IF(IVAC-I)205,300,205
```

```
  205 A127=NSET-1
      PROP(I)=.5*CSUBP(I)*RHO(I)*COND(I)
      DX(I)=THCK(I)/(12.*COND(I))
  212 A127 = A127 + 1.
      DXN(I)    = DX(I)   / A127
      DTHN(I)    = PROP(I)   * DXN(I)   * DXN(I)
      IF(A127-20.)220,223,223
  220 IF(DTHN(I)-DTHMIN)221,222,222
  221 DTHN(I)=DTHMIN
  222 IF(DTHN(I)-DTHMAX)223,223,212
  223 DTHM=MIN1F(DTHM,DTHN(I))
      IL(I) = A127
  300 CONTINUE
      DO 400 I=1,IW
      IF(IVAC-1)305,305,304
  304 IF(IVAC-I)305,390,305
  305 XKDX(I)=DTHM/(PROP(I)*DXN(I))
      GO TO 400
  390 XKDX(IVAC)=5.
      IL(IVAC)=1
      DXN(IVAC)=10.
  400 CONTINUE
      JTPR=(HRSOBT/DTHM)+.5
      JTPR=XMINOF(JTPR,100)
  970 DXNA=.5*DXN(1)
      DXNB=DXNA+1.
      DXNC=.5*DXN(IW)
      DXND=DXNC+1.
      CALL DOPT(2)
      CALL DOPT(6)
 8000 CALL DISTX
 9000 CALL  DATAA
      CALL TEMPER
      IF(NWALL-IWALL)9998,9998,9999
      RETURN
      END
```

```
      SUBROUTINE DISTX
C
      COMMON ANRO,ANRP,ANSO,ANSP,AR12,AR23,ARSI,ARSO,ARSSO,ARSTO,AS12,AS
     123,AVACI,AVACO,COND,CSUBP,CUE,CUEI,CUEO,CUESI,CUESO,
     2DATA,DD,DELT,DTHN,DX,DXN,DXNA,DXNB,DXNC,DXND,ER12,ER23
      COMMON ERKI,ERKO,FCI,FCO,HRSOBT,IDATA,IL,IND,INDX,ITPMAX,ITPMIN,IT
     1RN,IVAC,IW,IWALL,IWC,IWD,JDI,JTPR,KL,LBD,LBK,LBN,LT1,LT2,MA,MR,NDA
     2T,NSET,NSETR,NSETS,NWALL,PROP,RBIT,RHO
      COMMON SUMA,TAB,THCK,TI,TM,TO,TRKI,TRKO,TRSI,TRSO,TRSSO,TRSTO,TSUM
     1,TTEM,TWLI,TWLO,X,XD,XDD12,XDD23,XDD34,XDD45,XKDX,XWI,XWO,Y
      COMMON QO,QI,QRT,QST
      DIMENSION ANRO(101),ANRP(101),ANSO(101),ANSP(101),AR12(101),AR23(1
     101),ARSI(101),ARSO(101),ARSSO(101),ARSTO(101),AS12(101),AS23(101),
     2COND(5),CSUBP(5),CUE(10),CUEI(101),CUEO(101),DATA(201),DD(102,2)
      DIMENSION DTHN(5),DX(5),DXN(5),ER12(101),ER23(101),ERKI(101),ERKO(
     1101),FCI(101),FCO(101),IL(5),IND(20),LBK(30),PROP(5),RHO(5),TAB(40
     22),THCK(5),TI(101),TM(102,4),TO(101),TRKI(101),TRKO(101),TRSI(101)
      DIMENSION TRSO(101),TRSSO(101),TRSTO(101),TSUM(20),TTEM(100),TWLI(
     1101),TWLO(101),X(102,4),XD(5,20,5),XKDX(5)
C
      XD(1,1,1)=10.
      DO 100 I=1,IW
      IWA=IL(I)
      DO 100 J=1,IWA
      XD(I,J,5)=XD(I,J,1)+DXN(I)
      XD(I,J,3)=0.5*(XD(I,J,1)+XD(I,J,5))
      XD(I,J,2)=XD(I,J,3)-XKDX(I)
      XD(I,J,4)=XD(I,J,3)+XKDX(I)
      IF(J-IWA)10,20,10
   10 XD(I,J+1,1)=XD(I,J,5)
      GO TO 100
   20 XD(I+1,1,1)=XD(I,J,5)
      IF(I-IW)25,100,100
   25 XD99=.5*(DXN(I)+DXN(I+1))
   26 GO TO(30,40,50,60),I
   30 XW12=XD(I,J,5)
   31 XDD12=(XW12-XD(I,J,3))/XD99
      GO TO 100
   40 XW23=XD(I,J,5)
   41 XDD23=(XW23-XD(I,J,3))/XD99
      GO TO 100
   50 XW34=XD(I,J,5)
   51 XDD34=(XW34-XD(I,J,3))/XD99
      GO TO 100
   60 XW45=XD(I,J,5)
   61 XDD45=(XW45-XD(I,J,3))/XD99
  100 CONTINUE
      CALL DOPT(5)
      IWB=1
      DO 300 I=1,IW
      IWA=IL(I)
      DO 300 J=1,IWA
      IWB=IWB+1
      DO 300 KK=1,4
      X(IWB,KK)=XD(I,J,KK)
  300 CONTINUE
      IWC=IWB+1
```

```
      IWD=IWC-1
      XWO=XD(1,1,1)
      XWI=XD(I,J,5)
      X(IWC,1)=XWI
      X(I,3)=XWO-1.
      X(IWC,3)=XWI+1.
      DO 400 I=2,IWD
      DD(I,1)=(X(I,3)-X(I,2))/(X(I,3)-X(I-1,3))
      DD(I,2)=(X(I+1,3)-X(I,4))/(X(I+1,3)-X(I,3))
  400 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE DATAA
C
      COMMON ANRO,ANRP,ANSO,ANSP,AR12,AR23,ARSI,ARSO,ARSSO,ARSTO,AS12,AS
     123,AVACI,AVACO,COND,CSUBP,CUE,CUEI,CUEO,CUESI,CUESO,
     2DATA,DD,DELT,DTHN,DX,DXN,DXNA,DXNB,DXNC,DXND,ER12,ER23
      COMMON ERKI,ERKO,FCI,FCO,HRSOBT,IDATA,IL,IND,INDX,ITPMAX,ITPMIN,IT
     1RN,IVAC,IW,IWALL,IWC,IWD,JDI,JTPR,KL,LBD,LBK,LBN,LT1,LT2,MA,MR,NDA
     2T,NSET,NSETR,NSETS,NWALL,PROP,RBIT,RHO
      COMMON SUMA,TAB,THCK,TI,TM,TO,TRKI,TRKO,TRSI,TRSO,TRSSO,TRSTO,TSUM
     1,TTEM,TWLI,TWLO,X,XD,XDD12,XDD23,XDD34,XDD45,XKDX,XWI,XWO,Y
      COMMON QO,QI,QRT,QST
      DIMENSION ANRO(101),ANRP(101),ANSO(101),ANSP(101),AR12(101),AR23(1
     101),ARSI(101),ARSO(101),ARSSO(101),ARSTO(101),AS12(101),AS23(101),
     2COND(5),CSUBP(5),CUE(10),CUEI(101),CUEO(101),DATA(201),DD(102,2)
      DIMENSION DTHN(5),DX(5),DXN(5),ER12(101),ER23(101),ERKI(101),ERKO(
     1101),FCI(101),FCO(101),IL(5),IND(20),LBK(30),PROP(5),RHO(5),TAB(40
     22),THCK(5),TI(101),TM(102,4),TO(101),TRKI(101),TRKO(101),TRSI(101)
      DIMENSION TRSO(101),TRSSO(101),TRSTO(101),TSUM(20),TTEM(100),TWLI(
     1101),TWLO(101),X(102,4),XD(5,20,5),XKDX(5)
C
      WYEF(Y)=(Y*.01+4.6)**4
      DO 300 K=1,IDATA
      READ INPUT TAPE LT1,10,LBD,LBN,KL
   10 FORMAT(3I5)
   11 LBK(K)=LBD
      READ INPUT TAPE LT1,20,(DATA(I),I=1,LBN)
   20 FORMAT(7F10.5)
      LBM=LBN-1
      A2=LBM
      TPD=HRSOBT/A2
      TPDS=0.
      TAB(1)=0.
      TAB(2)=DATA(1)
      DO 100 I=2,LBN
      TPDS=TPDS+TPD
      TAB(2*I-1)=TPDS
      TAB(2*I)=DATA(I)
  100 CONTINUE
      A1=JTPR
      TP=HRSOBT/A1
      SUMA=0.
      DO 200 I=1,JTPR
      SUMA=SUMA+TP
      CALL INTLA
      GO TO (101,102,103,104,105,106,107,108,109,110,111,112,113,114,115
     1,116,117,118,119,120,121,122,123,124,125,126,127,128,129,130),LBD
  101 TO(I)=Y
      GO TO 200
  102 FCO(I)=DXNA+1./Y
      GO TO 200
  103 TI(I)=Y
      GO TO 200
  104 FCI(I)=DXNC+1./Y
      GO TO 200
  105 CUEO(I)=Y
      GO TO 200
  106 CUEI(I)=Y
```

```
      GO TO 200
  107 TWLO(I)=Y
      GO TO 200
  108 TWLI(I)=Y
      GO TO 200
  109 TRSO(I)=WYEF(Y)
      GO TO 200
  110 ARSO(I)=.173*Y
      GO TO 200
  111 TRSSO(I)=WYEF(Y)
      GO TO 200
  112 ARSSO(I)=.173*Y
      GO TO 200
  113 TRSTO(I)=WYEF(Y)
      GO TO 200
  114 ARSTO(I)=.173*Y
      GO TO 200
  115 TRKO(I)=WYEF(Y)
      GO TO 200
  116 ERKO(I)=.173*Y
      GO TO 200
  117 TRSI(I)=WYEF(Y)
      GO TO 200
  118 ARSI(I)=.173*Y
      GO TO 200
  119 TRKI(I)=WYEF(Y)
      GO TO 200
  120 ERKI(I)=.173*Y
      GO TO 200
  121 ANRO(I)=Y
      GO TO 200
  122 AR12(I)=Y
      GO TO 200
  123 ER12(I)=Y
      GO TO 200
  124 ANSO(I)=Y
      GO TO 200
  125 AS12(I)=Y
      GO TO 200
  126 ANRP(I)=Y
      GO TO 200
  127 AR23(I)=Y
      GO TO 200
  128 ER23(I)=Y
      GO TO 200
  129 ANSP(I)=Y
      GO TO 200
  130 AS23(I)=Y
  200 CONTINUE
  300 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE TEMPER
C
      COMMON ANRO,ANRP,ANSO,ANSP,AR12,AR23,ARSI,ARSO,ARSSO,ARSTO,AS12,AS
     123,AVACI,AVACO,COND,CSUBP,CUE,CUEI,CUEO,CUESI,CUESO,
     2DATA,DD,DELT,DTHN,DX,DXN,DXNA,DXNB,DXNC,DXND,ER12,ER23
      COMMON ERKI,ERKO,FCI,FCO,HRSOBT,IDATA,IL,IND,INDX,ITPMAX,ITPMIN,IT
     1RN,IVAC,IW,IWALL,IWC,IWD,JDI,JTPR,KL,LBD,LBK,LBN,LT1,LT2,MA,MR,NDA
     2T,NSET,NSETR,NSETS,NWALL,PROP,RBIT,RHO
      COMMON SUMA,TAB,THCK,TI,TM,TO,TRKI,TRKO,TRSI,TRSO,TRSSO,TRSTO,TSUM
     1,TTEM,TWLI,TWLO,X,XD,XDD12,XDD23,XDD34,XDD45,XKDX,XWI,XWO,Y
      COMMON QO,QI,QRT,QST
      DIMENSION ANRO(101),ANRP(101),ANSO(101),ANSP(101),AR12(101),AR23(1
     101),ARSI(101),ARSO(101),ARSSO(101),ARSTO(101),AS12(101),AS23(101),
     2COND(5),CSUBP(5),CUE(10),CUEI(101),CUEO(101),DATA(201),DD(102,2)
      DIMENSION DTHN(5),DX(5),DXN(5),ER12(101),ER23(101),ERKI(101),ERKO(
     1101),FCI(101),FCO(101),IL(5),IND(20),LBK(30),PROP(5),RHO(5),TAB(40
     22),THCK(5),TI(101),TM(102,4),TO(101),TRKI(101),TRKO(101),TRSI(101)
      DIMENSION TRSO(101),TRSSO(101),TRSTO(101),TSUM(20),TTEM(100),TWLI(
     1101),TWLO(101),X(102,4),XD(5,20,5),XKDX(5)
C
      TEEF(T)=(T*.01+4.6)**4
      JJJ=0
      N1=1
      N2=1
      N3=1
      N4=1
      N5=1
      N6=1
      N7=1
      N8=1
      N9=1
      DO 20 K=1,IDATA
      LBDA=LBK(K)
      GO TO(1,1,2,2,3,4,5,6,7,7,7,7,7,7,7,7,8,8,8,8,9,9,9,9,9,9,9,9,9,9)
     1,LBDA
    1 N1=N1+1
      GO TO 20
    2 N2=N2+1
      GO TO 20
    3 N3=N3+1
      GO TO 20
    4 N4=N4+1
      GO TO 20
    5 N5=N5+1
      GO TO 20
    6 N6=N6+1
      GO TO 20
    7 N7=N7+1
      GO TO 20
    8 N8=N8+1
      GO TO 20
    9 N9=N9+1
   20 CONTINUE
   22 IF(N1+N3+N5+N7-4)23,23,24
   23 NDAT=1
      CALL DOPT(1)
   24 IF(N2+N4+N6+N8-4)23,23,25
```

```
25 INDX=0
   GO TO(40,35,37),N1
35 NDAT=2
   CALL DOPT(1)
37 INDX=INDX+1
   IND(INDX)=1
40 GO TO(50,35,41),N2
41 INDX=INDX+1
   IND(INDX)=2
50 IF(N3+N4-3)60,51,36
36 NDAT=3
   CALL DOPT(1)
51 IF(N3-1)35,55,52
52 INDX=INDX+1
   IND(INDX)=3
   GO TO 60
55 IF(N4-1)35,60,56
56 INDX=INDX+1
   IND(INDX)=4
60 IF(N5+N6-3)70,61,36
61 IF(N5-1)35,65,62
62 INDX=INDX+1
   IND(INDX)=5
   GO TO 70
65 IF(N6-1)35,70,66
66 INDX=INDX+1
   IND(INDX)=6
70 GO TO (80,80,80,35,72,35,74,35,76),N7
72 INDX=INDX+1
   IND(INDX)=9
   GO TO 80
74 INDX=INDX+1
   IND(INDX)=8
   GO TO 80
76 INDX=INDX+1
   IND(INDX)=7
80 GO TO (82,35,35,35,81),N8
81 INDX=INDX+1
   IND(INDX)=10
82 GO TO (86,35,35,35,35,84,84,84,84,84,84),N9
84 INDX=INDX+1
   IND(INDX)=11
86 CALL TEMSET
87 B1=JTPR
   B2=MIN1F(B1,10.)
   IB3=1.+B1/B2
   B4=IWC-2
   B5=MIN1F(B4,10.)
   IB6=1.+B4/B5
   MR=0
   KSUM=0
88 TTEST=0.
   TSUMN=0.
   TSUMP=0.
   MI=0
   KMM=1
89 DO 500 M=1,JTPR
90 DO 100 I=1,10
```

```
100 CUE(I)=0.
    DO 400 I=1,INDX
    INDK=IND(I)
    GO TO (210,220,230,240,250,260,270,280,290,300,400),INDK
210 CUE(1)=(TO(M)-TM(2,1))/FCO(M)
    GO TO 400
220 CUE(2)=(TI(M)-TM(IWC,1))/FCI(M)
    GO TO 400
230 CUE(3)=CUEO(M)
    GO TO 400
240 CUE(4)=CUEI(M)
    GO TO 400
250 CUE(5)=(TWLO(M)-TM(2,3))/DXNA
    GO TO 400
260 CUE(6)=(TWLI(M)-TM(IWD,3))/DXNC
    GO TO 400
270 CONTINUE
280 CONTINUE
290 RWO=TEEF(TM(2,1))
    CUEA=ERKO(M)*(RWO-TRKO(M))
    CUE(9)=ARSO(M)*(TRSO(M)-RWO)-CUEA
    IF(INDK-9)292,400,35
292 CUE(8)=ARSSO(M)*(TRSSO(M)-RWO)
    IF(INDK-8)293,400,35
293 CUE(7)=ARSTO(M)*(TRSTO(M)-RWO)
    GO TO 400
300 RWI=TEEF(TM(IWC,1))
    CUEB=ERKI(M)*(RWI-TRKI(M))
    CUE(10)=ARSI(M)*(TRSI(M)-RWI)-CUEB
400 CONTINUE
    MA=M
    IF(IVAC-1)405,405,401
401 CALL DISVAC
405 IF(ITRN)410,410,406
406 CALL TEMTRN
410 CUESO=CUE(1)+CUE(3)+CUE(5)+CUE(7)+CUE(8)+CUE(9)
    CUESI=CUE(2)+CUE(4)+CUE(6)+CUE(10)
    TM(1,3)=TM(2,3)+DXNB*CUESO
    TM(IWC,3)=TM(IWD,3)+DXND*CUESI
418 TM(2,1)=TM(1,3)-CUESO
419 TM(IWC,1)=TM(IWC,3)-CUESI
420 CALL TEMCAL
    IF(JJJ)421,421,485
421 IF(M-KMM)500,430,430
430 DO 460 I=2,IWD,IB6
    MI=MI+1
431 TTEST=TM(I,3)-TTEM(MI)
    IF(TTEST)440,455,450
440 TSUMN=TSUMN+TTEST
    GO TO 455
450 TSUMP=TSUMP+TTEST
455 TTEM(MI)=TM(I,3)
460 CONTINUE
    IF(M-KMM)498,480,498
480 IF(JDI)492,492,491
485 QO=QO+CUESO
    QI=QI+CUESI
    GO TO 492
```

```
491 CALL DOPT(4)
492 CALL DOPT(7)
493 CALL DOPT(8)
498 KMM=KMM+IB3
500 CONTINUE
    IF(JJJ)501,501,600
501 MR=MR+1
    IF(MR-NSETR)509,509,512
509 DMI=MI+MI
    TSUM(MR)=(ABSF(TSUMP+TSUMN))/DMI
    IF(TSUM(MR)-DELT)520,520,510
510 IF(TSUM(MR)-TSUM(MR-1))514,514,511
511 KSUM=KSUM+1
    IF(KSUM-NSETS)515,515,512
512 CALL DOPT(3)
    CALL DOPT(4)
    CALL DOPT(7)
    CALL DOPT(8)
    IF(JDI)514,514,513
513 CALL DUMP
514 KSUM=0
515 GO TO 88
520 JJJ=1
521 GO TO 89
600 CONTINUE
    RETURN
    END
```

```
      SUBROUTINE TEMSET
C
      COMMON ANRO,ANRP,ANSO,ANSP,AR12,AR23,ARSI,ARSO,ARSSO,ARSTO,AS12,AS
     123,AVACI,AVACO,COND,CSUBP,CUE,CUEI,CUEO,CUESI,CUESO,
     2DATA,DD,DELT,DTHN,DX,DXN,DXNA,DXNB,DXNC,DXND,ER12,ER23
      COMMON ERKI,ERKO,FCI,FCO,HRSOBT,IDATA,IL,IND,INDX,ITPMAX,ITPMIN,IT
     1RN,IVAC,IW,IWALL,IWC,IWD,JDI,JTPR,KL,LBD,LBK,LBN,LT1,LT2,MA,MR,NDA
     2T,NSET,NSETR,NSETS,NWALL,PROP,RBIT,RHO
      COMMON SUMA,TAB,THCK,TI,TM,TO,TRKI,TRKO,TRSI,TRSO,TRSSO,TRSTO,TSUM
     1,TTEM,TWLI,TWLO,X,XD,XDD12,XDD23,XDD34,XDD45,XKDX,XWI,XWO,Y
      COMMON QO,QI,QRT,QST
      DIMENSION ANRO(101),ANRP(101),ANSO(101),ANSP(101),AR12(101),AR23(1
     101),ARSI(101),ARSO(101),ARSSO(101),ARSTO(101),AS12(101),AS23(101),
     2COND(5),CSUBP(5),CUE(10),CUEI(101),CUEO(101),DATA(201),DD(102,2)
      DIMENSION DTHN(5),DX(5),DXN(5),ER12(101),ER23(101),ERKI(101),ERKO(
     1101),FCI(101),FCO(101),IL(5),IND(20),LBK(30),PROP(5),RHO(5),TAB(40
     22),THCK(5),TI(101),TM(102,4),TO(101),TRKI(101),TRKO(101),TRSI(101)
      DIMENSION TRSO(101),TRSSO(101),TRSTO(101),TSUM(20),TTEM(100),TWLI(
     1101),TWLO(101),X(102,4),XD(5,20,5),XKDX(5)
C
      IF(ABSF(TWLO(1)-TWLI(1))-10.)1,1,2
    1 TSET=TWLO(1)-10.
      GO TO 3
    2 TSET=TWLI
    3 DO 10 I=2,IWD
   10 TM(I,3)=TSET
      RETURN
      END
```

```
      SUBROUTINE  INTLA
C
      COMMON ANRO,ANRP,ANSO,ANSP,AR12,AR23,ARSI,ARSO,ARSSO,ARSTO,AS12,AS
     123,AVACI,AVACO,COND,CSUBP,CUE,CUEI,CUEO,CUESI,CUESO,
     2DATA,DD,DELT,DTHN,DX,DXN,DXNA,DXNB,DXNC,DXND,ER12,ER23
      COMMON ERKI,ERKO,FCI,FCO,HRSOBT,IDATA,IL,IND,INDX,ITPMAX,ITPMIN,IT
     1RN,IVAC,IW,IWALL,IWC,IWD,JDI,JTPR,KL,LBD,LBK,LBN,LT1,LT2,MA,MR,NDA
     2T,NSET,NSETR,NSETS,NWALL,PROP,RBIT,RHO
      COMMON SUMA,TAB,THCK,TI,TM,TO,TRKI,TRKO,TRSI,TRSO,TRSSO,TRSTO,TSUM
     1,TTEM,TWLI,TWLO,X,XD,XDD12,XDD23,XDD34,XDD45,XKDX,XWI,XWO,Y
      COMMON QO,QI,QRT,QST
      DIMENSION ANRO(101),ANRP(101),ANSO(101),ANSP(101),AR12(101),AR23(1
     101),ARSI(101),ARSO(101),ARSSO(101),ARSTO(101),AS12(101),AS23(101),
     2COND(5),CSUBP(5),CUE(10),CUEI(101),CUEO(101),DATA(201),DD(102,2)
      DIMENSION DTHN(5),DX(5),DXN(5),ER12(101),ER23(101),ERKI(101),ERKO(
     1101),FCI(101),FCO(101),IL(5),IND(20),LBK(30),PROP(5),RHO(5),TAB(40
     22),THCK(5),TI(101),TM(102,4),TO(101),TRKI(101),TRKO(101),TRSI(101)
      DIMENSION TRSO(101),TRSSO(101),TRSTO(101),TSUM(20),TTEM(100),TWLI(
     1101),TWLO(101),X(102,4),XD(5,20,5),XKDX(5)
C
   50 N = LBN
      XX = SUMA
      K  = KL
  100 IF (XX- TAB(1)) 200, 300, 300
  200 L = 1
      GO TO 500
  300 N2 = N + N
      IF (XX- TAB(N2-1)) 600, 600, 400
  400 L = N2 -3
  500 K = 2
      GO TO 1600
  600 I = 3
  700 IF (XX - TAB(I)) 1000,800,900
  800 SUM = TAB(I + 1)
      GO  TO 2600
  900 I = I + 2
      GO TO 700
 1000 K2 =  K/2
      M = K2 + K2
      L = I - M
 1005 IF (M -K) 1010, 1100, 1010
 1010 IF (XX+XX- TAB(I) -TAB(I- 2)) 1020, 1100, 1100
 1020 L = L - 2
 1100 IF (L -1) 1200, 1300, 1300
 1200 L = 1
      GO TO 1600
 1300 M = 2*(N-K) +1
 1400 IF (L -M) 1600, 1600,1500
 1500 L = M
 1600 M = L + K +K -2
 1700 SUM = 0.
 1800 DO 2500  I =L,M,2
 1900 P = 1.
 2000 DO 2300  J = L, M, 2
 2100 IF (I -J) 2200, 2300, 2200
 2200 P = P* (XX-TAB(J))/ (TAB(I) - TAB(J))
 2300 CONTINUE
```

```
2400 SUM = SUM + P* TAB(I+1)
2500 CONTINUE
2600 Y = SUM
     RETURN
     END
```

```
      SUBROUTINE  TEMCAL
C
      COMMON ANRO,ANRP,ANSO,ANSP,AR12,AR23,ARSI,ARSO,ARSSO,ARSTO,AS12,AS
     123,AVACI,AVACO,COND,CSUBP,CUE,CUEI,CUEO,CUESI,CUESO,
     2DATA,DD,DELT,DTHN,DX,DXN,DXNA,DXNB,DXNC,DXND,ER12,ER23
      COMMON ERKI,ERKO,FCI,FCO,HRSOBT,IDATA,IL,IND,INDX,ITPMAX,ITPMIN,IT
     1RN,IVAC,IW,IWALL,IWC,IWD,JDI,JTPR,KL,LBD,LBK,LBN,LT1,LT2,MA,MR,NDA
     2T,NSET,NSETR,NSETS,NWALL,PROP,RBIT,RHO
      COMMON SUMA,TAB,THCK,TI,TM,TO,TRKI,TRKO,TRSI,TRSO,TRSSO,TRSTO,TSUM
     1,TTEM,TWLI,TWLO,X,XD,XDD12,XDD23,XDD34,XDD45,XKDX,XWI,XWO,Y
      COMMON QO,QI,QRT,QST
      DIMENSION ANRO(101),ANRP(101),ANSO(101),ANSP(101),AR12(101),AR23(1
     101),ARSI(101),ARSO(101),ARSSO(101),ARSTO(101),AS12(101),AS23(101),
     2COND(5),CSUBP(5),CUE(10),CUEI(101),CUEO(101),DATA(201),DD(102,2)
      DIMENSION DTHN(5),DX(5),DXN(5),ER12(101),ER23(101),ERKI(101),ERKO(
     1101),FCI(101),FCO(101),IL(5),IND(20),LBK(30),PROP(5),RHO(5),TAB(40
     22),THCK(5),TI(101),TM(102,4),TO(101),TRKI(101),TRKO(101),TRSI(101)
      DIMENSION TRSO(101),TRSSO(101),TRSTO(101),TSUM(20),TTEM(100),TWLI(
     1101),TWLO(101),X(102,4),XD(5,20,5),XKDX(5)
C
      DO 100 I=2,IWD
      TM(I,2)=TM(I-1,3)*DD(I,1)+TM(I,3)*(1.-DD(I,1))
      TM(I,4)=TM(I,3)*DD(I,2)+TM(I+1,3)*(1.-DD(I,2))
      TM(I,3)=.5*(TM(I,2)+TM(I,4))
  100 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE DOPT(JKL)
C
      COMMON ANRO,ANRP,ANSO,ANSP,AR12,AR23,ARSI,ARSO,ARSSO,ARSTO,AS12,AS
     123,AVACI,AVACO,COND,CSUBP,CUE,CUEI,CUEO,CUESI,CUESO,
     2DATA,DD,DELT,DTHN,DX,DXN,DXNA,DXNB,DXNC,DXND,ER12,ER23
      COMMON ERKI,ERKO,FCI,FCO,HRSOBT,IDATA,IL,IND,INDX,ITPMAX,ITPMIN,IT
     1RN,IVAC,IW,IWALL,IWC,IWD,JDI,JTPR,KL,LBD,LBK,LBN,LT1,LT2,MA,MR,NDA
     2T,NSET,NSETR,NSETS,NWALL,PROP,RBIT,RHO
      COMMON SUMA,TAB,THCK,TI,TM,TO,TRKI,TRKO,TRSI,TRSO,TRSSO,TRSTO,TSUM
     1,TTEM,TWLI,TWLO,X,XD,XDD12,XDD23,XDD34,XDD45,XKDX,XWI,XWO,Y
      COMMON QO,QI,QRT,QST
      DIMENSION ANRO(101),ANRP(101),ANSO(101),ANSP(101),AR12(101),AR23(1
     101),ARSI(101),ARSO(101),ARSSO(101),ARSTO(101),AS12(101),AS23(101),
     2COND(5),CSUBP(5),CUE(10),CUEI(101),CUEO(101),DATA(201),DD(102,2)
      DIMENSION DTHN(5),DX(5),DXN(5),ER12(101),ER23(101),ERKI(101),ERKO(
     1101),FCI(101),FCO(101),IL(5),IND(20),LBK(30),PROP(5),RHO(5),TAB(40
     22),THCK(5),TI(101),TM(102,4),TO(101),TRKI(101),TRKO(101),TRSI(101)
      DIMENSION TRSO(101),TRSSO(101),TRSTO(101),TSUM(20),TTEM(100),TWLI(
     1101),TWLO(101),X(102,4),XD(5,20,5),XKDX(5)
C
      GO TO(100,200,300,400,500,600,700,800,900),JKL
  100 WRITE OUTPUT TAPE LT2,101
  101 FORMAT(10X19HERROR IN INPUT DATA)
      GO TO(110,120,130,140,150),NDAT
  110 WRITE OUTPUT TAPE LT2,111
  111 FORMAT(10X28HONE SURFACE HAS NO HEAT LOAD)
      GO TO 998
  120 WRITE OUTPUT TAPE LT2,121,INDX,IND(INDX)
  121 FORMAT(10X26HINCOMPLETE HEAT LOAD INDX=,I5,5X10HIND(INDX)=,I5)
      GO TO 998
  130 WRITE OUTPUT TAPE LT2,131,INDX,IND(INDX)
  131 FORMAT(10X36HEXCESSIVE NUMBER OF HEAT LOADS INDX=,I5,5X10HIND(INDX
     1)=,I5)
      GO TO 998
  140 WRITE OUTPUT TAPE LT2,141
  141 FORMAT(10X32HINCORRECT INPUT FOR VACUUM LAYER)
      GO TO 998
  150 CONTINUE
      GO TO 999
  200 WRITE OUTPUT TAPE LT2,201,JTPR
  201 FORMAT(/5X20HTESTS PER ORBIT SET=,I5)
      GO TO 999
  300 WRITE OUTPUT TAPE LT2,301,MR
  301 FORMAT(10X34HSOLUTION FAILS TO CONVERGE,CYCLES=,I5)
      GO TO 999
  400 DO 450 I=1,IWC
      WRITE OUTPUT TAPE LT2,401,MA,I,(TM(I,J),J=1,4)
  401 FORMAT(/10X,2I5,4(2X,F10.5))
  450 CONTINUE
      GO TO 999
  500 DO 550 I=1,IW
      IWA=IL(I)
      DO 550 J=1,IWA
      WRITE OUTPUT TAPE LT2,501,I,J,(XD(I,J,KK),KK=1,5)
  501 FORMAT(/1X5HLAYER,I5,5X12HSLICE NUMBER,I5/1X9HOUTSIDE =,F10.5,3X12
     1HLEFT CONST =,F10.5,3X10HMIDPOINT =,F10.5,3X13HRIGHT CONST =,F10.5
     2,3X8HINSIDE =,F10.5)
```

```
550 CONTINUE
    GO TO 999
600 WRITE OUTPUT TAPE LT2,601
601 FORMAT(//5X5HLAYER,5X6HSLICES,6X3HDXN,9X2HDX,10X4HDTHN,8X4HPROP,8X
   14HXKDX)
    DO 650 I=1,IW
    WRITE OUTPUT TAPE LT2,603,I,IL(I),DXN(I),DX(I),DTHN(I),PROP(I),XKD
   1X(I)
603 FORMAT(//2(5X,I5),5(2X,F10.5))
650 CONTINUE
    GO TO 999
700 WRITE OUTPUT TAPE LT2,701,IWALL,MR,MA
701 FORMAT(//10X7HWALL NO,I5,5X8HORBIT NO,I5,5X14HTIME PERIOD NO,I5)
    IWX=1
    DO 750 I=1,IW
    IWX=IWX+IL(I)
    IF(IW-I)750,750,705
705 GO TO(710,720,730,740,750),I
710 TWL12=TM(IWX,3)+XDD12*(TM(IWX+1,3)-TM(IWX,3))
    GO TO 750
720 TWL23=TM(IWX,3)+XDD23*(TM(IWX+1,3)-TM(IWX,3))
    GO TO 750
730 TWL34=TM(IWX,3)+XDD34*(TM(IWX+1,3)-TM(IWX,3))
    GO TO 750
740 TWL45=TM(IWX,3)+XDD45*(TM(IWX+1,3)-TM(IWX,3))
750 CONTINUE
    WRITE OUTPUT TAPE LT2,751,TM(2,1),TM(IWC,1),TWL12,TWL23,TWL34,TWL4
   15
751 FORMAT(10X57HTEMPERATURES  OUTSIDE SURFACE  INSIDE SURFACE  INTERF
   1ACES,2X,6F7.2)
    GO TO  999
800 CUESOS = CUESOS + CUESO
    CUESIS = CUESIS + CUESI
    WRITE OUTPUT TAPE LT2,801,CUESO,CUESI,CUESOS,CUESIS,QO,QI
801 FORMAT(10X52HOUTSIDE AND INSIDE HEAT FLOW RATES AND TOTALS BTU/HR,
   1/6(5XF12.2))
    IF (ITRN-IW)999,810,999
810 WRITE OUTPUT TAPE LT2,811,QRT,QST
811 FORMAT(10X54HINFRARED AND SOLAR ENERGY TRANSMITTED THRU WALL BTU/H
   1R,2F12.2)
    GO TO 999
900 WRITE OUTPUT TAPE LT2,901,IWALL
901 FORMAT(1H1,5X30HSTARTING NEW PROBLEM,WALL NO =,I5)
    CUESOS =0.
    CUESIS=0.
    GO TO 999
998 CALL DUMP
999 CONTINUE
    RETURN
    END
```

```
      SUBROUTINE TEMTRN
C
      COMMON ANRO,ANRP,ANSO,ANSP,AR12,AR23,ARSI,ARSO,ARSSO,ARSTO,AS12,AS
     123,AVACI,AVACO,COND,CSUBP,CUE,CUEI,CUEO,CUESI,CUESO,
     2DATA,DD,DELT,DTHN,DX,DXN,DXNA,DXNB,DXNC,DXND,ER12,ER23
      COMMON ERKI,ERKO,FCI,FCO,HRSOBT,IDATA,IL,IND,INDX,ITPMAX,ITPMIN,IT
     1RN,IVAC,IW,IWALL,IWC,IWD,JDI,JTPR,KL,LBD,LBK,LBN,LT1,LT2,MA,MR,NDA
     2T,NSET,NSETR,NSETS,NWALL,PROP,RBIT,RHO
      COMMON SUMA,TAB,THCK,TI,TM,TO,TRKI,TRKO,TRSI,TRSO,TRSSO,TRSTO,TSUM
     1,TTEM,TWLI,TWLO,X,XD,XDD12,XDD23,XDD34,XDD45,XKDX,XWI,XWO,Y
      COMMON QO,QI,QRT,QST
      DIMENSION ANRO(101),ANRP(101),ANSO(101),ANSP(101),AR12(101),AR23(1
     101),ARSI(101),ARSO(101),ARSSO(101),ARSTO(101),AS12(101),AS23(101),
     2COND(5),CSUBP(5),CUE(10),CUEI(101),CUEO(101),DATA(201),DD(102,2)
      DIMENSION DTHN(5),DX(5),DXN(5),ER12(101),ER23(101),ERKI(101),ERKO(
     1101),FCI(101),FCO(101),IL(5),IND(20),LBK(30),PROP(5),RHO(5),TAB(40
     22),THCK(5),TI(101),TM(102,4),TO(101),TRKI(101),TRKO(101),TRSI(101)
      DIMENSION TRSO(101),TRSSO(101),TRSTO(101),TSUM(20),TTEM(100),TWLI(
     1101),TWLO(101),X(102,4),XD(5,20,5),XKDX(5)
C
      M=MA
      IF (MR)50,50,51
   50 DTMAP=0.
      DTMBP=0.
      DTMCP=0.
      DTMDP=0.
      DTMEP=0.
      DTMGP=0.
      DTMHP=0.
      DTMKP=0.
   51 LW12=1+IL(1)
      QR=CUE(3)*ER12(M)
      QS=CUE(3)-QR
      FR1=1.-AR12(M)-(ARSO(M)*5.78)
      FR2=ANRO(M)
      FR12=SQRTF(FR1*FR2)
      CR1=QR*(FR1-FR12)
      CR12=QR*(FR12-FR2)
      FS1=1.-AS12(M)-(ARSSO(M)*5.78)
      FS2=ANSO(M)
      FS12=SQRTF(FS1*FS2)
      CS1=QS*(FS1-FS12)
      CS12=QS*(FS12-FS2)
      CUE(9)=CUE(9)+CR1
      CUE(8)=CUE(8)+CS1
      DTMA=.5*(DXN(1)+DXN(2))*(CR12+CS12)
      TM(LW12,3)=TM(LW12,3)+DTMA-DTMAP
      DTMAP=DTMA
      GO TO (69,4,5),ITRN
   69 IF (IW-1)100,71,70
   70 DTMB=((FR2*QR)+(FS2*QS))*DXN(2)
      TM(LW12+1,3)=TM(LW12+1,3)+DTMB-DTMBP
      DTMBP=DTMB
      GO TO 100
   71 QRT=QR*FR2
      QST=QS*FS2
      GO TO 100
```

```
  5 FR21=FR2*AVACI
    GO TO 2
  4 FR21=FR2-AR23(M)*FR2
  2 FR3=FR2*ANRP(M)
    FR23=SQRTF(FR3*FR21)
    CR2=QR*FR2*(FR21-FR23)
    CR23=QR*FR2*(FR23-FR3)
    FS3=FS2*ANSP(M)
    FS21=FS2-AS23(M)*FS2
    FS23=SQRTF(FS3*FS21)
    CS2=QS*FS2*(FS21-FS23)
    CS23=QS*FS2*(FS23-FS3)
    GO TO (100,20,3),ITRN
 20 LW23=LW12+IL(2)
    DTMC=.5*(DXN(1)+DXN(2))*(CR2+CS2)
    DTMD=.5*(DXN(2)+DXN(3))*(CR23+CS23)
    TM(LW12+1,3)=TM(LW12+1,3)+DTMC-DTMCP
    TM(LW23,3)=TM(LW23,3)+DTMD-DTMDP
    DTMCP=DTMC
    DTMDP=DTMD
    IF (IW-2)100,22,21
 21 DTME=((FR3*QR)+(FS3*QS))*DXN(3)
    TM(LW23+1,3)=TM(LW23+1,3)+DTME-DTMEP
    DTMEP=DTME
    GO TO 100
 22 QRT=QR*FR3*FR2
    QST=QS*FS3*FS2
    GO TO 100
  3 LW34=LW12+1+IL(3)
    DTMG=.5*(DXN(2)+DXN(3))*(CR2+CS2)
    DTMH=.5*(DXN(3)+DXN(4))*(CR23+CS23)
    TM(LW12+2,3)=TM(LW12+2,3)+DTMG-DTMGP
    TM(LW34,3)=TM(LW34,3)+DTMH-DTMHP
    DTMGP=DTMG
    DTMHP=DTMH
    IF (IW-3)100,22,31
 31 DTMK=((FR3*QR)+(FS3*QS))*DXN(4)
    TM(LW34+1,3)=TM(LW34+1,3)+DTMK-DTMKP
    DTMKP=DTMK
100 IF(JDI)400,400,200
200 WRITE OUTPUT TAPE LT2,301,ITRN,M,LW12,LW23,LW34,QR,QS,TM(LW23+1,3)
   1,TM(LW34,3),TM(LW34+1,3)
301 FORMAT(5X,5I5,5F10.5)
    WRITE OUTPUT TAPE LT2,303,FR1,AR12(M),ARSO(M),FR2,ANRO(M),FR12,CR1
   1,CUE(3),ER12(M),CR12,CUE(9),FS1,AS12(M),FS2,ANSO(M),FS12,CS1,CS12,
   2TM(LW12,3),TM(LW12+1,3)
    WRITE OUTPUT TAPE LT2,303,FR3,ANRP(M),FR21,AR23(M),FR23,CR2,CR23,F
   1S3,ANSP(M),FS21,AS23(M),FS23,CS2,CS23,TM(LW23,3)
303 FORMAT(10X,7F10.5)
400 RETURN
    END
```

```
      SUBROUTINE DISVAC
C
      COMMON ANRO,ANRP,ANSO,ANSP,AR12,AR23,ARSI,ARSO,ARSSO,ARSTO,AS12,AS
     123,AVACI,AVACO,COND,CSUBP,CUE,CUEI,CUEO,CUESI,CUESO,
     2DATA,DD,DELT,DTHN,DX,DXN,DXNA,DXNB,DXNC,DXND,ER12,ER23
      COMMON ERKI,ERKO,FCI,FCO,HRSOBT,IDATA,IL,IND,INDX,ITPMAX,ITPMIN,IT
     1RN,IVAC,IW,IWALL,IWC,IWD,JDI,JTPR,KL,LBD,LBK,LBN,LT1,LT2,MA,MR,NDA
     2T,NSET,NSETR,NSETS,NWALL,PROP,RBIT,RHO
      COMMON SUMA,TAB,THCK,TI,TM,TO,TRKI,TRKO,TRSI,TRSO,TRSSO,TRSTO,TSUM
     1,TTEM,TWLI,TWLO,X,XD,XDD12,XDD23,XDD34,XDD45,XKDX,XWI,XWO,Y
      COMMON QO,QI,QRT,QST
      DIMENSION ANRO(101),ANRP(101),ANSO(101),ANSP(101),AR12(101),AR23(1
     101),ARSI(101),ARSO(101),ARSSO(101),ARSTO(101),AS12(101),AS23(101),
     2COND(5),CSUBP(5),CUE(10),CUEI(101),CUEO(101),DATA(201),DD(102,2)
      DIMENSION DTHN(5),DX(5),DXN(5),ER12(101),ER23(101),ERKI(101),ERKO(
     1101),FCI(101),FCO(101),IL(5),IND(20),LBK(30),PROP(5),RHO(5),TAB(40
     22),THCK(5),TI(101),TM(102,4),TO(101),TRKI(101),TRKO(101),TRSI(101)
      DIMENSION TRSO(101),TRSSO(101),TRSTO(101),TSUM(20),TTEM(100),TWLI(
     1101),TWLO(101),X(102,4),XD(5,20,5),XKDX(5)
C
      TEEF(T)=(T*.01+4.6)**4
      BVCO=1.0001/AVACO
      BVCI=1.0001/AVACI
      CVAC=.173/(BVCO+BVCI-1.)
      IWX=1
      DO 750 I=1,IW
      IWX=IWX+IL(I)
      IF(IW-I)750,750,705
  705 GO TO(710,720,730,740,750),I
  710 TWL12=TM(IWX,3)+XDD12*(TM(IWX+1,3)-TM(IWX,3))
      GO TO 750
  720 TWL23=TM(IWX,3)+XDD23*(TM(IWX+1,3)-TM(IWX,3))
      GO TO 750
  730 TWL34=TM(IWX,3)+XDD34*(TM(IWX+1,3)-TM(IWX,3))
      GO TO 750
  740 TWL45=TM(IWX,3)+XDD45*(TM(IWX+1,3)-TM(IWX,3))
  750 CONTINUE
  401 GO TO(400,402,403,404),IVAC
  402 TAV=TWL12
      TBV=TWL23
      GO TO 405
  403 TAV=TWL23
      TBV=TWL34
      GO TO 405
  404 TAV=TWL34
      TBV=TWL45
  405 IF(ABSF(TAV-TBV)-1.)406,407,407
  406 TAV=TBV+1.
  407 TCV=TEEF(TAV)
      TDV=TEEF(TBV)
      DXN(IVAC)=ABSF((TAV-TBV)/(CVAC*(TCV-TDV)))
      XKDX(IVAC)=.5*DXN(IVAC)
      CALL DISTX
  410 RETURN
      END
```