DOCUMENT NO. 65SD526

Thermodynamics Fundamentals
Memo No. 036
Revision A (October 25, 1965)

COATING SELECTION PROGRAM

PART II
PROGRAM DESCRIPTION
AND USER'S MANUAL

FINAL REPORT ON NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

CONTRACT NASw-960

PERFORMED BY:

THE GENERAL ELECTRIC COMPANY
RE-ENTRY SYSTEMS DEPARTMENT

FOR

THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
600 INDEPENDENCE AVENUE, N.W.
WASHINGTON, D. C.

APRIL 15, 1965

ABSTRACT

N66-15577

A rational and direct method has been developed for selecting the optical coating pattern for the external surface of a spacecraft, such that the spacecraft temperatures are as close as possible to the midpoint of their preselected ranges. The temperature control is maintained passively by radiation and conduction, using no active control devices. The complete range in mission environments is considered in the optimization procedure.

The selection technique has been programmed for use on the GE 600 Series, IBM 7094, or any other computer that uses the standard IBM Fortran IV system.

Author

FOREWORD

This document is a three-part final report on the Coating Selection Program. Part I describes the theory and basis for selection of: (1) the iteration scheme used to solve the heat balance equations; and (2) the optimization scheme. Part II describes the computer program, including the details of each subroutine and the details of input and output. Part II therefore includes the user's manual. Part III presents the Program Listing. Parts II and III have both been revised (Revision A) under a contract extension to incorporate descriptions of the first two month's usage, as well as a new Program Listing with improvements as found advisable during these two months.

The work reported herein was sponsored by the National Aeronautics and Space Administration and was monitored by Mr. Conrad Mook, of NASA-Headquarters, and Mr. Robert Kidwell, Jr., of NASA's Goddard Space Flight Center.

The chief contributors to the work reported were Mr. Frederick A. Costello, Engineer, who developed the techniques, Mr. Thomas P. Harper, Analyst, who converted the techniques to computer form, both of the Re-entry Systems Department's Thermodynamics Technology Component, and Miss Barbara Aston, Programmer-Analyst, from the Spacecraft Department, who programmed the techniques for computer usage.

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ILLUSTRATIONS

TABLES

1.0 INTRODUCTION

To assist in selecting optimum coating patterns for passive spacecraft-temperature control, a digital computer program has been developed. The mathematical bases for the program are described in Part I of this final report. In Part II the details of the computer solution are given, along with sufficient information to enable the designer to use the program as an effective tool.

2.0 PROBLEM STATEMENT

The problem that is solved by the IBM 7094 computer program described herein is as follows:

Given: A space-vehicle design in which the equipment temperatures must be maintained within their allowable limits using passive (coating) means only for all possible flight modes (orbits, attitudes, etc.).

Determine: If the equipment can be temperature-controlled passively and, if not, how close to their limits can the equipment be maintained using coatings only.

3.0 EQUATIONS USED

The temperature of the i^{th} node in the k^{th} orbit is given by the equation:

$$\sum_{j=1}^{N+S} K_{ij}(T_{ik} - T_{jk}) + \sum_{j=1}^{N+S} \sigma R_{ij}(T_{ik}^4 - T_{jk}^4) = \alpha_i(K_{Si}S_{ik} + K_{Ai}A_{ik}) +$$

$$+ \epsilon_i(K_{Ei}E_{ik} - \sigma a_i T_{ik}^4) + K_{Qi}Q_{ik} \qquad (3.1)$$

where the symbols are defined in the nomenclature, Appendix C (Section 9.0). Nodes 1 to N have temperatures governed by Equation (3.1). Nodes (N + 1) to (N + s) are known-temperature nodes.

The program minimizes the temperature deviation parameter

$$\beta = \max_{i,\,k} \beta_{ik}$$

where

$$\beta_{ik} = \max \left[\left(\frac{T_{ik} - T_{iU}}{T_{iU} - T_{iL}} \right) \; ; \; \left(\frac{T_{iL} - T_{ik}}{T_{iU} - T_{iL}} \right) \right] .$$

In other words, the node whose temperature is farthest from its allowable range is brought closer to its allowable range in a step-by-step fashion. Different nodes at different steps may govern the value of β.

4.0 PROGRAM DESCRIPTION BY SUBROUTINE

Figure 1 may be used as a guide in understanding the process described by many of the following subroutines.

START

Certain variables, such as $(K_{Si}S_i+K_{Ai}A_i)$, which are always used together, are combined to speed computation time.

The coating limits are adjusted by 0.001% so that no two α's or ϵ's are equal. This eases the problem of checking to determine if the limits are exceeded.

The initial values of α_i and ϵ_i are determined in this routine, using the equations

$$\epsilon_i a_i \sigma T_i^4 = \alpha_i(K_{Si}S_{ik} + K_{Ai}A_{ik}) + \epsilon_i K_{Ei}E_{ik} + K_{Qi}Q_{ik}$$

and

$$\beta_{ik} = \max \left[\left(\frac{T_{ik} - T_{iU}}{T_{iU} - T_{iL}}\right); \left(\frac{T_{iL} - T_{ik}}{T_{iU} - T_{iL}}\right)\right]$$

where

ϵ_i and α_i are selected such that

$$\max_k \beta_{ik}$$

is a minimum, using the four corner points of the "allowable α - ϵ" diagram (see Form 7 of input sheets).

ARANGE

The constant-temperature terms, $R_{ij}T_{jk}^4$ are added to the internal heat generation term in a further consolidation of terms.

TRANSFM

The input equations are reordered so the external nodes appear first. This saves computation time in the other subroutines. The rearrangement is performed using the transformation matrix, $\overline{P}$, which is a rearrangement of the identity matrix, so that matrices become

$$A'_{ij} = \sum_{k,\ell} \overline{P}_{ik} \overline{P}_{j\ell} A_{k\ell}$$

and vectors become

$$T'_i = \sum_k \overline{P}_{ik} T_k$$

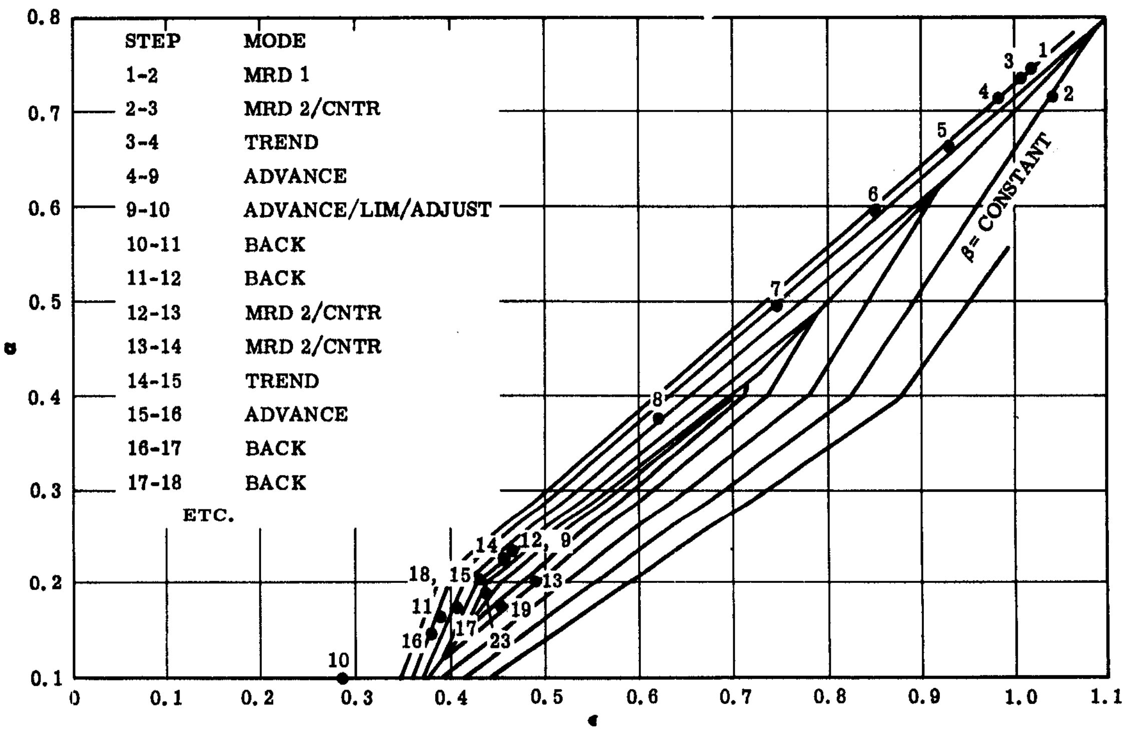

Figure 1. Map of β Surface for One-Node Case

INVRSE

The inverse of the conduction matrix, as augmented by the stability factors, X_i, is calculated in preparation for the iteration process used in MRD1.

MAIN

The calling of all major subroutines is performed in MAIN. Also all required initializations are performed here.

MRD1

The optimization process is started here, using the initially estimated values of α_i and ϵ_i. This subroutine is also used to calculate the temperatures, using the Linearized Matrix Inversion iteration scheme (See Part I).

ONEPT1

The derivatives, $\partial\beta/\partial\alpha$ and $\partial\beta/\partial\epsilon$, are calculated using the equations:

$$\frac{\partial T_{\ell_1 k_1}}{\partial \epsilon_p} = N_{\ell_1 p}\left(K_{Ep} E_{pk_1} - a_p \sigma T^4_{pk_1}\right) \qquad \text{(no sum)}$$

$$\frac{\partial T_{\ell_1 k_1}}{\partial \alpha_p} = N_{\ell_1 p}\left(K_{Sp} S_{pk_1} + K_{Ap} A_{pk_1}\right) \qquad \text{(no sum)}$$

where N is the inverse of P.

$$P_{ij} = \begin{cases} -K_{ij} - 4\,\sigma R_{ij} T^3_{jk_1} & i \neq j \\ \displaystyle\sum_{j=1}^{N+s} \left(K_{ij} + 4\,\sigma R_{ij} T^3_{jk_1}\right) + 4\,\epsilon_i\, a_i\, \sigma\, T^3_{ik_1} & i = j \end{cases}$$

MRD2

Using the derivatives calculated in ONEPT1, the step sizes are determined using the Maximum-Rate-of-Descent technique.

In addition, this routine is used to test the TREND step when necessary. The theory for TREND (Part I) pertains to three consecutive points only. If more than one point intervenes between two iteration points that lie on the same segment (β_{ikl}), it is necessary to determine if the TREND step has a component in the positive MRD direction. If it does, TREND is used; if not, MRD is used.

CNTR

Using the step sizes and directions from MRD2 or STEP, new α_i's and ϵ_i's are calculated, as well as the corresponding temperature, β_{ik}'s, and β.

STEP

If the CNTR result gives the same critical node, orbit, and limit for two consecutive iteration points, and if β increased, then STEP is used to decrease (Δs). Due to the monotonic character of β, STEP would never be used, if the iteration procedure gave the exact temperature. Due to the iteration limit, DT, being greater than zero, there is a possibility that STEP will be used, if the new α - ϵ point gives the critical temperature within DT of the old α - ϵ point.

TEST

A segment of the β-surface is identified by the values of i, k, and l for B_{ikl} where l = 1 implies the lower limit governs and l = 2, the upper. TEST checks to see if the most recent step brought the iteration procedure onto a segment that had previously been used. The check extends back only to the last iteration for which (Δs) was the same as that for the most recent step.

TREND

The TREND step is described in Part I. It corresponds to an extrapolation of the two most recent points on a given segment of β in the direction of the most recent point. The step size and direction are calculated here.

TREND 2

The TREND step is actually taken in this step. Temperatures are calculated as well as β.

ADVNCE

If the TREND extrapolation is successful, it is repeated with a larger step size, as calculated in ADVNCE.

This routine is also used to increase the step size if the result of CNTR gives the same critical node, orbit, and limit for two consecutive iteration points, and if β decreased.

STEP

If the CNTR result gives the same critical node, orbit, and limit for two consecutive iteration points, and if β increased, then STEP is used to decrease (Δs). Due to the monotonic character of β, STEP would never be used, if the iteration procedure gave the exact temperature. Due to the iteration limit, DT, being greater than zero, there is a possibility that STEP will be used, if the new $\alpha - \epsilon$ point gives the critical temperature within DT of the old $\alpha - \epsilon$ point.

TEST

A segment of the β-surface is identified by the values of i, k, and l for B_{ikl} where l = 1 implies the lower limit governs and l = 2, the upper. TEST checks to see if the most recent step brought the iteration procedure onto a segment that had previously been used. The check extends back only to the last iteration for which (Δs) was the same as that for the most recent step.

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If the TREND extrapolation is successful, it is repeated with a larger step size, as calculated in ADVNCE.

This routine is also used to increase the step size if the result of CNTR gives the same critical node, orbit, and limit for two consecutive iteration points, and if β decreased.

BACK

When the TREND step has been extended too far, it is necessary to cut the step size. One reduced-step is used, as calculated in BACK. If this fails to improve β, the second BACK step returns the iteration to the last good TREND point.

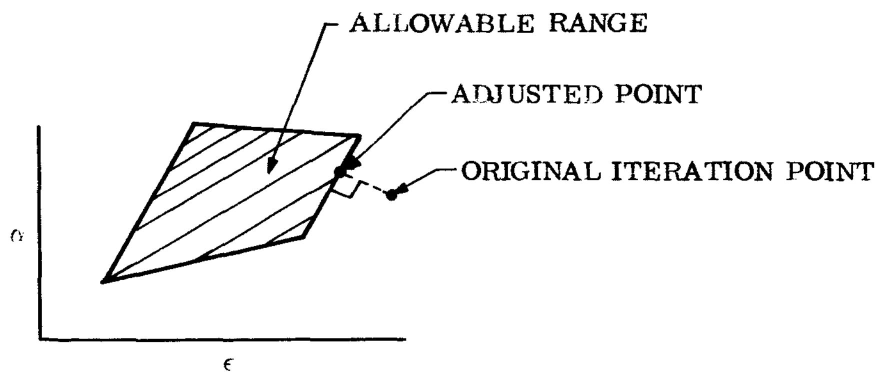
LIM

In LIM, the α_i's and ϵ_i's resulting from a step are checked to determine if the solution is within the allowable limits. It is within the bounds if

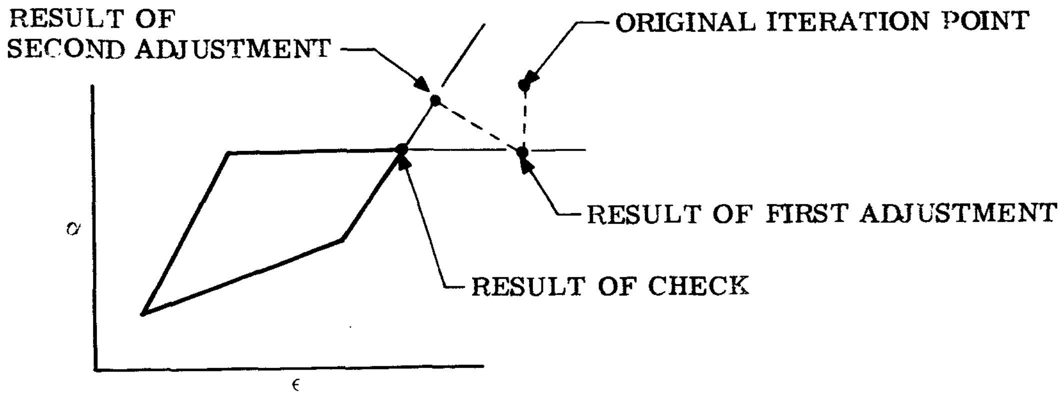
$$(\epsilon_i - \epsilon_{i,n})(\alpha_{i,n+1} - \alpha_{i,n}) - (\alpha_i - \alpha_{i,n})(\epsilon_{i,n+1} - \epsilon_{i,n}) \geq 0 \quad n = 1, 2, \ldots, 5$$

where ϵ_i and α_i is the iteration point in question and $\epsilon_{i,n}$ and $\alpha_{i,n}$ are the corner points in the "allowable α - ϵ" diagram (Form 7). Note that $\epsilon_{i,5} \equiv \epsilon_{i,1}$ and $\alpha_{i,5} \equiv \alpha_{i,1}$.

If LIM finds ϵ_i and α_i outside the allowable limits, then the iteration point is adjusted back to the closest point on the limit line (along a perpendicular through the original iteration point).



It is possible for this adjustment to leave a point outside the allowable limits. A check is made to determine if the new point is still outside the bounds. If it is, the adjusted point is brought to the closest corner point of the α - ϵ Diagram.



INPUT

The title of this subroutine is self-descriptive.

OUTPUT

The title of this subroutine is also self-descriptive.

5.0 INPUT SHEETS

The input sheets for the Coating Selection Program are shown in Figures 2 to 8. The nomenclature of the input is shown on pages 5-3 through 5-10 in the order that it appears on the input sheets. Column 1 lists the name of the input variable as it appears on the input sheet. Column 2 lists the FORTRAN name of the input variable as it appears in the program. Column 3 gives a brief explanation of the input variable. Column 4 lists the units of the input variables. Column 5 defines the input variable to be either fixed point (no decimal point permitted), floating point (decimal point must be included) or alpha-numeric (any combination of characters). The last column states the form number of the input sheets on which the variable is input.

Arrangement of Input Deck

The cards which make up the input deck must be arranged in a certain order prescribed by the program. The cards are to be arranged in the order that they appear on the input sheets. Then blank cards must be inserted into the deck.

Insert blank cards in the following places in the input deck.

1. After the last conduction interconnection data card (Form 3). Even if no conduction terms are included, a blank card is required.

2. After the last radiation interconnection data card (Form 4). Even if no radiation terms are included, a blank card must appear.

3. After last environmental and internal heating data card (Form 5) for last orbit only.

4. After last constant temperature node data card (Form 6). Even if no constant temperature nodes are included, a blank card must appear.

5. After the last coating specifications data card (Form 7).

Conventions Used by Program

To avoid confusion, a brief explanation of the signs of the input variable is given. All input variables are input as positive numbers except for internal heat generation which may or may not be negative. Positive generation implies heat input to the node. The conduction inter-connection between node i and node i is not input. The radiation inter-connection between node i and node i is not input. The conduction inter-connection between node i and node j is positive. The radiation inter-connection between node i and node j is positive.

INPUT SHEET TITLES	FORTRAN	EXPLANATION	UNITS	TYPE OF INPUT	FORM
Identification	TITLE	Any 71 characters, usually used for identification purposes	-	Alpha-numeric	1
Number of Nodes	NNODE	Number of nodes. This number does not include the number of constant-temperature nodes	-	Fixed point (No decimal point!)	1
Number of Orbits	NORB	Number of orbits	-	Fixed Point	1
Number of Constant Temperature Nodes	NCTN	Number of constant temperature nodes	-	Fixed Point	1
Number of Coatings	NCOAT	Number of coatings - not number of patches to be coated	-	Fixed Point	1
Number of External Nodes	NEXND	Number of nodes which have a surface exposed to the external environment	-	Fixed Point	1
Initial Step Size ΔS	DELTA	Increment in α and ϵ to be used in the optimization process	-	Floating Point (must have decimal point)	1
Minimum Step Size ΔS_{MIN}	DELMIN	Minimum (cut-off) value of step size used in the optimization process	-	Floating Point	1
Stephan-Boltzman Constant σ	BOLTZ	Stephan-Boltzman constant usually $.1713 \times 10^{-8}$	$\mathrm{BTU/hr\text{-}ft^2\,(^oR)^4}$	Floating Point	1

INPUT SHEET TITLES	FORTRAN	EXPLANATION	UNITS	TYPE OF INPUT	FORM
All-Temperatures Within Limits	NSTOP(1)	When all temperatures are less than their respective upper temperature limit (TU) and greater than their respective lower temperature limit (TL), the program will exit if NSTOP (1) = 1; if NSTOP (1) = 0, the program will continue	-	Fixed Point	1
K(I, J) ≠ K(J, I)	NSTOP(2)	When K(I, J) ≠ K(J, I), the program will exit if NSTOP(2) = 1. If NSTOP(2) = 0, program will continue. The location of the error will be printed if NSTOP(2) = 1	-	Fixed Point	1
R(I;J) ≠ R(J, I)	NSTOP(3)	When R(I, J) ≠ R(J, I) program will exit if NSTOP(3) = 1, if NSTOP(3) = 0 program will continue. The location of the error will be printed if NSTOP(3) = 1	-	Fixed Point	1
Any temperature less than zero or greater than 10, 000	NSTOP(4)	If any temperature is less than zero or greater than 10, 000, program will exit when NSTOP(4) = 1; if NSTOP(4) = 0, program will continue	-	Fixed Point	1
Program Sets K(J, I) = K(I, J) and R(J, I) = R(I, J) for J >I	NOPTN(1)	If NOPTN(1) = 1, the program will set K(J, I) = K(I, J) and R(J, I) = R(I, J) for J > I. If NOPTN(1) = 0, the program uses input values directly	-	Fixed Point	1

INPUT SHEET TITLES	FORTRAN	EXPLANATION	UNITS	TYPE OF INPUT	FORM
Program Calculates Initial Guess of α 's and ϵ 's	NOPTN(2)	If NOPTN(2) = 1, the program will calculate initial approximation for solar absorptance and infrared emittance. If NOPTN(2) = 0, the program will use the input values as initial approximation	-	Fixed Point	1
Allowable Error in Solving Heat Balance, DTEMP	DTEMP	Allowable difference between temperatures T_i at iteration (n) and iteration (n-1). This is used as a convergence criteria when solving the heat balance equation. Temperature convergence is assumed completed when $\left\| T_i^n - T_i^{n-1} \right\| < DTEMP$	^oR	Floating Point	1
Allowable Deviation from Residual, DR	DR	Allowable error in the residual, r_i This is used as a convergence criteria when solving the heat balance equation. Heat transfer convergence is assumed completed when $\left\| r_i \right\| < DR$	$\frac{BTU}{hr}$	Floating Point	1
Maximum No. of Iterations for Solving Heat Balance	ITERMAX	Maximum number of iterations allowed when solving heat balance equations. If the numbers of iterations required to solve heat balance exceeds this number, the program exits, printing an estimate of the number of iterations still required	-	Floating Point	1

INPUT SHEET TITLES	FORTRAN	EXPLANATION	UNITS	TYPE OF UNIT	FORM
Maximum No. of Iterations for Calculation of α's and ϵ's	MAXG	Program keeps a record of the number of times it calculates new α's and ϵ's. If this number exceeds MAXG, program exits	-	Floating Point	1
Insert to Stop for 1.0 DTEMP ONLY 2.0 DR ONLY 3.0 DTEMP AND DR	NCONV	Option. If DTEMP is to be used only as convergence criteria for solution of the heat balance equation, NCONV is set equal to 1.0. If DR is to be used as only convergence criteria, insert 2.0. If both DTEMP and DR are to be used as convergence criteria, insert 3.0. Use of 3.0 is recommended	-	Floating Point	1
Stability Option	NSO	Stability Option for Solving the heat balance equation. NSO = 1 gives Option 1, a stability factor that is large enough to generate convergence (see Equation B-7 of Part I). NSO = 2 gives Option 2, which uses equation B-11 of Part I to calculate the stability factor. Convergence cannot be guaranteed mathematically but has been found to prevail on all cases to date. Convergence speed is sometimes as large as twice that of Option 1. Option 2 is recommended	-	Floating Point	1
NODE	ND	Node Number	-	Fixed Point	2

INPUT SHEET TITLES	FORTRAN	EXPLANATION	UNITS	TYPE OF INPUT	FORM
TEMPERATURE LIMITS					
Lower	TL(ND)	Lower limit on Temperature for node ND	^oR	Floating Point	2
Upper	TU(ND)	Upper limit on Temperature for node ND	^oR	Floating Point	2
COATING ESTIMATES					
α	ALPA(ND)	Initial approximation of solar absorptance for node ND	-	Floating Point	2
ϵ	EMIS(ND)	Initial approximation of infrared emittance for node ND	-	Floating Point	2
Externally Exposed Area	EXAREA(ND)	Externally exposed area for node ND	ft^2	Floating Point	2
HEAT FLUX MULTIPLIERS					
K_S	HEATKS(ND)	Multiplier of incident solar flux for node ND	ft^2	Floating Point	2
K_A	HEATKA(ND)	Multiplier of incident albedo flux for node ND	ft^2	Floating	2
K_E	HEATKE(ND)	Multiplier of incident earth flux for node ND	ft^2	Floating Point	2

INPUT SHEET TITLES	FORTRAN	EXPLANATION	UNITS	TYPE OF INPUT	FORM
K_Q	HEATKQ(ND)	Multiplier of internal heat generations	-	Floating Point	2
Initial Temperature	TINTL(ND)	Initial approximation of temperature for node ND	^oR	Floating Point	2
Maximum Temperature	TEMMAX(ND)	Maximum expected temperature for node ND	^oR	Floating Point	2
Coating Number	KOAT(ND)	Coating number for node ND. Each node with externally exposed area has a coating pattern	-	Fixed Point	2
I	I1	Node I	-	Fixed Point	3-4
J	J2	Node J	-	Fixed Point	3-4
K(I, J)	CONDUC(I, J)	Conductance between nodes I and J	BTU/hr ^oF	Floating Point	3
R(I, J)	RADTN(I, J)	Product of radiant interchange factor from node I to node J and area of node I	ft^2	Floating Point	4
Orbit Number	KORB	ORBIT number corresponding to environmental and internal heating	-	Fixed Point	5
NODW	I1	Node	-	Fixed Point	5
Solar Heat Flux	SOLFX(I1, KORB)	Incident solar flux on node I1	BTU/hr ft^2	Floating Point	5

INPUT SHEET TITLES	FORTRAN	EXPLANATION	UNITS	TYPE OF INPUT	FORM
Albedo Heat Flux	ALPFX (I1, KORB)	Incident albedo flux on node I1	BTU/hr ft^2	Floating Point	5
Earth Heat Flux	EARFX(I1, KORB)	Incident earth flux on node I1	BTU/hr ft^2	Floating Point	5
Internal Heat Generation	QFX(I1, KORB)	Internal heat generation in node I1	BTU/hr	Floating Point	5
NODE Number	I1	Node number of constant temperature node. Starts with node number (NNODE + 1)	-	Fixed Point	6
ORBIT Number	I2	Orbit number for constant temperature node	-	Fixed Point	6
Temperature	T(I1, I2)	Fixed temperature of node I1 for orbit I2. I1 > NNODE is required	^{o}F	Floating Point	6
Coating Number	KOATN	Coating Number	-	Fixed Point	7
α_1	ASPEC(1)	Solar absorptance for Coating KOATN and limit point 1	-	Floating Point	7
ϵ_1	ESPEC(1)	Infrared emittance for coating KOATN and limit point 1	-	Floating Point	7
α_2	ASPEC(2)	Infrared emittance for coating KOATN and limit point 2	-	Floating Point	7
ϵ_2	ESPEC(2)	Infrared emittance for coating KOATN and limit point 2	-	Floating Point	7

INPUT SHEET TITLES	FORTRAN	EXPLANATION	UNITS	TYPE OF INPUT	FORM
α_3	ASPEC(3)	Infrared emittance for coating KOATN and limit point 3	-	Floating Point	7
ϵ_3	ESPEC(3)	Infrared emittance for coating KOATN and limit point 3	-	Floating Point	7
α_4	ASPEC(4)	Infrared emittance for coating KOATN and limit point 4	-	Floating Point	7
ϵ_4	ESPEC(4)	Infrared emittance for coating KOATN and limit point 4	-	Floating Point	7
Increase ΔS in MRD	USMRD	If an MRD step is successful and the new point is on the same β ik surface (same limit), ΔS is increased by the ratio USMRD	-	Floating Point	8
Decrease ΔS in MRD	DSMRD	If an MRD step is unsuccessful and the new point is on the same β ik surface (same limit), ΔS is decreased by the ratio DSMRD	-	Floating Point	8
Increase ΔS in TREND	USTRN	If a TREND step is successful, ΔS is increased by USTRN times the initial ΔS used in the run	-	Floating Point	8
Decrease ΔS in TREND	DSTRN	Every other time BACK is used twice, ΔS is decreased by the ratio DSTRN	-	Floating Point	8

COATING SELECTION PROGRAM INPUT SHEET

FORM 1

IDENTIFICATION CARD ANY 71 CHARACTERS

1 ← CARD COLUMN → 72

NUMBER OF NODES EXCLUDE CONSTANT TEMPERATURE NODES N (MAX = 34)	NUMBER OF ORBITS K (MAX = 20)	NUMBER OF CONSTANT TEMPERATURE NODES (MAX = 10)	NUMBER OF COATINGS (MAX = 10)	NUMBER OF EXTERNAL NODES (MAX = 34)
← CARD COLUMN →				
1 – 2	3 – 4	5 – 6	7 – 8	9 – 10

INITIAL STEP SIZE Δ S	MINIMUM STEP SIZE Δ S MIN	STEPHAN-BOLTZMAN CONSTANT USUALLY 0.1713×10^{-8}
← CARD COLUMN →		
1 – 5	6 – 12	13 – 26
		E–

STOPS: INSERT 1 TO STOP, OTHERWISE INSERT 0

ALL TEMPERATURES WITHIN LIMITS	$K(I, J) \neq K(J, I)$	$R(I, J) \neq R(J, I)$	ANY TEMPERATURE LESS THAN ZERO GREATER THAN 10000
← CARD COLUMN →			
1	2	3	4

OPTIONS: INSERT 1 FOR OPTION, OTHERWISE INSERT 0

PROGRAM SETS $K(J, I) = K(I, J)$ AND $R(J, I) = R(I, J)$ FOR $J > I$	PROGRAM CALCULATES INITIAL GUESS OF α'S AND ϵ'S
← CARD COLUMN →	
1	2

ALLOWABLE ERROR IN SOLVING HEAT BALANCE — D TEMP	ALLOWABLE DEVIATION FROM RESIDUAL DR	MAXIMUM NO. OF ITERATIONS FOR SOLVING HEAT BALANCE	MAXIMUM NO. OF ITERATIONS FOR CALCULATION OF α'S AND ϵ'S	INSERT TO STOP FOR 1.0 D TEMP ONLY 2.0 DR ONLY 3.0 D TEMP AND DR	STABILITY OPTION FOR SOLVING HEAT BALANCE EQUATION 1.0 OPTION 1 2.0 OPTION 2
← CARD COLUMN →					
1 – 8	9 – 16	17 – 24	25 – 32	33 – 40	41 – 48

SOLAR ABSORPTANCE - α
INFRA-RED EMITTANCE - ϵ
TEMPERATURE - T - ^{0}R
AREA - a - FT^2
HEAT FLUX MULTIPLIERS - K - DIMENSIONLESS

HEAT BALANCE EQUATION:

$$\sum_{\substack{J=1 \\ J \neq I}}^{N+S} K(I,J)\left[T(I,K) - T(J,K)\right] + \sum_{\substack{J=1 \\ J \neq I}}^{N+S} \sigma R(I,J)\left[T(I,K)^4 - T(J,K)^4\right] =$$

$$\alpha(I)\left[K_S(I)\cdot S(I,K) + K_A(I)\cdot A(I,K)\right] + \epsilon(I)\cdot K_E(I)\cdot E(I,K) + K_Q(I)\,Q(I)$$

$$- \epsilon(I)\cdot a(I)\cdot \sigma T(I,K)^4$$

Figure 2. Input Sheet Form 1

COATING SELECTION PROGRAM INPUT SHEET FORM

NODE SPECIFICATION

	TEMPERATURE LIMITS		COATING ESTIMATES		EXTERNALLY EXPOSED AREA	HEAT FLUX MULTIPLIERS OF				INITIAL TEMP	MAX. TEMP		CARD NUMBER
						SOLAR	ALBEDO	EARTH	INTRNL.				
NODE NO.	LOWER	UPPER	α	ϵ	AREA	K_S	K_A	K_E	K_Q	$T_{INITIAL}$	T_{MAX}	COATING NO.	
CARD COLUMN													
1 2	4 8	10 14	16 20	22 26	28 33	35 39	41 45	47 51	53 57	58 6[illegible]	63 67	69 70	73 80

Figure 3. Input Sheet Form 2

COATING SELECTION PROGRAM INPUT SHEET

FORM 3

CONDUCTION INTERCONNECTIONS

NODE I	NODE J	K (I, J)	NODE I	NODE J	K (I, J)	NODE I	NODE J	K (I, J)	CARD NUMBER
← CARD COLUMN →									
4 5	9 10	11 22	26 27	31 32	33 44	48 49	53 54	55 66	73 80

CONDUCTANCE BETWEEN NODE I AND NODE J K(I,J) BTU/HR °R

Figure 4. Input Sheet Form 3

COATING SELECTION PROGRAM INPUT SHEET — FORM 4

RADIATION INTERCONNECTIONS

NODE I	NODE J	R(I,J)	NODE I	NODE J	R (I,J)	NODE I	NODE J	R(I,J)	CARD NUMBER
←				CARD COLUMN					→
4 5	9 10	11 22	26 27	31 32	33 44	48 49	53 54	55 66	73 80

RADIATION FACTOR BETWEEN NODE I AND J — R(I,J) — FT^2

Figure 5. Input Sheet Form 4

COATING SELECTION PROGRAM INPUT SHEET

FORM 5

ORBIT NUMBER

2	3

ENVIRONMENTAL AND INTERNAL HEATING

NODE NO.	SOLAR HEAT FLUX	ALBEDO HEAT FLUX	EARTH HEAT FLUX	INTERNAL HEAT GENERATION	CARD NUMBER
CARD COLUMN					
1 2	10 21	26 37	42 53	58 69	73 80

SOLAR HEAT FLUX – S – BTU/HR

ALBEDO HEAT FLUX – A – BTU/HR

EARTH HEAT FLUX – E – BTU/HR

INTERNAL HEAT GENERATION – Q – BTU/HR

Figure 6. Input Sheet Form 5

COATING SELECTION PROGRAM INPUT SHEET FORM 6

KNOWN TEMPERATURE NODES

NODE NUMBER	ORBIT NUMBER	TEMPERATURE	CARD NUMBER
← CARD COLUMN →			
1 – 2	4 – 5	10 – 21	73 – 80

TEMPERATURE -- T – °R

NODE NUMBERS BEGIN WITH (N + 1) AND END WITH (N + S)

Figure 7. Input Sheet Form 6

COATING SELECTION PROGRAM INPUT SHEET FORM 7

COATING SPECIFICATIONS

COATING NUMBERS	POINT 1		POINT 2		POINT 3		POINT 4		CARD NUMBER
	α_1	ϵ_1	α_2	ϵ_2	α_3	ϵ_3	α_4	ϵ_4	
CARD COLUMN									
1 2	5 10	13 18	21 26	29 34	37 42	45 50	53 58	61 66	73 80

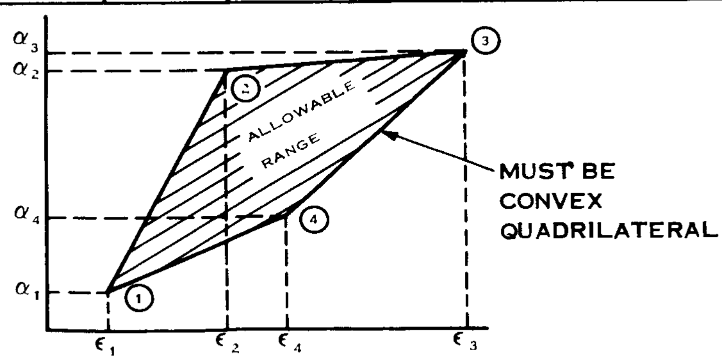


Figure 8. Input Sheet Form 7

COATING SELECTION PROGRAM INPUT SHEET FORM 8

STEP CHANGE PROCEDURE

INCREASE Δs IN MRD	DECREASE Δs IN MRD	INCREASE Δs IN TREND	DECREASE Δs IN TREND	CARD NUMBER
← CARD COLUMN →				
1 6	7 12	13 18	19 24	73 80

Figure 9. Input Sheet Form 8

6.0 OPERATING EXPERIENCE

It is to be recognized that operating experience will lead to operating efficiency for any computer program. The purpose of this section is to summarize the operating experience obtained in the first few months usage of the Coating Selection Program.

6.1 Initial Values of α and ϵ

The program uses the equations given in Section 4.0 to calculate the initial values of α and ϵ. It has been found that, of all the simple techniques tried, this gives the best value in terms of β. It has also been found that the engineer's inituition is usually superior to the simple procedure of Section 4.0.

6.2 Step Size

If NEXT is the number of external nodes, it is recommended that the initial step size be

$$\Delta S = 0.1 \sqrt{N_{EXT}}$$

if the allowable ranges in α and ϵ are approximately 0.5.

Good results are obtained if the step size is held constant for the entire run. That is, if Form 8 of the input sheets reads

1.0 1.0 0.0 1.0

A better understanding of the adequacy of the initial step size is obtained if 20% step-change increments are used, so Form 8 reads

1.2 0.8 0.2 0.64

The 0.64 arises since the reduction procedure is applied only every second time TREND fails. If the initial step size is too large, the 20% reduction procedure will tend to decrease it, but not to the point where the α and ϵ changes are insignificant.

6.3 Stability Option

Stability Option #2 has not failed in any cases attempted to date. In one case the maximum temperature of one node exceeded the estimated maximum, but convergence was still obtained.

6.4 The Iteration Process

The maximum anticipated temperatures and the condition of the conduction-plus-radiation matrix determine the running time and the most suitable values of the iteration limits, D_{Temp} and DR. The interdependence of the various factors can be recognized from the analysis given in Appendix C.

6.4.1 Selecting D_{Temp} and DR

As suggested in Appendix C, for completely new problems, it is necessary to make at least two computer runs to determine a suitable value for DR. If ΔC_i is the change from one orbit to the next in environmental fluxes absorbed by node 'i', then the two runs can be made with, for example

$$DR_1 = 0.001 \max_i \Delta C_i$$

$$DR_2 = 0.01 \max_i \Delta C_i$$

The resultant temperatures will deviate from their equilibrium values by

$$\frac{\max_i \left| T_i^{(n)} - T_i^{(\infty)} \right|}{DR} = \frac{\max_i \left| T_i^{(2)} - T_i^{(1)} \right|}{DR_2 - DR_1}$$

If a one degree error is permissible, this equation can be used to estimate the required value of DR.

The D_{Temp} iteration limit is not reliable, since it can be satisfied even if the solution is far from the correct one if the rate of convergence is slow enough. A nominal value of one degree will usually ensure that at least two iterations are taken. For this size, D_{Temp}, DR usually governs when the iteration process is terminated. D_{Temp} would be on the order of 0.001 if it were to govern termination.

6.4.2 Running Times

Appendix C shows the relationship between r_i and the $T_i^{(max)}$ estimate. At least to an approximate degree, the running time is inversely proportional to

$$\log (1 - \tau^3)$$

where

$$\tau = \frac{T^{(\infty)}}{T^{(max)}}$$

Therefore, if the running time is known for one case, the running time can be estimated for the second case by the equation

$$\frac{\theta_2}{\theta_1} = \frac{\log (1 - \tau_1^3)}{\log (1 - \tau_2^3)}$$

For example, if $\tau_1 = 2/3$ and $\tau_2 = 1/2$, $\theta_2/\theta_1 = 2.6$. If $\tau_2 = 0.9$, $\theta_2/\theta_1 = 0.27$.

Another factor that affects running time is the condition of the matrix. If the internal conduction and radiation terms are large compared to the external radiation terms, the spectral radius of the iteration matrix will be near unity and convergence will be slow. There is no convenient measure of this almost-singular behavior, although the ratio

$$\Gamma = \frac{\epsilon_i \sigma a_i T_i^{(\infty)^3}}{\bar{A}_{ii} + \bar{M}_{ii}}$$

can be used as a rough indication. If Γ is small (0.01 for all nodes), convergence will be slow.

From the above discussion, it is evident that a general equation for running times is not possible for the Coating Selection Program. Paragraph 6.7 shows some examples that may be useful in estimating time requirements. It is recommended that the first run of a new problem be limited to 10 minutes.

6.5 Analyzing Cases

The Coating Selection Program is a tool - not a panacea. It is not expected to be practical for the engineer to mechanically enter the design conditions and have the computer mechanically calculate the optimized solution. It has proven in the past, and will probably continue to prove more effective for the engineer to use his knowledge of the physical aspects of the problem to analyze the results of the computer calculations. In this section some ideas are given for methods of analyzing the results.

6.5.1 Maps

A graph showing the α- ϵ values for each node for each iteration (See Figure 14, Appendix D) is a great aid in understanding

(a) if the step-size is appropriate;

(b) if the step-size change rates are appropriate;

(c) what the general trend of the solution is;

(d) which are the most influential nodes; and

(e) what the effects of initial conditions are.

The best procedure is to plot the initial conditions and the final (best-β) conditions, then to insert intermediate points as required to indicate the progression of each α - ϵ pair.

6.5.2 Worst β's

Under ideal conditions, all the β_{ik} values would be equal. For most cases, however, there are only two or three β_{ik}'s that are equal. A listing of the maximum β_{ik}'s gives some indication of how close the solution is to the best attainable, especially if some of the temperatures are at their upper limits and others at their lower limits. For example, a listing as follows:

Node	Orbit	Limit	β
1	2	U	-0.300
1	3	L	-0.300
1	1	U	-0.303
2	4	L	-0.305
5	2	L	-0.306

would indicate that the solution was approximately optimum. If α were descreased to lower the temperature for node 1, orbit 2 and thereby decrease β for orbit 2, it would also decrease the temperature for node 1, orbit 3 and, therefore, increase β for orbit 3. Hence, the conclusion is drawn that the best solution has been attained.

A listing such as

Node	Orbit	Limit	β
1	2	U	-0.300
1	3	U	-0.300
1	1	U	-0.310
2	4	L	-0.320
5	2	L	-0.330

is less conclusive, since all the node-1 cases are at their upper limits.

A listing such as

Node	Orbit	Limit	β
1	2	U	-0.300
1	3	U	-0.350
1	1	U	-0.400
2	4	U	-0.450
5	2	U	-0.450

is reasonably conclusive in that the optimum has not been attained.

Further experience is required to determine how to judge the intermediate cases. Unfortunately the experience will probably be particular to each case. Section 6.7 gives some examples.

6.6 Recommended Procedures

6.6.1 General

It is recommended that the following procedure be used in applying the Coating Selection Program:

a) Estimate, by intuition if necessary, the best initial values of α and ϵ. If such an estimate is impossible due to a lack of understanding of the physical problem, let the computer select the initial values.

b) Set

$$\Delta S = 0.1 \sqrt{N_{EXT}}$$

and the ΔS change rates (Form 8) to 1.2, 0.8, 0.2, 0.64.

c) Use Stability Option 2

d) Set $\Delta T = 1.0$

e) Make two runs (two iterations each) with different values of DR:

$$DR_1 = 0.001 \max_i \Delta C_i$$

$$DR_2 = 0.01 \max_i \Delta C_i$$

Calculate the required DR from the equation

$$DR = E \cdot \left[\frac{DR_2 - DR_1}{\max_i (T_i^{(2)} - T_i^{(1)})} \right]$$

where E is the allowable error in the temperature calculation (usually 1 or 2 F^{o}). Calculate DR/E for both iterations and use the smaller value in the above equations.

f) From the temperatures calculated for the above trials, estimate new initial values of α and ϵ.

g) Run the new DR and α - ϵ values for approximately 10 iterations or 10 minutes running time, whichever is the maximum.

h) Map the progress of the α - ϵ optimization procedure. If the movement is small and the final ΔS is equal to or larger than the initial value, increase the ΔS. If ΔS has been reduced by the program, reduce the initial value of ΔS. If neither of these conditions is evident, use the same initial ΔS. Do not re-run unless Step (i) so indicates.

i) Calculate approximately the five largest β_{ik}'s

$$\beta_{ik} = \max \left(\frac{T_{ik} - T_{iU}}{T_{iU} - T_{iL}} \; ; \; \frac{T_{iL} - T_{ik}}{T_{iU} - T_{iL}} \right)$$

List the node, orbit, upper or lower limit, and β value for these largest β_{ik}'s. Judge from this if further gains are possible. If they are, re-run, starting at the best - β point of the previous runs.

j) Repeat steps (g), (h), and (i) until the best possible solution is obtained. The number of iterations and running time should be adjusted to suit the problem.

6.6.2 Special

There are instances in which either α or ϵ or both must remain fixed for some nodes. The values can be fixed by specifying a small restriction box around the required α - ϵ values (see Form 7). A more efficient means is as follows:

a) fixed α: Let

$$\left[K_{Qi}\ Q_{ik}\right]_{New} = \alpha_i \left(K_{Si}\ S_{ik} + K_{Ai}\ A_{ik}\right) + K_{Qi}\ Q_{ik}$$

and then set

$$K_{Si} = 0.0$$

$$K_{Ai} = 0.0$$

b) fixed ϵ: Let

$$\left[K_{Qi}\ Q_{ik}\right]_{New} = \epsilon_i\ K_{Ei}\ E_{ik} + K_{Qi}\ Q_{ik}$$

$$R_{ij_1} = \epsilon_i\ a_i$$

$$T_{j_1, k} = 0.0$$

where j_1 is the number of a constant temperature node (at 0° R).

6.7 Examples

6.7.1 EPE-D (Explorer XXVI)

The NASA EPE-D is described in Volume I. For reference purposes, the input data is shown in Appendix D. The results of the recommended procedures were as follows:

a) The computer was used to obtain the initial values of α and ϵ.

b) ΔS of 0.1 was used to determine the DR requirements, since this data was available from runs made while establishing the procedure.

c) Stability Option 2 was used.

d) D_{Temp} was set equal to 1.0.

e) The results of the DR check were:

Case	DR	$\max\limits_i \left\| T_i^{(n)} - T_i^{(1)} \right\|$	$\frac{E}{DR}$
1	0.01	-	-
2	0.10	0.16	1.78
3	5.00	9.09	1.85

For $E = 1.0^{o}F$, $DR = 0.54$

f) Initial values of α and ϵ were estimated using the temperatures calculated in the DR check. The initial values are shown in Appendix D.

g) A ten-minute run was made, the results of which are shown on Figure 13 (Appendix D).

h) Figure 14 (Appendix D) shows the α - ϵ map.

i) Since Node 17 governs so predominantly, another run would have been warranted had this not been a demonstration problem. β's as low as -0.126 had been attained in the cases used to develop the procedure.

Running times for this 20-node problem were approximately 3 minutes plus 0.3 minutes per iteration.

6.7.2 S-52

The input data for the NASA S-52 is shown in Appendix E. The results of the recommended procedure were as follows:

a) The computer was used to obtain the initial values of α and ϵ.

b) ΔS of 0.2 was used to determine the DR requirements, since this data was available.

c) Stability Option 2 was used.

d) D_{Temp} was set equal to 1.0.

e) The results of the DR check were

Case	DR	$\max_i \left| T_i^{(n)} - T_i^{(1)} \right|$	$\frac{E}{DR}$
1	0.2	-	-
2	0.2	0.10	-
3	1.0	1.55	1.94

Case 2 differed from Case 1 only in that the maximum temperatures were 990^o for Case 2 rather than 750^{o}R. The solutions were approximately 500^{o}R. For $E = 1.0^oF$, $DR = 0.52$.

f) Initial values of α and ϵ were estimated using the temperatures calculated in the DR check. The initial values are shown in Appendix E.

g) A ten-minute run was made, the results of which are shown on Figure 15 (Appendix E).

h) Figure 16 (Appendix E) shows the α - ϵ map.

i) Since the two worst β's are not equal, further improvement is possible. β's as low as - 0.198 had been attained in the computer runs used in establishing the procedures.

Running times for this 34 node problem were approximately 6 minutes plus 0.4 minutes per iteration.

6.7.3 IMP-C

The input data for the IMP-C is shown in Appendix F. The results of the recommended procedure were as follows:

a) The computer was used to obtain the initial values of α and ϵ.

b) ΔS of 0.4 was used to determine the DR requirements, since this data was available.

c) Stability Option 2 was used.

d) D_{Temp} was set equal to 1.0.

e) The results of the DR check were

Case	DR	$\max_i \left\lvert T_i^{(n)} - T_i^{(1)} \right\rvert$	$\frac{E}{DR}$
1	0.2	-	-
2	0.2	0.02	-
3	1.0	1.23	1.54

Case 2 differed from Case 1 only in that the maximum temperatures were 990°R for Case 2 rather than 750°R. The solutions were approximately 400°R. For E = 1.0°F, DR = 0.65.

f) Initial values of α and ϵ were estimated using the temperatures calculated in the DR check. The initial values are shown in Appendix F.

g) A ten-minute run was made (7 iterations) and the temperatures were still out of range. Two more twenty-minute runs (29 iterations each) were made, yielding, finally, a negative β. The results are shown on Figure 17 (Appendix F).

h) Figure 18 (Appendix F) shows the α - ϵ map. The three runs are all shown on this one diagram.

i) Little improvement in β is likely, since orbits 3 and 5 have nearly equal β's, one an upper limit, the other a lower limit.

Running times for this 34-node problem were approximately 6 minutes plus 0.4 minutes per iteration.

7.0 OUTPUT SHEETS

The following pages of this section show the output sheets for the sample case considered in Section 8. The sheets essentially are self-explanatory. There is one input check that needs explanation.

If one node has no entry in the conduction or radiation interconnections (K_{ij} or R_{ij}), either directly as input or implied by symmetry, the program will not run. The computer prints

DIAGONAL NOT GREATER THAN ZERO

Two checks are made during the computer run. Since the solution to the heat balance equations involves a matrix inversion, the accuracy of the inverse is checked. The heat fluxes are set to give all the temperatures equal to 1.0, if the inverse is exactly correct. The computer prints out the actual temperature calculated. Usually the single precision inversion is accurate to 5 places.

If the heat balance iteration process does not converge within the prescribed number of iterations, the program prints the last two values of the temperature changes (T1 and T2) and the residual vector (R1 and R2). It also prints an estimate of the number of iterations still required to obtain the solution. DELNT is the number of additional iterations based on the DT limit and DELNR is based on the DR limit. The estimate is made for each node based on an exponential decay in $[T^{(n+1)} - T^{(n)}]$ and $r^{(n)}$.

```
SAMPLE CASE FOR FINAL REPORT 4 EXTERNAL NODES

                                        COATING SELECTICN PROGRAM

    NUMBER OF NODES  =   5

    NUMBER OF ORBITS =  10

    NUMBER OF CONSTANT TEMPERATURE NODES  =   0

    NUMBER OF COATINGS =  1

    NUMBER OF EXTERNAL NODES =  4

    INITIAL STEP SIZE  (DELTA) =  0.100

    MINIMUM STEP SIZE  (DELTA-MIN)  = 0.00100

    STEPHAN BOLTZMANN CONSTANT =   1.71299998E-09

    THE PROGRAM WILL STOP IF

    K(I,J) DOES NOT EQUAL K(J,I)

    R(I,J) DOES NOT EQUAL R(J,I)

    ANY TEMPERATURE IS  LESS THAN 0 OR GREATER THAN 100000.


    ALLOWABLE TEMPERATURE ERROR IN SOLVING HEAT BALANCE   =    1.00000000E 00

    ALLOWABLE DEVIATION FROM THE RESIDUAL =    2.00000000E 00

    MAXIMUM NUMBER OF ITERATIONS = 100

    MAXIMUM G ALLOWED = 100

    STABILITY OPTION FOR SOLVING HEAT BALANCE EQUATION =  2
```

NODE SPECIFICATION

NODE	TEMPERATURE LIMITS LOWER	UPPER	COATING ESTIMATES ALPHA	EPSILON	EXTERNALLY EXPOSED AREA	HEAT FLUX MULTIPLIES OF SOLAR	ALBEDO	EARTH	INTERNAL	INITIAL TEMP	MAX TEMP EXPECTED	COATING NUMBER
1	200.00000	800.00000	0.50000	0.80000	3.920000E 01	39.20	39.20	39.20	39.20	500.00	800.00	1
2	200.00000	800.00000	0.50000	0.80000	3.920000E 01	39.20	39.20	39.20	39.20	500.00	800.00	1
3	200.00000	800.00000	0.50000	0.80000	3.920000E 01	39.20	39.20	39.20	39.20	500.00	800.00	1
4	200.00000	800.00000	0.50000	0.80000	3.920000E 01	39.20	39.20	39.20	39.20	500.00	800.00	1
5	525.00000	545.00000	0.	0.	0.	1.00	1.00	1.00	1.00	500.00	800.00	0

CONDUCTION INTER-CONNECTIONS

FROM NODE	TO NODE	CONDUCTION INTER-CONNECTION	FROM NODE	TO NODE	CONDUCTION INTER-CONNECTION	FROM NODE	TO NODE	CONDUCTION INTER-CONNECTION
1	2	8.4999999E-01	1	4	8.4999999E-01	2	1	8.49999988E-01
2	3	8.4999999E-01	3	2	8.4999999E-01	3	4	8.49999988E-01
4	3	8.4999999E-01	4	1	8.4999999E-01	-0	-0	-0.

RADIATION INTER-CONNECTIONS

FROM NODE	TO NODE	RADIATION INTER-CONNECTION	FROM NODE	TO NODE	RADIATION INTER-CONNECTION	FROM NODE	TO NODE	RADIATION INTER-CONNECTION
1	5	1.9600000E 00	2	5	1.9600000E 00	3	5	1.95999999E 00
4	5	1.9600000E 00	5	1	1.9600000E 00	5	2	1.95999999E 00
5	3	1.9600000E 00	5	4	1.9600000E 00	-0	-0	-0.

ENVIRONMENTAL AND INTERNAL HEATING ORBIT 1

NODE	SOLAR FLUX	ALBEDO FLUX	EARTH FLUX	HEAT GENERATION
1	7.7100	0.	6.3600	0.
2	226.2000	0.	6.3600	0.
3	173.1000	0.	53.4000	0.
4	23.7000	0.	53.4000	0.
5	0.	0.	0.	489.0000

ENVIRONMENTAL AND INTERNAL HEATING ORBIT 2

NODE	SOLAR FLUX	ALBEDO FLUX	EARTH FLUX	HEAT GENERATION
1	43.8000	0.	6.3600	0.
2	177.1000	0.	6.3600	0.
3	94.3000	0.	53.4000	0.
4	41.6000	0.	53.4000	0.
5	0.	0.	0.	489.0000

ENVIRONMENTAL AND INTERNAL HEATING ORBIT 3

NODE	SOLAR FLUX	ALBEDO FLUX	EARTH FLUX	HEAT GENERATION
1	103.5000	0.	6.3600	0.
2	103.5000	0.	6.3600	0.
3	55.5000	0.	53.4000	0.
4	55.5000	0.	53.4000	0.
5	0.	0.	0.	489.0000

ENVIRONMENTAL AND INTERNAL HEATING ORBIT 4

NODE	SOLAR FLUX	ALBEDO FLUX	EARTH FLUX	HEAT GENERATION
1	177.1000	0.	6.3600	0.
2	43.8000	0.	6.3600	0.
3	41.6000	0.	53.4000	0.
4	94.3000	0.	53.4000	0.
5	0.	0.	0.	489.0000

ENVIRONMENTAL AND INTERNAL HEATING ORBIT 5

NODE	SOLAR FLUX	ALBEDO FLUX	EARTH FLUX	HEAT GENERATION
1	226.2000	0.	6.3600	0.
2	7.7100	0.	6.3600	0.
3	23.7000	0.	53.4000	0.
4	173.1000	0.	53.4000	0.
5	0.	0.	0.	489.0000

ENVIRONMENTAL AND INTERNAL HEATING ORBIT 6

NODE	SOLAR FLUX	ALBEDO FLUX	EARTH FLUX	HEAT GENERATION
1	5.8300	0.	4.5400	0.
2	198.3000	0.	4.5400	0.
3	145.9000	0.	38.6000	0.
4	15.3000	0.	38.6000	0.
5	0.	0.	0.	489.0000

ENVIRONMENTAL AND INTERNAL HEATING ORBIT 7

NODE	SOLAR FLUX	ALBEDO FLUX	EARTH FLUX	HEAT GENERATION
1	36.9000	0.	4.5400	0.
2	154.3000	0.	4.5400	0.
3	69.0000	0.	38.6000	0.
4	22.6000	0.	38.6000	0.
5	0.	0.	0.	489.0000

ENVIRONMENTAL AND INTERNAL HEATING ORBIT 8

NODE	SOLAR FLUX	ALBEDO FLUX	EARTH FLUX	HEAT GENERATION
1	89.2000	0.	4.5400	0.
2	89.2000	0.	4.5400	0.
3	30.5000	0.	38.6000	0.
4	30.5000	0.	38.6000	0.
5	0.	0.	0.	489.0000

ENVIRONMENTAL AND INTERNAL HEATING ORBIT 9

NODE	SOLAR FLUX	ALBEDO FLUX	EARTH FLUX	HEAT GENERATION
1	154.3000	0.	4.5400	0.
2	36.9000	0.	4.5400	0.
3	22.6000	0.	38.6000	0.
4	69.0000	0.	38.6000	0.
5	0.	0.	0.	489.0000

ENVIRONMENTAL AND INTERNAL HEATING ORBIT 10

NODE	SOLAR FLUX	ALBEDO FLUX	EARTH FLUX	HEAT GENERATION
1	198.3000	0.	4.5400	0.
2	5.8300	0.	4.5400	0.
3	15.3000	0.	38.6000	0.
4	145.9000	0.	38.6000	0.
5	0.	0.	0.	489.0000

COATING SPECIFICATIONS

COATING NUMBER	LIMIT POINT 1		LIMIT POINT 2		LIMIT POINT 3		LIMIT POINT 4	
	ALPHA	EPSILON	ALPHA	EPSILON	ALPHA	EPSILON	ALPHA	EPSILON
1	0.100000	0.100000	0.900000	0.100000	0.900000	0.900000	0.100000	0.900000

STEP CHANGE PROCEDURE

IN MRD		IN TREND	
INCREASE	DECREASE	INCREASE	DECREASE
1.200	0.400	1.000	0.200

ERROR IN INVERSION

NODE	ERROR
1	9.99999940E-01
2	9.99999940E-01
3	9.99999976E-01
4	9.99999976E-01
5	1.00000000E 00

WOULD ALL BE 1.0 IF INVERSION WERE EXACT

```
SAMPLE CASE FOR FINAL REPORT 4 EXTERNAL NODES
 MODE    MRD1            ITERATION    1    NO. OF SURFACES ENCOUNTERED SINCE LAST TREND STEP     1  DELTA S =-0.00000
              BETA             NODE      ORBIT    LIMIT     MINIMUM BETA OCCURRED AT ITERATION   NODE  ORBIT LIMIT
          5.39958954E-01         5         5      UPPER      5.39959E-01               1           5     5   UPPER

        NODE       ABSORPTIVITY    EMISSIVITY
          1        0.50000000      0.80000000
          2        0.50000000      0.80000000
          3        0.50000000      0.80000000
          4        0.50000000      0.80000000
```

INPUT VALUES

ABSORPTIVITY AND EMISSIVITY CALCULATED IN THIS SUBROUTINE

TEMPERATURE VALUES

NODE \ ORBIT	1	2	3	4	5	6	7	8	9	10
1	355.65	402.94	458.98	510.44	538.76	340.19	384.89	439.74	491.03	519.69
2	538.76	510.44	458.98	402.94	355.65	519.69	491.03	439.74	384.89	340.19
3	551.88	507.64	480.04	469.12	455.48	522.86	470.73	435.80	427.85	422.04
4	455.48	469.12	480.04	507.64	551.88	422.04	427.85	435.80	470.73	522.86
5	555.80	545.72	540.22	545.72	555.80	539.33	526.93	520.12	526.93	539.33

SAMPLE CASE FOR FINAL REPORT 4 EXTERNAL NODES

NODE	PARTIAL BETA W/R TO ALPHA	PARTIAL BETA W/R TO EPSILON
1	1.00142938E-01	-6.10796934E-02
2	3.41336015E-03	-9.31736839E-03
3	1.04924302E-02	-9.00111008E-03
4	7.66345859E-02	-4.67088693E-02

$\frac{\partial \beta}{\partial \alpha}$ $\frac{\partial \beta}{\partial \epsilon}$

```
SAMPLE CASE FOR FINAL REPORT 4 EXTERNAL NODES

MODE    CNTR             ITERATION     1    NO. OF SURFACES ENCOUNTERED SINCE LAST TREND STEP     2  DELTA S = 0.10000

           BETA            NODE      ORBIT    LIMIT     MINIMUM BETA OCCURRED AT ITERATION   NODE  ORBIT LIMIT

        4.55513000E-01       5         1      UPPER      4.55513E-01                 1         5     1   UPPER


       NODE      ABSORPTIVITY    EMISSIVITY
         1       0.43264189     0.84108340
         2       0.49770410     0.80626704
         3       0.49294258     0.80605432
         4       0.44845407     0.83141730
```

TEMPERATURE VALUES

NODE \ ORBIT	1	2	3	4	5	6	7	8	9	10
1	350.53	391.58	441.94	489.28	515.55	335.42	374.07	423.28	470.48	497.11
2	537.05	508.58	456.80	400.13	351.68	518.03	489.22	437.59	382.05	336.14
3	549.86	505.99	478.53	467.43	453.53	520.86	469.20	434.43	426.22	419.95
4	452.01	463.79	473.34	498.27	538.90	418.97	423.66	430.40	461.96	509.95
5	554.11	543.06	535.96	539.18	547.05	537.85	524.71	516.39	520.94	531.09

SAMPLE CASE FOR FINAL REPORT 4 EXTERNAL NODES

NODE	PARTIAL BETA W/R TO ALPHA	PARTIAL BETA W/R TO EPSILON
1	3.29304209E-03	-8.32985878E-03
2	1.00093700E-01	-6.02417290E-02
3	7.66312182E-02	-4.56807876E-02
4	1.02043739E-02	-7.79526526E-03

SAMPLE CASE FOR FINAL REPORT 4 EXTERNAL NODES

```
MODE    CNTR             ITERATION    2    NO. OF SURFACES ENCOUNTERED SINCE LAST TREND STEP     3  DELTA S = 0.10000

            BETA            NODE      ORBIT     LIMIT     MINIMUM BETA OCCURRED AT ITERATION   NODE  ORBIT LIMIT

        6.12440485E-01        5          8      LOWER       4.55513E-01                 1          5     1   UPPER
```

NODE	ABSORPTIVITY	EMISSIVITY
1	0.43041421	0.84671837
2	0.42999283	0.84701929
3	0.44110318	0.83695640
4	0.44155102	0.83669063

TEMPERATURE VALUES

NODE \ ORBIT	1	2	3	4	5	6	7	8	9	10
1	346.70	388.80	439.84	487.52	513.98	331.47	371.25	421.19	468.76	495.58
2	513.83	487.39	439.76	388.74	346.69	495.43	468.64	421.13	371.20	331.47
3	536.90	496.65	471.88	462.14	450.13	507.97	460.45	429.13	422.07	416.97
4	450.15	462.18	471.93	496.72	537.00	416.98	422.11	429.15	460.51	508.08
5	545.41	536.53	531.73	536.54	545.46	529.65	518.74	512.75	518.75	529.70

SAMPLE CASE FOR FINAL REPORT 4 EXTERNAL NODES

NODE	PARTIAL BETA W/R TO ALPHA	PARTIAL BETA W/R TO EPSILON
1	-4.75581056E-02	2.63233143E-02
2	-4.75435919E-02	2.62974653E-02
3	-1.64252239E-02	1.04969606E-02
4	-1.64297581E-02	1.05069758E-02

```
SAMPLE CASE FOR FINAL REPORT 4 EXTERNAL NODES

MODE     CNTR              ITERATION    41    NO. OF SURFACES ENCOUNTERED SINCE LAST TREND STEP     3  DELTA S = 0.00239

           BETA             NODE      ORBIT    LIMIT     MINIMUM BETA OCCURRED AT ITERATION   NODE  ORBIT LIMIT

        2.84226605E-01       5          8      LOWER      2.84227E-01                 41         5     8   LOWER


      NODE       ABSORPTIVITY     EMISSIVITY
        1         0.54306658      0.80264252
        2         0.54065933      0.79787151
        3         0.38043698      0.86209663
        4         0.38396161      0.86193062
```

TEMPERATURE VALUES

NODE \ ORBIT	1	2	3	4	5	6	7	8	9	10
1	355.46	406.42	465.36	518.57	547.43	339.99	388.43	446.14	498.99	528.06
2	547.56	518.70	465.51	406.59	355.71	528.18	499.12	446.28	388.59	340.24
3	524.86	488.96	466.96	458.15	447.45	496.19	453.81	426.18	419.65	414.82
4	447.55	458.36	467.24	489.39	525.52	414.89	419.79	426.38	454.21	496.84
5	550.53	542.53	537.82	542.57	550.65	534.71	525.00	519.32	525.04	534.83

SAMPLE CASE FOR FINAL REPORT 4 EXTERNAL NODES

NODE	PARTIAL BETA W/R TO ALPHA	PARTIAL BETA W/R TO EPSILON
1	-4.80092317E-02	3.40071172E-02
2	-4.82487512E-02	3.42084494E-02
3	-1.54405773E-02	9.05898321E-03
4	-1.54397373E-02	9.11538064E-03

```
SAMPLE CASE FOR FINAL REPORT 4 EXTERNAL NODES

MODE    CNTR            ITERATION    42    NO. OF SURFACES ENCOUNTERED SINCE LAST TREND STEP     2  DELTA S = 0.00287

            BETA             NODE      ORBIT     LIMIT      MINIMUM BETA OCCURRED AT ITERATION   NODE  ORBIT LIMIT

        2.89941788E-01         5          5      UPPER       2.84227E-01               41           5     8  LOWER
```

NODE	ABSORPTIVITY	EMISSIVITY
1	0.54464504	0.80152442
2	0.54224566	0.79674679
3	0.38094464	0.86179879
4	0.38446924	0.86163092

TEMPERATURE VALUES

NODE \ ORBIT	1	2	3	4	5	6	7	8	9	10
1	355.56	406.71	465.78	519.08	547.96	340.09	388.67	446.54	499.49	528.59
2	548.10	519.22	465.93	406.89	355.82	528.71	499.61	446.68	388.88	340.35
3	524.99	489.07	467.04	458.22	447.49	496.33	453.91	426.25	419.70	414.86
4	447.59	458.43	467.32	489.50	525.65	414.92	419.83	426.44	454.31	496.98
5	550.68	542.70	537.97	542.74	550.80	534.87	525.14	519.45	525.19	534.99

SAMPLE CASE FOR FINAL REPORT 4 EXTERNAL NODES

NODE	PARTIAL BETA W/R TO ALPHA	PARTIAL BETA W/R TO EPSILON
1	1.02350684E-01	-6.70012885E-02
2	3.49419531E-03	-9.56248343E-03
3	1.00550222E-02	-6.48624820E-03
4	7.33811170E-02	-3.28042600E-02

```
SAMPLE CASE FOR FINAL REPORT 4 EXTERNAL NODES

MODE    CNTR              ITERATION    43    NO. OF SURFACES ENCOUNTERED SINCE LAST TREND STEP     3  DELTA S = 0.00287

           BETA             NODE     ORBIT    LIMIT    MINIMUM BETA OCCURRED AT ITERATION   NODE  ORBIT LIMIT

      2.84789273E-01         5         1      UPPER      2.84227E-01               41         5     8   LOWER


      NODE       ABSORPTIVITY    EMISSIVITY
        1        0.54265210      0.80282905
        2        0.54217763      0.79693299
        3        0.38074885      0.86192508
        4        0.38304038      0.86226968
```

TEMPERATURE VALUES

NODE \ ORBIT	1	2	3	4	5	6	7	8	9	10
1	355.55	406.54	465.38	518.52	547.35	340.08	388.58	446.19	498.97	527.99
2	548.09	519.20	465.92	406.91	355.85	528.71	499.61	446.69	388.91	340.37
3	524.98	489.04	467.02	458.20	447.48	496.32	453.91	426.24	419.70	414.85
4	447.57	458.34	467.18	489.29	525.35	414.91	419.80	426.36	454.13	496.68
5	550.70	542.70	537.93	542.64	550.68	534.88	525.15	519.42	525.11	534.86

SAMPLE CASE FOR FINAL REPORT 4 EXTERNAL NODES

NODE	PARTIAL BETA W/R TO ALPHA	PARTIAL BETA W/R TO EPSILON
1	3.47571784E-03	-9.47455025E-03
2	1.02923362E-01	-6.74422336E-02
3	7.34061819E-02	-3.25312990E-02
4	1.00532641E-02	-6.50653762E-03

```
SAMPLE CASE FOR FINAL REPORT 4 EXTERNAL NODES
 MODE    CNTR              ITERATION    44    NO. OF SURFACES ENCOUNTERED SINCE LAST TREND STEP      4  DELTA S = 0.00287
             BETA             NODE      ORBIT     LIMIT     MINIMUM BETA OCCURRED AT ITERATION   NODE  ORBIT LIMIT
          2.83499524E-01        5          8      LOWER       2.83500E-01                 44          5      8   LOWER

        NODE       ABSORPTIVITY    EMISSIVITY
          1        0.54258467     0.80301285
          2        0.54018094     0.79824135
          3        0.37932479     0.86255617
          4        0.38284535     0.86239590
```

TEMPERATURE VALUES

NODE \ ORBIT	1	2	3	4	5	6	7	8	9	10
1	355.48	406.43	465.28	518.45	547.30	340.02	388.46	446.08	498.89	527.95
2	547.43	518.61	465.46	406.66	355.81	528.07	499.06	446.27	388.68	340.34
3	524.63	488.82	466.86	458.09	447.44	495.98	453.71	426.13	419.62	414.82
4	447.50	458.29	467.13	489.23	525.30	414.86	419.75	426.32	454.08	496.63
5	550.51	542.54	537.81	542.55	550.64	534.72	525.03	519.33	525.04	534.83

SAMPLE CASE FOR FINAL REPORT 4 EXTERNAL NODES

NODE	PARTIAL BETA W/R TO ALPHA	PARTIAL BETA W/R TO EPSILON
1	-4.80222404E-02	3.40730974E-02
2	-4.82623804E-02	3.43035108E-02
3	-1.54321086E-C2	9.04965174E-03
4	-1.54312040E-02	9.09805310E-03

SAMPLE CASE FOR FINAL REPORT 4 EXTERNAL NODES

```
MODE    TREND2          ITERATION    45    NO. OF SURFACES ENCOUNTERED SINCE LAST TREND STEP     4  DELTA S = 0.00287

           BETA            NODE      ORBIT     LIMIT      MINIMUM BETA OCCURRED AT ITERATION   NODE  ORBIT LIMIT

      2.87558743E-01        5          8       LOWER       2.83500E-01                 44        5      8   LOWER
```

NODE	ABSORPTIVITY	EMISSIVITY
1	0.54186118	0.80356883
2	0.53946273	0.79879662
3	0.37765506	0.86324610
4	0.38116951	0.86309443

TEMPERATURE VALUES

NODE \ ORBIT	1	2	3	4	5	6	7	8	9	10
1	355.40	406.29	465.10	518.22	547.03	339.94	388.33	445.92	498.68	527.69
2	547.16	518.36	465.26	406.49	355.69	527.81	498.81	446.07	388.53	340.23
3	524.26	488.57	466.70	457.94	447.31	495.62	453.49	426.01	419.51	414.72
4	447.40	458.15	466.97	489.00	524.92	414.77	419.65	426.20	453.87	496.27
5	550.35	542.41	537.70	542.44	550.47	534.58	524.92	519.25	524.95	534.69

```
SAMPLE CASE FOR FINAL REPORT 4 EXTERNAL NODES

MODE     BACK            ITERATION    45    NO. OF SURFACES ENCOUNTERED SINCE LAST TREND STEP     4  DELTA S = 0.00287

      BETA            NODE      ORBIT      LIMIT      MINIMUM BETA OCCURRED AT ITERATION   NODE  ORBIT LIMIT

   2.87840649E-01       5          8       LOWER       2.83500E-01               44          5     8   LOWER
```

NODE	ABSORPTIVITY	EMISSIVITY
1	0.54229527	0.80323524
2	0.53989365	0.79846346
3	0.37865689	0.86283214
4	0.38217501	0.86267531

TEMPERATURE VALUES

NODE \ ORBIT	1	2	3	4	5	6	7	8	9	10
1	355.37	406.30	465.13	518.31	547.16	339.91	388.33	445.93	498.74	527.80
2	547.29	518.45	465.28	406.49	355.66	527.92	498.87	446.08	388.52	340.20
3	524.44	488.66	466.72	457.98	447.32	495.77	453.53	426.02	419.52	414.72
4	447.42	458.19	467.00	489.09	525.10	414.77	419.65	426.21	453.92	496.42
5	550.36	542.41	537.70	542.44	550.48	534.57	524.91	519.24	524.94	534.69

```
SAMPLE CASE FOR FINAL REPORT 4 EXTERNAL NODES

MODE    BACK           ITERATION   46   NO. OF SURFACES ENCOUNTERED SINCE LAST TREND STEP    5  DELTA S = 0.00287

        BETA           NODE     ORBIT    LIMIT    MINIMUM BETA OCCURRED AT ITERATION   NODE  ORBIT LIMIT

     2.83499524E-01      5         8     LOWER     2.83500E-01             44           5      8   LOWER


        NODE       ABSORPTIVITY    EMISSIVITY
          1        0.54258467     0.80301285
          2        0.54018094     0.79824135
          3        0.37932479     0.86255617
          4        0.38284535     0.86239590
```

TEMPERATURE VALUES

NODE \ ORBIT	1	2	3	4	5	6	7	8	9	10
1	355.37	406.30	465.13	518.31	547.16	339.91	388.33	445.99	498.74	527.80
2	547.29	518.45	465.28	406.49	355.66	527.92	498.87	446.13	388.52	340.20
3	524.44	488.66	466.72	457.98	447.32	495.77	453.53	426.05	419.52	414.72
4	447.42	458.19	467.00	489.09	525.10	414.77	419.65	426.25	453.92	496.42
5	550.36	542.41	537.70	542.44	550.48	534.57	524.91	519.25	524.94	534.69

SAMPLE CASE FOR FINAL REPORT 4 EXTERNAL NODES

NODE	PARTIAL BETA W/R TO ALPHA	PARTIAL BETA W/R TO EPSILON
1	-4.80222404E-02	3.40730974E-02
2	-4.82623804E-02	3.43035108E-02
3	-1.54321086E-02	9.04965174E-03
4	-1.54312040E-02	9.09805310E-03

```
SAMPLE CASE FOR FINAL REPORT 4 EXTERNAL NODES

MODE    CNTR             ITERATION    46    NO. OF SURFACES ENCOUNTERED SINCE LAST TREND STEP     6  DELTA S = 0.00287

          BETA            NODE      ORBIT     LIMIT     MINIMUM BETA OCCURRED AT ITERATION   NODE  ORBIT LIMIT

     2.83291242E-01         5          5      UPPER      2.83291E-01                 46         5     5   UPPER


      NODE      ABSORPTIVITY    EMISSIVITY
        1        0.54416225     0.80189350
        2        0.54176641     0.79711443
        3        0.37983175     0.86225888
        4        0.38335228     0.86209701
```

TEMPERATURE VALUES

NODE \ ORBIT	1	2	3	4	5	6	7	8	9	10
1	355.49	406.59	465.63	518.91	547.78	340.01	388.59	446.40	499.31	528.41
2	547.93	519.06	465.78	406.78	355.75	528.54	499.46	446.55	388.76	340.29
3	524.74	488.88	466.90	458.11	447.40	496.07	453.74	426.15	419.61	414.78
4	447.50	458.32	467.18	489.31	525.39	414.84	419.75	426.34	454.12	496.72
5	550.57	542.60	537.87	542.64	550.67	534.76	525.06	519.38	525.08	534.87

SAMPLE CASE FOR FINAL REPORT 4 EXTERNAL NODES

NODE	PARTIAL BETA W/R TO ALPHA	PARTIAL BETA W/R TO EPSILON
1	1.02377355E-01	-6.69256389E-02
2	3.49509272E-03	-9.55509639E-03
3	1.00569768E-02	-6.46426618E-03
4	7.33949667E-02	-3.26990107E-02

SAMPLE CASE FOR FINAL REPORT 4 EXTERNAL NODES

```
MODE    CNTR              ITERATION    47    NO. OF SURFACES ENCOUNTERED SINCE LAST TREND STEP     7  DELTA S = 0.00287
           BETA              NODE      ORBIT     LIMIT      MINIMUM BETA OCCURRED AT ITERATION   NODE  ORBIT LIMIT
        2.82257080E-01        5           8      LOWER      2.82257E-01                 47           5     8   LOWER
```

NODE	ABSORPTIVITY	EMISSIVITY
1	0.54216833	0.80319695
2	0.54169834	0.79730053
3	0.37963588	0.86238477
4	0.38192283	0.86273386

TEMPERATURE VALUES

NODE \ ORBIT	1	2	3	4	5	6	7	8	9	10
1	355.48	406.43	465.24	518.36	547.18	340.00	388.47	446.05	498.81	527.82
2	547.92	519.03	465.78	406.80	355.77	528.53	499.45	446.56	388.80	340.30
3	524.72	488.86	466.89	458.10	447.40	496.06	453.74	426.15	419.61	414.78
4	447.49	458.23	467.06	489.11	525.09	414.83	419.70	426.26	453.97	496.42
5	550.58	542.60	537.84	542.54	550.56	534.77	525.08	519.35	525.03	534.75

```
SAMPLE CASE FOR FINAL REPORT 4 EXTERNAL NODES

MODE    TREND2          ITERATION    48    NO. OF SURFACES ENCOUNTERED SINCE LAST TREND STEP      7  DELTA S = 0.00287

          BETA             NODE      ORBIT     LIMIT      MINIMUM BETA OCCURRED AT ITERATION   NODE  ORBIT LIMIT

      2.86347196E-01         5          1      UPPER       2.82257E-01                47          5     8   LOWER


      NODE        ABSORPTIVITY    EMISSIVITY
        1          0.54160489     0.80344611
        2          0.54375194     0.79602726
        3          0.38005690     0.86215281
        4          0.38067432     0.86319123
```

TEMPERATURE VALUES

NODE \ ORBIT	1	2	3	4	5	6	7	8	9	10
1	355.47	406.33	465.10	518.19	546.99	340.00	388.37	445.90	498.64	527.64
2	548.54	519.61	466.21	407.04	355.83	529.14	500.00	446.97	389.02	340.35
3	524.81	488.94	466.94	458.12	447.40	496.15	453.81	426.19	419.63	414.78
4	447.42	458.13	466.93	488.92	524.83	414.78	419.64	426.17	453.80	496.16
5	550.73	542.69	537.85	542.48	550.46	534.92	525.16	519.37	524.97	534.65

```
SAMPLE CASE FOR FINAL REPORT 4 EXTERNAL NODES

MODE    BACK            ITERATION   48    NO. OF SURFACES ENCOUNTERED SINCE LAST TREND STEP     7  DELTA S = 0.00287

            BETA             NODE      ORBIT     LIMIT     MINIMUM BETA OCCURRED AT ITERATION   NODE  ORBIT LIMIT

        2.84656140E-01         5          1      UPPER      2.82257E-01                  47         5     8   LOWER
```

NODE	ABSORPTIVITY	EMISSIVITY
1	0.54194295	0.80329661
2	0.54251978	0.79679122
3	0.37980428	0.86229198
4	0.38142342	0.86291680

SHOWS MINIMUM β ATTAINED AND ITERATION WHERE IT OCCURRED

TEMPERATURE VALUES

NODE \ ORBIT	1	2	3	4	5	6	7	8	9	10
1	355.47	406.34	465.14	518.24	547.06	340.00	388.37	445.94	498.69	527.71
2	548.18	519.30	466.03	406.99	355.82	528.81	499.72	446.81	388.98	340.34
3	524.76	488.90	466.92	458.11	447.39	496.10	453.78	426.17	419.62	414.77
4	447.44	458.17	466.98	488.98	524.94	414.80	419.65	426.19	453.83	496.26
5	550.69	542.66	537.84	542.48	550.45	534.89	525.14	519.36	524.97	534.65

DELTA IS SMALLER THAN MINIMUM DELTA ALLOWED

STEP SIZE (ΔS) IS SMALLER THAN MINIMUM ALLOWABLE AS SPECIFIED IN INPUT

8.0 SAMPLE PROBLEM

To illustrate the use of the input and output sheets, the application considered in Part I of this final report will be considered in detail for the case where four coating patches are used. Figures 10 and 11 give the pertinent geometrical data. Table I gives the orbital-heat flux data. Figure 12 shows the calculations pertinent to the input sheet data. The subsequent pages give the input sheets for this particular problem. The output sheets are shown in Section 7.0. Only the first and last few steps of the iteration sequence are shown, since these are typical of the other steps. Table II summarizes the results of this run as well as runs for one and eight patches for the same orbital conditions (See Table I).

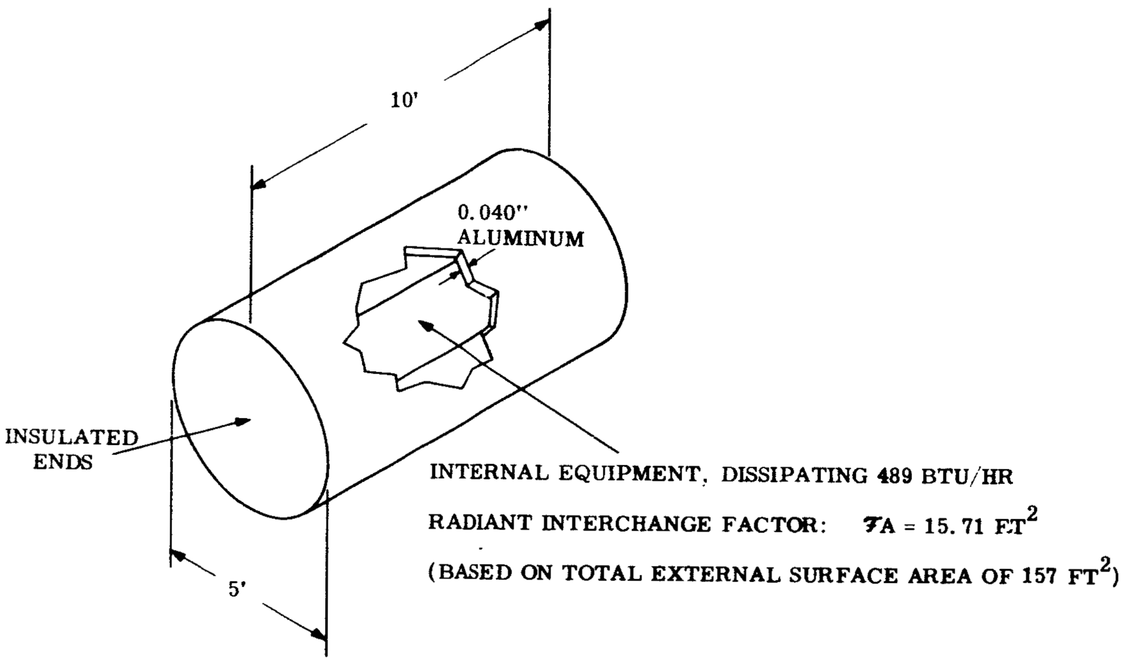


Figure 10. Vehicle Geometry

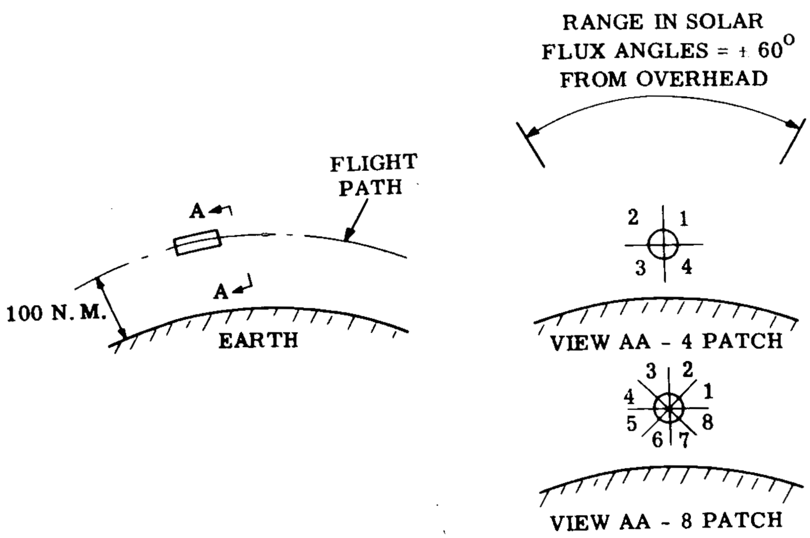
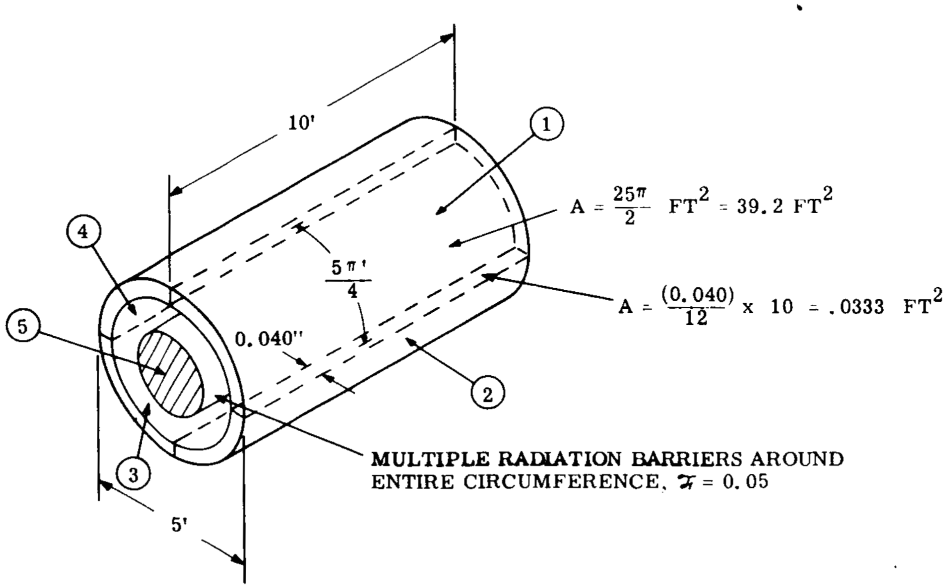


Figure 11. Orbit and Patch Geometry



CONDUCTANCE CALCULATIONS $(K = \frac{kA}{x})$ $k_{ALUMINUM} = 100$ BTU/HR FT °F

$$K_{12} = \frac{(100)\,(.0333)}{(\frac{5\pi}{4})} = 0.85 \text{ BTU/HR } ^{o}\text{F}$$

RADIANCE CALCULATIONS: $(R = \mathcal{F}\, A)$

$$R_{15} = (0.05)\ \frac{25\,\pi}{2} = 1.96 \text{ FT}^2$$

Figure 12. Calculations Pertinent to Input Sheet Data

TABLE I. ORBITAL HEAT FLUXES

Case	Patch	Flux (BTU/hr ft^2) \ Orbit	1	2	3	4	5	6	7	8	9	10
1 Patch	1	(S+A)	107.7	90.4	79.5	90.4	107.7	91.1	70.7	59.9	70.7	91.1
		E	30.2	30.2	30.2	30.2	30.2	21.6	21.6	21.6	21.6	21.6
4 Patches	1	(S+A)	7.71	43.8	103.5	177.1	226.2	5.83	36.9	89.2	154.3	198.3
		E	6.36	6.36	6.36	6.36	6.36	4.54	4.54	4.54	4.54	4.54
	2	(S+A)	226.2	177.1	103.5	43.8	7.71	198.3	154.3	89.2	36.9	5.83
		E	6.36	6.36	6.36	6.36	6.36	4.54	4.54	4.54	4.54	4.54
	3	(S+A)	173.1	94.3	55.5	41.6	23.7	145.9	69.0	30.5	22.6	15.3
		E	53.4	53.4	53.4	53.4	53.4	38.6	38.6	38.6	38.6	38.6
	4	(S+A)	23.7	41.6	55.5	94.3	173.1	15.3	22.6	30.5	69.0	145.9
		E	53.4	53.4	53.4	53.4	53.4	38.6	38.6	38.6	38.6	38.6
8 Patches	1	(S+A)	5.54	9.62	68.3	187.3	288.8	2.99	5.19	46.4	161.7	252.5
		E	12.6	12.6	12.6	12.6	12.6	9.0	9.0	9.0	9.0	9.0
	2	(S+A)	9.85	77.9	138.6	166.9	163.6	8.67	68.6	122.1	147.0	144.1
		E	.117	.117	.117	.117	.117	.08	.08	.08	.08	.08
	3	(S+A)	163.6	166.8	138.6	77.9	9.85	144.1	147.0	122.1	68.6	8.67
		E	.117	.117	.117	.117	.117	.08	.08	.08	.08	.08
	4	(S+A)	288.8	187.3	68.3	9.62	5.58	252.5	161.7	56.4	5.19	2.98
		E	12.6	12.6	12.6	12.6	12.6	9.0	9.0	9.0	9.0	9.0
	5	(S+A)	254.9	116.2	43.7	30.8	17.8	221.5	91.9	22.1	16.6	12.7
		E	40.5	40.5	40.5	40.5	40.5	28.9	28.9	28.9	28.9	28.9
	6	(S+A)	91.4	72.4	67.3	52.4	29.7	70.4	46.2	39.0	28.6	16.0
		E	67.5	67.5	67.5	67.5	67.5	48.3	48.3	48.3	48.3	48.3
	7	(S+A)	29.7	52.4	67.3	72.4	91.4	16.0	28.6	39.0	46.2	70.4
		E	67.5	67.5	67.5	67.5	67.5	48.3	48.3	48.3	48.3	48.3
	8	(S+A)	17.8	30.8	43.7	116.2	254.9	12.7	16.6	22.1	91.9	221.5
		E	40.5	40.5	40.5	40.5	40.5	28.9	28.9	28.9	28.9	28.9

TABLE II. RESULTS OF COATING-OPTIMIZATION STUDY

Specifications: Allowable $\alpha - \epsilon$ Range: $0.1 \le \epsilon \le 0.9$, $0.1 \le \alpha \le 0.9$
Allowable Temperature Range:
Skin Temperatures: $200^{o}R$ to $800^{o}R$
Internal Temperature: $525^{o}R$ to $545^{o}R$

Results:

Node	Coating α	Coating ϵ	Temperature Range ^{o}R		
	Uniform Coating				
1 (External)	0.524	0.885	488.4	433.6	
2 (Internal)	-		552.5	517.5	(35^{o})
	4 Patches				
1	0.542	0.803	547.0	340.0	
2	0.544	0.796	548.5	340.4	
3	0.380	0.862	524.8	414.8	
4	0.381	0.863	524.8	414.8	
5 (Internal)	-		550.7	519.4	(31.7^{o})
	8 Patches				
1	0.362	0.862	529.8	342.6	
2	0.660	0.723	533.6	364.0	
3	0.652	0.727	531.9	363.9	
4	0.376	0.858	533.3	342.8	
5	0.314	0.878	527.2	388.8	
6	0.490	0.816	515.8	436.3	
7	0.492	0.814	516.3	436.4	
8	0.323	0.877	529.1	388.9	
9 (Internal)	-		546.0	523.1	(22.9^{o})

COATING SELECTION PROGRAM INPUT SHEET

FORM 1

IDENTIFICATION CARD ANY 71 CHARACTERS

2 ← CARD COLUMN → 72
SAMPLE CASE FOR FINAL REPORT 4 EXTERNAL NODES

NUMBER OF NODES EXCLUDE CONSTANT TEMPERATURE NODES N (MAX = 34)	NUMBER OF ORBITS K (MAX = 20)	NUMBER OF CONSTANT TEMPERATURE NODES (MAX = 10)	NUMBER OF COATINGS (MAX = 10)	NUMBER OF EXTERNAL NODES (MAX = 34)
← CARD COLUMN →				
1 – 2	3 – 4	5 – 6	7 – 8	9 – 10
05	10	0	01	04

INITIAL STEP SIZE ΔS	MINIMUM STEP SIZE ΔS MIN	STEPHAN-BOLTZMAN CONSTANT USUALLY 0.1713×10^{-8}
← CARD COLUMN →		
1 – 5	6 – 12	13 – 26
0.1	0.001	1.713E-09

STOPS: INSERT 1 TO STOP, OTHERWISE INSERT 0

ALL TEMPERATURES WITHIN LIMITS	$K(I,J) \neq K(J,I)$	$R(I,J) \neq R(J,I)$	ANY TEMPERATURE LESS THAN ZERO GREATER THAN 10000
← CARD COLUMN →			
1	2	3	4
0	1	1	1

OPTIONS: INSERT 1 FOR OPTION, OTHERWISE INSERT 0

PROGRAM SETS $K(J,I) = K(I,J)$ AND $R(J,I) = R(I,J)$ FOR $J > I$	PROGRAM CALCULATES INITIAL GUESS OF α'S AND ϵ'S
← CARD COLUMN →	
1	2
0	0

ALLOWABLE ERROR IN SOLVING HEAT BALANCE — D TEMP	ALLOWABLE DEVIATION FROM RESIDUAL DR	MAXIMUM NO. OF ITERATIONS FOR SOLVING HEAT BALANCE	MAXIMUM NO. OF ITERATIONS FOR CALCULATION OF α'S AND ϵ'S	INSERT TO STOP FOR 1.0 D TEMP ONLY 2.0 DR ONLY 3.0 D TEMP AND DR	STABILITY OPTION FOR SOLVING HEAT BALANCE EQUATION 1.0 OPTION 1 2.0 OPTION 2
← CARD COLUMN →					
1 – 8	9 – 16	17 – 24	25 – 32	33 – 40	41 – 48
1.0	2.0	100.0	100.0	3.0	2.0

SOLAR ABSORPTANCE - α
INFRA-RED EMITTANCE - ϵ
TEMPERATURE - T - ^{o}R
AREA - a - FT^2
HEAT FLUX MULTIPLIERS - K - DIMENSIONLESS

HEAT BALANCE EQUATION:

$$\sum_{\substack{J=1 \\ J \neq I}}^{N+S} K(I,J)\left[T(I,K) - T(J,K)\right] + \sum_{\substack{J=1 \\ J \neq I}}^{N+S} \sigma R(I,J)\left[T(I,K)^4 - T(J,K)^4\right] =$$

$$\alpha(I)\left[K_S(I) \cdot S(I,K) + K_A(I) \cdot A(I,K)\right] + \epsilon(I) \cdot K_E(I) \cdot E(I,K) + K_Q(I)\, Q(I)$$

$$- \epsilon(I) \cdot a(I) \cdot \sigma\, T(I,K)^4$$

COATING SELECTION PROGRAM INPUT SHEET

FORM 2

NODE SPECIFICATION

	TEMPERATURE LIMITS		COATING ESTIMATES		EXTERNALLY EXPOSED AREA	HEAT FLUX MULTIPLIERS OF				INITIAL TEMP.	MAX. TEMP.		CARD NUMBER
						SOLAR	ALBEDO	EARTH	INTRNL.				
NODE NO.	LOWER	UPPER	α	ϵ	AREA	K_S	K_A	K_E	K_Q	$T_{INITIAL}$	T_{MAX}	COATING NO.	
CARD COLUMN													
1 2	4 8	10 14	16 20	22 26	28 33	35 39	41 45	47 51	53 57	58	63 67	69 70	73 80
01	200.0	800.0	0.5	0.8	39.2	39.2	39.2	39.2	39.2	500.0	800.0	01	01
02	200.0	800.0	0.5	0.8	39.2	39.2	39.2	39.2	39.2	500.0	800.0	01	02
03	200.0	800.0	0.5	0.8	39.2	39.2	39.2	39.2	39.2	500.0	800.0	01	03
04	200.0	800.0	0.5	0.8	39.2	39.2	39.2	39.2	39.2	500.0	800.0	01	04
05	525.0	545.0	0.0	0.0	0.0	1.0	1.0	1.0	1.0	500.0	800.0	00	05

COATING SELECTION PROGRAM INPUT SHEET FORM 3

CONDUCTION INTERCONNECTIONS

NODE I (4–5)	NODE J (9–10)	K (I, J) (11–22)	NODE I (26–27)	NODE J (31–32)	K (I, J) (33–44)	NODE I (48–49)	NODE J (53–54)	K (I, J) (55–66)	CARD NUMBER (73–80)
01	02	0.85	01	04	0.85	02	01	0.85	01
02	03	0.85	03	02	0.85	03	04	0.85	02
04	03	0.85	04	01	0.85				03

CARD COLUMN

CONDUCTANCE BETWEEN NODE I AND NODE J K(I,J) BTU/HR °R

COATING SELECTION PROGRAM INPUT SHEET

RADIATION INTERCONNECTIONS

NODE I	NODE J	R(I,J)	NODE I	NODE J	R (I,J)	NODE I	NODE J	R(I,J)	CARD NUMBER
CARD COLUMN									
4 5	9 10	11 22	26 27	31 32	33 44	48 49	53 54	55 66	73 80
01	05	1.96	02	05	1.96	03	05	1.96	01
04	05	1.96	05	01	1.96	05	02	1.96	02
05	03	1.96	05	04	1.96				03

RADIATION FACTOR BETWEEN NODE I AND J — R(I,J) — FT^2

COATING SELECTION PROGRAM INPUT SHEET

FORM 5

ORBIT NUMBER

2 3
01

ENVIRONMENTAL AND INTERNAL HEATING

NODE NO.	SOLAR HEAT FLUX	ALBEDO HEAT FLUX	EARTH HEAT FLUX	INTERNAL HEAT GENERATION	CARD NUMBER
CARD COLUMN					
1 2	10 21	26 37	42 53	58 69	73 80
01	7.71	0.0	6.36	0.0	01
02	226.2	0.0	6.36	0.0	01
03	173.1	0.0	53.40	0.0	01
04	23.7	0.0	53.40	0.0	01
05	0.0	0.0	0.0	489.0	01

SOLAR HEAT FLUX — S — BTU/HR
ALBEDO HEAT FLUX — A — BTU/HR
EARTH HEAT FLUX — E — BTU/HR
INTERNAL HEAT GENERATION — Q — BTU/HR

FORM 5

ORBIT NUMBER

2 3
02

ENVIRONMENTAL AND INTERNAL HEATING

NODE NO.	SOLAR HEAT FLUX	ALBEDO HEAT FLUX	EARTH HEAT FLUX	INTERNAL HEAT GENERATION	CARD NUMBER
CARD COLUMN					
1 2	10 21	26 37	42 53	58 69	73 80
01	43.8	0.0	6.36	0.0	02
02	177.1	0.0	6.36	0.0	02
03	94.3	0.0	53.4	0.0	02
04	41.6	0.0	53.4	0.0	02
05	0.0	0.0	0.0	489.0	02

SOLAR HEAT FLUX – S – BTU/HR
ALBEDO HEAT FLUX – A – BTU/HR
EARTH HEAT FLUX – E – BTU/HR
INTERNAL HEAT GENERATION – Q – BTU/HR

COATING SELECTION PROGRAM INPUT SHEET

FORM 5

ORBIT NUMBER (2–3): 03

ENVIRONMENTAL AND INTERNAL HEATING

NODE NO.	SOLAR HEAT FLUX	ALBEDO HEAT FLUX	EARTH HEAT FLUX	INTERNAL HEAT GENERATION	CARD NUMBER
CARD COLUMN					
1–2	10–21	26–37	42–53	58–69	73–80
01	103.5	0.0	6.36	0.0	03
02	103.5	0.0	6.36	0.0	03
03	55.5	0.0	53.4	0.0	03
04	55.5	0.0	53.4	0.0	03
05	0.0	0.0	0.0	489.0	03

SOLAR HEAT FLUX – S – BTU/HR
ALBEDO HEAT FLUX – A – BTU/HR
EARTH HEAT FLUX – E – BTU/HR
INTERNAL HEAT GENERATION – Q – BTU/HR

COATING SELECTION PROGRAM INPUT SHEET

FORM 5

ORBIT NUMBER (2–3): 04

ENVIRONMENTAL AND INTERNAL HEATING

NODE NO.	SOLAR HEAT FLUX	ALBEDO HEAT FLUX	EARTH HEAT FLUX	INTERNAL HEAT GENERATION	CARD NUMBER
CARD COLUMN					
1 2	10 21	26 37	42 53	58 69	73 80
01	177.1	0.0	6.36	0.0	04
02	43.8	0.0	6.36	0.0	04
03	41.6	0.0	53.4	0.0	04
04	94.3	0.0	53.4	0.0	04
05	0.0	0.0	0.0	489.0	04

SOLAR HEAT FLUX — S — BTU/HR
ALBEDO HEAT FLUX — A — BTU/HR
EARTH HEAT FLUX — E — BTU/HR
INTERNAL HEAT GENERATION — Q — BTU/HR

COATING SELECTION PROGRAM INPUT SHEET

FORM

ORBIT NUMBER

2 3
05

ENVIRONMENTAL AND INTERNAL HEATING

NODE NO.	SOLAR HEAT FLUX	ALBEDO HEAT FLUX	EARTH HEAT FLUX	INTERNAL HEAT GENERATION	CARD NUMBER
CARD COLUMN					
1 2	10 21	26 37	42 53	58 69	73 80
01	226.2	0.0	6.36	0.0	05
02	7.71	0.0	6.36	0.0	05
03	23.7	0.0	53.4	0.0	05
04	173.1	0.0	53.4	0.0	05
05	0.0	0.0	0.0	489.0	05

SOLAR HEAT FLUX — S — BTU/HR
ALBEDO HEAT FLUX — A — BTU/HR
EARTH HEAT FLUX — E — BTU/HR
INTERNAL HEAT GENERATION — Q — BTU/HR

COATING SELECTION PROGRAM INPUT SHEET

FORM 5

ORBIT NUMBER

2 3
06

ENVIRONMENTAL AND INTERNAL HEATING

NODE NO.	SOLAR HEAT FLUX	ALBEDO HEAT FLUX	EARTH HEAT FLUX	INTERNAL HEAT GENERATION	CARD NUMBER
CARD COLUMN					
1 2	10 21	26 37	42 53	58 69	73 80
01	5.83	0.0	4.54	0.0	06
02	198.3	0.0	4.54	0.0	06
03	145.9	0.0	38.6	0.0	06
04	15.3	0.0	38.6	0.0	06
05	0.0	0.0	0.0	489.0	06

SOLAR HEAT FLUX — S — BTU/HR
ALBEDO HEAT FLUX — A — BTU/HR
EARTH HEAT FLUX — E — BTU/HR
INTERNAL HEAT GENERATION — Q — BTU/HR

COATING SELECTION PROGRAM INPUT SHEET

FORM 5

ORBIT NUMBER

2 3
07

ENVIRONMENTAL AND INTERNAL HEATING

NODE NO.	SOLAR HEAT FLUX	ALBEDO HEAT FLUX	EARTH HEAT FLUX	INTERNAL HEAT GENERATION	CARD NUMBER
CARD COLUMN					
1 2	10 21	26 37	42 53	58 69	73 80
01	36.9	0.0	4.54	0.0	07
02	154.3	0.0	4.54	0.0	07
03	69.0	0.0	38.6	0.0	07
04	22.6	0.0	38.6	0.0	07
05	0.0	0.0	0.0	489.0	07

SOLAR HEAT FLUX — S — BTU/HR
ALBEDO HEAT FLUX — A — BTU/HR
EARTH HEAT FLUX — E — BTU/HR
INTERNAL HEAT GENERATION — Q — BTU/HR

COATING SELECTION PROGRAM INPUT SHEET

FORM 5

ORBIT NUMBER
2 3
08

ENVIRONMENTAL AND INTERNAL HEATING

NODE NO.	SOLAR HEAT FLUX	ALBEDO HEAT FLUX	EARTH HEAT FLUX	INTERNAL HEAT GENERATION	CARD NUMBER
CARD COLUMN					
1 2	10 21	26 37	42 53	58 69	73 80
01	89.2	0.0	4.54	0.0	08
02	89.2	0.0	4.54	0.0	08
03	30.5	0.0	38.6	0.0	08
04	30.5	0.0	38.6	0.0	08
05	0.0	0.0	0.0	489.0	08

SOLAR HEAT FLUX — S — BTU/HR
ALBEDO HEAT FLUX — A — BTU/HR
EARTH HEAT FLUX — E — BTU/HR
INTERNAL HEAT GENERATION — Q — BTU/HR

COATING SELECTION PROGRAM INPUT SHEET

FORM 5

ORBIT NUMBER

2 3
09

ENVIRONMENTAL AND INTERNAL HEATING

NODE NO.	SOLAR HEAT FLUX	ALBEDO HEAT FLUX	EARTH HEAT FLUX	INTERNAL HEAT GENERATION	CARD NUMBER
CARD COLUMN					
1 2	10 21	26 37	42 53	58 69	73 80
01	154.3	0.0	4.54	0.0	09
02	36.9	0.0	4.54	0.0	09
03	22.6	0.0	38.6	0.0	09
04	69.0	0.0	38.6	0.0	09
05	0.0	0.0	0.0	489.0	09

SOLAR HEAT FLUX — S — BTU/HR
ALBEDO HEAT FLUX — A — BTU/HR
EARTH HEAT FLUX — E — BTU/HR
INTERNAL HEAT GENERATION — Q — BTU/HR

COATING SELECTION PROGRAM INPUT SHEET

FORM 5

ORBIT NUMBER
2 3
10

ENVIRONMENTAL AND INTERNAL HEATING

NODE NO.	SOLAR HEAT FLUX	ALBEDO HEAT FLUX	EARTH HEAT FLUX	INTERNAL HEAT GENERATION	CARD NUMBER
CARD COLUMN					
1 2	10 21	26 37	42 53	58 69	73 80
01	198.3	0.0	4.54	0.0	10
02	5.83	0.0	4.54	0.0	10
03	15.3	0.0	38.6	0.0	10
04	145.9	0.0	38.6	0.0	10
05	0.0	0.0	0.0	489.0	10

SOLAR HEAT FLUX — S — BTU/HR
ALBEDO HEAT FLUX — A — BTU/HR
EARTH HEAT FLUX — E — BTU/HR
INTERNAL HEAT GENERATION — Q — BTU/HR

COATING SELECTION PROGRAM INPUT SHEET FORM 6

KNOWN TEMPERATURE NODES

NODE NUMBER	ORBIT NUMBER	TEMPERATURE	CARD NUMBER
← CARD COLUMN →			
1 2	4 5	10 21	73 80

TEMPERATURE -- T — ^{o}R

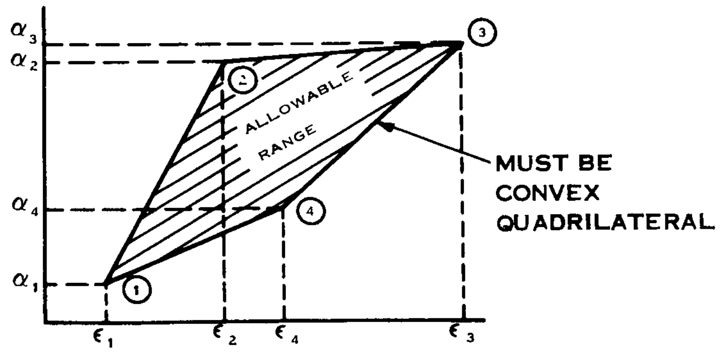
NODE NUMBERS BEGIN WITH (N + 1) AND END WITH (N + S)

COATING SELECTION PROGRAM INPUT SHEET

FORM 7

COATING SPECIFICATIONS

COATING NUMBERS	POINT 1		POINT 2		POINT 3		POINT 4		CARD NUMBER
	α_1	ϵ_1	α_2	ϵ_2	α_3	ϵ_3	α_4	ϵ_4	
CARD COLUMN									
1 2	5 10	13 18	21 26	29 34	37 42	45 50	53 58	61 66	73 80
01	0.1	0.1	0.9	0.1	0.9	0.9	0.1	0.9	01



COATING SELECTION PROGRAM INPUT SHEET

FORM 8

STEP CHANGE PROCEDURE

INCREASE Δs IN MRD	DECREASE Δs IN MRD	INCREASE Δs IN TREND	DECREASE Δs IN TREND	CARD NUMBER
← CARD COLUMN				→
1 … 6	7 … 12	13 … 18	19 … 24	73 … 80
1.2	0.4	1.0	0.2	

9.0 APPENDICES

Appendix A. Program Storage

Approximately 12,000 words of storage are required for the program logic. The remainder is used for data storage. The data storage requirements of various arrays as found in COMMON and DIMENSION are shown on Tables III and IV, respectively. The total requirement is

$$DSR = 6N^2 + N(59 + 3c + 8b + 2r) + 3r + 8k + 26$$

where

N = maximum number of nodes (excluding constant temperature nodes)

r = maximum number of TREND steps to be remembered

b = maximum number of orbits

c = maximum number of constant-temperature nodes

k = maximum number of coatings.

The values of these parameters in the present program are:

N = 34

r = 40

b = 20

c = 10

k = 10

giving DSR = 18348.

If a problem will not fit within the above dimensions, it is possible to change the dimensions of the arrays shown on Tables III and IV, then recompile the program. The above DSR limit may not be exceeded, however. It is also necessary to change the following:

1. The calling sequence for MTINV must be

   CALL MTINV (ARRAY NAME, NNŌDE, NNŌDE, N, SCRAT)

   where N is the only change and must correspond to the maximum number of nodes.

2. The upper limits on the DO-loops in the INPUT SUBROUTINE numbered 400, 450, and 460 must correspond to N, N, and (N + c), respectively.

3. In SUBROUTINE OUTPUT, four statements must be changed

if r is changed:

Statement 86: IF (LR. LT.____) Go to 95

Statement 87: LR = _____

Statement 871: IA = M + ____

Statement 89: DO 90 M = ____ ____

In Statement 86, the value of "r" should be put in the blank.

If the number of TREND steps to be remembered exceeds the maximum number allowed (r), the TREND memory is shifted back X values. Then, if r equals 40, X equals 10, and 40 consecutive MRD steps are taken, the TREND memory will shift at the 40th step to store step 39 in the location of 29, 38 in 28, etc., and 40 in 30. Steps 1 to 10 would be erased (forgotten) and replaced by steps 11 to 20. In Statement 87, the blank should be filled in with the value of (r - X). In Statement 871, the blank should be filled in with the value of X. In Statement 89, the first blank should be filled in with the value of (r - X + 1); the second, with the value of r.

The present program uses X = 10.

TABLE III. ARRAYS IN COMMON

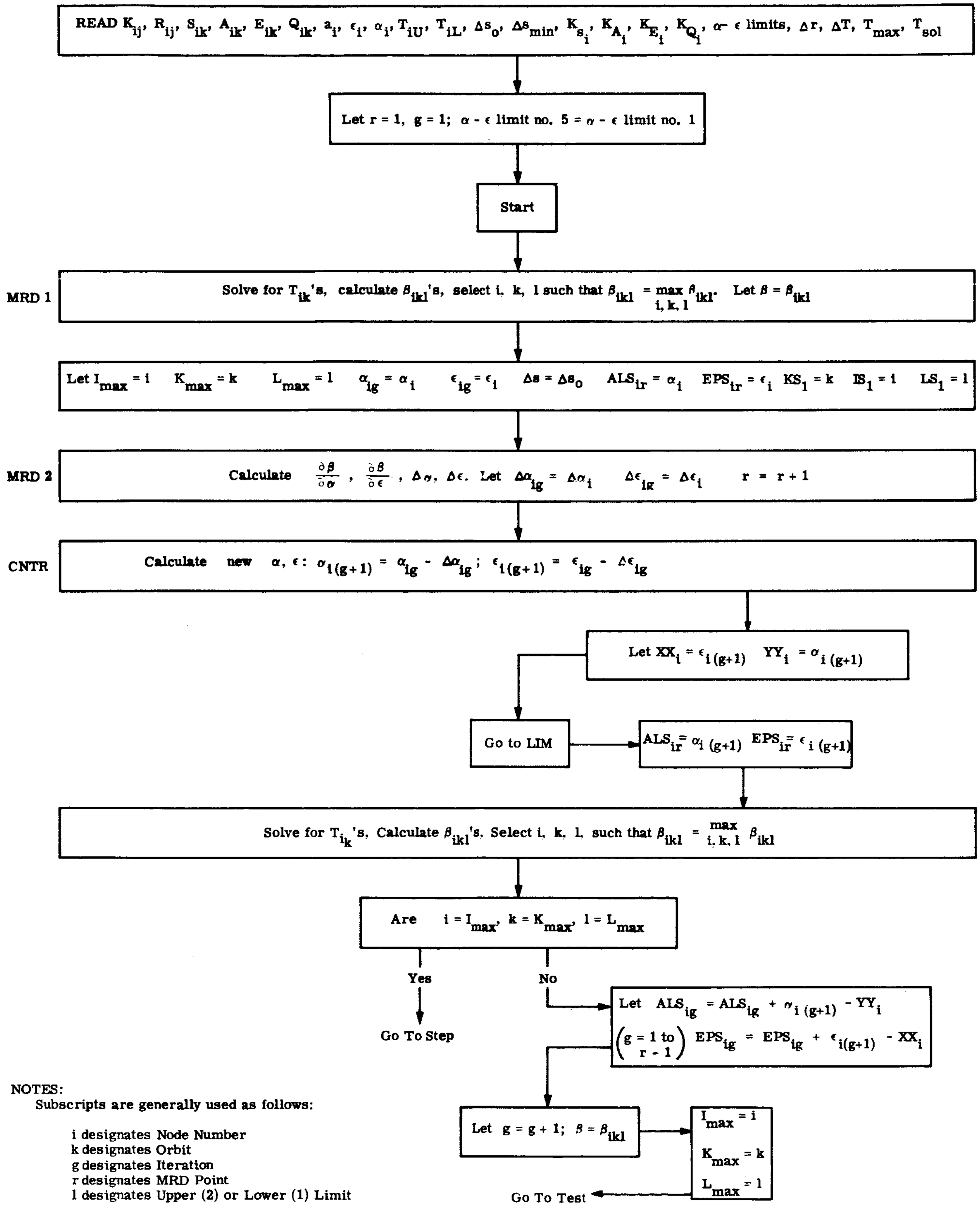
ALPHA	N x 1	TU	N x 1
ALPFX	N x b	ALOW	N x 6
ASPEC	4 x k	ALS	N x r
CONDUC	N x (N + c)	AT	N x N
CONVER	6 x 1	DALPHS	N x 1
EARFX	N x b	DALS	N x 2
EMIS	N x 1	DASTH	N x 1
ESPEC	4 x k	DEMISS	N x 1
EXAREA	N x 1	DES	N x 2
HEATKA	N x 1	DESTH	N x 1
HEATKE	N x 1	EMLOW	N x 6
HEATKQ	N x 1	EPS	N x r
HEATKS	N x 1	IS	r x 1
KOAT	N x 1	KS	r x 1
NOPTN	5 x 1	LS	r x 1
NSTOP	5 x 1	NN	N x 1
QFX	N x b	PBA	N x 1
RADTN	N x (N + c)	PBE	N x 1
SOLFX	N x b	R	N x 1
T	N x (N + c)	SCRAT	N x 1
TEMMAX	(N + c) x b	SUMKT	N x b
TINTL	(N + c) x 1	TITLE	12 x 1
TL	(N + c) x 1	TM	N x N

TABLE IV. ARRAYS IN DIMENSION STATEMENTS

SUBROUTINE	ARRAYS
CNTR	XX(N), YY(N)
INVRSE	EMAX(N), X(N), ERROR (N)
MRD2	DA(N), DE(N)
ONEPT1	PTE(N), PTA(N), TFT(N, b), DUM1(N), BT(N, N)
START	BETAMX(N, 4)
TRANSFM	AP(N)
MRD1	TD(N, 3), C(N), RR(N), SUM1(N), MAXL(N, b), TRHS(N, b), AMAXV(N, b)

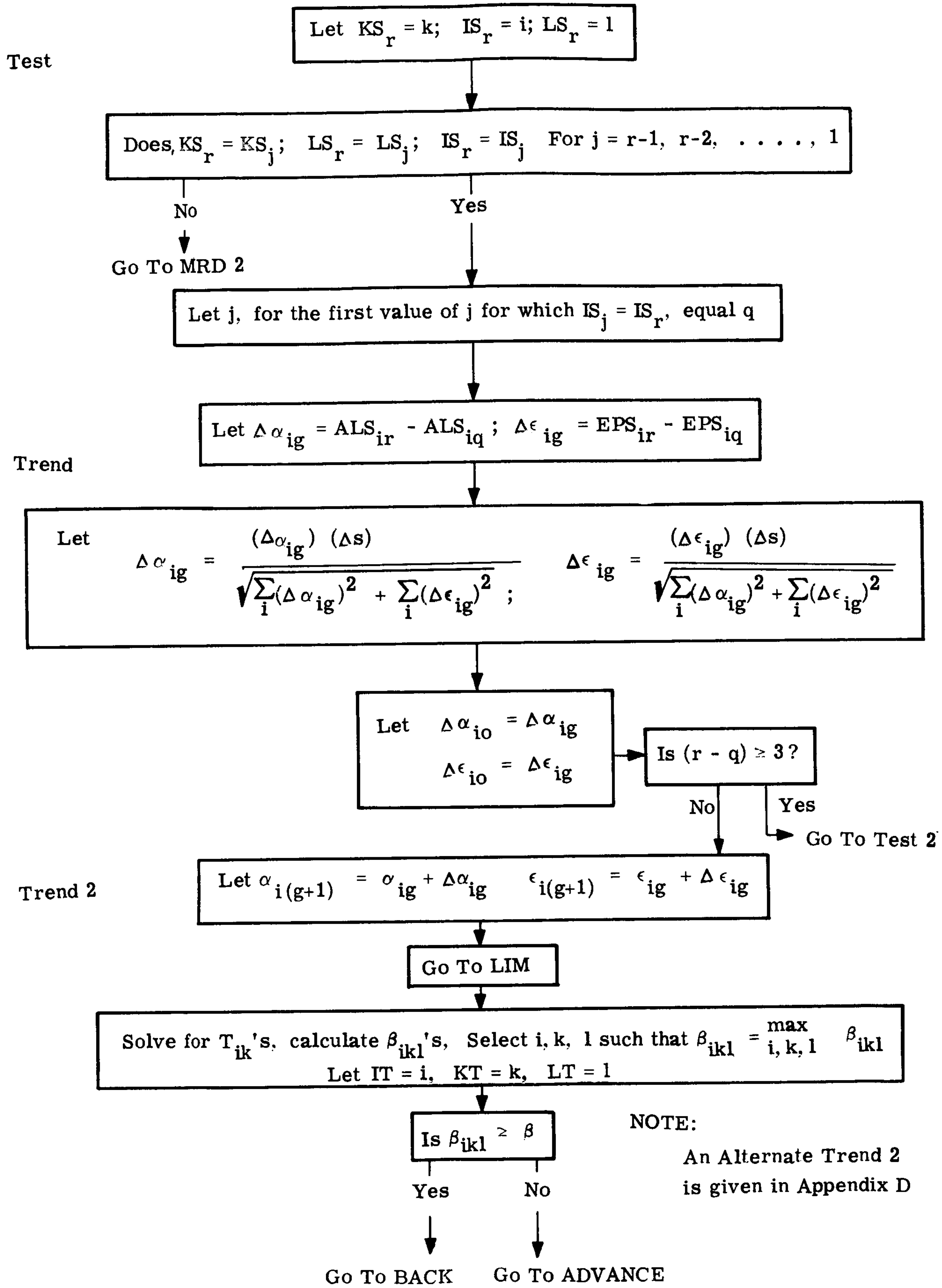
Appendix B. Logic Diagrams

LOGIC DIAGRAM FOR TREND



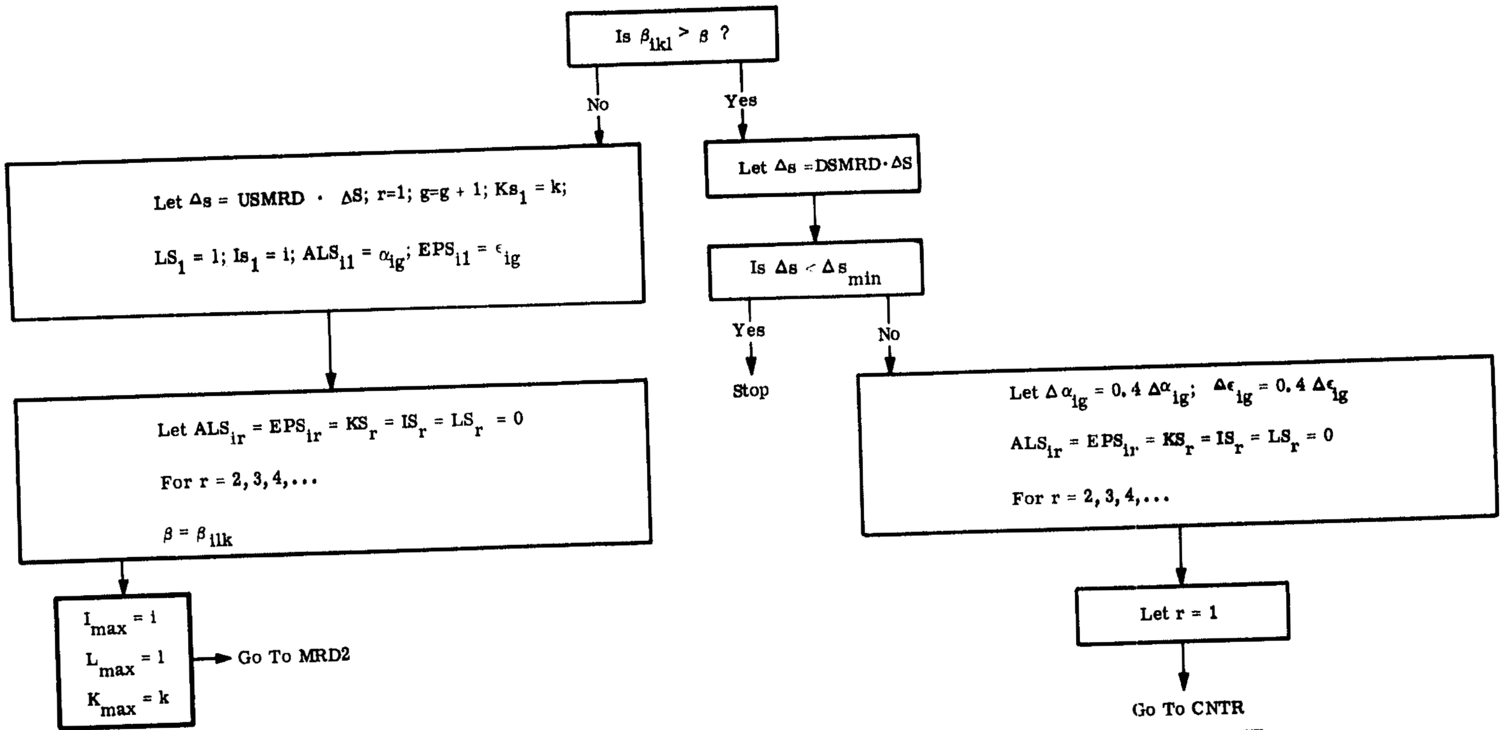
NOTES:
Subscripts are generally used as follows:

- i designates Node Number
- k designates Orbit
- g designates Iteration
- r designates MRD Point
- l designates Upper (2) or Lower (1) Limit

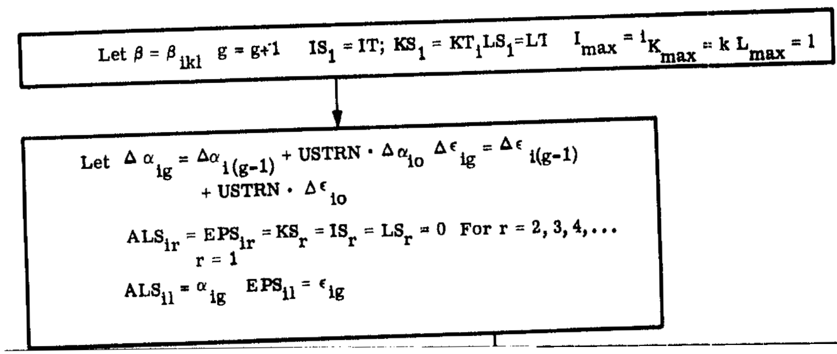


Test
Let $KS_r = k$; $IS_r = i$; $LS_r = 1$
Does, $KS_r = KS_j$; $LS_r = LS_j$; $IS_r = IS_j$ For $j = r-1, r-2, \ldots, 1$
No
Yes
Go To MRD 2
Let j, for the first value of j for which $IS_j = IS_r$, equal q
Trend
Let $\Delta\alpha_{ig} = ALS_{ir} - ALS_{iq}$; $\Delta\epsilon_{ig} = EPS_{ir} - EPS_{iq}$
Let $\Delta\alpha_{ig} = \frac{(\Delta\alpha_{ig})(\Delta s)}{\sqrt{\sum_i(\Delta\alpha_{ig})^2 + \sum_i(\Delta\epsilon_{ig})^2}}$; $\Delta\epsilon_{ig} = \frac{(\Delta\epsilon_{ig})(\Delta s)}{\sqrt{\sum_i(\Delta\alpha_{ig})^2 + \sum_i(\Delta\epsilon_{ig})^2}}$
Let $\Delta\alpha_{io} = \Delta\alpha_{ig}$
$\Delta\epsilon_{io} = \Delta\epsilon_{ig}$
Is $(r - q) \geq 3$?
No
Yes
Go To Test 2
Trend 2
Let $\alpha_{i(g+1)} = \alpha_{ig} + \Delta\alpha_{ig}$ $\epsilon_{i(g+1)} = \epsilon_{ig} + \Delta\epsilon_{ig}$
Go To LIM
Solve for T_{ik}'s, calculate β_{ikl}'s, Select i, k, l such that $\beta_{ikl} = \max_{i,k,l} \beta_{ikl}$
Let IT = i, KT = k, LT = l
Is $\beta_{ikl} \geq \beta$
Yes
No
Go To BACK
Go To ADVANCE
NOTE:
An Alternate Trend 2 is given in Appendix D

STEP

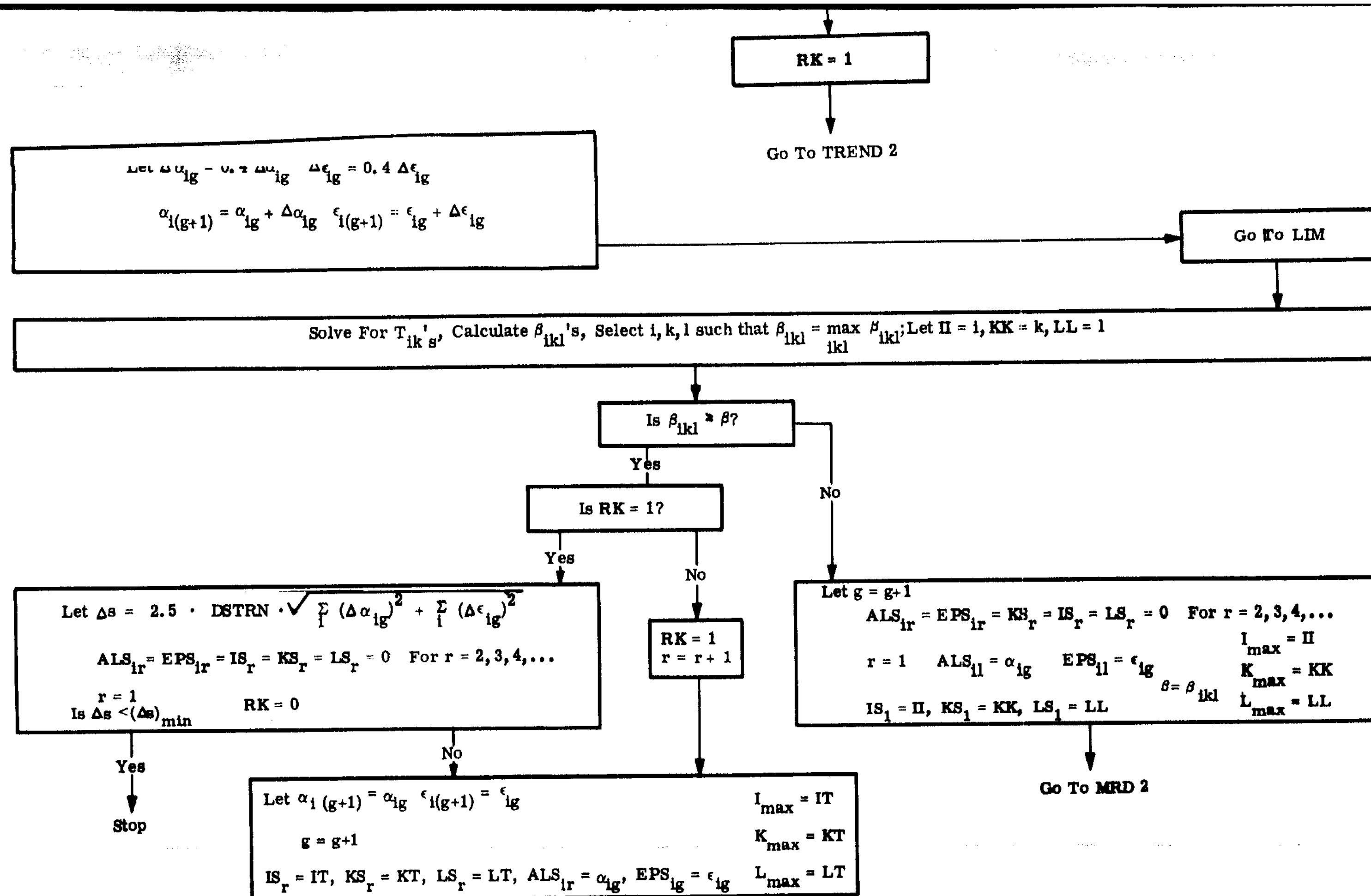


ADVANCE

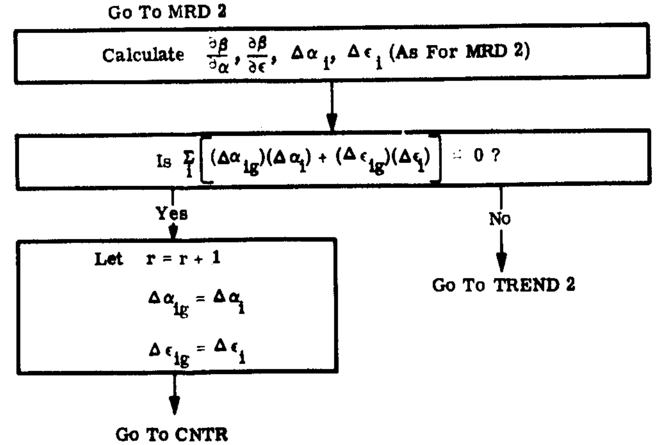


#1

BACK


RK = 1
Go To TREND 2
Δε_ig = 0.4 Δε_ig
α_i(g+1) = α_ig + Δα_ig   ε_i(g+1) = ε_ig + Δε_ig
Go To LIM
Solve For T_ik's, Calculate β_ikl's, Select i, k, l such that β_ikl = max_ikl β_ikl; Let II = i, KK = k, LL = l
Is β_ikl ≥ β?
Yes
No
Is RK = 1?
Yes
No
Let Δs = 2.5 · DSTRN · √(Σ_i (Δα_ig)² + Σ_i (Δε_ig)²)
ALS_ir = EPS_ir = IS_r = KS_r = LS_r = 0   For r = 2, 3, 4, ...
r = 1
Is Δs < (Δs)_min
RK = 0
Yes
Stop
No
RK = 1
r = r + 1
Let g = g+1
ALS_ir = EPS_ir = KS_r = IS_r = LS_r = 0   For r = 2, 3, 4, ...
r = 1   ALS_i1 = α_ig   EPS_i1 = ε_ig
IS_1 = II, KS_1 = KK, LS_1 = LL
β = β_ikl
I_max = II
K_max = KK
L_max = LL
Go To MRD 2
Let α_i(g+1) = α_ig   ε_i(g+1) = ε_ig
g = g+1
IS_r = IT, KS_r = KT, LS_r = LT, ALS_ir = α_ig, EPS_ig = ε_ig
I_max = IT
K_max = KT
L_max = LT
Go To MRD 2

TEST 2


Calculate ∂β/∂α, ∂β/∂ε, Δα_i, Δε_i (As For MRD 2)
Is Σ_i [(Δα_ig)(Δα_i) + (Δε_ig)(Δε_i)] ≥ 0 ?
Yes
No
Let r = r + 1
Δα_ig = Δα_i
Δε_ig = Δε_i
Go To CNTR
Go To TREND 2

#2

LIM: $n = 1$

LIM1: Is $(\epsilon_{i,(g+1)} - \epsilon L_{i,n}) \cdot (\alpha L_{i,(n+1)} - \alpha L_{i,n}) - (\alpha_{i,(g+1)} - \alpha L_{i,n}) \cdot (\epsilon L_{i,(n+1)} - \epsilon L_{i,n}) \geq 0$

- YES → $n = n + 1$ → Is $n > 4$
  - NO → LIM1
  - YES → RETURN
- NO → ADJUST

ADJUST:

$X = \epsilon_{i,(g+1)}$

$Y = \alpha_{i,(g+1)}$

$$X1 = \frac{\epsilon L_{i,(n+1)} - \epsilon L_{i,n}}{\alpha L_{i,(n+1)} - \alpha L_{i,n}}$$

$Y1 = 1/X1$

$$\epsilon_{i,(g+1)} = \frac{(\alpha_{i,(g+1)} - \alpha L_{i,n}) + X1 \cdot X + Y1 \cdot \epsilon L_{i,n}}{Y1 + X1}$$

$\alpha_{i,(g+1)} = Y - X1 \cdot (\epsilon_{i,(g+1)} - X)$

Is $n = 1$

- YES → RETURN
- NO → CHECK

CHECK: Is $(\epsilon_{i,(g+1)} - \epsilon L_{i,(n-1)}) \cdot (\alpha L_{i,n} - \alpha L_{i,(n-1)}) - (\alpha_{i,(g+1)} - \alpha L_{i,(n-1)}) \cdot (\epsilon L_{i,n} - \epsilon L_{i,(n-1)}) < 0$

- YES → $\alpha_{i,(g+1)} = \alpha L_{i,n}$, $\epsilon_{i,(g+1)} = \epsilon L_{i,n}$ → RETURN
- NO → $n = n + 1$ → Is $n > 4$
  - YES → RETURN
  - NO → LIM1

Appendix C. Analysis of the Iteration Process

The heat-balance equations can be writted (Equation 3.5, Volume I):

$$(C.1) \qquad 0 = C_i - \sum_j \bar{A}_{ij} T_j - \sum_j M_{ij} \varphi_{ij} T_j + \sum_j M_{ij} \varphi_{ij} T_j - \sum_j M_{ij} T_j^4$$

$$+ 4 \epsilon_i a_i \sigma \tilde{T}_i^3 T_i - 4 \epsilon_i a_i \sigma \tilde{T}_i^3 T_i - \epsilon_i a_i \sigma T_i^4$$

where

$$C_i = \alpha_i S_i + \epsilon_i E_i + Q_i$$

$$\varphi_{ij} = \sigma (\tilde{T}_i + \tilde{T}_j)(\tilde{T}_i^2 + \tilde{T}_j^2)$$

The residual vector is then given by the equation:

$$(C.2) \qquad r_i = C_i - \sum_j \bar{A}''_{ij} T_j + \sum_j M_{ij} \varphi_{ij} T_j + 4 \epsilon_i \sigma a_i \tilde{T}_i^3 T_i$$

$$- \sum_j M_{ij} T_j^4 - \epsilon_i \sigma a_i T_i^4$$

Let

$$(C.3) \qquad E^{(n)} = T^{(n)} - T^{(\infty)}$$

Then

$$(C.4) \qquad r_i^{(n)} = - \sum_j \bar{A}_{ij} E^{(n)} - \sum_j \bar{M}_{ij} \left[4 T_j^{(\infty)^3} E_j^{(n)} + 6 T_j^{(\infty)^2} E_j^{(n)^2} \right.$$

$$\left. + 4 T_j^{(\infty)} E_j^{(\infty)^3} + E_j^{(n)^4} \right]$$

where

$$\bar{M}_{ij} = M_{ij} + \delta_{ij} \epsilon_i \sigma a_i$$

If $E^{(n)}$ is small enough (for example, 10^o compare to 500^o), Equation (C.4) can be approximated by

$$(C.5) \qquad r_i^{(n)} = - \sum_j (\bar{A}_{ij} + 4 \bar{M}_{ij} T_j^{(\infty)^3}) E_j^{(n)}$$

This equation gives the relationship between the residual, r_i, and the deviation of the n^{th} iterate from the exact solution.

If an iteration limit was placed on $E_i^{(n)}$, Equation (C.5) could not be used to relate this to an iteration limit on $r_i^{(n)}$. Note that $E_i^{(n)}$ cannot be used directly since $T_i^{(n)}$ is not known. If the worst combination of $E_i^{(n)}$ limits were used in attempting to relate an $E_i^{(n)}$ limit to an $r_i^{(n)}$ limit, a large value of DR might result; then, in the actual calculation, all the $E_i^{(n)}$'s might be small except for one, which would be large - possibly intolerably large. Therefore, the conversion of an $E_i^{(n)}$ limit to an $r_i^{(n)}$ limit fails.

Equation (C.5) can be used to compare several iteration values. Thus

$$\text{(C.6)} \qquad r_i^{(n+p)} - r_i^{(n)} = \sum_j \left(\bar{A}_{ij} + 4\,\bar{M}_{ij}\,T_j^{(\infty)^3}\right)\left(T_j^{(n+p)} - T_j^{(n)}\right)$$

Using the iteration formula to relation $(T^{(n+1)} - T^{(n)})$ gives

$$\text{(C.7)} \qquad r_i^{(n+1)} - r_i^{(n)} = \sum_j \left(\bar{A}_{ij} + 4\,\bar{M}_{ij}\,T_j^{(\infty)^3}\right)\left(J''_{ij}\right) r_k^{(n)}$$

Therefore, the r_i's follow an exponential decay. In the most elementary case, $\left\{J''_{ij}\right\}$ is exactly the inverse of $\left\{\bar{A}_{ij} + 4\,\bar{M}_{ij}\,T_j^{(\infty)^3}\right\}$ and r_i follows the relationship

$$\text{(C.8)} \qquad r_i^{(n)} = r_i^{(o)}\,e^{-n}$$

Therefore, at least approximately

$$\text{(C.9)} \qquad r_i^{(o)}\left[e^{-(n+p)} - e^{-n}\right] = -\Sigma\left[\bar{A}_{ij} + 4\,\bar{M}_{ij}\,T_j^{(\infty)^3}\right]\left[T_j^{(n+p)} - T_j^{(n)}\right]$$

From Equation (C.2), it is evident that

$$\text{(C.10)} \qquad r_i^{(o)} \doteq \Delta C_i$$

where ΔC_i is the change in C_i from one case to the next.

Several important conclusions can be drawn from Equations (C.5) to (C.10):

a. the $r_i^{(o)}$ that is largest will depend on which C_i changes the most from case to case (α - ϵ set to α - ϵ set);

b. the relative magnitudes of the $r_i^{(n)}$'s will remain the same throughout the iteration process;

c. the node that has the largest temperature change from iteration to iteration is also the node that is furthest from the solution (strictly speaking, the comparison should be made only between every second iteration, to eliminate the effect of oscillatory convergence);

d. for a given set of initial conditions ($r_i^{(o)}$'s and $T_i^{(o)}$'s), the values of

$$\text{(C.11)} \qquad DR^{(n)} \equiv \max_i r_i^{(n)} \text{ and } DE^{(n)} \equiv \max_i E_i^{(n)}$$

can be related by Equation (C.6)

$$\text{(C.12)} \qquad \frac{DR^{(n+p)} - DR^{(n)}}{\max_i \left| T_i^{(n+p)} - T_i^{(n)} \right|} = \frac{DR^{(n+p)}}{DE^{(n+p)}}$$

Therefore by performing the iteration process for two different values of DR and noting the maximum temperature change, the value of DE can be approximated by Equation (C.12). It must be ascertained that p is an even number for the approximation to be valid. If the DR's differ sufficiently, the error in approximating DE should be small, however, if p is an odd number.

Equation (C.7) can be used to study the rate of convergence of the iteration process. J'' is the inverse of the conduction-plus-linearized-radiation terms. Although the linearization is somewhat different from the form

$$\left\{ \bar{A}_{ij} + 4\, \bar{M}_{ij}\, T_j^{(\infty)^3} \right\}$$

the result will be assumed the same. Then

$$\left\{ J''_{ij} \right\} = \left\{ \bar{A}_{ij} + 4\, \bar{M}_{ij}\, T_j^{(\max)^3} \right\}^{-1}$$

$$= \left\{ \bar{A}_{ij} + 4\, \bar{M}_{ij}\, T_j^{(\infty)^3} + 4\, \bar{M}_{ij}\, T_j^{(\max)^3} - 4\, \bar{M}_{ij}\, T_j^{(\infty)^3} \right\}^{-1}$$

and, for $(T^{(\max)^3} - T_i^{(\infty)^3})$ small

$$r_i^{(n+1)} \doteq + \sum_{j,k} 4\, \bar{M}_{ij}\, (T_i^{(\max)^3} - T_j^{(\infty)^3})\, J''_{jk}\, r_k^{(n)}$$

or

$$r_i^{(n+1)} \doteq \sum_{j,k} 4\, \bar{M}_{ij}\, (T_j^{(\max)^3} - T_j^{(\infty)^3})\, (T_j^{(n+1)} - T_j^{(n)})$$

Therefore, the larger $T^{(\max)}$ is, the larger r_i will be for a given iteration number and the slower will be the convergence. If the problem involves radiation only and all the $T^{(\infty)}$'s and $T^{(\max)}$'s are the same for all nodes,

$$r_i^{(n)} \;\alpha\; \left(\frac{T_j^{(\max)^3} - T^{(\infty)^3}}{T_j^{(\max)^3}} \right)^n$$

Further insight into the iteration process can be obtained by considering the spectral radius of the iteration matrix

$$Z = (\bar{A} + \bar{R} + X)^{-1} X$$

$$\rho (Z) = \frac{\rho\left[(\bar{A} + \bar{R} + X)^{-1} X\right]}{1 + \rho\left[(\bar{A} + \bar{R} + X)^{-1} X\right]} \leq 1$$

(See Appendix B, Volume I.) If the internal conduction and radiation is dominant and if X is near zero

$$(A + R + X)$$

is nearly singular, so $\rho\left[(\bar{A} + \bar{R} + X)^{-1}\right]$ is very large and ρ (Z) is approximately equal to unity, so convergence is very slow.

```
EXPLORE     OCTOBER  13,1965

                                   COATING SELECTION PROGRAM

  NUMBER OF NODES  =  20
  NUMBER OF ORBITS =   7
  NUMBER OF CONSTANT TEMPERATURE NODES  =   0
  NUMBER OF COATINGS =  1
  NUMBER OF EXTERNAL NODES = 14
  INITIAL STEP SIZE  (DELTA) =  0.400
  MINIMUM STEP SIZE  (DELTA-MIN)  = 0.00100
  STEPHAN BOLTZMANN CONSTANT =   1.71300000E-09

  THE PROGRAM WILL STOP IF
  ANY TEMPERATURE IS  LESS THAN 0 OR GREATER THAN 100000.

  THE PROGRAM WILL
  SET  K(I,J) = K(J,I)   AND   SET  R(I,J)=R(J,I)
  ALLOWABLE TEMPERATURE ERROR IN SOLVING HEAT BALANCE   =    1.00000000E 00
  ALLOWABLE DEVIATION FROM THE RESIDUAL =     5.40000000E-01
  MAXIMUM NUMBER OF ITERATIONS FOR SOLUTION OF TEMPERATURE = 500

  MAXIMUM G ALLOWED =  30
  STABILITY OPTION FOR SOLVING HEAT BALANCE EQUATION =  2
```

NODE SPECIFICATION

NODE	TEMPERATURE LIMITS LOWER	TEMPERATURE LIMITS UPPER	COATING ESTIMATES ALPHA	COATING ESTIMATES EPSILON	EXTERNALLY EXPOSED AREA	HEAT FLUX MULTIPLIES OF SOLAR	ALBEDO	EARTH	INTERNAL	INITIAL TEMP	MAX TEMP EXPECTED	COATING NUMBER
1	420.00000	564.00000	0.18000	0.10000	4.570000E-01	1.00	1.00	1.00	1.00	500.00	750.00	1
2	200.00000	900.00000	0.18000	0.10000	5.490000E-01	1.00	1.00	1.00	1.00	500.00	750.00	1
3	200.00000	900.00000	0.18000	0.10000	5.490000E-01	1.00	1.00	1.00	1.00	500.00	750.00	1
4	200.00000	900.00000	0.18000	0.10000	5.490000E-01	1.00	1.00	1.00	1.00	500.00	750.00	1
5	200.00000	900.00000	0.18000	0.10000	3.930000E-01	1.00	1.00	1.00	1.00	500.00	750.00	1
6	456.00000	600.00000	0.20000	0.20000	1.217000E 00	1.00	1.00	1.00	1.00	500.00	750.00	1
7	456.00000	600.00000	0.20000	0.20000	1.217000E 00	1.00	1.00	1.00	1.00	500.00	750.00	1
8	456.00000	600.00000	0.20000	0.20000	1.217000E 00	1.00	1.00	1.00	1.00	500.00	750.00	1
9	200.00000	900.00000	0.20000	0.20000	3.475900E 00	1.00	1.00	1.00	1.00	500.00	750.00	1
10	200.00000	900.00000	0.20000	0.20000	6.620000E-01	1.00	1.00	1.00	1.00	500.00	750.00	1
11	200.00000	900.00000	0.20000	0.20000	1.038000E 00	1.00	1.00	1.00	1.00	500.00	750.00	1
12	200.00000	900.00000	0.20000	0.20000	3.908000E 00	1.00	1.00	1.00	1.00	500.00	750.00	1
13	200.00000	900.00000	0.20000	0.20000	2.950000E-01	1.00	1.00	1.00	1.00	500.00	750.00	1
14	200.00000	900.00000	0.20000	0.20000	4.800000E-01	1.00	1.00	1.00	1.00	500.00	750.00	1
15	200.00000	900.00000	0.00000	0.00000	0.000000E-39	1.00	1.00	1.00	1.00	500.00	750.00	1
16	200.00000	900.00000	0.00000	0.00000	0.000000E-39	1.00	1.00	1.00	1.00	500.00	750.00	1
17	492.00000	546.00000	0.00000	0.00000	0.000000E-39	1.00	1.00	1.00	1.00	500.00	750.00	1
18	492.00000	546.00000	-0.00000	0.00000	0.000000E-39	1.00	1.00	1.00	1.00	500.00	750.00	1
19	200.00000	900.00000	0.00000	0.00000	0.000000E-39	1.00	1.00	1.00	1.00	500.00	750.00	1
20	474.00000	582.00000	0.00000	0.00000	0.000000E-39	1.00	1.00	1.00	1.00	500.00	750.00	1

CONDUCTION INTER•CONNECTIONS

FROM NODE	TO NODE	CONDUCTION INTER-CONNECTION	FROM NODE	TO NODE	CONDUCTION INTER-CONNECTION	FROM NODE	TO NODE	CONDUCTION INTER-CONNECTION
2	3	6.3000000E-01	3	4	6.3000000E-01	1	2	1.13000000E 00
4	5	1.2600000E 00	5	6	8.8000000E-01	6	7	8.80000000E-01
7	8	2.0200000E 00	8	9	1.4500000E 00	10	11	2.40000000E 00
10	16	1.0000000E 02	11	12	5.5500000E 00	12	13	1.58000000E 00
13	14	3.5300000E 00	13	15	1.4500000E 00	5	15	4.40000000E-01
15	20	7.6000000E-01	17	18	9.5000000E-01	16	17	1.83000000E 00
18	19	1.8300000E 00	-0	-0	-0.0000000E-39	-0	-0	-0.00000000E-39

RADIATION INTER•CONNECTIONS

FROM NODE	TO NODE	RADIATION INTER-CONNECTION	FROM NODE	TO NODE	RADIATION INTER-CONNECTION	FROM NODE	TO NODE	RADIATION INTER-CONNECTION
12	15	1.4600000E 00	12	16	2.1500000E 00	15	16	4.60000000E-01
15	20	1.9200000E-01	16	17	3.2300000E 00	17	18	1.67000000E 00
8	17	1.1400000E-01	7	17	1.9500000E-01	6	17	2.85000000E-01
18	19	3.3380000E 00	8	18	2.5000000E-01	7	18	1.70000000E-01
6	18	8.0000000E-02	9	19	3.3380000E 00	-0	-0	-0.00000000E-39

ENVIRONMENTAL AND INTERNAL HEATING ORBIT 1

NODE	SOLAR FLUX	ALBEDO FLUX	EARTH FLUX	HEAT GENERATION
1	56.5000	0.00000	0.0000	0.0000
2	37.8000	0.00000	0.0000	0.0000
3	37.8000	0.00000	0.0000	0.0000
4	37.8000	0.00000	0.0000	0.0000
5	105.1000	0.00000	0.0000	0.0000
6	464.3000	0.00000	0.0000	0.0000
7	464.3000	0.00000	0.0000	0.0000
8	464.3000	0.00000	0.0000	0.0000
9	233.6000	0.00000	0.0000	0.0000
10	0.0000	0.00000	0.0000	0.0000
11	0.0000	0.00000	0.0000	0.0000
12	0.0000	0.00000	0.0000	0.0000
13	0.0000	0.00000	0.0000	0.0000
14	0.0000	0.00000	0.0000	0.0000
15	0.0000	0.00000	0.0000	0.0000
16	0.0000	0.00000	0.0000	0.0000
17	0.0000	0.00000	0.0000	13.8300
18	0.0000	0.00000	0.0000	13.8300
19	0.0000	0.00000	0.0000	0.0000
20	0.0000	0.00000	0.0000	15.0000

ENVIRONMENTAL AND INTERNAL HEATING ORBIT 2

NODE	SOLAR FLUX	ALBEDO FLUX	EARTH FLUX	HEAT GENERATION
1	59.6000	0.00000	0.0000	0.0000
2	53.5000	0.00000	0.0000	0.0000
3	53.5000	0.00000	0.0000	0.0000
4	53.5000	0.00000	0.0000	0.0000
5	90.9000	0.00000	0.0000	0.0000
6	380.6000	0.00000	0.0000	0.0000
7	380.6000	0.00000	0.0000	0.0000
8	380.6000	0.00000	0.0000	0.0000
9	338.7000	0.00000	0.0000	0.0000
10	0.0000	0.00000	0.0000	0.0000
11	0.0000	0.00000	0.0000	0.0000
12	0.0000	0.00000	0.0000	0.0000
13	0.0000	0.00000	0.0000	0.0000
14	0.0000	0.00000	0.0000	0.0000
15	0.0000	0.00000	0.0000	0.0000
16	0.0000	0.00000	0.0000	0.0000
17	0.0000	0.00000	0.0000	13.8300
18	0.0000	0.00000	0.0000	13.8300
19	0.0000	0.00000	0.0000	0.0000
20	0.0000	0.00000	0.0000	15.0000

ENVIRONMENTAL AND INTERNAL HEATING ORBIT 3

NODE	SOLAR FLUX	ALBEDO FLUX	EARTH FLUX	HEAT GENERATION
1	58.1000	0.00000	0.0000	0.0000
2	65.3000	0.00000	0.0000	0.0000
3	65.3000	0.00000	0.0000	0.0000
4	65.3000	0.00000	0.0000	0.0000
5	73.8000	0.00000	0.0000	0.0000
6	268.4000	0.00000	0.0000	0.0000
7	268.4000	0.00000	0.0000	0.0000
8	268.4000	0.00000	0.0000	0.0000
9	416.2000	0.00000	0.0000	0.0000
10	0.0000	0.00000	0.0000	0.0000
11	0.0000	0.00000	0.0000	0.0000
12	90.6000	0.00000	0.0000	0.0000
13	35.5000	0.00000	0.0000	0.0000
14	0.0000	0.00000	0.0000	0.0000
15	0.0000	0.00000	0.0000	0.0000
16	0.0000	0.00000	0.0000	0.0000
17	0.0000	0.00000	0.0000	13.8300
18	0.0000	0.00000	0.0000	13.8300
19	0.0000	0.00000	0.0000	0.0000
20	0.0000	0.00000	0.0000	15.0000

ENVIRONMENTAL AND INTERNAL HEATING   ORBIT 4

NODE	SOLAR FLUX	ALBEDO FLUX	EARTH FLUX	HEAT GENERATION
1	43.3000	0.00000	0.0000	0.0000
2	75.8000	0.00000	0.0000	0.0000
3	75.8000	0.00000	0.0000	0.0000
4	75.8000	0.00000	0.0000	0.0000
5	42.6000	0.00000	0.0000	0.0000
6	0.0000	0.00000	0.0000	0.0000
7	0.0000	0.00000	0.0000	0.0000
8	0.0000	0.00000	0.0000	0.0000
9	446.0000	0.00000	0.0000	0.0000
10	0.0000	0.00000	0.0000	0.0000
11	154.8000	0.00000	0.0000	0.0000
12	332.3000	0.00000	0.0000	0.0000
13	40.8000	0.00000	0.0000	0.0000
14	0.0000	0.00000	0.0000	0.0000
15	0.0000	0.00000	0.0000	0.0000
16	0.0000	0.00000	0.0000	0.0000
17	0.0000	0.00000	0.0000	13.8300
18	0.0000	0.00000	0.0000	13.8300
19	0.0000	0.00000	0.0000	0.0000
20	0.0000	0.00000	0.0000	15.0000

ENVIRONMENTAL AND INTERNAL HEATING ORBIT 5

NODE	SOLAR FLUX	ALBEDO FLUX	EARTH FLUX	HEAT GENERATION
1	44.0000	0.00000	0.0000	0.0000
2	68.7000	0.00000	0.0000	0.0000
3	68.7000	0.00000	0.0000	0.0000
4	34.4000	0.00000	0.0000	0.0000
5	0.0000	0.00000	0.0000	0.0000
6	0.0000	0.00000	0.0000	0.0000
7	0.0000	0.00000	0.0000	0.0000
8	0.0000	0.00000	0.0000	0.0000
9	387.8000	0.00000	0.0000	0.0000
10	86.8000	0.00000	0.0000	0.0000
11	142.0000	0.00000	0.0000	0.0000
12	701.5000	0.00000	0.0000	0.0000
13	21.3000	0.00000	0.0000	0.0000
14	100.5000	0.00000	0.0000	0.0000
15	0.0000	0.00000	0.0000	0.0000
16	0.0000	0.00000	0.0000	0.0000
17	0.0000	0.00000	0.0000	13.8300
18	0.0000	0.00000	0.0000	13.8300
19	0.0000	0.00000	0.0000	0.0000
20	0.0000	0.00000	0.0000	15.0000

ENVIRONMENTAL AND INTERNAL HEATING   ORBIT 6

NODE	SOLAR FLUX	ALBEDO FLUX	EARTH FLUX	HEAT GENERATION
1	39.8000	0.00000	0.0000	0.0000
2	45.2000	0.00000	0.0000	0.0000
3	45.2000	0.00000	0.0000	0.0000
4	0.0000	0.00000	0.0000	0.0000
5	0.0000	0.00000	0.0000	0.0000
6	0.0000	0.00000	0.0000	0.0000
7	0.0000	0.00000	0.0000	0.0000
8	0.0000	0.00000	0.0000	0.0000
9	310.3000	0.00000	0.0000	0.0000
10	144.8000	0.00000	0.0000	0.0000
11	83.8000	0.00000	0.0000	0.0000
12	846.3000	0.00000	0.0000	0.0000
13	15.6000	0.00000	0.0000	0.0000
14	147.7000	0.00000	0.0000	0.0000
15	0.0000	0.00000	0.0000	0.0000
16	0.0000	0.00000	0.0000	0.0000
17	0.0000	0.00000	0.0000	13.8300
18	0.0000	0.00000	0.0000	13.8300
19	0.0000	0.00000	0.0000	0.0000
20	0.0000	0.00000	0.0000	15.0000

ENVIRONMENTAL AND INTERNAL HEATING   ORBIT 7

NODE	SOLAR FLUX	ALBEDO FLUX	EARTH FLUX	HEAT GENERATION
1	32.8000	0.00000	0.0000	0.0000
2	32.8000	0.00000	0.0000	0.0000
3	0.0000	0.00000	0.0000	0.0000
4	0.0000	0.00000	0.0000	0.0000
5	0.0000	0.00000	0.0000	0.0000
6	0.0000	0.00000	0.0000	0.0000
7	0.0000	0.00000	0.0000	0.0000
8	0.0000	0.00000	0.0000	0.0000
9	240.7000	0.00000	0.0000	0.0000
10	157.6000	0.00000	0.0000	0.0000
11	79.6000	0.00000	0.0000	0.0000
12	1059.3000	0.00000	0.0000	0.0000
13	6.5000	0.00000	0.0000	0.0000
14	181.8000	0.00000	0.0000	0.0000
15	0.0000	0.00000	0.0000	0.0000
16	0.0000	0.00000	0.0000	0.0000
17	0.0000	0.00000	0.0000	13.8300
18	0.0000	0.00000	0.0000	13.8300
19	0.0000	0.00000	0.0000	0.0000
20	0.0000	0.00000	0.0000	15.0000

COATING SPECIFICATIONS

COATING NUMBER	LIMIT POINT 1		LIMIT POINT 2		LIMIT POINT 3		LIMIT POINT 4	
	ALPHA	EPSILON	ALPHA	EPSILON	ALPHA	EPSILON	ALPHA	EPSILON
1	0.120000	0.030000	0.360000	0.260000	0.970000	0.860000	0.350000	0.850000

STEP CHANGE PROCEDURE

IN MRD		IN TREND	
INCREASE	DECREASE	INCREASE	DECREASE
1.200	0.800	0.200	0.640

ERROR IN INVERSION

NODE	ERROR
1	9.99999850E-01
2	9.99999860E-01
3	9.99999850E-01
4	9.99999840E-01
5	9.99999880E-01
6	9.99999880E-01
7	9.99999900E-01
8	9.99999900E-01
9	9.99999930E-01
10	9.99999960E-01
11	9.99999920E-01
12	9.99999910E-01
13	9.99999900E-01
14	9.99999910E-01
15	9.99999990E-01
16	9.99999980E-01
17	1.00000000E 00
18	1.00000000E 00
19	1.00000000E 00
20	1.00000000E 00

```
EXPLORE     OCTOBER  13,1965

MODE    MRD1             ITERATION     1     NO. OF SURFACES ENCOUNTERED SINCE LAST TREND STEP      1  DELTA S =-0.00000

         BETA             NODE     ORBIT     LIMIT     MINIMUM BETA OCCURRED AT ITERATION    NODE  ORBIT LIMIT

     4.50685820E-02         1          3     UPPER      4.50686E-02                  1          1     3   UPPER
```

NODE	ABSORPTIVITY	EMISSIVITY
1	0.18000000	0.10000000
2	0.18000000	0.10000000
3	0.18000000	0.10000000
4	0.18000000	0.10000000
5	0.18000000	0.10000000
6	0.20000000	0.20000000
7	0.20000000	0.20000000
8	0.20000000	0.20000000
9	0.20000000	0.20000000
10	0.20000000	0.20000000
11	0.20000000	0.20000000
12	0.20000000	0.20000000
13	0.20000000	0.20000000
14	0.20000000	0.20000000

TEMPERATURE VALUES

NODE \ ORBIT	1	2	3	4	5	6	7
1	560.53	569.05	570.49	545.95	543.44	517.06	494.51
2	558.31	566.82	568.58	545.21	542.48	515.68	493.43
3	558.03	562.96	562.10	535.39	534.06	510.85	490.99
4	561.45	558.82	551.87	516.17	518.16	503.28	497.23
5	565.17	556.39	544.36	501.03	510.69	504.29	504.92
6	586.12	569.82	547.23	476.71	491.04	488.86	492.00
7	585.42	568.91	545.33	471.03	486.47	485.23	488.49
8	574.80	561.29	541.28	475.39	490.33	488.51	491.03
9	538.88	535.84	528.59	492.29	505.62	501.68	502.11
10	508.03	500.77	498.07	492.76	532.24	540.99	554.46
11	492.47	485.90	486.57	494.25	536.84	545.27	560.76
12	489.52	483.05	485.19	493.14	539.03	549.77	566.95
13	492.59	486.34	489.81	493.28	539.56	551.44	568.03
14	489.91	483.79	487.18	490.58	541.26	555.37	573.30
15	506.60	500.06	500.36	498.49	538.99	547.97	562.75
16	508.56	501.27	498.49	492.86	532.14	540.79	554.21
17	526.65	518.68	512.28	494.36	526.51	532.31	542.78
18	539.83	532.99	524.55	495.06	517.83	519.36	525.42
19	539.39	534.07	526.09	494.10	513.14	512.67	516.64
20	522.55	516.13	516.42	514.62	554.37	563.18	577.68

EXPLORE OCTOBER 13,1965

MODE CNTR ITERATION 19 NO. OF SURFACES ENCOUNTERED SINCE LAST TREND STEP 3 DELTA S = 0.24159

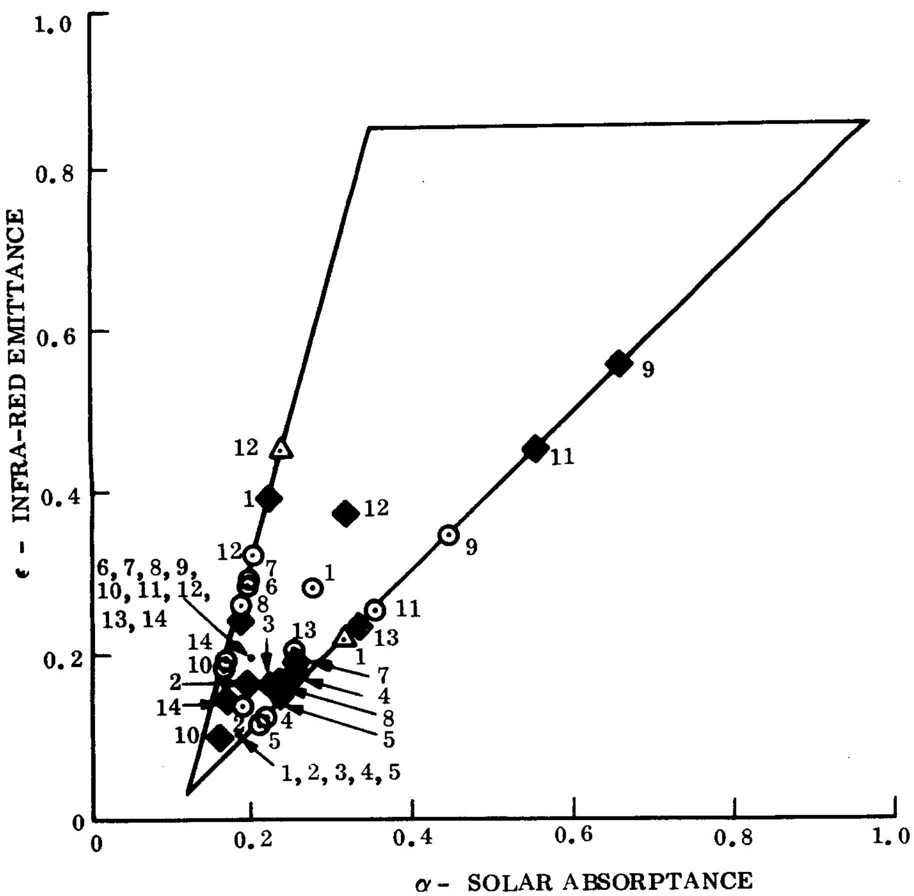
BETA	NODE	ORBIT	LIMIT	MINIMUM BETA OCCURRED AT ITERATION	NODE	ORBIT	LIMIT
-9.54318570E-02	17	1	LOWER	-9.54319E-02 19	17	1	LOWER

NODE	ABSORPTIVITY	EMISSIVITY
1	0.22342671	0.39873870
2	0.19905263	0.16377667
3	0.22305891	0.16339320
4	0.25540102	0.17674042
5	0.23250719	0.15124079
6	0.18352432	0.25409298
7	0.25669077	0.19590135
8	0.23441247	0.16465845
9	0.65989131	0.56132349
10	0.16162893	0.10029010
11	0.55651087	0.45433175
12	0.32042908	0.37578417
13	0.33664102	0.23858683
14	0.17075838	0.14457952

TEMPERATURE VALUES

NODE \ ORBIT	1	2	3	4	5	6	7
1	492.46	502.65	507.38	497.51	489.92	464.25	441.92
2	497.45	508.50	514.20	505.87	497.14	469.21	445.97
3	509.43	518.42	522.89	512.92	503.30	475.67	452.53
4	524.45	527.02	526.68	510.01	500.77	478.60	469.31
5	534.27	530.65	525.48	502.11	500.83	486.98	484.10
6	562.60	551.90	535.94	483.97	488.21	477.87	475.96
7	580.70	569.90	551.34	488.72	493.12	482.22	478.21
8	567.51	562.58	549.90	498.34	500.92	488.32	481.95
9	514.19	527.72	534.74	522.51	519.94	502.76	490.85
10	472.93	473.80	481.96	507.71	538.11	537.75	548.52
11	449.56	450.10	461.85	507.94	541.80	540.23	553.74
12	445.40	445.82	459.77	502.21	541.69	545.30	561.70
13	453.41	453.51	469.57	504.42	542.40	546.72	561.64
14	452.01	452.11	467.96	502.28	544.30	550.76	566.96
15	469.06	468.82	479.98	507.94	540.77	542.21	555.40
16	473.54	474.42	482.50	507.78	537.98	537.55	548.24
17	497.15	498.41	502.57	511.36	533.45	529.73	535.97
18	515.11	520.11	523.20	517.12	527.68	518.44	517.28
19	514.81	523.17	527.86	519.30	524.74	512.60	507.64
20	485.68	485.45	496.42	523.90	556.13	557.55	570.48

Figure 13. Results of EPE-D Computer Study



SYMBOL	ITERATION	β
•	1	.0451
○	4	.0441
△	12	.0083
◆	19	-.0954

5 WORST β's

NODE	ORBIT	LIMIT	β
1	7	L	-0.1522
6	7	L	-0.1386
7	1	U	-0.1340
17	1	L	-0.0954
20	3	L	-0.2076

Figure 14. Results of Ten-Minute Computer Calculation for EPE-D

Appendix E. Input/Output Data for S-52

```
S-52     100  SUNLIGHT   OCTOBER  13,1965


                                   COATING SELECTION PROGRAM

   NUMBER OF NODES  =  34

   NUMBER OF ORBITS =   7

   NUMBER OF CONSTANT TEMPERATURE NODES  =   1

   NUMBER OF COATINGS =  1

   NUMBER OF EXTERNAL NODES = 10

   INITIAL STEP SIZE  (DELTA) =  0.320

   MINIMUM STEP SIZE  (DELTA-MIN)  = 0.00100

   STEPHAN BOLTZMANN CONSTANT =   1.71300000E-09


   THE PROGRAM WILL STOP IF

   K(I,J) DOES NOT EQUAL K(J,I)

   R(I,J) DOES NOT EQUAL R(J,I)

   THE PROGRAM WILL

   SET  K(I,J) = K(J,I)   AND   SET  R(I,J)=R(J,I)

   ALLOWABLE TEMPERATURE ERROR IN SOLVING HEAT BALANCE   =    1.00000000E 00

   ALLOWABLE DEVIATION FROM THE RESIDUAL =    5.00000000E-01

   MAXIMUM NUMBER OF ITERATIONS FOR SOLUTION OF TEMPERATURE = 500


   MAXIMUM G ALLOWED =  30

   STABILITY OPTION FOR SOLVING HEAT BALANCE EQUATION =  2
```

NODE SPECIFICATION

NODE	TEMPERATURE LIMITS LOWER	UPPER	COATING ESTIMATES ALPHA	EPSILON	EXTERNALLY EXPOSED AREA	HEAT FLUX MULTIPLIES OF SOLAR	ALBEDO	EARTH	INTERNAL	INITIAL TEMP	MAX TEMP EXPECTED	COATING NUMBER
1	100.00000	900.00000	0.00000	0.00000	0.000000E-39	1.00	1.00	1.00	1.00	500.00	750.00	1
2	100.00000	900.00000	0.43000	0.87000	2.840000E 00	1.00	1.00	1.00	1.00	500.00	750.00	1
3	100.00000	900.00000	0.43000	0.87000	2.500000E 00	1.00	1.00	1.00	1.00	500.00	750.00	1
4	465.00000	565.00000	0.00000	0.00000	0.000000E-39	1.00	1.00	1.00	1.00	500.00	750.00	1
5	100.00000	900.00000	0.43000	0.87000	2.580000E 00	1.00	1.00	1.00	1.00	500.00	750.00	1
6	465.00000	565.00000	0.00000	0.00000	0.000000E-39	1.00	1.00	1.00	1.00	500.00	750.00	1
7	100.00000	900.00000	0.43000	0.87000	2.530000E 00	1.00	1.00	1.00	1.00	500.00	750.00	1
8	100.00000	900.00000	0.00000	0.00000	0.000000E-39	1.00	1.00	1.00	1.00	500.00	750.00	1
9	100.00000	900.00000	0.38000	0.87000	2.950000E-01	1.00	1.00	1.00	1.00	500.00	750.00	1
10	465.00000	565.00000	0.00000	0.00000	0.000000E-39	1.00	1.00	1.00	1.00	500.00	750.00	1
11	100.00000	900.00000	0.00000	0.00000	0.000000E-39	1.00	1.00	1.00	1.00	500.00	750.00	1
12	100.00000	900.00000	0.00000	0.00000	0.000000E-39	1.00	1.00	1.00	1.00	500.00	750.00	1
13	465.00000	565.00000	0.00000	0.00000	0.000000E-39	1.00	1.00	1.00	1.00	500.00	750.00	1
14	100.00000	900.00000	0.00000	0.00000	0.000000E-39	1.00	1.00	1.00	1.00	500.00	750.00	1
15	400.00000	580.00000	0.00000	0.00000	0.000000E-39	1.00	1.00	1.00	1.00	500.00	750.00	1
16	100.00000	900.00000	0.00000	0.00000	0.000000E-39	1.00	1.00	1.00	1.00	500.00	750.00	1
17	100.00000	900.00000	0.33000	0.87000	5.500000E-02	1.00	1.00	1.00	1.00	500.00	750.00	1
18	400.00000	580.00000	0.00000	0.00000	0.000000E-39	1.00	1.00	1.00	1.00	500.00	750.00	1
19	100.00000	900.00000	0.00000	0.00000	0.000000E-39	1.00	1.00	1.00	1.00	500.00	750.00	1
20	100.00000	900.00000	0.33000	0.87000	3.400000E-02	1.00	1.00	1.00	1.00	500.00	750.00	1
21	100.00000	900.00000	0.00000	0.00000	0.000000E-39	1.00	1.00	1.00	1.00	500.00	750.00	1
22	100.00000	900.00000	0.00000	0.00000	0.000000E-39	1.00	1.00	1.00	1.00	500.00	750.00	1
23	100.00000	900.00000	0.00000	0.00000	0.000000E-39	1.00	1.00	1.00	1.00	500.00	750.00	1
24	100.00000	900.00000	0.00000	0.00000	0.000000E-39	1.00	1.00	1.00	1.00	500.00	750.00	1
25	100.00000	900.00000	0.00000	0.00000	0.000000E-39	1.00	1.00	1.00	1.00	500.00	750.00	1
26	100.00000	900.00000	0.00000	0.00000	0.000000E-39	1.00	1.00	1.00	1.00	500.00	750.00	1
27	400.00000	580.00000	0.00000	0.00000	0.000000E-39	1.00	1.00	1.00	1.00	500.00	750.00	1
28	100.00000	900.00000	0.38000	0.87000	3.940000E-01	1.00	1.00	1.00	1.00	500.00	750.00	1
29	100.00000	900.00000	0.89000	0.87000	8.950000E-01	1.00	1.00	1.00	1.00	500.00	750.00	1
30	100.00000	900.00000	0.00000	0.00000	0.000000E-39	1.00	1.00	1.00	1.00	500.00	750.00	1
31	100.00000	900.00000	0.00000	0.00000	0.000000E-39	1.00	1.00	1.00	1.00	500.00	750.00	1
32	100.00000	900.00000	0.73000	0.87000	1.160000E 00	1.00	1.00	1.00	1.00	500.00	750.00	1
33	100.00000	900.00000	0.00000	0.00000	0.000000E-39	1.00	1.00	1.00	1.00	500.00	750.00	1
34	100.00000	900.00000	0.00000	0.00000	0.000000E-39	1.00	1.00	1.00	1.00	500.00	750.00	1

CONDUCTION INTER•CONNECTIONS

FROM NODE	TO NODE	CONDUCTION INTER-CONNECTION	FROM NODE	TO NODE	CONDUCTION INTER-CONNECTION	FROM NODE	TO NODE	CONDUCTION INTER-CONNECTION
1	2	1.0000000E-03	1	24	5.0000000E 00	2	3	2.00000000E-03
2	32	5.4000000E-02	3	5	4.0000000E-03	3	14	5.60000000E-02
4	14	1.0000000E 01	4	31	1.0000000E 02	5	12	4.80000000E-02
6	12	1.4000000E 01	7	9	9.0000000E-03	7	12	1.20000000E-02
8	9	3.0000000E-01	8	11	3.0000000E-01	8	12	1.00000000E 00
9	11	1.0000000E 01	10	28	1.0000000E-02	11	12	1.00000000E 00
11	34	2.0000000E 00	13	14	1.0000000E 00	15	16	3.10000000E-02
16	17	1.9000000E-02	17	18	5.3000000E-02	17	20	3.57000000E 00
18	19	3.2900000E 00	20	33	4.5000000E-02	21	22	8.00000000E 00
21	33	4.5000000E-02	22	23	1.5000000E 00	22	25	1.29000000E-01
22	26	1.0800000E 01	22	32	8.0000000E-03	23	24	8.00000000E 00
23	26	3.0000000E 00	25	26	7.7000000E-01	26	27	5.00000000E 00

RADIATION INTER•CONNECTIONS

FROM NODE	TO NODE	RADIATION INTER-CONNECTION	FROM NODE	TO NODE	RADIATION INTER-CONNECTION	FROM NODE	TO NODE	RADIATION INTER-CONNECTION
1	2	1.0000000E-01	1	4	5.0000000E-01	1	13	1.80000000E-02
1	14	1.4000000E-02	1	21	1.0000000E-03	1	22	1.00000000E-03
1	23	1.0000000E-03	1	24	4.0000000E-04	1	27	3.00000000E-05
1	32	6.4000000E-01	2	3	3.0000000E-01	2	4	1.85000000E 00
2	13	2.8000000E-02	2	14	5.8000000E-02	3	4	2.00000000E 00
3	13	9.0000000E-03	3	14	3.0000000E-01	4	13	3.00000000E-02
4	14	5.4600000E-01	4	30	1.5000000E-01	4	31	5.00000000E-01
5	6	2.1500000E 00	5	12	2.4400000E-01	5	14	2.44000000E-01
6	12	7.8000000E-02	5	14	2.2000000E 00	6	34	6.41000000E-01
7	11	2.1000000E-01	7	12	7.2000000E-01	10	11	5.20000000E-01
10	34	1.7000000E-01	11	12	3.4000000E-01	12	14	1.55000000E-01
13	14	1.2400000E-02	13	34	1.8700000E-01	15	16	6.00000000E-03
15	17	3.0000000E-03	15	18	1.0000000E-03	17	20	2.50000000E-03
19	33	3.0000000E-04	21	25	1.0000000E-04	21	33	6.00000000E-04
22	26	4.0000000E-04	22	32	3.0000000E-03	23	32	1.00000000E-03
24	32	2.0000000E-04	25	26	8.0000000E-04	12	35	1.94400000E-01
15	35	9.8999999E-03	15	35	2.4300000E-02	30	35	1.91000000E-02
31	35	4.5000000E-01	33	35	2.0610000E-01	-0	-0	-0.00000000E-39

ENVIRONMENTAL AND INTERNAL HEATING ORBIT 1

NODE	SOLAR FLUX	ALBEDO FLUX	EARTH FLUX	HEAT GENERATION
1	-0.0000	-0.00000	-0.0000	-0.0000
2	560.2000	-0.00000	56.8000	-0.0000
3	288.0000	-0.00000	50.0000	-0.0000
4	-0.0000	-0.00000	-0.0000	1.7300
5	301.2000	-0.00000	51.6000	-0.0000
6	-0.0000	-0.00000	-0.0000	22.4400
7	8.4000	-0.00000	50.6000	-0.0000
8	-0.0000	-0.00000	-0.0000	-0.0000
9	3.8400	-0.00000	5.9000	-0.0000
10	-0.0000	-0.00000	-0.0000	-0.0000
11	-0.0000	-0.00000	-0.0000	-0.0000
12	-0.0000	-0.00000	-0.0000	6.0280
13	-0.0000	-0.00000	-0.0000	1.7100
14	-0.0000	-0.00000	-0.0000	-0.0000
15	-0.0000	-0.00000	-0.0000	1.7802
16	-0.0000	-0.00000	-0.0000	2.2860
17	7.5000	-0.00000	1.1000	-0.0000
18	-0.0000	-0.00000	-0.0000	1.9710
19	-0.0000	-0.00000	-0.0000	0.1800
20	10.1200	-0.00000	0.6800	-0.0000
21	-0.0000	-0.00000	-0.0000	1.8000
22	-0.0000	-0.00000	-0.0000	-0.0000
23	-0.0000	-0.00000	-0.0000	-0.0000
24	-0.0000	-0.00000	-0.0000	-0.0000
25	-0.0000	-0.00000	-0.0000	-0.0000
26	-0.0000	-0.00000	-0.0000	-0.0000
27	-0.0000	-0.00000	-0.0000	-0.0000
28	-0.0000	-0.00000	4.8000	-0.0000
29	82.1000	-0.00000	17.9000	-0.0000
30	-0.0000	-0.00000	-0.0000	-0.0000
31	-0.0000	-0.00000	-0.0000	53.9000
32	363.0000	-0.00000	23.2000	-0.0000
33	-0.0000	-0.00000	-0.0000	5.2620
34	-0.0000	-0.00000	-0.0000	1.7100

ENVIRONMENTAL AND INTERNAL HEATING ORBIT 2

NODE	SOLAR FLUX	ALBEDO FLUX	EARTH FLUX	HEAT GENERATION
1	-0.0000	-0.00000	-0.0000	-0.0000
2	479.2000	-0.00000	56.8000	-0.0000
3	349.0000	-0.00000	50.0000	-0.0000
4	-0.0000	-0.00000	-0.0000	1.7300
5	377.6000	-0.00000	51.6000	-0.0000
6	-0.0000	-0.00000	-0.0000	22.4400
7	44.4000	-0.00000	50.6000	-0.0000
8	-0.0000	-0.00000	-0.0000	-0.0000
9	48.7000	-0.00000	5.9000	-0.0000
10	-0.0000	-0.00000	-0.0000	-0.0000
11	-0.0000	-0.00000	-0.0000	4.0000
12	-0.0000	-0.00000	-0.0000	6.0280
13	-0.0000	-0.00000	-0.0000	1.7100
14	-0.0000	-0.00000	-0.0000	-0.0000
15	-0.0000	-0.00000	-0.0000	1.3202
16	-0.0000	-0.00000	-0.0000	2.6835
17	8.4000	-0.00000	1.1000	-0.0000
18	-0.0000	-0.00000	-0.0000	1.4310
19	-0.0000	-0.00000	-0.0000	0.6200
20	7.5200	-0.00000	0.6800	-0.0000
21	-0.0000	-0.00000	-0.0000	2.1400
22	-0.0000	-0.00000	-0.0000	-0.0000
23	-0.0000	-0.00000	-0.0000	-0.0000
24	-0.0000	-0.00000	-0.0000	-0.0000
25	-0.0000	-0.00000	-0.0000	0.0290
26	-0.0000	-0.00000	-0.0000	-0.0000
27	-0.0000	-0.00000	-0.0000	-0.0000
28	-0.0000	-0.00000	4.8000	-0.0000
29	93.4000	-0.00000	17.9000	-0.0000
30	-0.0000	-0.00000	-0.0000	-0.0000
31	-0.0000	-0.00000	-0.0000	65.3000
32	260.0000	-0.00000	23.2000	-0.0000
33	-0.0000	-0.00000	-0.0000	5.5220
34	-0.0000	-0.00000	-0.0000	1.7100

ENVIRONMENTAL AND INTERNAL HEATING ORBIT 3

NODE	SOLAR FLUX	ALBEDO FLUX	EARTH FLUX	HEAT GENERATION
1	-0.0000	-0.00000	-0.0000	-0.0000
2	349.2000	-0.00000	56.8000	-0.0000
3	389.0000	-0.00000	50.0000	-0.0000
4	-0.0000	-0.00000	-0.0000	1.7300
5	430.6000	-0.00000	51.6000	-0.0000
6	-0.0000	-0.00000	-0.0000	22.4400
7	122.4000	-0.00000	50.6000	-0.0000
8	-0.0000	-0.00000	-0.0000	-0.0000
9	76.4000	-0.00000	5.9000	-0.0000
10	-0.0000	-0.00000	-0.0000	-0.0000
11	-0.0000	-0.00000	-0.0000	12.0000
12	-0.0000	-0.00000	-0.0000	6.0280
13	-0.0000	-0.00000	-0.0000	1.7100
14	-0.0000	-0.00000	-0.0000	-0.0000
15	-0.0000	-0.00000	-0.0000	0.7728
16	-0.0000	-0.00000	-0.0000	2.9460
17	8.9000	-0.00000	1.1000	-0.0000
18	-0.0000	-0.00000	-0.0000	0.7880
19	-0.0000	-0.00000	-0.0000	0.9300
20	3.2200	-0.00000	0.6800	-0.0000
21	-0.0000	-0.00000	-0.0000	2.3200
22	-0.0000	-0.00000	-0.0000	-0.0000
23	-0.0000	-0.00000	-0.0000	-0.0000
24	-0.0000	-0.00000	-0.0000	-0.0000
25	-0.0000	-0.00000	-0.0000	0.0290
26	-0.0000	-0.00000	-0.0000	-0.0000
27	-0.0000	-0.00000	-0.0000	-0.0000
28	-0.0000	-0.00000	4.8000	-0.0000
29	101.3000	-0.00000	17.9000	-0.0000
30	-0.0000	-0.00000	-0.0000	-0.0000
31	-0.0000	-0.00000	-0.0000	70.2000
32	211.0000	-0.00000	23.2000	-0.0000
33	-0.0000	-0.00000	-0.0000	5.6820
34	-0.0000	-0.00000	-0.0000	1.7100

ENVIRONMENTAL AND INTERNAL HEATING ORBIT 4

NODE	SOLAR FLUX	ALBEDO FLUX	EARTH FLUX	HEAT GENERATION
1	-0.0000	-0.00000	-0.0000	-0.0000
2	216.2000	-0.00000	56.8000	-0.0000
3	395.0000	-0.00000	50.0000	-0.0000
4	-0.0000	-0.00000	-0.0000	1.7300
5	451.6000	-0.00000	51.6000	-0.0000
6	-0.0000	-0.00000	-0.0000	22.4400
7	224.4000	-0.00000	50.6000	-0.0000
8	-0.0000	-0.00000	-0.0000	-0.0000
9	73.4000	-0.00000	5.9000	-0.0000
10	-0.0000	-0.00000	-0.0000	-0.0000
11	-0.0000	-0.00000	-0.0000	15.0000
12	-0.0000	-0.00000	-0.0000	6.0280
13	-0.0000	-0.00000	-0.0000	1.7100
14	-0.0000	-0.00000	-0.0000	-0.0000
15	-0.0000	-0.00000	-0.0000	0.2070
16	-0.0000	-0.00000	-0.0000	3.0135
17	8.9000	-0.00000	1.1000	-0.0000
18	-0.0000	-0.00000	-0.0000	0.1240
19	-0.0000	-0.00000	-0.0000	0.9300
20	1.6200	-0.00000	0.6800	-0.0000
21	-0.0000	-0.00000	-0.0000	2.4200
22	-0.0000	-0.00000	-0.0000	-0.0000
23	-0.0000	-0.00000	-0.0000	-0.0000
24	-0.0000	-0.00000	-0.0000	-0.0000
25	-0.0000	-0.00000	-0.0000	0.0290
26	-0.0000	-0.00000	-0.0000	-0.0000
27	-0.0000	-0.00000	-0.0000	-0.0000
28	-0.0000	-0.00000	4.8000	-0.0000
29	97.6000	-0.00000	17.9000	-0.0000
30	-0.0000	-0.00000	-0.0000	-0.0000
31	-0.0000	-0.00000	-0.0000	72.3000
32	163.0000	-0.00000	23.2000	-0.0000
33	-0.0000	-0.00000	-0.0000	5.7270
34	-0.0000	-0.00000	-0.0000	10.7100

ENVIRONMENTAL AND INTERNAL HEATING ORBIT 5

NODE	SOLAR FLUX	ALBEDO FLUX	EARTH FLUX	HEAT GENERATION
1	-0.0000	-0.00000	-0.0000	-0.0000
2	108.2000	-0.00000	56.8000	-0.0000
3	373.0000	-0.00000	50.0000	-0.0000
4	-0.0000	-0.00000	-0.0000	1.7300
5	430.6000	-0.00000	51.6000	-0.0000
6	-0.0000	-0.00000	-0.0000	22.4400
7	385.4000	-0.00000	50.6000	-0.0000
8	-0.0000	-0.00000	-0.0000	-0.0000
9	101.1000	-0.00000	5.9000	-0.0000
10	-0.0000	-0.00000	-0.0000	-0.0000
11	-0.0000	-0.00000	-0.0000	-0.0000
12	-0.0000	-0.00000	-0.0000	47.0280
13	-0.0000	-0.00000	-0.0000	1.7100
14	-0.0000	-0.00000	-0.0000	-0.0000
15	-0.0000	-0.00000	-0.0000	0.2070
16	-0.0000	-0.00000	-0.0000	2.9460
17	8.4000	-0.00000	1.1000	-0.0000
18	-0.0000	-0.00000	-0.0000	0.1240
19	-0.0000	-0.00000	-0.0000	0.9300
20	1.2200	-0.00000	0.5800	-0.0000
21	-0.0000	-0.00000	-0.0000	2.3200
22	-0.0000	-0.00000	-0.0000	-0.0000
23	-0.0000	-0.00000	-0.0000	-0.0000
24	-0.0000	-0.00000	-0.0000	-0.0000
25	-0.0000	-0.00000	-0.0000	0.0290
26	-0.0000	-0.00000	-0.0000	-0.0000
27	-0.0000	-0.00000	-0.0000	-0.0000
28	48.0000	-0.00000	4.8000	-0.0000
29	98.6000	-0.00000	17.9000	-0.0000
30	-0.0000	-0.00000	-0.0000	-0.0000
31	-0.0000	-0.00000	-0.0000	68.4000
32	85.5000	-0.00000	23.2000	-0.0000
33	-0.0000	-0.00000	-0.0000	5.6820
34	-0.0000	-0.00000	-0.0000	1.7100

ENVIRONMENTAL AND INTERNAL HEATING ORBIT 6

NODE	SOLAR FLUX	ALBEDO FLUX	EARTH FLUX	HEAT GENERATION
1	-0.0000	-0.00000	-0.0000	-0.0000
2	37.5000	-0.00000	56.8000	-0.0000
3	262.0000	-0.00000	50.0000	-0.0000
4	-0.0000	-0.00000	-0.0000	1.7300
5	323.6000	-0.00000	51.6000	-0.0000
6	-0.0000	-0.00000	-0.0000	22.4400
7	372.4000	-0.00000	50.5000	-0.0000
8	-0.0000	-0.00000	-0.0000	-0.0000
9	87.9000	-0.00000	5.9000	-0.0000
10	-0.0000	-0.00000	-0.0000	-0.0000
11	-0.0000	-0.00000	-0.0000	-0.0000
12	-0.0000	-0.00000	-0.0000	46.0280
13	-0.0000	-0.00000	-0.0000	1.7100
14	-0.0000	-0.00000	-0.0000	-0.0000
15	-0.0000	-0.00000	-0.0000	0.2070
16	-0.0000	-0.00000	-0.0000	2.6835
17	7.5000	-0.00000	1.1000	-0.0000
18	-0.0000	-0.00000	-0.0000	0.1240
19	-0.0000	-0.00000	-0.0000	0.8400
20	1.1100	-0.00000	0.6800	-0.0000
21	-0.0000	-0.00000	-0.0000	2.1400
22	-0.0000	-0.00000	-0.0000	-0.0000
23	-0.0000	-0.00000	-0.0000	-0.0000
24	-0.0000	-0.00000	-0.0000	-0.0000
25	-0.0000	-0.00000	-0.0000	0.0290
26	-0.0000	-0.00000	-0.0000	-0.0000
27	-0.0000	-0.00000	-0.0000	-0.0000
28	77.0000	-0.00000	4.8000	-0.0000
29	75.3000	-0.00000	17.9000	-0.0000
30	-0.0000	-0.00000	-0.0000	-0.0000
31	-0.0000	-0.00000	-0.0000	50.0000
32	37.2000	-0.00000	23.2000	-0.0000
33	-0.0000	-0.00000	-0.0000	5.5220
34	-0.0000	-0.00000	-0.0000	1.7100

ENVIRONMENTAL AND INTERNAL HEATING   ORBIT 7

NODE	SOLAR FLUX	ALBEDO FLUX	EARTH FLUX	HEAT GENERATION
1	-0.0000	-0.00000	-0.0000	-0.0000
2	6.6800	-0.00000	56.8000	-0.0000
3	235.0000	-0.00000	50.0000	-0.0000
4	-0.0000	-0.00000	-0.0000	1.7300
5	279.6000	-0.00000	51.6000	-0.0000
6	-0.0000	-0.00000	-0.0000	22.4400
7	511.4000	-0.00000	50.6000	-0.0000
8	-0.0000	-0.00000	-0.0000	-0.0000
9	108.6000	-0.00000	5.9000	-0.0000
10	-0.0000	-0.00000	-0.0000	-0.0000
11	-0.0000	-0.00000	-0.0000	-0.0000
12	-0.0000	-0.00000	-0.0000	61.0280
13	-0.0000	-0.00000	-0.0000	1.7100
14	-0.0000	-0.00000	-0.0000	-0.0000
15	-0.0000	-0.00000	-0.0000	0.2070
16	-0.0000	-0.00000	-0.0000	2.2860
17	5.8000	-0.00000	1.1000	-0.0000
18	-0.0000	-0.00000	-0.0000	0.1240
19	-0.0000	-0.00000	-0.0000	0.5800
20	0.9800	-0.00000	0.6800	-0.0000
21	-0.0000	-0.00000	-0.0000	0.3000
22	-0.0000	-0.00000	-0.0000	-0.0000
23	-0.0000	-0.00000	-0.0000	-0.0000
24	-0.0000	-0.00000	-0.0000	-0.0000
25	-0.0000	-0.00000	-0.0000	0.0290
26	-0.0000	-0.00000	-0.0000	-0.0000
27	-0.0000	-0.00000	-0.0000	-0.0000
28	148.2000	-0.00000	4.8000	-0.0000
29	67.9000	-0.00000	17.9000	-0.0000
30	-0.0000	-0.00000	-0.0000	-0.0000
31	-0.0000	-0.00000	-0.0000	45.7000
32	-0.0000	-0.00000	23.2000	-0.0000
33	-0.0000	-0.00000	-0.0000	4.9770
34	-0.0000	-0.00000	-0.0000	1.7100

KNOWN TEMPERATURE NODES

NODE	ORBIT	TEMPERATURE
35	1	0.00000
35	2	0.00000
35	3	0.00000
35	4	0.00000
35	5	0.00000
35	6	0.00000
35	7	0.00000

COATING SPECIFICATIONS

COATING NUMBER	LIMIT POINT 1		LIMIT POINT 2		LIMIT POINT 3		LIMIT POINT 4	
	ALPHA	EPSILON	ALPHA	EPSILON	ALPHA	EPSILON	ALPHA	EPSILON
1	0.120000	0.030000	0.960000	0.860000	0.970000	0.870000	0.250000	0.870000

ERROR IN INVERSION

NODE	ERROR
2	9.99999870E-01
3	9.99999820E-01
5	9.99999830E-01
7	9.99999840E-01
9	9.99999840E-01
17	9.99999780E-01
20	9.99999790E-01
28	9.99999910E-01
29	9.99999990E-01
32	9.99999880E-01
11	9.99999850E-01
12	9.99999900E-01
13	9.99999890E-01
14	9.99999950E-01
15	9.99999890E-01
16	9.99999900E-01
6	9.99999940E-01
18	1.00000010E 00
19	1.00000010E 00
4	1.00000000E 00
21	1.00000050E 00
22	1.00000050E 00
23	1.00000040E 00
24	1.00000040E 00
25	1.00000050E 00
26	1.00000050E 00
27	1.00000050E 00
8	9.99999900E-01
1	1.00000030E 00
30	1.00000000E 00
31	1.00000000E 00
10	9.99999990E-01
33	1.00000010E 00
34	1.00000000E 00

STEP CHANGE PROCEDURE

IN MRD		IN TREND	
INCREASE	DECREASE	INCREASE	DECREASE
1.200	0.800	0.200	0.640

S-52 100 SUNLIGHT OCTOBER 13,1965

MODE MRD1 ITERATION 1 NO. OF SURFACES ENCOUNTERED SINCE LAST TREND STEP 1 DELTA S =-0.00000

BETA	NODE	ORBIT	LIMIT	MINIMUM BETA OCCURRED AT ITERATION	NODE	ORBIT	LIMIT
1.01297910E-01	4	7	LOWER	1.01298E-01 1	4	7	LOWER

NODE	ABSORPTIVITY	EMISSIVITY
2	0.43000000	0.87000000
3	0.43000000	0.87000000
5	0.43000000	0.87000000
7	0.43000000	0.87000000
9	0.38000000	0.87000000
17	0.33000000	0.87000000
20	0.33000000	0.87000000
28	0.38000000	0.87000000
29	0.89000000	0.87000000
32	0.73000000	0.87000000

S-52 100 SUNLIGHT OCTOBER 13,1965

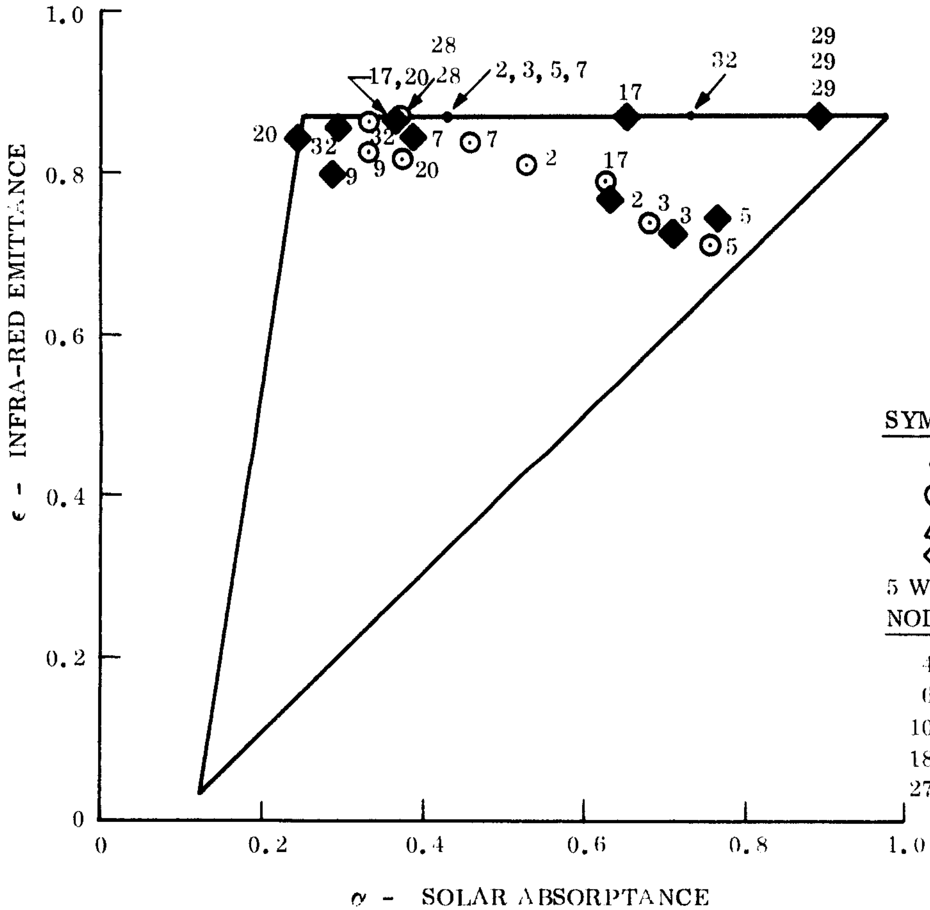
MODE	CNTR	ITERATION	14	NO. OF SURFACES ENCOUNTERED SINCE LAST TREND STEP	5	DELTA S = 0.32000				
	BETA	NODE	ORBIT	LIMIT	MINIMUM BETA OCCURRED AT ITERATION		NODE	ORBIT	LIMIT	
	-1.85163350E-01	4	7	LOWER	-1.85163E-01	14	4	7	LOWER	

NODE	ABSORPTIVITY	EMISSIVITY
2	0.63166574	0.76821230
3	0.71225131	0.72080007
5	0.76631729	0.74336664
7	0.39002003	0.84245990
9	0.29043328	0.79875099
17	0.65155156	0.86987242
20	0.24616075	0.84326081
28	0.37032478	0.86606051
29	0.89000000	0.87000000
32	0.29714779	0.85538070

TEMPERATURE VALUES

NODE \ ORBIT	1	2	3	4	5	6	7
2	550.13	543.81	527.09	504.25	480.05	442.34	429.40
3	529.98	543.08	548.22	545.13	535.59	499.79	490.81
5	520.96	542.26	555.32	559.89	553.58	527.54	520.54
7	410.17	429.23	452.33	473.65	501.44	489.91	511.56
9	491.13	513.68	529.87	536.98	539.35	515.44	521.53
17	500.20	498.75	488.00	475.08	468.64	456.16	434.97
20	499.37	497.77	486.88	474.03	467.60	455.20	434.21
28	316.79	319.32	321.11	322.01	444.73	487.25	562.75
29	507.73	521.56	530.61	526.43	527.57	498.84	488.58
32	525.74	503.35	489.52	472.51	442.60	408.85	385.54
11	492.72	514.53	530.38	537.79	539.32	515.25	521.03
12	504.08	521.35	532.48	536.90	543.23	517.36	520.32
13	523.77	534.26	537.97	535.72	529.70	497.92	493.55
14	525.38	535.27	537.99	534.34	528.06	495.31	489.90
15	519.25	510.19	492.00	467.72	463.69	453.26	435.48
16	505.10	505.60	497.73	483.77	473.24	467.23	446.97
6	509.27	526.49	537.10	540.77	544.39	517.31	518.36
18	539.91	536.50	519.57	494.32	487.93	473.86	447.95
19	539.95	536.68	519.85	494.60	483.21	474.11	448.13
4	528.83	536.99	537.58	531.92	523.31	490.10	483.52
21	525.40	518.49	511.60	500.19	482.34	450.18	433.69
22	525.70	518.71	511.78	500.32	482.42	450.16	433.87
23	526.30	519.19	512.19	500.64	482.66	450.21	434.36
24	526.60	519.43	512.39	500.81	482.78	450.24	434.60
25	525.81	518.84	511.89	500.41	482.50	450.20	434.00
26	525.83	518.82	511.87	500.39	482.47	450.17	433.98
27	525.83	518.82	511.87	500.39	482.47	450.17	433.98
8	499.52	518.63	531.60	537.08	541.77	516.61	520.70
1	527.07	519.81	512.72	501.07	482.98	450.28	434.98
30	513.15	521.06	521.62	516.12	507.75	475.49	469.10
31	528.77	537.00	537.63	532.02	523.41	490.15	483.55
10	490.85	512.42	527.90	535.72	538.20	514.71	521.19
33	433.31	432.69	429.50	424.21	413.36	406.85	394.47
34	498.27	518.72	532.74	541.55	540.32	515.22	519.49

Figure 15. Results of S-52 Computer Study



SYMBOL	ITERATION	β
•	1	0.1013
○	8	-0.1471
△		
◇	14	-0.1852

5 WORST β's

NODE	ORBIT	LIMIT	β
4	7	L	-0.1852
6	5	U	-0.2061
10	5	U	-0.2680
18	1	U	-0.2227
27	5	L	-0.4582

Figure 16. Results of Ten-Minute Calculation for S-52

Appendix F. Input/Output Data for IMP-C

```
NASA IMP C    OCTOBER 13,1965

                                        COATING SELECTION PROGRAM

NUMBER OF NODES  =  34

NUMBER OF ORBITS =   9

NUMBER OF CONSTANT TEMPERATURE NODES  =   0

NUMBER OF COATINGS =  1

NUMBER OF EXTERNAL NODES = 16

INITIAL STEP SIZE  (DELTA) =  0.400

MINIMUM STEP SIZE  (DELTA-MIN)  = 0.00100

STEPHAN BOLTZMANN CONSTANT =   1.71300000E-09

THE PROGRAM WILL

SET  K(I,J) = K(J,I)   AND   SET  R(I,J)=R(J,I)

ALLOWABLE TEMPERATURE ERROR IN SOLVING HEAT BALANCE   =    1.00000000E 00

ALLOWABLE DEVIATION FROM THE RESIDUAL =    6.50000000E-01

MAXIMUM NUMBER OF ITERATIONS FOR SOLUTION OF TEMPERATURE = 300

MAXIMUM G ALLOWED =  30

STABILITY OPTION FOR SOLVING HEAT BALANCE EQUATION =  2
```

NODE SPECIFICATION

NODE	TEMPERATURE LIMITS LOWER	UPPER	COATING ESTIMATES ALPHA	EPSILON	EXTERNALLY EXPOSED AREA	HEAT FLUX MULTIPLIES OF SOLAR	ALBEDO	EARTH	INTERNAL	INITIAL TEMP	MAX TEMP EXPECTED	COATING NUMBER
1	100.00000	900.00000	0.40000	0.50000	4.310000E-01	1.00	1.00	1.00	1.00	500.00	750.00	1
2	501.00000	555.00000	-0.00000	-0.00000	-0.000000E-39	1.00	1.00	1.00	1.00	500.00	750.00	1
3	501.00000	555.00000	-0.00000	-0.00000	-0.000000E-39	1.00	1.00	1.00	1.00	500.00	750.00	1
4	492.00000	555.00000	0.60000	0.50000	4.650000E-01	1.00	1.00	1.00	1.00	200.00	750.00	1
5	100.00000	900.00000	0.40000	0.50000	2.100000E-01	1.00	1.00	1.00	1.00	200.00	750.00	1
6	100.00000	900.00000	0.40000	0.50000	5.370000E-01	1.00	1.00	1.00	1.00	500.00	750.00	1
7	100.00000	900.00000	0.25000	0.85000	8.610000E-01	1.00	1.00	1.00	1.00	500.00	750.00	1
8	100.00000	900.00000	-0.00000	-0.00000	-0.000000E-39	1.00	1.00	1.00	1.00	500.00	750.00	1
9	100.00000	900.00000	0.40000	0.50000	1.451000E 00	1.00	1.00	1.00	1.00	500.00	750.00	1
10	501.00000	555.00000	-0.00000	-0.00000	-0.000000E-39	1.00	1.00	1.00	1.00	500.00	750.00	1
11	100.00000	900.00000	0.25000	0.85000	4.680000E-01	1.00	1.00	1.00	1.00	500.00	750.00	1
12	100.00000	900.00000	-0.00000	-0.00000	-0.000000E-39	1.00	1.00	1.00	1.00	500.00	750.00	1
13	100.00000	900.00000	0.25000	0.85000	6.180000E-01	1.00	1.00	1.00	1.00	500.00	750.00	1
14	100.00000	900.00000	-0.00000	-0.00000	-0.000000E-39	1.00	1.00	1.00	1.00	500.00	750.00	1
15	100.00000	900.00000	0.40000	0.50000	4.390000E-01	1.00	1.00	1.00	1.00	500.00	750.00	1
16	100.00000	900.00000	-0.00000	-0.00000	-0.000000E-39	1.00	1.00	1.00	1.00	500.00	750.00	1
17	474.00000	600.00000	-0.00000	-0.00000	-0.000000E-39	1.00	1.00	1.00	1.00	500.00	750.00	1
18	492.00000	555.00000	-0.00000	-0.00000	-0.000000E-39	1.00	1.00	1.00	1.00	500.00	750.00	1
19	501.00000	555.00000	-0.00000	-0.00000	-0.000000E-39	1.00	1.00	1.00	1.00	500.00	750.00	1
20	474.00000	564.00000	-0.00000	-0.00000	-0.000000E-39	1.00	1.00	1.00	1.00	500.00	750.00	1
21	501.00000	555.00000	-0.00000	-0.00000	-0.000000E-39	1.00	1.00	1.00	1.00	500.00	750.00	1
22	100.00000	900.00000	-0.00000	-0.00000	-0.000000E-39	1.00	1.00	1.00	1.00	500.00	750.00	1
23	100.00000	900.00000	0.40000	0.50000	6.670000E-01	1.00	1.00	1.00	1.00	500.00	750.00	1
24	100.00000	900.00000	-0.00000	-0.00000	-0.000000E-39	1.00	1.00	1.00	1.00	500.00	750.00	1
25	100.00000	900.00000	0.40000	0.50000	4.390000E-01	1.00	1.00	1.00	1.00	500.00	750.00	1
26	100.00000	900.00000	-0.00000	-0.00000	-0.000000E-39	1.00	1.00	1.00	1.00	500.00	750.00	1
27	100.00000	900.00000	0.40000	0.50000	2.815000E 00	1.00	1.00	1.00	1.00	500.00	750.00	1
28	100.00000	900.00000	-0.00000	-0.00000	-0.000000E-39	1.00	1.00	1.00	1.00	500.00	750.00	1
29	100.00000	900.00000	0.40000	0.50000	3.706000E 00	1.00	1.00	1.00	1.00	500.00	750.00	1
30	100.00000	900.00000	-0.00000	-0.00000	-0.000000E-39	1.00	1.00	1.00	1.00	500.00	750.00	1
31	100.00000	900.00000	0.40000	0.50000	2.636000E 00	1.00	1.00	1.00	1.00	500.00	750.00	1
32	100.00000	900.00000	-0.00000	-0.00000	-0.000000E-39	1.00	1.00	1.00	1.00	500.00	750.00	1
33	100.00000	900.00000	0.40000	0.50000	4.680000E-01	1.00	1.00	1.00	1.00	500.00	750.00	1
34	100.00000	900.00000	0.25000	0.85000	4.430000E-01	1.00	1.00	1.00	1.00	500.00	750.00	1

CONDUCTION INTER•CONNECTIONS

FROM NODE	TO NODE	CONDUCTION INTER-CONNECTION	FROM NODE	TO NODE	CONDUCTION INTER-CONNECTION	FROM NODE	TO NODE	CONDUCTION INTER-CONNECTION
1	2	3.8900000E-01	1	9	9.5000000E-02	1	12	2.70000000E-02
1	22	2.7000000E-02	1	28	1.6200000E-01	2	3	7.38000000E-01
2	8	3.9700000E 00	2	9	7.1000000E-02	2	10	7.15000000E-01
3	4	2.3000000E 00	3	10	3.7300000E-01	3	15	5.60000000E-02
3	16	2.5000000E-02	3	26	2.5000000E-02	3	25	5.60000000E-02
3	31	4.6000000E-02	3	32	2.0000000E-02	4	5	1.00000000E 00
7	8	7.9000000E-02	11	12	3.6200000E-01	12	14	1.80000000E-02
12	22	4.0000000E-02	12	28	4.0000000E-02	13	14	5.16000000E-01
14	16	1.9000000E-02	14	24	2.4000000E-02	14	30	2.40000000E-02
15	16	4.6800000E-01	15	25	7.9000000E-02	15	31	7.90000000E-02
16	18	4.0000000E-02	16	26	4.0000000E-02	16	32	4.00000000E-02
17	19	8.0000000E-03	17	34	7.9400000E-01	18	20	8.00000000E-03
19	20	8.0000000E-03	20	26	6.0000000E-01	21	32	1.58800000E 00
22	24	1.8000000E-02	22	32	1.6000000E-02	23	24	5.16000000E-01
24	26	1.9000000E-02	24	30	8.0000000E-03	25	26	4.68000000E-01
25	31	2.6000000E-02	26	32	1.6000000E-02	27	28	2.18000000E 00
28	30	1.1000000E-01	29	30	3.1000000E 00	30	32	1.13000000E-01
31	32	2.8200000E 00	22	33	3.6200000E-01	-0	-0	-0.00000000E-39

RADIATION INTER•CONNECTIONS

FROM NODE	TO NODE	RADIATION INTER-CONNECTION	FROM NODE	TO NODE	RADIATION INTER-CONNECTION	FROM NODE	TO NODE	RADIATION INTER-CONNECTION
1	2	1.7300000E-01	1	8	6.2000000E-02	1	18	1.20000000E-02
1	19	6.0000000E-03	1	20	6.0000000E-03	1	21	7.40000000E-02
2	8	4.4600000E-01	2	10	3.4300000E-01	2	12	1.60000000E-02
2	16	2.1000000E-02	2	17	1.1000000E-02	2	18	3.40000000E-02
2	19	3.9000000E-02	2	20	6.0000000E-03	2	21	2.70000000E-01
2	22	1.6000000E-02	2	26	2.1000000E-02	2	28	9.50000000E-02
2	32	1.2300000E-01	3	10	7.3000000E-01	4	6	2.09000000E-01
4	10	2.4000000E-02	4	15	1.3000000E-02	4	25	1.30000000E-02
4	31	8.0000000E-02	6	15	3.3000000E-02	6	25	3.30000000E-02
6	31	1.9800000E-01	8	12	1.6000000E-02	8	16	2.20000000E-02
8	17	1.7000000E-02	8	18	8.9000000E-02	8	19	8.50000000E-02
8	20	2.1000000E-02	8	21	6.3800000E-01	8	22	1.60000000E-02
8	26	2.2000000E-02	8	28	9.8000000E-02	8	32	1.31000000E-01
11	12	1.8700000E-01	12	16	5.0000000E-03	12	17	2.05000000E-01
12	18	2.1000000E-02	13	14	2.6700000E-01	14	17	1.25000000E-01
14	18	4.6300000E-01	15	16	1.8200000E-01	16	17	3.20000000E-02
16	18	3.0100000E-01	19	22	4.1800000E-01	19	26	3.52000000E-01
20	22	1.4000000E-02	20	24	8.3000000E-02	20	26	5.00000000E-02
21	28	2.5870000E 00	21	30	3.7080000E 00	21	32	2.41400000E 00
22	26	5.0000000E-03	22	33	1.8700000E-01	23	24	2.67000000E-01
19	24	5.8400000E-01	25	26	1.8200000E-01	27	28	1.12500000E 00
28	32	2.4000000E-02	29	30	1.6020000E 00	31	32	1.09300000E 00

ENVIRONMENTAL AND INTERNAL HEATING ORBIT 1

NODE	SOLAR FLUX	ALBEDO FLUX	EARTH FLUX	HEAT GENERATION
1	220.1000	-0.00000	-0.0000	-0.0000
2	-0.0000	-0.00000	-0.0000	-0.0000
3	-0.0000	-0.00000	-0.0000	-0.0000
4	-0.0000	-0.00000	-0.0000	-0.0000
5	-0.0000	-0.00000	-0.0000	-0.0000
6	-0.0000	-0.00000	-0.0000	-0.0000
7	133.5000	-0.00000	-0.0000	41.2000
8	-0.0000	-0.00000	-0.0000	-0.0000
9	184.6000	-0.00000	-0.0000	-0.0000
10	-0.0000	-0.00000	-0.0000	-0.0000
11	164.2000	-0.00000	-0.0000	-0.0000
12	-0.0000	-0.00000	-0.0000	-0.0000
13	42.7000	-0.00000	-0.0000	-0.0000
14	-0.0000	-0.00000	-0.0000	-0.0000
15	-0.0000	-0.00000	-0.0000	-0.0000
16	-0.0000	-0.00000	-0.0000	-0.0000
17	-0.0000	-0.00000	-0.0000	42.6000
18	-0.0000	-0.00000	-0.0000	3.4100
19	-0.0000	-0.00000	-0.0000	3.6900
20	-0.0000	-0.00000	-0.0000	26.9800
21	-0.0000	-0.00000	-0.0000	24.1400
22	-0.0000	-0.00000	-0.0000	-0.0000
23	46.2000	-0.00000	-0.0000	-0.0000
24	-0.0000	-0.00000	-0.0000	-0.0000
25	-0.0000	-0.00000	-0.0000	-0.0000
26	-0.0000	-0.00000	-0.0000	-0.0000
27	984.9000	-0.00000	-0.0000	-0.0000
28	-0.0000	-0.00000	-0.0000	-0.0000
29	256.3000	-0.00000	-0.0000	-0.0000
30	-0.0000	-0.00000	-0.0000	-0.0000
31	-0.0000	-0.00000	-0.0000	-0.0000
32	-0.0000	-0.00000	-0.0000	-0.0000
33	164.2000	-0.00000	-0.0000	-0.0000
34	73.0000	-0.00000	-0.0000	-0.0000

ENVIRONMENTAL AND INTERNAL HEATING ORBIT 2

NODE	SOLAR FLUX	ALBEDO FLUX	EARTH FLUX	HEAT GENERATION
1	191.8000	-0.00000	-0.0000	-0.0000
2	-0.0000	-0.00000	-0.0000	-0.0000
3	-0.0000	-0.00000	-0.0000	-0.0000
4	-0.0000	-0.00000	-0.0000	-0.0000
5	-0.0000	-0.00000	-0.0000	-0.0000
6	-0.0000	-0.00000	-0.0000	-0.0000
7	115.1000	-0.00000	-0.0000	75.2600
8	-0.0000	-0.00000	-0.0000	-0.0000
9	211.5800	-0.00000	-0.0000	-0.0000
10	-0.0000	-0.00000	-0.0000	-0.0000
11	137.0300	-0.00000	-0.0000	-0.0000
12	-0.0000	-0.00000	-0.0000	-0.0000
13	60.3500	-0.00000	-0.0000	-0.0000
14	-0.0000	-0.00000	-0.0000	-0.0000
15	-0.0000	-0.00000	-0.0000	-0.0000
16	-0.0000	-0.00000	-0.0000	-0.0000
17	-0.0000	-0.00000	-0.0000	42.6000
18	-0.0000	-0.00000	-0.0000	3.4100
19	-0.0000	-0.00000	-0.0000	3.6900
20	-0.0000	-0.00000	-0.0000	26.9800
21	-0.0000	-0.00000	-0.0000	24.1400
22	-0.0000	-0.00000	-0.0000	-0.0000
23	65.1800	-0.00000	-0.0000	-0.0000
24	-0.0000	-0.00000	-0.0000	-0.0000
25	-0.0000	-0.00000	-0.0000	-0.0000
26	822.1800	-0.00000	-0.0000	-0.0000
27	-0.0000	-0.00000	-0.0000	-0.0000
28	-0.0000	-0.00000	-0.0000	-0.0000
29	361.9600	-0.00000	-0.0000	-0.0000
30	-0.0000	-0.00000	-0.0000	-0.0000
31	-0.0000	-0.00000	-0.0000	-0.0000
32	-0.0000	-0.00000	-0.0000	-0.0000
33	137.0300	-0.00000	-0.0000	-0.0000
34	91.7300	-0.00000	-0.0000	-0.0000

ENVIRONMENTAL AND INTERNAL HEATING ORBIT 3

NODE	SOLAR FLUX	ALBEDO FLUX	EARTH FLUX	HEAT GENERATION
1	150.5200	-0.00000	-0.0000	-0.0000
2	-0.0000	-0.00000	-0.0000	-0.0000
3	-0.0000	-0.00000	-0.0000	-0.0000
4	-0.0000	-0.00000	-0.0000	-0.0000
5	-0.0000	-0.00000	-0.0000	-0.0000
6	-0.0000	-0.00000	-0.0000	-0.0000
7	95.1400	-0.00000	-0.0000	105.1800
8	-0.0000	-0.00000	-0.0000	-0.0000
9	222.9400	-0.00000	-0.0000	-0.0000
10	-0.0000	-0.00000	-0.0000	-0.0000
11	96.9900	-0.00000	-0.0000	-0.0000
12	-0.0000	-0.00000	-0.0000	-0.0000
13	74.1200	-0.00000	-0.0000	-0.0000
14	-0.0000	-0.00000	-0.0000	-0.0000
15	-0.0000	-0.00000	-0.0000	-0.0000
16	-0.0000	-0.00000	-0.0000	-0.0000
17	-0.0000	-0.00000	-0.0000	42.6000
18	-0.0000	-0.00000	-0.0000	3.4100
19	-0.0000	-0.00000	-0.0000	3.6900
20	-0.0000	-0.00000	-0.0000	26.9800
21	-0.0000	-0.00000	-0.0000	24.1400
22	-0.0000	-0.00000	-0.0000	-0.0000
23	80.0900	-0.00000	-0.0000	-0.0000
24	-0.0000	-0.00000	-0.0000	-0.0000
25	-0.0000	-0.00000	-0.0000	-0.0000
26	-0.0000	-0.00000	-0.0000	-0.0000
27	581.6300	-0.00000	-0.0000	-0.0000
28	-0.0000	-0.00000	-0.0000	-0.0000
29	444.6000	-0.00000	-0.0000	-0.0000
30	-0.0000	-0.00000	-0.0000	-0.0000
31	-0.0000	-0.00000	-0.0000	-0.0000
32	-0.0000	-0.00000	-0.0000	-0.0000
33	96.9900	-0.00000	-0.0000	-0.0000
34	105.2200	-0.00000	-0.0000	-0.0000

ENVIRONMENTAL AND INTERNAL HEATING ORBIT 4

NODE	SOLAR FLUX	ALBEDO FLUX	EARTH FLUX	HEAT GENERATION
1	119.2800	-0.00000	-0.0000	-0.0000
2	-0.0000	-0.00000	-0.0000	-0.0000
3	-0.0000	-0.00000	-0.0000	-0.0000
4	-0.0000	-0.00000	-0.0000	-0.0000
5	19.8800	-0.00000	-0.0000	-0.0000
6	23.5700	-0.00000	-0.0000	-0.0000
7	90.9800	-0.00000	-0.0000	119.2800
8	-0.0000	-0.00000	-0.0000	-0.0000
9	215.9400	-0.00000	-0.0000	-0.0000
10	-0.0000	-0.00000	-0.0000	-0.0000
11	48.5600	-0.00000	-0.0000	-0.0000
12	-0.0000	-0.00000	-0.0000	-0.0000
13	80.5100	-0.00000	-0.0000	-0.0000
14	-0.0000	-0.00000	-0.0000	-0.0000
15	-0.0000	-0.00000	-0.0000	-0.0000
16	-0.0000	-0.00000	-0.0000	-0.0000
17	-0.0000	-0.00000	-0.0000	42.6000
18	-0.0000	-0.00000	-0.0000	3.4100
19	-0.0000	-0.00000	-0.0000	3.6900
20	-0.0000	-0.00000	-0.0000	26.9800
21	-0.0000	-0.00000	-0.0000	24.1400
22	-0.0000	-0.00000	-0.0000	-0.0000
23	87.0500	-0.00000	-0.0000	-0.0000
24	-0.0000	-0.00000	-0.0000	-0.0000
25	-0.0000	-0.00000	-0.0000	-0.0000
26	-0.0000	-0.00000	-0.0000	-0.0000
27	291.3800	-0.00000	-0.0000	-0.0000
28	-0.0000	-0.00000	-0.0000	-0.0000
29	483.0800	-0.00000	-0.0000	-0.0000
30	-0.0000	-0.00000	-0.0000	-0.0000
31	-0.0000	-0.00000	-0.0000	-0.0000
32	-0.0000	-0.00000	-0.0000	-0.0000
33	48.5600	-0.00000	-0.0000	-0.0000
34	108.7700	-0.00000	-0.0000	-0.0000

ENVIRONMENTAL AND INTERNAL HEATING ORBIT 5

NODE	SOLAR FLUX	ALBEDO FLUX	EARTH FLUX	HEAT GENERATION
1	41.7500	-0.00000	-0.0000	-0.0000
2	-0.0000	-0.00000	-0.0000	-0.0000
3	-0.0000	-0.00000	-0.0000	-0.0000
4	-0.0000	-0.00000	-0.0000	-0.0000
5	30.2500	-0.00000	-0.0000	-0.0000
6	47.1400	-0.00000	-0.0000	-0.0000
7	75.2600	-0.00000	-0.0000	95.1400
8	-0.0000	-0.00000	-0.0000	-0.0000
9	200.7900	-0.00000	-0.0000	-0.0000
10	-0.0000	-0.00000	-0.0000	-0.0000
11	-0.0000	-0.00000	-0.0000	-0.0000
12	-0.0000	-0.00000	-0.0000	-0.0000
13	75.5400	-0.00000	-0.0000	-0.0000
14	-0.0000	-0.00000	-0.0000	-0.0000
15	4.1200	-0.00000	-0.0000	-0.0000
16	-0.0000	-0.00000	-0.0000	-0.0000
17	-0.0000	-0.00000	-0.0000	42.6000
18	-0.0000	-0.00000	-0.0000	3.4100
19	-0.0000	-0.00000	-0.0000	3.6900
20	-0.0000	-0.00000	-0.0000	26.9800
21	-0.0000	-0.00000	-0.0000	24.1400
22	-0.0000	-0.00000	-0.0000	-0.0000
23	81.6500	-0.00000	-0.0000	-0.0000
24	-0.0000	-0.00000	-0.0000	-0.0000
25	4.1200	-0.00000	-0.0000	-0.0000
26	-0.0000	-0.00000	-0.0000	-0.0000
27	-0.0000	-0.00000	-0.0000	-0.0000
28	-0.0000	-0.00000	-0.0000	-0.0000
29	453.4100	-0.00000	-0.0000	-0.0000
30	-0.0000	-0.00000	-0.0000	-0.0000
31	24.5700	-0.00000	-0.0000	-0.0000
32	-0.0000	-0.00000	-0.0000	-0.0000
33	-0.0000	-0.00000	-0.0000	-0.0000
34	54.5300	-0.00000	-0.0000	-0.0000

ENVIRONMENTAL AND INTERNAL HEATING ORBIT 6

NODE	SOLAR FLUX	ALBEDO FLUX	EARTH FLUX	HEAT GENERATION
1	-0.0000	-0.00000	-0.0000	-0.0000
2	-0.0000	-0.00000	-0.0000	-0.0000
3	-0.0000	-0.00000	-0.0000	-0.0000
4	30.9600	-0.00000	-0.0000	-0.0000
5	19.3100	-0.00000	-0.0000	-0.0000
6	70.5700	-0.00000	-0.0000	-0.0000
7	90.8800	-0.00000	-0.0000	124.9600
8	-0.0000	-0.00000	-0.0000	-0.0000
9	181.9000	-0.00000	-0.0000	-0.0000
10	-0.0000	-0.00000	-0.0000	-0.0000
11	-0.0000	-0.00000	-0.0000	-0.0000
12	-0.0000	-0.00000	-0.0000	-0.0000
13	71.2800	-0.00000	-0.0000	-0.0000
14	-0.0000	-0.00000	-0.0000	-0.0000
15	39.4800	-0.00000	-0.0000	-0.0000
16	-0.0000	-0.00000	-0.0000	-0.0000
17	-0.0000	-0.00000	-0.0000	42.6000
18	-0.0000	-0.00000	-0.0000	3.4100
19	-0.0000	-0.00000	-0.0000	3.6900
20	-0.0000	-0.00000	-0.0000	26.9800
21	-0.0000	-0.00000	-0.0000	24.1400
22	-0.0000	-0.00000	-0.0000	-0.0000
23	77.1100	-0.00000	-0.0000	-0.0000
24	-0.0000	-0.00000	-0.0000	-0.0000
25	39.4800	-0.00000	-0.0000	-0.0000
26	-0.0000	-0.00000	-0.0000	-0.0000
27	-0.0000	-0.00000	-0.0000	-0.0000
28	-0.0000	-0.00000	-0.0000	-0.0000
29	427.8500	-0.00000	-0.0000	-0.0000
30	-0.0000	-0.00000	-0.0000	-0.0000
31	235.4400	-0.00000	-0.0000	-0.0000
32	-0.0000	-0.00000	-0.0000	-0.0000
33	-0.0000	-0.00000	-0.0000	-0.0000
34	26.1300	-0.00000	-0.0000	-0.0000

ENVIRONMENTAL AND INTERNAL HEATING ORBIT 7

NODE	SOLAR FLUX	ALBEDO FLUX	EARTH FLUX	HEAT GENERATION
1	-0.0000	-0.00000	-0.0000	-0.0000
2	-0.0000	-0.00000	-0.0000	-0.0000
3	-0.0000	-0.00000	-0.0000	-0.0000
4	104.3700	-0.00000	-0.0000	-0.0000
5	14.4800	-0.00000	-0.0000	-0.0000
6	98.8300	-0.00000	-0.0000	-0.0000
7	126.3800	-0.00000	-0.0000	112.1800
8	-0.0000	-0.00000	-0.0000	-0.0000
9	134.0500	-0.00000	-0.0000	-0.0000
10	-0.0000	-0.00000	-0.0000	-0.0000
11	-0.0000	-0.00000	-0.0000	-0.0000
12	-0.0000	-0.00000	-0.0000	-0.0000
13	61.6300	-0.00000	-0.0000	-0.0000
14	-0.0000	-0.00000	-0.0000	-0.0000
15	84.9200	-0.00000	-0.0000	-0.0000
16	-0.0000	-0.00000	-0.0000	-0.0000
17	-0.0000	-0.00000	-0.0000	42.6000
18	-0.0000	-0.00000	-0.0000	3.4100
19	-0.0000	-0.00000	-0.0000	3.6900
20	-0.0000	-0.00000	-0.0000	26.9800
21	-0.0000	-0.00000	-0.0000	24.1400
22	-0.0000	-0.00000	-0.0000	-0.0000
23	66.6000	-0.00000	-0.0000	-0.0000
24	-0.0000	-0.00000	-0.0000	-0.0000
25	84.9200	-0.00000	-0.0000	-0.0000
26	-0.0000	-0.00000	-0.0000	-0.0000
27	-0.0000	-0.00000	-0.0000	-0.0000
28	-0.0000	-0.00000	-0.0000	-0.0000
29	369.6300	-0.00000	-0.0000	-0.0000
30	-0.0000	-0.00000	-0.0000	-0.0000
31	507.3700	-0.00000	-0.0000	-0.0000
32	-0.0000	-0.00000	-0.0000	-0.0000
33	-0.0000	-0.00000	-0.0000	-0.0000
34	12.9200	-0.00000	-0.0000	-0.0000

ENVIRONMENTAL AND INTERNAL HEATING ORBIT 8

NODE	SOLAR FLUX	ALBEDO FLUX	EARTH FLUX	HEAT GENERATION
1	-0.0000	-0.00000	-0.0000	-0.0000
2	-0.0000	-0.00000	-0.0000	-0.0000
3	-0.0000	-0.00000	-0.0000	-0.0000
4	147.6800	-0.00000	-0.0000	-0.0000
5	8.6600	-0.00000	-0.0000	-0.0000
6	129.3600	-0.00000	-0.0000	-0.0000
7	160.4600	-0.00000	-0.0000	78.1000
8	-0.0000	-0.00000	-0.0000	-0.0000
9	70.2900	-0.00000	-0.0000	-0.0000
10	-0.0000	-0.00000	-0.0000	-0.0000
11	-0.0000	-0.00000	-0.0000	-0.0000
12	-0.0000	-0.00000	-0.0000	-0.0000
13	54.5300	-0.00000	-0.0000	-0.0000
14	-0.0000	-0.00000	-0.0000	-0.0000
15	109.7700	-0.00000	-0.0000	-0.0000
16	-0.0000	-0.00000	-0.0000	-0.0000
17	-0.0000	-0.00000	-0.0000	42.6000
18	-0.0000	-0.00000	-0.0000	3.4100
19	-0.0000	-0.00000	-0.0000	3.6900
20	-0.0000	-0.00000	-0.0000	26.9800
21	-0.0000	-0.00000	-0.0000	24.1400
22	-0.0000	-0.00000	-0.0000	-0.0000
23	57.9400	-0.00000	-0.0000	-0.0000
24	-0.0000	-0.00000	-0.0000	-0.0000
25	109.7700	-0.00000	-0.0000	-0.0000
26	-0.0000	-0.00000	-0.0000	-0.0000
27	-0.0000	-0.00000	-0.0000	-0.0000
28	-0.0000	-0.00000	-0.0000	-0.0000
29	321.3500	-0.00000	-0.0000	-0.0000
30	-0.0000	-0.00000	-0.0000	-0.0000
31	657.8900	-0.00000	-0.0000	-0.0000
32	-0.0000	-0.00000	-0.0000	-0.0000
33	-0.0000	-0.00000	-0.0000	-0.0000
34	4.2600	-0.00000	-0.0000	-0.0000

ENVIRONMENTAL AND INTERNAL HEATING ORBIT 9

NODE	SOLAR FLUX	ALBEDO FLUX	EARTH FLUX	HEAT GENERATION
1	-0.0000	-0.00000	-0.0000	-0.0000
2	-0.0000	-0.00000	-0.0000	-0.0000
3	-0.0000	-0.00000	-0.0000	-0.0000
4	181.0500	-0.00000	-0.0000	-0.0000
5	-0.0000	-0.00000	-0.0000	-0.0000
6	157.7600	-0.00000	-0.0000	-0.0000
7	186.0200	-0.00000	-0.0000	36.9200
8	-0.0000	-0.00000	-0.0000	-0.0000
9	45.4400	-0.00000	-0.0000	-0.0000
10	-0.0000	-0.00000	-0.0000	-0.0000
11	-0.0000	-0.00000	-0.0000	-0.0000
12	-0.0000	-0.00000	-0.0000	-0.0000
13	36.9200	-0.00000	-0.0000	-0.0000
14	-0.0000	-0.00000	-0.0000	-0.0000
15	143.9900	-0.00000	-0.0000	-0.0000
16	-0.0000	-0.00000	-0.0000	-0.0000
17	-0.0000	-0.00000	-0.0000	42.6000
18	-0.0000	-0.00000	-0.0000	3.4100
19	-0.0000	-0.00000	-0.0000	3.6900
20	-0.0000	-0.00000	-0.0000	26.9800
21	-0.0000	-0.00000	-0.0000	24.1400
22	-0.0000	-0.00000	-0.0000	-0.0000
23	39.9000	-0.00000	-0.0000	-0.0000
24	-0.0000	-0.00000	-0.0000	-0.0000
25	143.9900	-0.00000	-0.0000	-0.0000
26	-0.0000	-0.00000	-0.0000	-0.0000
27	-0.0000	-0.00000	-0.0000	-0.0000
28	-0.0000	-0.00000	-0.0000	-0.0000
29	221.6600	-0.00000	-0.0000	-0.0000
30	-0.0000	-0.00000	-0.0000	-0.0000
31	953.3900	-0.00000	-0.0000	-0.0000
32	-0.0000	-0.00000	-0.0000	-0.0000
33	-0.0000	-0.00000	-0.0000	-0.0000
34	-0.0000	-0.00000	-0.0000	-0.0000

COATING SPECIFICATIONS

COATING NUMBER	LIMIT POINT 1		LIMIT POINT 2		LIMIT POINT 3		LIMIT POINT 4	
	ALPHA	EPSILON	ALPHA	EPSILON	ALPHA	EPSILON	ALPHA	EPSILON
1	0.120000	0.030000	0.200000	0.040000	0.970000	0.860000	0.250000	0.850000

STEP CHANGE PROCEDURE

IN MRD		IN TREND	
INCREASE	DECREASE	INCREASE	DECREASE
1.200	0.800	0.200	0.640

ERROR IN INVERSION

NODE	ERROR
1	9.99999750E-01
4	9.99999840E-01
5	9.99999840E-01
6	9.99999810E-01
7	9.99999850E-01
9	9.99999810E-01
11	9.99999860E-01
13	9.99999910E-01
15	9.99999880E-01
23	9.99999840E-01
25	9.99999870E-01
27	9.99999870E-01
29	9.99999900E-01
31	9.99999930E-01
33	9.99999870E-01
34	9.99999840E-01
17	9.99999840E-01
18	9.99999880E-01
19	9.99999890E-01
20	9.99999910E-01
21	9.99999930E-01
22	9.99999920E-01
10	9.99999990E-01
24	9.99999910E-01
3	9.99999940E-01
26	9.99999970E-01
12	9.99999910E-01
28	9.99999960E-01
8	9.99999990E-01
30	1.00000000E 00
14	1.00000000E 00
32	1.00000000E 00
2	1.00000000E 00
16	1.00000000E 00

NASA IMP C OCTOBER 13,1965

MODE MRD1 ITERATION 1 NO. OF SURFACES ENCOUNTERED SINCE LAST TREND STEP 1 DELTA S =-0.00000

BETA	NODE	ORBIT	LIMIT	MINIMUM BETA OCCURRED AT ITERATION		NODE	ORBIT	LIMIT
1.41448310E 00	21	5	LOWER	1.41448E 00	1	21	5	LOWER

NODE	ABSORPTIVITY	EMISSIVITY
1	0.40000000	0.50000000
4	0.60000000	0.50000000
5	0.40000000	0.50000000
6	0.40000000	0.50000000
7	0.25000000	0.85000000
9	0.40000000	0.50000000
11	0.25000000	0.85000000
13	0.25000000	0.85000000
15	0.40000000	0.50000000
23	0.40000000	0.50000000
25	0.40000000	0.50000000
27	0.40000000	0.50000000
29	0.40000000	0.50000000
31	0.40000000	0.50000000
33	0.40000000	0.50000000
34	0.25000000	0.85000000

TEMPERATURE VALUES

NODE \ ORBIT	1	2	3	4	5	6	7	8	9
1	561.67	508.15	527.05	500.03	435.20	437.25	463.79	471.04	482.74
4	462.21	422.93	449.93	445.20	422.81	461.82	526.55	556.09	582.83
5	454.53	417.46	443.00	446.03	428.82	461.39	519.26	543.83	564.56
6	408.73	369.99	398.47	418.13	428.08	475.19	528.87	560.18	591.01
7	495.23	528.92	560.13	571.94	538.80	576.44	575.45	550.27	509.67
9	503.00	505.63	516.17	508.28	489.19	481.61	461.39	421.32	406.51
11	510.59	485.67	474.83	439.75	379.06	383.33	394.46	398.18	403.47
13	426.31	421.09	437.89	435.01	416.94	424.12	433.73	436.39	435.81
15	443.42	413.92	436.11	427.36	409.78	462.47	520.34	545.90	576.33
23	485.35	485.41	500.86	495.09	472.93	481.93	490.83	491.35	486.88
25	472.91	449.65	464.85	454.67	436.53	483.81	536.37	559.55	586.78
27	579.46	386.01	523.93	468.26	378.44	398.15	422.60	431.98	443.97
29	472.92	441.29	486.46	479.00	454.24	465.56	476.09	477.63	475.59
31	451.05	396.04	439.23	424.40	400.11	455.12	512.93	538.53	577.12
33	584.78	556.54	532.58	480.64	399.17	414.67	435.77	443.27	452.12
34	509.92	509.13	517.69	513.32	478.08	467.99	468.38	466.97	468.42
17	541.86	534.83	542.91	535.48	503.35	498.73	503.40	504.25	507.53
18	473.63	447.88	469.07	459.20	433.93	457.49	487.91	500.32	514.44
19	523.30	502.66	511.02	491.95	456.63	477.50	503.84	513.59	524.27
20	544.13	521.67	535.61	522.56	498.25	528.65	562.80	576.46	591.78
21	502.72	425.57	486.49	464.27	424.62	453.23	485.30	497.87	514.35
22	553.42	527.65	520.65	484.51	421.72	440.28	465.89	475.14	486.04
10	490.92	444.39	475.70	462.50	429.43	459.38	506.52	526.15	546.67
24	503.48	493.13	506.06	494.41	467.14	481.87	499.64	505.03	508.68
3	476.27	433.15	462.52	453.30	425.80	461.02	516.21	540.09	563.25
26	510.11	486.47	500.93	487.82	463.86	498.32	537.18	553.26	571.65
12	520.38	492.80	495.27	467.45	410.93	416.44	430.92	435.82	442.82
28	545.07	406.09	508.18	468.02	397.20	420.47	449.82	461.21	475.97
8	505.79	454.03	489.71	472.20	433.73	459.23	495.63	508.89	524.51
30	485.98	435.20	486.42	472.88	442.92	460.28	479.61	486.07	492.59
14	454.48	441.00	459.25	452.89	429.62	441.12	457.96	464.19	469.70
32	478.03	411.70	463.73	444.92	412.59	454.53	499.17	517.90	544.59
2	505.20	454.27	488.05	470.94	432.54	457.77	496.02	510.26	526.85
16	460.88	430.08	453.59	443.42	421.09	462.60	509.03	528.69	551.71

NASA IMP C OCTOBER 13,1965

MODE TREND2 ITERATION 9 NO. OF SURFACES ENCOUNTERED SINCE LAST TREND STEP 1 DELTA S = 0.40000

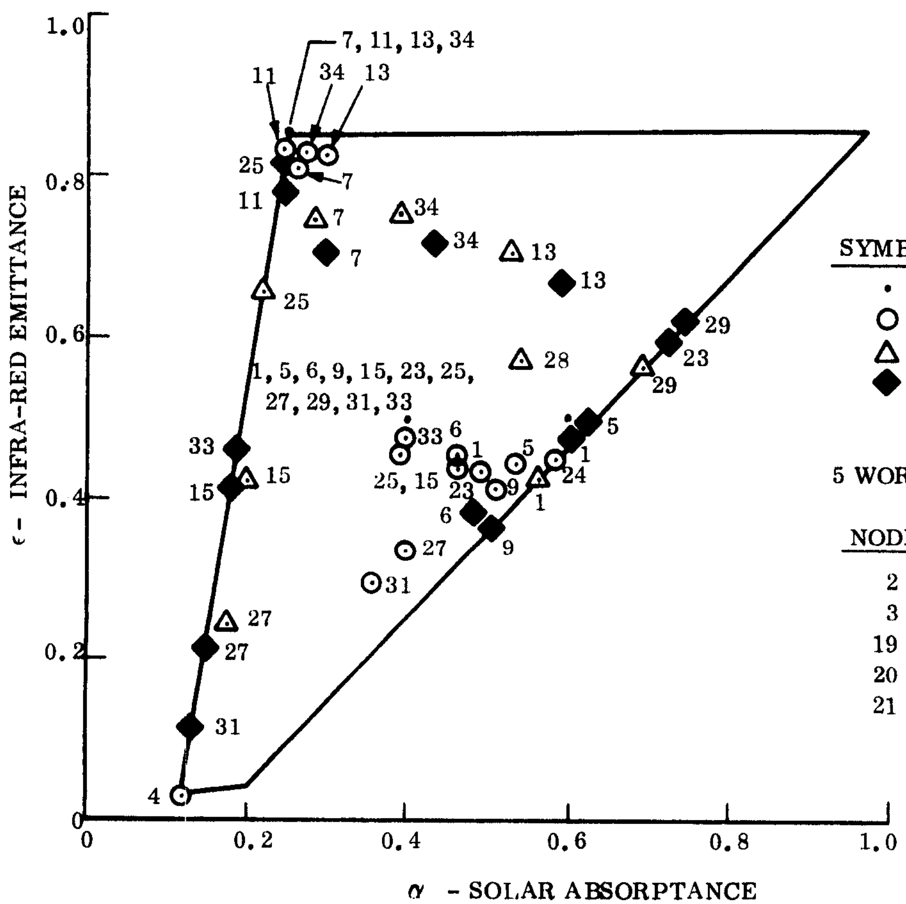
BETA	NODE	ORBIT	LIMIT	MINIMUM BETA OCCURRED AT ITERATION		NODE	ORBIT	LIMIT
-4.57612780E-02	20	3	UPPER	-4.57613E-02	9	20	3	UPPER

NODE	ABSCRPTIVITY	EMISSIVITY
1	0.61312174	0.47994784
4	0.12000000	0.03000000
5	0.62863871	0.49647240
6	0.48612265	0.38736656
7	0.29874663	0.70437435
9	0.50420038	0.36395366
11	0.24698362	0.78575539
13	0.59102167	0.66970084
15	0.18099000	0.41470618
23	0.72394593	0.59796841
25	0.24446232	0.81507004
27	0.14983138	0.21816718
29	0.74541483	0.62083139
31	0.13285321	0.11107408
33	0.18794889	0.45860070
34	0.43513775	0.71775860

TEMPERATURE VALUES

NODE \ ORBIT	1	2	3	4	5	6	7	8	9
1	618.50	591.28	589.47	570.31	508.45	484.07	487.73	482.65	478.94
4	513.76	496.49	513.11	521.06	504.85	507.74	526.81	533.89	538.91
5	502.38	486.49	501.79	520.45	511.63	507.99	522.59	525.70	525.31
6	463.72	446.91	465.80	490.10	497.28	521.90	553.56	576.05	596.01
7	530.24	565.55	594.21	606.90	573.45	610.04	608.57	583.61	542.63
9	570.54	581.66	589.31	582.91	564.41	549.27	516.90	461.68	435.39
11	529.24	514.78	502.80	475.81	423.65	416.07	415.24	412.48	409.20
13	487.78	502.24	520.73	524.53	506.96	501.51	494.48	487.22	467.83
15	480.58	471.61	486.11	485.92	469.60	484.54	507.83	518.17	530.01
23	503.03	519.78	538.58	542.31	526.75	523.20	515.61	506.66	484.88
25	475.26	468.81	478.74	477.85	465.06	480.41	502.44	512.27	523.28
27	561.38	474.21	539.24	514.70	468.66	469.27	475.06	474.57	472.16
29	502.74	507.78	537.92	540.95	523.87	520.77	513.97	505.23	484.71
31	510.58	487.84	515.37	512.09	491.21	506.37	528.91	538.41	552.50
33	536.34	522.43	512.65	488.00	444.30	443.56	447.20	446.18	442.43
34	554.58	564.05	574.51	573.61	527.12	503.86	493.53	485.17	479.07
17	579.46	583.21	591.58	588.26	550.19	533.75	527.14	520.84	515.21
18	517.28	514.15	529.77	528.39	504.78	504.70	510.18	509.96	506.18
19	528.50	524.79	534.80	529.43	505.49	506.45	510.91	509.74	504.21
20	554.25	548.85	559.88	557.07	538.51	544.59	555.45	558.43	559.69
21	531.46	504.26	537.44	531.10	504.23	507.05	514.13	514.06	511.66
22	535.55	525.40	525.86	510.46	473.75	472.85	477.26	476.02	471.48
10	534.02	514.71	532.09	530.99	505.10	505.11	517.69	519.97	521.16
24	516.60	523.22	537.95	537.43	518.36	517.20	515.69	510.71	496.98
3	523.29	505.02	522.23	525.14	503.88	505.80	521.60	526.27	529.53
26	518.85	512.75	523.75	521.10	503.16	511.19	524.59	529.08	532.50
12	545.05	533.79	532.98	514.98	466.34	456.34	455.25	451.62	447.34
28	549.04	491.61	539.74	523.91	485.42	486.10	492.54	492.00	489.31
8	543.33	522.88	542.52	537.01	506.56	505.79	514.36	513.74	511.96
30	516.07	506.05	537.61	536.25	514.99	514.47	513.85	509.02	496.58
14	507.85	514.71	531.37	532.26	509.83	505.13	502.50	497.72	484.82
32	521.93	497.08	527.29	522.40	498.09	506.62	521.03	525.48	530.95
2	545.41	524.64	542.55	537.21	506.27	504.31	513.37	512.97	511.84
16	500.60	492.62	508.38	507.24	486.26	494.49	510.30	516.08	521.58

Figure 17. Results of IMP-C Computer Study



SYMBOL	ITERATION	β
•	1	1.4145
○	6	0.4336
△	29	0.0611
◆	36	-0.0458

5 WORST β's

NODE	ORBIT	LIMIT	β
2	6	L	-0.0613
3	5	L	-0.0533
19	9	L	-0.0594
20	3	U	-0.0458
21	2	L	-0.0604

Figure 18. Results of Fifty-Minute Computer Caluclation for IMP-C

Appendix G. Nomenclature

Symbol	Description	Suggested Units
A	incident albedo flux	BTU/hr ft^2
$\bar{A}$	conduction matrix term	BTU/hr ^oF
C	defined by Equation (3.4)	BTU/hr
D	defined by Equation (8.2)	BTU/hr
E	incident earth flux	BTU/hr ft^2
$\tilde{E}_{ij}$	$(\partial r_i/\partial T_j)$ at $T_i = T_j^{(0)}$	BTU/hr ^oF
J	inverse matrix of $\bar{A}$	hr ^oF/BTU
K_{Ai}	multiplier of incident albedo flux for node 'i'	ft^2
K_{Ei}	multiplier of incident earth flux for node 'i'	ft^2
K_{Qi}	multiplier of internal heat generation	BTU/watt hr
K_{ij}	conductance from node 'i' to node 'j'	BTU/hr ^oF
K_{Si}	multiplier of incident solar flux for node 'i'	ft^2
L	defined by Equation (3.4)	BTU/hr ^oF
M	radiation-matrix term	BTU/hr $ft^2(^oR)^4$
N	defined by Equation (4.3)	BTU/hr $(^oR)^4$
P	inverse of $N_{ij} + \epsilon_i \delta_{ij}$	hr $(^oF)^4$/BTU
Q	internal heat generation	watts
$\bar{R}$	defined by Equation (9.2.1)	BTU/hr ^oF
R_{ij}	product of radiant interchange factor between nodes 'i' and 'j' and area of node 'i'	ft^2
(RHS)	defined by Equation (4.10)	BTU/hr
S	incident solar flux	BTU/hr ft^2
T	absolute temperature	^oR
$(WC_p)_i$	heat capacitance of node 'i'	BTU/^oF
X	stability parameter in matrix inversion methods	BTU/hr ^oF

Symbol	Description	Suggested Units
Y	$\sigma a_i T_i^4 - K_{Ei} E_i$	BTU/hr
a_i	re-radiating area for node 'i' (external area)	ft^2
c	weighting factor, Equation (2.3)	-
d	weighting factor, Equation (2.4)	-
r	residual vector (Equation 3.5)	BTU/hr
α	solar absorptance	-
α_n	iteration scheme extrapolation parameter	-
β	temperature deviation parameter	-
γ	criterion function, Equations (2.3) and (2.4)	-
$\tilde{\gamma}$	form factor, $(\overline{T^4})/(\bar{T})^4$	-
δ_{ij}	Kronecker delta (=1 if i=j; =o if $i \neq j$)	-
ϵ	infrared emittance	-
θ	time	hr
λ	interpolation parameter	-
σ	Stephen-Boltzmann constant (0.1713×10^{-8})	BTU/hr $ft^2 (^oR)^4$
τ_{ci}	$(WC_p)_i / L_{ii}$	hrs

Subscripts

i	usually node number
iL	corresponding to lower limit on T_i
iU	corresponding to upper limit on T_i
k	usually orbit number

Superscript

n	iteration number