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SINGLE NODE ORBIT ANALYSIS WITH RADIATION HEAT TRANSFER ONLY

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Preliminary Design Office

September 1977

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16. ABSTRACT

The steady-state temperature of a single node which dissipates energy by radiation only is discussed for a non-time-varying thermal environment. Relationships are developed to illustrate how shields can be utilized to represent a louver system. A computer program is presented which can assess periodic temperature characteristics of a single node in a time-varying thermal environment having energy dissipation by radiation only. The computer program performs thermal orbital analysis for five combinations of plate, shields, and louvers.

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SYMBOLS AND DEFINITIONS

Symbols	Computer Notations	Definition
ϵ_o	Eϕ	Equipment emittance
ϵ	E	Shield emittance
ϵ_n	EN	Sunshade emittance
q	Q	Equipment power (W)
A	AA	Radiating area (ft^2)
α	A	Absorptivity (Solar)
σ	SIG	Stefan-Boltzmann Const. (Btu/h-ft^2-°R^4)
G	G	Solar insolation or albedo (Btu/h-ft^2)
T	Y, YY	Plate temperature (° F)
τ	X	Time (as indicated)
$dT/d\tau$	YP	Temperature rate (°F/time)
MC_p	CPM	Equipment capacitance (Btu/°F)
	Xϕ	Start time (min)
	XP	Orbit period (min)
	TS	Day cycle time (min)
	DX	Time increment (min)
	AL	Louver angle (degree)
	AI	Incident angle (degree)
	QT	Energy radiated minus energy absorbed (Btu/ft^2-h)
	F	View factor

SINGLE NODE ORBIT ANALYSIS WITH RADIATION HEAT TRANSFER ONLY

INTRODUCTION

In many cases, it is desirable to simulate an orbital analysis of a thermal responsive system without applying LOHARP or SINDA. These are library programs capable of handling the most complex and sophisticated thermal system. However, in many cases, the depth which can be penetrated by these programs are not warranted on the basis of required turnaround time and technical level.

A need exists, therefore, to handle an orbital thermal problem where the fidelity of the analysis is commensurate with the level of decision making demanded by a phase A/B study. This includes problem modeling and problem solution to be accomplished within a few days.

One approach to satisfying this need is to consider selected types of thermal systems. The purpose of this report is to provide background techniques leading to orbital analysis of a single node having radiation heat transfer only. To this end, a computer program has been developed to handle this category of thermal systems. Specifically, these are:

1. Louvers systems

2. Flat plates.

These two basic categories are subdivided into five combinations involving thermal systems having shields, sunshades, and louvers. Each combination is given further definition in "Thermal Transients Resulting from a Time Varying Thermal Environment," contained herein.

For illustration, the same inputs have been applied to each combination. Unless otherwise stated, these conditions are:

1. Orbit period — 90 min

2. Orbit day period — 60 min

3. Solar constant — 430 Btu/h-ft^2

4. Albedo and IR — 30 Btu/h-ft^2 (orbit average)

5. Optical properties —

   a. Equipment emittance — 0.80

   b. Shield emittance — 0.80

   c. Sun shield emittance — 0.80

   d. Sun shield absorption — 0.10

6. Equipment capacitance — 3 Btu/°F

7. Initial node temperature — 70°F.

These inputs have been selected for example purposes only (no significance is to be attached to them). All are variables within the program and can be changed to suit a specific problem.

STEADY-STATE TEMPERATURE CHARACTERISTICS RESULTING FROM A NON-TIME-VARYING THERMAL ENVIRONMENT

In considering steady-state results, it is important to differentiate between a time-varying thermal environment and a fixed thermal environment. In general, the results are not the same. In the general case, the thermal capacitance of the system prevents the temperature from increasing or decreasing to the level predicted by a fixed thermal environment. Sometimes, the parameters of the system can be such that very great differences exist.

Consider a flat plate exposed to a radiation flux, G, as illustrated in Figure 1. The plate has properties as indicated with insulation on the antiflux side. An internal heat source, q/A, represents the presence of electronic equipment that may be attached to the plate. In the steady-state, all of the energy inputs to the plate must be equal to the energy radiated:

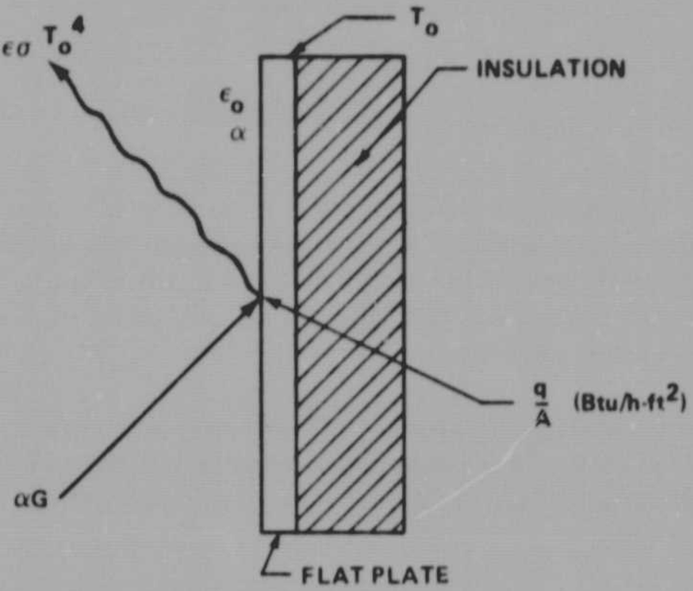

Figure 1. Flat plate showing energy components. (The entire plate is considered as a single node.)

$$\alpha G + \frac{q}{A} = \sigma \epsilon_o T_o^4 \quad . \tag{1}$$

Solving for temperature, T_o,

$$T_o = \sqrt[4]{\frac{1}{\sigma \epsilon_o} \left(\alpha G + \frac{q}{A}\right)} \quad . \tag{2}$$

The steady-state temperature as defined in equation (2) is independent of plate mass. The plate is at a uniform temperature with no gradients. Actually, equation (2) is a strong tool for evaluating the combined effect of optical properties, internal heat generation, and incident radiation. However, unless the system has low mass per unit area, additional analyses are warranted.

Note that the plate temperature and surface emittance has been subscribed with the letter (o). This subscript is meant to imply the surface on which electronic equipment is mounted. This clarification is helpful when shields are considered.

SHIELDS

The next level of sophistication to be considered in this type problem is the introduction of a shield. Sometimes, shields are referred to as sunshades. This is especially true if the shield is used to interrupt solar radiation from impending upon the plate. With the use of multishields, the outermost shield is referred to as the sunshade.

The geometry of a shield is illustrated in Figure 2. The shield is placed in fro ' of the plate. The outer area between the shield and plate is designed to be as small as possible. For purposes of analysis, this area is assumed to be a thermal barrier.

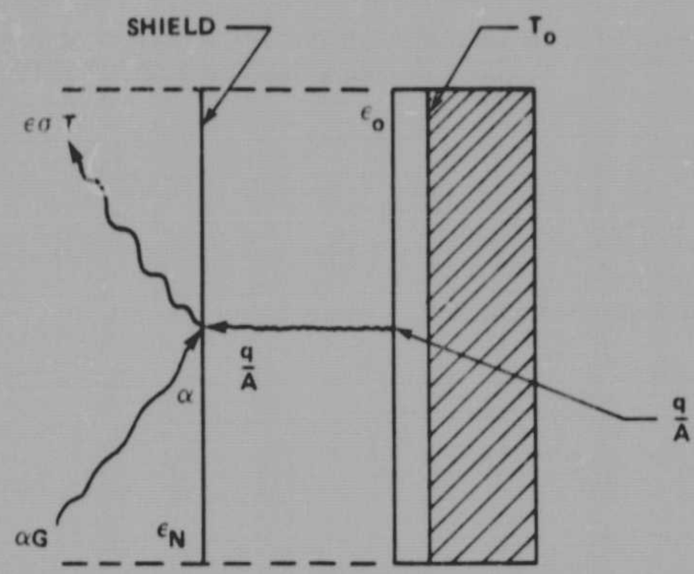

Figure 2. Shield configuration with surface emissivity of ϵ_n.

In application to thermal control systems, the shield concept has the ability to limit the temperature extremes predicted by a single plate. The thermal cycle is "smoothed out."

The steady plate temperature, T_o, can be obtained by writing an energy balance between the shield and plate. Under steady-state conditions, all of the equipment energy must be radiated to the shield. Thus, the steady-state temperature of the shield from equation (2) becomes

$$T_{shield} = \sqrt[4]{\frac{1}{\sigma \epsilon_N} \left(\alpha G + \frac{q}{A}\right)} \quad . \tag{3}$$

The energy balance between the shield and plate is

$$q = \frac{\sigma A [T_o^4 - T^4]}{\frac{1}{\epsilon_N} + \frac{1}{\epsilon_o} - 1} \quad . \tag{4}$$

Substituting equation (3) into equation (4) yields

$$\frac{q}{A} = \frac{1}{\frac{\epsilon_N}{\epsilon_o} - \epsilon_N + 2} [\epsilon_N \sigma T_o^4 - \alpha G] \ \ldots \tag{5}$$

Equation (5) can be easily solved for T_o, but is much less complicated in this form.

It is noted that equation (5) applies for a single shield having an emissivity value of ϵ_N on both outside and inside. If the inside value is ϵ, equation (5) becomes

$$\frac{q}{A} = \frac{[\epsilon_N \sigma T_o^4 - \alpha G]}{\frac{\epsilon_N}{\epsilon} + \frac{\epsilon_N}{\epsilon_o} - \epsilon_N + 1} \quad . \tag{6}$$

This equation is important because it illustrates how the heat dissipation capability can be reduced by making ϵ a small value. In certain applications it may be desirable to reduce the heat dissapation rate. Also, a small power input may be desirable to maintain a constant temperature. The rate loss can be easily reduced by a factor of ten by adjusting the value of ϵ.

Analysis of shields and sunshades are directly applicable to louver systems. A louver system is one where the surface area being shaded is variable. Thus, the rate of heat dissipation can be varied over a wide range. Generally, there are two louver configurations of interest. These are known as "with sunshade" and "without sunshade." A louver system with sunshade is known as an "internal louver system."

For the internal configuration, one shield would represent a "full-open" louver situation, and two shields would represent the "full-closed" situation. Equation (6) represents the full-open situation. This equation is plotted in Figure 3. Emissivities have been selected to give near maximum heat dissipation capability. Equation (2) represents the full open situation for the "without sunshade" configuration.

The same techniques as already presented can be applied to two shields as illustrated in Figure 4. This configuration is applicable to an internal louver system with the louvers closed. Under steady-state conditions the equipment energy which can be radiated for the configuration illustrated in Figure 4 is

$$\frac{q}{A} = \epsilon_N \sigma \left[\frac{T_o^4 + C_2 C_3}{C_1 C_2 + 1}\right] - \alpha G \tag{7}$$

$$C_1 = \frac{\epsilon_N}{\epsilon} [2 - \epsilon]$$

$$C_2 = \frac{\epsilon + 3 \epsilon_o - 2 \epsilon_o \epsilon}{\epsilon_o (2 - \epsilon)}$$

$$C_3 = \left[\frac{2 - \epsilon}{\epsilon}\right] \frac{\alpha G}{\sigma} .$$

Equation (7) is plotted in Figure 3 for typical values. The position of the two lines can be changed by varying the emissivities. However, the position shown is for a value of 0.8. The opened louver position curve represents the near outer capability of louvers to control temperature.

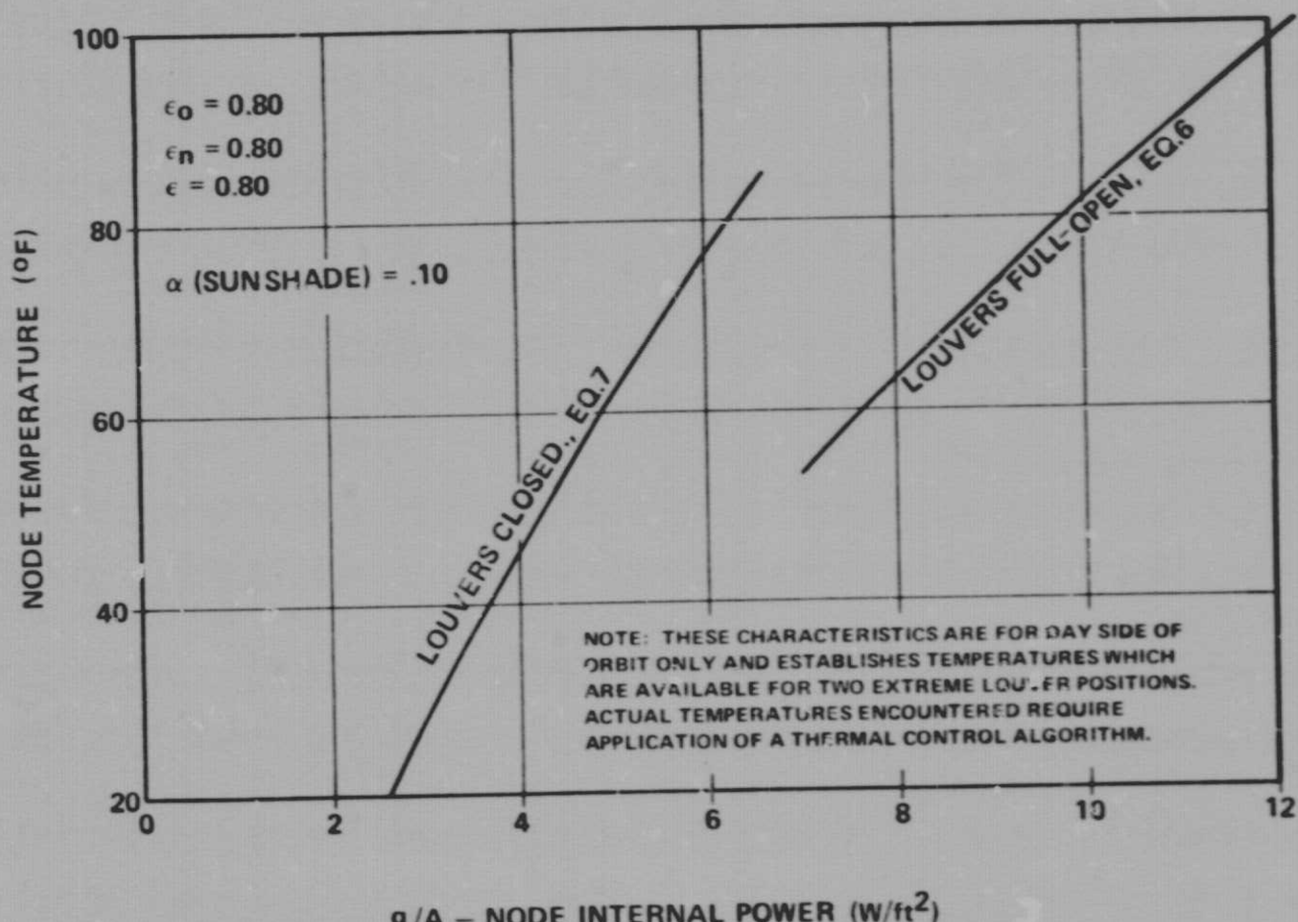

Figure 3. Steady-state performance characteristics of a louver system in a nonvarying thermal environment.

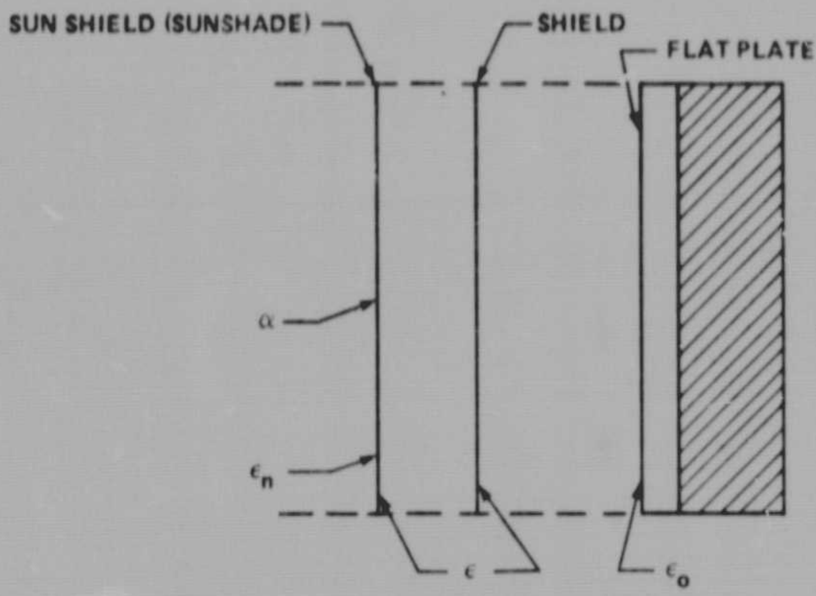

Figure 4. Configuration of a flat plate with shield and sunshade.

It is important to recognize that Figure 3 applies to steady-state conditions on the day side of the orbit. An identical curve can be developed for the night cycle (Fig. 5). However, as will be illustrated later, Figure 5 is a poor compromise for results of orbital analysis. As a consequence, day conditions are sometimes substituted for orbital analysis results. It will be demonstrated later that orbital analysis of louver system results in greater heat dissipation than indicated in Figure 3.

TEMPERATURE TRANSIENTS RESULTING FROM A NON-TIME-VARYING THERMAL ENVIRONMENT

Knowledge of the transients occurring within a thermal system adds to the understanding of the problem and inspires solution techniques. The approach to establishing the transient can be stated in the form of an instantaneous heat balance:

$$M\,C_p \frac{dT}{d\tau} = \sum Q \qquad (8)$$

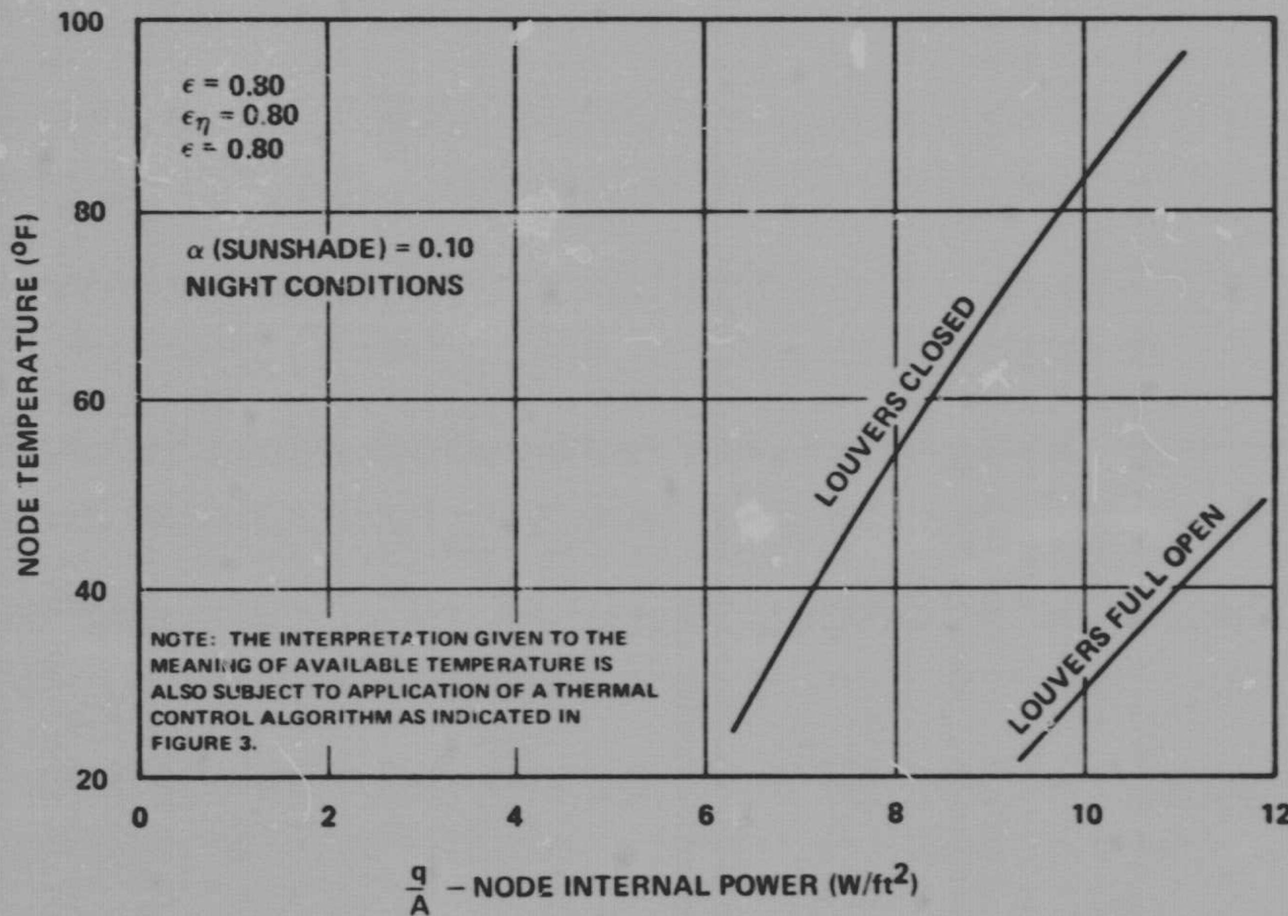

Figure 5. Steady-state performance characteristics of a louver system during the night portion of the cycle.

where $\sum Q$ is the net energy rate gain (or loss) of the system. In general, $\sum Q$ is represented by a radiation term, thermal flux, and equipment power. If the equipment power and thermal flux are zero, equation (8) reduces to

$$M C_p \frac{dT}{d\tau} = - \sigma \epsilon A T^4 \quad . \tag{9}$$

This expression can be easily integrated to obtain a temperature time expression. For those systems involving shields, heat flux, equipment power, and a time-varying environment, a computer analyzer program is the only practical way to approach the problem. However, there is a special case that can be handled mathematically. This is a simple flat plate under radiation heating, not subject to a varying thermal environment. Equation (8) becomes

$$\frac{dT}{d\tau} + \frac{\sigma \epsilon A T^4}{M C_p} = \frac{\alpha G A}{M C_p} \quad \therefore \tag{10}$$

Solution to this equation can be found in the literature, but will be repeated here for purposes of completeness:

$$\tau = \frac{1}{2} \frac{1}{a^4} \left(\frac{a}{b}\right)^3 \left\{ \left[\frac{1}{2} \log_e \frac{\left(1 + \frac{a}{b} T\right)}{\left(1 + \frac{a}{b} T_o\right)} \frac{\left(1 - \frac{a}{b} T_o\right)}{\left(1 - \frac{a}{b} T\right)} + \tan^{-1} \frac{a}{b} T - \tan^{-1} \frac{a}{b} T_o \right] \right\} \tag{11}$$

$$a = \left[\frac{\sigma \epsilon A}{M C_p}\right]^{1/4} \quad , \qquad b = \left[\frac{\alpha G A}{M C_p}\right]^{1/4}$$

T_o = initial plate temperature (°R) .

Equation (11) gives temperature as the independent variable. However, this equation can be generalized upon by plotting $\tau \frac{a^4}{\sigma}$ as an independent variable (Fig. 6). Note that in a mathematical sense, steady-state temperature is obtained only after an infinite time. The value of the steady-state temperature can be determined by

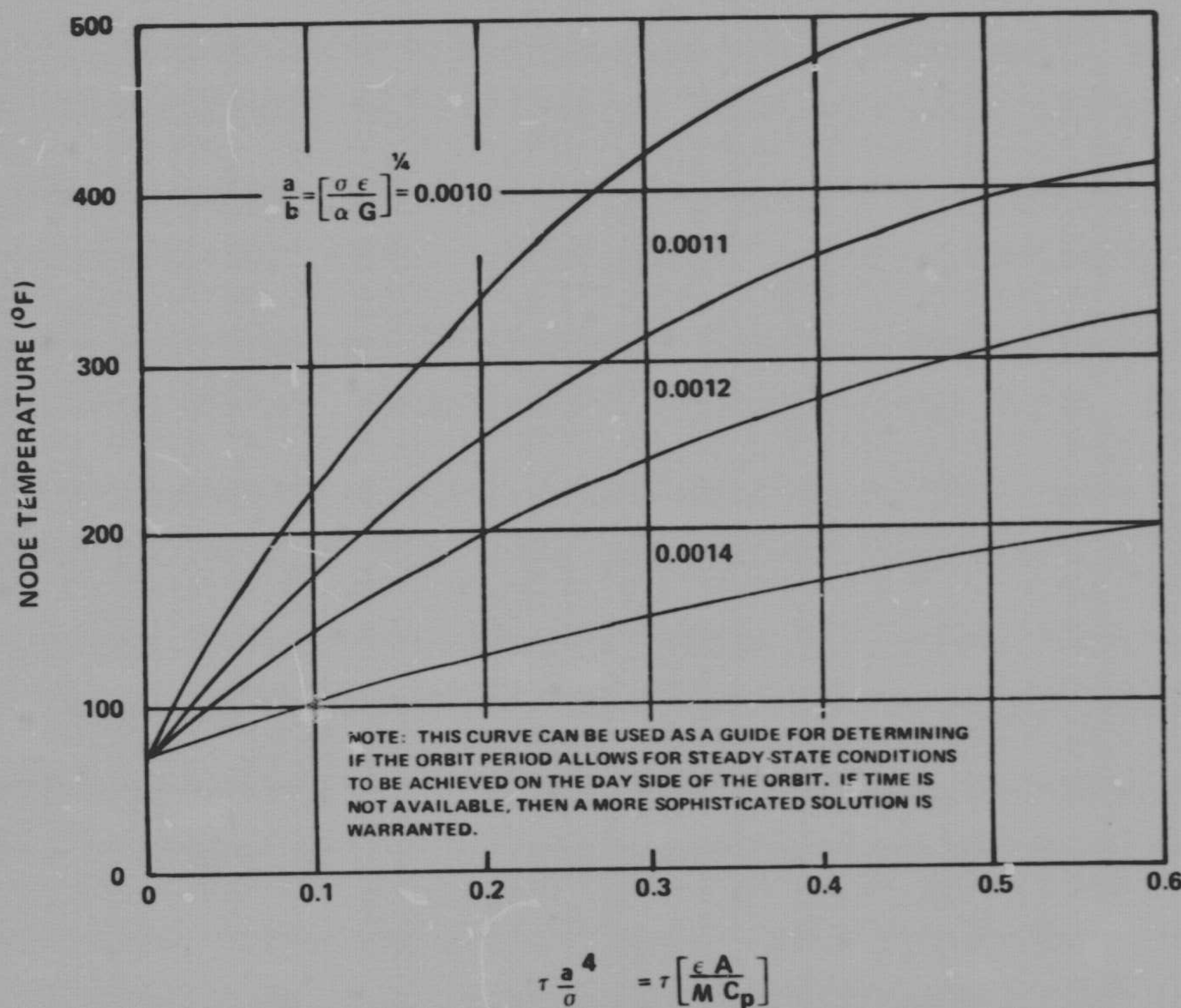

Figure 6. Characteristics of transient heating of a single mode by a fixed radiation flux, G.

$$T\text{ (steady-state)} = \frac{b}{a} = \left[\frac{\alpha G}{\epsilon \sigma}\right]^{1/4} \quad \ldots \qquad (12)$$

The argument of this parametric plot is b/a, reciprocal of the steady-state temperature (Rankine). The independent variable allows representation of all combinations.

$$\tau \frac{a^4}{\sigma} = \tau \frac{\epsilon A}{M C_p} \quad .$$

However, Figure 6 is valid only for an initial plate temperature of 70°F. Thus, a complete generalization of equation (11) cannot be made.

If it is desirable to determine just the time to reach the steady-state temperature, it becomes necessary to talk in terms of "time to reach a percentage of steady-state temperature." This is necessary since in a mathematical sense an infinite time is required. To solve for the time to achieve 0.98 percent of the steady-state temperature, let

$$T = 0.98\,\frac{b}{a} = 0.98\left[\frac{\alpha G}{\epsilon \sigma}\right]^{1/4} \quad .$$

In most cases the tangent functions can be eliminated since the equation is dominated by the logarithm function. This fact allows for quick calculations.

The following is a sample case to use in conjunction with Figure 6:

How long will it take a solar array to reach 180°F under the following conditions:

T_o = 70°F (initial temperature)

$$\frac{a}{b} = \left[\frac{\epsilon \sigma}{\alpha G}\right]^{1/4} = 0.0012 \quad ; \quad \left(\frac{1}{0.0012} - 460 = 373°F_{\text{steady-state}}\right)$$

$$\epsilon = 0.8 \quad , \quad C_p = 0.2 \text{ Btu/lb-°F} \quad , \quad \frac{M}{A} = 2 \text{ lb/ft}^2 \quad ?$$

Enter Figure 6 at 180°F for a (a/b) value of 0.0012:

$$\tau \frac{\epsilon A}{M C_p} = 0.1776 \quad .$$

Making the necessary substitutions and solving for τ gives:

$$\tau = 0.1776 \frac{(2)\ (0.2)}{0.8} = 0.0888\ \text{h}\ (5.32\ \text{min}) \quad .$$

The value of this type calculation is established if sufficient time exists for steady-state conditions. If time is not available, then a more sophisticated solution is warranted.

Note how the emittance has a dual effect. It affects the value of a/b and τa^4; however, its effects on τa^4 is much more sensitive. A greater emissivity will decrease the heating time. Also, the mass per unit area is important.

Equation (11) has been demonstrated as considering a heating problem. Cooling problems can be solved by the same equation. For example, if $T_o >$ b/a, cooling will occur. Also, T must be less than b/a.

As a matter of clarification of the units involved in equation (6), it is noted that

$$\frac{1}{a^3}\left(\frac{a}{b}\right)^3$$

must have units of time. At first this is not obvious. By making the substitutions into this set of parameters, the time unit of τ can be verified:

$$\tau \approx \frac{1}{a^4}\left(\frac{a}{b}\right)^3 = \left[\frac{W C_p}{\epsilon \sigma A}\right]\left[\frac{\epsilon \sigma}{\alpha G}\right]^{3/4}$$

$$= \frac{\text{lb}\left(\frac{\text{Btu}}{\text{lb}-{}^\circ\text{F}}\right)}{\left[\frac{\text{Btu}}{\text{h-ft}^2-({}^\circ\text{F})^4}\right]\text{ft}^2} \left\{\frac{\left[\frac{\text{Btu}}{\text{h-ft}^2-({}^\circ\text{F})^4}\right]}{\left[\frac{\text{Btu}}{\text{h-ft}^2}\right]}\right\}^{3/4} = \text{h-}({}^\circ\text{F})^3 \left\{\frac{1}{({}^\circ\text{F})^4}\right\}^{3/4}$$

$$= [h\text{-}(°F)^3]\left[\frac{1}{°F}\right]^3 = h \quad .$$

TEMPERATURE TRANSIENTS RESULTING FROM A TIME-VARYING THERMAL ENVIRONMENT

The application of equations presented previously for a fixed environment have limited utility. They apply only for a unique set of circumstances which the engineer seldom has the luxury to afford.

At best, application of the previous equations represents no more than "first impressions" and, in general, cannot meet the feasibility definition required for a Phase A Level Study. As an example of what is implied by this disposition, consider the temperature of a flat plate in Earth orbit having the following characteristics:

$$\epsilon_o = 0.5$$

$$\alpha = 0.5$$

$$\frac{q}{A} = 5\ \text{W/ft}^2 \quad .$$

From equation (1), the steady-state temperature on the Sun side is 261°F. On the night cycle, the steady-state temperature is +28° F. The actual temperature profile resulting from computerized analysis is illustrated in Figure 7. In the steady-state, the plate temperature will vary from a maximum of 212°F on the day cycle to a low of 190°F on the night cycle. The capacitance of the systems combined with the cycle environment prevents the system from reaching peaks predicted by equation (1). Note that steady-state conditions are achieved after 900 min (10 orbits).

The real value of treating a problem above the sophistication of equation (1) is the inherent expansion of knowledge about the behavior of thermal systems. The data of Figure 7 were developed from the computer program described in the appendices.

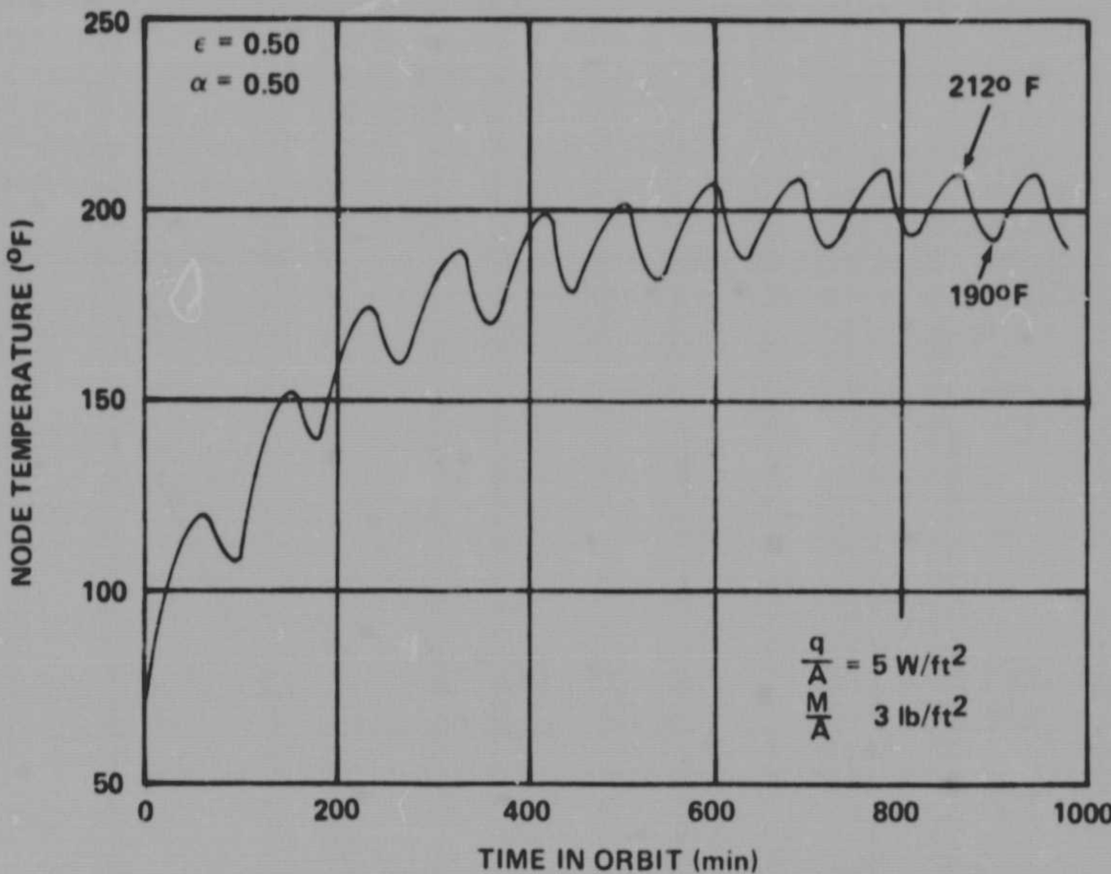

Figure 7. Temperature response of a flat plate.

THERMAL CONTROL ALGORITHM FOR LOUVER SYSTEMS

One consideration that expands knowledge of a louver system is the relationship between temperature and the deflection angle of the louvers. This relationship is called the thermal control algorithm. This control law determines the actual equipment temperatures. The steady-state full-open/closed characteristics given in Figures 3 and 5 only establish the other temperature boundaries that are thermally possible for a given equipment power. All of these possible temperatures are not desirable. Figures 3 and 5 can be misleading since they do not illustrate actual temperatures achieved. Thermal capacitance combined with the thermal control algorithm allows any of the temperatures indicated (within small fluctuations) to be maintained during the entire orbit.

For purposes of illustrating how temperature can be controlled, two thermal control algorithms will be introduced. These are given in Figure 8 and labeled (1) and (2). Both have a slope of 3 degrees/°F. However, for (1), the louvers do not open fully (90 degrees) until 80°F is reached. For (2), the louvers are fully open at 60°F. Thus, it is obvious that control law (2) will maintain the equipment at a lower temperature. Figure 9 shows the steady-state orbital temperature for algorithms (1). The louver system accomplishes a near constant 80°F over the entire power range of interest. Superimposed upon this figure is the day side analysis of Figure 3. Notice how trivial the day side analysis is compared to a simulated orbital analysis.

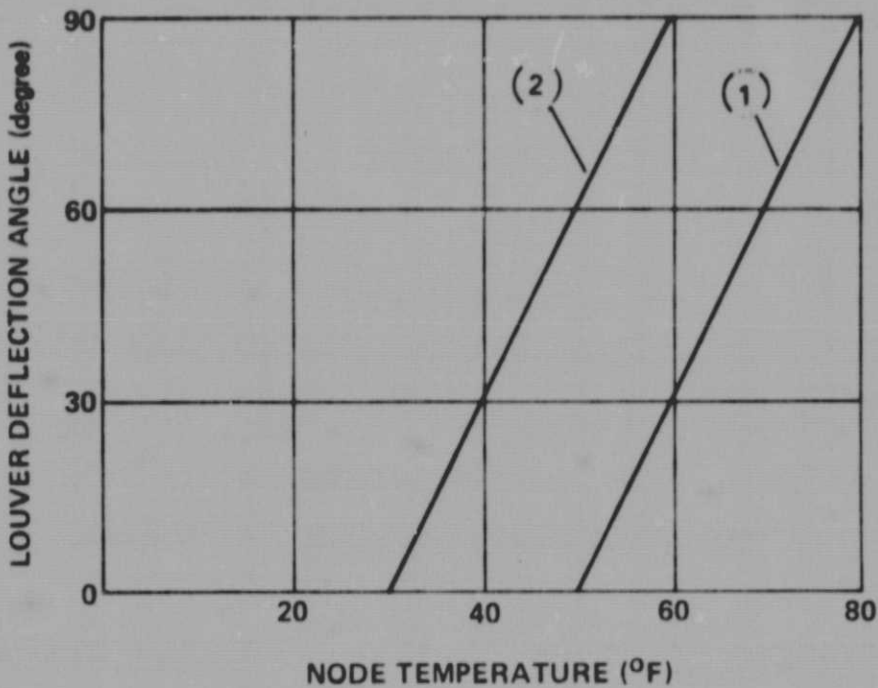

Figure 8. Illustration of the two example thermal control algorithms. (Specific temperatures encountered by a louver system are determined primarily by the algorithm employed).

Figure 10 is equivalent information using algorithm (2). Here, two cases are shown with and without sunshade. As expected, this algorithm maintains a lower equipment temperature. The capability of a louver system can be doubled by not employing a sunshade. Use of a sunshade will depend upon the equipment power level and the range through which it must be modulated. Figure 11 illustrates the temperature and louver angle variation during the orbit. The louvers vary through an 8 degree angle while the trough is approximately a 1.5 degree change.

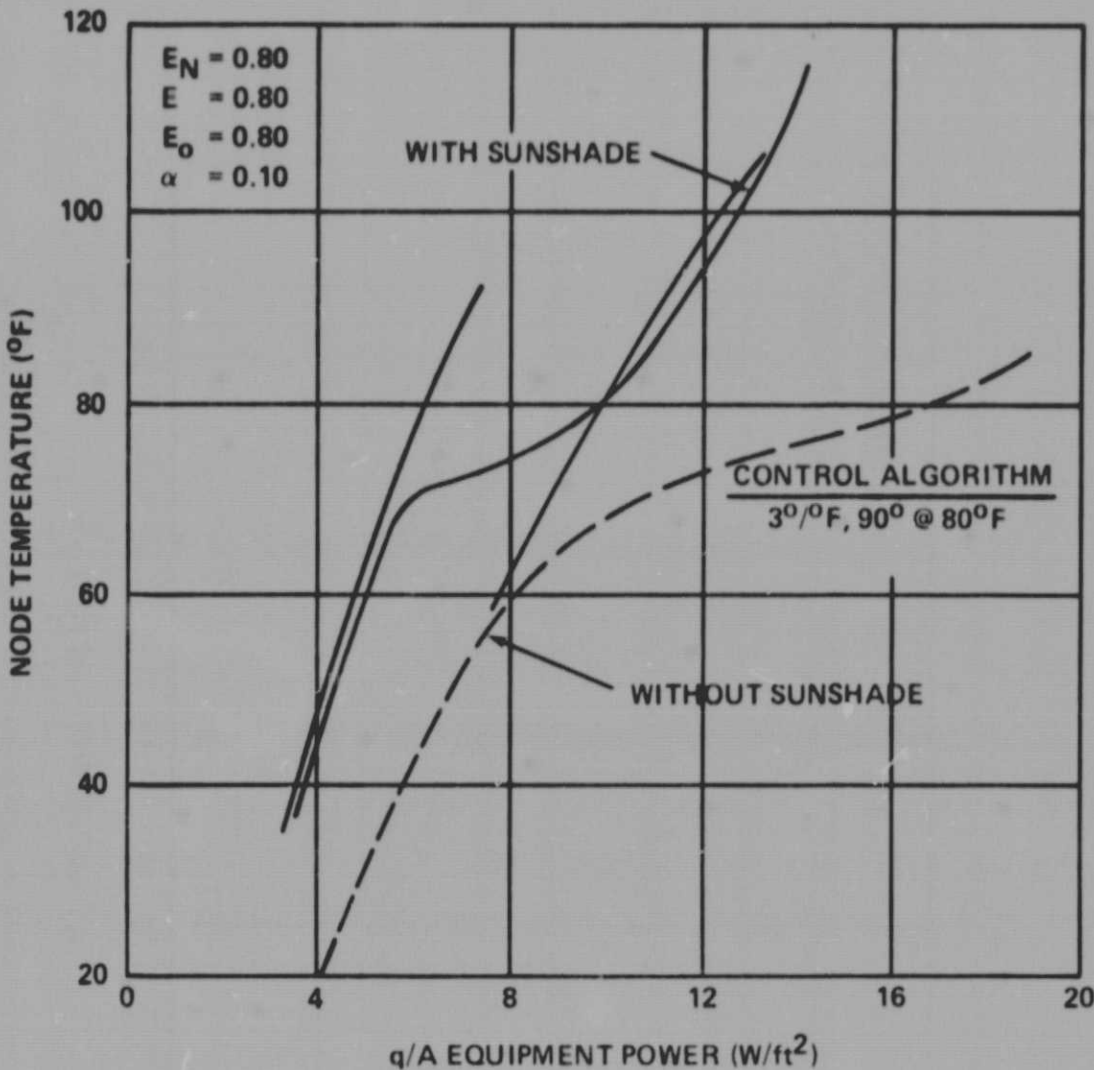

Figure 9. Steady-state orbit temperatures resulting from application of algorithm (1). (The performance sensitivity to a sunshade is dramatic. In general, heat rejection capability can be doubled by removal of the Sun shield.)

It is noted that application of a shield increases the thermal radiation resistance. A system without sunshade allows for greater heat dissipation since there is less thermal resistance to radiation.

For purposes of providing the capability for sophisticated analysis and, at the same time, one simple enough for quick turn-around, a computer program

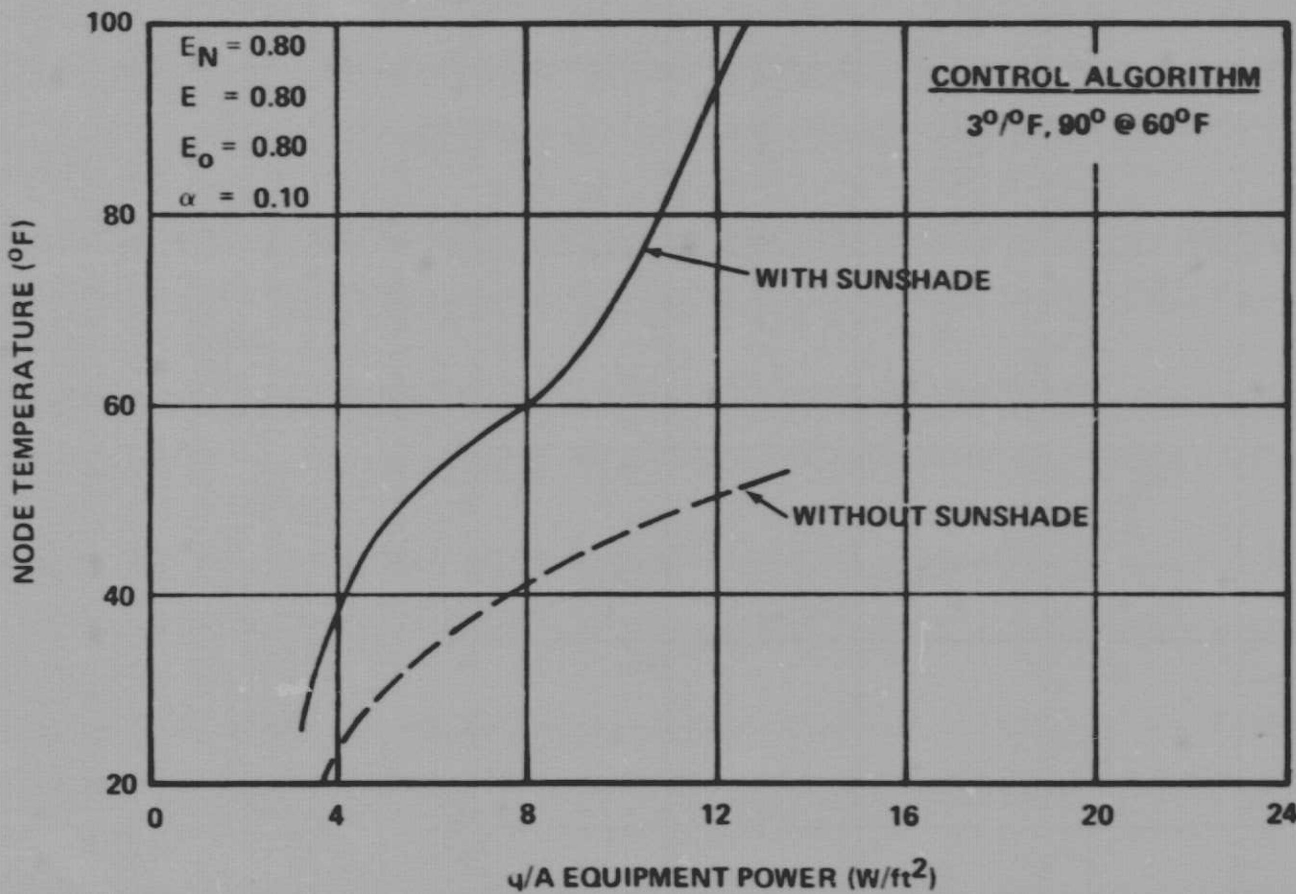

Figure 10. Steady-state orbit temperature resulting from algorithm (2).

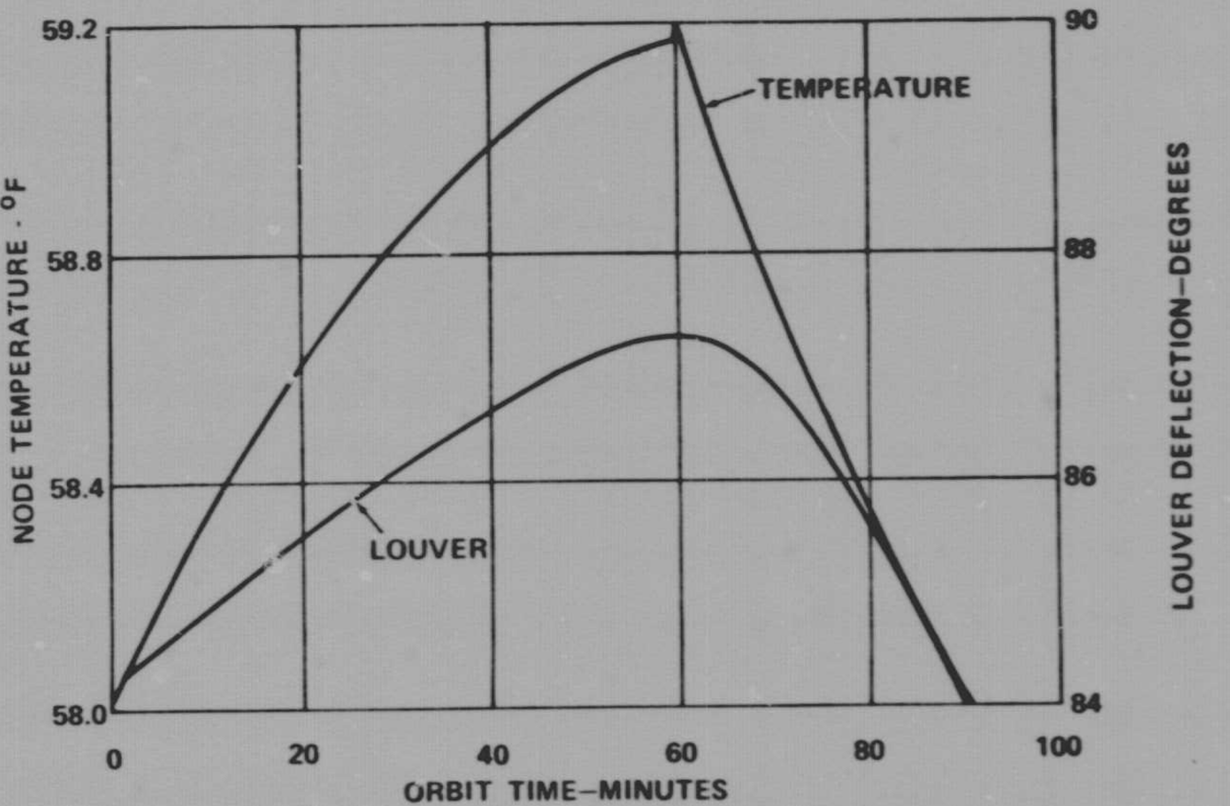

Figure 11. Equipment temperature response during on-orbit for equipment power of 16 W/ft^2. Louver angle movements are also given. Only slight temperature variations are encountered. The data resulted from application of algorithm (2).

has been developed for studying the temperature transients of a single node in a time varying thermal environment which considers radiation heat transfer only. A listing of this program and an explaration of the limitations and constraints are given in Appendix A. Appendix B develops the rationale and assumptions used in this program. The computer program is flexible in that five types of thermal systems can be facilitated:

1. Louver system with sunshade.

2. Louver system without sunshade.

3. Flat plate without louvers or sunshade.

4. Flat plate with one fixed shield.

5. Flat plate with two fixed shields.

Comments stated within the program indicate how each thermal system may be executed.

APPENDIX A. LIMITATIONS, CONSTRAINTS, AND OPERATION OF THE COMPUTER PROGRAM

In applying the computer program, the operator should be aware of the following limitations and instructions. Exercise judgement in development of the inputs. This caution is consistent with the simplicity represented in executing the program for quick model development and turnaround.

1. Comments are provided to execute one of the five configurations available. The instructions cause the program to default to the proper configuration. Note the specifics of the following statements:

a. Statement 74 — Orbit time (min).

b. Statement 75 — Sun time (min).

c. Statement 76 — View factor, Earth to node.

d. Statement 91 — Solar and albedo flux (Btu/h-ft^2).

e. Statement 87 — Earth IR (Btu h-ft^2).

f. Statement 108 — gives temperature at a 90 degree louver angle.

g. Statement 109 — gives temperature at a 0 degree louver angle.

h. Statement 110 — Algorithm, equation of louver angle versus temperature.

i. Statement 93 — Node view factor to space on day cycle.

j. Statement 97 — Node view factor to space on night cycle.

2. The program, as presented, does not accommodate a flat plate with albedo. As written, the flat plate is insulated on one side. For a flat plate without insulation, replace equation in statement 19 with QT = [F(93) + F(97)]* EN*SIG*[Y**4] - G*AC.

3. Start point is at the terminator toward the day side.

4. The time into and out of the terminator is considered to be instantaneous. Statement 89 determines the day side flux and statement 85 determines the night side flux (IR).

```
C     SINGLE NODE ORBIT ANALYSIS WITH RADIATION ONLY
C
C     LOUVER SYSTEM WITH SUN SHADE
C       XN=1.
C       XC=2.
C
C     LOUVER SYSTEM WITHOUT SUN SHADE
C       XN ; DONT MATTER
C       XC=1.
C       C2N=0.0
C
C     FOR FLAT PLATE IN SPACE
C       XN ; DONT MATTER
C       XC ; DONT MATTER
C       C2N ; DONT MATTER
C       C2C ; DONT MATTER
C       OUTTER SURFACE [E] BECOMES [EN]
C       OTHER [E] VALUES  DONT MATTER
C       REPLACE [GT] WITH  GT=F*EN*SIG*[Y**4]-G*AC
C
C     FOR FLAT PLATE WITH ONE SHIELD
C       XN=1.0
C       XC=DONT MATTER
C       C2C=DONT MATTER
C       COMMAND [AL] TO EQUAL 3.1415/2.0
C
C     FOR FLAT PLATE WITH TWO SHIELDS
C       XN=DONT MATTER
C       XC=2.0
C       C2N=DONT MATTER
C       COMMAND [AL] TO EQUAL 0.0
C
        COMMON EN,C2C,C3,C1,AC,AL,Q,CPM,AA,C2N,G,SIG,F
        READ 1,E0,E,EN,A,AI,Q,CPM,X0,Y0,DX,AA
C
        XN=1.
        XC=2.
        C2N=[E+E0-E*E0]/[E0*[2.-F]]+XN-1.
        C2C=[E+E0-E*E0]/[E0*[2.-F]]+XC-1.
C
        PRINT 100,E0
  100 FORMAT [10X,36H EQUIPMENT EMISSIVITY                ,F10.3]
        PRINT 101,E
  101 FORMAT [10X,36H LOUVER SURFACE EMISSIVITY           ,F10.3]
        PRINT 102,EN
  102 FORMAT [10X,36H SUN SHIELD EMISSIVITY               ,F10.3]
        PRINT 103,A
  103 FORMAT [10X,36H SUN SHIELD ALPHA                    ,F10.3]
        PRINT 104,AI
  104 FORMAT [10X,36H SOLAR INCIDENT ANGLE;  DEG          ,F10.3]
        PRINT 105,Q
  105 FORMAT [10X,36H EQUIPMENT POWER ;    WATTS          ,F10.3]
        PRINT 106,CPM
  106 FORMAT [10X,36H EQUIPMENT CPACITANCE ; BTU/F        ,F10.3]
        PRINT 107,Y0
  107 FORMAT [10X,36H INITIAL EQUIP. TEMP.  ;  F          ,F10.3]
        PRINT 108,X0
  108 FORMAT [10X,36H INITIAL TIME ;        MINUTES       ,F10.3]
        PRINT 109,DX
  109 FORMAT [10X,36H TIME INCREMENT ;      MINUTES       ,F10.3]
        PRINT 110,AA
```

```
  110 FORMAT [10X,36H RADIATING AREA ;  FT2                   ,F10.3]
      PRINT 88
      PRINT 55
   55 FORMAT [5X,99HTIME-MIN   TEMP.-F    LOUV. ANGLE   TEMP. RATE
     *FLUX                                                          ]
      PRINT 88
      NEQ=1
C
C   XP=ORBIT PERIOD  MIN.
C   TS=TIME ON SUN SIDE  MIN.
C   VFEN=VIEW FACTOR FROM EARTH TO NODE
C
      XP=90.
      TS=60.
      VFEN=.05
      N=0
      SIG=.1714E-08
      C1=EN*[2.-E]/E
      X=X0
      Y=Y0 +460.
      AC=A*COS[AI*3.1415/180.]
      T=0.
      AL=60.*3.1415/180.00
      ALD=AL*180./3.1415
C  THIS SECTION FOR SOLAR CONSTANT ALBEDO   IR
      XIR=75.
   97 IF [T-XP] 500,600,600
  600 T=0.
  500 IF [T-TS] 300,400,400
  300 G=430.
      GG=430.
      F=1.
      GO TO 1200
  400 G=[EN*XIR/AC]*VFEN
      GG=XIR
      F=.8
 1200 C3=[[2.-E]/[E*SIG]]*G*AC
C
   98 CALL DIFFE [X,Y,YP,DX,NEQ]
      N=N+DX
      T=T+DX
      IF [N-H ] 98,99,99
   99 N=0
      YY=Y-460.
      PRINT 2,X,YY,ALD,YP,GG
C  THIS SECTION FOR THERMAL CONTROL ALGORITHM
      IF [YY-80.] 11,10,10
   11 IF [YY-50.] 12,13,13
   13 AL=[3.*YY-150.]*3.1415/180.0
      GO TO 77
   10 AL=3.1415/2.00
      GO TO 77
   12 AL=0.0
   77 ALD=AL*180./3.1415
C
      GO TO 97
   88 FORMAT [///]
    2 FORMAT [5F12.2]
    1 FORMAT [11F7.2]
      END
```

COMMON ALLOCATION

```
77776 FN        77774 C2C       77772 C3        77770 C1
77766 AC        77764 AL        77762 G         77760 CPM
77756 AA        77754 C2N       77752 G         77750 SIG
77746 F
```

PROGRAM ALLOCATION

```
00004 NEQ       00005 N         00006 EM        00010 E
00012 A         00014 AI        00016 XM        00020 Y0
00022 DX        00024 XN        00026 XC        00030 XP
00032 TS        00034 VFEN      00036 X         00040 Y
00042 T         00044 ALD       00046 XIR       00050 GG
00052 YP        00054 YY
```

SUBPROGRAMS REQUIRED

```
  COS         DIFFE
THE END
```

```
      SUBROUTINE DIFFE [X,Y,YP,DX,NEQ]
      DIMENSION Y[5],YP[5],Y0[5],XK[5,5]
      DO 1 J=1,NEQ
    1 Y0[J]=Y[J]
      DO 10 I=1,4
      GO TO [7,2,3,5],I
    2 X=X+.5*DX
    3 DO 4 J=1,NEQ
    4 Y[J]=Y0[J]+.5*XK[J,I-1]
      GO TO 7
    5 X=X+.5*DX
      DO 6 J=1,NEQ
    6 Y[J]=Y0[J]+XK[J,3]
    7 CALL YFUNC [X,Y,YP,DX,NEQ]
      DO 8 J=1,NEQ
    8 XK[J,I]=YP[J]*DX
   10 CONTINUE
      DO 11 I=1,NEQ
   11 Y[J]=Y0[J]+[XK[J,1]+2.*XK[J,2]+2.*XK[J,3]+XK[J,4]]/6.
      RETURN
      END
```

PROGRAM ALLOCATION

```
DUMMY Y         DUMMY YP        00025 Y0        00037 XK
00121 J         DUMMY NEQ       00122 I         00123 DIFFE
DUMMY X         DUMMY DX
```

SUBPROGRAMS REQUIRED

```
  YFUNC
THE END
```

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OF POOR QUALITY

```
      SUBROUTINE YFUNC (X,Y,YP,DX,NEN)
      COMMON EN,C2C,C3,C1,AC,AL,Q,CPM,AA,C2N,G,SIG,F
C  CCC    CC ARE CORRECTIONS FOR BULK TEMP.
      CCC=(1.-COS(AL))
      CC=(COS(AL))
C
      GT=(EN*SIG*((Y**4)*CC+C2C*C3)*COS(AL)/(C2C*C1+1.))*F+
     $(EN*SIG*((Y**4)*CCC+C2N*C3)*(1.-COS(AL))/(C2N*C1+1.))*F-G*AC
      YP=3.4129*Q/(CPM*60.)-AA*GT/(CPM*60.)
      RETURN
      END

COMMON ALLOCATION

  77776 EN        77774 C2C        77772 C3        77770 C1
  77766 AC        77764 AL         77762 Q         77760 CPM
  77756 AA        77754 C2N        77752 G         77750 SIG
  77746 F

PROGRAM ALLOCATION

  00033 YFUNC     00035 CCC        00037 CC        00041 GT
  DUMMY Y         DUMMY YP

SUBPROGRAMS REQUIRED

  COS
THE END
```

EQUIPMENT EMISSIVITY	.800
LOUVER SURFACE EMISSIVITY	.800
SUN SHIELD EMISSIVITY	.800
SUN SHIELD_ALPHA	.100
SOLAR INCIDENT ANGLE; DEG	.000
EQUIPMENT POWER ; WATTS	6.000
EQUIPMENT CAPACITANCE ; BTU/F	3.000
INITIAL EQUIP. TEMP. ; F	60.000
INITIAL TIME ; MINUTES	.000
TIME INCREMENT ; MINUTES	1.000
RADIATING AREA ; FT2	1.000

TIME-MIN	TEMP.-F	LOUV. ANGLE	TEMP. RATE	FLUX
5.00	60.49	60.00	.10	430.00
10.00	60.82	31.48	.06	430.00
15.00	61.15	32.45	.07	430.00
20.00	61.49	33.44	.07	430.00
25.00	61.84	34.46	.07	430.00
30.00	62.20	35.51	.07	430.00
35.00	62.57	36.59	.07	430.00
40.00	62.95	37.70	.08	430.00
45.00	63.34	38.84	.08	430.00
50.00	63.74	40.01	.08	430.00
55.00	64.15	41.21	.08	430.00
60.00	64.57	42.44	.08	430.00
65.00	64.80	43.70	.05	75.00
70.00	65.03	44.40	.05	75.00
75.00	65.27	45.10	.05	75.00
80.00	65.51	45.81	.05	75.00
85.00	65.75	46.53	.05	75.00
90.00	65.99	47.25	.05	75.00
95.00	66.45	47.98	.09	430.00
100.00	66.91	49.34	.09	430.00
105.00	67.37	50.72	.09	430.00
110.00	67.84	52.11	.09	430.00
115.00	68.30	53.51	.09	430.00
120.00	68.77	54.91	.09	430.00
125.00	69.24	56.32	.09	430.00
130.00	69.70	57.72	.09	430.00
135.00	70.16	59.11	.09	430.00
140.00	70.61	60.48	.09	430.00
145.00	71.05	61.83	.09	430.00
150.00	71.48	63.15	.09	430.00
155.00	71.66	64.43	.04	75.00
160.00	71.85	64.99	.04	75.00
165.00	72.02	65.54	.04	75.00
170.00	72.19	66.07	.03	75.00
175.00	72.36	66.58	.03	75.00
180.00	72.51	67.07	.03	75.00
185.00	72.89	67.54	.07	430.00
190.00	73.24	68.67	.07	430.00
195.00	73.58	69.73	.07	430.00
200.00	73.90	70.75	.06	430.00
205.00	74.20	71.70	.06	430.00

APPENDIX B. DEVELOPMENT OF RATIONALE FOR ORBITAL ANALYSIS OF A SINGLE NODE EXHIBITING HEAT TRANSFER BY RADIATION ONLY

Consider the flat surface shown in Figure B-1 which has external heat generation distributed equally over the surface. In the general case the surface is shaded by a louver and sunshade. The louver rotated through angle θ which varies the area shaded by the louver. At $\theta = 90$ degree, the flat surface is shielded only by the sunshade. At $\theta = 0$ degree the flat surface is shaded by two shields.

Mathematically, the temperature of the plate with one effective shield is T_N and the temperature of the plate with two effective shields is T_C. The bulk temperature, T, of the plate becomes

$$T = \frac{M_C T_C}{M_C + M_N} + \frac{M_N T_N}{M_C + M_N} \qquad \text{(B-1)}$$

where M_C and M_N are the respective shielded mass of the flat plate. The bulk temperature, T, is defined as the node temperature and is the combined effective temperature of the shielded plate.

It can be easily shown that M_C and the projected area, A_C is

$$A_C = A \cos \theta \qquad \text{(B-2)}$$

$$\frac{M_C}{M_C + M_N} = \cos \theta \qquad \text{(B-3)}$$

$$M_C + M_N = M \qquad \text{(B-4)}$$

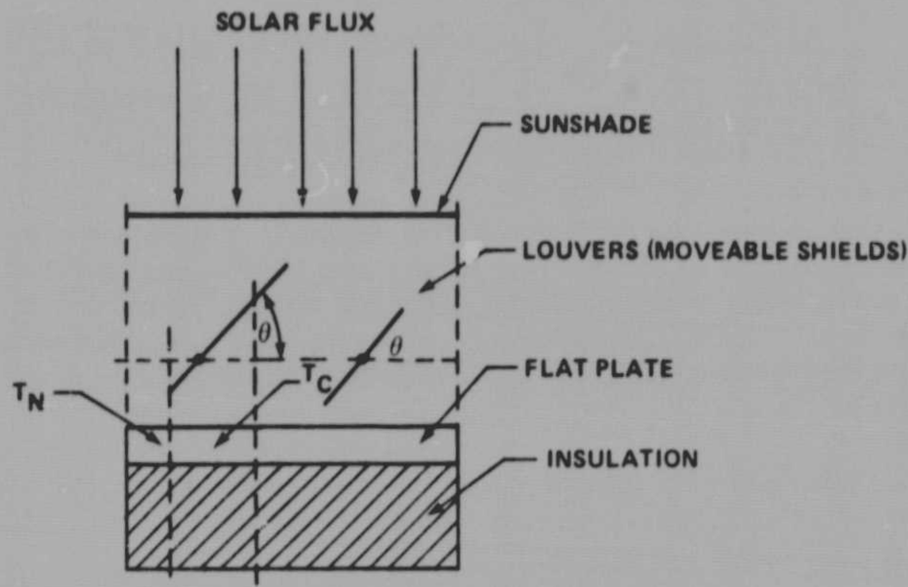

Figure B-1. General configuration of an internal louver system.

and

$$A_N = A\,(1 - \cos\theta) \tag{B-5}$$

$$\frac{M_N}{M_C + M_N} = 1 - \cos\theta \tag{B-6}$$

where A is the total area.

The equation describing T_C becomes

$$M_C\, C_p\, \frac{dT_C}{d\tau} = \alpha\, A_C G(t) + \left(\frac{q}{A_C}\right)_{(EQUIP)} - \left(\frac{q}{A_C}\right)_{(RADIATED)} \tag{B-7}$$

$$M_N\, C_p\, \frac{dT_N}{d\tau} = \alpha\, A_N G(t) + \left(\frac{q}{A_N}\right)_{(EQUIP)} - \left(\frac{q}{A_N}\right)_{(RADIATED)} . \tag{B-8}$$

These two equations can be represented as a single equation involving only the node temperature, T:

$$\frac{M}{A} C_p \frac{dT}{d\tau} = \alpha G(t) + \left(\frac{q}{A}\right)_{(EQUIP)} - \left(\frac{q}{A}\right)_{(RADIATED)} \quad . \qquad (B-9)$$

The term (q/A) equipment is simply an input equivalent to the equipment power applied to the node. Equations (6) and (7) of text can be combined to obtain the equipment power capable of being radiated. It is noted that the solar flux falling on surface A is a function of time depending upon orbit parameters and orientation.

Equation (B-9) is the problem representation included in Appendix A.

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APPROVAL

SINGLE NODE ORBIT ANALYSIS WITH RADIATION HEAT TRANSFER ONLY

By Jerry A. Peoples

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

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