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AN IMPROVED TEST TO DETERMINE FUEL EXOSION
RESISTANCE IN FUEL NOZE CONES

By
George R. Loney, Jr.
Richard W. ...

JULY 1971

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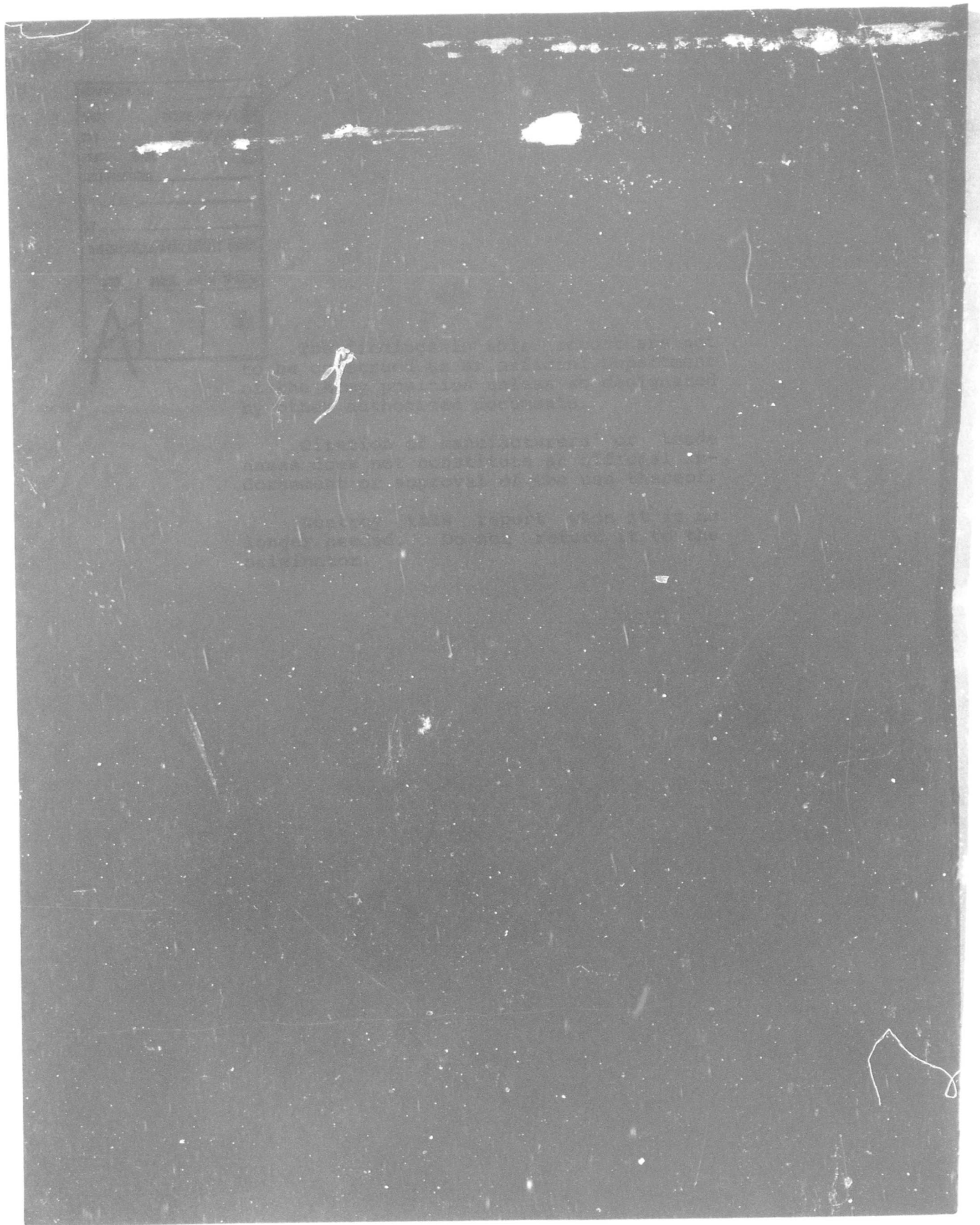
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CONTENTS

	<u>Page</u>
ABSTRACT.....	3
1. GENERAL DESCRIPTION.....	7
2. SAMPLE CALCULATIONS.....	9
ACKNOWLEDGEMENT.....	13
DISTRIBUTION.....	63

ILLUSTRATIONS

Figure

1. View from top of a transparent artillery fuze nose cone after a wind tunnel test simulating a 175-mm projectile flight.....	7
2. Two nose cones of SIF artillery fuzes showing rain damage following rocket sled test.....	8
3. Holloman AFB rocket sled at end of an HDL rain test.....	10
4. Flight characteristics of a 175-mm projectile fired at a 10-deg elevation, zone 3.....	12
Table I. Temperature gradients in the blunt tip of an SIF nose cone.....	11

APPENDICES

A. Transient heat transfer computer program.....	15
B. Data deck preparation.....	35
C. Computer printout.....	45
D. Rocket sled calculations.....	55

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1. GENERAL DESCRIPTION

Plastic nose cones mounted on high-velocity projectiles are subjected to aerodynamic heating that degrades the physical properties of the material (fig. 1). If the projectile were to enter a rainfield some distance downrange from the point of launch, thermal degradation of the physical properties would greatly reduce the ability of the nose cone to resist erosion (fig. 2). Damage to the nose cone can produce erratic flight of the projectile, degradation of range, and fuze damage that could result in a dud or an early function.

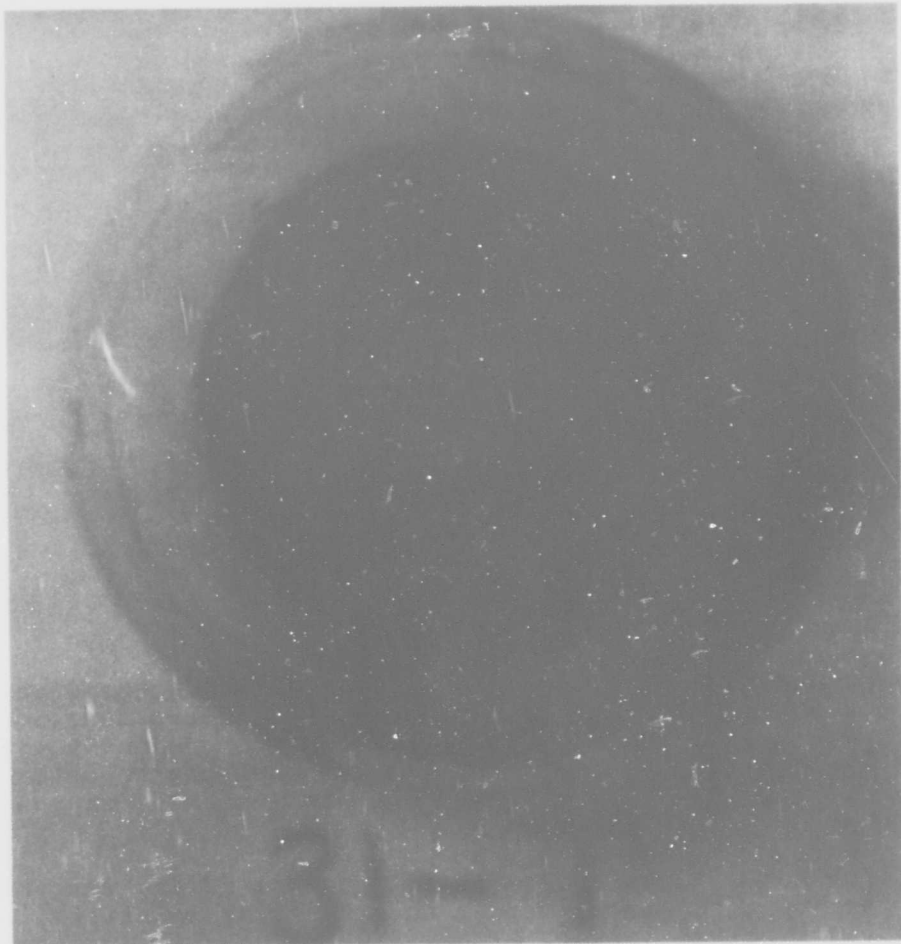


FIGURE 1. VIEW FROM TOP OF A TRANSPARENT ARTILLERY FUZE NOSE CONE AFTER A WIND TUNNEL TEST SIMULATING A 175-MM PROJECTILE FLIGHT.

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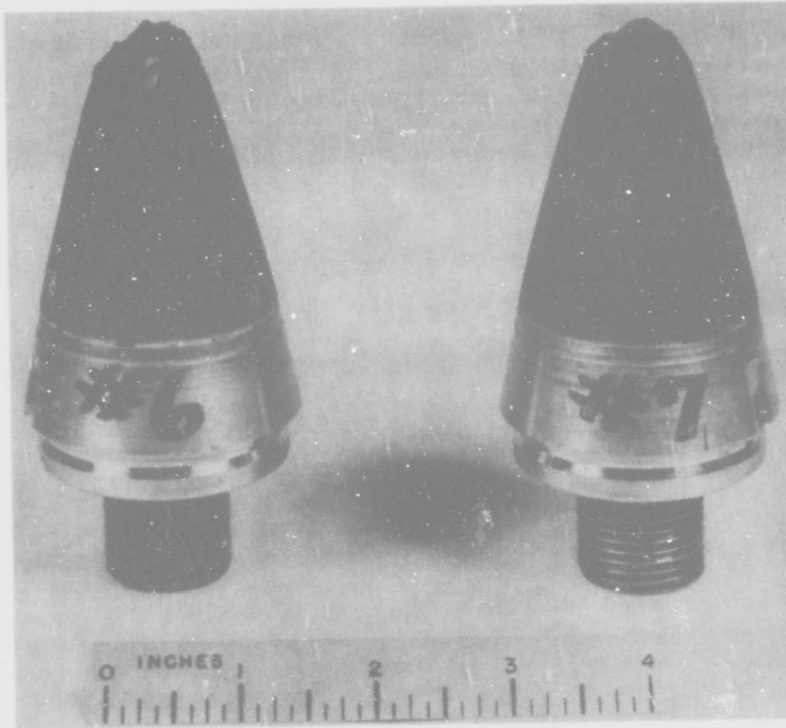


FIGURE 2. TWO NOSE CONES OF SIF ARTILLERY FUZES, SHOWING RAIN DAMAGE FOLLOWING ROCKET SLED TEST.

In each fuze design, rain erosion must be considered when specifying a nose cone material, configuration, and wall thickness. The safest approach is to conduct tests and then perform a cost-effectiveness analysis to determine if some type of protective cap must be designed for the fuze.

The conventional tests are (1) actual firing into rain, (2) rocket sled tests through an artificial rainfield, and (3) whirling-arm tests. A Mach 3 whirling-arm apparatus has recently become available at the Wright-Patterson AFB, but because of the newness of this device the Harry Diamond Laboratories (HDL) has only made use of the Holloman AFB

rocket sled (fig. 3) and artillery firings into rainstorms. The latter test is an end-product test and of limited value for development programs. The rocket sled, on the other hand, is useful because the samples are recoverable and the test conditions are controllable.

Ordinarily, the requirements for establishing a rocket sled test are to specify the velocity at which the sled is to enter the rainfield, the velocity profile through the rain, the length of the rainfield, and the rain conditions such as drop size and density. A proposal is put forth in this text that the test can be improved by specifying the aerodynamic heating that occurs on the nose cone before entering the rainfield. This involves defining the velocity profile of the sled during the approach; thus, at the instant of entry into the rainfield, the velocity, surface temperature, and temperature gradient of the nose cone are as close as possible to the values that occur when the nose cone is mounted on an actual projectile and fired downrange toward a rainstorm.

In the instance of artillery-fuze nose cones, the rocket sled may be used to investigate only the damage that occurs when the rainstorm is located within one or two miles of the gun. The reason is that the sled mass, booster rockets, and length of track are limited, hence the rate of heat flux and total heat that can be supplied to the nose cone before entering the rainfield are also limited. If greater amounts of heating are desired, the whirling-arm apparatus must be used.

Rocket sled tests on the SIF nose cone were conducted by HDL during Aug 1970. In these tests, the aerodynamic preheating was specified. The preheat was similar to that which occurs when the 175-mm projectile is fired at low angle and maximum charge toward a rainstorm located sufficiently far downrange to allow the maximum surface temperature to develop on the tip of the nose cone. The calculations used to determine the necessary velocity profile of the rocket sled to achieve this preheat are presented in the following section.

2. SAMPLE CALCULATIONS

The first step was to perform an analysis of the unsteady-state heat transfer to the SIF nose cone during flight of the 175-mm projectile. This was accomplished by using the computer program included in appendix A. Appendix B shows the manner in which data were inserted into the program, and

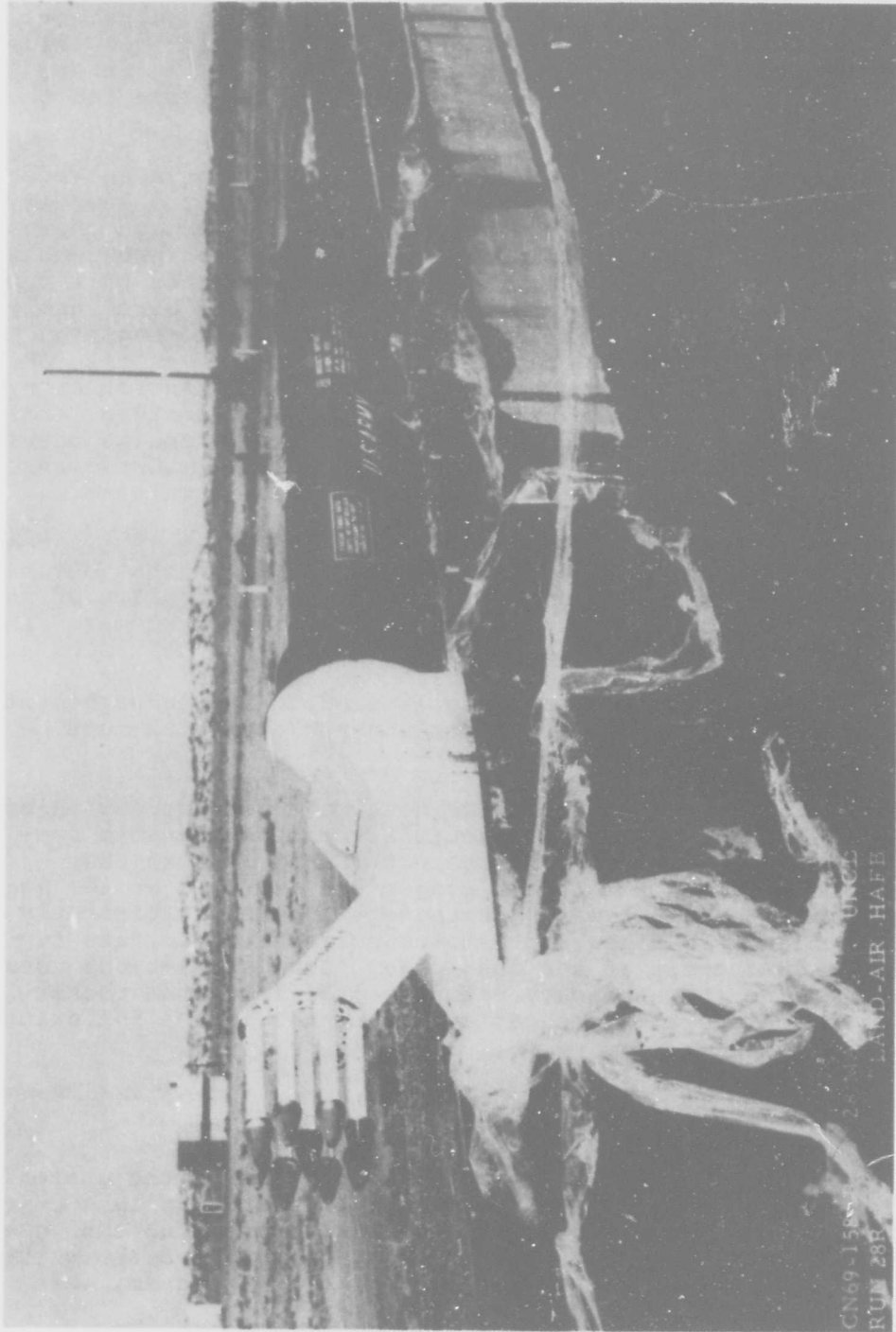


FIGURE 3. HOLLOMAN AFB ROCKET SLED AT THE END OF AN HDL RAIN TEST.

appendix C shows the data output. The maximum surface temperature is seen to occur at 0.66 sec. The calculated gradient within the tip of the nose cone is shown in the data and repeated in column 1 of table I.

Table I. Temperature gradients in the blunt tip of a modified polyphenylene oxide, SIF nose cone. Column 1 represents conditions that occur at 0.66 sec into flight of the 175-mm projectile fired at zone 3, 10-deg elevation angle into 57°F sea-level air. This is the time of maximum surface temperature. Column 2 depicts the temperature conditions expected on the SIF as the Holloman AFB rocket sled enters the rainfield. The sled booster system consists of nine HVAR's, one NIKE, and three M58 rockets.

Position in.	Temperature (°F)	
	Column 1	Column 2
Surface	674	691
0.0166	215	282
0.0333	83	123
0.0499	60	73
0.0666	57	60
0.0833	57	57
0.0999	57	57
0.1166	57	57

The second step was to consult firing tables to determine the projectile velocity at 0.66 sec of flight time so that this value could be specified for the rocket sled at the rainfield entrance. The velocity profile of the sled through the rainfield is also determined from the firing tables, and the method is illustrated in figure 4.

The third step was to contact Lt Gustafson at Holloman AFB Test Group (TKO) to determine the set of boosters capable of providing the desired sled velocities in the vicinity of the rainfield, and to request information as to the velocity profile of this sled arrangement during approach to the rainfield. The approach velocities were inserted into the computer and the temperature conditions within the nose-cone tip at the instant of entry into the rainfield were calculated and compared with those in column 1 of table I. If the calculations were not reasonably similar, the approach profile was modified on paper until the desired temperatures were calculated. Holloman AFB was then contacted to determine whether the modified profile could be obtained. This

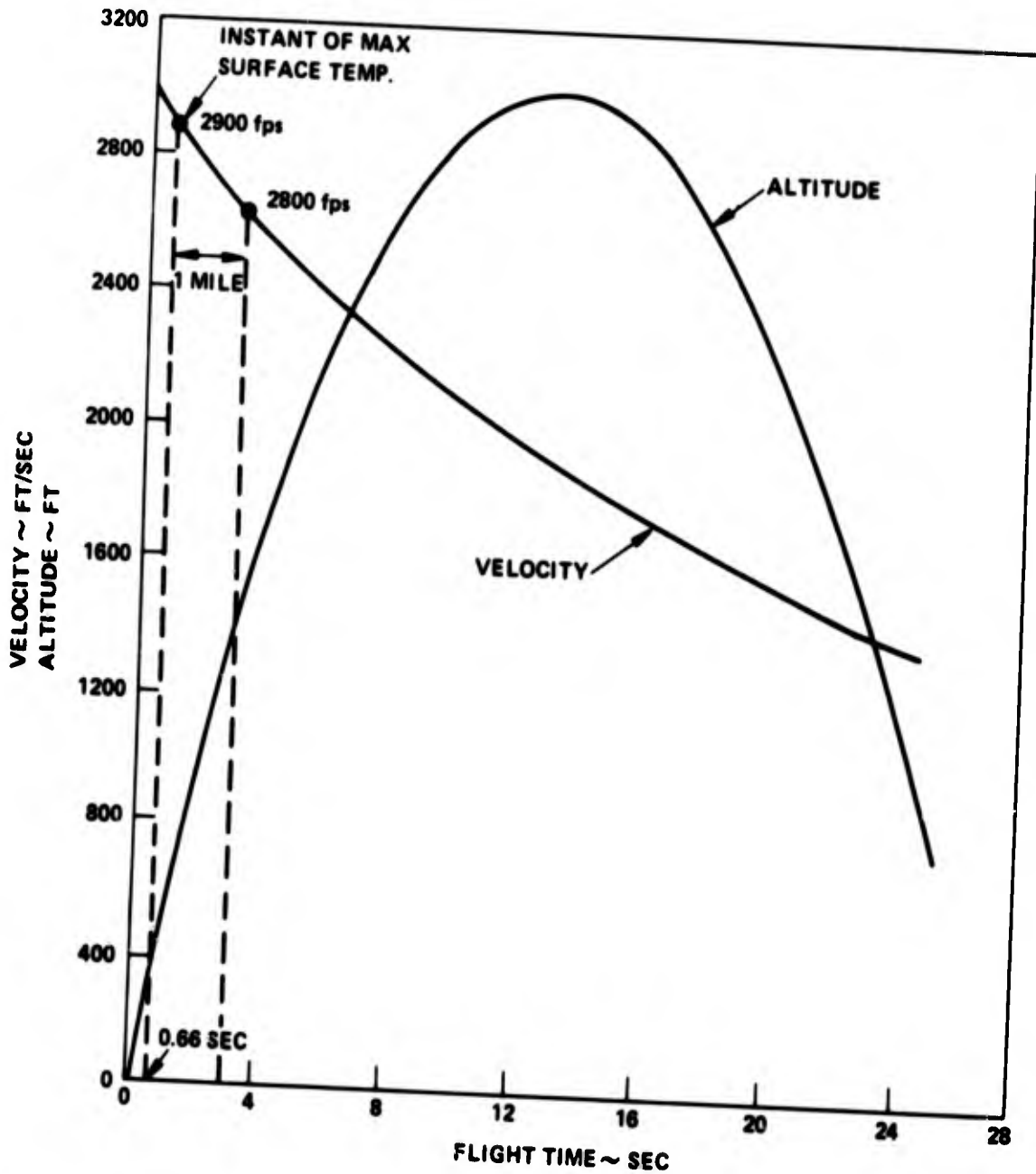


FIGURE 4. FLIGHT CHARACTERISTICS OF A 175-MM PROJECTILE FIRED AT 10-DEG ELEVATION, ZONE 3.

procedure was continued until a reasonable agreement was obtained.

Appendix D shows the rocket sled data inserted into the program and the data output. Column 2 of table I shows that the temperature conditions within the nose-cone tip at the entrance to the rainfield are reasonably close to those calculated for the 175-mm flight.

ACKNOWLEDGEMENT

The authors wish to express appreciation for the assistance of J. Achstetter, HDL staff member, in the preparation of the computer program presented in this text.

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APPENDIX A. TRANSIENT HEAT TRANSFER COMPUTER PROGRAM

A-1. PROGRAM FORMAT

The Fortran program presented in this section is a modification of a program written by Dr. J. H. Kraft as part of a feasibility study to be reported by HDL on the applicability of certain direct energy conversion processes to fuze design. The modifications consisted of removing thermoelectric calculations, providing a graph of surface temperature variation with time, calling for a printout of data cards and units of the variables, correcting an error in a subroutine used for interpolations, and adding a subroutine that calculates the film coefficient of heat transfer at the blunt tip of a nose cone flying in the troposphere.

Figure A-1 shows a flow chart for the program; one-dimensional transient heat transfer through stacked plates is treated. Each plate is called a section, and each section is imagined to be divided into segments called nodes. The thermal conductivity at each node is allowed to vary with temperature, but density and specific heat are assumed to be constants. Material properties are calculated in the PROP subroutine.

The boundary conditions considered for the two end plates on the stack are radiation, constant surface temperature, and convection. In the instance of convection, the film coefficient of heat transfer may vary during the course of heating, and this variation must be inserted into the program data in tabular form. An interpolation subroutine (INT) is used to calculate values of coefficients not specifically listed in the table.

If the convection problem under consideration is one of aerodynamic heating on the blunt tip of a projectile in flight, then a table of heat transfer coefficients need not be included in the program data. Instead, ballistic data such as projectile height and velocity are needed; the HTSTAR subroutine calculates the necessary relationships for film coefficient. The TEMP subroutine is used to calculate nodal temperature variations as a function of time. The calculations continue until all nodes have been treated and the time span listed in the ballistics table or the heat transfer table is covered.

When the calculations are completed a graph of surface temperature variation with time is provided. A printout of temperature gradient at specified instants of time is also

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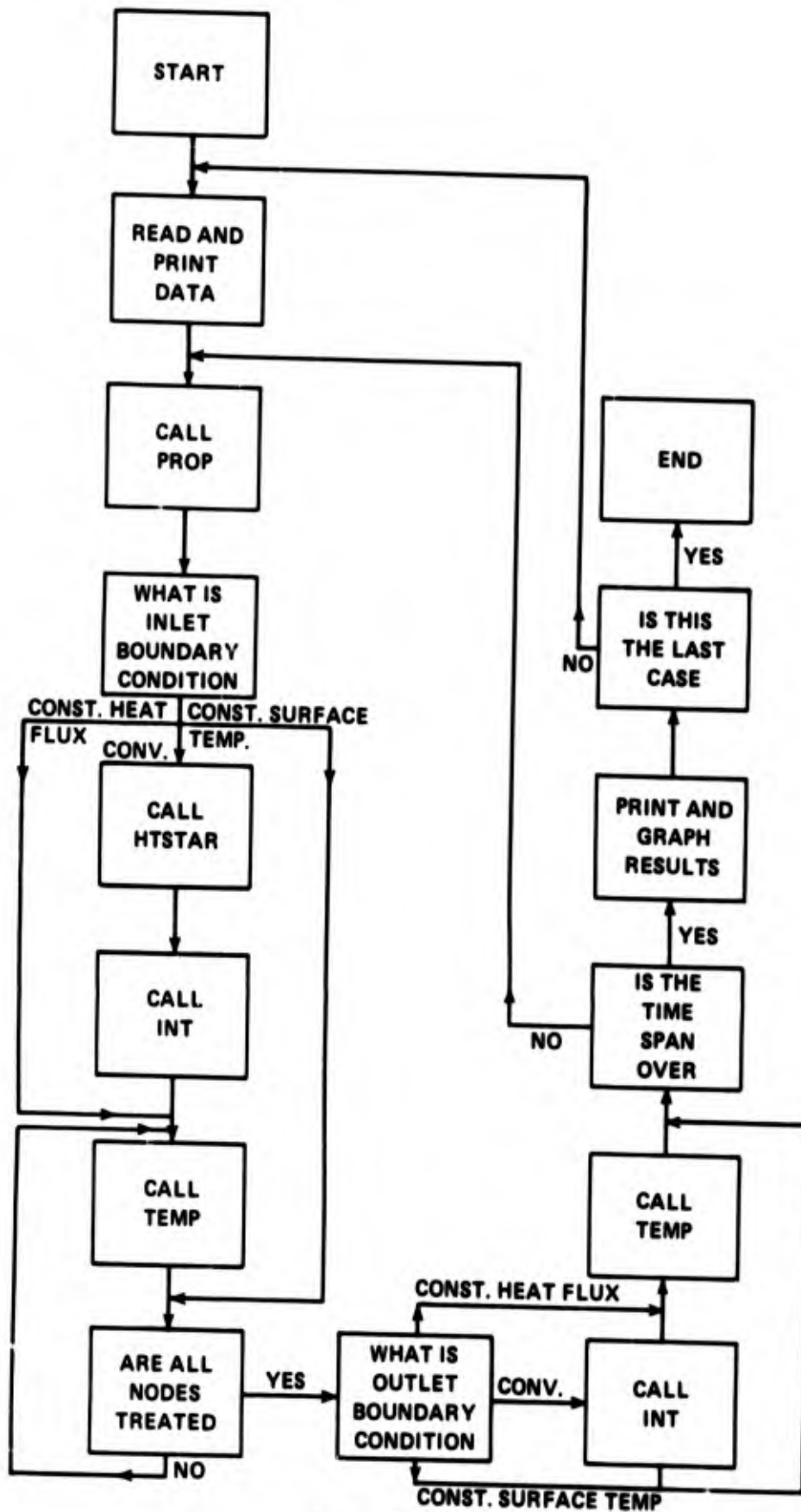


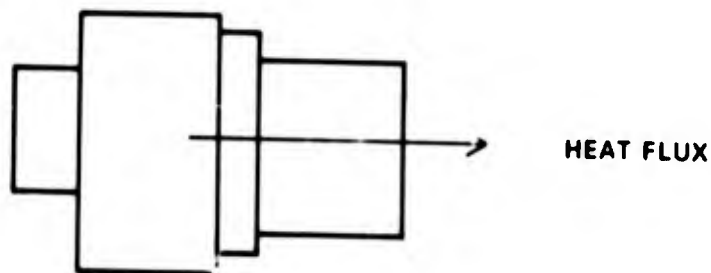
FIGURE A-1. FLOW CHART

provided along with the temperature of the hot air, the heat transfer coefficient, the instantaneous rate of heat transfer, and the total heat supplied up to the instant of interest.

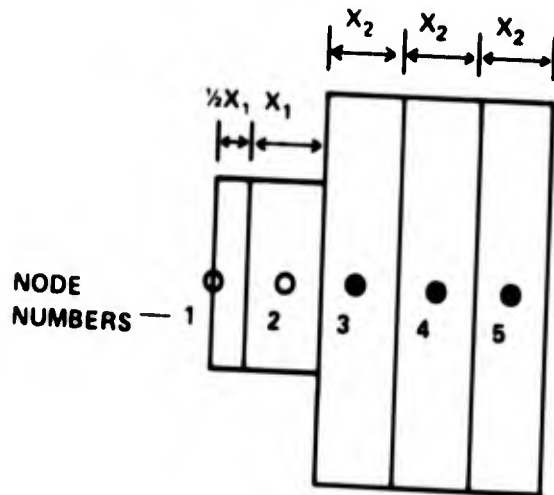
The graph of surface temperature is provided only for one side of the stack of plates, but the printout data are for both end surfaces. The manner in which data are inserted into the program and the appearance of data printed by the program are shown in the following sections.

A-2. PROGRAM FUNDAMENTALS

The program treats a set of stacked plates subjected to transient heat flow from left to right as shown below.



The individual plates are of arbitrary width, area, and material. Heat losses through the sides are disregarded. Each plate is called a section, and is imagined to be divided into incremental masses called nodes. Node widths may vary from plate to plate, but the width is constant within the individual plates. The only exception to this is on either end plate; a half width is used for boundary nodes. An illustration of an end plate containing two nodes and one internal plate with three nodes is shown below.



From this illustration, it is apparent that the node width is defined by the relations

$$X = L / (\#nodes - 1/2 \text{ node})$$

for surface plates,

$$X = L / (\#nodes)$$

for interior plates,

where

X = node width,

L = plate width.

Any number of nodes may be selected for each plate, but improved accuracy in temperature calculations results when X is small.

Three boundary conditions are considered for the two end plates; these are constant heat flux (radiation):

$$q = \text{CONST},$$

applied surface temperature

$$T(1) = \text{CONST},$$

and convection

$$q = hA[T_{\text{amb}} - T(1)],$$

where

q = rate of heat transfer,

$T(1)$ = surface temperature (the number 1 denotes the first node),

h = film coefficient of heat transfer,

A = area,

T_{amb} = ambient air temperature for general convection such as in an oven, but for aerodynamic heat transfer, as during the flight of a projectile, this is the adiabatic recovery temperature.

In the case of general convection (such as in an oven), variations of h with time may be included in the program in the form of a table. Similarly, a function of h called COHT may be inserted in tabular form for aerodynamic heating. Values of COHT have been presented by Buckley.¹ In general,

$$COHT = h T^*P$$

where

$$T^* = [T(1) + T_e] / 2 + C_m T_e M^2,$$

C_m, p = dimensionless constants,

T_e = temperature at the boundary layer edges,

$M = V/C =$ Mach number ,

$V =$ projectile velocity,

$C = (YRT)^{1/2} =$ sound speed

$T =$ static air temperature,

$Y =$ ratio of specific heats (1.4 for air),

$R =$ air gas constant = 1716.5 ft²/OF-S².

In the particular instance of stagnation point aerodynamic heating on the blunt tip of a nose cone flying with $M \geq 1.8$,

¹HDL report TR-1466, "Constant Mach Number Simulation of Flight Loads on High Velocity Projectile Fuzes," by Frank T. Buckley, May, 1970.

$$C_m = 0,$$

$$p = 0.069,$$

$$T_e = T_{amb} = T_t = \text{stagnation temperature},$$

$$COHT = 7.31 \times 10^{-6} (P_{t2B})^{1/2},$$

$$B = (0.6/D) (\gamma R T_t)^{1/2},$$

where

D = diameter of the blunt tip.

The stagnation air conditions behind the shock wave are given by

$$T_t = T \left(1 + \frac{(\gamma-1)}{2} M^2 \right),$$

$$P_{t2} = P \left(\frac{\gamma+1}{2} M^2 \right)^{\gamma/(\gamma-1)} \left(\frac{\gamma+1}{2\gamma M^2 - (\gamma-1)} \right)^{1/(\gamma-1)}$$

The static air conditions in front of the shock wave are

$$T = T_0 - 0.003566H,$$

$$P = P_0 (T/T_0)^{5.256},$$

where

T_0 = atmospheric temperature at the launch site,

P_0 = atmospheric pressure at the launch site,

H_0 = elevation of the launch site above sea level,

H = instantaneous elevation of the projectile above the launch site.

These static relationships are valid in the troposphere only. In addition, the general set of equations for COHT are valid for Mach numbers greater than 1.8, but the relation

$$P_{t2} = P \left[1 + \frac{(\gamma-1)}{2} M^2 \right]^{3.5}$$

was included in the program for continuity in the event Mach numbers less than unity were inserted. For many applications, the error associated with using Mach numbers less than 1.8 is quite tolerable, because the heating at these velocities is small.

All that is needed in the program for blunt tip stagnation point aerodynamic heat transfer problems is a table of projectile height and velocity as a function of time. A table of COHT, M, T_e , T_{am} , and time is then generated. The problem of interpolating between the tabulated values is handled by the Aitkins polynomial method in the INT subroutine; the mechanics of these calculations are presented by Abramowitz and Stegun.¹

The presentation above completely defines the equations programmed for convective boundary conditions. Heat transfer into the interior of a plate is described by

$$q = \frac{T(N) - T(N+1)}{(X/2kA)_N + (X/2kA)_{N+1}},$$

where N denotes an arbitrary node number. This equation accounts for changes that may occur in node size, plate area across an internal boundary of two plates, and for variations in thermal conductivity with temperature. The thermal conductivity, k, is given by

$$k = C_0 + C_1/T + C_2T.$$

Values for the C_0 , C_1 , C_2 constants must be supplied to the program. Variations in nodal temperatures with time are calculated, using the following "future" temperature equations. For the left-side boundary, the temperature $T(N)$ next at (time + an increment of time) is found from instantaneous conditions according to:

$$T(N) = 2 \alpha(N) \left(\frac{T(N)}{2\alpha(N)} - \frac{2T(N)}{r(N) + r(N+1)} + \frac{2T(N+1)}{r(N) + r(N+1)} + q \right),$$

where

$$r = X/kA,$$

$$\alpha(N) = \Delta\theta/CYAX,$$

$\Delta\theta$ = time increment, and

C = specific heat.

¹"Handbook of Mathematical Functions," Abramowitz and Stegun, NBS, Applied Mathematics, series 55, 1964.

Values of r , T , α , and q are those associated with the time before $\Delta\theta$ is added. If this happens to be time zero, then these values are obtained from information supplied the program about the initial conditions of the plates and boundaries. The size of the time increment used in the calculations is supplied to the program, and should be selected initially from the equations

$$\Delta\theta \leq CYX^2/2k,$$

$$\Delta\theta \leq (CYX^2/2k) \left(\frac{1}{1 + hX/k} \right)$$

These are relations that assure the numerical analysis does not violate conservation of energy. The first relation is the stability criteria for nodes within a plate, and the second is for a convective boundary. The second equation is to be ignored if there is no convective boundary condition, and the first is ignored if there is. Accuracy of temperature calculations is improved if a small time increment is selected.

Knowing the surface temperature, the interior node future temperatures are found in succession from

$$T(N)_{\text{next}} = \alpha(N) \left\{ \frac{T(N)}{\alpha(N)} - \frac{2T(N)}{r(N+1)+r(N)} + \frac{2T(N+1)}{r(N+1)+r(N)} + \frac{2T(N-1)}{r(N-1)+r(N)} \right\}$$

And when the right-side boundary is reached,

$$T(N)_{\text{next}} = 2\alpha(N) \left\{ \frac{T(N)}{2\alpha(N)} - \frac{2T(N)}{r(N-1)+r(N)} + \frac{2T(N-1)}{r(N-1)+r(N)} - q \right\}$$

Once the complete set of future temperatures is defined for all nodes at any given instant of time + $\Delta\theta$, the rate of heat input at the boundaries is calculated from the gradient, ΔT , across the first two nodes.

$$q = (kA/X)\Delta T,$$

and the total heat put into the system is found by continuous summation

$$Q = Q_{\text{initial}} + \Sigma q\Delta\theta .$$

The printout for this program is included on pages 23 through 33.

DECK1 - EFN SOURCE STATEMENT - IFN(S) -

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C ONE DIMENSIONAL TRANSIENT HEAT TRANSFER ANALYSIS INCLUDING THE
C EFFECTS OF VARIABLE THERMAL CONDUCTIVITY.
COMMON NE(10),CON(4,10),T(2000),X(10),A(10),R(1000),
2 TIMEI(200),TIMBO(100),COEFI(200),COEFO(100),
3 TAMBI(200),TAMBO(100),ZETA(10),TE(200),ACH(200),CP(10),
4 IBUF(1000),XARRAY(300),YARRAY(300),H(200),V(200),
5 TIN(2000),TAMBY(200),TEA(200),TAMBO(100),
6 N,KN,NFIN,IO,END,DEL,TIME,QI,QO,Q,TAMB,TNEXT,COHT,
7 P,CM,NAERO,NTRY,NTRA,D,KONE,PZERO,HZERO,TZERO
CALL PLOTS (IBUF,1000,6)
CALL PLOT (0.5,0.5,-3)
KLP = 0
8 READ(5,9) NUMBER
9 FORMAT(I1)
11 WRITE(6,12)
12 FORMAT(1H1,31HCNE DIM. HEAT TRANSFER ANALYSIS)
13 READ(5,15)
15 FORMAT(60H0 A DESCRIPTION OF THE CASE GOES ON 4 CARDS.
1 /60H BEGIN WRITING IN COLUMN 2
2 /60H
3 /60H
4 )
WRITE(6,15)
WRITE(6,16)
16 FORMAT(1H0,52HUNITS FOR THE INPUT VARIABLES ARE AS FOLLOWS...
1/1X,59HDIMENSIONLESS= (KN,NFIN,JIN,JOUT,NTRY,NTRA,
1/1X,59H NCASE,IFIN,NAERO,IZ,KONE,NE,ACH,CM,P)
1/1X,59HS=(DEL,TIMEZ,SEC,TIMEI,TIMEO)
1/1X,59HDEGREES F= (TZERO,T,T(1),T(N),TAMBI,TAMBO,TE,T(NFIN),TSMPL)
1/1X,59HFT= (H,HZERO,X)
1/1X,59HFT**2.0= A
1/1X,59HFT/S= V
1/1X,59HBTU= (QTOI,QTOO)
1/1X,59HBTU/S= (QIN,QOUT)
1/1X,59HBTU/F**2.0= CP
1/1X,59HBTU/S**2.0= COND
1/1X,59HBTU/S**2.0= COEFI WHEN NAERO IS 0 OR SMALLER
1/1X,59HBTU**P/S**2.0= COEFO WHEN NAERO IS GREATER THAN 0
1/1X,59HWHEN A COEF TABLE IS INSERTED TAMBI,TAMBO,TE ARE DEGREES R)
C INPUT STATEMENTS
C LIMITING AND IDENTIFYING CONSTANTS
20 READ(5,21) KN,NFIN,JIN,JOUT,NTRY,NTRA,NCASE,IFIN,NAERO,IZ
21 FORMAT(10I7)
NTRY = NTRY
22 FORMAT(6E12.6)
23 READ (5,21) KCNE
25 READ(5,26) (NE(K),K=1,KN)
26 FORMAT(11I7)
C HEAT, TIME, AND ATMOSPHERE VALUES
27 READ(5,22) CEL,TIMEZ,QTOO,QTOI,SEC
28 READ (5,22) D,TZERO,PZERO,HZERO
IF(NCASE)29,29,30
29 READ(5,22)TSMPL
30 TZEROW = TZERC
TZERO = TZERC +460.0

```

DECK1 - EFN SOURCE STATEMENT - IFN(S) -

```

C INITIALIZE TEMPERATURES
35 IF(INCASE)36,36,40
36 DO 37 N=1,NFIN
   T(N) = TSMPL + 460.0
37 CCNTINUE
   GO TO 45
40 READ(5,22)(T(N),N=1,NFIN)
   DO 42 N=1,NFIN
     TIN(N) = T(N)
     T(N) = TIN(N) + 460.0
42 CONTINUE
C THERMAL CONDUCTIVITIES
45 DO 50 K=1,KK
   READ(5,22)(CCN(J,K),J=1,3)
50 CONTINUE
C NODE SIZES AND SPECIFIC HEAT X DENSITY (CP)
55 DO 59 K=1,KK
   READ(5,56)X(K),A(K),CP(K)
56 FORMAT(3E12.6)
57 ZETA(K)=DEL/(CP(K)*A(K)*X(K))
59 CCNTINUE
C BOUNDARY CCNDITICNS
   IF(JIN)60,61,70
60 READ(5,22)T(1)
   T1 = T(1)
   T(1) = T(1) + 460.0
   GO TO 72
C STAGNATION POINT HTSTAR CALCULATIONS FOR THE TROPOPAUSE
61 IF (KCNE) 65,65,62
62 READ (5,56)(TIMEI(J),H(J),V(J),J=1,KONE)
   DO 64 N=1,KCNE
     CALL HTSTAR
64 CCNTINUE
   GO TO 69
65 IF(NAERC)66,66,67
66 READ(5,56)(TIMEI(J),COEFI(J),TAMBI(J),J=1,NTRY)
   GO TO 72
67 READ(5,68)(TIMEI(J),COEFI(J),TAMBI(J),TE(J),ACH(J),J=1,NTRY)
68 FORMAT(5E12.6)
69 READ(5,22)CP,P
   GO TO 72
70 READ(5,22)QIN
72 DO 74 J=1,NTRY
   TAPBY(J) = TAMBI(J)
   IF(NAERC)74,74,73
73 TEA(J) = TE(J)
74 CCNTINUE
   IF(JOUT)75,80,85
75 READ(5,22)T(NFIN)
   TNFIN = T(NFIN)
   T(NFIN) = TNFIN + 460.0
   GO TO 90
80 READ(5,56)(TIMEO(J),COEFO(J),TAMBO(J),J=1,NTRA)
   DO 81 J=1,NTRA
     TAPBO(J) = TAMBO(J)
     TAMBO(J) = TAPBO(J) + 460.0

```

DECK1 - EFN SOURCE STATEMENT - IFN(S) -

```

81 CONTINUE
GO TO 90
85 READ(5,22)QCUT
90 QTCTO=QTOO
QTCTI=QTOI
TIME=TIMEZ
SELL=TIME-.1*CEL
TAI = 0.0
TAC = 0.0
TAIN = 0.0
TACUT = 0.0
CI = 0.0
CO = 0.0
IO=1
C PRINT OF DATA CARDS
490 WRITE(6,491)
491 FORMAT(///1X,41HDATA USED IN THE PROGRAM ARE SHOWN BELOW.)
500 WRITE(6,501)
501 FORMAT(1H0,5X,2HKN,3X,4HNFIN,4X,3HJIN,3X,4HJOUT,3X,4HNTRY,3X,4HNTR
1A,2X,5HNCASE,3X,4HIFIN,2X,5HNAERO,5X,2HIZ)
505 WRITE (6,506)KN,NFIN,JIN,JOUT,NTRY,NTRA,NCASE,IFIN,NAERO,IZ
506 FORMAT(10I7)
507 WRITE(6,508)
508 FORMAT(1H0,3X,4HK(NE)
WRITE(6,509)KCNE
509 FORMAT(I7)
510 WRITE(6,511)
511 FORMAT(1H0,2X,5HNE(K))
515 WRITE(6,516)(NE(K),K=1,KN)
516 FORMAT(11I7)
520 WRITE(6,521)
521 FORMAT(1H0,9X,3HDEL,7X,5HTIMEZ,8X,4HQTOO,8X,4HQTOI,9X,3
1HSEC)
524 WRITE(6,525)DEL,TIMEZ,QTOO,QTOI,SEC
525 FORMAT(F12.3,4F12.2)
526 WRITE(6,527)
527 FORMAT(1H0,11X,1H0,7X,5HTZERO,7X,5HPZERO,7X,5HMZERO)
528 WRITE(6,529)D,TZEROW,PZERO,HZERO
529 FORMAT(F12.3,3F12.2)
530 IF(NCASE)550,550,531
531 WRITE(6,532)
532 FORMAT(1H0,8X,4HT(N))
533 WRITE(6,534)(TIN(N),N=1,NFIN)
534 FORMAT(6F12.2)
550 WRITE(6,551)
551 FORMAT(1H0,6X,5HTSMPL)
WRITE(6,589)TSMP
WRITE(6,552)
552 FORMAT(1H0,4X,8HCON(J,K))
553 WRITE(6,554)((CON(J,K),J=1,31,K=1,KN)
554 FORMAT(3F12.6)
580 WRITE(6,581)
581 FORMAT(1H0,8X,4HX(K),8X,4HA(K),7X,5HCP(K))
582 WRITE(6,583)(X(K),A(K),CP(K),K=1,KN)
583 FORMAT(2F12.6,F12.2)
585 IF(JIN)586,591,671

```

DECK1 - EFN SOURCE STATEMENT - IFN(S) -

```

586 WRITE(6,587)
587 FORMAT(1H0,27HAPPLIED SURFACE TEMPERATURE)
588 WRITE(6,589)T1
589 FORMAT(F12.1)
590 GO TO 680
591 IF(KONE)595,595,625
595 IF(NAERO)596,596,620
596 WRITE(6,597)
597 FORMAT(1H0,4X,8HTIMEI(J),4X,8HCOEFI(J),4X,8HTAMBI(J))
598 WRITE(6,599)(TIMEI(J),COEFI(J),TAMBY(J),J=1,NTRY)
599 FORMAT(F12.2,F12.4,F12.2)
600 GO TO 680
620 WRITE(6,621)
621 FORMAT(1H0,4X,8HTIMEI(J),4X,8HCOEFI(J),4X,8HTAMBI(J),7X,5HTE(J),6X
1,6HACH(J))
622 WRITE(6,623)(TIMEI(J),COEFI(J),TAMBY(J),TEA(J),ACH(J),J=1,NTRY)
623 FORMAT(F12.2,F12.4,3F12.2)
625 IF (KONE)650,650,626
626 WRITE(6,627)
627 FORMAT(1H0,5X,7HTIME(J),8X,4HH(J),8X,4HV(J))
628 WRITE(6,629)(TIMEI(J),H(J),V(J),J=1,KONE)
629 FORMAT(3F12.2)
650 WRITE(6,651)
651 FORMAT(1H0,10X,2HCM,11X,1HP)
652 WRITE(6,653)CP,P
653 FORMAT(2F12.3)
654 GO TO 680
671 WRITE(6,672)
672 FORMAT(1H0,9X,3HQIN)
673 WRITE(6,589)CIN
680 IF(JOUT)681,690,698
681 WRITE(6,682)
682 FORMAT(1H0,5X,7HT(NFIN))
683 WRITE(6,589)TNFIN
684 GO TO 750
690 WRITE(6,691)
691 FORMAT(1H0,4X,8HTIMEO(J),4X,8HCOEFO(J),4X,8HTAMBO(J))
692 WRITE(6,693)(TIMEO(J),COEFO(J),TAMBO(J),J=1,NTRA)
693 FORMAT(F12.2,F12.4,F12.2)
694 GO TO 750
698 WRITE(6,699)
699 FORMAT(1H0,8X,4HQOUT)
700 WRITE(6,589)CCUT
750 WRITE(6,751)
751 FORMAT(1H0,45HCALCULATIONS FROM THE PROGRAM ARE SHOWN BELOW)
KJA=0
100 DO 400 I=1,IFIN
FACT=I
DO 105 N=1,NFIN
CALL PROP
105 CONTINUE
TIME=TIME+DEL
C TEMPERATURE CALCULATIONS
C NODE 1 CALCULATIONS
N=1
QC=1.

```

DECK1 - EFN SOURCE STATEMENT - IFN(S) -

```

    IF(JIN)200,120,150
120 ENC=-1.
125 CALL INT
    Q=COHT *(TAMB -T(1))*A(1)
    QI=0.
    QIA=Q
    CI=COHT
    TAI=TAMB
    TAIN = TAI - 460.0
130 CALL TEMP
    CONTINUE
    GO TO 160
150 Q=QIN
    QI=0.
155 CALL TEMP
160 T(1)=TNEXT
C NODE (2) THROUGH (NFIN-1)CALCULATIONS
200 Q=0.
    QI=1.
    QO=1.
    NFINM=NFIN-1
    DO 205 N=2,NFINM
    CALL TEMP
    T(N)=TNEXT
205 CONTINUE
C NODE NFIN CALCULATIONS
    N=NFIN
    QI=1.
    IF(JOUT)285,220,250
220 ENC=+1.
221 CALL INT
    Q=COHT*(TAMB-T(NFIN))*A(KN)
    QO=0.
    CO=COHT
    TAC=TAMB
    TACUT = TAO - 460.0
230 CALL TEMP
    QOLT=Q
    CONTINUE
    GO TO 260
250 Q=QOUT
    QO=0.
255 CALL TEMP
260 T(NFIN)=TNEXT
    DO 270 N=1,NFIN
    TIN(N) = T(N) - 460.0
270 CONTINUE
C HEAT CALCULATIONS
285 IF(JIN)290,300,300
290 QIA=(T(1)-T(2))/((R(1)+R(2))/2.)
300 IF(JOUT)301,305,305
301 NM=NFIN-1
    QOLT=(T(NM)-T(NFIN))/((R(NFIN)+R(NM))/2.)
305 DQ=QIN*DEL
    QTCTI=QTOTI+DQ
    DQ=QOUT*DEL

```

DECK1 - EFN SOURCE STATEMENT - IFN(S) -

```

      QTCTO=QTOTO+CC
C  DATA PRINT OUT
      IF(I-IZ)315,315,310
310  IF(SEC+SELL-TIME)315,315,380
315  WRITE(6, 316)
316  FORMAT(1H0,3X,4HTIME,9X,9HAMB.TEMP.,6X,19HHEAT TRANSFER COEF.,1X,1
      18HHEAT TRANSFER RATE,6X,10HTOTAL HEAT)
317  WRITE(6,318)
318  FORMAT(1H0,8H (SEC.),5X,5HINLET,4X,6HOUTLET,5X,5HINLET,4X,6HCUTLE
      1T5X,5HINPUT,4X,6HOUTPUT,5X,5HINPUT,4X,6HOUTPUT)
319  WRITE(6,320)TIME,TAIN,TAOUT,CI,CO,QIN,QOUI,QTOTI,QTOTO
      KJA=KJA+1
      XARRAY(KJA) = TIME
      YARRAY(KJA) = T(1)- 460.0
320  FORMAT(12E10.3)
321  WRITE(6,322)
322  FORMAT(1H0,12H NODE TEMP.,3X,11HNODE TEMP.,3X,11HNODE TEMP.,3X,
      11HNODE TEMP.,3X,11HNODE TEMP.,3X,11HNODE TEMP.,3X,
      2.,3X,11HNODE TEMP.)
323  WRITE(6,324)(N,TIN(N),N=1,NFIN)
324  FORMAT(8(I5,F9.3))
      SELL=TIME-.1*CEL
380  CONTINUE
400  CONTINUE
C  CALCOMP PLOTTING OF NODE 1 TEMPERATURE VS FLIGHT TIME.
      ICJ = KJA + 1
      ICK = KJA + 2
      CALL SCALE(XARRAY,6.0,KJA,1)
      CALL SCALE(YARRAY,9.0,KJA,1)
      CALL AXIS(0.0,0.0,15HTIME IN SECONDS,-15,6.0,0.0,XARRAY(ICJ),
      XARRAY(ICK))
      CALL AXIS(0.0,0.0,25HTEMPERATURE IN FAHRENHEIT,25,9.0,90.0,YARRA
      2Y(ICJ),YARRAY(ICK))
      CALL LINE(XARRAY,YARRAY,KJA,1,0,0)
      CALL SYMBOL (1.0,8.5,0.21,20HSURFACE TEMPERATURES,0.0,20)
      CALL PLCT(8.0,0.0,-3)
      KLM = KLM + 1
      IF(NUMBER - KLM)401,401,8
401  CALL PLCT (12.0,0.0,999)
      STCP
      ENC

```

DECK2 - EFN SOURCE STATEMENT - IFN(S) -

```
SUBROUTINE PRCP
C PROPERTY CALCULATIONS SUBROUTINE
COMMON NE(10),CON(4,10),T(2000),X(10),A(10),R(1000),
2 TIMEI(200),TIMEO(100),COEFI(200),COEFO(100),
3 TAMBI(200),TAMBO(100),ZETA(10),TE(200),ACH(200),CP(10),
4 IBUF(1000),XARRAY(300),YARRAY(300),H(200),V(200),
5 TIN(2000),TAMBY(200),TEA(200),TAMBOW(100),
6 N,KN,NFIN,IO,END,DEL,TIME,QI,QO,Q,TAMB,TNEXT,COHT,
7 P,CM,NAERO,NTRY,NTRA,D,KONE,PZERO,HZERO,TZERO
10 DO 15 K=1,KN
    IF(NE(K)-N)15,20,20
15 CONTINUE
20 CCND=CON(1,K)+CON(2,K)/T(N)+CON(3,K)*T(N)
25 R(N)=X(K)/(CCND*A(K))
45 RETURN
ENC
```

```

SUBROUTINE INT
C INTERPLATING PCLYNMIAL SUBROUTINE (USING AIKENS METHOD)
COMMON NE(10),CON(4,10),T(2000),X(10),A(10),R(1000),
2 TIMEI(200),TIMSO(100),COEFI(200),COEFO(100),
3 TAMBI(200),TAMBO(100),ZETA(10),TE(200),ACH(200),CP(10),
4 IBUF(1000),XARRAY(300),YARRAY(300),H(200),V(200),
5 TIN(2000),TAMBY(200),TEA(200),TAMBO(100),
6 N,KN,NFIN,IO,END,DEL,TIME,QI,QO,Q,TAMB,TNEXT,COMT,
7 P,CM,NAERO,NTRY,NTRA,D,KONE,PZERO,HZERO,TZERO
DIMENSION Y(4),YF(4),YI(4,4)
I=10
IM=0
IP=L
L=NTRY
9 IF(ENC)10,10,7
7 L=NTRA
GO TO 11
10 IF(TIME-TIMEI(I))12,20,30
11 IF(TIME-TIMEC(I))12,20,30
12 IP=I
IF(IP-IM-2)60,13,13
13 I=I-1
GO TO 9
20 IF(END)21,21,22
21 COMT=COEFI(I)
TAMB=TAMBI(I)
IF(NAERO)210,210,211
211 TEE=TE(I)
ACTE=ACH(I)
GO TO 300
22 COMT=COEFO(I)
TAMB=TAMBO(I)
GO TO 210
30 IM=I
IF(IP-IM-2)60,32,32
32 I=I+1
GO TO 10
60 IF(IM-2)61,61,65
61 K=1
GO TO 72
65 IF(IP+1-L)70,66,66
66 K = L-3
GO TO 72
70 K=IM-1
72 K1=K+1
K2=K+2
K3=K+3
IF(END)73,73,100
73 X1=TIMEI(K)
X2=TIMEI(K1)
X3=TIMEI(K2)
X4=TIMEI(K3)
IO=IM
80 IF(NAERO)81,81,82
81 MC=2

```

DECK3 - EFN SOURCE STATEMENT - IFN(S) -

```

GO TO 85
82 MC=4
85 DO 90 J=K,K3
    I=J-K+1
    YI(1,I)=COEFI(J)
    YI(2,I)=TAMBI(J)
    IF(NAERO)90,90,87
87 YI(3,I)=TE(J)
    YI(4,I)=ACH(J)
90 CONTINUE
    GO TO 200
100 X1=TIMEO(K)
    X2=TIMEO(K1)
    X3=TIMEO(K2)
    X4=TIMEO(K3)
    IO=IM
101 MC=2
    DO 110 J=K,K3
        I=J-K+1
        YI(1,I)=COEFC(J)
        YI(2,I)=TAMBO(J)
110 CONTINUE
200 Z=TIME
    DO 215 M=1,MC
        DO 205 J=1,4
            Y(J)=YI(M,J)
205 CONTINUE
    Z1=(Y(1)*(X2-Z)-Y(2)*(X1-Z))/(X2-X1)
    Z2=(Y(1)*(X3-Z)-Y(3)*(X1-Z))/(X3-X1)
    Z3=(Y(1)*(X4-Z)-Y(4)*(X1-Z))/(X4-X1)
    Z4=(Z1*(X3-Z)-Z2*(X2-Z))/(X3-X2)
    Z5=(Z1*(X4-Z)-Z3*(X2-Z))/(X4-X2)
    F=(Z4*(X4-Z)-Z5*(X3-Z))/(X4-X3)
    YF(M)=F
215 CONTINUE
220 COHT=YF(1)
    TAPB=YF(2)
    IF(MC-2)210,210,225
225 TEE=YF(3)
    ACHE=YF(4)
300 TSTAR=0.5*(T(1)+TEE)+CM*TEE*ACHE*ACHE
    COHT=COHT/(TSTAR**P)
210 RETURN
    ENC

```

DECK4 - EFN SOURCE STATEMENT - IFN(S) -

```

SUBROUTINE TEMP
C TEMPERATURE SUBRCUTINE
COMMON NE(10),CON(4,10),T(2000),X(10),A(10),R(1000),
2 TIMEI(200),TIMEO(100),COEFI(200),COEFO(100),
3 TAMBI(200),TAMBO(100),ZETA(10),TE(200),ACH(200),CP(10),
4 IBUF(1000),XARRAY(300),YARRAY(300),H(200),V(200),
5 TIN(2000),TAMBY(200),TEA(200),TAMBOW(100),
6 N,KN,NFIN,IO,END,DEL,TIME,QI,QO,Q,TAMB,TNEXT,COHT,
7 P,CM,NAERO,NTRY,NTRA,D,KONE,PZERO,HZERO,TZERO
10 NM=N-1
NP=N+1
Z=1.
DO 11 K=1,KN
IF(NE(K)-N)11,12,12
11 CONTINUE
12 IF(N-1)13,13,15
13 Z=.5
RM=0.
NM=1
GO TO 19
15 RM=2./(R(NM)+R(N))*QI
IF(N-NFIN)19,16,16
16 Z=.5
RP=0.
NP=NFIN
GO TO 20
19 RP=2./(R(NP)+R(N))*QO
20 C1= Z/ZETA(K)-RM-RP
C3=RP
C4=RM
25 TNEXT=ZETA(K)*(T(N)*C1+T(NP)*C3+T(NM)*C4+Q)/Z
RETURN
ENC

```

DECK5 - EFN SOURCE STATEMENT - IFN(S) -

```

SUBROUTINE HTSTAR
C HTSTAR CALCULATIONS FOR STAGNATION POINTS BELOW THE TROPOPAUSE
C CALCULATIONS ARE NOT ACCURATE BELOW UNITY MACH NUMBERS
COMMON NE(10),CON(4,10),T(2000),X(10),A(10),R(1000),
2 TIMEI(200),TIMEO(100),COEFI(200),COEFO(100),
3 TAMBI(200),TAMBO(100),ZETA(10),TE(200),ACH(200),CP(10),
4 IBUF(1000),XARRAY(300),YARRAY(300),H(200),V(200),
5 TIN(2000),TAMBY(200),TEA(200),TAMBO(100),
6 N,KN,NFIN,IO,END,DEL,TIME,QI,QO,Q,TAMB,TNEXT,COHT,
7 P,CM,NAER(),NTRY,NTRA,D,KCNE,PZERO,HZERO,TZERO
C AMBIENT AIR CONDITIONS
TAIR = TZERC - 0.003566*H(N)
PAIR = PZERC*(TAIR/TZERO)**5.256
C = SQRT(2403.1*TAIR)
ACH(N) = V(N)/C
C STAGNANT AIR CONDITIONS
TAMBI(N) = TAIR*(1.0 + 0.2*ACH(N)**2.0)
IF(ACH(N)-1.0)10,10,5
5 TTT = ((7.0 * ACH(N)**2.0)-1.0)
PAMBI = PAIR*((1.2*ACH(N)**2.0)**3.5)*(6.0/TTT)**2.5
GO TO 20
10 PAMBI = PAIR*(1.0 + 0.2*ACH(N)**2.0)**3.5
20 BETA = (0.6/C)*SQRT(2403.1*TAMBI(N))
COEFI(N) = 0.0000073*SQRT(PAMBI*BETA)
NTRY = N
TE(N) = TAMBI(N)
40 RETURN
ENC

```

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APPENDIX B. DATA DECK PREPARATION

Preparing data for the transient heat transfer program requires consideration of the 45 distinct variables summarized in figure B-1. Not all of these are actually used, nor do they all have the same format. Some variables are I7, while others are in E12.6 format. However, F12.6 may be used where desired in place of E12.6.

The variables that are used in the program depend upon the type of boundary conditions being considered. In the following sample problem, aerodynamic heating on the blunt tip of the SIF (Short Intrusion Fuze) during the flight of a 175-mm projectile is of interest. The information that must be made available for this data deck are: diameter of the blunt tip, initial temperature of the material, the atmospheric temperature and pressure at the launch site, elevation of the launch site above sea level, thermal conductivity, specific heat and specific weight of the nose cone material, and ballistics data; that is, flight time, velocity, and altitude above launch site.

The manner in which each of the 45 variables is considered in preparation of the data deck for the SIF flight is shown in the following pages. The first card to be used is NUMBER.

NUMBER: This card describes the number of different data decks that are to be attached to the program deck at the same time. Values of integers from 1 to 9 may be written in the first column. Numeral 1 is used for this program.

The next four cards are used to describe the case under study; blank cards must be inserted if fewer than four cards are used. Positions 1 through 60 may be used. For uniformity in appearance of data printout, begin writing in column 2.

The sixth card presents values for the variables KN, NFIN, JIN, JOUT, NTRY, NTRA, NCASE, IFIN, NAERO, IZ. An I7 format justified right is used.

KN: The number of sections is the number of independent plates being heated. The possibility of 11 plates has been programmed, but the blunt tip of the SIF nose cone is imagined to be composed of two plates as shown below. One plate is the nose cone material, and the other is the foam potting. For simplicity, the widths and areas of the two sections are made equal.

NBS CODING FORM

FORTRAN C STATEMENT NUMBER	TITLE	TASK NUMBER	PROGRAMMER	DATE	SHEET 1 OF 1
C	FAP OP				
1	LOCATION				
2	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80				
3	4	5	6	7	8
9	10	11	12	13	14
15	16	17	18	19	20
21	22	23	24	25	26
27	28	29	30	31	32
33	34	35	36	37	38
39	40	41	42	43	44
45	46	47	48	49	50
51	52	53	54	55	56
57	58	59	60	61	62
63	64	65	66	67	68
69	70	71	72	73	74
75	76	77	78	79	80

SECTION	KIN	NFIN	JIN	JOUT	NTRY	NTRA	NCASE	IFTI	NAERO	I7
SECTIONS	4	2	2	2	2	2	2	2	2	2
ENTRIES IN										
PARAMETERS										
NE										

DEL	TIMEZ	QTOO	QTOI	SEC
SIZE OF THE MESH - MEANS TO BE IN THE CALCULATIONS, SEC.	TIME AT THE START OF TRANSIENT HEATING, SEC.	AMOUNT OF HEAT REJECTED AT OUTLET AT TIMES, DIM.	AMOUNT OF HEAT RECEIVED AT INLET AT TIMES, DIM.	SIZE OF PERIOD-TO- PERIOD INCREMENTS AFTER TIME INCREMENTS AFTER TIME INCREMENTS, SEC.
DIAMETER IN THE MESH CODE YTD, OF	SYMMETRIC TEMP. AT THE END OF THE MESH, DIM.	TEMPERATURE AT THE END OF THE MESH, DIM.	TEMPERATURE AT THE END OF THE MESH, DIM.	PERIOD OF THE MESH, SEC.

NOT REPRODUCIBLE

NBS CODING FORM

FORTRAN C STATEMENT NUMBER		TITLE		TASK NUMBER	PROGRAMMER	DATE	SHEET 5 OF 5
1	1	1	1	1	1	1	1
2	2	2	2	2	2	2	2
3	3	3	3	3	3	3	3
4	4	4	4	4	4	4	4
5	5	5	5	5	5	5	5
6	6	6	6	6	6	6	6
7	7	7	7	7	7	7	7
8	8	8	8	8	8	8	8
9	9	9	9	9	9	9	9
10	10	10	10	10	10	10	10
11	11	11	11	11	11	11	11
12	12	12	12	12	12	12	12
13	13	13	13	13	13	13	13
14	14	14	14	14	14	14	14
15	15	15	15	15	15	15	15
16	16	16	16	16	16	16	16
17	17	17	17	17	17	17	17
18	18	18	18	18	18	18	18
19	19	19	19	19	19	19	19
20	20	20	20	20	20	20	20
21	21	21	21	21	21	21	21
22	22	22	22	22	22	22	22
23	23	23	23	23	23	23	23
24	24	24	24	24	24	24	24
25	25	25	25	25	25	25	25
26	26	26	26	26	26	26	26
27	27	27	27	27	27	27	27
28	28	28	28	28	28	28	28
29	29	29	29	29	29	29	29
30	30	30	30	30	30	30	30
31	31	31	31	31	31	31	31
32	32	32	32	32	32	32	32
33	33	33	33	33	33	33	33
34	34	34	34	34	34	34	34
35	35	35	35	35	35	35	35
36	36	36	36	36	36	36	36
37	37	37	37	37	37	37	37
38	38	38	38	38	38	38	38
39	39	39	39	39	39	39	39
40	40	40	40	40	40	40	40

E12.4 Format. Omit card if NCASE > 0

CONC(2,3) CONC(3,3)
 THERM: CONDUCTIVITY A=CON+CONHT+CON3T
 E12.6 Format. One card for each of the ALL sections.
 T(1) T(N)

NOT REPRODUCIBLE

E12.6 Format. One card for each of the KN sections.

E12.6 Format. Omit card if JIN > 0.

E12.6 Format. Ballistics table is to contain KONE cards,
 one card for each time entry. Omit table if KONE = 0

NBS CODING FORM

FORTRAN C STATEMENT NUMBER	TITLE	TASK NUMBER	PROGRAMMER	DATE	SHEET
1	TIME, SEC.				IDENTIFICATION 2 OF 3
2	TIME, SEC.				
3	TIME, SEC.				
4	TIME, SEC.				
5	TIME, SEC.				
6	TIME, SEC.				
7	TIME, SEC.				
8	TIME, SEC.				
9	TIME, SEC.				
10	TIME, SEC.				
11	TIME, SEC.				
12	TIME, SEC.				
13	TIME, SEC.				
14	TIME, SEC.				
15	TIME, SEC.				
16	TIME, SEC.				
17	TIME, SEC.				
18	TIME, SEC.				
19	TIME, SEC.				
20	TIME, SEC.				
21	TIME, SEC.				
22	TIME, SEC.				
23	TIME, SEC.				
24	TIME, SEC.				
25	TIME, SEC.				
26	TIME, SEC.				
27	TIME, SEC.				
28	TIME, SEC.				
29	TIME, SEC.				
30	TIME, SEC.				

- E12.6 Format. Omit card if NAERO > 0 LIST
 MEANS TABLE. ONE CARD FOR EACH TIME ENTRY. TOTAL CARD IS ENTRY COUNT. IF KONE > 0 OR JIITC.

NOT REPRODUCIBLE

ACH

IF NAERO > 0 LIST
 IF NAERO > 0 LIST
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TE

IF NAERO > 0 LIST
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 IF NAERO > 0 LIST

TA:BI

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COEPI

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QIN

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QIN

IF NAERO > 0 LIST
 IF NAERO > 0 LIST
 IF NAERO > 0 LIST

- E12.6 Format. Omit card if NAERO > 0 LIST
 Omit table if JOINT = 0

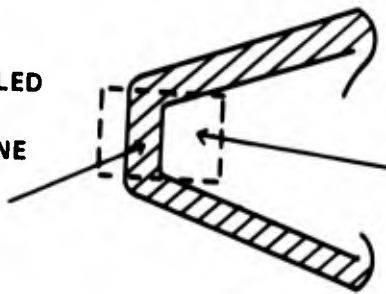
- E12.6 Format. Omit card if NAERO > 0 LIST
 Omit table if JOINT = 0

- E12.6 Format. Omit card if NAERO > 0 LIST
 Omit table if JOINT = 0

- E12.6 Format. Omit card if NAERO > 0 LIST
 Omit table if JOINT = 0

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30

SECTION #1
20% GLASS FILLED
MODIFIED
POLYPHENYLENE
OXIDE NOSE
CONE



SECTION #2
24 LB/FT³
POLYURETHANE
FOAM POTTING

- NFIN: Arbitrarily selected for this system are 16 nodes, 8 for each section. NFIN = 16.
- JIN: Aerodynamic heating is the inlet boundary condition on the left plate, so JIN = 0 is used.
- JOUT: Since polyurethane foam potting used inside the SIF is a good insulator, the boundary condition for the plate on the right side is taken to be a perfect insulator. This is expressed in the program as constant heat flux of zero magnitude. Thus, JOUT = 1 is used.
- NTRY: Since stagnation-point heating on a blunt tip nose cone flying below the tropopause is being considered, a table of heat transfer coefficient variation with time need not be included. The calculation is done by a subroutine in the program using ballistic data. NTRY = 0.
- NTRA: The boundary condition on the right plate was constant heat flux, so there are 0 entries for the convection table at this boundary. NTRA = 0.
- NCASE: This variable prepares the computer for the possibility that there is an initial temperature distribution within the nose cone at the instant of launch. For this problem, a uniform temperature is assumed; hence, zero or any negative integer may be used. NCASE = 0.
- IFIN: No convection table is to be included in the data deck, but a ballistic table will be. When the total time span of this table is divided by the size of the time increments to be used by the program in making temperature calculations, the number of time increments to be studied is defined. As will be shown later,

the time span of the ballistic table is 24 sec and the time increments are 0.02 sec. IFIN = 1200.

Note that had time not begun at zero, as is the case with rocket sled calculations, then

$$\text{IFIN} = (\text{Time}_{\text{final}} - \text{Time}_{\text{initial}}) / \text{Time increment.}$$

NAERO: This variable prepares the computer for the type of convective heating that is to be encountered. For the SIF, aerodynamic heating is of interest; hence, zero or any positive integer may be used. NAERO = 0.

IZ: In order to observe temperature variations closely at the beginning of the transient heating, the program provides for two types of data printout. The first set is a number (IZ) of printouts at the short time intervals (DEL) selected for the program temperature calculations. The manner in which DEL is initially selected is discussed later. After IZ printouts are accomplished, larger size time increments are used in all remaining printouts. The size of the larger increments is specified by the variable SEC, as will be shown later. For the SIF program, 75 is usually specified for IZ to assure that a smooth graph will be obtained in the vicinity of the maximum surface temperature. For the sake of saving space in this report, IZ = 3 is used.

Sometimes, as in the case of the rocket-sled calculations, it is desired to have the last printout in the data output to occur at a particular instant of time; that is, at the last time listed in the ballistics table or the heat transfer coefficient table. In such an instance, the values selected for IZ, DEL, and SEC are interrelated by

$$\text{Total Time} = \text{IZ}(\text{DEL}) + \text{M}(\text{SEC}).$$

All values in this equation are known but M, and the only requirement for selecting values of IZ, DEL, and SEC when the Total Time is given is that M be an integer, since the computer cannot have a fractional number of SEC size printouts.

The seventh card in the data deck is KONE; the format is I7 justified right.

KONE: Ballistics tables for the 175-mm projectile usually list flight data in 1-second increments. This means that for a time span of 24 sec beginning at zero time, there will be 25 entries. KONE = 25.

Card number 8 is NE. The format is I7 justified right.

NE: The last node in each section must be listed so that the computer can assign the proper material properties in the temperature calculations. Eleven possible listings can be made, but for the SIF only two are required (8, 16).

Either F12.6 or E12.6 format must be used in all remaining cards. The choice is one of convenience and familiarity. Justification is always to the right. Card number 9 requires values for DEL, TIMEZ, QTOO, QTOI, SEC.

DEL: The boundary condition of interest for the SIF calculation is one of aerodynamic heating; hence, the stability criterion is

$$\Delta\theta \leq (CYX^2/2k) \left(\frac{1}{1 + hX/k} \right),$$

where for 20-percent glass-filled modified polyphenylene oxide SIF nose cones at room temperature

$$C = 0.28 \text{ btu/lb-}^\circ\text{F},$$

$$Y = 75.5 \text{ lb/ft}^3,$$

$$k = 26 \times 10^{-6} \text{ btu/s-ft-}^\circ\text{F};$$

and

$$X = \text{plate thickness}/(\#\text{NODES} - 0.5 \text{ NODES}) = \\ 0.125/(8-0.5)12 = 0.001388 \text{ ft},$$

$h = (1/2) \text{ Btu/sec-ft}^2\text{-}^\circ\text{F}$ is assumed as an exaggerated value for the sake of this calculation.

Substituting shows $\theta < 0.03 \text{ sec}$; hence, to improve accuracy a smaller value is selected; that is, DEL = 0.02.

TIMEZ: The time at the start of the transient heating is 0. TIMEZ = 0.0 (note that the decimal must be included in all remaining data).

- QTOO: No heat is assumed to have been withdrawn from the SIF prior to launch; hence, QTOO = 0.0.
- QTOI: No heat is assumed to have been added to the SIF prior to launch, QTOI = 0.0.
- SEC: The size of the printouts after the first IZ prints is usually set at 1 sec, but 0.6 sec was used for this text so that a printout would be obtained for 0.66 sec, which is known from more detailed printouts to be the time of maximum surface temperature.

Card 10 requires values for D, TZERO, PZERO, HZERO.

- D: The diameter of the nose cone tip is 0.5 in./12 = 0.042 ft; D = 0.042.
- TZERO: The atmospheric conditions at the launch site are taken to be those listed in STANDARD ATMOSPHERE tables. For sea-level temperature this is 57°F; TZERO = 57.0.
- PZERO: The standard atmospheric pressure at sea level is 2116 lb/ft²; PZERO = 2116.0.
- HZERO: The launch site is 0 ft above sea level; HZERO = 0.0.

Note that only flights below the tropopause may be considered when values on this card are specified.

The eleventh card to be used is TSMPL.

- TSMPL: The variable NCASE was set equal to 0 to show that there was no initial temperature distribution in the nose cone before launch. The value of the uniform temperature of the material is then taken to be 57°F; TSMPL = 57.0.

The card that describes the initial temperature gradient within the nose cone is omitted. If it were included, only 11 nodes within the system must be used to describe the gradient.

Cards 12 and 13 describe the manner in which thermal conductivity varies with temperature. A separate card is provided for each section (plate) in the system. The variables are COND (1,J), COND (2,J), COND (3,J) where J is an integer depicting the section being considered. For the SIF, J may

have 1,2 as values. The first listing describes the first plate (that is, the nose cone), and the second listing describes the foam potting. The relationship of the three COND variables to thermal conductivity and temperature is

$$k = \text{COND } (1,J) + \text{COND } (2,J)/T + \text{COND } (3,J)T.$$

No variation with temperature is included in the SIF calculation, so the data inserted for GFN-2 and 24 lb/ft³ polyurethane foam are:

$$\begin{aligned} \text{COND } (1,1) &= 26 \times 10^{-6} & \text{COND } (2,1) &= 0.0 & \text{COND } (3,1) &= 0.0, \\ \text{COND } (1,2) &= 8.6 \times 10^{-6} & \text{COND } (2,2) &= 0.0 & \text{COND } (3,2) &= 0.0. \end{aligned}$$

The units for conductivity are Btu/sec-ft-°F. Note that the constant which is independent of the temperature is listed first on the card, so listings for the other constants could have been omitted.

Cards 14 and 15 describe the dimensions and properties of the sections. One card is provided for each section, and the variables are X, A, CP.

X: The length of each node depends upon whether or not a boundary plate or an interior plate is being considered. For the SIF problem, two boundary plates are of interest; hence,

$$X = \frac{\text{Plate width}}{\# \text{ NODES} - 0.5 \text{ NODES}} = (0.125)/12 (8 - 0.5) = 0.001388 \text{ ft.}$$

This same value is used for both sections since they are of equal widths and nodes.

A: The areas of the two sections are also equal and are found from

$$A = \pi D^2/4 = 3.14 (0.5/12)^2/4 = 0.00136 \text{ ft}^2 .$$

CP: The product of specific heat and specific weight is different for the GFN-2 section and the 24 lb/ft³ polyurethane foam. The values are

$$CP = (0.28)(75.5) = 22.6 \text{ Btu/}^\circ\text{F-ft}^3,$$

$$CP = (0.26)(24) = 6.2,$$

respectively.

The variable JIN was set equal to zero to denote a convective boundary condition; hence, the card describing T(1), the applied surface temperature, is omitted.

Cards 16 through 40 include a tabulation of ballistics data for the 175-mm projectile fired at 3000-fps muzzle velocity and 10-deg elevation angle. These data may be seen in the printout section presented in appendix C. Since the ballistics table is provided, there is no reason to present a table of heat transfer coefficients.

Card 41 introduces values for two dimensionless aerodynamic heating constants. The variables are C_m, p .

C_m : This is a multiplication factor involved in T^* calculations shown in appendix A. For stagnation-point heating on the blunt tip of the SIF, $C_m = 0.0$.

p : This is an exponent to T^* in h calculations shown in appendix A. For stagnation-point heating on the blunt tip of the SIF, $p = 0.069$.

The card that treats QIN is omitted because the left-side boundary condition is one of convection, not radiation. The right-side boundary condition is a perfectly insulated wall; the cards for T(N FIN) and the heat-transfer coefficient table are therefore omitted.

Card 42 is QOUT.

QOUT: To describe a boundary on the right side as one of perfect insulation, the condition is stated as being constant heat flux of zero magnitude; QOUT = 0.0.

APPENDIX C. COMPUTER PRINTOUT

For each case studied the computer begins the printout at the top of a page with a statement of the program title followed by a description of the case and a listing of units of variables. Data inserted into the program are tabulated and then the computer calculations are listed.

The variables studied are listed as TIME, AMBIENT TEMPERATURE, HEAT TRANSFER COEFFICIENT, HEAT-TRANSFER RATE, and TOTAL HEAT. A line is skipped, and then the units of time are listed as SECONDS, and statements are made that the INLET and OUTLET boundary conditions are described. Values for the variables are listed on the next line in E format. A line is skipped and eight statements of NODE TEMPERATURE are listed. On the next line, the number beneath the word NODE identifies the node being discussed; the number beneath the word TEMPERATURE is the temperature in degrees Fahrenheit, F format, calculated for that node. A line is skipped and the variables studied are listed again. The numbers provided in this new section are part of the three IZ printouts called for with DEL = 0.02 size time increments. Once the three printouts are completed all remaining printouts are SEC = 0.6 time increments. The printing is continued until the time span listed in the ballistics table is completed. A graph of surface temperature variation with time is shown in figure C-1.

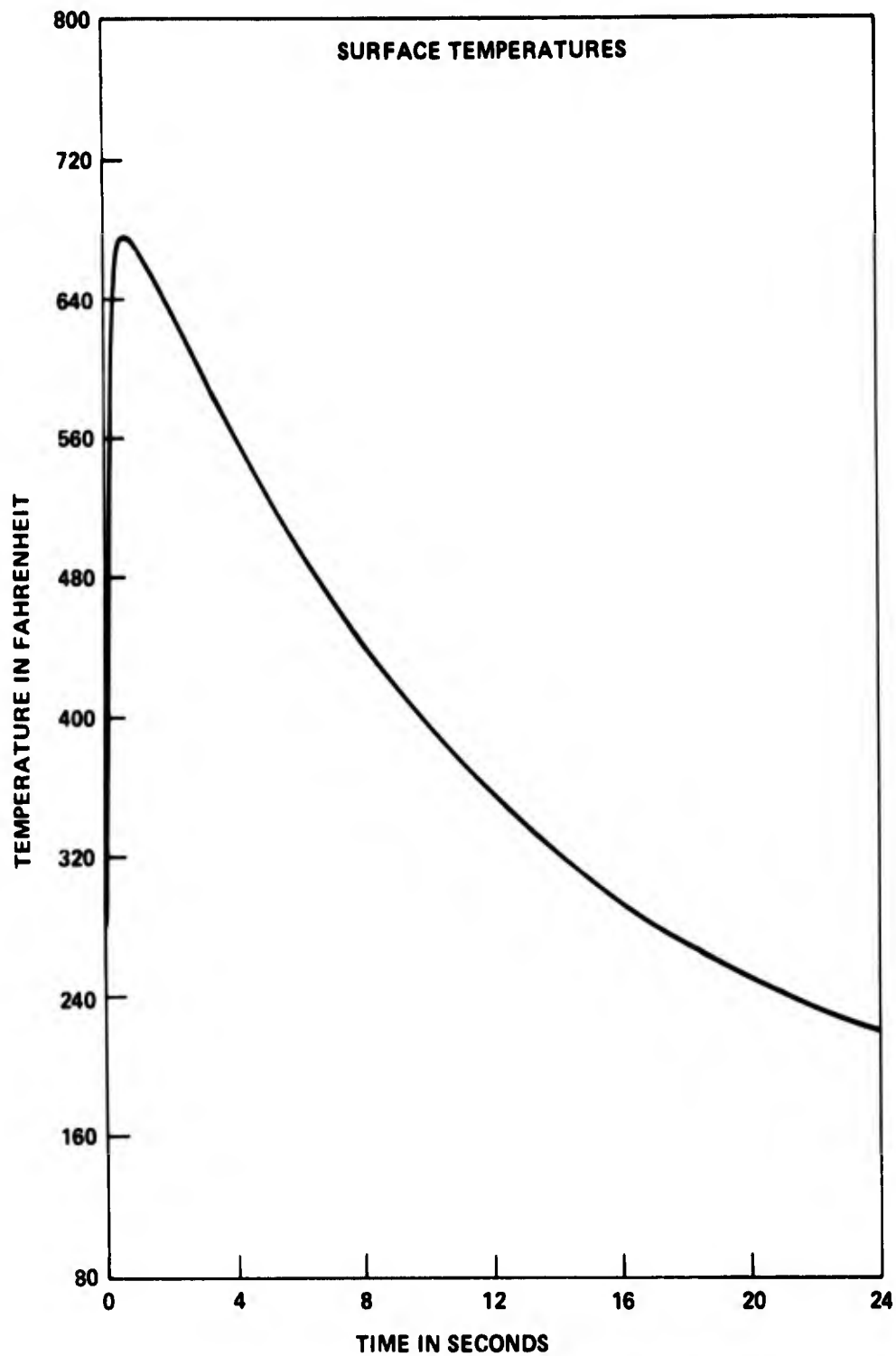


FIGURE C-1. GRAPH OF THE SIF TIP TEMPERATURES DURING THE 175-MM FLIGHT.

CNE DIM. HEAT TRANSFER ANALYSIS
 AERODYNAMIC HEATING ON THE BLUNT TIP OF THE SIF NOSE COME
 WHEN FIRED FROM THE 175MM GUN AT ZONE 3 INTO 57 DEG F
 AIR AT SEA LEVEL AND 10 DEG ELEVATION ANGLE
 GFN-2 IS THE NOSE CCNE MATERIAL

UNITS FOR THE INPUT VARIABLES ARE AS FOLLOWS...
 DIMENSIONLESS= (KN,NFIN,JIN,JOUT,NTRY,MTRA,NCASE,IFIN,NAERO,IZ
 S=IDEL,TIMEZ,SEC,TIMEI,TIMEO)
 DEGREES F= (TZERO,T(1),T(N),TAMBI,TAMBO,TE,(NFIN),TSMPL)
 FT= (h,MZERO,X)
 FT**2.0= A
 FT/5= V
 BTU= (QTCI,QTCO)
 BTU/S= (CIN,QUOT)
 BTU/FT**2.0= Cp
 BTU/S**FT= COND
 BTU/S**FT**2.0= COEFF WHEN NAERO IS 0 OR SMALLER
 BTU/FT**2.0= COEFF WHEN NAERO IS GREATER THAN 0
 WHEN A CCEF TABLE IS INSERTED TAMBI,TAMBO,TE ARE DEGREES R

DATA USED IN THE PROGRAM ARE SHOWN BELOW.

KN	NFIN	JIN	JOUT	NTRY	MTRA	NCASE	IFIN	NAERO	IZ
2	16	0	1	0	0	0	1200	1	3

KOME
25

NE(K)
8 16

DEL	TIMEZ	QTOO	QTOI	SEC
0.020	0.00	0.00	0.00	0.60
0.042	TZERO	PZERO	MZERO	
	57.00	2116.00	0.00	

TSPPL
57.0

CON(J,K)	
0.000026	0.000000
0.000008	0.000000

X(K)	A(K)	CP(K)
0.001388	0.001360	22.60
0.001388	0.001360	6.70

TIME(J)	H(J)	VL(J)
0.00	0.00	2998.00
1.00	494.00	2873.00
2.00	938.00	2758.00
3.00	1331.00	2650.00
4.00	1682.00	2548.00
5.00	1987.00	2456.00
6.00	2250.00	2368.00

7.00	2473.00	2282.00
8.00	2653.00	2204.00
9.00	2801.00	2132.00
10.00	2909.00	2063.00
11.00	2981.00	1997.00
12.00	3024.00	1935.00
13.00	3030.00	1876.00
14.00	2876.00	1820.00
15.00	2848.00	1764.00
16.00	2863.00	1715.00
17.00	2748.00	1666.00
18.00	2604.00	1623.00
19.00	2433.00	1584.00
20.00	2236.00	1538.00
21.00	2013.00	1502.00
22.00	1764.00	1463.00
23.00	1489.00	1430.00
24.00	1190.00	1394.00

CM P
0.000 0.069

COUT
C.0

CALCULATIONS FROM THE PROGRAM ARE SHOWN BELOW

TIME	APB. TEMP.	HEAT TRANSFER COEFF.	HEAT TRANSFER RATE	TOTAL HEAT													
(SEC.)	INLET	OUTLET	INLET	OUTLET	INPUT	OUTPUT											
0.200E-01	0.804E C3	0.000E-38	0.104E 00	0.000E-38	0.105E 00	0.000E-38											
					0.211E-02	0.000E-38											
NODE TEMP.	NODE TEMP.	NODE TEMP.	NODE TEMP.	NODE TEMP.	NODE TEMP.	NODE TEMP.											
1	155.697	2	58.179	3	57.014	4	57.000	5	57.000	6	57.000	7	57.000	8	57.000	16	57.000
9	57.000	10	57.000	11	57.000	12	57.000	13	57.000	14	57.000	15	57.000	16	57.000		
TIME	APB. TEMP.	HEAT TRANSFER COEFF.	HEAT TRANSFER RATE	TOTAL HEAT													
(SEC.)	INLET	OUTLET	INLET	OUTLET	INPUT	OUTPUT											
0.400E-01	0.802E 03	0.000E-38	0.103E 00	0.000E-38	0.907E-01	0.000E-38											
					0.392E-02	0.000E-38											
NODE TEMP.	NODE TEMP.	NODE TEMP.	NODE TEMP.	NODE TEMP.	NODE TEMP.	NODE TEMP.											
1	238.423	2	60.317	3	57.053	4	57.001	5	57.000	6	57.000	7	57.000	8	57.000	16	57.000
9	57.000	10	57.000	11	57.000	12	57.000	13	57.000	14	57.000	15	57.000	16	57.000		
TIME	APB. TEMP.	HEAT TRANSFER COEFF.	HEAT TRANSFER RATE	TOTAL HEAT													
(SEC.)	INLET	OUTLET	INLET	OUTLET	INPUT	OUTPUT											
0.600E-01	0.801E 03	0.000E-38	0.103E 00	0.000E-38	0.786E-01	0.000E-38											
					0.549E-02	0.000E-38											
NODE TEMP.	NODE TEMP.	NODE TEMP.	NODE TEMP.	NODE TEMP.	NODE TEMP.	NODE TEMP.											
1	307.859	2	63.235	3	57.127	4	57.002	5	57.000	6	57.000	7	57.000	8	57.000	16	57.000
9	57.000	10	57.000	11	57.000	12	57.000	13	57.000	14	57.000	15	57.000	16	57.000		
TIME	APB. TEMP.	HEAT TRANSFER COEFF.	HEAT TRANSFER RATE	TOTAL HEAT													
(SEC.)	INLET	OUTLET	INLET	OUTLET	INPUT	OUTPUT											
0.660E 00	0.763E 03	0.000E-38	0.978E-01	0.000E-38	0.120E-01	0.000E-38											
					0.204E-01	0.000E-38											
NODE TEMP.	NODE TEMP.	NODE TEMP.	NODE TEMP.	NODE TEMP.	NODE TEMP.	NODE TEMP.											

TIME	AMB. TEMP.	HEAT TRANSFER COEF.	HEAT TRANSFER RATE	INLET	OUTLET	INPUT	OUTPUT	INPUT	OUTPUT	INPUT	OUTPUT				
1	672.548	2	209.127	3	80.970	4	59.804	5	57.263	6	57.020	7	57.001	8	56.999
9	56.999	10	56.999	11	56.999	12	56.999	13	56.999	14	56.999	15	56.999	16	56.999
HEAT TRANSFER COEF. HEAT TRANSFER RATE													TOTAL HEAT		
(SEC.) INLET OUTLET INLET OUTLET INPUT OUTPUT INPUT OUTPUT INPUT OUTPUT													TOTAL HEAT		
0.126E 01	0.727E 03	0.000E-38	0.945E-01	0.000E-38	0.859E-02	0.000E-38	0.264E-01	0.000E-38							
NODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP. MCDE TEMP. MCDE TEMP. MCDE TEMP. MCDE TEMP.													TOTAL HEAT		
1	659.714	2	300.034	3	124.642	4	71.249	5	59.414	6	57.342	7	57.041	8	57.004
9	56.999	10	56.998	11	56.998	12	56.998	13	56.998	14	56.998	15	56.998	16	56.998
HEAT TRANSFER COEF. HEAT TRANSFER RATE													TOTAL HEAT		
(SEC.) INLET OUTLET INLET OUTLET INPUT OUTPUT INPUT OUTPUT INPUT OUTPUT													TOTAL HEAT		
0.186E 01	0.694E 03	0.000E-38	0.915E-01	0.000E-38	0.667E-02	0.000E-38	0.309E-01	0.000E-38							
NODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP. MCDE TEMP. MCDE TEMP. MCDE TEMP. MCDE TEMP.													TOTAL HEAT		
1	639.825	2	350.674	3	166.628	4	88.999	5	64.627	6	58.533	7	57.266	8	57.042
9	57.007	10	56.999	11	56.998	12	56.997	13	56.997	14	56.997	15	56.998	16	56.998
HEAT TRANSFER COEF. HEAT TRANSFER RATE													TOTAL HEAT		
(SEC.) INLET OUTLET INLET OUTLET INPUT OUTPUT INPUT OUTPUT INPUT OUTPUT													TOTAL HEAT		
0.246E 01	0.663E 03	0.000E-38	0.887E-01	0.000E-38	0.533E-02	0.000E-38	0.344E-01	0.000E-38							
NODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP. MCDE TEMP. MCDE TEMP. MCDE TEMP. MCDE TEMP.													TOTAL HEAT		
1	618.154	2	379.632	3	201.520	4	109.153	5	72.635	6	60.994	7	57.889	8	57.188
9	57.046	10	57.005	11	56.998	12	56.997	13	56.997	14	56.997	15	56.997	16	56.997
HEAT TRANSFER COEF. HEAT TRANSFER RATE													TOTAL HEAT		
(SEC.) INLET OUTLET INLET OUTLET INPUT OUTPUT INPUT OUTPUT INPUT OUTPUT													TOTAL HEAT		
0.306E 01	0.634E 03	0.000E-38	0.860E-01	0.000E-38	0.434E-02	0.000E-38	0.373E-01	0.000E-38							
NODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP. MCDE TEMP. MCDE TEMP. MCDE TEMP. MCDE TEMP.													TOTAL HEAT		
1	596.008	2	395.930	3	229.085	4	129.158	5	82.551	6	64.794	7	59.091	8	57.546
9	57.165	10	57.031	11	57.002	12	56.997	13	56.996	14	56.996	15	56.996	16	56.996
HEAT TRANSFER COEF. HEAT TRANSFER RATE													TOTAL HEAT		
(SEC.) INLET OUTLET INLET OUTLET INPUT OUTPUT INPUT OUTPUT INPUT OUTPUT													TOTAL HEAT		
0.366E 01	0.606E 03	0.000E-38	0.834E-01	0.000E-38	0.357E-02	0.000E-38	0.397E-01	0.000E-38							
NODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP. MCDE TEMP. MCDE TEMP. MCDE TEMP. MCDE TEMP.													TOTAL HEAT		
1	572.956	2	404.314	3	250.360	4	147.708	5	93.661	6	69.760	7	60.966	8	58.221
9	57.424	10	57.098	11	57.018	12	57.000	13	56.996	14	56.995	15	56.995	16	56.995
HEAT TRANSFER COEF. HEAT TRANSFER RATE													TOTAL HEAT		
(SEC.) INLET OUTLET INLET OUTLET INPUT OUTPUT INPUT OUTPUT INPUT OUTPUT													TOTAL HEAT		
0.426E 01	0.581E 03	0.000E-38	0.811E-01	0.000E-38	0.299E-02	0.000E-38	0.416E-01	0.000E-38							
NODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP. MCDE TEMP. MCDE TEMP. MCDE TEMP. MCDE TEMP.													TOTAL HEAT		
1	552.793	2	407.545	3	266.521	4	164.257	5	104.648	6	75.612	7	63.522	8	59.257
9	57.891	10	57.237	11	57.055	12	57.008	13	56.997	14	56.995	15	56.994	16	56.995
HEAT TRANSFER COEF. HEAT TRANSFER RATE													TOTAL HEAT		
(SEC.) INLET OUTLET INLET OUTLET INPUT OUTPUT INPUT OUTPUT INPUT OUTPUT													TOTAL HEAT		

```

0.486E 01 0.557E 03 0.000E-38 0.789E-01 0.000E-38 0.253E-02 0.000E-38 0.433E-01 0.000E-38
NODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP.
1 532.989 2 407.439 3 278.623 4 178.677 5 115.614 6 82.054 7 66.702 8 60.823
9 58.622 10 57.130 11 57.029 12 57.029 13 57.002 14 56.995 15 56.994 16 56.994
TIME APB.TEMP. HEAT TRANSFER COEF. HEAT TRANSFER RATE TOTAL HEAT
(SEC.) INLET OUTLET INLET OUTLET INLET OUTLET INPUT OUTPUT INPUT OUTPUT
0.546E 01 0.535E 03 0.000E-38 0.768E-01 0.000E-38 0.212E-02 0.000E-38 0.447E-01 0.000E-38
NODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP.
1 513.975 2 405.067 3 287.531 4 191.048 5 126.047 6 88.824 7 70.416 8 62.812
9 59.656 10 57.869 11 57.260 12 57.069 13 57.013 14 56.998 15 56.994 16 56.994
TIME APB.TEMP. HEAT TRANSFER COEF. HEAT TRANSFER RATE TOTAL HEAT
(SEC.) INLET OUTLET INLET OUTLET INLET OUTLET INPUT OUTPUT INPUT OUTPUT
0.606E 01 0.514E 03 0.000E-38 0.748E-01 0.000E-38 0.177E-02 0.000E-38 0.450E-01 0.000E-38
NODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP.
1 495.521 2 401.027 3 293.898 4 201.541 5 135.773 6 95.711 7 74.557 8 65.246
9 61.014 10 58.423 11 57.466 12 57.138 13 57.034 14 57.003 15 56.995 16 56.994
TIME APB.TEMP. HEAT TRANSFER COEF. HEAT TRANSFER RATE TOTAL HEAT
(SEC.) INLET OUTLET INLET OUTLET INLET OUTLET INPUT OUTPUT INPUT OUTPUT
0.666E 01 0.493E 03 0.000E-38 0.728E-01 0.000E-38 0.146E-02 0.000E-38 0.460E-01 0.000E-38
NODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP.
1 477.447 2 395.713 3 298.208 4 210.346 5 144.705 6 102.552 7 79.021 8 68.089
9 62.698 10 59.166 11 57.764 12 57.248 13 57.071 14 57.015 15 56.995 16 56.995
TIME APB.TEMP. HEAT TRANSFER COEF. HEAT TRANSFER RATE TOTAL HEAT
(SEC.) INLET OUTLET INLET OUTLET INLET OUTLET INPUT OUTPUT INPUT OUTPUT
0.726E 01 0.473E 03 0.000E-38 0.710E-01 0.000E-38 0.122E-02 0.000E-38 0.476E-01 0.000E-38
NODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP.
1 460.244 2 389.461 3 300.835 4 217.653 5 152.819 6 109.230 7 83.708 8 71.288
9 64.695 10 60.109 11 58.170 12 57.409 13 57.130 14 57.035 15 57.004 16 56.958
TIME APB.TEMP. HEAT TRANSFER COEF. HEAT TRANSFER RATE TOTAL HEAT
(SEC.) INLET OUTLET INLET OUTLET INLET OUTLET INPUT OUTPUT INPUT OUTPUT
0.786E 01 0.458E 03 0.000E-38 0.693E-01 0.000E-38 0.103E-02 0.000E-38 0.483E-01 0.000E-38
NODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP.
1 444.320 2 382.670 3 302.102 4 223.638 5 160.121 6 115.666 7 88.534 8 74.785
9 66.982 10 61.256 11 58.697 12 57.632 13 57.217 14 57.066 15 57.016 16 57.004
TIME APB.TEMP. HEAT TRANSFER COEF. HEAT TRANSFER RATE TOTAL HEAT
(SEC.) INLET OUTLET INLET OUTLET INLET OUTLET INPUT OUTPUT INPUT OUTPUT
0.846E 01 0.439E 03 0.000E-38 0.677E-01 0.000E-38 0.864E-03 0.000E-38 0.480E-01 0.000E-38
NODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP.
1 429.431 2 375.604 3 302.298 4 228.472 5 166.645 6 121.803 7 93.423 8 78.521
9 69.526 10 62.604 11 59.351 12 57.925 13 57.340 14 57.114 15 57.035 16 57.016
TIME APB.TEMP. HEAT TRANSFER COEF. HEAT TRANSFER RATE TOTAL HEAT

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(SEC.) INLET OUTLET INLET OUTLET INLET OUTLET INPUT OUTPUT INPUT OUTPUT
0.906E 01 0.424E 03 0.000E-38 0.662E-01 0.000E-38 0.715E-03 0.000E-38 0.493E-01 0.000E-38
MODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP.
1 413.390 2 368.402 3 301.652 4 232.312 5 172.436 6 127.610 7 98.314 8 82.436
9 72.291 10 64.144 11 60.138 12 58.297 13 57.503 14 57.182 15 57.063 16 57.034
TIME AMB.TEMP. HEAT TRANSFER COEF. HEAT TRANSFER RATE TOTAL HEAT
(SEC.) INLET OUTLET INLET OUTLET INLET OUTLET INPUT OUTPUT INPUT OUTPUT
0.966E 01 0.409E 03 0.000E-38 0.648E-01 0.000E-38 0.577E-03 0.000E-38 0.497E-01 0.000E-38
MODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP.
1 401.947 2 361.123 3 300.338 4 235.300 5 177.550 6 133.069 7 103.157 8 86.475
9 75.241 10 65.861 11 61.057 12 58.752 13 57.714 14 57.274 15 57.105 16 57.062
TIME AMB.TEMP. HEAT TRANSFER COEF. HEAT TRANSFER RATE TOTAL HEAT
(SEC.) INLET OUTLET INLET OUTLET INLET OUTLET INPUT OUTPUT INPUT OUTPUT
0.103E 02 0.395E 03 0.000E-38 0.634E-01 0.000E-38 0.455E-03 0.000E-38 0.500E-01 0.000E-38
MODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP.
1 389.078 2 353.800 3 298.483 4 237.556 5 182.044 6 138.175 7 107.911 8 90.589
9 78.336 10 67.739 11 62.106 12 59.295 13 57.976 14 57.395 15 57.162 16 57.102
TIME AMB.TEMP. HEAT TRANSFER COEF. HEAT TRANSFER RATE TOTAL HEAT
(SEC.) INLET OUTLET INLET OUTLET INLET OUTLET INPUT OUTPUT INPUT OUTPUT
0.109E 02 0.381E 03 0.000E-38 0.621E-01 0.000E-38 0.349E-03 0.000E-38 0.502E-01 0.000E-38
MODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP.
1 376.778 2 346.477 3 296.186 4 239.181 5 185.974 6 142.931 7 112.543 8 94.734
9 81.542 10 69.759 11 63.278 12 59.927 13 58.296 14 57.549 15 57.240 16 57.158
TIME AMB.TEMP. HEAT TRANSFER COEF. HEAT TRANSFER RATE TOTAL HEAT
(SEC.) INLET OUTLET INLET OUTLET INLET OUTLET INPUT OUTPUT INPUT OUTPUT
0.115E 02 0.369E 03 0.000E-38 0.609E-01 0.000E-38 0.260E-03 0.000E-38 0.504E-01 0.000E-38
MODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP.
1 365.113 2 339.207 3 293.534 4 240.262 5 189.392 6 147.345 7 117.030 8 98.872
9 84.824 10 71.901 11 64.566 12 60.648 13 58.674 14 57.740 15 57.341 16 57.233
TIME AMB.TEMP. HEAT TRANSFER COEF. HEAT TRANSFER RATE TOTAL HEAT
(SEC.) INLET OUTLET INLET OUTLET INLET OUTLET INPUT OUTPUT INPUT OUTPUT
0.121E 02 0.357E 03 0.000E-38 0.597E-01 0.000E-38 0.186E-03 0.000E-38 0.505E-01 0.000E-38
MODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP.
1 354.069 2 332.049 3 290.601 4 240.873 5 192.346 6 151.428 7 121.354 8 102.970
9 88.152 10 74.145 11 65.962 12 61.457 13 59.114 14 57.971 15 57.468 16 57.330
TIME AMB.TEMP. HEAT TRANSFER COEF. HEAT TRANSFER RATE TOTAL HEAT
(SEC.) INLET OUTLET INLET OUTLET INLET OUTLET INPUT OUTPUT INPUT OUTPUT
0.127E 02 0.345E 03 0.000E-38 0.585E-01 0.000E-38 0.108E-03 0.000E-38 0.506E-01 0.000E-38
MODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP.
1 343.508 2 325.020 3 287.455 4 241.082 5 194.881 6 155.194 7 125.501 8 107.001
9 91.498 10 76.470 11 67.454 12 62.349 13 59.617 14 58.245 15 57.626 16 57.453
TIME AMB.TEMP. HEAT TRANSFER COEF. HEAT TRANSFER RATE TOTAL HEAT

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TIME          AMB.TEMP.      HEAT TRANSFER COEFF. HEAT TRANSFER RATE      TOTAL HEAT
(SEC.)  INLET  OUTLET  INLET  OUTLET  INPUT  OUTPUT  INPUT  OUTPUT  INPUT  OUTPUT
0.133E 02 0.335E 03 0.000E-38 0.576E-01 0.000E-38 0.686E-04 0.000E-38 0.507E-01 0.000E-38
NODE TEMP.  NODE TEMP.  NODE TEMP.  NODE TEMP.  NODE TEMP.  NODE TEMP.  NODE TEMP.  NODE TEMP.
1 333.678 2 318.154 3 284.145 4 240.947 5 197.039 6 158.659 7 129.463 8 110.943
9 94.838 10 78.859 11 69.032 12 63.322 13 60.183 14 58.564 15 57.818 16 57.6C5

TIME          AMB.TEMP.      HEAT TRANSFER COEFF. HEAT TRANSFER RATE      TOTAL HEAT
(SEC.)  INLET  OUTLET  INLET  OUTLET  INPUT  OUTPUT  INPUT  OUTPUT  INPUT  OUTPUT
0.139E 02 0.325E 03 0.000E-38 0.568E-01 0.000E-38 0.235E-04 0.000E-38 0.507E-01 0.000E-38
NODE TEMP.  NODE TEMP.  NODE TEMP.  NODE TEMP.  NODE TEMP.  NODE TEMP.  NODE TEMP.  NODE TEMP.
1 324.747 2 311.573 3 280.735 4 240.519 5 198.857 6 161.837 7 133.234 8 114.777
9 98.152 10 81.294 11 70.685 12 64.369 13 60.812 14 58.931 15 58.045 16 57.750

TIME          AMB.TEMP.      HEAT TRANSFER COEFF. HEAT TRANSFER RATE      TOTAL HEAT
(SEC.)  INLET  OUTLET  INLET  OUTLET  INPUT  OUTPUT  INPUT  OUTPUT  INPUT  OUTPUT
0.145E 02 0.315E 03 0.000E-38 0.557E-01 0.000E-38 0.739E-04 0.000E-38 0.507E-01 0.000E-38
NODE TEMP.  NODE TEMP.  NODE TEMP.  NODE TEMP.  NODE TEMP.  NODE TEMP.  NODE TEMP.  NODE TEMP.
1 315.543 2 305.186 3 277.277 4 239.851 5 200.372 6 164.744 7 136.811 8 118.469
9 101.420 10 83.758 11 72.401 12 65.487 13 61.5C1 14 59.346 15 58.312 16 58.010

TIME          AMB.TEMP.      HEAT TRANSFER COEFF. HEAT TRANSFER RATE      TOTAL HEAT
(SEC.)  INLET  OUTLET  INLET  OUTLET  INPUT  OUTPUT  INPUT  OUTPUT  INPUT  OUTPUT
0.151E 02 0.305E 03 0.000E-38 0.545E-01 0.000E-38 0.134E-03 0.000E-38 0.506E-01 0.000E-38
NODE TEMP.  NODE TEMP.  NODE TEMP.  NODE TEMP.  NODE TEMP.  NODE TEMP.  NODE TEMP.  NODE TEMP.
1 306.063 2 298.747 3 273.748 4 238.978 5 201.616 6 167.396 7 140.193 8 122.069
9 104.628 10 86.236 11 74.170 12 66.668 13 62.250 14 59.811 15 58.620 16 58.269

TIME          AMB.TEMP.      HEAT TRANSFER COEFF. HEAT TRANSFER RATE      TOTAL HEAT
(SEC.)  INLET  OUTLET  INLET  OUTLET  INPUT  OUTPUT  INPUT  OUTPUT  INPUT  OUTPUT
0.157E 02 0.296E 03 0.000E-38 0.536E-01 0.000E-38 0.141E-03 0.000E-38 0.505E-01 0.000E-38
NODE TEMP.  NODE TEMP.  NODE TEMP.  NODE TEMP.  NODE TEMP.  NODE TEMP.  NODE TEMP.  NODE TEMP.
1 297.745 2 292.420 3 270.136 4 237.918 5 202.615 6 169.810 7 143.383 8 125.5C8
9 107.764 10 88.715 11 75.930 12 67.906 13 63.055 14 60.325 15 58.970 16 58.567

TIME          AMB.TEMP.      HEAT TRANSFER COEFF. HEAT TRANSFER RATE      TOTAL HEAT
(SEC.)  INLET  OUTLET  INLET  OUTLET  INPUT  OUTPUT  INPUT  OUTPUT  INPUT  OUTPUT
0.163E 02 0.288E 03 0.000E-38 0.528E-01 0.000E-38 0.175E-03 0.000E-38 0.505E-01 0.000E-38
NODE TEMP.  NODE TEMP.  NODE TEMP.  NODE TEMP.  NODE TEMP.  NODE TEMP.  NODE TEMP.  NODE TEMP.
1 290.143 2 286.403 3 266.504 4 236.695 5 203.391 6 171.998 7 146.382 8 128.8C0
9 11C.816 10 91.183 11 77.823 12 69.196 13 63.915 14 60.890 15 59.365 16 58.9C8

TIME          AMB.TEMP.      HEAT TRANSFER COEFF. HEAT TRANSFER RATE      TOTAL HEAT
(SEC.)  INLET  OUTLET  INLET  OUTLET  INPUT  OUTPUT  INPUT  OUTPUT  INPUT  OUTPUT
0.169E 02 0.280E 03 0.000E-38 0.520E-01 0.000E-38 0.207E-03 0.000E-38 0.503E-01 0.000E-38
NODE TEMP.  NODE TEMP.  NODE TEMP.  NODE TEMP.  NODE TEMP.  NODE TEMP.  NODE TEMP.  NODE TEMP.

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1	282.657	2	280.609	3	262.895	4	235.341	5	203.966	6	173.975	7	149.196	8	131.942		
9	112.777	10	93.629	11	79.690	12	70.531	13	64.825	14	61.503	15	59.806	16	59.252		
HEAT TRANSFER COEF. HEAT TRANSFER RATE																	
TIME	AMB. TEMP.		HEAT TRANSFER COEF.		HEAT TRANSFER RATE		TOTAL HEAT		TOTAL HEAT		TOTAL HEAT		TOTAL HEAT		TOTAL HEAT		
(SEC.)	INLET	OUTLET	INLET	OUTLET	INLET	OUTPUT	INPUT	OUTPUT	INPUT	OUTPUT	INPUT	OUTPUT	INPUT	OUTPUT	INPUT	OUTPUT	
0.175E 02	0.273E 03	0.000E-38	0.513E-01	0.000E-38	0.217E-03	0.000E-38	0.502E-01	0.000E-38									
NODE TEMP.	NODE TEMP.	NODE TEMP.	NODE TEMP.	NODE TEMP.	NODE TEMP.	NODE TEMP.	NODE TEMP.	NODE TEMP.	MCDE TEMP.	MCDE TEMP.	MCDE TEMP.	MCDE TEMP.	MCDE TEMP.	MCDE TEMP.	MCDE TEMP.	MCDE TEMP.	
1	275.691	2	275.015	3	259.316	4	233.881	5	204.361	6	175.754	7	151.827	8	134.932	9	119.722
9	116.639	10	96.044	11	81.570	12	71.904	13	65.784	14	62.164	15	60.292	16	59.722		
HEAT TRANSFER COEF. HEAT TRANSFER RATE																	
TIME	AMB. TEMP.		HEAT TRANSFER COEF.		HEAT TRANSFER RATE		TOTAL HEAT		TOTAL HEAT		TOTAL HEAT		TOTAL HEAT		TOTAL HEAT		
(SEC.)	INLET	OUTLET	INLET	OUTLET	INLET	OUTPUT	INPUT	OUTPUT	INPUT	OUTPUT	INPUT	OUTPUT	INPUT	OUTPUT	INPUT	OUTPUT	
0.181E 02	0.266E 03	0.000E-38	0.506E-01	0.000E-38	0.222E-03	0.000E-38	0.501E-01	0.000E-38									
NODE TEMP.	NODE TEMP.	NODE TEMP.	NODE TEMP.	NODE TEMP.	NODE TEMP.	NODE TEMP.	NODE TEMP.	NODE TEMP.	MCDE TEMP.	MCDE TEMP.	MCDE TEMP.	MCDE TEMP.	MCDE TEMP.	MCDE TEMP.	MCDE TEMP.	MCDE TEMP.	
1	265.365	2	269.693	3	255.793	4	232.338	5	204.555	6	177.346	7	154.281	8	137.769	9	122.157
9	119.399	10	98.421	11	83.457	12	73.310	13	66.787	14	62.873	15	60.825	16	60.157		
HEAT TRANSFER COEF. HEAT TRANSFER RATE																	
TIME	AMB. TEMP.		HEAT TRANSFER COEF.		HEAT TRANSFER RATE		TOTAL HEAT		TOTAL HEAT		TOTAL HEAT		TOTAL HEAT		TOTAL HEAT		
(SEC.)	INLET	OUTLET	INLET	OUTLET	INLET	OUTPUT	INPUT	OUTPUT	INPUT	OUTPUT	INPUT	OUTPUT	INPUT	OUTPUT	INPUT	OUTPUT	
0.187E 02	0.260E 03	0.000E-38	0.501E-01	0.000E-38	0.225E-03	0.000E-38	0.499E-01	0.000E-38									
NODE TEMP.	NODE TEMP.	NODE TEMP.	NODE TEMP.	NODE TEMP.	NODE TEMP.	NODE TEMP.	NODE TEMP.	NODE TEMP.	MCDE TEMP.	MCDE TEMP.	MCDE TEMP.	MCDE TEMP.	MCDE TEMP.	MCDE TEMP.	MCDE TEMP.	MCDE TEMP.	
1	263.614	2	264.675	3	252.352	4	230.734	5	204.687	6	178.765	7	156.565	8	140.454	9	124.717
9	122.051	10	100.752	11	85.344	12	74.744	13	67.830	14	63.627	15	61.4C3	16	60.717		
HEAT TRANSFER COEF. HEAT TRANSFER RATE																	
TIME	AMB. TEMP.		HEAT TRANSFER COEF.		HEAT TRANSFER RATE		TOTAL HEAT		TOTAL HEAT		TOTAL HEAT		TOTAL HEAT		TOTAL HEAT		
(SEC.)	INLET	OUTLET	INLET	OUTLET	INLET	OUTPUT	INPUT	OUTPUT	INPUT	OUTPUT	INPUT	OUTPUT	INPUT	OUTPUT	INPUT	OUTPUT	
0.193E 02	0.254E 03	0.000E-38	0.494E-01	0.000E-38	0.264E-03	0.000E-38	0.498E-01	0.000E-38									
NODE TEMP.	NODE TEMP.	NODE TEMP.	NODE TEMP.	NODE TEMP.	NODE TEMP.	NODE TEMP.	NODE TEMP.	NODE TEMP.	MCDE TEMP.	MCDE TEMP.	MCDE TEMP.	MCDE TEMP.	MCDE TEMP.	MCDE TEMP.	MCDE TEMP.	MCDE TEMP.	
1	257.911	2	259.916	3	249.013	4	229.090	5	204.654	6	180.022	7	158.683	8	142.989	9	124.595
9	124.595	10	103.032	11	87.223	12	76.199	13	68.911	14	64.424	15	62.027	16	61.284		
HEAT TRANSFER COEF. HEAT TRANSFER RATE																	
TIME	AMB. TEMP.		HEAT TRANSFER COEF.		HEAT TRANSFER RATE		TOTAL HEAT		TOTAL HEAT		TOTAL HEAT		TOTAL HEAT		TOTAL HEAT		
(SEC.)	INLET	OUTLET	INLET	OUTLET	INLET	OUTPUT	INPUT	OUTPUT	INPUT	OUTPUT	INPUT	OUTPUT	INPUT	OUTPUT	INPUT	OUTPUT	
0.199E 02	0.247E 03	0.000E-38	0.487E-01	0.000E-38	0.304E-03	0.000E-38	0.496E-01	0.000E-38									
NODE TEMP.	NODE TEMP.	NODE TEMP.	NODE TEMP.	NODE TEMP.	NODE TEMP.	NODE TEMP.	NODE TEMP.	NODE TEMP.	MCDE TEMP.	MCDE TEMP.	MCDE TEMP.	MCDE TEMP.	MCDE TEMP.	MCDE TEMP.	MCDE TEMP.	MCDE TEMP.	
1	251.769	2	255.216	3	245.755	4	227.423	5	204.514	6	181.130	7	160.644	8	145.375	9	127.028
9	127.028	10	105.255	11	89.090	12	77.671	13	70.025	14	65.264	15	62.696	16	61.655		
HEAT TRANSFER COEF. HEAT TRANSFER RATE																	
TIME	AMB. TEMP.		HEAT TRANSFER COEF.		HEAT TRANSFER RATE		TOTAL HEAT		TOTAL HEAT		TOTAL HEAT		TOTAL HEAT		TOTAL HEAT		
(SEC.)	INLET	OUTLET	INLET	OUTLET	INLET	OUTPUT	INPUT	OUTPUT	INPUT	OUTPUT	INPUT	OUTPUT	INPUT	OUTPUT	INPUT	OUTPUT	
0.205E 02	0.242E 03	0.000E-38	0.482E-01	0.000E-38	0.292E-03	0.000E-38	0.495E-01	0.000E-38									
NODE TEMP.	NODE TEMP.	NODE TEMP.	NODE TEMP.	NODE TEMP.	NODE TEMP.	NODE TEMP.	NODE TEMP.	NODE TEMP.	MCDE TEMP.	MCDE TEMP.	MCDE TEMP.	MCDE TEMP.	MCDE TEMP.	MCDE TEMP.	MCDE TEMP.	MCDE TEMP.	
1	246.189	2	250.581	3	242.537	4	225.732	5	204.279	6	182.101	7	162.453	8	147.617	9	129.350
9	129.350	10	107.419	11	90.939	12	79.155	13	71.170	14	66.143	15	63.4C9	16	62.552		
HEAT TRANSFER COEF. HEAT TRANSFER RATE																	
TIME	AMB. TEMP.		HEAT TRANSFER COEF.		HEAT TRANSFER RATE		TOTAL HEAT		TOTAL HEAT		TOTAL HEAT		TOTAL HEAT		TOTAL HEAT		

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C.211E 02 0.237E 03 C.000E-38 0.477E-01 0.000E-38 0.291E-03 0.000E-38 0.493E-01 0.000E-38
  NODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP.
  1 241.380 2 246.207 3 239.381 4 224.018 5 203.958 6 182.943 7 164.119 8 149.718
  9 131.561 10 109.519 11 92.766 12 80.647 13 72.342 14 67.060 15 64.164 16 63.253
  TIME AMB.TEMP. HEAT TRANSFER COEF. HEAT TRANSFER RATE TOTAL HEAT
  (SEC.) INLET OUTLET INLET OUTLET INLET OUTPUT INPUT OUTPUT
  0.217E 02 0.232E 03 0.000E-38 0.471E-01 0.000E-38 0.316E-03 0.000E-38 0.491E-01 0.000E-38
  NODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP.
  1 236.486 2 242.045 3 236.316 4 222.294 5 203.559 6 183.667 7 165.647 8 151.662
  9 133.663 10 111.534 11 94.566 12 82.142 13 73.537 14 68.011 15 64.960 16 63.996
  TIME AMB.TEMP. HEAT TRANSFER COEF. HEAT TRANSFER RATE TOTAL HEAT
  (SEC.) INLET OUTLET INLET OUTLET INLET OUTPUT INPUT OUTPUT
  0.223E 02 0.227E 03 0.000E-38 0.466E-01 0.000E-38 0.315E-03 0.000E-38 0.489E-01 0.000E-38
  NODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP.
  1 231.767 2 238.000 3 233.330 4 220.569 5 203.092 6 184.280 7 167.045 8 153.515
  9 135.657 10 113.523 11 96.337 12 83.637 13 74.753 14 68.996 15 65.754 16 64.780
  TIME AMB.TEMP. HEAT TRANSFER COEF. HEAT TRANSFER RATE TOTAL HEAT
  (SEC.) INLET OUTLET INLET OUTLET INLET OUTPUT INPUT OUTPUT
  0.229E 02 0.223E 03 0.000E-38 0.462E-01 0.000E-38 0.309E-03 0.000E-38 0.487E-01 0.000E-38
  NODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP.
  1 227.611 2 234.153 3 230.424 4 218.845 5 202.564 6 184.790 7 168.320 8 155.221
  9 137.546 10 115.423 11 98.076 12 85.129 13 75.986 14 70.012 15 66.669 16 65.604
  TIME AMB.TEMP. HEAT TRANSFER COEF. HEAT TRANSFER RATE TOTAL HEAT
  (SEC.) INLET OUTLET INLET OUTLET INLET OUTPUT INPUT OUTPUT
  0.235E 02 0.219E 03 0.000E-38 0.458E-01 0.000E-38 0.318E-03 0.000E-38 0.485E-01 0.000E-38
  NODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP. NODE TEMP.
  1 223.631 2 230.516 3 227.615 4 217.132 5 201.984 6 185.205 7 169.477 8 156.805
  9 139.331 10 117.255 11 99.779 12 86.614 13 77.233 14 71.055 15 67.577 16 66.466

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APPENDIX D. ROCKET SLED CALCULATIONS

Figure D-1 shows the variation of surface temperature on the SIF tip during approach to the rainfield. The data used in making the calculations is shown in the printout on pages 57 through 62.

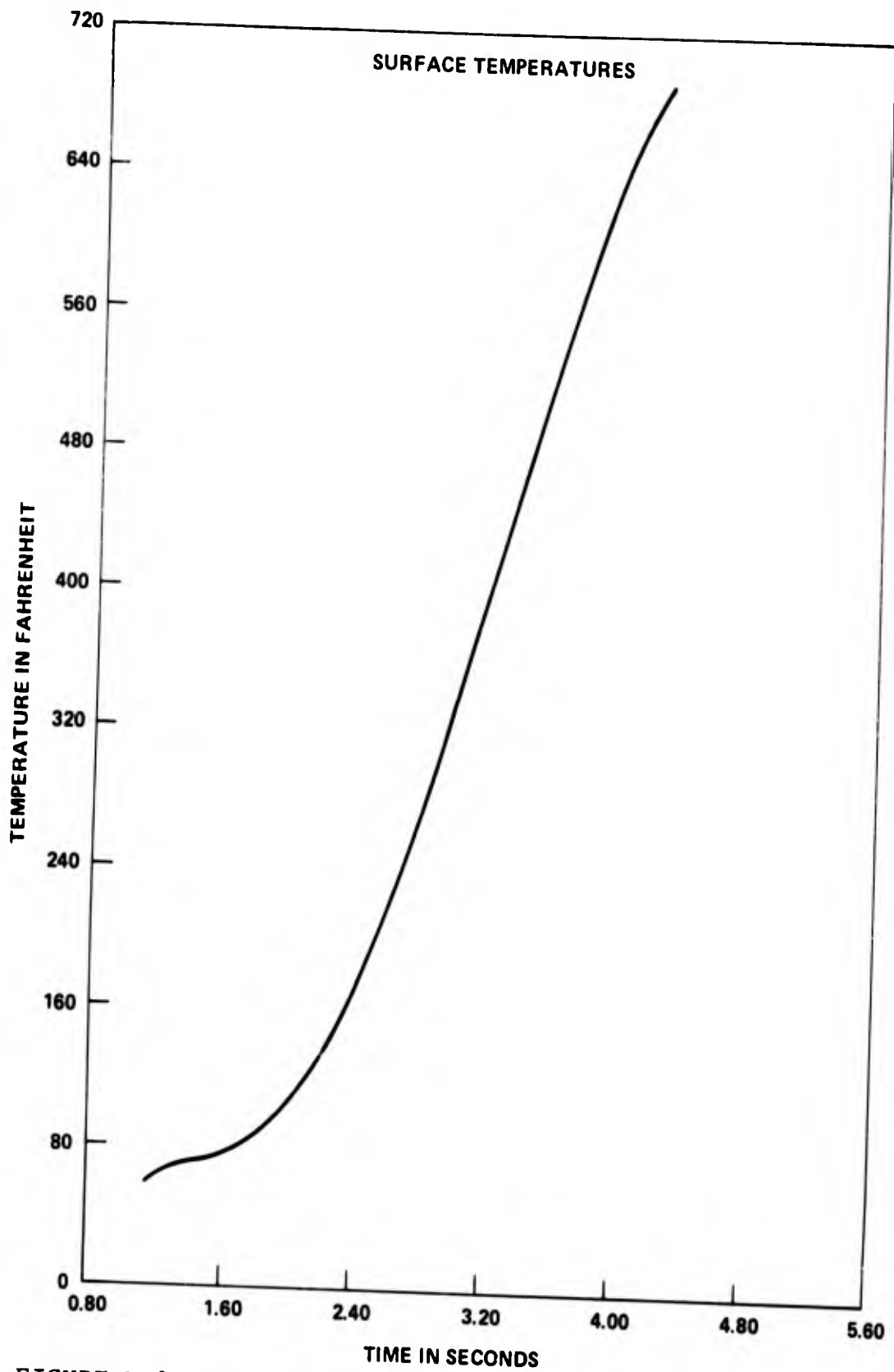


FIGURE D-1. GRAPH OF THE SIF TIP TEMPERATURES DURING THE HOLLOMAN AFB ROCKET SLED APPROACH TO THE RAINFIELD.

ONE DIM. HEAT TRANSFER ANALYSIS
 AERODYNAMIC HEATING OF AN SIF NOSE CONE MADE OF GFN-2
 DURING A RUN OF THE HOLLOWAN ROCKET SLED TOWARD THE
 ARTIFICIAL RAINFOIELD. THE BOOSTER WAS A THREE STAGE TYPE
 WITH 9 MVARS ON THE FIRST, 1 MIKE ON THE SECOND, AND 3 M50S.

UNITS FOR THE INPUT VARIABLES ARE AS FOLLOWS...
 DIMENSIONLESS= (KN, MFIN, JIN, JOUT, NTRY, NTRA, NCASE, IFIN, MAERO, IZ, MONE, NE, ACH, CM, P)
 S=(DEL, TIMEZ, SEC, TIMEI, TIMEO)
 DEGREES F= (TZERC, T(1), T(N), TAMBI, TAMBO, TE, T(INFIN), TSMPL)
 FI= (H, HZERC, XI)
 FT*2.0= A
 FT/S= V

BTU= (OTCI, CTCO)
 BTU/S= (CIN, OCUT)
 BTU/FT*2.0= CP
 BTU/S*FT*2.0= COMD
 BTU/S*FT*2.0= COEPI WHEN MAERO IS 0 OR SMALLER
 BTU/S*FT*2.0= COEPI WHEN MAERO IS GREATER THAN 0
 WHEN A CEEF TABLE IS INSERTED TAMBI, TAMBO, TE ARE DEGREES R

DATA USED IN THE PROGRAM ARE SHOWN BELOW.

KN	MFIN	JIN	JOUT	NTRY	NTRA	NCASE	IFIN	MAERO	IZ
2	16	0	1	0	0	0	158	1	10

KONE
7

NE(K)
8 16

DEL	TIMEZ	QTDD	QTOI	SEC
0.020	1.12	0.00	0.00	0.20
0.042	TZERO	PZERO	HZERO	
	57.00	2116.00	0.00	

TSPPL
57.0

CON(J,K)		
0.000026	0.000000	0.000000
0.000008	0.000000	0.000000

X(K)	A(K)	CPI(K)
0.001288	0.001360	22.60
0.001288	0.001360	6.70

TIME(J)	H(J)	V(J)
1.12	0.00	763.00
2.57	0.00	1753.00
4.03	0.00	2806.00
4.11	0.00	2918.00
4.18	0.00	2941.00
4.25	0.00	2946.00
4.28	0.00	2935.00

9	57.000	10	57.000	11	57.000	12	57.000	13	57.000	14	57.000	15	57.000	16	57.000
TIME	APB.TEMP.	HEAT TRANSFER COEF. HEAT TRANSFER RATE TOTAL HEAT													
(SEC.)	IMLFT	OUTLET	IMLET	OUTLET	IMLET	OUTLET	IMLET	OUTLET	IMLET	OUTLET	IMLET	OUTLET	IMLET	OUTLET	IMLET
0.128E	01	0.947E	02	0.000E-38	0.324E-01	0.000E-38	0.127E-02	0.000E-38	0.227E-03	0.000E-38					
MODE	TEMP.	NCDE	TEMP.	NCDE	TEMP.	NCDE	TEMP.	NCDE	TEMP.	NCDE	TEMP.	NCDE	TEMP.	NCDE	TEMP.
1	66.875	2	57.498	3	57.018	4	57.000	5	57.000	6	57.000	7	57.000	8	57.000
9	57.000	10	57.000	11	57.000	12	57.000	13	57.000	14	57.000	15	57.000	16	57.000
TIME	APB.TEMP.	HEAT TRANSFER COEF. HEAT TRANSFER RATE TOTAL HEAT													
(SEC.)	IMLFT	OUTLET	IMLET	OUTLET	IMLET	OUTLET	IMLET	OUTLET	IMLET	OUTLET	IMLET	OUTLET	IMLET	OUTLET	IMLET
0.128E	01	0.939E	02	0.000E-38	0.324E-01	0.000E-38	0.119E-02	0.000E-38	0.251E-03	0.000E-38					
MODE	TEMP.	NCDE	TEMP.	NCDE	TEMP.	NCDE	TEMP.	NCDE	TEMP.	NCDE	TEMP.	NCDE	TEMP.	NCDE	TEMP.
1	67.766	2	57.615	3	57.025	4	57.001	5	57.000	6	57.000	7	57.000	8	57.000
9	57.000	10	57.000	11	57.000	12	57.000	13	57.000	14	57.000	15	57.000	16	57.000
TIME	APB.TEMP.	HEAT TRANSFER COEF. HEAT TRANSFER RATE TOTAL HEAT													
(SEC.)	IMLFT	OUTLET	IMLET	OUTLET	IMLET	OUTLET	IMLET	OUTLET	IMLET	OUTLET	IMLET	OUTLET	IMLET	OUTLET	IMLET
0.130E	01	0.932E	02	0.000E-38	0.324E-01	0.000E-38	0.112E-02	0.000E-38	0.274E-03	0.000E-38					
MODE	TEMP.	NCDE	TEMP.	NCDE	TEMP.	NCDE	TEMP.	NCDE	TEMP.	NCDE	TEMP.	NCDE	TEMP.	NCDE	TEMP.
1	68.575	2	57.739	3	57.033	4	57.001	5	57.000	6	57.000	7	57.000	8	57.000
9	57.000	10	57.000	11	57.000	12	57.000	13	57.000	14	57.000	15	57.000	16	57.000
TIME	APB.TEMP.	HEAT TRANSFER COEF. HEAT TRANSFER RATE TOTAL HEAT													
(SEC.)	IMLFT	OUTLET	IMLET	OUTLET	IMLET	OUTLET	IMLET	OUTLET	IMLET	OUTLET	IMLET	OUTLET	IMLET	OUTLET	IMLET
0.132E	01	0.927E	02	0.000E-38	0.324E-01	0.000E-38	0.107E-02	0.000E-38	0.295E-03	0.000E-38					
MODE	TEMP.	NCDE	TEMP.	NCDE	TEMP.	NCDE	TEMP.	NCDE	TEMP.	NCDE	TEMP.	NCDE	TEMP.	NCDE	TEMP.
1	69.315	2	57.869	3	57.043	4	57.001	5	57.000	6	57.000	7	57.000	8	57.000
9	57.000	10	57.000	11	57.000	12	57.000	13	57.000	14	57.000	15	57.000	16	57.000
TIME	APB.TEMP.	HEAT TRANSFER COEF. HEAT TRANSFER RATE TOTAL HEAT													
(SEC.)	IMLFT	OUTLET	IMLET	OUTLET	IMLET	OUTLET	IMLET	OUTLET	IMLET	OUTLET	IMLET	OUTLET	IMLET	OUTLET	IMLET
0.134E	01	0.924E	02	0.000E-38	0.325E-01	0.000E-38	0.102E-02	0.000E-38	0.315E-03	0.000E-38					
MODE	TEMP.	NCDE	TEMP.	NCDE	TEMP.	NCDE	TEMP.	NCDE	TEMP.	NCDE	TEMP.	NCDE	TEMP.	NCDE	TEMP.
1	69.998	2	58.004	3	57.054	4	57.002	5	57.000	6	57.000	7	57.000	8	57.000
9	57.000	10	57.000	11	57.000	12	57.000	13	57.000	14	57.000	15	57.000	16	57.000
TIME	APB.TEMP.	HEAT TRANSFER COEF. HEAT TRANSFER RATE TOTAL HEAT													
(SEC.)	IMLFT	OUTLET	IMLET	OUTLET	IMLET	OUTLET	IMLET	OUTLET	IMLET	OUTLET	IMLET	OUTLET	IMLET	OUTLET	IMLET
0.136E	01	0.923E	02	0.000E-38	0.325E-01	0.000E-38	0.985E-03	0.000E-38	0.335E-03	0.000E-38					
MODE	TEMP.	NCDE	TEMP.	NCDE	TEMP.	NCDE	TEMP.	NCDE	TEMP.	NCDE	TEMP.	NCDE	TEMP.	NCDE	TEMP.
1	70.835	2	58.143	3	57.066	4	57.003	5	57.000	6	57.000	7	57.000	8	57.000
9	57.000	10	57.000	11	57.000	12	57.000	13	57.000	14	57.000	15	57.000	16	57.000
TIME	APB.TEMP.	HEAT TRANSFER COEF. HEAT TRANSFER RATE TOTAL HEAT													
(SEC.)	IMLFT	OUTLET	IMLET	OUTLET	IMLET	OUTLET	IMLET	OUTLET	IMLET	OUTLET	IMLET	OUTLET	IMLET	OUTLET	IMLET
0.138E	01	0.923E	02	0.000E-38	0.326E-01	0.000E-38	0.959E-03	0.000E-38	0.354E-03	0.000E-38					

NCDE	TEMP.	NCDE	TEMP.	NCDE	TEMP.	NCDE	TEMP.	NCDE	TEMP.	NCDE	TEMP.	NCDE	TEMP.	NCDE	TEMP.
1	71.236	2	58.287	3	57.080	4	57.004	5	57.000	6	57.000	7	57.000	8	57.000
9	57.000	10	57.000	11	57.000	12	57.000	13	57.000	14	57.000	15	57.000	16	57.000

TIME APB.TEMP. HEAT TRANSFER COEFF. HEAT TRANSFER RATE TOTAL HEAT

(SEC.) INLET CUTLET INLET OUTLET INPUT OUTPUT INPUT OUTPUT INPUT OUTPUT
0.140E 01 0.924E 02 C.000E-38 0.327E-01 C.000E-38 0.943E-03 0.000E-38 0.373E-03 0.000E-38

NCDE	TEMP.	NCDE	TEMP.	NCDE	TEMP.	NCDE	TEMP.	NCDE	TEMP.	NCDE	TEMP.	NCDE	TEMP.	NCDE	TEMP.
1	71.810	2	58.434	3	57.095	4	57.005	5	57.000	6	57.000	7	57.000	8	57.000
9	57.000	10	57.000	11	57.000	12	57.000	13	57.000	14	57.000	15	57.000	16	57.000

TIME APB.TEMP. HEAT TRANSFER COEFF. HEAT TRANSFER RATE TOTAL HEAT

(SEC.) INLET CUTLET INLET OUTLET INPUT OUTPUT INPUT OUTPUT INPUT OUTPUT
0.142E 01 0.928E 02 C.000E-38 0.328E-01 C.000E-38 0.935E-03 0.000E-38 0.392E-03 0.000E-38

NCDE	TEMP.	NCDE	TEMP.	NCDE	TEMP.	NCDE	TEMP.	NCDE	TEMP.	NCDE	TEMP.	NCDE	TEMP.	NCDE	TEMP.
1	72.367	2	58.584	3	57.112	4	57.006	5	57.000	6	57.000	7	57.000	8	57.000
9	57.000	10	57.000	11	57.000	12	57.000	13	57.000	14	57.000	15	57.000	16	57.000

TIME APB.TEMP. HEAT TRANSFER COEFF. HEAT TRANSFER RATE TOTAL HEAT

(SEC.) INLET CUTLET INLET OUTLET INPUT OUTPUT INPUT OUTPUT INPUT OUTPUT
0.144E 01 0.932E 02 C.000E-38 0.329E-01 C.000E-38 0.935E-03 0.000E-38 0.410E-03 0.000E-38

NCDE	TEMP.	NCDE	TEMP.	NCDE	TEMP.	NCDE	TEMP.	NCDE	TEMP.	NCDE	TEMP.	NCDE	TEMP.	NCDE	TEMP.
1	72.915	2	58.738	3	57.130	4	57.007	5	57.000	6	57.000	7	57.000	8	57.000
9	57.000	10	57.000	11	57.000	12	57.000	13	57.000	14	57.000	15	57.000	16	57.000

TIME APB.TEMP. HEAT TRANSFER COEFF. HEAT TRANSFER RATE TOTAL HEAT

(SEC.) INLET CUTLET INLET OUTLET INPUT OUTPUT INPUT OUTPUT INPUT OUTPUT
0.146E 01 0.939E 02 C.000E-38 0.331E-01 C.000E-38 0.943E-03 0.000E-38 0.429E-03 0.000E-38

NCDE	TEMP.	NCDE	TEMP.	NCDE	TEMP.	NCDE	TEMP.	NCDE	TEMP.	NCDE	TEMP.	NCDE	TEMP.	NCDE	TEMP.
1	73.460	2	58.894	3	57.150	4	57.009	5	57.000	6	57.000	7	57.000	8	57.000
9	57.000	10	57.000	11	57.000	12	57.000	13	57.000	14	57.000	15	57.000	16	57.000

TIME APB.TEMP. HEAT TRANSFER COEFF. HEAT TRANSFER RATE TOTAL HEAT

(SEC.) INLET CUTLET INLET OUTLET INPUT OUTPUT INPUT OUTPUT INPUT OUTPUT
0.148E 01 0.947E 02 C.000E-38 0.332E-01 C.000E-38 0.958E-03 0.000E-38 0.449E-03 0.000E-38

NCDE	TEMP.	NCDE	TEMP.	NCDE	TEMP.	NCDE	TEMP.	NCDE	TEMP.	NCDE	TEMP.	NCDE	TEMP.	NCDE	TEMP.
1	74.011	2	59.054	3	57.171	4	57.011	5	57.000	6	57.000	7	57.000	8	57.000
9	57.000	10	56.999	11	56.999	12	56.999	13	56.999	14	56.999	15	56.999	16	57.000

TIME APB.TEMP. HEAT TRANSFER COEFF. HEAT TRANSFER RATE TOTAL HEAT

(SEC.) INLET CUTLET INLET OUTLET INPUT OUTPUT INPUT OUTPUT INPUT OUTPUT
0.168E 01 0.111E 03 C.000E-38 0.355E-01 C.000E-38 0.147E-02 0.000E-38 0.686E-03 0.000E-38

NCDE	TEMP.	NCDE	TEMP.	NCDE	TEMP.	NCDE	TEMP.	NCDE	TEMP.	NCDE	TEMP.	NCDE	TEMP.	NCDE	TEMP.
1	81.085	2	60.870	3	57.464	4	57.043	5	57.003	6	57.000	7	56.999	8	56.999
9	56.999	10	56.999	11	56.999	12	56.999	13	56.999	14	56.999	15	56.999	16	56.999

TIME APB.TEMP. HEAT TRANSFER COEFF. HEAT TRANSFER RATE TOTAL HEAT

(SEC.) INLET CUTLET INLET OUTLET INPUT OUTPUT INPUT OUTPUT INPUT OUTPUT

0.188E 01 0.140E 03 0.000E-38 0.390E-01 0.000E-38 0.250E-02 0.000E-38 0.109E-02 0.000E-38

MCDE	TEMP.	NCDE	TEMP.	MCDE	TEMP.	MCDE	TEMP.	MCDE	TEMP.	MCDE	TEMP.	MCDE	TEMP.	MCDE	TEMP.
1	94.009	2	63.421	3	57.934	4	57.111	5	57.010	6	57.000	7	56.999	8	56.959
9	56.999	10	56.999	11	56.999	12	56.999	13	56.999	14	56.999	15	56.999	16	56.999

TIME APB.TEMP. HEAT TRANSFER COEF. HEAT TRANSFER RATE TOTAL HEAT

(SEC.) INLET OUTLET INLET OUTLET INLET OUTPUT INPUT OUTPLT
 0.208E 01 0.180E 03 0.000E-38 0.435E-01 0.000E-38 0.394E-02 0.000E-38 0.174E-02 0.000E-38

MCDE	TEMP.	NCDE	TEMP.	MCDE	TEMP.	MCDE	TEMP.	MCDE	TEMP.	MCDE	TEMP.	MCDE	TEMP.	MCDE	TEMP.
1	115.588	2	67.387	3	58.668	4	57.231	5	57.027	6	57.002	7	56.999	8	56.999
9	56.999	10	56.999	11	56.999	12	56.999	13	56.999	14	56.999	15	56.999	16	56.999

TIME APB.TEMP. HEAT TRANSFER COEF. HEAT TRANSFER RATE TOTAL HEAT

(SEC.) INLET OUTLET INLET OUTLET INLET OUTPUT INPUT OUTPLT
 0.228E 01 0.229E 03 0.000E-38 0.487E-01 0.000E-38 0.566E-02 0.000E-38 0.271E-02 0.000E-38

MCDE	TEMP.	NCDE	TEMP.	MCDE	TEMP.	MCDE	TEMP.	MCDE	TEMP.	MCDE	TEMP.	MCDE	TEMP.	MCDE	TEMP.
1	147.154	2	73.522	3	59.812	4	57.430	5	57.057	6	57.006	7	57.000	8	56.959
9	56.999	10	56.998	11	56.998	12	56.998	13	56.998	14	56.998	15	56.998	16	56.999

TIME APB.TEMP. HEAT TRANSFER COEF. HEAT TRANSFER RATE TOTAL HEAT

(SEC.) INLET OUTLET INLET OUTLET INLET OUTPUT INPUT OUTPLT
 0.248E 01 0.285E 03 0.000E-38 0.549E-01 0.000E-38 0.751E-02 0.000E-38 0.405E-02 0.000E-38

MCDE	TEMP.	NCDE	TEMP.	MCDE	TEMP.	MCDE	TEMP.	MCDE	TEMP.	MCDE	TEMP.	MCDE	TEMP.	MCDE	TEMP.
1	188.745	2	82.499	3	61.565	4	57.749	5	57.110	6	57.014	7	57.000	8	56.959
9	56.998	10	56.998	11	56.998	12	56.998	13	56.998	14	56.998	15	56.998	16	56.998

TIME APB.TEMP. HEAT TRANSFER COEF. HEAT TRANSFER RATE TOTAL HEAT

(SEC.) INLET OUTLET INLET OUTLET INLET OUTPUT INPUT OUTPLT
 0.268E 01 0.347E 03 0.000E-38 0.606E-01 0.000E-38 0.934E-02 0.000E-38 0.575E-02 0.000E-38

MCDE	TEMP.	NCDE	TEMP.	MCDE	TEMP.	MCDE	TEMP.	MCDE	TEMP.	MCDE	TEMP.	MCDE	TEMP.	MCDE	TEMP.
1	239.281	2	94.803	3	64.148	4	58.244	5	57.198	6	57.027	7	57.002	8	56.959
9	56.998	10	56.998	11	56.998	12	56.998	13	56.998	14	56.998	15	56.998	16	56.998

TIME APB.TEMP. HEAT TRANSFER COEF. HEAT TRANSFER RATE TOTAL HEAT

(SEC.) INLET OUTLET INLET OUTLET INLET OUTPUT INPUT OUTPLT
 0.288E 01 0.412E 03 0.000E-38 0.669E-01 0.000E-38 0.110E-01 0.000E-38 0.781E-02 0.000E-38

MCDE	TEMP.	NCDE	TEMP.	MCDE	TEMP.	MCDE	TEMP.	MCDE	TEMP.	MCDE	TEMP.	MCDE	TEMP.	MCDE	TEMP.
1	296.862	2	110.670	3	67.780	4	58.984	5	57.335	6	57.051	7	57.006	8	56.959
9	56.998	10	56.998	11	56.998	12	56.998	13	56.998	14	56.998	15	56.998	16	56.998

TIME APB.TEMP. HEAT TRANSFER COEF. HEAT TRANSFER RATE TOTAL HEAT

(SEC.) INLET OUTLET INLET OUTLET INLET OUTPUT INPUT OUTPLT
 0.308E 01 0.479E 03 0.000E-38 0.732E-01 0.000E-38 0.125E-01 0.000E-38 0.102E-01 0.000E-38

MCDE	TEMP.	NCDE	TEMP.	MCDE	TEMP.	MCDE	TEMP.	MCDE	TEMP.	MCDE	TEMP.	MCDE	TEMP.	MCDE	TEMP.
1	359.123	2	130.072	3	72.649	4	60.048	5	57.545	6	57.089	7	57.012	8	57.000
9	56.998	10	56.997	11	56.997	12	56.997	13	56.997	14	56.997	15	56.997	16	56.998

TIME APB.TEMP. HEAT TRANSFER COEF. HEAT TRANSFER RATE TOTAL HEAT

```

(SEC.)  IMLFT  OUTLET  IMLT  OUTLET  INPUT  OUTPUT  INPUT  OUTPLT
0.328E 01 0.544E 03 0.000E-38 0.792E-01 0.000E-38 0.137E-01 0.000E-38 0.128E-01 0.000E-38
NODE TEMP.  MCDE TEMP.  NODE TEMP.  NODE TEMP.  NODE TEMP.  MCDE TEMP.  MCDE TEMP.
1 423.530 2 152.737 3 78.892 4 61.516 5 57.854 6 57.148 7 57.022 8 57.002
9 56.998 10 56.997 11 56.997 12 56.997 13 56.997 14 56.997 15 56.997 16 56.997
TIME  APB. TEMP.  HEAT TRANSFER COEF.  HEAT TRANSFER RATE  TOTAL HEAT
(SEC.)  IMLT  OUTLET  IMLT  OUTLET  INPUT  OUTPUT  INPUT  OUTPLT
0.348E 01 0.607E 03 0.000E-38 0.849E-01 0.000E-38 0.145E-01 0.000E-38 0.157E-01 0.000E-38
NODE TEMP.  MCDE TEMP.  NODE TEMP.  NODE TEMP.  NODE TEMP.  MCDE TEMP.  MCDE TEMP.
1 487.573 2 178.193 3 86.585 4 63.467 5 58.290 6 57.236 7 57.039 8 57.005
9 56.999 10 56.997 11 56.997 12 56.997 13 56.997 14 56.997 15 56.997 16 56.997
TIME  APB. TEMP.  HEAT TRANSFER COEF.  HEAT TRANSFER RATE  TOTAL HEAT
(SEC.)  IMLT  OUTLET  IMLT  OUTLET  INPUT  OUTPUT  INPUT  OUTPLT
0.368E 01 0.665E 03 0.000E-38 0.901E-01 0.000E-38 0.150E-01 0.000E-38 0.186E-01 0.000E-38
NODE TEMP.  MCDE TEMP.  NODE TEMP.  NODE TEMP.  NODE TEMP.  MCDE TEMP.  MCDE TEMP.
1 548.851 2 205.810 3 95.734 4 65.969 5 58.887 6 57.364 7 57.064 8 57.009
9 57.000 10 56.997 11 56.997 12 56.997 13 56.996 14 56.996 15 56.997 16 56.997
TIME  APB. TEMP.  HEAT TRANSFER COEF.  HEAT TRANSFER RATE  TOTAL HEAT
(SEC.)  IMLFT  OUTLET  IMLT  OUTLET  INPUT  OUTPUT  INPUT  OUTPLT
0.388E 01 0.717E 03 0.000E-38 0.945E-01 0.000E-38 0.151E-01 0.000E-38 0.216E-01 0.000E-38
NODE TEMP.  MCDE TEMP.  NODE TEMP.  NODE TEMP.  NODE TEMP.  MCDE TEMP.  MCDE TEMP.
1 605.100 2 234.841 3 106.277 4 69.076 5 59.677 6 57.543 7 57.101 8 57.017
9 57.002 10 56.997 11 56.996 12 56.996 13 56.996 14 56.996 15 56.996 16 56.997
TIME  APB. TEMP.  HEAT TRANSFER COEF.  HEAT TRANSFER RATE  TOTAL HEAT
(SEC.)  IMLFT  OUTLET  IMLT  OUTLET  INPUT  OUTPUT  INPUT  OUTPLT
0.408E 01 0.760E 03 0.000E-38 0.980E-01 0.000E-38 0.147E-01 0.000E-38 0.246E-01 0.000E-38
NODE TEMP.  MCDE TEMP.  NODE TEMP.  NODE TEMP.  NODE TEMP.  MCDE TEMP.  MCDE TEMP.
1 654.221 2 264.455 3 118.081 4 72.822 5 60.892 6 57.787 7 57.154 8 57.028
9 57.005 10 56.997 11 56.996 12 56.996 13 56.996 14 56.996 15 56.996 16 56.996
TIME  APB. TEMP.  HEAT TRANSFER COEF.  HEAT TRANSFER RATE  TOTAL HEAT
(SEC.)  IMLT  OUTLET  IMLT  OUTLET  INPUT  OUTPUT  INPUT  OUTPLT
0.428E 01 0.774E 03 0.000E-38 0.991E-01 0.000E-38 0.116E-01 0.000E-38 0.274E-01 0.000E-38
NODE TEMP.  MCDE TEMP.  NODE TEMP.  NODE TEMP.  NODE TEMP.  MCDE TEMP.  MCDE TEMP.
1 689.021 2 293.632 3 130.952 4 77.220 5 61.961 6 58.110 7 57.228 8 57.045
9 57.009 10 56.998 11 56.996 12 56.996 13 56.996 14 56.996 15 56.996 16 56.996

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