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EFFECT OF MATERIAL MASS DISTRIBUTION ON THE LIFE OF SMALL ARMS BARRELS

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APRIL 1976

FINAL REPORT

RESEARCH DIRECTORATE

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GENERAL THOMAS J. RODMAN LABORATORY

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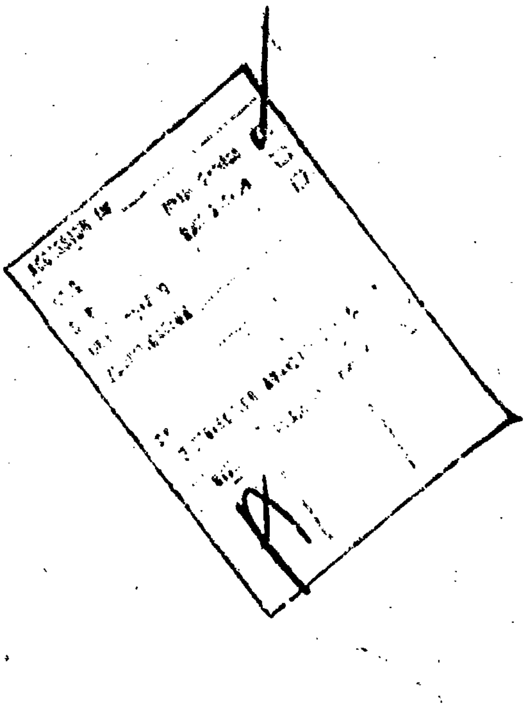

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report covers FY75 efforts on a project entitled, "Effect of Material Mass Distribution on the Life of Small Arms Barrels." The objective of this project is to develop a semi-empirical technique for determining gun barrel wear (or erosion) as a function of barrel material properties, wall thickness (or ratio) and firing rate. The past years task involved analytical design of test specimens (barrel geometries) for firing experiments wherein regression analyses will be performed in the determination of the effect of mass distribution on barrel life. A useful design tool applicable in the optimum design of gun barrels was developed with the addition of a CALCOMP plot routine to an existing implicit finite difference computer solution. Examples of these plots are given as part of the results for the parametric barrel specimen design study.

CONTENTS

EFFECT OF MATERIAL MASS DISTRIBUTION ON THE LIFE OF SMALL ARMS BARRELS

INTRODUCTION

Much effort has been spent in the pursuit of meaningful gun barrel erosion analyses. Most of these efforts have dealt with specific mechanisms and consequently have comprised only fragmentary parts of the over-all erosion problem. It is commonly accepted that a more unified approach is required to accomplish comprehensive erosion research. Further, it is believed that an immediate need exists for empirical or semi-empirical techniques which predict erosion as a function of the basic parameters involved. Toward this objective, the task herein described was undertaken to define erosion in small arms gun barrels as a semi-empirical function of barrel mass, material properties and firing rate.

A report[1] published during FY74 entitled, "Small Arms Gun Barrel Thermal Experimental Correlation Studies," describes a correlation between muzzle end wall thickness and barrel life. As shown in Figure 1, rounds to failure based on firing accuracy measurements decreased from 10,000 rounds to 2,000 rounds as barrel wall thickness decreased from .461 inches to .125 inches. These efforts are a continuation of this work toward the stated objective of better quantifying the over-all erosion process.

ANALYTICAL APPROACH

Print-outs of the two computer programs utilized in this effort are contained in the appendixes. The first program (Appendix 1) calculates effective bore boundary conditions (propellant gas convection coefficients and temperatures) based on experimentally measured barrel temperatures. This solution utilizes an energy balance wherein the gun barrel performs as a mass type calorimeter. A complete

[1]Report No. R-TR-74-034

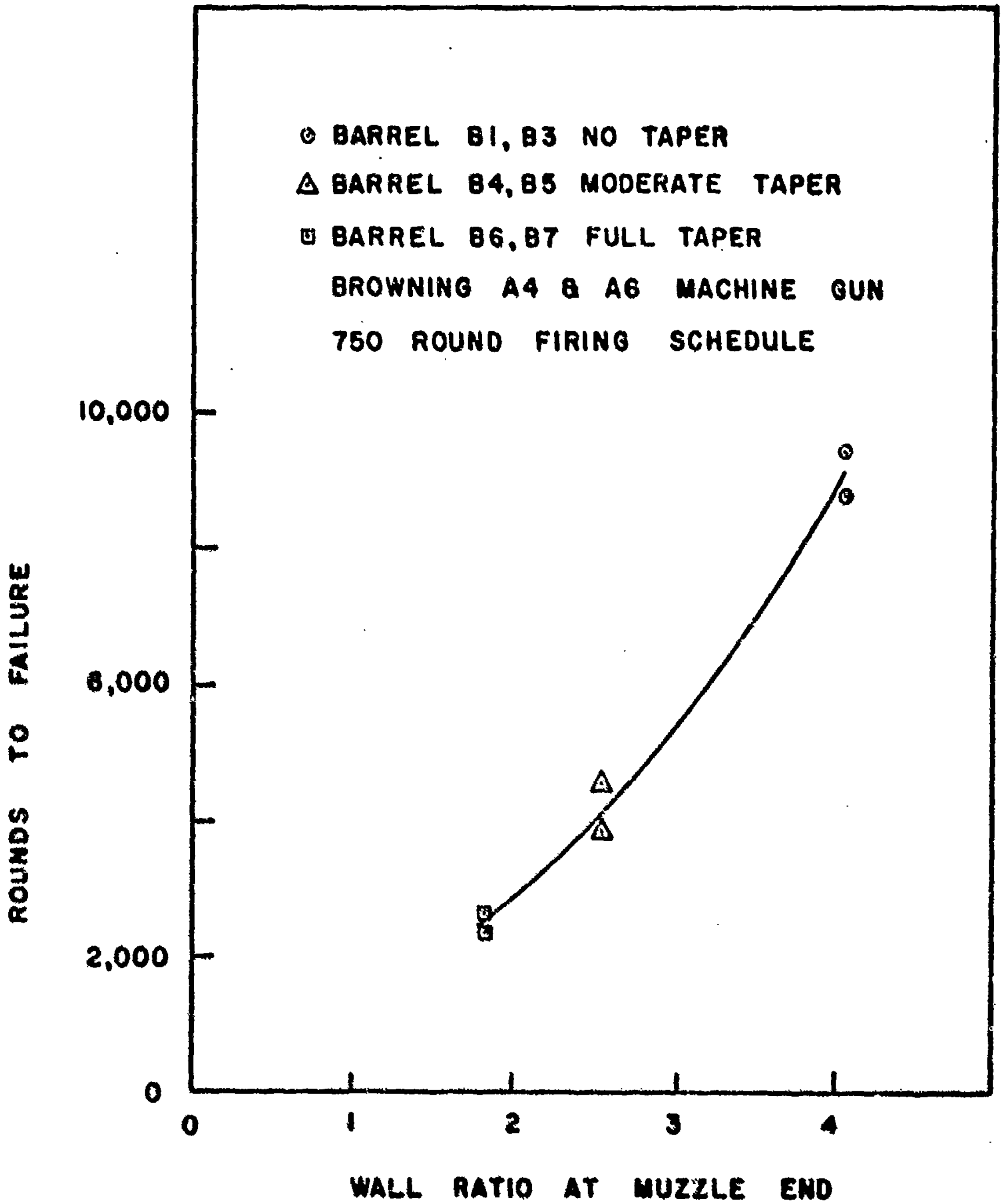

Figure 1 Geometry Effect on Barrel Life

description of this program is given in a report[1] entitled, "A Theoretical and Experimental Thermal Analysis To Determine Wall Ratios For A 30mm Tactical Barrel."

The second computer program (see Appendix 2) calculates transient gun barrel temperatures as a function of firing schedule and environmental conditions. This solution uses bore boundary conditions determined in the first program. The computer program employs an implicit finite-difference algorithm and continually performs an error analysis based on a numerical integrated energy balance. A major contribution to this effort was achieved by the incorporation of a plot routine capability. Computer graphics options which are available include:

1. Bore temperature versus firing time.
2. External barrel-temperature versus firing time.
3. Average radial temperature versus firing time.
4. Radial temperature distribution at prescribed times.

The main criteria used in selection of a test gun included; gun and ammo availability, ease of operation, and mechanism reliability. Based on these criteria, the Browning A4 was selected as a test vehicle. The over-all objective was to design axial barrel wall ratios such that the barrel would be subjected to uniform temperatures along the length of the barrel. A "gating" criterion was that of combined thermal pressure stresses. That is, the minimum thickness at any barrel section was designed of sufficient structural integrity to contain the propellant gas pressures. Consequently, subsequent to the heat transfer study, coupled thermal and pressure analyses were performed as the final design step. Once the minimum wall thickness barrel was designed, two larger barrels were designed where the wall thicknesses were arbitrarily increased in steps of .0625 inch. That is, the largest barrel has an outer diameter .250 inch larger at all axial locations than the minimum thickness barrel.

[1]Report No. R-TR-75-023

The overall procedure applied in the design of the test barrels included the following steps:

1. Experimentally firing representative gun barrels to determine bore boundary conditions.

2. Calculating effective propellant gas temperatures and convection coefficients.

3. Parametric analyses wherein barrel temperatures were calculated for a fixed rate of fire and varying wall thicknesses.

4. Combined thermal pressure stress analyses to determine the minimum allowable barrel thickness as a function of the previously determined temperatures.

RESULTS

Results of the thermal analysis are given in Appendix 3. As previously stated the objective of this parametric study was to design gun barrels of various wall ratios to determine the effect of barrel mass on erosion. The design firing schedule was fixed at continuous burst of 400 rounds total at a firing rate of 600 rounds per minute. Results are presented at axial locations 5, 9, 15 and 21 inches from the breech end. The notes for each curve give effective convection coefficients and gas temperatures. A summary of the various wall thicknesses considered is shown in Table 1.

Shown in Table 2 is a summary of the results including calculated maximum bore pressure stresses and average barrel operating temperatures for the various outer radii. Also given is the dynamic yield strength temperature corresponding to the maximum calculated pressure stresses. The final criterion used in the design of the minimum wall ratio barrels was a maximum barrel operating temperature of 1400°F average. This criterion satisfies the yield strength requirement at all locations and is conservative at the 15 and 21 inch locations. A sketch showing the outer profiles of the minimum wall ratio test barrel is given in Figure 30 (Appendix 3). It is recommended that the two larger barrels be constructed with increasing wall thicknesses of 1/16 inch and 1/8 inch respectively at each axial location.

TABLE 1

Various Outer Radii Analyzed

Axial Location (Inches) & Figure Number (Appendix 3)							
Inches	Fig.	Inches	Fig.	Inches	Fig.	Inches	Fig.
5	2 (Unlined)	9	10	15	18	21	22
↑	3 (Unlined)	↑	11	↕	19	↑	23
	4 (Unlined)		12		20		24
	5 (Unlined)		13	15	21		25
	6 (Lined)		14				26
	7 (Lined)		15				27
↓	8 (Lined)	↓	16			↓	28
5	9 (Lined)	9	17			21	29

TABLE 2

Summary of Analytical Results
(See Appendix 3)

Axial Location From Breech End Inches	Outer Radius Inch	Max. Yield Stress PSI	Average Barrel Operating Temperature °F	Limiting Temperature °F Based on Dynamic Yield Strength of Cr-Mo-V Steel
5.0	.674	92,251	1222	1240
5.0	.612	93,545	1361	1400 (Data Pt.) 1230 (Curve)
5.0	.542	95,194	1516	1400 (Data Pt.) 1220 (Curve)
9.0	.450	71,133	1352	1420
9.0	.420	72,453	1438	1410
15.0	.450	45,673	1287	1600*
15.0	.420	46,521	1351	1600*
15.0	.400	47,218	1390	1600
15.0	.37	48,537	1438	1600*
15.0	.34	50,332	1473	1560
21.0	.40	31,350	1319	1600*
21.0	.34	33,418	1434	1600*
21.0	.31	35,111	1470	1600*
21.0	.28	37,666	1492	1600*
21.0	.25	41,874	1503	1600*
21.0	.22	49,680	1511	1570
21.0	.20	60,678	1516	1510

*Extrapolated

APPENDIX 1

```
//MP3CARTC JOB (2T03,M151,7,6,9999),'D. THOMSEN',CLASS=K                 JOB 272
// EXEC FORTGCLG,REGION=100K
XXDEFAULTS PROC SYSOUT=A                                                 00000100
XXFORT     EXEC PGM=IEYFORT,REGION=100K,DPRTY=(3,3)                       00000200
XXSYSPRINT DD   SYSOUT=&SYSOUT                                           00000300
IEF653I SUBSTITUTION JCL - SYSOUT=A
XXSYSLIN   DD   DSN=&&OBJECT,UNIT=DISK,SPACE=(CYL,(1,1)),                C00000400
XX              DCB=BLKSIZE=800,DISP=(,PASS)                             00000500
//FORT.SYSIN DD *
IEF236I ALLOC. FOR MP3CARTC FORT
IEF237I 0C0   ALLOCATED TO SYSPRINT
IEF237I 155   ALLOCATED TO SYSLIN
IEF237I C91   ALLOCATED TO SYSIN
IEF142I - STEP WAS EXECUTED - COND CODE 0000
IEF285I   SYS75154.T073908.RV000.MP3CARTC.OBJECT          PASSED
IEF285I   VOL SER NOS= DFSE*4.
IEF373I STEP /FORT    / START 75154.0739
IEF374I STEP /FORT    / STOP  75154.0739 CPU    0MIN 01.02SEC MAIN  94K LCS   0K

*STEP FORT    **JOB MP3CARTC*************************************************************************
*RESOURCE- CORE(K)  DISK(IO)  TAPE(IO)--UNITS(U)    IN-HASP(IO)-OUT OTHER(IO)    CPU TIME(C) STEP TIME(T)  *
*USAGE-       100         3        0          0         27        32         0    00:00:01.02  00:00:04.72  *
*****************************************************************************************************

XXLKED     EXEC PGM=FTIAUHAA,PARM='LIST,LET,XREF,SCTR',REGION=100K,       00000600
XX              COND=(4,LT,FORT),DPRTY=(3,3)                              00000700
XXSYSPRINT DD   SYSOUT=&SYSOUT                                           00000800
IEF653I SUBSTITUTION JCL - SYSOUT=A
XXSYSLIB   DD   DSN=NONO.FORTLIB,DISP=SHR                                00000900
XXSYSLIN   DD   DSN=&&OBJECT,DISP=(OLD,DELETE)                           00001000
XX         DD   DDNAME=SYSIN                                             00001100
XXSYSUT1   DD   UNIT=DISK,SPACE=(CYL,(1,1))                              00001200
XXSYSLMOD  DD   DSN=&&LOAD(MAIN),UNIT=DISK,SPACE=(CYL,(1,5,1)),          C00001300
XX              DISP=(,PASS)                                             00001400
IEF236I ALLOC. FOR MP3CARTC LKED
IEF237I 0C0   ALLOCATED TO SYSPRINT
IEF237I 150   ALLOCATED TO SYSLIB
IEF237I 155   ALLOCATED TO SYSLIN
IEF237I 155   ALLOCATED TO SYSUT1
IEF237I 145   ALLOCATED TO SYSLMOD
IEF142I - STEP WAS EXECUTED - COND CODE 0000
IEF285I   SYS1.FORTLIB                                    KEPT
IEF285I   VOL SER NOS= DFSELB.
IEF285I   SYS75154.T073908.RV000.MP3CARTC.OBJECT          DELETED
IEF285I   VOL SER NOS= DFSE*4.
IEF285I   SYS75154.T073908.RV000.MP3CARTC.R0000004        DELETED
IEF285I   VOL SER NOS= DFSE*4.
IEF285I   SYS75154.T073908.RV000.MP3CARTC.LOAD            PASSED
IEF285I   VOL SER NOS= DFSE*3.
IEF373I STEP /LKED    / START 75154.0739
IEF374I STEP /LKED    / STOP  75154.0740 CPU    0MIN 01.04SEC MAIN  95K LCS   0K

*STEP LKED    **JOB MP3CARTC*************************************************************************
*RESOURCE- CORE(K)  DISK(IO)  TAPE(IO)--UNITS(U)    IN-HASP(IO)-OUT OTHER(IO)    CPU TIME(C) STEP TIME(T)  *
*USAGE-       100       162        0          0          0        74         0    00:00:01.04  00:00:37.23  *
*****************************************************************************************************

XXGO       EXEC PGM=*.LKED.SYSLMOD,COND=((4,LT,FORT),(4,LT,LKED)),        C00001500
XX              DPRTY=(3,3)                                               00001600
XXFT05F001 DD   DDNAME=SYSIN                                             00001700
```

```
XXFT06F001 DD   SYSOUT=&SYSOUT                                                    00001800
IEF653I SUBSTITUTION JCL - SYSOUT=A
XXFT07F001 DD   SYSOUT=A                                                          00001900
//GO.SYSIN DD *
//
IEF236I ALLOC. FOR MP3CARTC GO
IEF237I 145   ALLOCATED TO PGM=*.DD
IEF237I 093   ALLOCATED TO FT05F001
IEF237I 0C9   ALLOCATED TO FT06F001
IEF237I 140   ALLOCATED TO FT07F001
IEF142I - STEP WAS EXECUTED - COND CODE 0000
IEF285I   SYS75154.T073635.RV000.MP3CARTC.LOAD             PASSED
IEF285I   VOL SER NOS= FSE#3.
IEF373I STEP /GO      / START 75154.0740
IEF374I STEP /GO      / STOP  75154.0740 CPU    0MIN 00.20SEC MAIN  20K LCS    0K

*STEP GO      **JOB MP3CARTC******************************************************************
*RESOURCE- CORE(K)  DISK(IO)  TAPE(IO)--UNITS(U)     IN-HASP(IO)-OUT OTHER(IO)    CP   TIME(C) STEP TIME(T)  *
*USAGE-      130       6          0          0          3        7          0    00..  0.20  00:00:02.4
******************************************************************************************************

IEF285I   SYS75154.T073906.RV000.MP3CARTC.LOAD             DELETED
IEF285I   VOL SER NOS= FSE#3.
IEF375I  JOB /MP3CARTC/ START 75154.0739
IEF376I  JOB /MP3CARTC/ STOP  75154.0740 CPU    0MIN 02.26SEC

*JOB MP3CARTC**2T03***151***L THOMSEN*****************************************************************
*UNITS- CORE(K*T)   DISK(IO)   TAPE(IO)  TAPE(U*T)  HASPI(IO)  HASPO(IO)  OTHER(IO)     CPU(C)      TOTAL  *
*COSTS-    $0.01     $0.05      $0.00     $0.00      $0.00      $0.00      $0.00        $0.14       $0.20  *
******************************************************************************************************
```

```
      IMPLICIT REAL*8(A-Z)
      READ 1,P,MO,TA,T1,T2,DTOT1,DTOT2,MO1,MO2,M1,M2,CP,DT2
      PRINT 1,P,MO,TA,T1,T2,DTOT1,DTOT2,MO1,MO2,M1,M2,CP,DT2
    1 FORMAT(8F10.5/6F10.5)
      CC=MO*CP*(R2**2-R1**2)
      KA1=CC*DTOT1*3600.
      KA2=CC*DTOT2*3600.
      KB1=MO1*2.*MO*(T1-TA)
      KB2=MO2*2.*MO*(T2-TA)
      K1=(KA1+KB1)/(2.*M1)
      K2=(KA2+KB2)/(2.*M2)
      A=DTOT1/DTOT2
      C3=T2-T1
      MG=(K1-K2)/(C3*DT2*(1.-A))
      TG = 1./MG*((KA2 + KB2)/(2.*M2)) + T2 + DT2
      GDYR=15.0/MG
      PRINT 2,MG,TG,GDYR
      PRINT 3,KA1,KA2
      PRINT 3,KB1,KB2
      PRINT 3,K1,K2
      PRINT 3,C3
    3 FORMAT(10X,3F20.10)
    2 FORMAT(10X,'MG=',F13.5,10X,'TG=',F13.5,10X,'GDYR=',F10.5)
      CALL EXIT
      END
```

```
490.00000  45.00000 225.00000 1050.00000  30.00000   6.50000   1.00000   5.00000
  0.00788   0.02446   0.11000 150.00000
        HG= 726.85686            TG=1266.49134          RI TAB   1.02064
             3190.9742422443        438.1458524480
                6.8056300000        245.6230000000
           225973.5072203304      62430.7099146441
              625.0000000000
```

APPENDIX 2

```
//MKOL4801 JOB (2T03,M140,5,4,9999),'D.  THOMSEN: PLOT'                 JOB 897
// EXEC SIMPLOTF,PLOTTER=PLOTTER,MAXPLTS=24,PARM.PLOT='D. THOMSEN',
// REGION=150K
XXSIMPLOTF PROC SYSOUT=A,MAXPLTS=10,PLOTTER=PRINTER                       00000010
XXFORT     EXEC PGM=IEYFORT,REGION=100K,DPRTY=(3,3)                       00000020
XXSYSPRINT DD   SYSOUT=&SYSOUT                                            00000030
IEF653I SUBSTITUTION JCL - SYSOUT=A
XXSYSLIN   DD   DSN=&&OBJECT,UNIT=DISK,SPACE=(CYL,(1,1)),               C00000040
XX              DCB=BLKSIZE=400,DISP=(,PASS)                              00000050
//FORT.SYSIN DD *
IEF236I ALLOC. FOR MKOL4801 FORT
IEF237I 000   ALLOCATED TO SYSPRINT
IEF237I 145   ALLOCATED TO SYSLIN
IEF237I 090   ALLOCATED TO SYSIN
IEF142I - STEP WAS EXECUTED - COND CODE 0000
IEF285I   SYS75094.T113535.RV000,MKOL4801.OBJECT        PASSED
IEF285I   VOL SER NOS= DFSEW3.
IEF373I STEP /FORT    / START 75094.1135
IEF374I STEP /FORT    / STOP  75094.1137 CPU    0MIN 19.34SEC MAIN 100K LCS    0K

*STEP FORT     **JOB MKOL4801**************************************************************
*RESOURCE- CORE(K)  DISK(IO)  TAPE(IO)--UNITS(U)     IN-HASP(IO)-OUT OTHER(IO)   CPU TIME(C) STEP TIME(T)  *
*USAGE-      150       44        0          0         556      617        0     00:00:19.34  00:01:10.43  *
*******************************************************************************************

XXLKED     EXEC PGM=FTIAOMAA,PARM='LIST,LET,NOXREF,SCTR',REGION=98K,  C00000060
XX              COND=(4,LT,FORT),DPRTY=(3,3)                              00000070
XXSYSPRINT DD   SYSOUT=&SYSOUT                                            00000080
IEF653I SUBSTITUTION JCL - SYSOUT=A
XXSYSLIB   DD   DSN=SYS1.FORTLIB,DISP=SHR                                 00000090
XX         DD   DSN=MPATSCH.SIMPLOT.FORTLIB,DISP=SHR                      00000100
XXSYSLIN   DD   DSN=&&OBJECT,DISP=(OLD,DELETE)                            00000110
XX         DD   DDNAME=SYSIN                                              00000120
XXSYSUT1   DD   UNIT=DISK,SPACE=(CYL,(1,1))                               00000130
XXSYSLMOD  DD   DSN=&&LOAD(MAIN),UNIT=DISK,SPACE=(CYL,(1,5,1)),        C00000140
XX              DISP=(,PASS)                                              00000150
IEF236I ALLOC. FOR MKOL4801 LKED
IEF237I 000   ALLOCATED TO SYSPRINT
IEF237I 150   ALLOCATED TO SYSLIB
IEF237I 265   ALLOCATED TO
IEF237I 145   ALLOCATED TO SYSLIN
IEF237I 145   ALLOCATED TO SYSUT1
IEF237I 145   ALLOCATED TO SYSLMOD
IEF142I - STEP WAS EXECUTED - COND CODE 0000
IEF285I   SYS1.FORTLIB                                  KEPT
IEF285I   VOL SER NOS= DFSEL8.
IEF285I   MPATSCH.SIMPLOT.FORTLIB                       KEPT
IEF285I   VOL SER NOS= DMSE01.
IEF285I   SYS75094.T113535.RV000,MKOL4801.OBJECT        DELETED
IEF285I   VOL SER NOS= DFSEW3.
IEF285I   SYS75094.T113535.RV000.MKOL4801.R0000004      DELETED
IEF285I   VOL SER NOS= DFSEW3.
IEF285I   SYS75094.T113535.RV000.MKOL4801.LOAD          PASSED
IEF285I   VOL SER NOS= DFSEW3.
IEF373I STEP /LKED    / START 75094.1137
IEF374I STEP /LKED    / STOP  75094.1138 CPU    0MIN 01.79SEC MAIN  98K LCS    0K

*STEP LKED     **JOB MKOL4801**************************************************************
*RESOURCE- CORE(K)  DISK(IO)  TAPE(IO)--UNITS(U)     IN-HASP(IO)-OUT OTHER(IO)   CPU TIME(C) STEP TIME(T)  *
*USAGE-      150      356        0          0          0        5         0     00:00:01.79  00:01:01.63  *
```

13

```
XXGO       EXEC PGM=* LKED.SYSLMOD,COND=((4,LT,FORT),(4,LT,LKED)),     C00000160
XX                 C  (*,1,3)                                          00000170
XXGO.FT14F001 DD   DSNAME=&SM,UNIT=SYSDA,DISP=(NEW,PASS),              00000180
XX SPACE=(800,(120,15)),DCB=(RECFM=VS,LRECL=796,BLKSIZE=800)           00000190
XXFT05F001 DD   DDNAME=SYSIN                                           00000200
XXFT06F001 DD   SYSOUT=&SYSOUT                                         00000210
IEF653I SUBSTITUTION JCL - SYSOUT=A
XXFT07F001 DD   SYSOUT=A                                               00000215
//GO.SYSIN DD *
IEF236I ALLOC. FOR MKOL4801 GO
IEF237I 145   ALLOCATED TO PGM=*.DD
IEF237I 145   ALLOCATED TO FT14F001
IEF237I 091   ALLOCATED TO FT05F001
IEF237I 00C   ALLOCATED TO FT06F001
IEF237I 1A0   ALLOCATED TO FT07F001
IEF142I - STEP WAS EXECUTED - COND CODE 0016
IEF285I   SYS75094.T113535.RV000.MKOL4801.LOAD          PASSED
IEF285I   VOL SER NOS= DFSE=3.
IEF285I   SYS75094.T113535.RV000.MKOL4801.SM            PASSED
IEF285I   VOL SER NOS= DFSE=3.
IEF373I STEP /GO      / START 75094.1136
IEF374I STEP /GO      / STOP  75094.1140 CPU   1MIN 08.34SEC MAIN  96K LCS   0K

*STEP GO      **JOB MKOL4801**************************************************************
*RESOURCE- CORE(K)  DISK(IO)  TAPE(IO)--UNITS(U)     IN-HASP(IO)-OUT OTHER(IO)   CPU TIME(C) STEP TIME(T)  *
*USAGE-       150       49       0         0          61      3026         0    00:01:08.34  00:02:28.85  *
*******************************************************************************************************

XXPLOT EXEC PGM=&PLOTTER,REGION=104K,                                  00000220
IEF653I SUBSTITUTION JCL - PGM=PLOTTER,REGION=104K,
XX  COND=((4,LT,FORT),(4,LT,LKED),(16,LT,GO))                          00000230
XXSTEPLIB DD DSN=MPATSCH.SIMPLOT.PROG,DISP=SHR                         00000240
XXFT03F001 DD SYSOUT=&,SPACE=(1458&,(&MAXPLTS)),                       00000250
IEF653I SUBSTITUTION JCL - SYSOUT=A,SPACE=(1458R,(24)),
XX DCB=(RECFM=FBA,LRECL=133,BLKSIZE=1862,HIARCHY=1)                    00000260
XXFT05F001 DD SYSOUT=A,DCB=HIARCHY=1                                   00000270
XXFT14F001 DD DSNAME=&SM,DISP=(OLD,PASS),DCB=HIARCHY=1                 00000280
XXFT15F001 DD SYSOUT=(H,,4),DCB=(RECFM=VBS,LRECL=76,BLKSIZE=80)        00000290
//
IEF236I ALLOC. FOR MKOL4801 PLOT
IEF237I 265   ALLOCATED TO STEPLIB
IEF237I 0C1   ALLOCATED TO FT03F001
IEF237I 00D   ALLOCATED TO FT06F001
IEF237I 145   ALLOCATED TO FT14F001
IEF237I 1F0   ALLOCATED TO FT15F001
IEF142I - STEP WAS EXECUTED - COND CODE 0000
IEF285I   MPATSCH.SIMPLOT.PROG                          KEPT
IEF285I   VOL SER NOS= UMSE01.
IEF285I   SYS75094.T113535.RV000.MKOL4801.SM            PASSED
IEF285I   VOL SER NOS= DFSE=3.
IEF373I STEP /PLOT    / START 75094.1140
IEF374I STEP /PLOT    / STOP  75094.1141 CPU   0MIN 05.19SEC MAIN  92K LCS   0K

*STEP PLOT    **JOB MKOL4801**************************************************************
*RESOURCE- CORE(K)  DISK(IO)  TAPE(IO)--UNITS(U)     IN-HASP(IO)-OUT OTHER(IO)   CPU TIME(C) STEP TIME(T)  *
*USAGE-       150      110       0         0           0       448         0    00:00:05.19  00:00:29.77  *
*******************************************************************************************************
```

```
IEF285I   SYS75094.T113535.RV000.MKOLAB01.LOAD          DELETED
IEF285I   VOL SER NOS= DFSEW3.
IEF285I   SYS75094.T113535.RV000.MKOLAB01.SM            DELETED
IEF285I   VOL SER NOS= DFSEW3.
IEF375I  JOB /MKOLAB01/ START 75094.1135
IEF376I  JOB /MKOLAB01/ STOP  75094.1141 CPU    1MIN 34.66SEC

*JOB MKOLAB01**2T03***16J**'.  THOMSEN PLOT****************************************************************
*UNITS- CORE(K*T)   DISK(IO)   TAPE(IO)  TAPE(U*T)  MASPI(IO)  MASPO(IO)  OTHER(IO)      CPU(C)       TOTAL  *
*COSTS-    $0.05      $0.17      $0.00     $0.00      $0.00      $0.00      $0.00        $5.78        $6.80  *
*************************************************************************************************************
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```
      C  ONE-DIMENSIONAL TRANSIENT HEAT CONDUCTION PROGRAM (HT-2A)
      C  PROGRAMMED BY A.M.CLAUSING.  VERSION = 1 JULY 1970
      C  THIS PROGRAM IS A GENERAL PROGRAM FOR THE SOLUTION OF CONDUCTION
      C  PROBLEMS WITH TEN OR LESS REGIONS INCLUDING INTERFACIAL RESISTANCES
      C  BETWEEN REGIONS
0001        DIMENSION ANS(99),NPLOT(11),TT(150),RHOP(100),CPP(100),TTT(150)
      C
      C**DEFINITION OF LABELED COMMON -- BLK1,BLK2, AND BLK3
0002        COMMON /BLK1/ T(150),C(150),C4(150),H(150),HX(150),IBODY(10,2)
0003        COMMON /BLK2/ RADII(11),NODES(10),XKZ(150),BETA(10),CP(10),
           2RHO(10),EMISS,RHOZ,CPZ,XKRZ,RDTR(11),RI(150),RII(150),UR(10),
           2A(9),ITB(11)
0004        COMMON /BLK3/ YY(500,10),TAU(500),Q(500),ISYM,XMIN,XMAX,YMIN,YMAX,
           2IPLOT(11), TIM(150),TTR(150) , TTO(150),TS(150)
0005        COMMON /BLK4/ KOUNT,J1,J2,J3,J4,NSUP
      C
      C**INITIALIZATION OF VARIABLES NOT LOCATED IN LABELED COMMON
0006        DATA ANS,NPLOT,TNUM,TDENOM,DZ,DTIMEX,DDTX,IX,NBODY/.2,.4,1.0,2.0,
           2950.0, 11*0, .0, 1., 1., .0005,.25, 3, 2/
      C
      C**READ CHARACTERISTICS OF PROBLEM -- RAW INPUT DATA
      C
      C**DEFINITION OF NAM AND NAM1
0007        NAMELIST /NAM/ T,ANS,ISYM,YMAX,YMIN,XMAX,XMIN,NPLOT,TNUM,TDENOM,
           2NODES,XKZ,BETA,CP,RHO,RDTR,EMISS,DZ,   DTIMEX,DDTX,IX,NBODY,CPZ,
           3RHOZ,XKRZ,RADII,A,ITB,NSUP
           4/NAM1/DTIMEX,DDTX,DZ,II,NBODY,IX,XKRZ,RHOZ,CPZ,EMISS,TNUM,TDENOM,
           5ISYM,XMAX,XMIN,YMAX,YMIN,NPLOT,NODES,ANS,A,ITB,IPLOT
0008        DIMENSION TIMEF(250),F(250)
0009        READ 100,N
0010  100   FORMAT(I5)
0011        READ 200, (TIMEF(I),F(I),I=1,N)
0012  200   FORMAT (8F10.5)
0013        PRINT 202
0014  202   FORMAT (8X,'TIMEF',25X,'F')
0015        PRINT 203, (TIMEF(I),F(I),I=1,N)
0016  203   FORMAT (5X,F10.5,16X,F10.5)
0017        KOUNT=1
0018        J1=1
0019        J2=1
0020        J3=1
0021        J4=1
0022  26    READ(5,NAM)
      C
      C**CALCULATE DIMENSIONLESS LUMPED PARAMETERS, HX(I) AND C(I)
0023        CALL LUMP (II,NBODY,DZ)
      C
      C**WRITE PROBLEM PARAMETERS
0024        WRITE(6,3)
0025  3     FORMAT(29H1HEAT TRANSFER PROGRAM HT-2A /27H PROGRAMMED BY A.M.CLAU
           2SING/30H CRANK-NICOLSON ALGORITHM
           3    /26H VERSION = 1 JULY 1970     ///25H THE INPUT PARAMETERS ARE)
0026        WRITE(6,NAM1)
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0027           WRITE(6,5)                                                       00370
0028     5     FORMAT(7H0SEGMENT,3X5HIBODY,3X 9HRADII(FT),5X6HDR(FT),5X8HBDYR(FT), 00380
              26X2HCP,8X3HRHO,6X2HK2,6X4HBETA )                                 00390
0029           WRITE(6,7) (J,IBODY(J,1),IBODY(J,2),RADII(J),DR(J),BDYR(J),CP(J), 00400
              2RHO(J),XK2(J), BETA(J), J=1,NBODY)                               00410
0030     7     FORMAT(I3,I9,I4,3E12.3,  F10.3,2F10.1,F11.6)                     00420
0031           I = NBODY + 1                                                    00430
0032           WRITE(6, 9)I,RADII(I),BDYR(I)                                    00440
0033     9     FORMAT(I3,12X,E12.3,12X,E12.3//)                                 00450
0034           WRITE(6,11)                                                      00460
0035    11     FORMAT(3X1HI,7X5H M(I), 12X4HC(I), 12X4HT(I),   7X6HRADIUS )     00470
0036           WRITE(6,13)(I, M(I),C(I),T(I),RI(I),   I=1,II)                   00480
0037    13     FORMAT(I4,2E16.4,F13.2,F13.5)                                    00490
         C                                                                      00500
         C**CALCULATE OR INITIALIZE VARIOUS QUANTITIES --- SAVE T(I) AND DTIMEX 00510
0038           TSEC = DZ**2*R*DZ*CP2*3600./XKRZ                                 00520
0039           IIM1 = II - 1                                                    00530
0040           IIM2 = II - 2                                                    00540
0041           IIP1 = II + 1                                                    00550
0042           IF(ANS(1).GT..0) GO TO 131                                       00560
0043           DO 133 I=1,29                                                    00570
0044     133   ANS(I) = ANS(I)/TSEC                                             00580
0045           ANS(1) = -ANS(1)                                                 00590
0046     131   DO 15 I=1,IIP1                                                   00600
0047    15     T(T(I) = T(I)                                                    00610
0048           ATIME = DTIMEX                                                   00620
0049           DDTX=DDTX                                                        00630
0050           N=0                                                              00640
0051           IANS=1                                                           00650
0052           TAUT = .0                                                        00660
0053           TAU(1) = .0                                                      00670
0054           ITIM = 0
         C
0055           SQIN=0.0
0056           SQSTR=0.0
0057           SQUT=0.0
0058           NT=0
0059           DO 17 J=1,NBODY
0060           NT1=NT + 1
0061           NT=NODES(J) + NT
0062           NTM1 = NT - 1
0063           DO 17 I=NT1,NT
0064           CPP(I)=CP(J)
0065      17   RHOP(I)=RHO(J)
         C                                                                      00680
         C                                                                      00820
         C**START OF SOLUTION OF PROBLEM                                        00830
         C  POINT OF MAJOR LOOP ENTRY -- SN25(NO NEW DTIMEX), SN24(NEW DTIMEX)  00840
0066     24    DO 14 I=2,IIM1                                                   00850
0067     14    CX(I) = C(I)/DTIMEX*2.                                           00860
0068      25   CALL LUMP (II,NBODY,DZ)                                          00870
0069           CALL CHANGE(NBODY,TSEC,TAUT,II,IX,N)                             00871
         C     TIME=TAUT*TSEC
```

```
             C      WA(I) = WAOT(I)/ROTP(I)
             C      CALL LINEAR(TIME,TIMEF,F,FACTOR)
             C      WA(I)=WA(I)*FACTOR                                          00880
 0070               CALL SOLVE (IIM1,IIM2,II,MDOT,BETA)
             C  ENERGY BALANCE (ONE BODY)
 0071               DETM=DTIMEX*TSEC/3600.0
 0072               USTM=0.0
 0073               USTR = (RI(2) - RI(1))/2.*RHOP(1)*CPP(1)*6.2832*(RI(1) +
                   1(RI(2) - RI(1))/4.)*(T(2) - TS(2))
 0074               QSTR = (RI(NT+1) - RI(NT))/2.*RHOP(NT)*CPP(NT)*6.2832*(RI(NT+1) -
                   1(RI(NT+1) - RI(NT))/4.)*(T(NT+1) - TS(NT+1)) + QSTR
 0075               DO 27 I= 2,NT-1
 0076               QSTR=(RI(I+1) - RI(I))*RHOP(I)*CPP(I)*6.2832*RI(I)*(T
                   1(I+1) - TS(I+1)) + QSTR
 0077            27 CONTINUE
 0078               QIN=HI(1)*XKRZ*6.2832*(T(1) - T(2))
 0079               QOUT = HE(IIM1)*XKRZ*6.2832*(T(IIM1) - T(II))
 0080               SQIN = SQIN + QIN*DETM
 0081               SQSTR = SQSTR + QSTR
 0082               SQUT = SQUT + QOUT * DETM
 0083               SUM = SQSTR + SQUT
 0084               ENBL = (SQIN - SUM) / SQIN*100.0
             C
 0085               DO 30 I = 1,IIP1
 0086          30   TS(I) = T(I)                                                00890
 0087               N = N + 1                                                   00900
 0088               TAUT = TAUT +DTIMEX                                         00910
             C                                                                  01010
             C                                                                  01020
             C**END OF TIME STEP                                                01030
             C**IF TIMEX=DDDTX DOUBLE TIME INCREMENT                            01040
 0089          21   IF(TAUT.LT.DDDTX) GO TO 29                                  01050
 0090               IRET = 1                                                    01060
 0091               DTIMEX = DTIMEX*2.                                          01070
 0092               DDDTX = 2.*DDDTX                                            01080
 0093               WRITE(6,31) DTIMEX,TAUT                                     01090
 0094          31 FORMAT(//57H TIME INCREMENT DOUBLED. NEW DIMENSIONLESS INCREMENT 1   01100
                   2S = ,F7.4/34H THE CURRENT DIMENSIONLESS TIME IS =,F7.4)     01040
             C 21   IF(TAUT.LT.DDDTX) GO TO 29                                  01050
             C      IRET = 1                                                    01060
             C      DTIMEX = DTIMEX*2.                                          01070
             C      DDDTX = 2.*DDDTX                                            01080
             C      WRITE(6,31) DTIMEX,TAUT                                     01090
             C  31 FORMAT(//57H TIME INCREMENT DOUBLED. NEW DIMENSIONLESS INCREMENT 1   01100
             C      2S = ,F7.4/34H THE CURRENT DIMENSIONLESS TIME IS =,F7.4)
             C    INCREASE TIME INCREMENT FOR COOLING
             C      IF(FACTOR .LT. .5 ) GO TO 260
             C      IF(FACTOR .GT. .5 ) GO TO 280
             C 260 DTIMEX = .005
             C      GO TO 300
             C 280 DTIMEX = .0005
             C 300 IRET = 1
 0095               GO TO 33
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0096          24  IWRT = 2                                                  
                C                                                           01130
                C***IF TAUT.GT.ANS(IANS) PRINT TEMPERATURE DISTRIBUTIONS ETC.  01140
0097          33      IF(TAUT.LT.ANS(IANS)) GO TO (24,25),IRET              01150
0098                  IANS = IANS + 1                                       01160
0099                  CALL RESULT(TAUT,TIME,TI,THUM,TOEXOM,DZ,HBODY,ANS,IANS,NC,NPLT,  01170
                    *NPLOT,NTIMES,TIP1,SOIN,SOSTM,SWUT,ENBL,IIM2,ITIM)      01180
0100                  IF(ANS(IANS).NE.0) GO TO (24,25),IRET                 01190
                C                                                           01200
                C***RESET INITIAL CONDITION AND TIME INCREMENT -- READ NEXT CASE -- SN26  01210
0101          35      DTIME = DTIME                                         01220
0102                  DO 37 I=1,IIM                                         01230
0103                  TS(I) = TTT(I)                                        01239
0104          37      T(I) = TTT(I)                                         01240
0105                  GO TO 26                                              01250
0106                  END                                                   01260
```

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*OPTIONS IN EFFECT*  NOID,EBCDIC,SOURCE,NOLIST,NODECK,LOAD,NOMAP
*OPTIONS IN EFFECT*  NAME = MAIN     , LINECNT =       56
*STATISTICS*     SOURCE STATEMENTS =       106,PROGRAM SIZE =      [illegible]734
*STATISTICS*  NO DIAGNOSTICS GENERATED
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```
      SUBROUTINE LUMP(II,NBODY,DZ)
      COMMON /BLK1/ T(150),C(150),CR(150),M(150),MR(150),INODT(10,2)
      COMMON /BLK2/ RADII(11),NODES(10),AKZ(150),BETA(10),CP(10),
     2RHO(11),EM(55),RHOZ,CPZ,AKRZ,RDTR(11),RI(150),RII(150),DR(10),
     2A(9),ITH(11)
C**THIS SUBROUTINE CALCULATES THE DIMENSIONLESS LUMPED PARAMETERS
      AZ=RHOZ*CPZ*DZ**2
      CI = .0
      C(1) = .0
      IF(RDTR(1).EQ..0) GO TO 3
      MR(1) = RADII(1)/RDTR(1)
      M(1) = MR(1)
      INODT(1,1) = 2
      GO TO 5
 3    INODT(1,1) = 1
 5    RI(1) = RADII(1)
C
C**BEGINNING OF LOOP TO CALCULATE C(I) AND M(I) FOR NBODY REGIONS(J)
      DO 9 J=1,NBODY
      DRR = RADII(J+1) - RADII(J)
      DR(J) = DRR/FLOAT(NODES(J)-1)
      INODT(J,2) = INODT(J,1) + NODES(J) - 1
      IB = INODT(J,1)
      IE = INODT(J,2) - 1
      RI(IB) = RADII(J)
C
C**CALCULATION OF C(I) AND M(I) FOR REGION J
      AJ = RHO(J)*CP(J)*DR(J)/AZ
      C(IB) = AJ*(RI(IB) + DR(J)/4.)/2.+ CI
      BJ = AKZ(J)/(AKRZ*DR(J))
      DO 1 I=IB,IE
      IF(T(I)-1672.) 10,10,14
 10   AKZ(I) = 24.3-.00870*T(I)
      GO TO 20
 14   AKZ(I) = 10.39+.00347*T(I)
 20   M(I) = BJ*(RI(I) + DR(J)/2.)
C     M(I) = BJ*(RI(I)+DR(J)/2.)
      RI(I+1) = RI(I) + DR(J)
 1    C(I+1) = AJ*RI(I+1)
      C(IE+1) = AJ*(RI(IE+1)-DR(J)/4.)/2.
C
C**CHECK TO SEE IF INTERFACIAL RESISTANCE IS ZERO AND PROCEED ACCORDINGLY
      IF(RDTR(J+1).EQ..0) GO TO 2
      CI = .0
      INODT(J+1,1) = INODT(J,2) + 1
      MR(IE+1)= RI(IE+1)/RDTR(J+1)
      M(IE +1) = MR(IE+1)
      GO TO 9
 2    CI = C(IE+1)
      INODT(J+1,1) = INODT(J,2)
 9    CONTINUE
      IF(RDTR(NBODY+1).NE..0) GO TO 11
      II = IE + 1
```

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FORTRAN IV G LEVEL  21              LUMP              DATE = 750?4           11/35/51              PAGE 0002

 0044               GO TO 13                                                         01750
 0045        11     II = IE +2                                                       01760
 0046               C(II) = .0                                                       01770
 0047        13     H(II) = .0                                                       01780
 0048               RI(II)= RADII(NBODY + 1)                                         01790
             C                                                                       01800
             C**CALCULATE THE DIMENSIONLESS RADIUS RII                               01810
 0049               DO 16 I=1,II                                                     01820
 0050        16     RII(I) = (RI(I) - RADII(1))/(RADII(NBODY+1) - RADII(1))          01830
 0051               RETURN                                                           01840
 0052               END                                                              01850
```

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FORTRAN IV G LEVEL  21                 LUMP              DATE = 75094          11/35/51              PAGE 0003

  *OPTIONS IN EFFECT*  NOID,EBCDIC,SOURCE,NOLIST,NODECK,LOAD,NOMAP
  *OPTIONS IN EFFECT*  NAME = LUMP    , LINECNT =       55
  *STATISTICS*    SOURCE STATEMENTS =       52,PROGRAM SIZE =      1504
  *STATISTICS*  NO DIAGNOSTICS GENERATED
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```
0001            SUBROUTINE LINEAR(A,X,Y,YY)
0002            DIMENSION X(1),Y(1)
0003            I=1
          C   1 IF(Y(I+1) .LT. Y(I)) GO TO 100
          C         USE FOLLOWING IF AS Y INCREASES X INCREASES
0004         11 IF(A-X(I))3,2,2
          C         USE FOLLOWING IF AS Y INCREASES X DECREASES
          C 100 IF(A-X(I))2,2,3
0005          2 I=I+1
0006            GO TO 11
0007          3 I=I-1
0008            YY=Y(I)*(A-X(I+1))/(X(I)-X(I+1))+Y(I+1)*(A-X(I))/(X(I+1)-X(I))
0009            RETURN
0010            END
```

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FORTRAN IV G LEVEL  21                 LINEAR           DATE = 75094         11/35/51              PAGE 0002

  *OPTIONS IN EFFECT*  NOID,EBCDIC,SOURCE,NOLIST,NODECK,LOAD,NOMAP
  *OPTIONS IN EFFECT*  NAME = LINEAR  , LINECNT =       55
  *STATISTICS*    SOURCE STATEMENTS =       10,PROGRAM SIZE =      506
  *STATISTICS*  NO DIAGNOSTICS GENERATED
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```
FORTRAN IV G LEVEL  21                SOLVE              DATE = 75094          11/35/51              PAGE 0001

0001            SUBROUTINE SOLVE (IIM1,IIM2,II,NBODY,BETA)
0002            DIMENSION GE(150),FE(150),DE(150),BETA(10),BE(150), BI(150)
0003            COMMON /ALF1/ T(150),C(150),CX(150),H(150),HX(150),IBODY(10,2)
          C
          C**CORRECT THE BODY CONDUCTANCES FOR VARIABLE CONDUCTIVITIES
0004      1     DO 3  J=1,NBODY
0005            IB = IBODY(J,1)
0006            IE= IBODY(J,2) - 1
0007            DO 3  I=IB,IE
0008      3     HX(I) = H(I)*(1. + BETA(J)*(T(I) + T(I+1))/2.)
          C
          C**START OF ELIMINATION -- CRANK-NICOLSON ALGORITHM
0009            DO 9 I=2,IIM1
0010            C1 = HX(I) + HX(I-1)
0011            BE(I) = CX(I) + C1
0012      9     BI(I) = CX(I) - C1
0013            GE(2) = BE(2)
0014            FE(2) = (BI(2)*T(2) + HX(2)*T(3) + HX(1)*T(1)*2.)/GE(2)
0015            DO 5 I=3,IIM1
0016            DE(I) = -HX(I-1)/GE(I-1)
0017            GE(I) = BE(I) + HX(I-1)*DE(I)
0018      5     FE(I) = (HX(I)*T(I+1) + HX(I-1)*T(I-1) + BI(I)*T(I) + HX(I-1)*
               2 FE(I-1))/GE(I)
0019            FE(IIM1) = FE(IIM1) + HX(IIM1)*T(II)/GE(IIM1)
          C
          C**BACK SUBSTITUTION
0020            T(IIM1) = FE(IIM1)
0021            DO 7 I=2,IIM2
0022            J = II - I
0023      7     T(J) = FE(J) - DE(J+1)*T(J+1)
0024            RETURN
0025            END
```

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*OPTIONS IN EFFECT*  NOID,EBCDIC,SOURCE,NOLIST,NODECK,LOAD,NOMAP
*OPTIONS IN EFFECT*  NAME = SOLVE    , LINECNT =       55
*STATISTICS*    SOURCE STATEMENTS =       25,PROGRAM SIZE =      4034
*STATISTICS*  NO DIAGNOSTICS GENERATED
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```
0001          SUBROUTINE RESULT(TAUT,IIM1,II,TNUM,TDENOM,DZ,NBODY,ANS,IANS,NC,  02180
             2NPT,NPLOT,DTIMEX,IIP1,SQIN,SQSTR,SQUT,ENBL,IIM2,ITIM)
0002          DIMENSION TSTAR(150),XM(10),ANS(30),NPLOT(11),Y(500), TT(150)     02200
0003          COMMON /BLK1/ T(150),C(150),CX(150),H(150),HX(150),IBODY(10,2)    02210
0004          COMMON /BLK2/ RADII(11),NODES(10),XKZ(150),BETA(10),CP(10),       02220
             2RHO(10),EMISS,RHOZ,CPZ,XKRZ,RDYR(11),RI(150),RII(150),DR(10),     02230
             2A(9),ITB(11)                                                      02231
0005          COMMON /BLK3/ YY(500,10),TAU(500),Q(500),ISYM,XMIN,XMAX,YMIN,YMAX, 02240
             2IPLOT(11), TIM(150),TTR(150) , TTO(150),TS(150)                   02241
0006          COMMON /BLK4/ KOUNT,J1,J2,J3,J4,NSUP
0007          REAL DATX(50),DATY(50)
        C                                                                       02250
        C**CALCULATE DIMENSIONAL TIME,HEAT FLOWS PER UNIT DEPTH, TSTARS, M'S    02260
        C**AND WEIGHTED AVERAGE TEMPERATURE.  PRINT THESE QUANTITIES.           02270
0008           CALL TAVE(II,IIP1)                                               02280
0009           TSEC  = DZ**2 * RHOZ* CPZ * 3600./ XKRZ                          02290
0010          TIME = TAUT * TSEC                                                02300
0011          QIN = HX(1)*XKRZ*6.2832*(T(1) - T(2))                             02310
0012          QOUT = HX(IIM1)*XKRZ*6.2832*(T(IIM1) - T(II))                     02320
0013          HOUT=HX(IIM1)*XKRZ/RI(IIM1)
0014          HCON=XKRZ/RDYR(NBODY+1)
0015          HRA=HOUT-HCON
0016          HIN=HX(1)*XKRZ/RADII(1)
0017          DO 1 I=1,IIP1                                                     02330
0018    1     TSTAR(I) = (T(I) - TNUM)/TDENOM                                   02340
0019          DO 3 J=1,NBODY                                                    02350
0020    3     XM(J) = DR(J)**2/(DTIMEX*DZ**2)                                   02360
0021          WRITE(6,5) TAUT                                                   02370
0022    5     FORMAT(////22H0 DIMENSIONLESS TIME =,F7.3,10X28HHEAT FLOW PER FT (  02380
             2BTU/HR-FT),10X48HCOMBINED CONVECTION COEFFICIENT (BTU/HR-FT**2-F)) 02390
0023          WRITE(6,7) TIME,QIN,QOUT,HOUT,HRA                                 02400
0024    7     FORMAT(22H  REAL TIME (SECONDS)=,E11.3,3X4HQIN=E12.3,7H  QOUT=,E12  02410
             2.3,3X7H HR+HC=,E12.3,3X3HHR=,E12.3)
0025          WRITE(6,20) SQIN,SQSTR,SQUT,ENBL
0026    20    FORMAT(/5X,'SUMQIN=',F10.5,10X,'SUMQSTR=',F10.5,10X,'SUMQOUT=',
             2F10.5,10X,'ENERGY BALANCE=',F10.5)
0027          WRITE(6,9) (XM(I),I=1,NBODY)                                      02430
0028    9     FORMAT(39H0 M VALUES FOR REGIONS 1 THRU NBODY ARE,10F6.2)         02440
0029          WRITE(6,8) HIN
0030    8     FORMAT(25H0  HIN  (BTU/HR-FT**2-F)=,10F8.2)
        C*****PRINT THERMAL CONDUCTIVITIES
0031          WRITE(6,14) IIM2,(XKZ(I),I=2,IIM2)                                02443
0032    14    FORMAT(5X,'THERMAL CONDUCTIVITIES FOR XKZ(2) THRU XKZ(',I3,')  FOL  02444
             2LOW'/(5F10.2,5X,5F10.2))                                          02445
        C                                                                       02450
        C**PRINT THE DIMENSIONAL TEMPERATURES                                   02460
0033          WRITE(6,11) T(1),IIM1,(T(I),I=2,IIM1)                             02470
0034    11    FORMAT(  /35H0THE DIMENSIONAL TEMPERATURES ARE  /6H T(1)=,F10.2/  02480
             213H T(2) THRU T(,I3,7H)  FOLLOW/(5F10.2,5X,5F10.2))               02490
0035          WRITE(6,13)II, T(II), T(IIP1)                                     02500
0036    13    FORMAT(3H T(,I3,2H)=,F12.2,6X,7HT(AVE)=,F12.2)                    02510
        C                                                                       02520
        C**IF ANS(30).NE..0. PRINT THE DIMENSIONLESS TEMPERATURES               02530
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0037              WRITE(6,15)TSTAR(1),IIM1,(TSTAR(I),I=2,IIM1)          02550
0038              WRITE(6,13) II,TSTAR(II), TSTAR(IIP1)                   02560
0039        15    FORMAT( /35HOTHE DIMENSIONLESS TEMPERATURES ARE/6H T(1)=,F10.2/  02570
                 213H T(2) THRU T(,I3,9H)  FOLLOW/(5F10.3,5X,5F10.3))     02580
            C     PLOT OF AVG TEMP. VS TIME
0040              REAL DATAAX(150), DATAAY(150)
0041              ITIM = ITIM + 1
            C     TAVE = T(IIP1)
0042              TT(ITIM) = T(IIP1)
0043              TTM(ITIM) = T(2)
0044              TTB(ITIM) = T(IIM1)
0045              TIM(ITIM) = TAUT*TSEC
0046              IF(IPLOT(11) .EQ. 0) GO TO 18
0047              IF(ANS(IANS) .NE..0) GO TO 18
0048              DO 17 J = 1, ITIM
0049              DATAAY(J1) = TT(J)
0050              DATAAX(J1) = TIM(J)
0051           17 J1=J1+1
0052              IF(NSUP.EQ.0) GO TO 162
0053              IF(KOUNT.LT.(NSUP+1)) GO TO 18
0054          162 CALL GRAPH (ITIM, DATAAX, DATAAY, 3, 1, 8.0, 8.0, 0.0, 0.0,
                 20.0, 0.0,  'TIME SECONDS', 'TEMPERATURE (AVE) F',
                 2'TRANSIENT TEMP.', 'VARIOUS RADII')
0055              ITIM1=ITIM +1
0056              IF(NSUP.EQ.0) GO TO 18
0057              DO 161 IT=1,NSUP
0058              DO 160 I=1,ITIM
0059              DATX(I)=DATAAX(ITIM1)
0060              DATY(I)=DATAAY(ITIM1)
0061          160 ITIM1=ITIM1+1
0062          161 CALL GRAPH(ITIM,DATX,DATY,3,1,0.0,8.0,0.0,0.0,
                 20.0, 0.0,  'TIME SECONDS', 'TEMPERATURE (AVE) F',
                 2'TRANSIENT TEMP.', 'VARIOUS RADII')
0063        18    CONTINUE
            C     PLOT BORE TEMP. VS TIME
0064              IF(IPLOT(10) .EQ. 0) GO TO 19
0065              IF(ANS(IANS) .NE..0) GO TO 19
0066              REAL DATAXA(150), DATAYA(150)
0067              DO 21 J = 1,ITIM
0068              DATAYA(J2) = TTB(J)
0069              DATAXA(J2) = TIM(J)
0070           21 J2=J2+1
0071              IF(NSUP.EQ.0) GO TO 172
0072              IF(KOUNT.LT.(NSUP+1)) GO TO 19
0073          172 CALL GRAPH (ITIM, DATAXA, DATAYA, 3, 1, 8.0, 8.0, 0.0, 0.0, 0.0,
                 20.0, 'TIME SECONDS','TEMPERATURE (BORE) F',
                 2'TRANSIENT BORE TEMP','CALCULATED DATA')
0074              ITIM2=ITIM+1
0075              IF(NSUP.EQ.0) GO TO 19
0076              DO 171 IT=1,NSUP
0077              DO 170 I=1,ITIM
0078              DATX(I)=DATAXA(ITIM2)
0079              DATY(I)=DATAYA(ITIM2)
```

```
0080        173 ITIM2=ITIM2+1
0081        171 CALL GRAPH(ITIM+DATX,DATY+3,1+0.0+8.0+6.0+6.0+0.0,
               20.0+ 'TIME SECONDS','TEMPERATURE (BORE) F',
               2'TRANSIENT BORE TEMP','CALCULATED DATA')
0082       19     CONTINUE
           C   PLOT BARREL EXTERNAL TEMP. VS TIME
0083              IF(IPLOT(9) .EQ. 0) GO TO 25
0084              IF(ANS(IANS) .NE..0) GO TO 25
0085              REAL DATAIX(150), DATAIY(150)
0086              DO 23 I = 1,ITIM
0087              DATAIY(J3) = TTO(J)
0088              DATAIX(J3) = TIM(J)
0089         23 J3=J3+1
0090              IF(NSUP.EQ.0) GO TO 212
0091              IF(KOUNT.LT.(NSUP+1)) GO TO 25
0092        212 CALL GRAPH (ITIM, DATAIX,  DATAIY,  3, 1, 8.0, 6.0, 0.0, 0.0,
               20.0, 0.0, 'TIME SECONDS','TEMPERATURE(EXTERNAL) F', '
               2TRANSIENT EXTERNAL TEMP.', 'CALCULATED DATA')
0093              ITIM3=ITIM+1
0094              IF(NSUP.EQ.0) GO TO 25
0095              DO 211 II=1,NSUP
0096              DO 210 I=1,ITIM
0097              DATX(I)=DATAIX(ITIM3)
0098              DATY(I)=DATAIY(ITIM3)
0099        210 ITIM3=ITIM3+1
0100        211 CALL GRAPH(ITIM+DATX,DATY+3,1+0.0+8.0+0.0+0.0,
               20.0, 0.0, 'TIME SECONDS','TEMPERATURE(EXTERNAL) F', '
               2TRANSIENT EXTERNAL TEMP.', 'CALCULATED DATA')
0101       25     CONTINUE
           C PLOT TEMP VS RADII
0102              REAL DATAX(150),DATAY(150)
0103              IF(ANS(IANS) .NE..0) RETURN
0104              DO 16 I = 2,IIM1
0105              DATAY(J4)=T(I)
0106              DATAX(J4)=RI(I)
0107         16 J4=J4+1
0108              IF(NSUP.EQ.0) GO TO 232
0109              IF(KOUNT.LT.(NSUP+1)) GO TO 27
0110        232 CALL GRAPH (IIM2, DATAX, DATAY, 3, 1, 8.0, 8.0, 0.0, 0.0, 0.0,0.0,
               2'RADIUS FT', 'TEMPERATURE F', 'THERMAL DATA ', 'RADIAL TEMP.')
0111              ITIM4=IIM2+1
0112              IF(NSUP.EQ.0) GO TO 27
0113              DO 231 II=1,NSUP
0114              DO 230 I=1,IIM2
0115              DATX(I)=DATAX(ITIM4)
0116              DATY(I)=DATAY(ITIM4)
0117        230 ITIM4=ITIM4+1
0118        231 CALL GRAPH(IIM2+DATX,DATY+3,1+0.0+8.0+0.0+0.0+0.0+0.0,
               2'RADIUS FT', 'TEMPERATURE F', 'THERMAL DATA ', 'RADIAL TEMP.')
           C                                                               02590
0119       27     KOUNT = KOUNT + 1
0120              RETURN                                                   02870
0121              END                                                      02880
```

```
*OPTIONS IN EFFECT*  NOID,EBCDIC,SOURCE,NOLIST,NODECK,LOAD,NOMAP
*OPTIONS IN EFFECT*  NAME = RESULT  , LINECNT =       55
*STATISTICS*    SOURCE STATEMENTS =      121,PROGRAM SIZE =    13794
*STATISTICS*  NO DIAGNOSTICS GENERATED
```

```
FORTRAN IV G LEVEL  21                TAVE                DATE = 75094         11/35/51              PAGE 0001

 0001              SUBROUTINE TAVE(II,IIP1)                                              02890
 0002              COMMON /BLK1/ T(150),C(150),CX(150),H(150),HX(150),IBODY(10,2)       02900
             C                                                                           02910
             C**CALCULATE WEIGHTED AVERAGED TEMPERATURE AND STORE IT IN T(IIP1)         02920
 0003              SUM = .0                                                              02930
 0004              SUM2 = .0                                                             02940
 0005              DO 39 I=1,II                                                          02950
 0006              SUM = SUM + C(I)*T(I)                                                 02960
 0007        39    SUM2 = SUM2 + C(I)                                                    02970
 0008              T(IIP1) = SUM/SUM2                                                    02980
 0009              RETURN                                                                02990
 0010              END                                                                   03000
```

```
FORTRAN IV G LEVEL  21              TAVE              DATE = 75094          11/35/51              PAGE 0002

   *OPTIONS IN EFFECT*  NOID,EBCDIC,SOURCE,NOLIST,NODECK,LOAD,NOMAP
   *OPTIONS IN EFFECT*  NAME = TAVE     , LINECNT =        55
   *STATISTICS*    SOURCE STATEMENTS =        10,PROGRAM SIZE =       [illegible]2
   *STATISTICS*  NO DIAGNOSTICS GENERATED
```

```
0001            SUBROUTINE CHANGE (NBODY,TSEC,TAUT,II,I1,NNN)                        03010
0002            DIMENSION HZ(1),N1(1),N2(1)                                          03020
0003            COMMON /BLK1/ T(150),C(150),CR(150),H(150),HX(150),IBODY(10,P)       03030
0004            COMMON /BLK2/ RADII(11),NODES(10),XXZ(150),BETA(10),CP(10),          03040
               2RHO(10),EMISS,RHOZ,COZ,AKRZ,ROTR(11),RI(150),RII(150),DR(10),       03050
               2A(9),ITR(11)                                                        03051
          C                                                                         03060
          C     J     = NUMBER OF R'S WHICH ARE TEMP. OR TIME DEPENDENT             03070
          C     N1(J)= RESISTOR NUMBER -- N1(J) = J1                                03080
          C     N2(J)= RESISTOR TYPE                                                03090
          C     HZ(J)= RESISTOR'S INITIAL VALUE                                     03100
          C     A     = ARRAY CONTAINING COEFFICIENTS FOR FUNCTIONS, EXPONENTS ETC. 03110
          C     TSEC = CONVERSION FACTOR (REAL TIME IN SECONDS = TIMEX*TSEC)        03120
          C     EXPO1= EXPONENT N WHERE H = HZ*ABS(T(J1) - T(J1+1))**EXPO1          03130
          C     ITR  = ARRAY CONTAINING TYPE KEY FOR ALL BOUNDARY RESISTORS         03140
          C     TYPE = 1   H = CONSTANT                                             03150
          C     TYPE = 2   H = HZ*F3(TIME)                                          03160
          C     TYPE = 3   H = HZ*(DT)**EXPO1                                       03170
          C     TYPE = 4   H = HR + HC                                              03180
          C     TYPE = 5 H = HZ*F5(TIME) -- F5 IS A PERODIC RECTANGULAR WAVE        03190
          C                                                                         03200
          C  STORE INITIAL VALUES AND DETERMINE WHICH RESISTORS ARE NOT OF TYPE 1   03210
0005            IF(TAUT.GT..0) GO TO 1                                              03220
0006            N=0                                                                 03230
0007            N8 = IFIX( A(8) )                                                   03240
0008            N9 = IFIX( A(9) )                                                   03250
0009            TI = T(I)                                                           03260
0010            TII = T(II)                                                         03270
0011            HR = EMISS*.1714E-8/XKPZ                                            03280
0012            EXPO1 = A(7)                                                        03290
0013            J = 0                                                               03300
0014            IF(ITR(1).EQ.1) GO TO 7                                             03310
0015            J = 1                                                               03320
0016            N1(1) = 1                                                           03330
0017            N2(1) = ITR(1)                                                      03340
0018            HZ(1) = HX(1)                                                       03350
0019          7 DO 5 I=1,NBODY                                                      03360
0020            IF(ITR(I+1).EQ.1) GO TO 5                                           03370
0021            J = J + 1                                                           03380
0022            N1(J) = IBODY(I,2)                                                  03390
0023            N2(J) = ITR(I+1)                                                    03400
0024            J1 = N1(J)                                                          03410
0025            HZ(J) = HX(J1)                                                      03420
0026          5 CONTINUE                                                            03430
          C                                                                         03440
          C**POINT OF ENTRY FOR TIME.GT.ZERO -- CALCULATE NEW BDY TEMPERATURES      03450
0027          1 TIME = TAUT*TSEC                                                    03460
0028            T(I) = TI*(1. + A(1)*SIN(A(2)*TIME))                                03470
          C                                                                         03490
0029            T(II) = TII*(1. + TIME*(A(3) + A(4)*TIME))                          03480
          C**IF ALL H'S ARE CONSTANTS RETURN OTHERWISE RECALCULATE THOSE CHANGING   03500
0030            IF(J.EQ.0) RETURN                                                   03510
0031            DO 11 I=1,J                                                         03520
```

```
0032          J1 = N1(I)                                            03530
0033          DTEMP = ABS(T(J1)-T(J1+1))                            03540
0034          IF(DTEMP.EQ..0) DTEMP=1.                              03550
0035          N = N2(I)                                             03560
0036          GO TO (11,12,13,14,15,16,17),N                        03570
0037     12   IF(TIME.GT. 0.) GO TO 11
0038          MX(J1) = MZ(I)-A(5)*TIME*RADII(J1)/EKR2               03585
0039          GO TO 11                                              03590
0040     13   MX(J1) = MZ(I) *      DTEMP          **EXP51          03600
0041          GO TO 11                                              03610
0042     14   TA = T(J1) + 460.                                     03620
0043          TB = T(J1+1) + 460.                                   03630
0044          MX(J1) =  MD*RI(J1)     *(TA**2 + TB**2)*(TA + TB)    03640
             2  * MZ(I) * DTEMP ** EXP01                            03650
0045          GO TO 11                                              03660
0046     15   IF(N.EQ.0) MX(J1) = MZ(I) * A(5)                      03670
0047          IF(N.EQ.N8) MX(J1) = MZ(I)                            03680
0048          IF(N.EQ.N9) N =-1                                     03690
0049          N = N + 1                                             03700
0050          GO TO 11                                              03710
0051     16   GO TO 11                                              03720
0052     17   GO TO 11                                              03730
0053     11   CONTINUE                                              03740
0054          NN1 = NNN + 1                                         03750
0055          IF((MOD(NN1,IX).NE.0).OR.(J.EQ.0)) RETURN             03760
0056          DO 21 I=1,J                                           03770
0057          J1 = N1(I)                                            03780
0058     21   T(I1+I+I) = MX(J1) * EKR2 / RI(J1)                    03790
0059          RETURN                                                03800
0060          END                                                   03810
```

```
*OPTIONS IN EFFECT*  NOID,EBCDIC,SOURCE,NOLIST,NODECK,LOAD,NOMAP
*OPTIONS IN EFFECT*  NAME = CHANGE  , LINECNT =       55
*STATISTICS*    SOURCE STATEMENTS =       60,PROGRAM SIZE =     1952
*STATISTICS*  NO DIAGNOSTICS GENERATED
```

```
0001          BLOCK DATA                                                        03820
        C                                                                       03830
        C**INITIALIZATION OF LABELED COMMON TO DEFAULT VALUES                   03840
0002          COMMON /BLK1/ T(150),C(150),CX(150),H(150),HX(150),IBODY(10,2)   03850
0003          COMMON /BLK2/ RADII(11),NODES(10),XKZ(150),BETA(10),CP(10),      03860
             2RHO(10),EMISS,RHOZ,CPZ,XKRZ,BDYR(11),PI(150),RII(150),DR(10),     03870
             2A(9),ITB(11)                                                      03871
0004          COMMON /BLK3/ TY(500,10),TAU(500),Q(500),ISYM,XMIN,XMAX,YMIN,YMAX, 03880
             2IPLOT(11), TIM(150),TTR(150) , TTO(150) ,TS(150)                  03881
0005          COMMON /BLK4/ KOUNT,J1,J2,J3,J4,NSUP
0006          DATA ISYM,XMIN,XMAX,YMIN,YMAX,EMISS,RHOZ,CPZ,XKRZ,XKZ,BETA,CP,RHO/ 03890
             2 2, .0, 1., .0, 1., 1., 490.,.11, 10.,150*10., 10*.0,10*.11,10*490 03900
             3./,NODES,T,BDYR/10*5, 1.,149*.0,11*.0/,A,ITB/6*.0,    3*.0,11*1  03910
             4/,IPLOT/8*0,1,1,1/,NSUP/0/
0007          END                                                               03920
```

```
FORTRAN IV G LEVEL  21                  BLK DATA           DATE = 75094          11/35/51              PAGE 0002

   *OPTIONS IN EFFECT*  NOID,EBCDIC,SOURCE,NOLIST,NODECK,LOAD,NOMAP
   *OPTIONS IN EFFECT*  NAME = BLK DATA, LINECNT =       55
   *STATISTICS*  NO DIAGNOSTICS GENERATED

   *STATISTICS*  NO DIAGNOSTICS THIS STEP
```

```
F66-LEVEL LINKAGE EDITOR OPTIONS SPECIFIED LIST,LET,NOXREF,SCTR
         DEFAULT OPTION(S) USED -   SIZE=(92160,8192)
****MAIN        DOES NOT EXIST BUT HAS BEEN ADDED TO DATA SET
```

TIMEF	F
0.0	1.00000
2.50000	1.00000
2.51000	0.0
30.00000	0.0
30.00999	1.00000
32.50000	1.00000
32.50999	0.0
60.00000	0.0
60.00999	1.00000
62.50000	1.00000
62.50999	0.0
90.00000	0.0
90.00999	1.00000
92.50000	1.00000
92.50999	0.0
120.00000	0.0
120.00999	1.00000
122.50000	1.00000
122.50999	0.0
150.00000	0.0
150.00999	1.00000
152.50000	1.00000
152.50999	0.0
180.00000	0.0
180.00999	1.00000
182.50000	1.00000
182.50999	0.0
210.00000	0.0
210.00999	1.00000
212.50000	1.00000
212.50999	0.0
240.00000	0.0
240.00999	1.00000
242.50000	1.00000
242.50999	0.0
270.00000	0.0
270.01001	1.00000
272.50000	1.00000
272.51001	0.0
300.00000	0.0
300.01001	1.00000
302.50000	1.00000
302.51001	0.0
330.00000	0.0
330.01001	1.00000
332.50000	1.00000
332.51001	0.0
360.00000	0.0
360.01001	1.00000
362.50000	1.00000
362.51001	0.0
390.00000	0.0
390.01001	1.00000
392.50000	1.00000
392.51001	0.0
420.00000	0.0
420.01001	1.00000
422.50000	1.00000

422.51001	0.0
450.00000	0.0
450.01001	1.00000
452.50000	1.00000
452.51001	0.0
540.00000	0.0
540.01001	1.00000
542.50000	1.00000
542.51001	0.0
570.00000	0.0
570.01001	1.00000
572.50000	1.00000
572.51001	0.0
600.00000	0.0
600.01001	1.00000
602.50000	1.00000
602.51001	0.0
630.00000	0.0
630.01001	1.00000
632.50000	1.00000
632.51001	0.0
660.00000	0.0
660.01001	1.00000
662.50000	1.00000
662.51001	0.0
690.00000	0.0
690.01001	1.00000
692.50000	1.00000
692.51001	0.0
720.00000	0.0
720.01001	1.00000
722.50000	1.00000
722.51001	0.0
750.00000	0.0
750.01001	1.00000
752.50000	1.00000
752.51001	0.0
780.00000	0.0
780.01001	1.00000
782.50000	1.00000
782.51001	0.0
810.00000	0.0
810.01001	1.00000
812.50000	1.00000
812.51001	0.0
840.00000	0.0
840.01001	1.00000
842.50000	1.00000
842.51001	0.0
870.00000	0.0
870.01001	1.00000
872.50000	1.00000
872.51001	0.0
900.00000	0.0
900.01001	1.00000
902.50000	1.00000
902.51001	0.0
930.00000	0.0
930.01001	1.00000
932.50000	1.00000

932.51001	0.0
960.00000	0.0
960.01001	1.00000
962.50000	1.00000
962.51001	0.0
990.00000	0.0
990.01001	1.00000
992.50000	1.00000
992.51001	0.0
1080.00000	0.0
1080.01001	1.00000
1082.50000	1.00000
1082.51001	0.0
1110.00000	0.0
1110.01001	1.00000
1112.50000	1.00000
1112.51001	0.0
1140.00000	0.0
1140.01001	1.00000
1142.50000	1.00000
1142.51001	0.0
1170.00000	0.0
1170.01001	1.00000
1172.50000	1.00000
1172.51001	0.0
1200.00000	0.0
1200.01001	1.00000
1202.50000	1.00000
1202.51001	0.0
1230.00003	0.0
1230.01001	1.00000
1232.50000	1.00000
1232.51001	0.0
1260.00000	0.0
1260.01001	1.00000
1262.50000	1.00000
1262.51001	0.0
1290.00000	0.0
1290.01001	1.00000
1292.50000	1.00000
1292.51001	0.0
1320.00000	0.0
1320.01001	1.00000
1322.50000	1.00000
1322.51001	0.0
1350.00000	0.0
1350.01001	1.00000
1352.50000	1.00000
1352.51001	0.0
1380.00000	0.0
1380.01001	1.00000
1382.50000	1.00000
1382.51001	0.0
1410.00000	0.0
1410.01001	1.00000
1412.50000	1.00000
1412.51001	0.0
1440.00000	0.0
1440.01001	1.00000
1442.50000	1.00000

1442.51001	0.0
1470.00000	0.0
1470.01001	1.00000
1472.50000	1.00000
1472.51001	0.0
1500.00000	0.0
1500.01001	1.00000
1502.50000	1.00000
1502.51001	0.0
1530.00000	0.0
1530.01001	1.00000
1532.50000	1.00000
1532.51001	0.0
1700.00000	0.0

```
HEAT TRANSFER PROGRAM HT-2A
PROGRAMMED BY A.M.CLAUSING
CRANK-NICOLSON ALGORITHM
VERSION = 1 JULY 1970

THE INPUT PARAMETERS ARE
&NAM1
DTIMEX=  .499999849E-03,DDTX=  .250000000   ,DZ=  .384000015E-01,II=          17,NBODY=           1,IX=           3,XKRZ=
  15.0000000     ,RHOZ=  490.000000    ,CPZ=  .110000014     ,EMISS=  .500000000     ,THUM=  .0                ,TDENOM=  1.00000000    ,
ISYM=            0,XMAX=  1.00000000    ,XMIN=  .0                ,YMAX=  1.00000000     ,YMIN=  .0                ,NPLOT=          0,
         0,         0,         0,         0,         0,         0,         0,         0,         0,NODES=
        15,         5,         5,         5,         5,         5,         5,         5,         5,ANS=
 -1.00000000  ,  5.00000000  ,  10.0000000  ,  20.0000000  ,  30.0000000  ,  40.0000000  ,  50.0000000  ,
 60.0000000   ,  70.0000000  ,  80.0000000  ,  90.0000000  ,  120.000000  ,  150.000000  ,  180.000000  ,
 210.000000   ,  240.000000  ,  260.000000  ,  300.000000  ,  .0          ,  .0          ,  .0          ,
 .0           ,  .0          ,  .0          ,  .0          ,  .0          ,  .0          ,  .0          ,
 .0           ,  .0          ,  .0          ,  .0          ,  .0          ,  .0          ,  .0          ,
 .0           ,  .0          ,  .0          ,  .0          ,  .0          ,  .0          ,  .0          ,
 .0           ,  .0          ,  .0          ,  .0          ,  .0          ,  .0          ,  .0          ,
 .0           ,  .0          ,  .0          ,  .0          ,  .0          ,  .0          ,  .0          ,
 .0           ,  .0          ,  .0          ,  .0          ,  .0          ,  .0          ,  .0          ,
 .0           ,  .0          ,  .0          ,  .0          ,  .0          ,  .0          ,  .0          ,
 .0           ,  .0          ,  .0          ,  .0          ,  .0          ,  .0          ,  .0          ,
 .0           ,  .0          ,  .0          ,  .0          ,  .0          ,  .0          ,  .0          ,
 .0           ,  .0          ,  .0          ,  .0          ,  .0          ,  .0          ,  .0          ,
 .0           ,  .0          ,  .0          ,  .0          ,  .0          ,  .0          ,  .0          ,
 .0           ,KA=  .0       ,  .0          ,  .0          ,  .0          ,  .0          ,  .0          ,
 .0           ,  .0          ,  .0          ,IT8=         1,         4,         1,         1,         1,         1,
         1,         1,         1,         1,         1,IPLOT=         0,         0,         0,         0,         0,
         0,         0,         0,         1,         1,         1
&END

REGION   IBODY   RADII(FT)   DR(FT)      BDYR(FT)    CP      RHO     KZ     BETA
  1      2  16   0.124E-01   0.353E-02   0.267E-01   0.110   490.0   15.0   0.0
  2              0.618E-01               0.150E+02

  I      H(I)          C(I)          T(I)       RADIUS
  1      0.4644E+00    0.0           1563.00    0.01240
  2      0.4014E+01    0.1573E-01      80.00    0.01240
  3      0.5014E+01    0.3772E-01      80.00    0.01593
  4      0.6014E+01    0.4608E-01      80.00    0.01946
  5      0.7014E+01    0.5444E-01      80.00    0.02299
  6      0.8014E+01    0.6279E-01      80.00    0.02651
  7      0.9014E+01    0.7115E-01      80.00    0.03004
  8      0.1001E+02    0.7950E-01      80.00    0.03357
  9      0.1101E+02    0.8786E-01      80.00    0.03710
 10      0.1201E+02    0.9622E-01      80.00    0.04063
 11      0.1301E+02    0.1046E+00      80.00    0.04416
 12      0.1401E+02    0.1129E+00      80.00    0.04769
 13      0.1501E+02    0.1213E+00      80.00    0.05121
 14      0.1601E+02    0.1296E+00      80.00    0.05474
 15      0.1701E+02    0.1380E+00      80.00    0.05827
 16      0.4120E-02    0.7213E-01      80.00    0.06180
 17      0.0           0.0             80.00    0.06180
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DIMENSIONLESS TIME =  0.052          HEAT FLOW PER FT (BTU/HR-FT)          COMBINED CONVECTION COEFFICIENT (BTU/HR-FT**2-F)
REAL TIME (SECONDS)=  0.100E+01   QIN=   0.501E+05  QOUT=   0.118E-01    HR+HC=   0.154E+01   HR=   0.540E+00

   SUMQIN=  15.05021           SUMQSTR=  54.86342           SUMQOUT=   0.00000           ENERGY BALANCE=-264.53564

 M VALUES FOR REGIONS 1 THRU NBODY ARE 16.71
  MIN  (BTU/HR-FT**2-F)=  561.80
   THERMAL CONDUCTIVITIES FOR KKZ(2) THRU KKZ( 15)  FOLLOW
    24.67     25.75     26.47     26.94     27.23           27.41     27.51     27.56     27.58     27.59
    27.60     27.60     27.60     27.60

THE DIMENSIONAL TEMPERATURES ARE
T(1)=   1563.00
T(2) THRU T( 16)  FOLLOW
   418.80    294.50    211.27    157.03    123.13          102.98     91.63     85.58     82.55     81.10
    80.45     80.18     80.07     80.03     80.02
T( 17)=        80.00      T(AVE)=       104.28

THE DIMENSIONLESS TEMPERATURES ARE
T(1)=   1563.00
T(2) THRU T( 16)  FOLLOW
  418.707   294.504   211.270   157.030   123.131         102.976    91.625    85.583    82.546    81.103
   80.455    80.180    80.070    80.029    80.020
T( 17)=        80.00      T(AVE)=       104.28

TIME INCREMENT DOUBLED. NEW DIMENSIONLESS INCREMENT IS = 0.0010
THE CURRENT DIMENSIONLESS TIME IS = 0.2505


DIMENSIONLESS TIME =  0.259          HEAT FLOW PER FT (BTU/HR-FT)          COMBINED CONVECTION COEFFICIENT (BTU/HR-FT**2-F)
REAL TIME (SECONDS)=  0.500E+01   QIN=   0.422E+05  QOUT=   0.170E+02    HR+HC=   0.158E+01   HR=   0.582E+00

   SUMQIN=  65.22284           SUMQSTR=  97.91985           SUMQOUT=   0.00594           ENERGY BALANCE= -50.14029

 M VALUES FOR REGIONS 1 THRU NBODY ARE  8.36
  MIN  (BTU/HR-FT**2-F)=  561.80
   THERMAL CONDUCTIVITIES FOR KKZ(2) THRU KKZ( 15)  FOLLOW
    23.10     24.06     24.80     25.38     25.84           26.21     26.51     26.75     26.94     27.08
    27.19     27.27     27.32     27.36

THE DIMENSIONAL TEMPERATURES ARE
T(1)=   1563.00
T(2) THRU T( 16)  FOLLOW
   597.76    487.78    403.29    336.65    283.37          240.58    206.25    178.85    157.23    140.45
   127.76    118.56    112.18    108.85    107.71
T( 17)=        80.00      T(AVE)=       105.13

THE DIMENSIONLESS TEMPERATURES ARE
T(1)=   1563.00
T(2) THRU T( 16)  FOLLOW
  597.763   487.777   403.291   336.646   283.374         240.584   206.247   178.852   157.231   140.451
  127.761   118.562   112.377   108.845   107.707
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T( 17)=       80.00      T(AVE)=      185.13

TIME INCREMENT DOUBLED. NEW DIMENSIONLESS INCREMENT IS = 0.0020
THE CURRENT DIMENSIONLESS TIME IS = 0.5005


 DIMENSIONLESS TIME =  2.520          HEAT FLOW PER FT (BTU/HR-FT)          COMBINED CONVECTION COEFFICIENT (BTU/HR-FT**2-F)
 REAL TIME (SECONDS)=  0.103E+02  QIN=   0.387E+05  QOUT=   0.746E+02    HR+HC=   0.173E+01   HR=   0.725E+00

    SUMQIN= 121.53964          SUMQSTR= 148.45602          SUMQOUT=   0.06755          ENERGY BALANCE= -22.20175

 N VALUES FOR REGIONS 1 THRU NBODY ARE  4.18
  HIN  (BTU/HR-FT**2-F)=  561.80
    THERMAL CONDUCTIVITIES FOR XKZ(2) THRU XKZ( 15)  FOLLOW
    22.40     23.28     23.97     24.52     24.97          25.35     25.66     25.92     26.13     26.29
    26.42     26.52     26.59     26.63

THE DIMENSIONAL TEMPERATURES ARE
T(1)=   1563.00
T(2) THRU T( 16)  FOLLOW
   678.98    577.68    498.67    435.07    382.96          339.89    304.20    274.75    250.67    231.33
   216.22    204.95    197.18    192.66    191.17
T( 17)=      80.00       T(AVE)=      275.77

THE DIMENSIONLESS TEMPERATURES ARE
T(1)=   1563.00
T(2) THRU T( 16)  FOLLOW
  678.981   577.681   498.666   435.067   382.959         339.886   304.201   274.748   250.674   231.334
  216.224   204.947   197.180   192.659   191.169
T( 17)=      80.00       T(AVE)=      275.77

TIME INCREMENT DOUBLED. NEW DIMENSIONLESS INCREMENT IS = 0.0040
THE CURRENT DIMENSIONLESS TIME IS = 1.0005


 DIMENSIONLESS TIME =  1.040          HEAT FLOW PER FT (BTU/HR-FT)          COMBINED CONVECTION COEFFICIENT (BTU/HR-FT**2-F)
 REAL TIME (SECONDS)=  0.201E+02   QIN=   0.337E+05  QOUT=   0.232E+03    HR+HC=   0.212E+01   HR=   0.112E+01

    SUMQIN= 222.10065          SUMQSTR= 239.08818          SUMQOUT=   0.48493          ENERGY BALANCE=  -7.86691

 N VALUES FOR REGIONS 1 THRU NBODY ARE  2.09
  HIN  (BTU/HR-FT**2-F)=  561.80
    THERMAL CONDUCTIVITIES FOR XKZ(2) THRU XKZ( 15)  FOLLOW
    21.42     22.19     22.79     23.27     23.67          24.00     24.28     24.51     24.70     24.85
    24.97     25.06     25.12     25.16

THE DIMENSIONAL TEMPERATURES ARE
T(1)=   1563.00
T(2) THRU T( 16)  FOLLOW
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    792.10     703.70     634.59     578.79     532.93          494.86     463.19     436.93     415.36     397.94
    384.27     374.01     366.30     362.71     361.26
 T( 17)=        80.00        T(AVE)=        437.10

 THE DIMENSIONLESS TEMPERATURES ARE
 T(1)=   1563.00
 T(2) THRU T( 16)   FOLLOW
   792.105    703.695    634.543    578.794    532.927         494.862    463.190    436.926    415.355    397.942
   384.270    374.011    366.809    362.712    361.263
 T( 17)=        80.00        T(AVE)=        437.10



  DIMENSIONLESS TIME =   1.563          HEAT FLOW PER FT (BTU/HR-FT)            COMBINED CONVECTION COEFFICIENT (BTU/HR-FT**2-F)
  REAL TIME (SECONDS)=  0.301E+02   QIN=    0.295E+05  QOUT=    0.433E+03     HR+HC=    0.259E+01    HR=    0.159E+01

     SUMQIN= 309.98145              SUMQSTR= 317.85913              SUMQOUT=    1.40301              ENERGY BALANCE=  -2.99389

  H VALUES FOR REGIONS 1 THRU NROOT ARE  2.00
   HIN   (BTU/HR-FT**2-F)=  561.80
     THERMAL CONDUCTIVITIES FOR XKZ(2) THRU XKZ( 15)   FOLLOW
     20.58      21.25      21.78      22.20      22.55          22.84      23.09      23.29      23.45      23.58
     23.49      23.77      23.82      23.86

 THE DIMENSIONAL TEMPERATURES ARE
 T(1)=   1563.00
 T(2) THRU T( 16)   FOLLOW
    888.38     811.00     750.50     701.66     661.48          628.12     600.35     577.30     558.34     543.02
    530.96     521.89     515.54     511.75     510.35
 T( 17)=        80.00        T(AVE)=        577.26

 THE DIMENSIONLESS TEMPERATURES ARE
 T(1)=   1563.00
 T(2) THRU T( 16)   FOLLOW
   888.378    811.003    750.504    701.656    661.480         628.121    600.346    577.295    558.343    543.018
   530.958    521.876    515.538    511.750    510.349
 T( 17)=        80.00        T(AVE)=        577.26

 TIME INCREMENT DOUBLED. NEW DIMENSIONLESS INCREMENT IS = 0.0080
 THE CURRENT DIMENSIONLESS TIME IS = 2.0004



 DIMENSIONLESS TIME =   2.082          HEAT FLOW PER FT (BTU/HR-FT)            COMBINED CONVECTION COEFFICIENT (BTU/HR-FT**2-F)
 REAL TIME (SECONDS)=  0.401E+02   QIN=    0.259E+05  QOUT=    0.674E+03     HR+HC=    0.310E+01    HR=    0.210E+01

    SUMQIN= 386.01895              SUMQSTR= 386.18479              SUMQOUT=    2.03897              ENERGY BALANCE=  -0.56467

 H VALUES FOR REGIONS 1 THRU NROOT ARE  1.04
  HIN   (BTU/HR-FT**2-F)=  561.80
    THERMAL CONDUCTIVITIES FOR XKZ(2) THRU XKZ( 15)   FOLLOW
    19.85      20.45      [illegible]      21.24      21.49          21.84      22.06      22.23      22.38      22.50
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22.53     22.66     22.71     22.74

THE DIMENSIONAL TEMPERATURES ARE
T(1)=   1563.00
T(2) THRU T( 16)  FOLLOW
  971.02     904.12     851.10     808.27     773.03          743.75     719.35     699.07     682.38     668.85
  658.17     650.08     644.38     640.91     639.51
T( 17)=      80.00       T(AVE)=      698.60

THE DIMENSIONLESS TEMPERATURES ARE
T(1)=   1563.00
T(2) THRU T( 16)  FOLLOW
  971.023    904.125    851.100    808.271    773.028         743.747    719.347    699.073    682.377    668.848
  658.160    650.079    644.383    640.906    639.507
T( 17)=      80.00       T(AVE)=      698.60


DIMENSIONLESS TIME =  2.600          HEAT FLOW PER FT (BTU/HR-FT)          COMBINED CONVECTION COEFFICIENT (BTU/HR-FT**2-F)
REAL TIME (SECONDS)=  0.501E+02   QIN=   0.227E+05  QOUT=   0.944E+03    HR+HC=   0.363E+01    HR=   0.263E+01

  SUMQIN= 454.35742          SUMQSTR= 445.24878          SUMQOUT=   5.19321          ENERGY BALANCE=   0.86177

 M VALUES FOR REGIONS 1 THRU KBODY ARE  1.04
  HIN  (BTU/HR-FT**2-F)=  561.80
   THERMAL CONDUCTIVITIES FOR XKZ(2) THRU XKZ( 15)  FOLLOW
   19.22      19.74      20.15      20.48      20.75          20.97      21.16      21.31      21.44      21.55
   21.63      21.69      21.74      21.77

THE DIMENSIONAL TEMPERATURES ARE
T(1)=   1563.00
T(2) THRU T( 16)  FOLLOW
  1044.27     984.76     938.21     900.58     869.60          843.84     822.35     804.46     789.70     777.70
   768.16     760.93     755.76     752.51     751.08
T( 17)=      80.00       T(AVE)=      803.93

THE DIMENSIONLESS TEMPERATURES ARE
T(1)=   1563.00
T(2) THRU T( 16)  FOLLOW
 1044.271    984.764    938.208    900.583    869.603         843.840    822.347    804.459    789.697    777.696
  768.162    760.928    755.755    752.515    751.080
T( 17)=      80.00       T(AVE)=      803.93


DIMENSIONLESS TIME =  3.125          HEAT FLOW PER FT (BTU/HR-FT)          COMBINED CONVECTION COEFFICIENT (BTU/HR-FT**2-F)
REAL TIME (SECONDS)=  0.601E+02   QIN=   0.200E+05  QOUT=   0.124E+04    HR+HC=   0.416E+01    HR=   0.316E+01

  SUMQIN= 513.60229          SUMQSTR= 496.19019          SUMQOUT=   8.23736          ENERGY BALANCE=   1.78636

 M VALUES FOR REGIONS 1 THRU KBODY ARE  1.04
  HIN  (BTU/HR-FT**2-F)=  561.80
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THERMAL CONDUCTIVITIES FOR KZ(2) THRU KZ( 15)  FOLLOW
  18.48     19.14     19.49     19.78     20.02          20.22     20.38     20.52     20.64     20.73
  20.80     20.86     20.90     20.93

THE DIMENSIONAL TEMPERATURES ARE
T(1)=   1503.00
T(2) THRU T( 16)  FOLLOW
 1106.73   1054.38   1013.40    980.27    952.98         930.22    911.22    895.38    882.26    871.56
  863.03    856.47    851.72    848.65    847.15
T( 17)=        80.00      T(AVE)=      894.56

THE DIMENSIONLESS TEMPERATURES ARE
T(1)=   1503.00
T(2) THRU T( 16)  FOLLOW
 1106.770  1054.379  1013.402   980.266   952.456       930.219   911.221   895.377   882.264   871.564
  863.031   856.469   851.720   848.652   847.154
T( 17)=        80.00      T(AVE)=      894.54

DIMENSIONLESS TIME =  3.632           HEAT FLOW PER FT (BTU/HR-FT)          COMBINED CONVECTION COEFFICIENT (BTU/HR-FT**2-F)
REAL TIME (SECONDS)=  0.700E+07   QIN=   2.177E+35  QOUT=   0.154E+04     HR+HC=   0.466E+01   HR=   0.366E+01

   SUMQIN= 545.03174              SUMDSTR= 539.35571            SUMQOUT=  12.04518           ENERGY BALANCE=   2.41241
 K VALUES FOR REGIONS 1 THRU NROOT ARE  1.06
  HIN  (BTU/HR-FT**2-F)=  561.80
   THERMAL CONDUCTIVITIES FOR KZ(2) THRU KZ( 15)  FOLLOW
   18.22     18.62     18.94     19.19     19.40          19.58     19.73     19.85     19.95     20.04
   20.10     20.15     20.19     20.22

THE DIMENSIONAL TEMPERATURES ARE
T(1)=   1503.00
T(2) THRU T( 16)  FOLLOW
 1159.73   1113.45   1077.20   1047.86   1023.46        1003.48    986.59    972.46    960.73    951.12
  943.40    937.40    932.98    930.04    928.45
T( 17)=        80.00      T(AVE)=      971.40

THE DIMENSIONLESS TEMPERATURES ARE
T(1)=   1503.00
T(2) THRU T( 16)  FOLLOW
 1159.725  1113.445  1077.190  1047.863  1023.450      1003.480   986.586   972.462   960.733   951.116
  943.396   937.399   932.934   930.035   928.454
T( 17)=        80.00      T(AVE)=      971.40

TIME INCREMENT DOUBLED, NEW DIMENSIONLESS INCREMENT IS = 0.0160
THE CURRENT DIMENSIONLESS TIME IS = 4.0001

DIMENSIONLESS TIME =  4.160           HEAT FLOW PER FT (BTU/HR-FT)          COMBINED CONVECTION COEFFICIENT (BTU/HR-FT**2-F)
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REAL TIME (SECONDS)=  0.302E+02   QIN=   0.156E+05  QOUT=   0.184E+04    HR+HC=   0.514E+01   HR=   0.414E+01

   SUMQIN= 511.88949          SUMQSTR= 577.51367          SUMQOUT=  15.82306          ENERGY BALANCE=   2.86869

 M VALUES FOR REGIONS 1 THRU NBODY ARE  0.52
  HIN  (BTU/HR-FT**2-F)=  561.90
   THERMAL CONDUCTIVITIES FOR XKZ(2) THRU XKZ( 15)  FOLLOW
   17.91     18.17     18.45     18.68     18.87          19.02     19.15     19.26     19.35     19.43
   19.49     19.54     19.58     19.60

THE DIMENSIONAL TEMPERATURES ARE
T(1)=   1563.00
T(2) THRU T( 16)  FOLLOW
  1206.63   1165.72   1133.66   1107.68   1086.23        1068.30   1053.26   1040.65   1030.13   1021.45
  1014.43   1008.92   1004.78   1001.91   1000.23
T( 17)=        80.00       T(AVE)=      1039.31

THE DIMENSIONLESS TEMPERATURES ARE
T(1)=   1563.00
T(2) THRU T( 16)  FOLLOW
 1206.627  1165.719  1133.657  1107.684  1086.226       1068.302  1053.261  1040.646  1030.127  1021.454
 1014.435  1008.917  1004.777  1001.911  1000.233
T( 17)=        80.00       T(AVE)=      1039.31

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 DIMENSIONLESS TIME =  4.672          HEAT FLOW PER FT (BTU/HR-FT)          COMBINED CONVECTION COEFFICIENT (BTU/HR-FT**2-F)
 REAL TIME (SECONDS)=  0.901E+02   QIN=   0.139E+05  QOUT=   0.212E+04    HR+HC=   0.558E+01   HR=   0.458E+01

   SUMQIN= 652.17725          SUMQSTR= 609.14966          SUMQOUT=  22.26405          ENERGY BALANCE=   3.18375

 M VALUES FOR REGIONS 1 THRU NBODY ARE  0.52
  HIN  (BTU/HR-FT**2-F)=  561.20
   THERMAL CONDUCTIVITIES FOR XKZ(2) THRU XKZ( 15)  FOLLOW
   17.47     17.79     18.04     18.24     18.41          18.55     18.67     18.77     18.85     18.92
   18.98     19.02     19.06     19.08

THE DIMENSIONAL TEMPERATURES ARE
T(1)=   1563.00
T(2) THRU T( 16)  FOLLOW
  1245.56   1209.11   1180.62   1157.33   1138.14        1122.08   1108.57   1097.20   1087.67   1079.77
  1073.32   1068.19   1064.26   1061.44   1059.66
T( 17)=        80.00       T(AVE)=      1095.61

THE DIMENSIONLESS TEMPERATURES ARE
T(1)=   1563.00
T(2) THRU T( 16)  FOLLOW
 1245.561  1209.110  1180.519  1157.331  1138.144       1122.084  1108.573  1097.201  1087.675  1079.772
 1073.321  1068.187  1064.258  1061.443  1059.664
T( 17)=        80.00       T(AVE)=      1095.61
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DIMENSIONLESS TIME =  5.247          HEAT FLOW PER FT (BTU/HR-FT)          COMBINED CONVECTION COEFFICIENT (BTU/HR-FT**2-F)
REAL TIME (SECONDS)=  5.120E+03   QIN=  0.101E+05  QOUT=  0.288E+04    HR+HC=  0.667E+01   HR=  0.567E+01

   SUMQIN= 751.33954           SUMQSTR= 679.94505          SUMQOUT= 43.43138          ENERGY BALANCE=  3.71696

H VALUES FOR REGIONS 1 THRU NBODY ARE  0.52
 MIN  (BTU/HR-FT**2-F)=  561.80
   THERMAL CONDUCTIVITIES FOR XKZ(2) THRU XKZ( 15)  FOLLOW
   16.71      16.94      17.12      17.27      17.39          17.50      17.59      17.66      17.72      17.78
   17.82      17.86      17.89      17.92

THE DIMENSIONAL TEMPERATURES ARE
T(1)=   1563.00
T(2) THRU T( 16)  FOLLOW
  1332.87   1306.41   1285.59   1268.64   1254.52          1242.62   1232.59   1223.88   1216.54   1210.31
  1205.08   1200.75   1197.23   1194.47   1192.39
T( 17)=       80.00        T(AVE)=      1221.61

THE DIMENSIONLESS TEMPERATURES ARE
T(1)=   1563.00
T(2) THRU T( 16)  FOLLOW
 1332.847  1306.411  1285.594  1268.635  1254.520        1242.615  1232.500  1223.879  1216.537  1210.313
 1205.084  1200.751  1197.236  1194.467  1192.393
T( 17)=       80.00        T(AVE)=      1221.61
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DIMENSIONLESS TIME =  7.792          HEAT FLOW PER FT (BTU/HR-FT)          COMBINED CONVECTION COEFFICIENT (BTU/HR-FT**2-F)
REAL TIME (SECONDS)=  0.150E+03   QIN=  0.777E+04  QOUT=  0.343E+04    HR+HC=  0.740E+01   HR=  0.640E+01

   SUMQIN= 824.51929           SUMQSTR= 722.51904          SUMQOUT= 69.79770          ENERGY BALANCE=  3.90563

H VALUES FOR REGIONS 1 THRU NBODY ARE  0.52
 MIN  (BTU/HR-FT**2-F)=  561.80
   THERMAL CONDUCTIVITIES FOR XKZ(2) THRU XKZ( 15)  FOLLOW
   16.25      16.43      16.57      16.68      16.76          16.86      16.93      16.99      17.05      17.09
   17.13      17.17      17.19      17.22

THE DIMENSIONAL TEMPERATURES ARE
T(1)=   1563.00
T(2) THRU T( 16)  FOLLOW
  1385.51   1365.08   1348.94   1335.73   1324.65          1315.23   1307.14   1300.15   1294.10   1288.85
  1284.32   1280.43   1277.11   1274.32   1272.02
T( 17)=       80.00        T(AVE)=      1297.40

THE DIMENSIONLESS TEMPERATURES ARE
T(1)=   1563.00
T(2) THRU T( 16)  FOLLOW
 1385.510  1365.077  1348.940  1335.726  1324.654        1315.235  1307.145  1300.153  1294.096  1288.850
 1284.319  1280.426  1277.112  1274.323  1272.020
T( 17)=       80.00        T(AVE)=      1297.40

TIME INCREMENT DOUBLED, NEW DIMENSIONLESS INCREMENT IS = 0.0320
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THE CURRENT DIMENSIONLESS TIME IS = 8.0002


 DIMENSIONLESS TIME =  9.344          HEAT FLOW PER FT (BTU/HR-FT)          COMBINED CONVECTION COEFFICIENT (BTU/HR-FT**2-F)
 REAL TIME (SECONDS)=  0.180E+03   QIN=   0.638E+04  QOUT=   0.379E+04    HR+HC=   0.787E+01   HR=   0.687E+01

    SUMQIN= 882.70020          SUMQSTR= 748.12891          SUMQOUT=  99.90506           ENERGY BALANCE=   3.92730

 H VALUES FOR REGIONS 1 THRU NBODY ARE  0.26
  HIN  (BTU/HR-FT**2-F)=  561.80
    THERMAL CONDUCTIVITIES FOR XKZ(2) THRU XKZ( 15)  FOLLOW
    15.97     16.12     16.24     16.33     16.41         16.48     16.54     16.60     16.64     16.68
    16.72     16.75     16.78     16.80

THE DIMENSIONAL TEMPERATURES ARE
T(1)=   1563.00
T(2) THRU T( 16)  FOLLOW
  1417.22   1400.42   1387.09   1376.13   1366.89        1358.96   1352.08   1346.06   1340.77   1336.10
  1331.98   1328.33   1325.12   1322.30   1319.84
T( 17)=        80.00        T(AVE)=      1342.99

THE DIMENSIONLESS TEMPERATURES ARE
T(1)=   1563.00
T(2) THRU T( 16)  FOLLOW
 1417.221  1400.415  1387.094  1376.132  1366.898       1358.960  1352.082  1346.064  1340.772  1336.102
 1331.977  1328.334  1325.124  1322.304  1319.841
T( 17)=        80.00        T(AVE)=      1342.99



 DIMENSIONLESS TIME = 10.912          HEAT FLOW PER FT (BTU/HR-FT)          COMBINED CONVECTION COEFFICIENT (BTU/HR-FT**2-F)
 REAL TIME (SECONDS)=  0.210E+03   QIN=   0.555E+04  QOUT=   0.402E+04    HR+HC=   0.817E+01   HR=   0.717E+01

    SUMQIN= 932.38144          SUMQSTR= 763.50000          SUMQOUT= 132.78827           ENERGY BALANCE=   3.87113

 H VALUES FOR REGIONS 1 THRU NBODY ARE  0.26
  HIN  (BTU/HR-FT**2-F)=  561.80
    THERMAL CONDUCTIVITIES FOR XKZ(2) THRU XKZ( 15)  FOLLOW
    15.81     15.93     16.04     16.12     16.19         16.25     16.31     16.35     16.40     16.43
    16.47     16.50     16.52     16.55

THE DIMENSIONAL TEMPERATURES ARE
T(1)=   1563.00
T(2) THRU T( 16)  FOLLOW
  1434.28   1421.66   1410.03   1400.42   1392.27        1385.23   1379.08   1373.64   1368.80   1364.47
  1360.58   1357.08   1353.93   1351.08   1348.51
T( 17)=        80.00        T(AVE)=      1370.36

THE DIMENSIONLESS TEMPERATURES ARE
T(1)=   1563.00
T(2) THRU T( 16)  FOLLOW
```

```
 1436.282  1421.658  1410.928  1400.418  1392.269       1385.233  1379.079  1373.640  1368.801  1364.471
 1360.582  1357.082  1353.926  1351.079  1348.512
T( 17)=       80.00        T(AVE)=      1370.36


 DIMENSIONLESS TIME = 12.494          HEAT FLOW PER FT (BTU/HR-FT)          COMBINED CONVECTION COEFFICIENT (BTU/HR-FT**2-F)
 REAL TIME (SECONDS)=  0.241E+03   QIN=   0.505E+04  QOUT=   0.416E+04    HR+HC=   0.834E+01   HR=   0.734E+01

    SUMQIN= 976.65063           SUMQSTR= 772.54980          SUMQOUT= 167.21022           ENERGY BALANCE=   3.77726

 M VALUES FOR REGIONS 1 THRU NBODY ARE  0.24
  MIN  (BTU/HR-FT**2-F)=  561.80
    THERMAL CONDUCTIVITIES FOR XKZ(2) THRU XKZ( 15)  FOLLOW
    15.71      15.82      15.92      15.99      16.06          16.12      16.17      16.21      16.25      16.29
    16.32      16.35      16.38      16.40

THE DIMENSIONAL TEMPERATURES ARE
T(1)=   1563.00
T(2) THRU T( 16)  FOLLOW
  1447.52    1434.18    1423.54    1414.73    1407.23         1400.71    1394.09    1389.89    1385.31    1381.18
  1377.43    1374.01    1370.88    1368.02    1365.39
T( 17)=       80.00        T(AVE)=      1386.48

THE DIMENSIONLESS TEMPERATURES ARE
T(1)=   1563.00
T(2) THRU T( 16)  FOLLOW
 1447.517  1434.177  1423.543  1414.729  1407.225       1400.715  1394.986  1389.887  1385.312  1381.180
 1377.429  1374.010  1370.884  1368.019  1365.387
T( 17)=       80.00        T(AVE)=      1386.48


 DIMENSIONLESS TIME = 13.504          HEAT FLOW PER FT (BTU/HR-FT)          COMBINED CONVECTION COEFFICIENT (BTU/HR-FT**2-F)
 REAL TIME (SECONDS)=  0.260E+03   QIN=   0.485E+04  QOUT=   0.422E+04    HR+HC=   0.842E+01   HR=   0.742E+01

    SUMQIN=1003.74585           SUMQSTR= 776.32959          SUMQOUT= 190.21936           ENERGY BALANCE=   3.70582

 M VALUES FOR REGIONS 1 THRU NBODY ARE  0.26
  MIN  (BTU/HR-FT**2-F)=  561.80
    THERMAL CONDUCTIVITIES FOR XKZ(2) THRU XKZ( 15)  FOLLOW
    15.67      15.78      15.87      15.94      16.00          16.06      16.11      16.15      16.19      16.22
    16.26      16.29      16.31      16.34

THE DIMENSIONAL TEMPERATURES ARE
T(1)=   1563.00
T(2) THRU T( 16)  FOLLOW
  1452.21    1439.41    1429.19    1420.71    1413.47         1407.18    1401.63    1396.67    1392.21    1388.16
  1384.47    1381.08    1377.97    1375.09    1372.44
T( 17)=       80.00        T(AVE)=      1393.22

THE DIMENSIONLESS TEMPERATURES ARE
```

```
T(1)=   1563.00
T(2) THRU T( 16)  FOLLOW
 1452.210  1439.407  1429.191  1420.710  1413.475      1407.163  1401.631  1396.674  1392.210  1388.160
 1384.666  1381.081  1377.947  1375.093  1372.435
T( 17)=        80.00        T(AVE)=       1393.22


 DIMENSIONLESS TIME = 15.564          HEAT FLOW PER FT (BTU/HR-FT)          COMBINED CONVECTION COEFFICIENT (BTU/HR-FT**2-F)
 REAL TIME (SECONDS)=  0.300E+03   QIN=   0.460E+04  QOUT=   0.??0E+04    HR+HC=   0.851E+01   HR=   0.752E+01

   SUMQIN=1056.1650?          SUMQSTR= 780.92163          SUMQOUT= 237.73306          ENERGY BALANCE=   3.55157

 H VALUES FOR REGIONS 1 THRU NBODY ARE  0.26
  HIN  (BTU/HR-FT**2-F)=  561.80
    THERMAL CONDUCTIVITIES FOR XKZ(2) THRU XKZ( 15)  FOLLOW
    15.62     15.72     15.81     15.88     15.94          15.99     16.04     16.08     16.12     16.15
    16.18     16.21     16.24     16.26

THE DIMENSIONAL TEMPERATURES ARE
T(1)=   1563.00
T(2) THRU T( 16)  FOLLOW
  1457.02   1445.77   1436.06   1427.98   1421.07        1415.05   1409.71   1404.93   1400.60   1396.65
  1393.02   1389.68   1386.58   1383.69   1381.00
T( 17)=        80.00        T(AVE)=      1401.41

THE DIMENSIONLESS TEMPERATURES ARE
T(1)=   1563.00
T(2) THRU T( 16)  FOLLOW
 1457.919  1445.770  1436.060  1427.982  1421.074      1415.049  1409.713  1404.928  1400.598  1396.648
 1393.072  1389.677  1386.577  1383.693  1381.000
T( 17)=        80.00        T(AVE)=      1401.41
```

APPENDIX 3

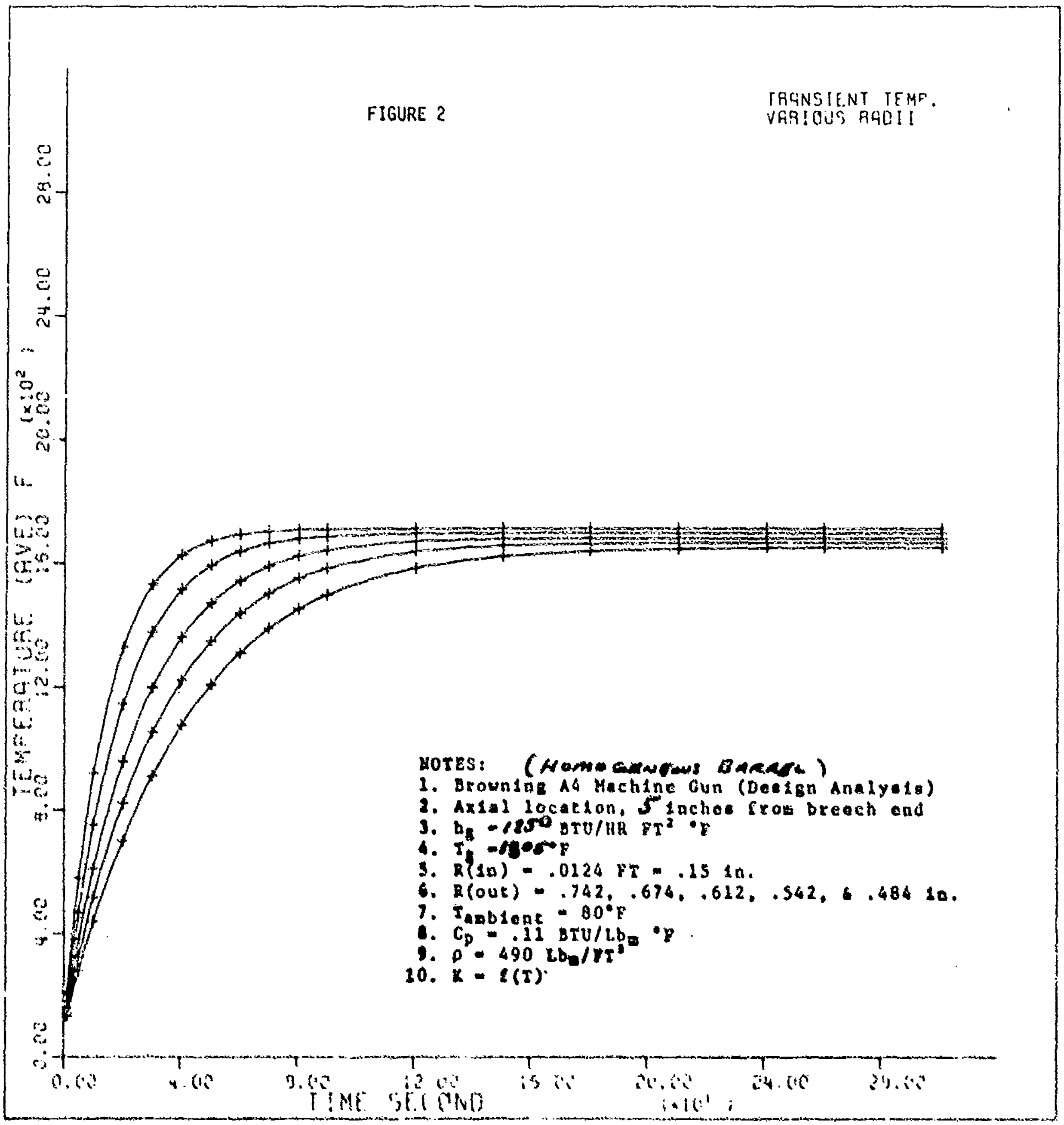
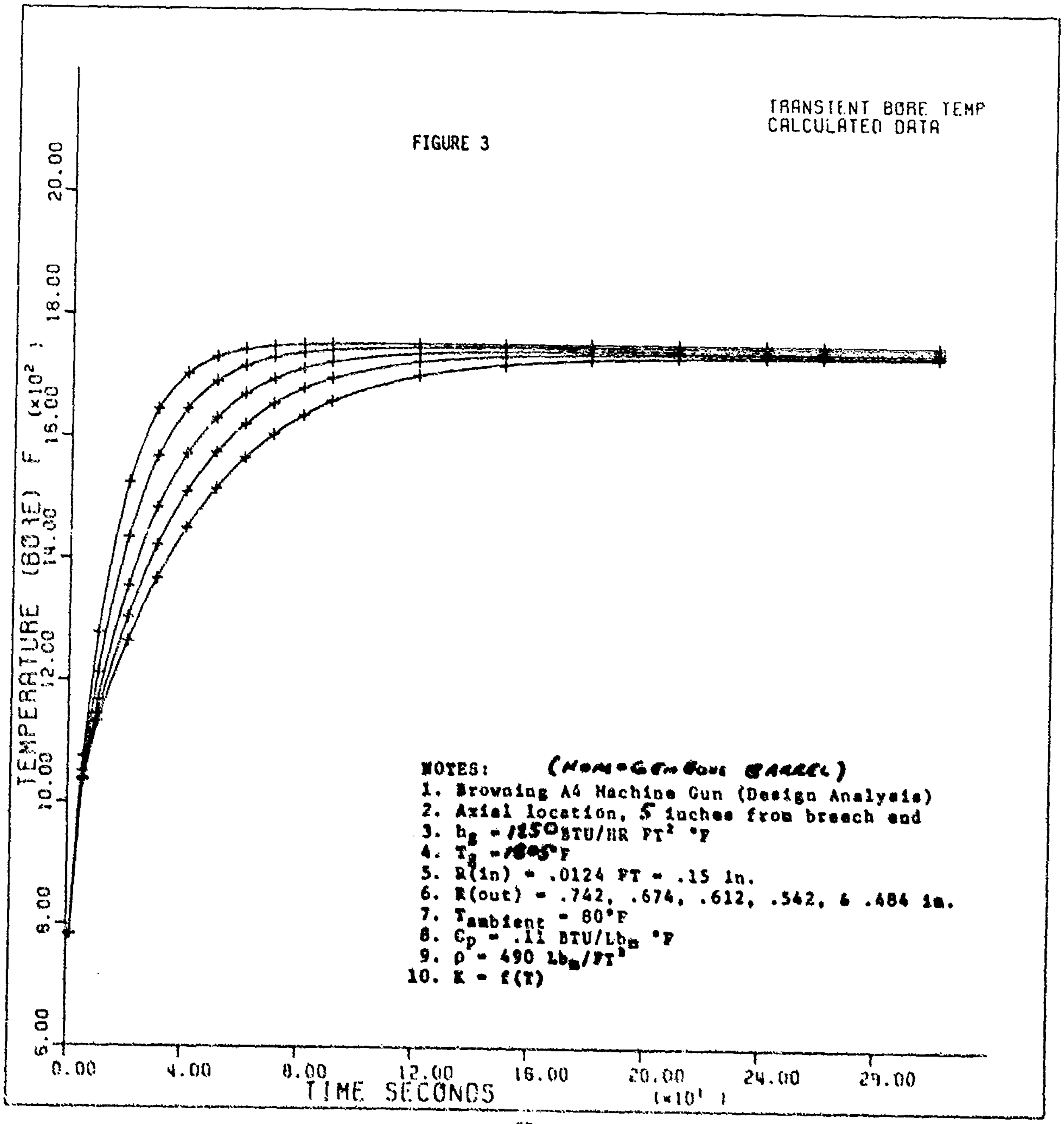
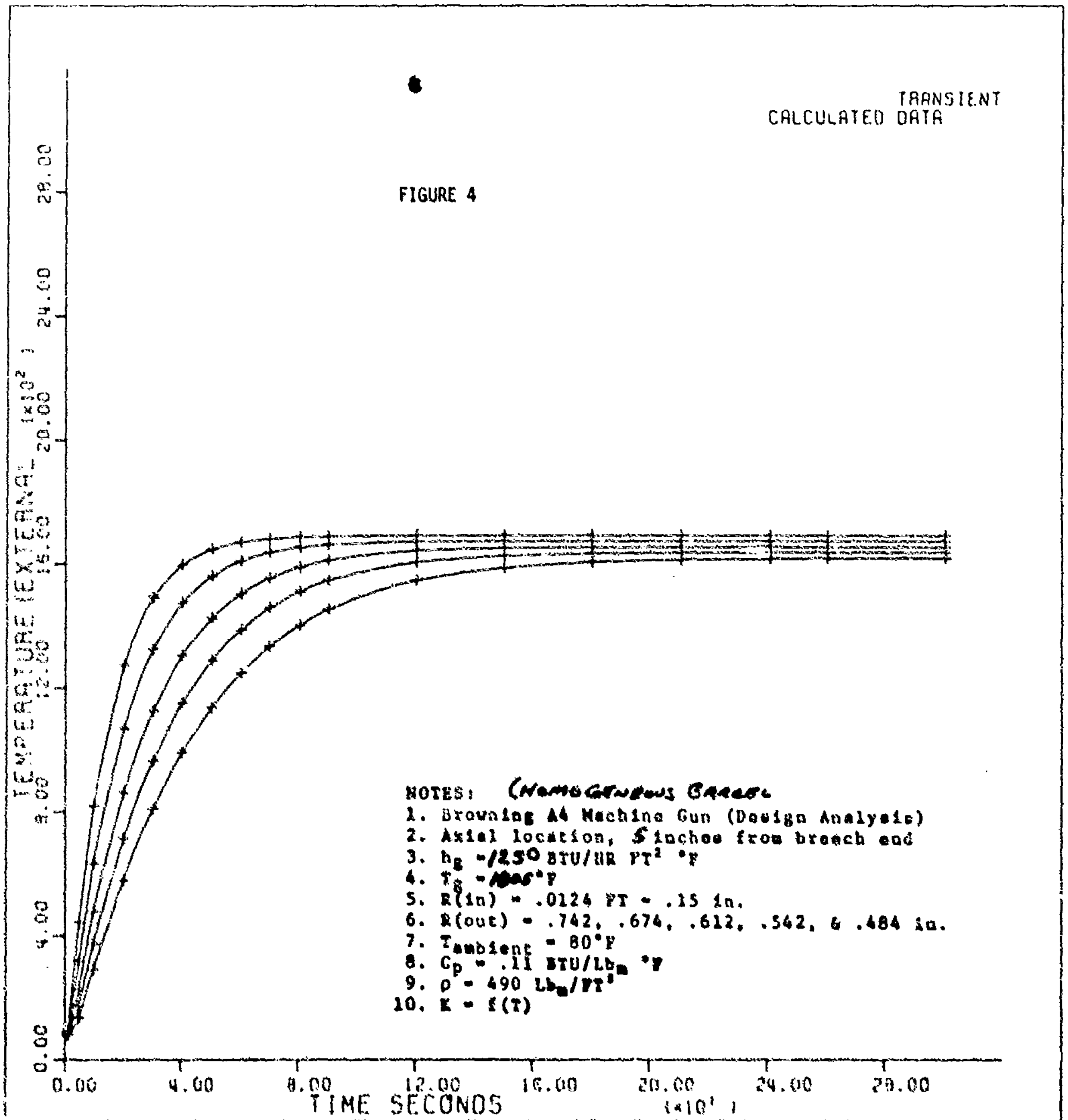
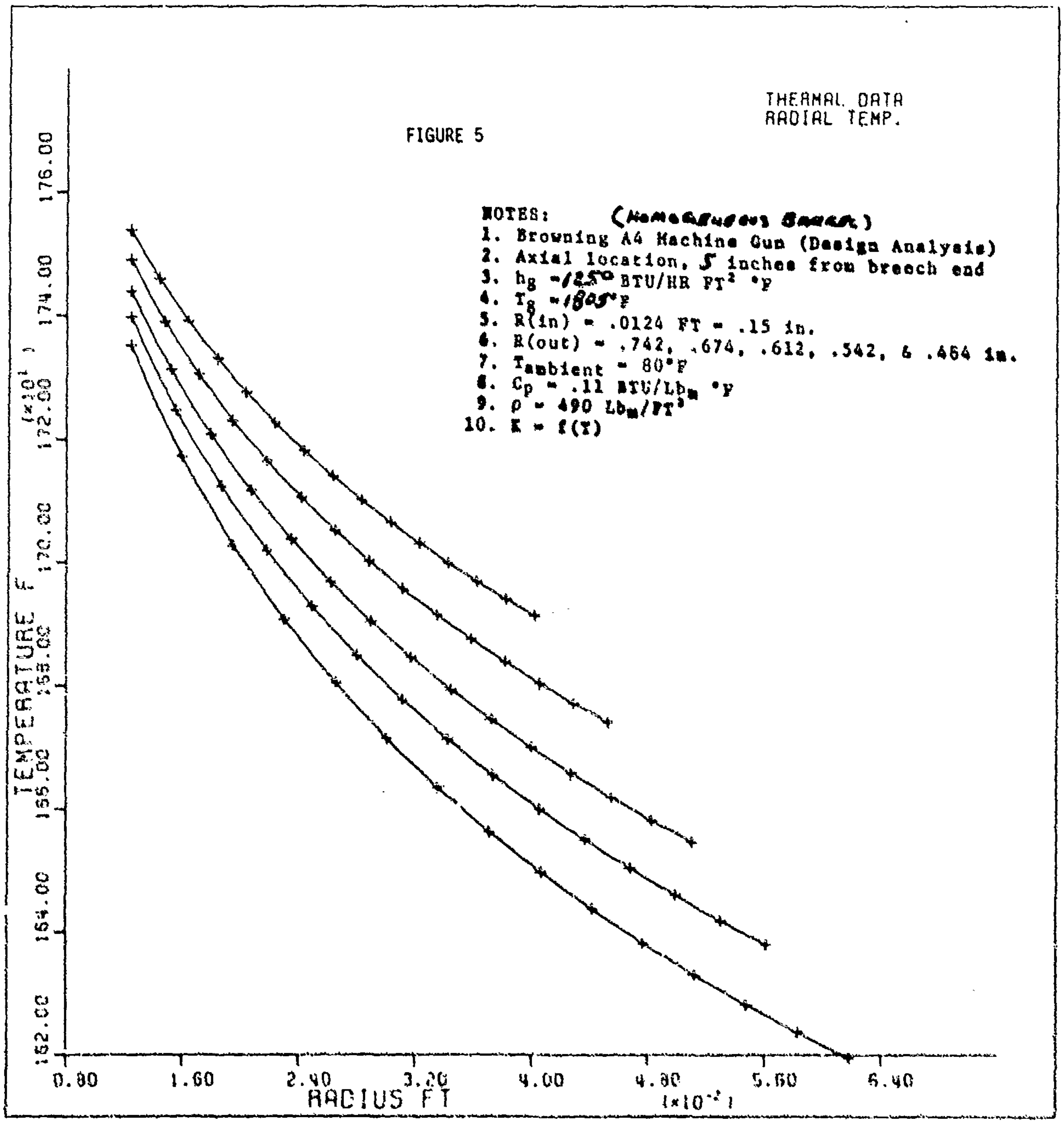
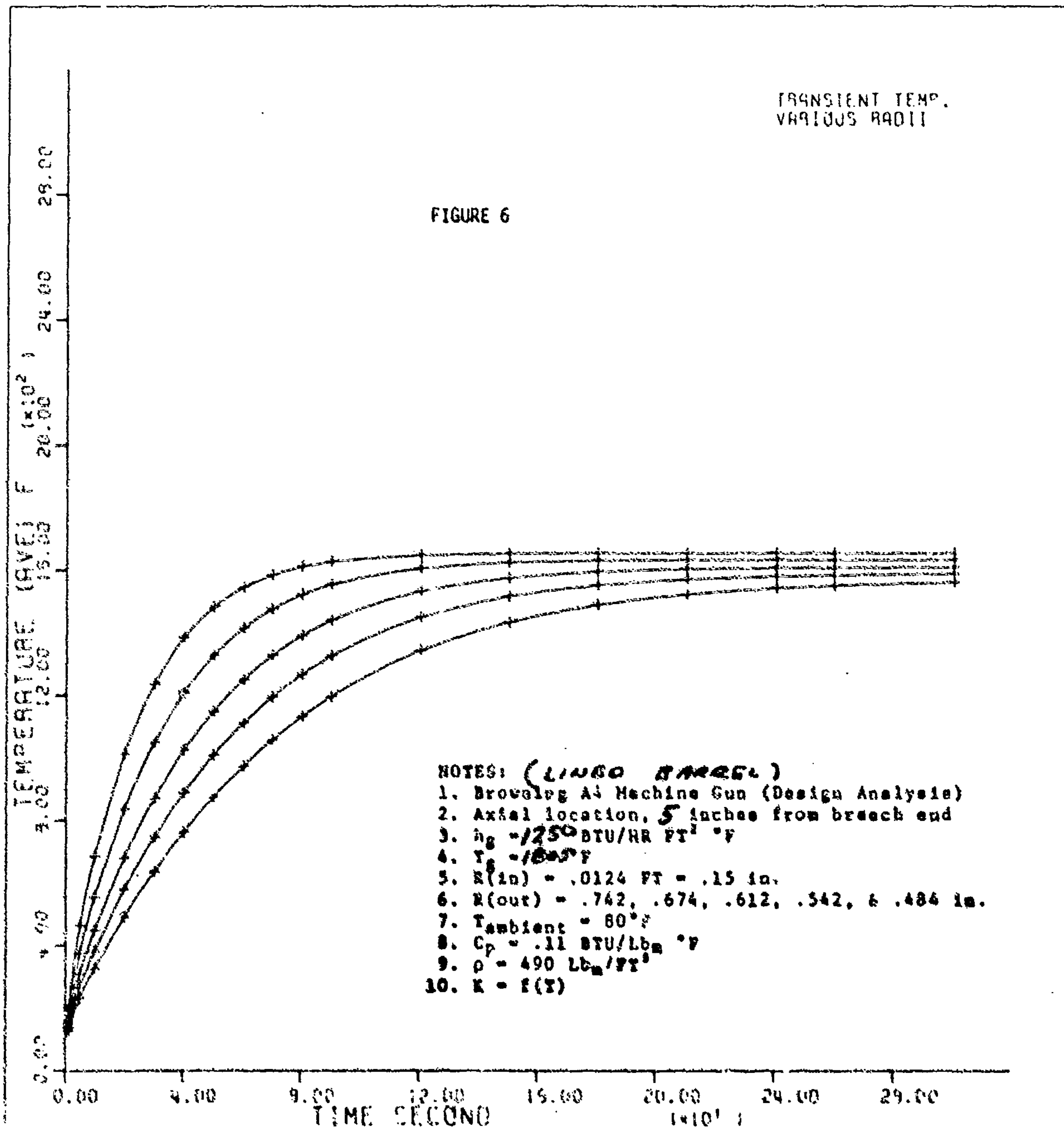


FIGURE 2
TRANSIENT TEMP.
VARIOUS RADII
TEMPERATURE (AVE) F (x10²)
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
TIME SECOND (x10¹)
NOTES: (Homogeneous Barrel)
1. Browning A4 Machine Gun (Design Analysis)
2. Axial location, 5" inches from breech end
3. h_g = BTU/HR FT² °F
4. T_g = °F
5. R(in) = .0124 FT = .15 in.
6. R(out) = .742, .674, .612, .542, & .484 in.
7. T_ambient = 80°F
8. C_p = .11 BTU/Lb_m °F
9. ρ = 490 Lb_m/FT³
10. K = f(T)


TRANSIENT BORE TEMP
CALCULATED DATA
FIGURE 3
TEMPERATURE (BORE) F (×10²)
6.00
8.00
10.00
12.00
14.00
16.00
18.00
20.00
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
TIME SECONDS (×10¹)
NOTES: (HOMOGENEOUS BARREL)
1. Browning A4 Machine Gun (Design Analysis)
2. Axial location, 5 inches from breech end
3. hg = 1250 BTU/HR FT² °F
4. Tg = 1805 °F
5. R(in) = .0124 FT = .15 in.
6. R(out) = .742, .674, .612, .542, & .484 in.
7. Tambient = 80°F
8. Cp = .11 BTU/Lbm °F
9. ρ = 490 Lbm/FT³
10. K = f(T)


TRANSIENT
CALCULATED DATA
FIGURE 4
TEMPERATURE (EXTERNAL) (x10^2)
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
TIME SECONDS (x10^1)
NOTES: (Homogeneous Barrel
1. Browning A4 Machine Gun (Design Analysis)
2. Axial location, 5 inches from breech end
3. h_g = 1250 BTU/HR FT^2 °F
4. T_g = °F
5. R(in) = .0124 FT = .15 in.
6. R(out) = .742, .674, .612, .542, & .484 in.
7. T_ambient = 80°F
8. C_p = .11 BTU/Lb_m °F
9. ρ = 490 Lb_m/FT^3
10. K = f(T)


THERMAL DATA
RADIAL TEMP.
FIGURE 5
NOTES:
1. Browning A4 Machine Gun (Design Analysis)
2. Axial location, inches from breech end
3. h_g = BTU/HR FT² °F
4. T_g = °F
5. R(in) = .0124 FT = .15 in.
6. R(out) = .742, .674, .612, .542, & .464 in.
7. $T_{ambient}$ = 80°F
8. C_p = .11 BTU/Lb_m °F
9. ρ = 490 Lb_m/FT³
10. K = f(T)
TEMPERATURE F (×10¹)
176.00
174.00
172.00
170.00
168.00
166.00
164.00
162.00
0.80
1.60
2.40
3.20
4.00
4.80
5.60
6.40
RADIUS FT (×10⁻²)


TRANSIENT TEMP.
VARIOUS RADII
TEMPERATURE (AVE) F (x10²)
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
TIME SECOND (x10¹)
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
NOTES: (LINGO BARREL)
1. Browning A4 Machine Gun (Design Analysis)
2. Axial location, 5 inches from breech end
3. h_g = 1250 BTU/HR FT² °F
4. T_g = 1805 °F
5. R(in) = .0124 FT = .15 in.
6. R(out) = .742, .674, .612, .542, & .484 in.
7. $T_{ambient}$ = 80°F
8. C_p = .11 BTU/Lb_m °F
9. ρ = 490 Lb_m/FT³
10. K = f(T)
FIGURE 6

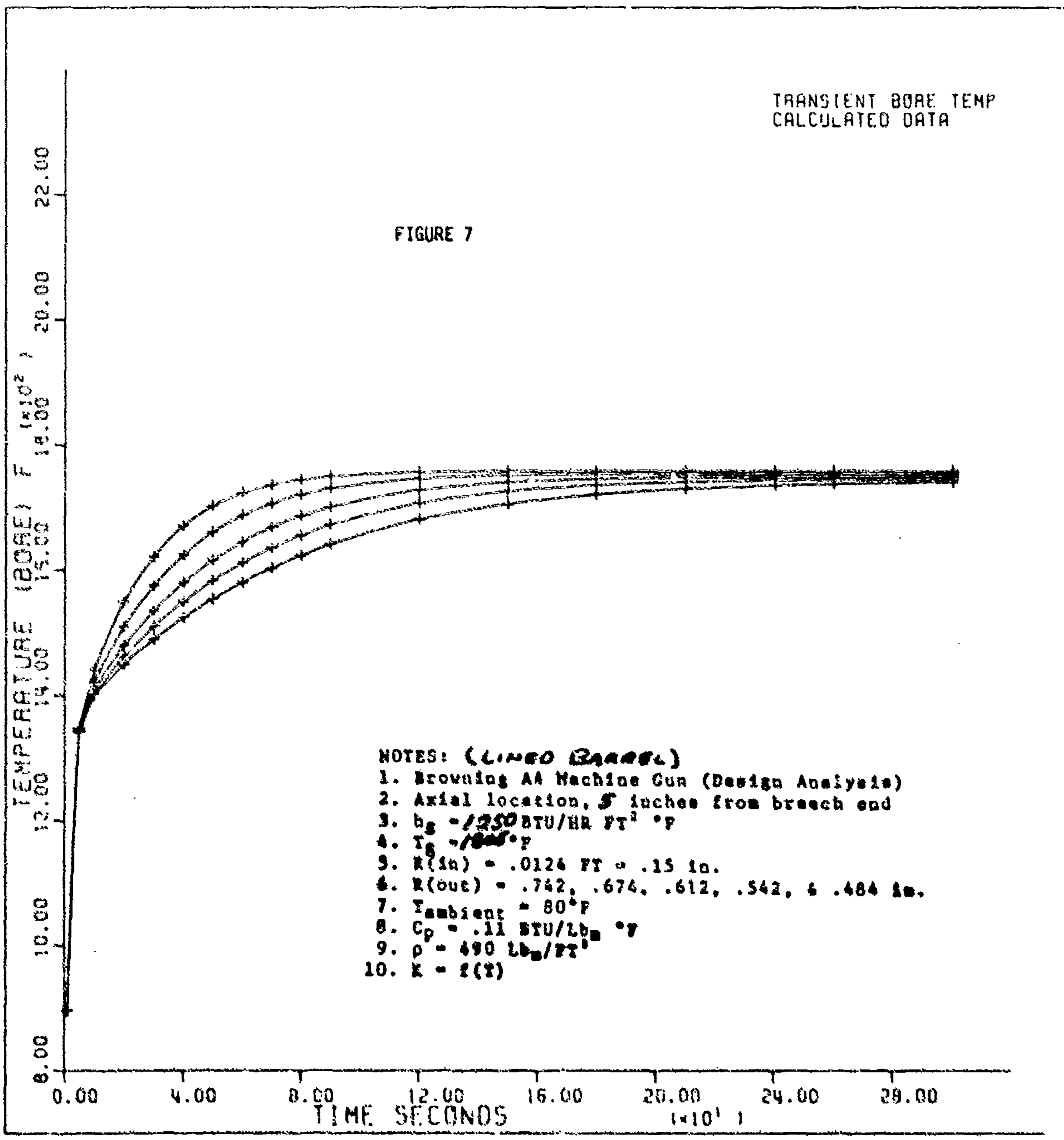
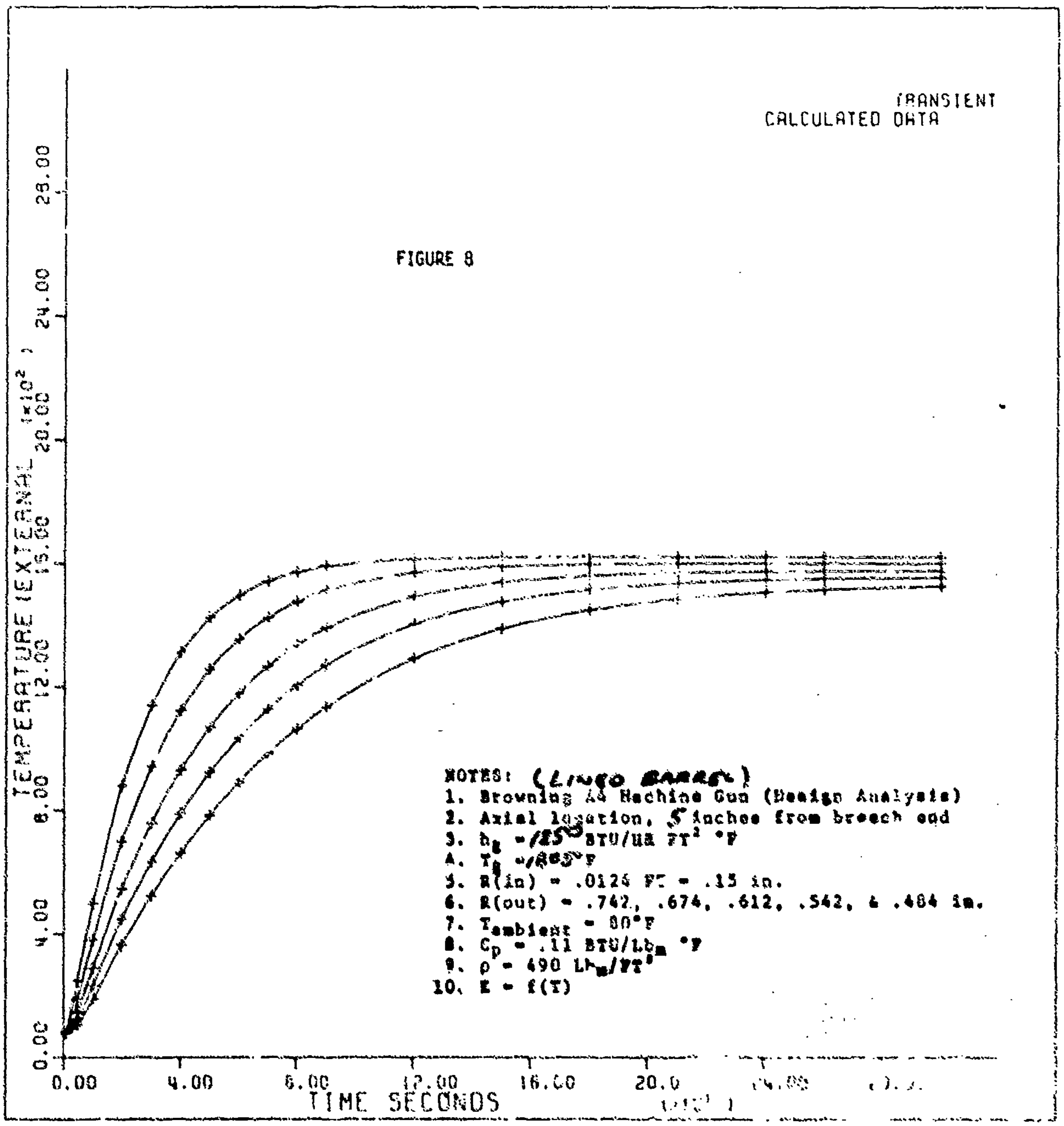

TRANSIENT BORE TEMP
CALCULATED DATA
TEMPERATURE (BORE) F (x10²)
8.00
10.00
12.00
14.00
16.00
18.00
20.00
22.00
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
TIME SECONDS (x10¹)
NOTES: (LINED BARREL)
1. Browning AA Machine Gun (Design Analysis)
2. Axial location, 5 inches from breech end
3. h_g = 1250 BTU/HR FT² °F
4. T_g = °F
5. R(in) = .0124 FT = .15 in.
6. R(out) = .742, .674, .612, .542, & .484 in.
7. $T_{ambient}$ = 80°F
8. C_p = .11 BTU/Lb_m °F
9. ρ = 490 Lb_m/FT³
10. K = f(T)

FIGURE 7



TRANSIENT
CALCULATED DATA
TEMPERATURE (EXTERNAL)
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
TIME SECONDS
NOTES:
1. Browning A4 Machine Gun (Design Analysis)
2. Axial location, 5 inches from breech end
3. h_g = BTU/HR FT² °F
4. T_g = °F
5. R(in) = .0124 FT = .15 in.
6. R(out) = .742, .674, .612, .542, & .484 in.
7. $T_{ambient}$ = 80°F
8. C_p = .11 BTU/Lb_m °F
9. ρ = 490 Lb_m/FT³
10. E = f(T)

FIGURE 8

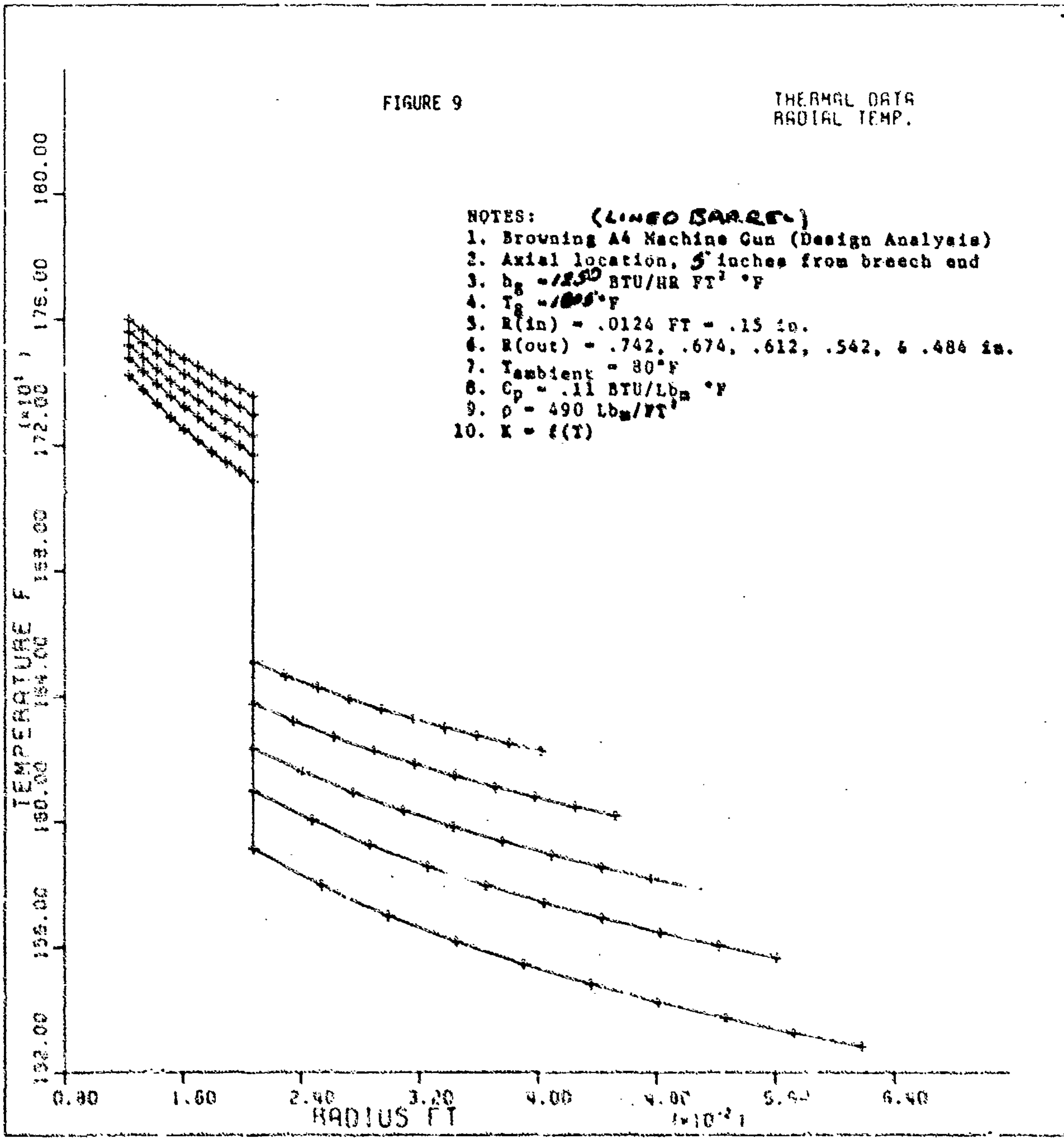


FIGURE 9
THERMAL DATA
RADIAL TEMP.
NOTES: (LINED BARREL)
1. Browning A4 Machine Gun (Design Analysis)
2. Axial location, 5 inches from breech end
3. h_g = BTU/HR FT² °F
4. T_g = °F
5. R(in) = .0124 FT = .15 in.
6. R(out) = .742, .674, .612, .542, & .486 in.
7. $T_{ambient}$ = 80°F
8. C_p = .11 BTU/Lb_m °F
9. ρ = 490 Lb_m/FT³
10. K = f(T)
TEMPERATURE F
(×10¹)
152.00
156.00
160.00
164.00
168.00
172.00
176.00
180.00
0.80
1.60
2.40
3.20
4.00
6.40
RADIUS FT
(×10⁻²)

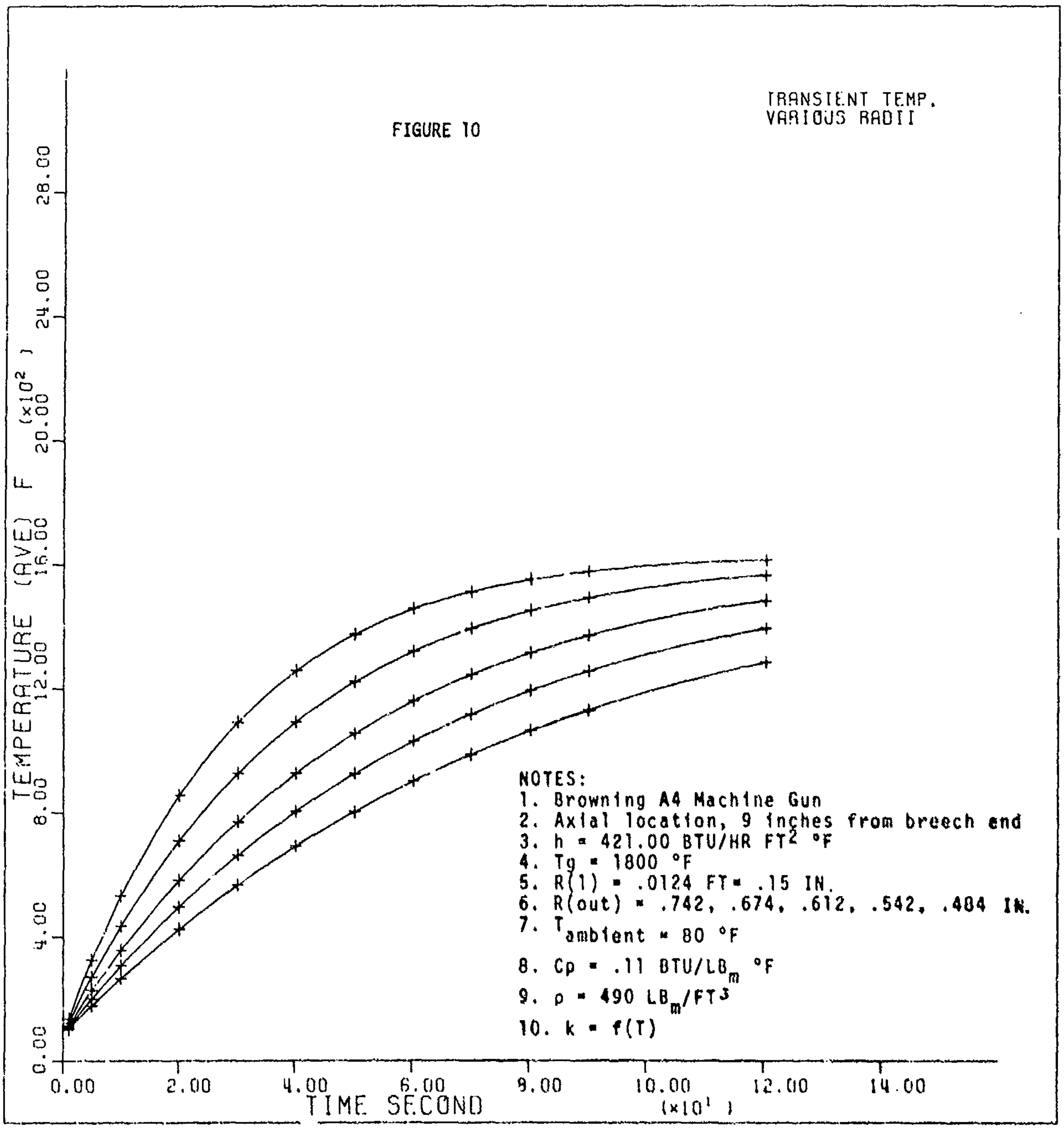


FIGURE 10
TRANSIENT TEMP.
VARIOUS RADII
TEMPERATURE (AVE) F (x10²)
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
TIME SECOND (x10¹)
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
NOTES:
1. Browning A4 Machine Gun
2. Axial location, 9 inches from breech end
3. h = 421.00 BTU/HR FT² °F
4. Tg = 1800 °F
5. R(1) = .0124 FT = .15 IN.
6. R(out) = .742, .674, .612, .542, .484 IN.
7. T ambient = 80 °F
8. Cp = .11 BTU/LBm °F
9. ρ = 490 LBm/FT³
10. k = f(T)

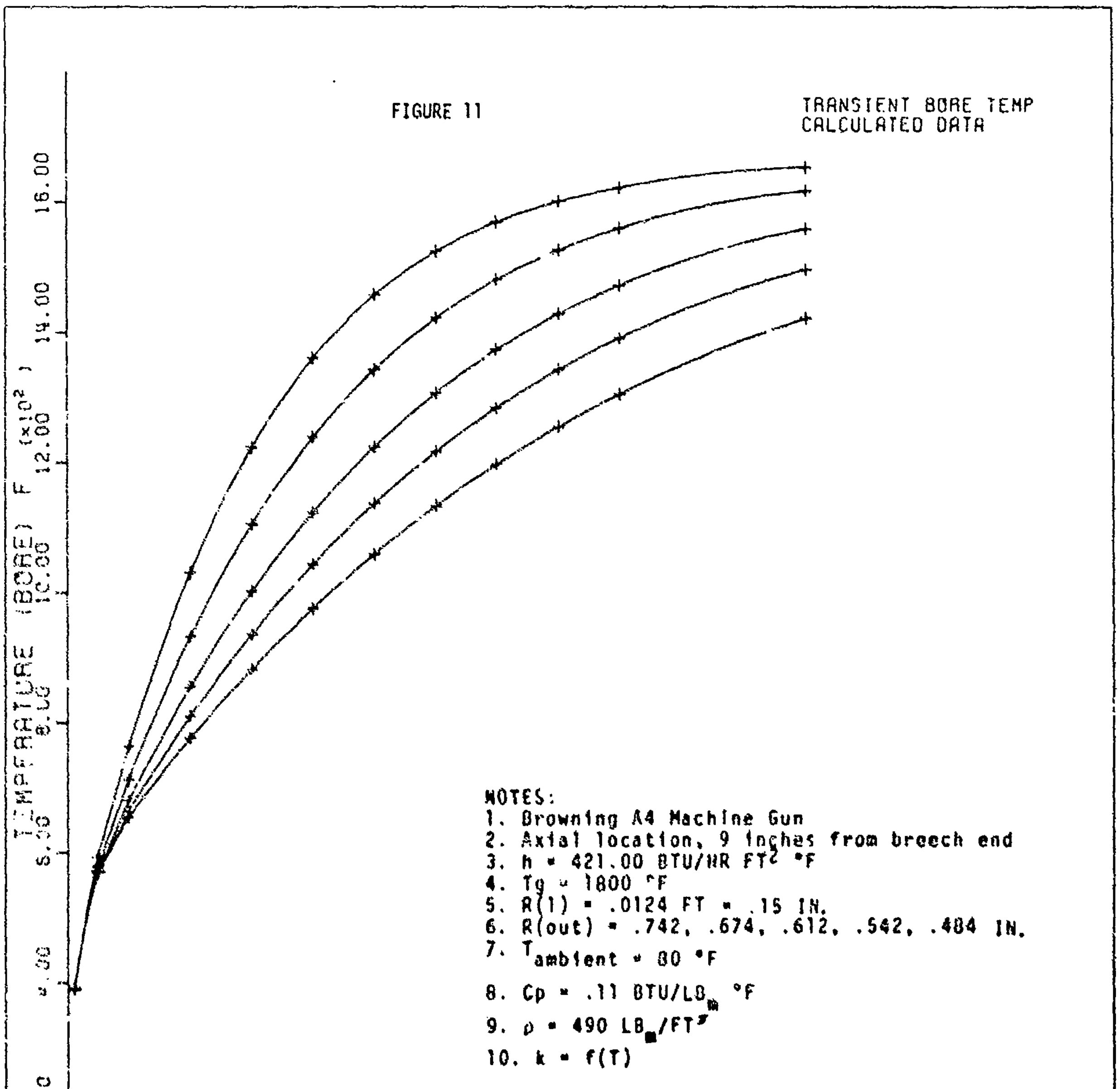


FIGURE 11
TRANSIENT BORE TEMP
CALCULATED DATA
TEMPERATURE (BORE) F (×10²)
TIME SECONDS (×10¹)
NOTES:
1. Browning A4 Machine Gun
2. Axial location, 9 inches from breech end
3. h = 421.00 BTU/HR FT² °F
4. Tg = 1800 °F
5. R(1) = .0124 FT = .15 IN.
6. R(out) = .742, .674, .612, .542, .484 IN.
7. T ambient = 80 °F
8. Cp = .11 BTU/LBm °F
9. ρ = 490 LBm/FT³
10. k = f(T)

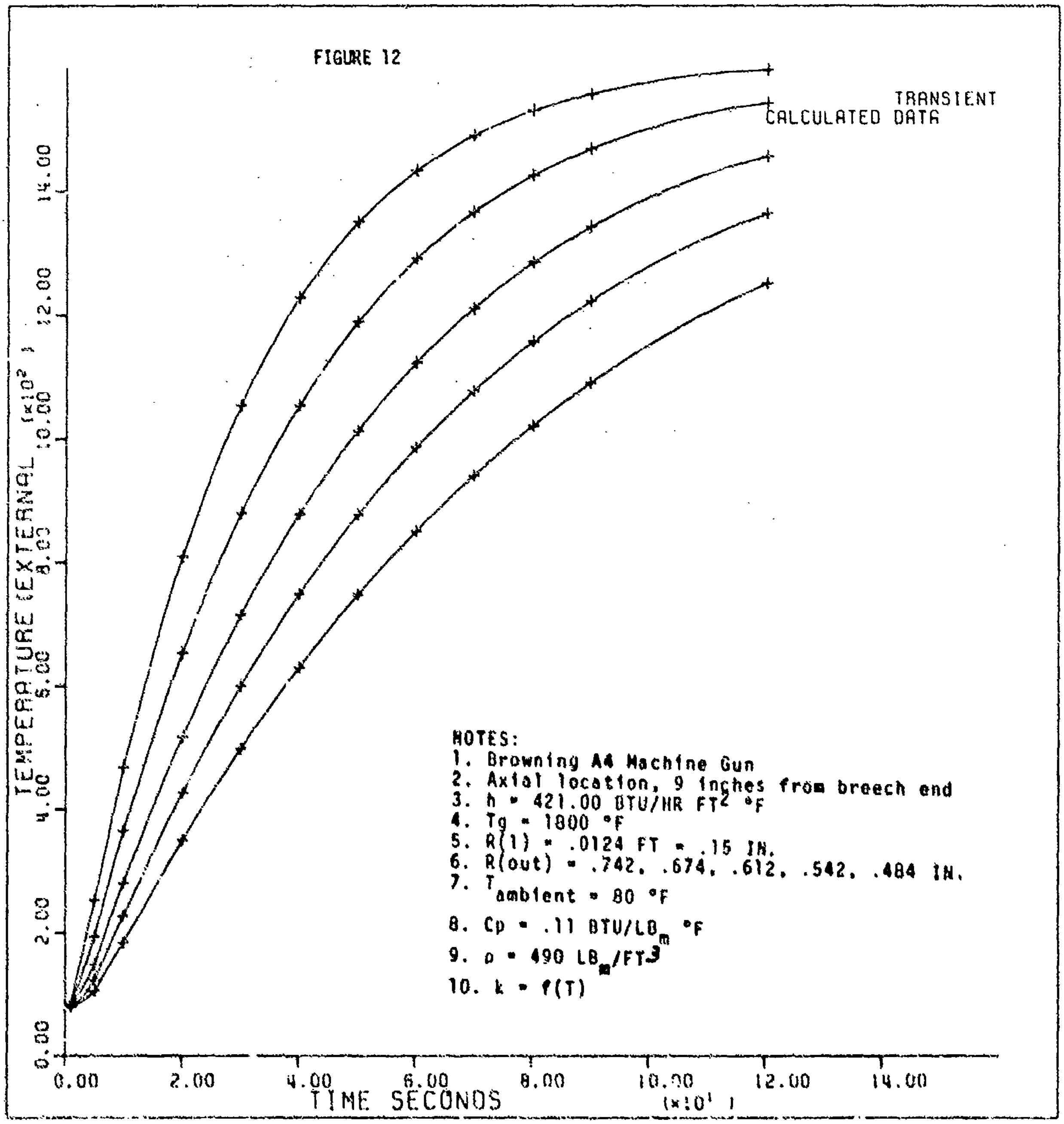


FIGURE 12
TRANSIENT
CALCULATED DATA
TEMPERATURE (EXTERNAL (x10²)
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
TIME SECONDS
(x10¹)
NOTES:
1. Browning A4 Machine Gun
2. Axial location, 9 inches from breech end
3. h = 421.00 BTU/HR FT² °F
4. Tg = 1800 °F
5. R(1) = .0124 FT = .15 IN.
6. R(out) = .742, .674, .612, .542, .484 IN.
7. T ambient = 80 °F
8. Cp = .11 BTU/LBm °F
9. ρ = 490 LBm/FT³
10. k = f(T)

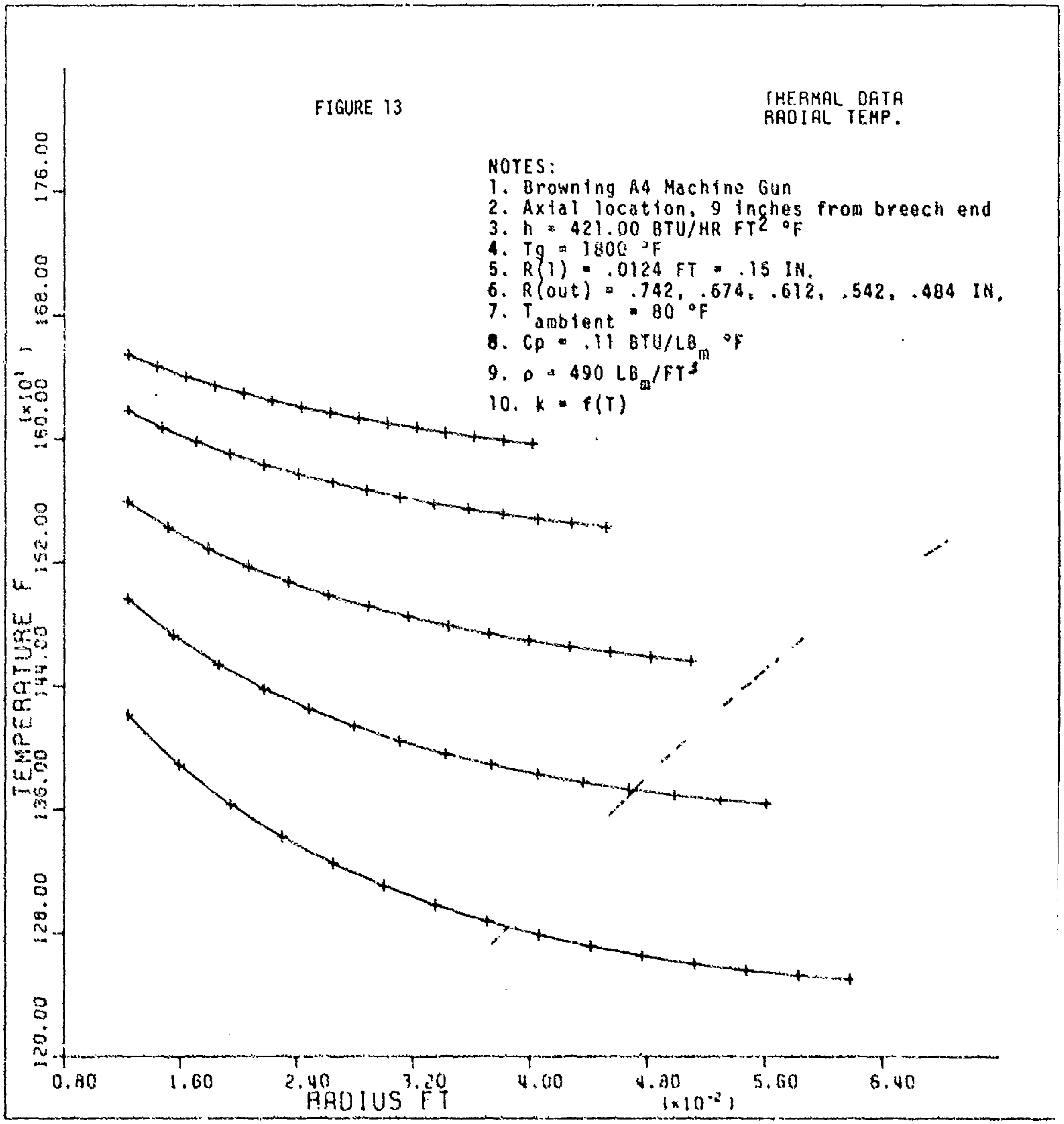
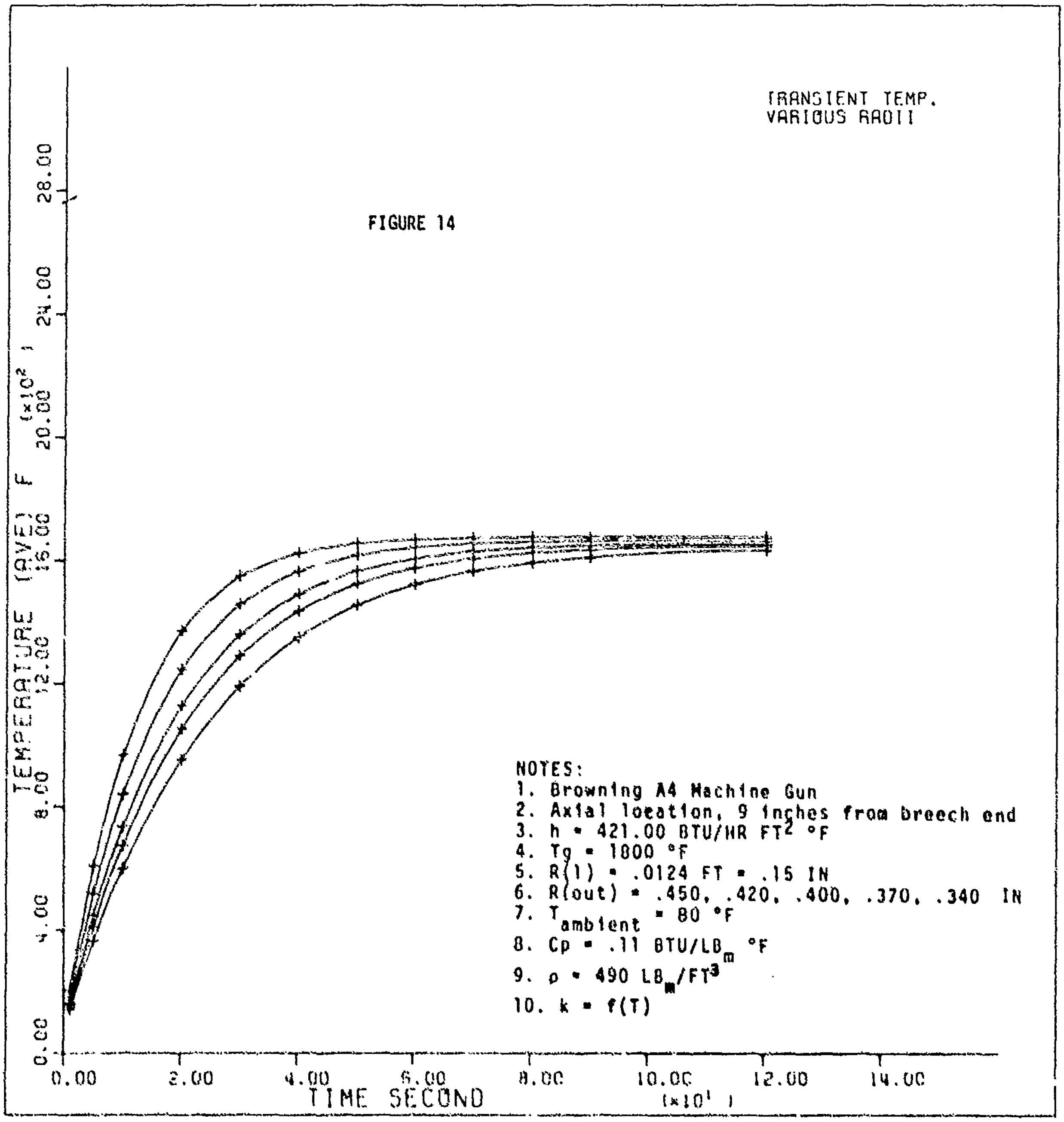
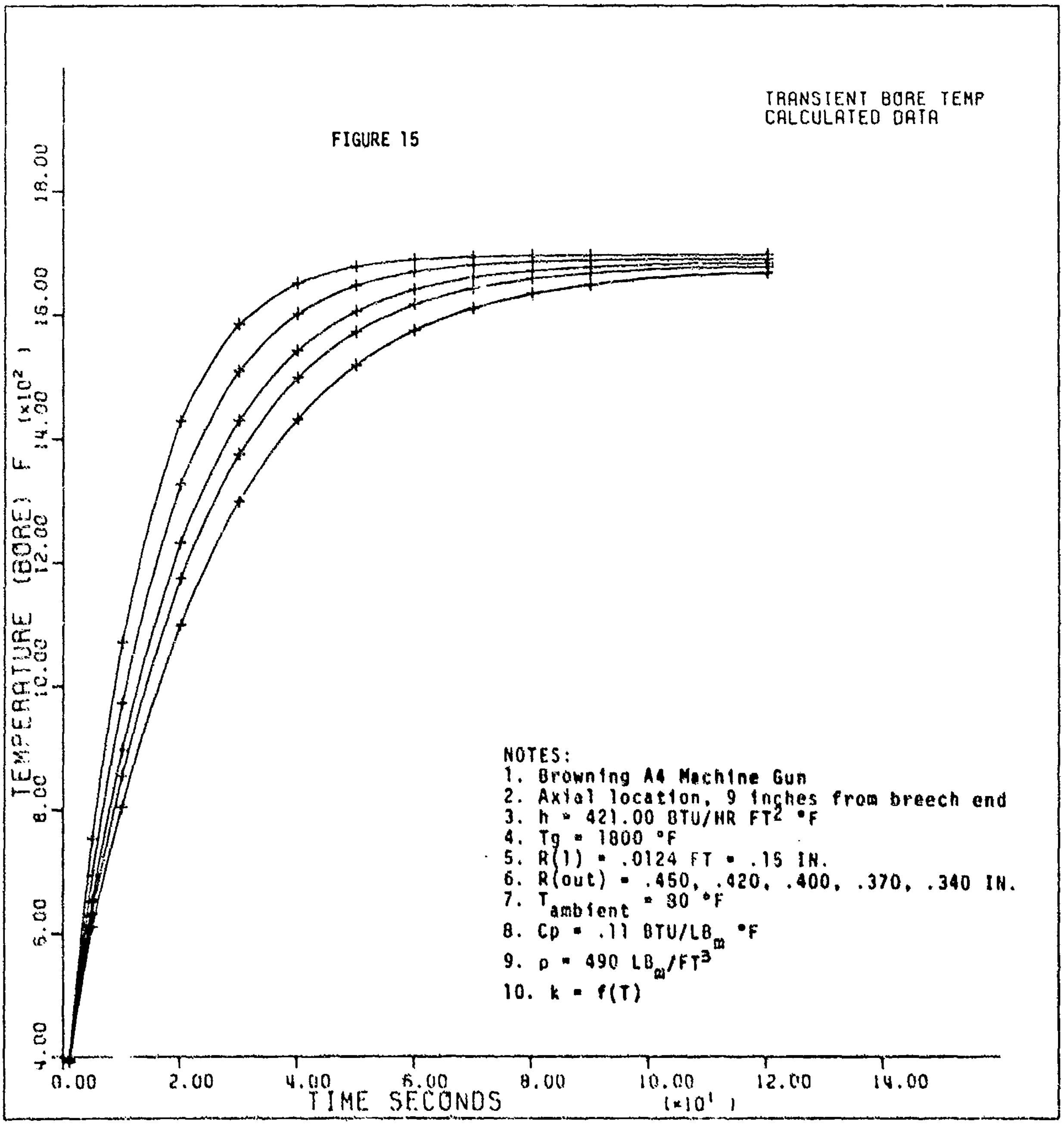


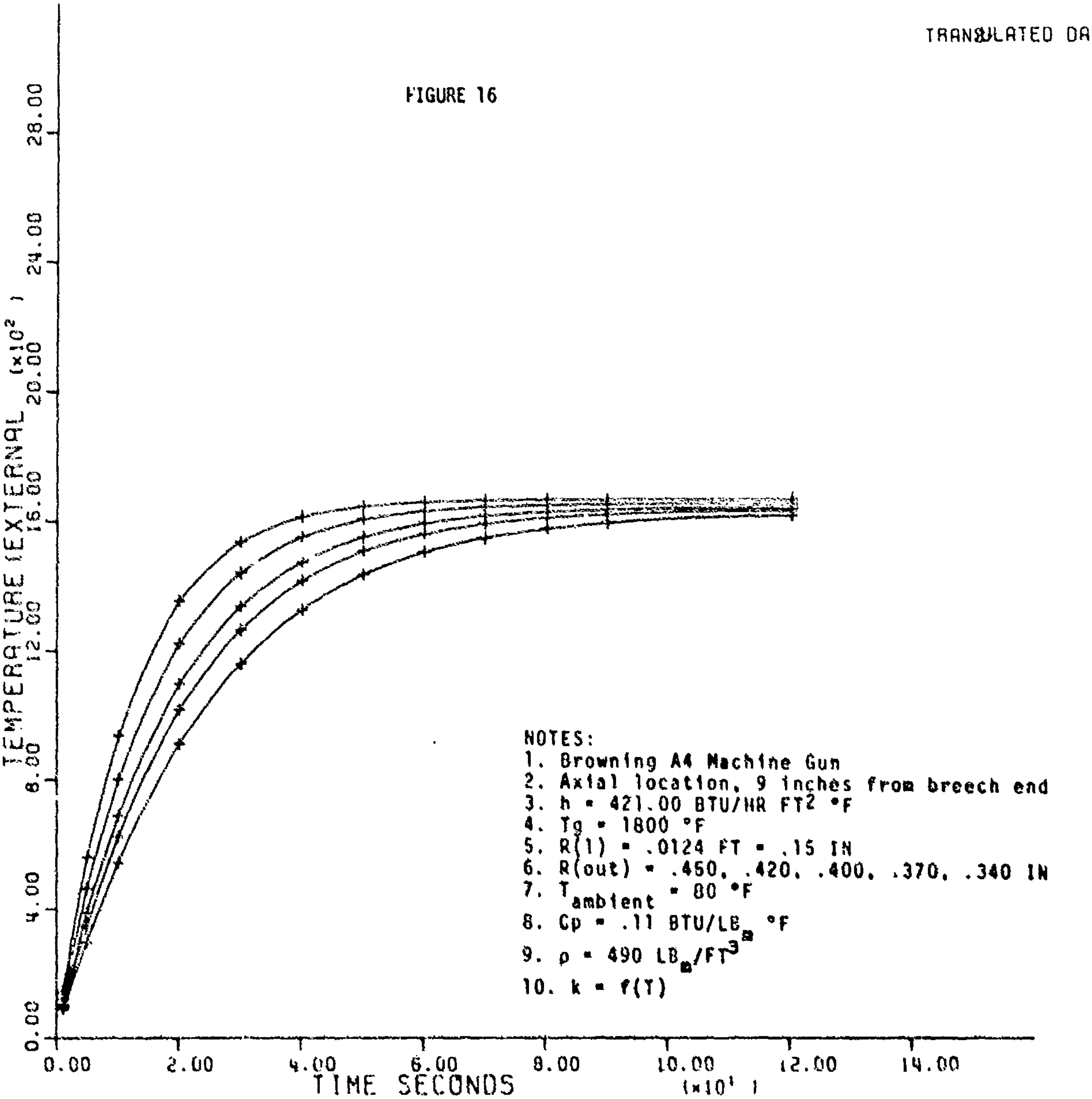
FIGURE 13
THERMAL DATA
RADIAL TEMP.
NOTES:
1. Browning A4 Machine Gun
2. Axial location, 9 inches from breech end
3. h = 421.00 BTU/HR FT² °F
4. Tg = 1800 °F
5. R(1) = .0124 FT = .15 IN.
6. R(out) = .742, .674, .612, .542, .484 IN.
7. T ambient = 80 °F
8. Cp = .11 BTU/LBm °F
9. ρ = 490 LBm/FT³
10. k = f(T)
TEMPERATURE F (×10¹)
120.00
128.00
136.00
144.00
152.00
160.00
168.00
176.00
RADIUS FT (×10⁻²)
0.80
1.60
2.40
3.20
4.00
4.80
5.60
6.40


TRANSIENT TEMP.
VARIOUS RADII
FIGURE 14
TEMPERATURE (AVE) F (x10²)
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
NOTES:
1. Browning A4 Machine Gun
2. Axial location, 9 inches from breech end
3. h = 421.00 BTU/HR FT² °F
4. Tg = 1800 °F
5. R(1) = .0124 FT = .15 IN
6. R(out) = .450, .420, .400, .370, .340 IN
7. T ambient = 80 °F
8. Cp = .11 BTU/LBm °F
9. ρ = 490 LBm/FT³
10. k = f(T)
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
TIME SECOND
(x10¹)


TRANSIENT BORE TEMP
CALCULATED DATA
FIGURE 15
TEMPERATURE (BORE) F (×10²)
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
TIME SECONDS (×10¹)
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
NOTES:
1. Browning A4 Machine Gun
2. Axial location, 9 inches from breech end
3. h = 421.00 BTU/HR FT² °F
4. Tg = 1800 °F
5. R(1) = .0124 FT = .15 IN.
6. R(out) = .450, .420, .400, .370, .340 IN.
7. T ambient = 80 °F
8. Cp = .11 BTU/LBm °F
9. ρ = 490 LBm/FT³
10. k = f(T)

TRANSULATED DATA

FIGURE 16



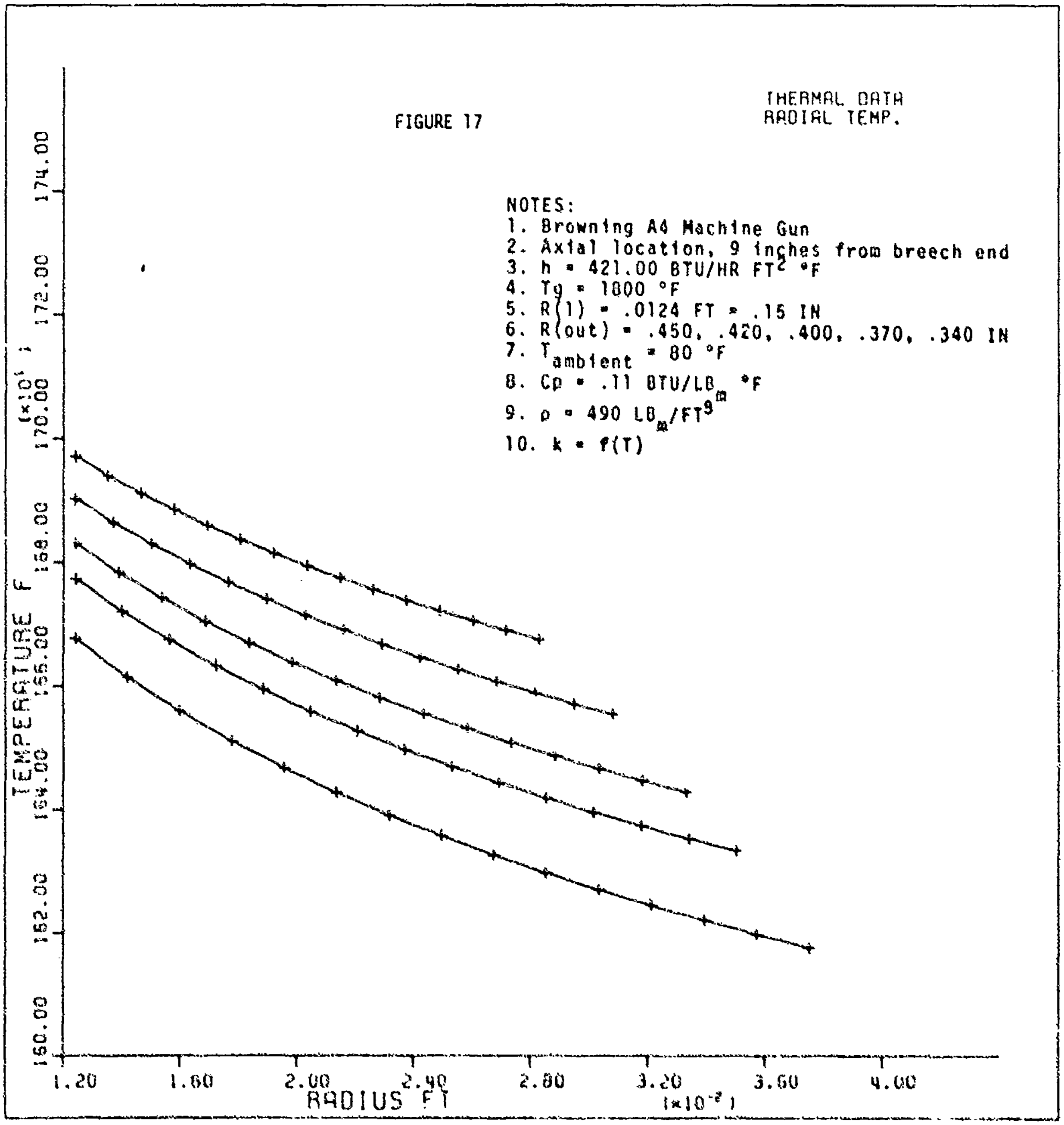
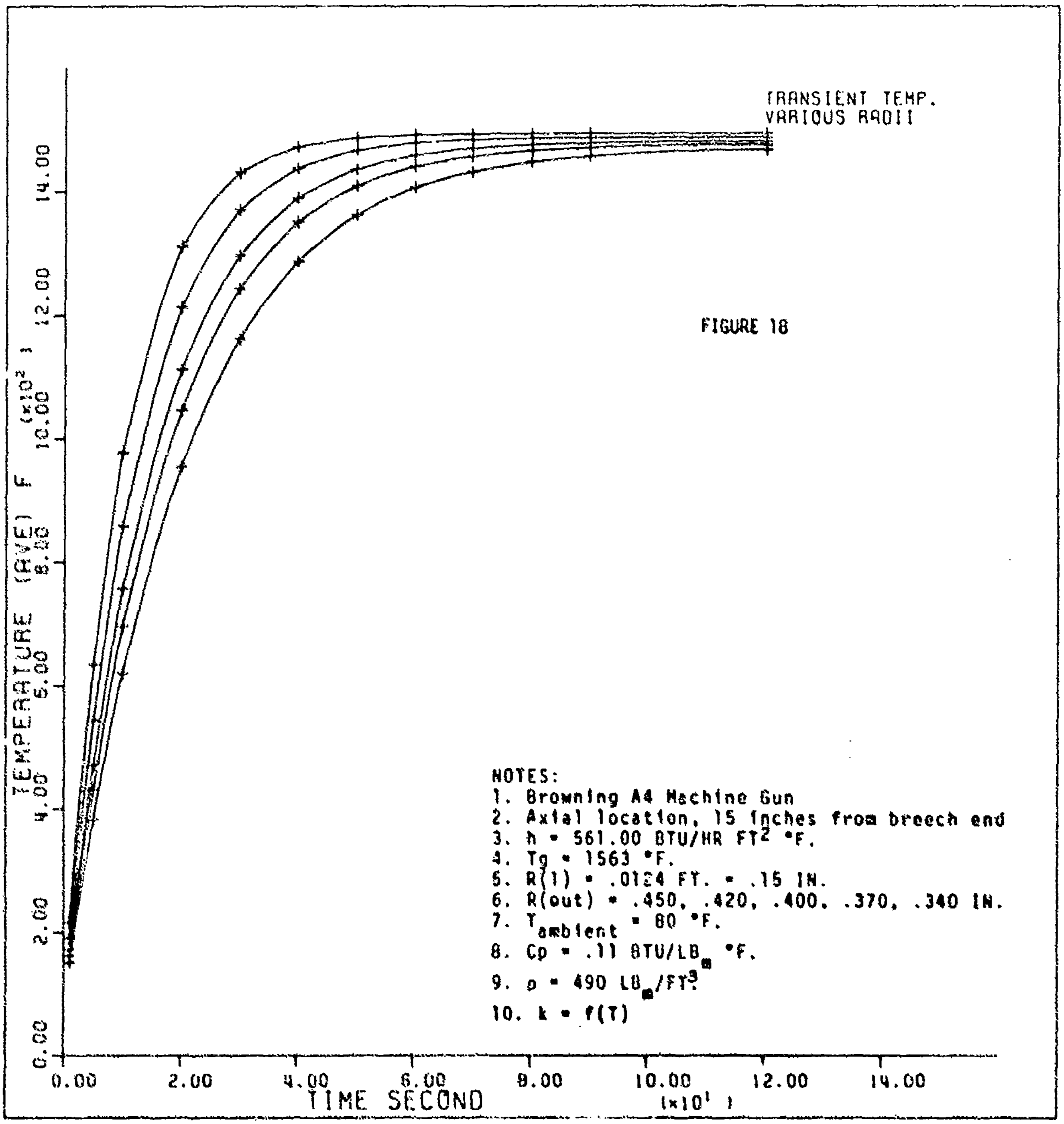
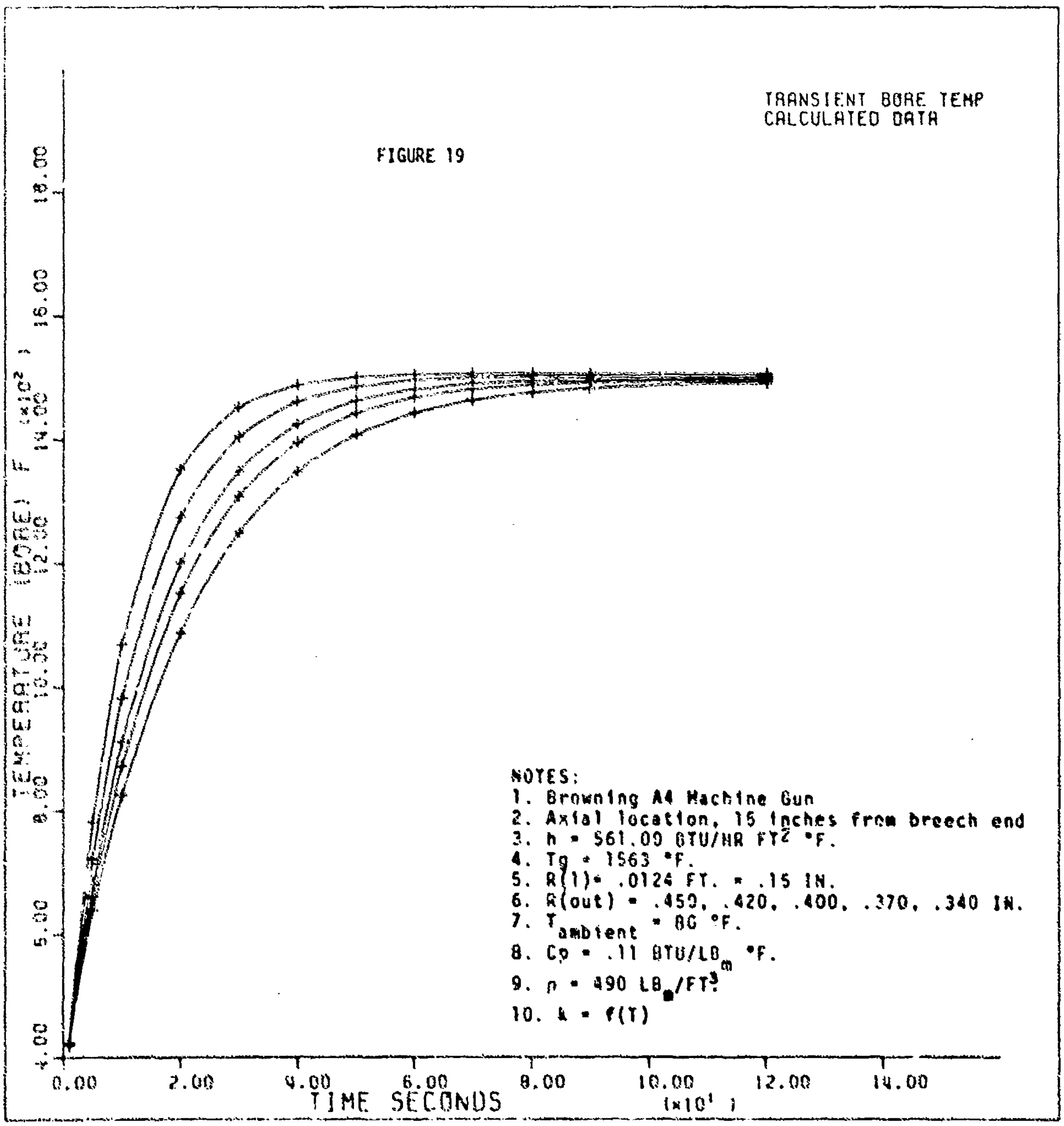


FIGURE 17
THERMAL DATA
RADIAL TEMP.
NOTES:
1. Browning A4 Machine Gun
2. Axial location, 9 inches from breech end
3. h = 421.00 BTU/HR FT^2 °F
4. Tg = 1800 °F
5. R(1) = .0124 FT = .15 IN
6. R(out) = .450, .420, .400, .370, .340 IN
7. T$_{ambient}$ = 80 °F
8. Cp = .11 BTU/LB$_m$ °F
9. ρ = 490 LB$_m$/FT^3
10. k = f(T)
TEMPERATURE F (×10^1)
174.00
172.00
170.00
168.00
166.00
164.00
162.00
160.00
RADIUS FT (×10^{-2})
1.20
1.60
2.00
2.40
2.80
3.20
3.60
4.00



TRANSIENT TEMP.
VARIOUS RADII
FIGURE 18
TEMPERATURE (AVE) F (x10²)
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
TIME SECOND (x10¹)
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
NOTES:
1. Browning A4 Machine Gun
2. Axial location, 15 inches from breech end
3. h = 561.00 BTU/HR FT² °F.
4. Tg = 1563 °F.
5. R(1) = .0124 FT. = .15 IN.
6. R(out) = .450, .420, .400, .370, .340 IN.
7. T ambient = 80 °F.
8. Cp = .11 BTU/LBm °F.
9. ρ = 490 LBm/FT³.
10. k = f(T)



TRANSIENT BORE TEMP
CALCULATED DATA
FIGURE 19
TEMPERATURE (BORE) F (x10²)
4.00
5.00
8.00
10.00
12.00
14.00
16.00
18.00
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
TIME SECONDS
(x10¹)
NOTES:
1. Browning A4 Machine Gun
2. Axial location, 15 inches from breech end
3. h = 561.00 BTU/HR FT² °F.
4. Tg = 1563 °F.
5. R(1)= .0124 FT. = .15 IN.
6. R(out) = .450, .420, .400, .370, .340 IN.
7. T ambient = 80 °F.
8. Cp = .11 BTU/LBm °F.
9. ρ = 490 LBm/FT³
10. k = f(T)

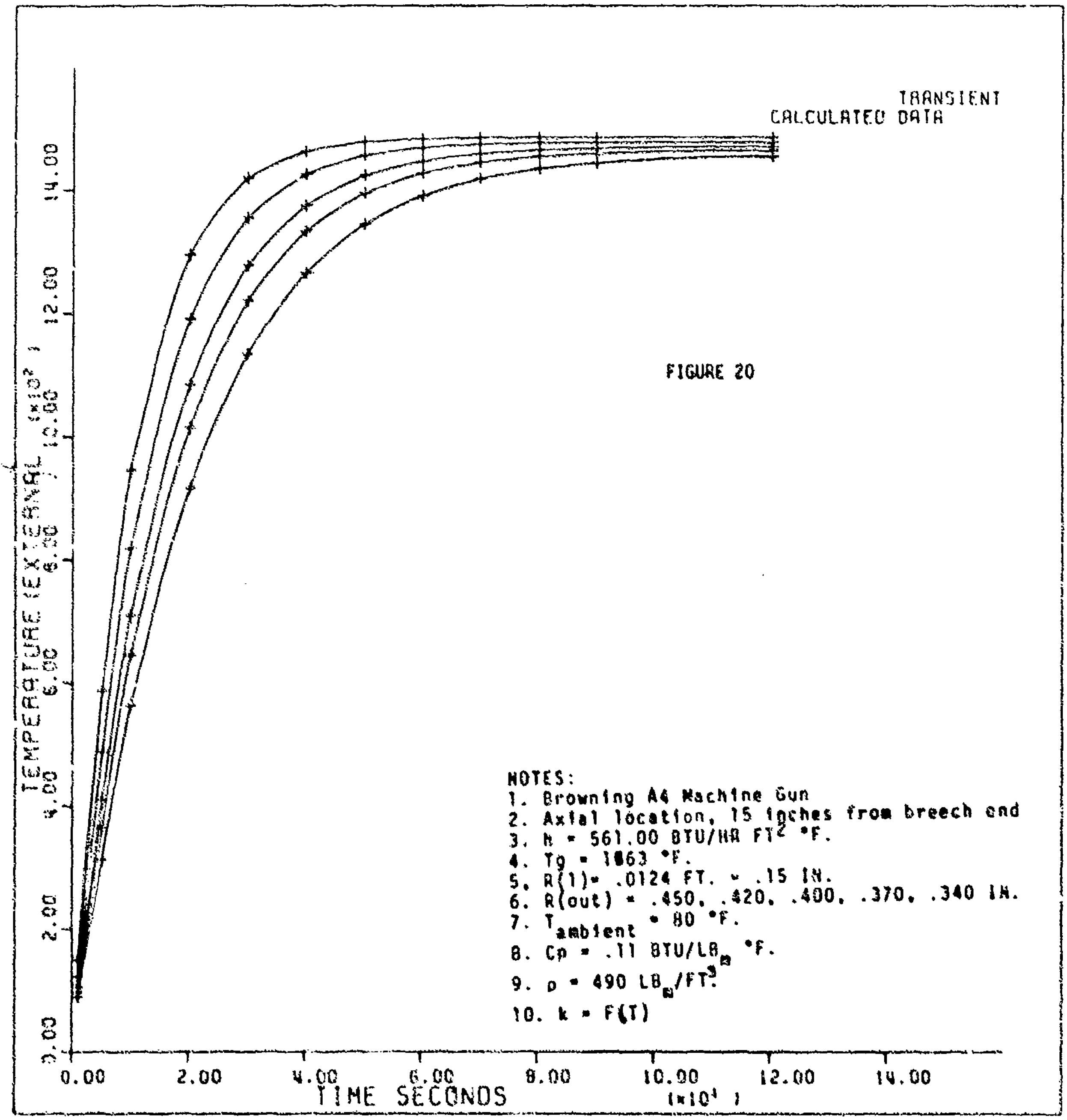

TRANSIENT
CALCULATED DATA
TEMPERATURE (EXTERNAL (x10^2)
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
TIME SECONDS (x10^1)
NOTES:
1. Browning A4 Machine Gun
2. Axial location, 15 inches from breech end
3. h = 561.00 BTU/HR FT^2 °F.
4. Tg = 1863 °F.
5. R(1) = .0124 FT. = .15 IN.
6. R(out) = .450, .420, .400, .370, .340 IN.
7. T ambient = 80 °F.
8. Cp = .11 BTU/LBm °F.
9. ρ = 490 LBm/FT^3
10. k = F(T)

FIGURE 20

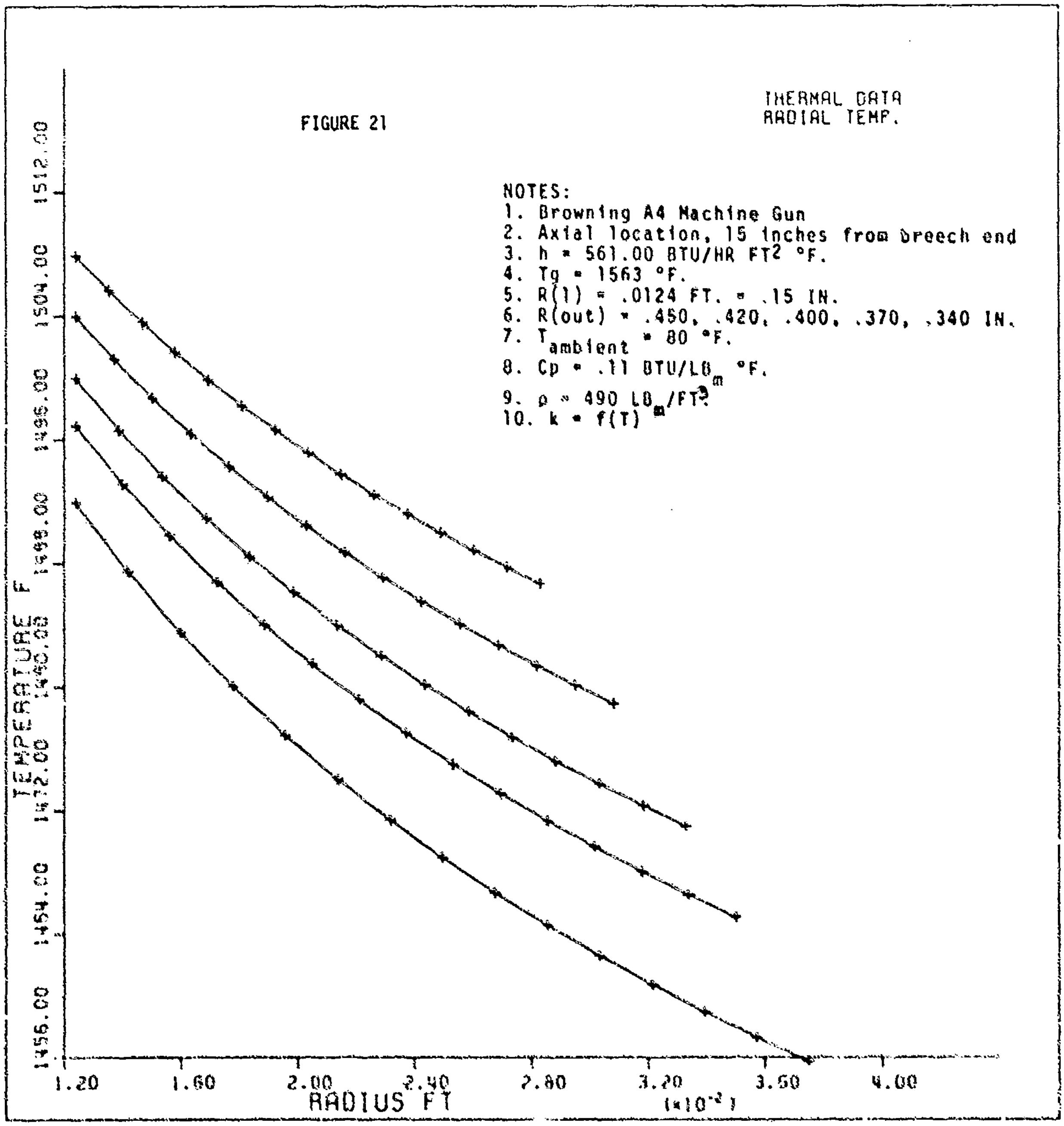


FIGURE 21
THERMAL DATA
RADIAL TEMP.
NOTES:
1. Browning A4 Machine Gun
2. Axial location, 15 inches from breech end
3. h = 561.00 BTU/HR FT2 °F.
4. Tg = 1563 °F.
5. R(1) = .0124 FT. = .15 IN.
6. R(out) = .450, .420, .400, .370, .340 IN.
7. T ambient = 80 °F.
8. Cp = .11 BTU/LBm °F.
9. ρ = 490 LBm/FT3
10. k = f(T)
TEMPERATURE F
1512.00
1504.00
1496.00
1488.00
1480.00
1472.00
1464.00
1456.00
RADIUS FT
(x10^-2)
1.20
1.60
2.00
2.40
2.80
3.20
3.60
4.00

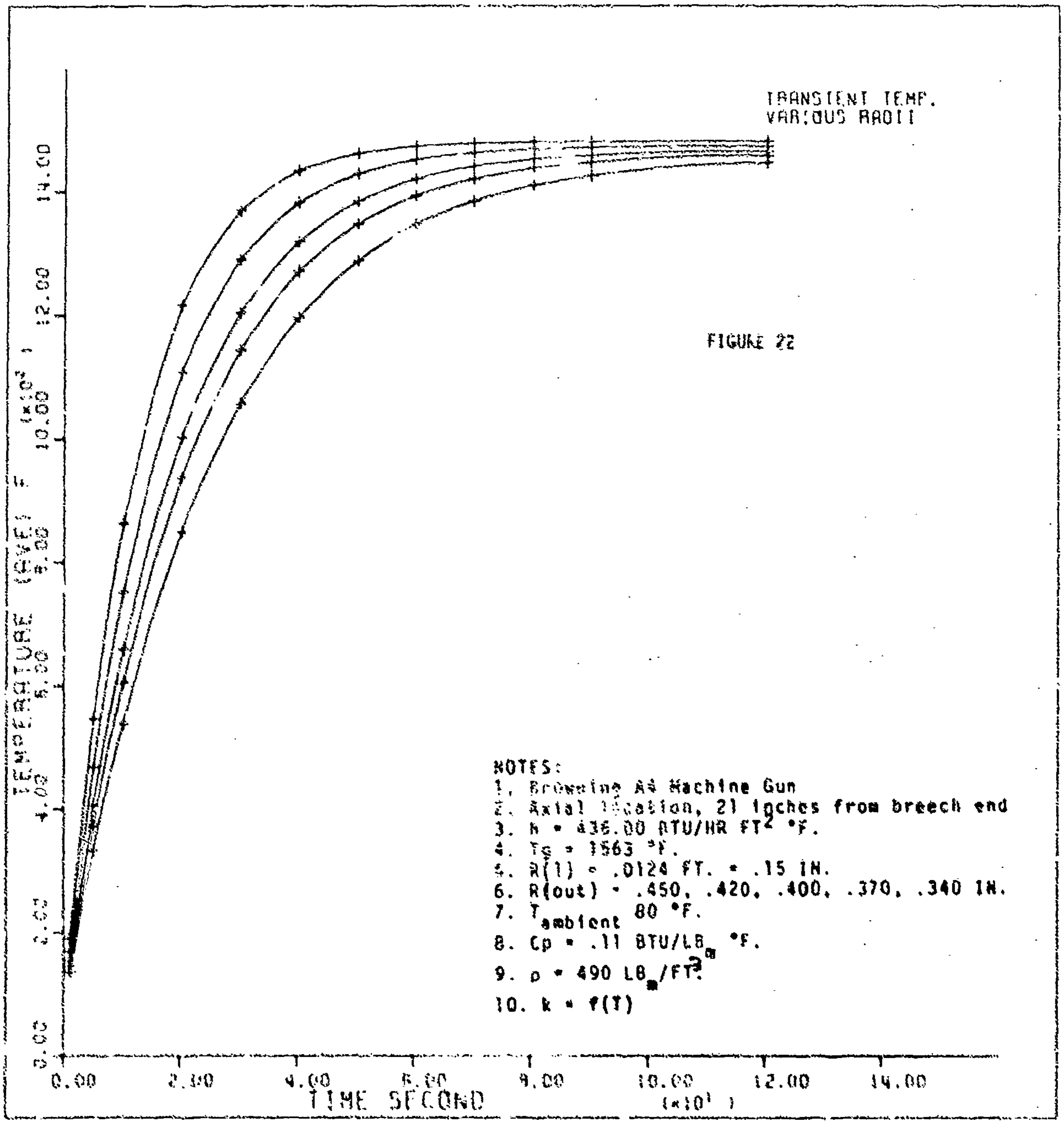
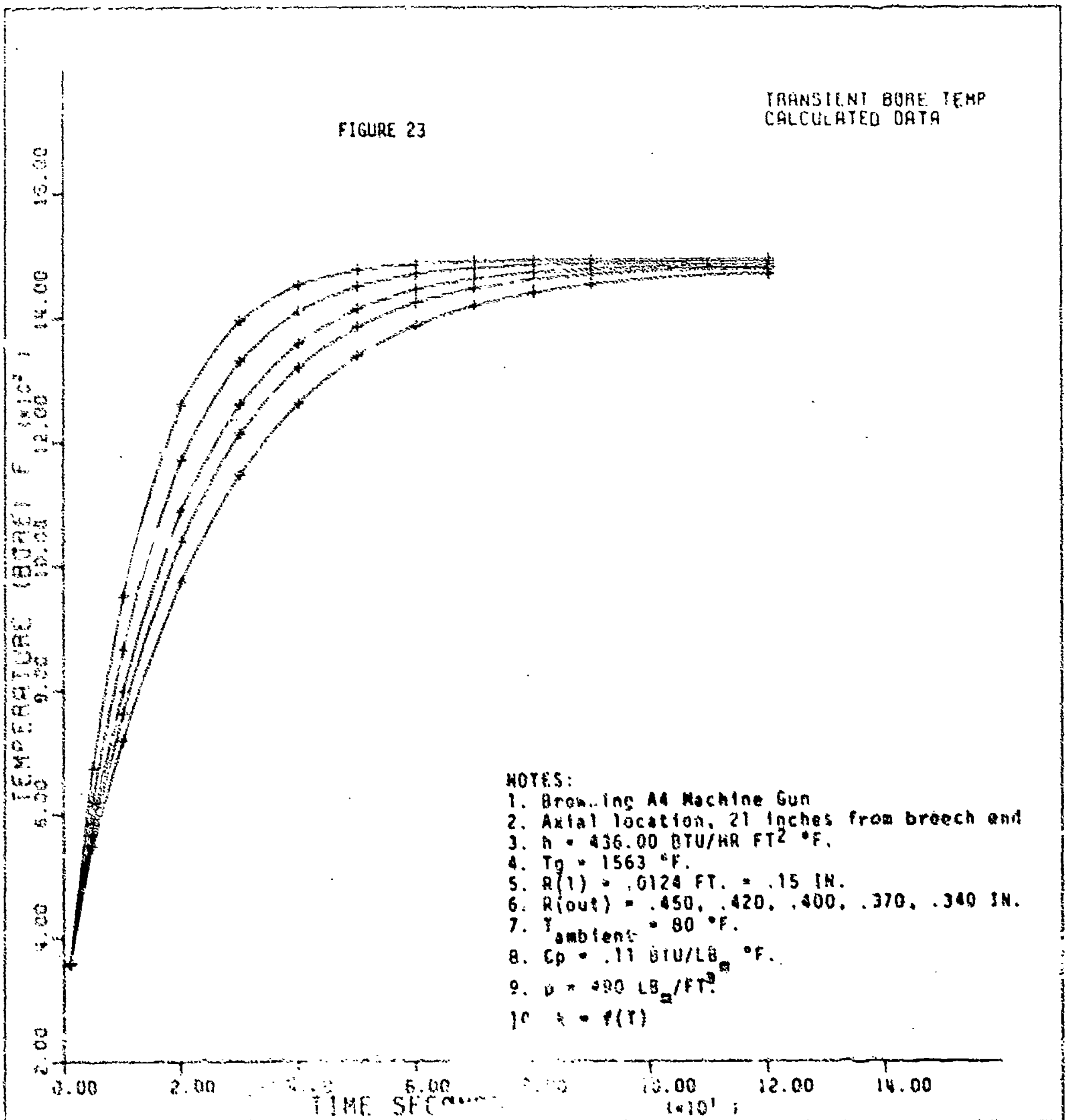

TRANSIENT TEMP.
VARIOUS RADII
TEMPERATURE (AVE) F (x10^2)
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
TIME SECOND (x10^1)
NOTES:
1. Browning A4 Machine Gun
2. Axial location, 21 inches from breech end
3. h = 436.00 BTU/HR FT² °F.
4. Tg = 1563 °F.
5. R(1) = .0124 FT. = .15 IN.
6. R(out) = .450, .420, .400, .370, .340 IN.
7. T ambient 80 °F.
8. Cp = .11 BTU/LBm °F.
9. ρ = 490 LBm/FT³
10. k = f(T)

FIGURE 22


TRANSIENT BORE TEMP
CALCULATED DATA
FIGURE 23
TEMPERATURE (BORE) F (x10²)
TIME SEC
(x10¹)
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
0.00
2.00
6.00
10.00
12.00
14.00
NOTES:
1. Browning A4 Machine Gun
2. Axial location, 21 inches from breech end
3. h = 436.00 BTU/HR FT² °F.
4. Tg = 1563 °F.
5. R(1) = .0124 FT. = .15 IN.
6. R(out) = .450, .420, .400, .370, .340 IN.
7. T ambient = 80 °F.
8. Cp = .11 BTU/LBm °F.
9. ρ = 490 LBm/FT³
10. k = f(T)

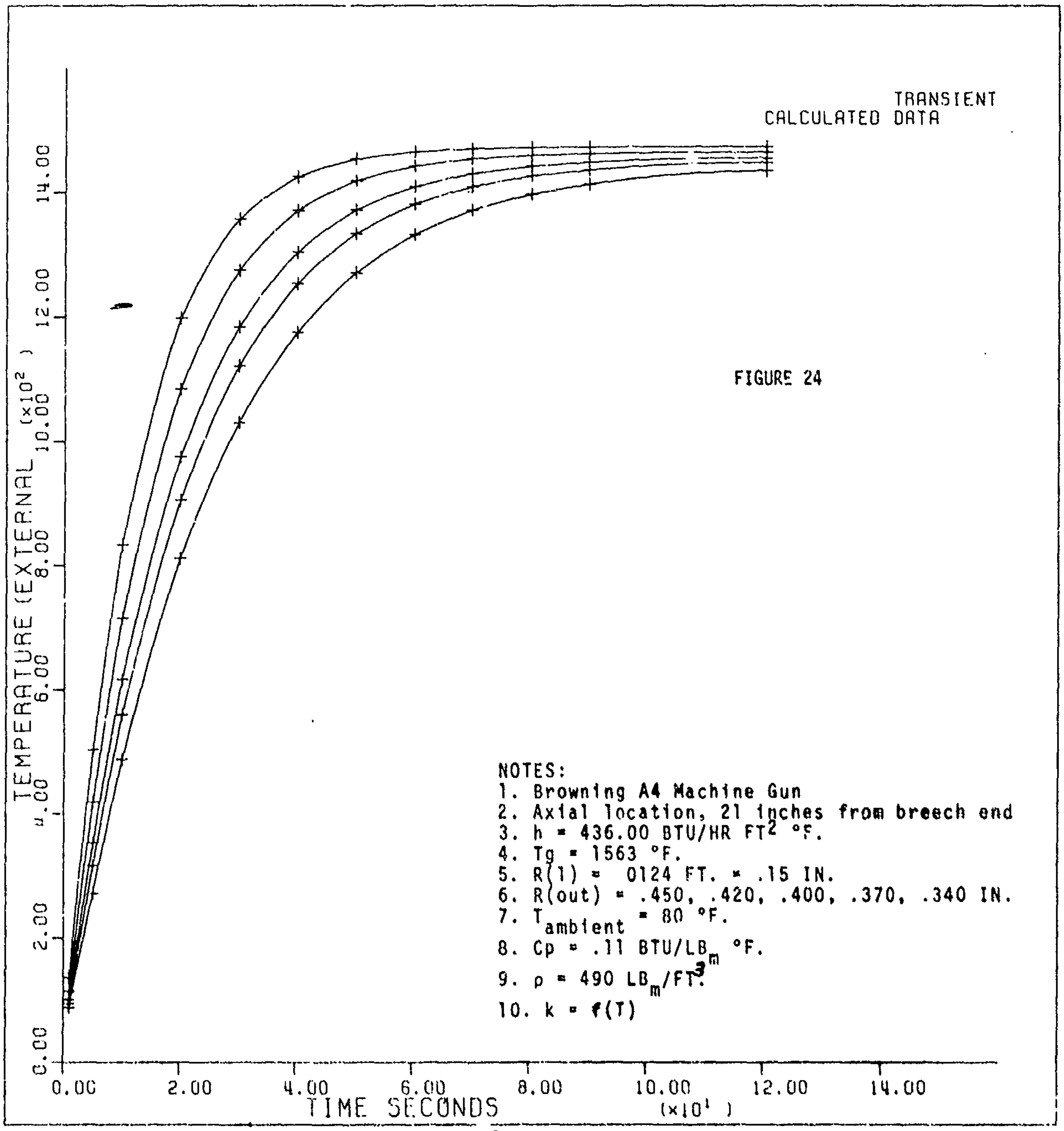

TRANSIENT
CALCULATED DATA
TEMPERATURE (EXTERNAL (x10^2)
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
TIME SECONDS
(x10^1)
NOTES:
1. Browning A4 Machine Gun
2. Axial location, 21 inches from breech end
3. h = 436.00 BTU/HR FT^2 °F.
4. Tg = 1563 °F.
5. R(1) = 0124 FT. = .15 IN.
6. R(out) = .450, .420, .400, .370, .340 IN.
7. T ambient = 80 °F.
8. Cp = .11 BTU/LB m °F.
9. ρ = 490 LB m /FT^3
10. k = f(T)

FIGURE 24

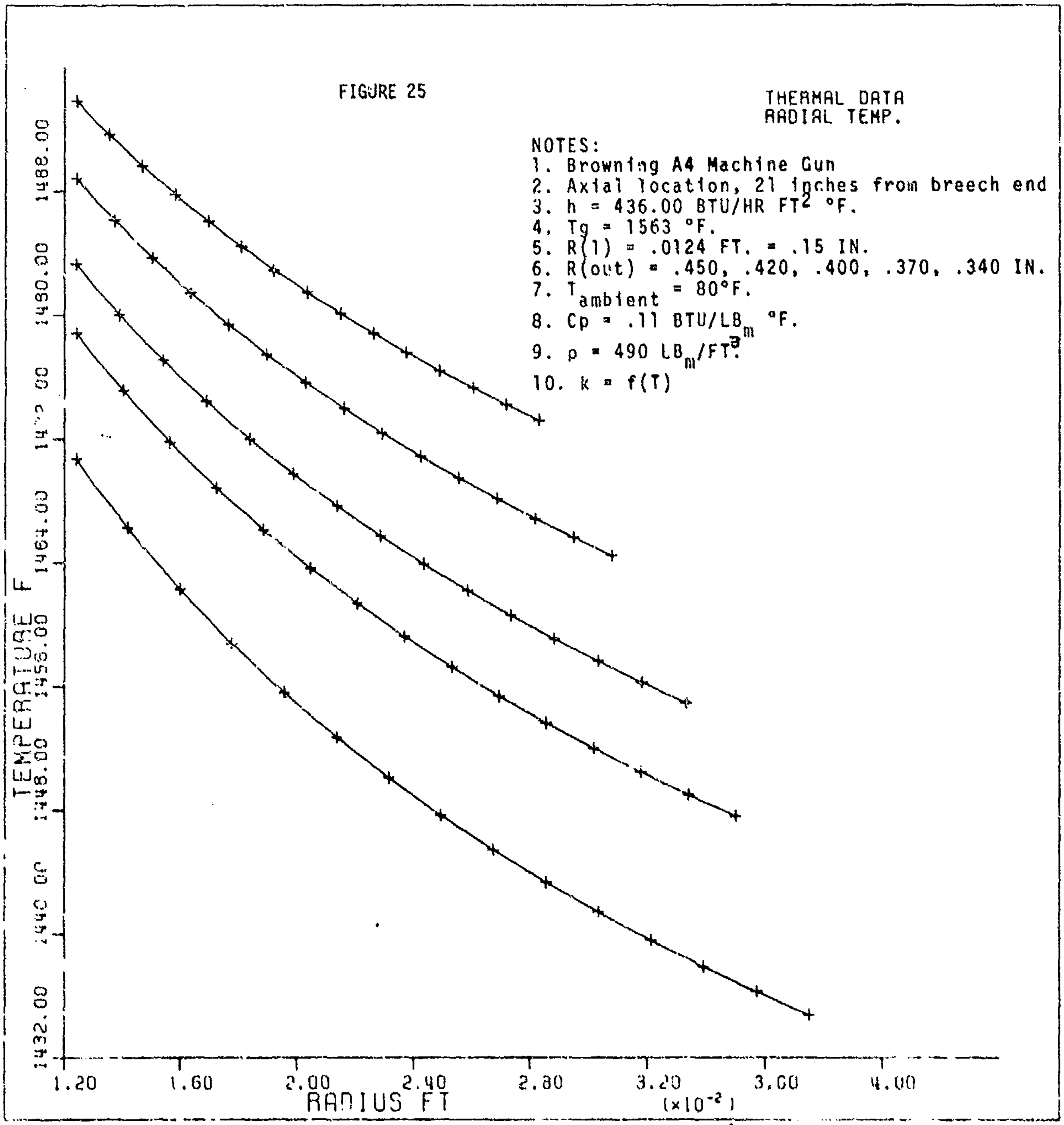


FIGURE 25
THERMAL DATA
RADIAL TEMP.
NOTES:
1. Browning A4 Machine Gun
2. Axial location, 21 inches from breech end
3. h = 436.00 BTU/HR FT² °F.
4. Tg = 1563 °F.
5. R(1) = .0124 FT. = .15 IN.
6. R(out) = .450, .420, .400, .370, .340 IN.
7. T ambient = 80°F.
8. Cp = .11 BTU/LBm °F.
9. ρ = 490 LBm/FT³
10. k = f(T)
TEMPERATURE F
1432.00
1448.00
1456.00
1464.00
1480.00
1488.00
RADIUS FT
1.20
1.60
2.00
2.40
2.80
3.20
3.60
4.00
(x10⁻²)

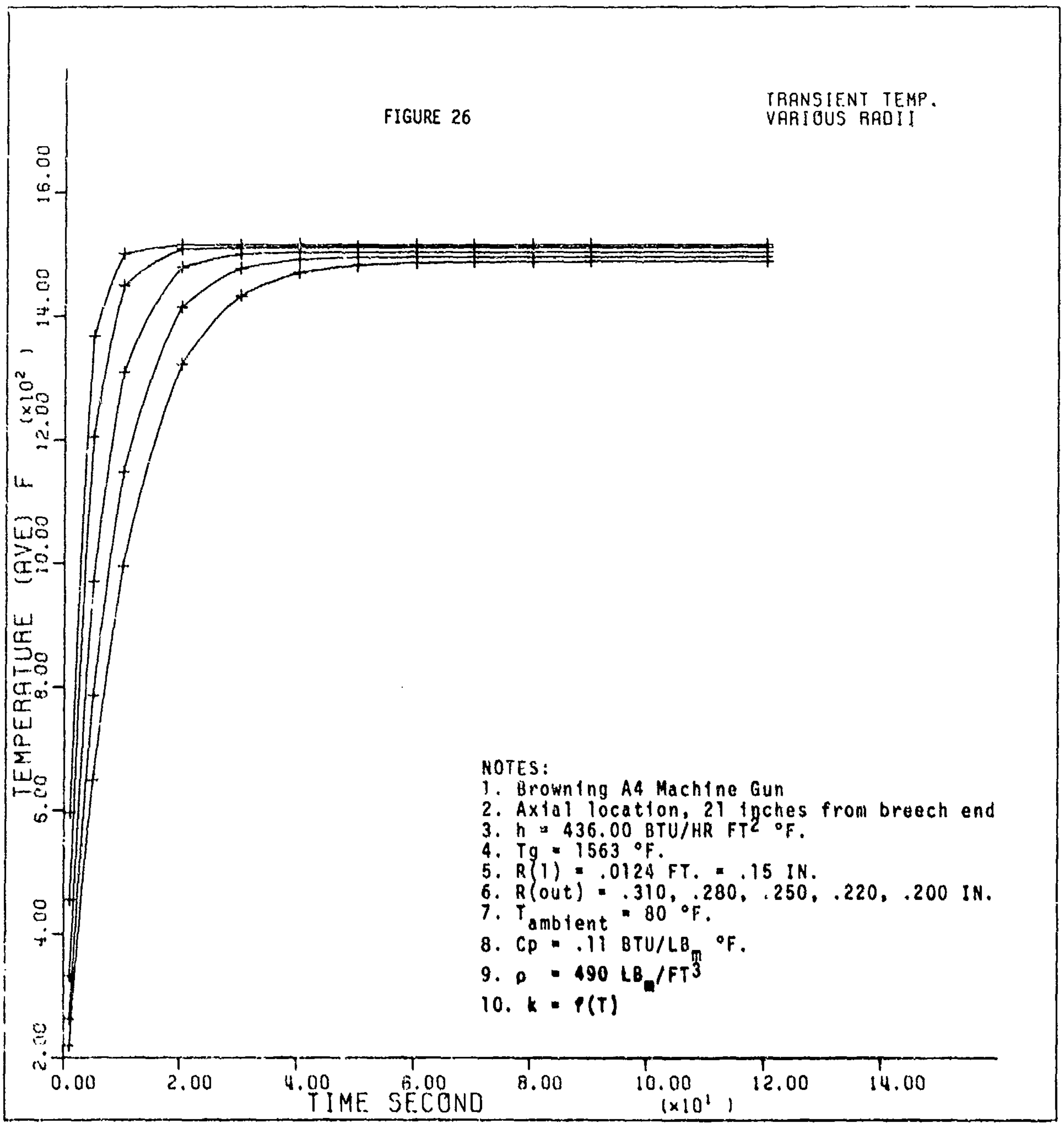
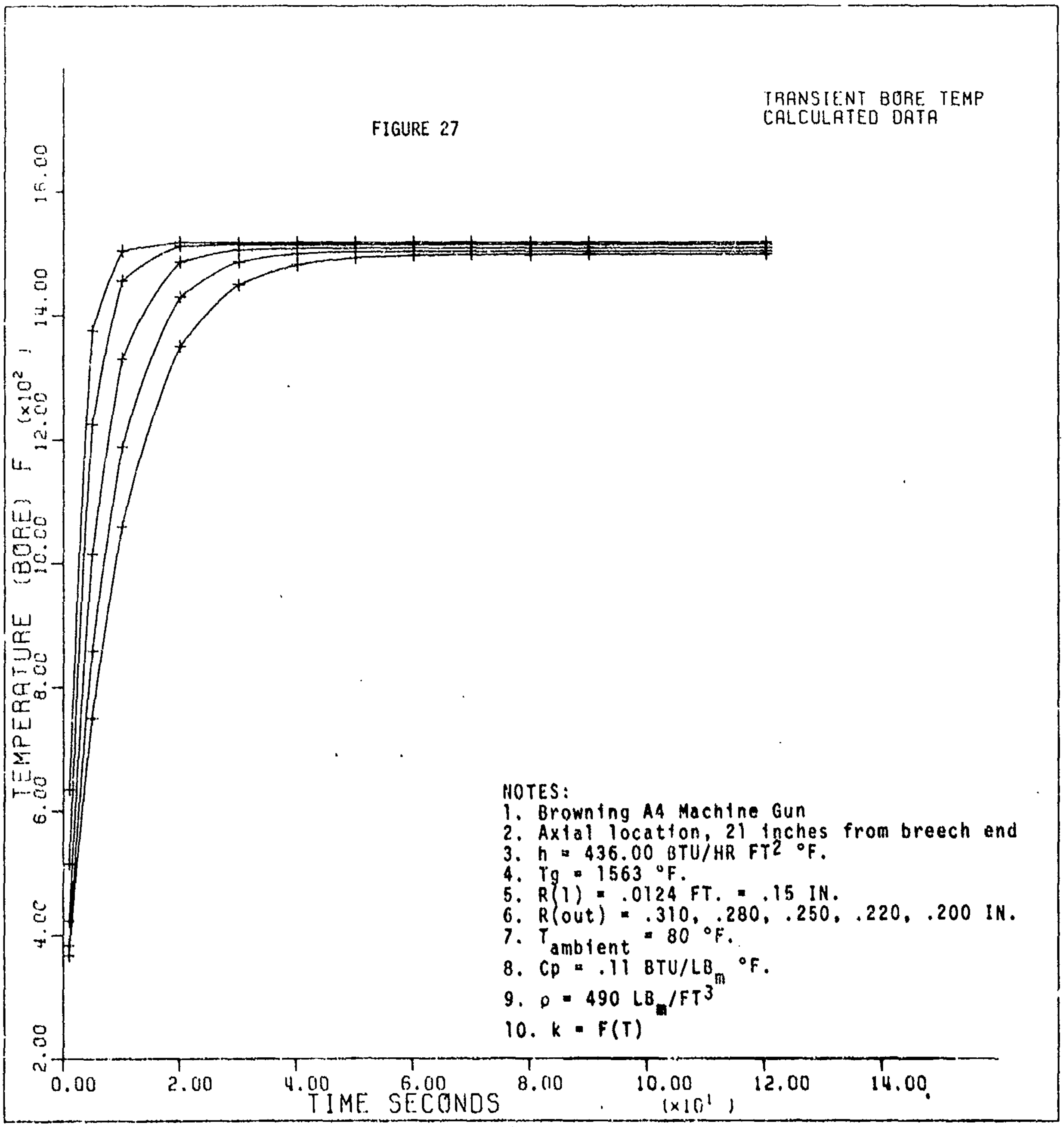


FIGURE 26
TRANSIENT TEMP.
VARIOUS RADII
TEMPERATURE (AVE) F (x10²)
TIME SECOND (x10¹)
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
NOTES:
1. Browning A4 Machine Gun
2. Axial location, 21 inches from breech end
3. h = 436.00 BTU/HR FT² °F.
4. Tg = 1563 °F.
5. R(1) = .0124 FT. = .15 IN.
6. R(out) = .310, .280, .250, .220, .200 IN.
7. T ambient = 80 °F.
8. Cp = .11 BTU/LBm °F.
9. ρ = 490 LBm/FT³
10. k = f(T)



TRANSIENT BORE TEMP
CALCULATED DATA
FIGURE 27
TEMPERATURE (BORE) F (x10²)
TIME SECONDS (x10¹)
NOTES:
1. Browning A4 Machine Gun
2. Axial location, 21 inches from breech end
3. h = 436.00 BTU/HR FT² °F.
4. Tg = 1563 °F.
5. R(1) = .0124 FT. = .15 IN.
6. R(out) = .310, .280, .250, .220, .200 IN.
7. T ambient = 80 °F.
8. Cp = .11 BTU/LBm °F.
9. ρ = 490 LBm/FT³
10. k = F(T)

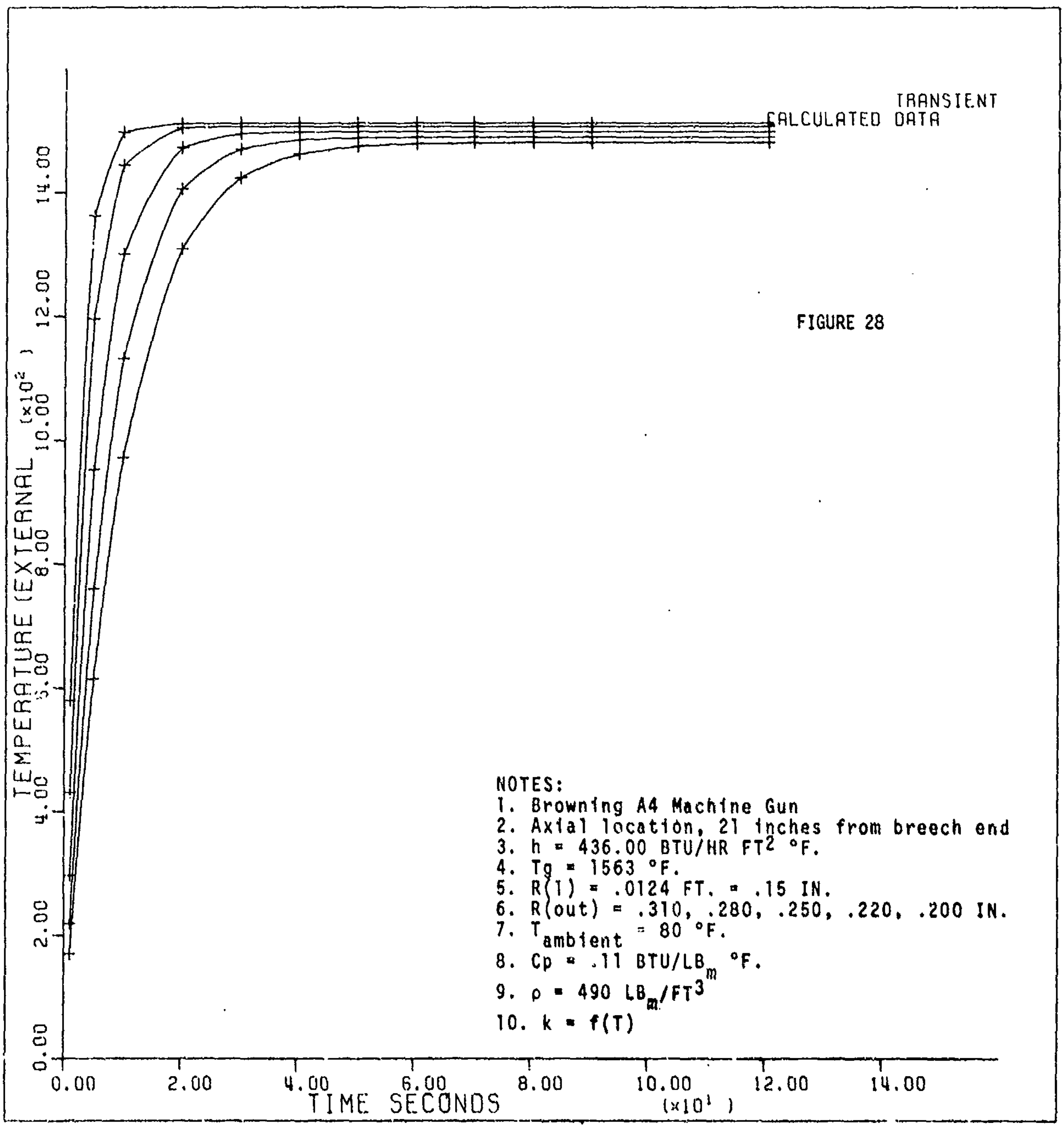
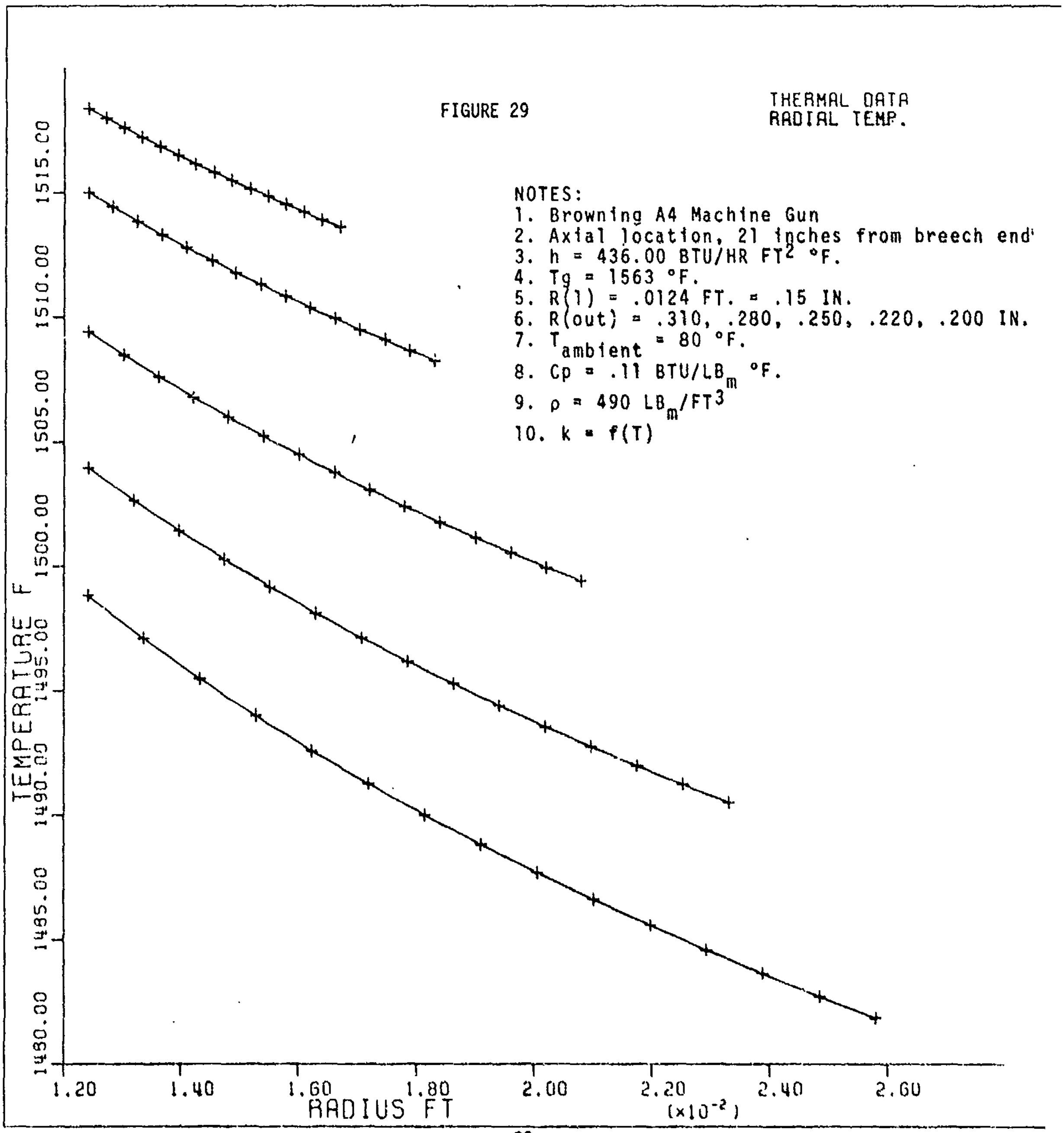

TRANSIENT
CALCULATED DATA
TEMPERATURE (EXTERNAL (×10²)
TIME SECONDS (×10¹)
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
NOTES:
1. Browning A4 Machine Gun
2. Axial location, 21 inches from breech end
3. h = 436.00 BTU/HR FT² °F.
4. Tg = 1563 °F.
5. R(I) = .0124 FT. = .15 IN.
6. R(out) = .310, .280, .250, .220, .200 IN.
7. T ambient = 80 °F.
8. Cp = .11 BTU/LB m °F.
9. ρ = 490 LB m/FT³
10. k = f(T)

FIGURE 28

FIGURE 29


THERMAL DATA
RADIAL TEMP.
NOTES:
1. Browning A4 Machine Gun
2. Axial location, 21 inches from breech end
3. h = 436.00 BTU/HR FT² °F.
4. Tg = 1563 °F.
5. R(1) = .0124 FT. = .15 IN.
6. R(out) = .310, .280, .250, .220, .200 IN.
7. T ambient = 80 °F.
8. Cp = .11 BTU/LBm °F.
9. ρ = 490 LBm/FT3
10. k = f(T)
TEMPERATURE F
1480.00
1485.00
1490.00
1495.00
1500.00
1505.00
1510.00
1515.00
1.20
1.40
1.60
1.80
2.00
2.20
2.40
2.60
RADIUS FT
(x10⁻²)

PROPOSED EXPERIMENTAL
30 CAL PROFILE

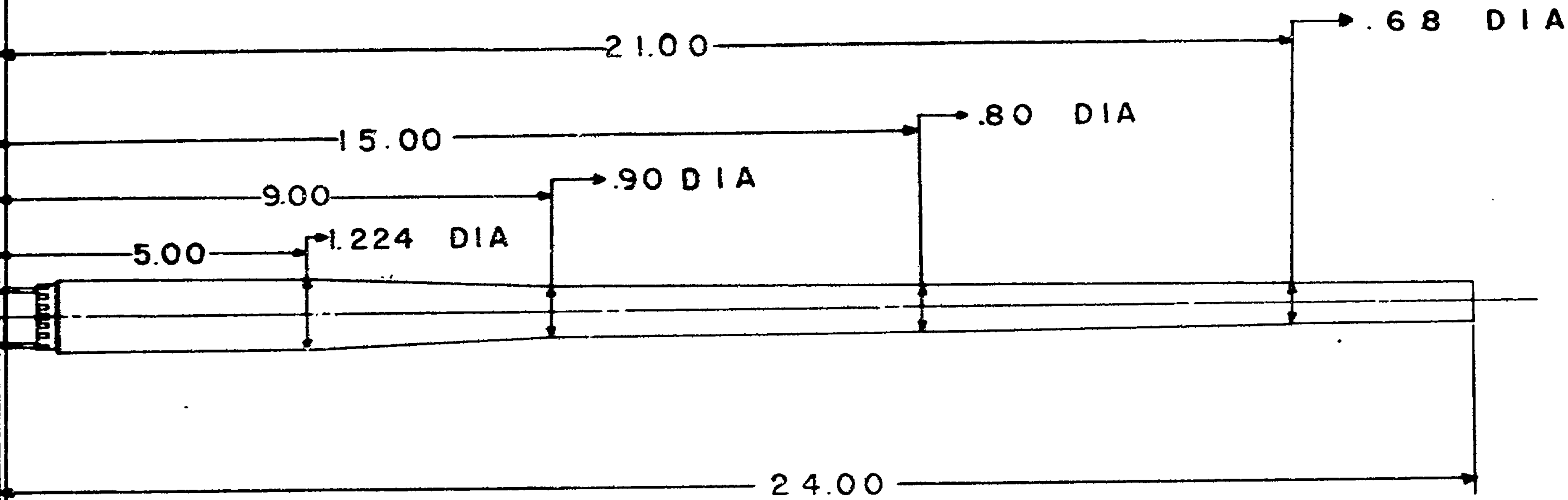


FIGURE 30

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Prepared by: Darrel M. Thomsen

Technical Report No.

83 pages, Incl Figures & Tables

This report covers FY76 efforts on a project entitled, "Effect of Material Mass Distribution on the Life of Small Arms Barrels." The objective of this project is to develop a semi-empirical technique for determining gun barrel wear (or erosion) as a function of barrel material properties, wall thickness (or ratio) and firing rate. The past years task involved analytical design of test specimens (barrel geometries) for firing experiments wherein regression analyses will be performed in the determination of the effect of mass distribution on barrel life. A useful design tool (cont.) over

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1. Erosion
2. Gun Barrels
3. Materials
4. Firing Rate
5. Temperature

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1. Erosion
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(cont.) over

1. Erosion
2. Gun Barrels
3. Materials
4. Firing Rate
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(cont.) over

1. Erosion
2. Gun Barrels
3. Materials
4. Firing Rate
5. Temperature

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1. Erosion
2. Gun Barrels
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Technical Report No.

83 pages, Incl Figures & Tables

This report covers FY76 efforts on a project entitled, "Effect of Material Mass Distribution on the Life of Small Arms Barrels." The objective of this project is to develop a semi-empirical technique for determining gun barrel wear (or erosion) as a function of barrel material properties, wall thickness (or ratio) and firing rate. The past years task involved analytical design of test specimens (barrel geometries) for firing experiments wherein regression analyses will be performed in the determination of the effect of mass dis-

1. Erosion
2. Gun Barrels
3. Materials
4. Firing Rate
5. Temperature

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