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A THEORETICAL AND EXPERIMENTAL THERMAL ANALYSIS TO DETERMINE WALL RATIOS FOR A 30MM TACTICAL BARREL

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SEPTEMBER 1975



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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER R-TR-75-023	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) A THEORETICAL AND EXPERIMENTAL THERMAL ANALYSIS TO DETERMINE WALL RATIOS FOR A 30MM TACTICAL BARREL		5. TYPE OF REPORT & PERIOD COVERED
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) PHILIP D. BENZKOEFER		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Research Directorate, SARRI-LR GEN Thomas J. Rodman Laboratory Rock Island Arsenal, Rock Island, IL 61201		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS DA 1F16326D044 AMS Code 513F.12.04400.01
11. CONTROLLING OFFICE NAME AND ADDRESS Research Directorate, SARRI-LR GEN Thomas J. Rodman Laboratory Rock Island Arsenal, Rock Island, IL 61201		12. REPORT DATE September 1975
		13. NUMBER OF PAGES 33
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) 1. Heat Transfer 2. Experimental Analysis 3. Theoretical Analysis 4. Barrel Design 5. Wall Ratios		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) A combined theoretical-experimental analysis procedure is presented in the determination of wall ratios for a 30mm tactical barrel. Preliminary efforts for this task were devoted to the design of a single-shot barrel fixture; whereas, the current effort addresses the task of designing a barrel capable of withstanding prolonged automatic fire. The final result of this study is a recommended 30mm tactical barrel configuration based on thermal and pressure stress analyses for a prescribed firing schedule.		

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INTRODUCTION

The design of gun barrel wall ratios at any axial location is determined by the combined thermal and pressure stresses to which the barrel will be subjected. These stresses are defined by the type of propellant, material properties, projectile configuration and firing schedule. Therefore, in order to design a structurally sound barrel, experimental thermal and pressure data must be available.

Initial or preliminary work on the design of a 30mm barrel was performed¹ on the AMC30 on the basis of propellant data from Hercules² and gas convection coefficients from XM-140³ analyses. As a result of this effort, a single-shot barrel was designed.

OBJECTIVE

The purpose of the current study was to design a 30mm tactical barrel configuration capable of performing satisfactorily under an extended firing schedule. At present, the firing capacity is limited to one 12-round burst. Since future plans include the firing of a more severe schedule, an extreme schedule has been arbitrarily defined as 500 total rounds, in 10-round bursts, with 30-second cooling periods between bursts, at a rate of 240 round per minute. This study is directed toward the task of designing a barrel to satisfy the above firing schedule.

¹Progress Report, "Gun Barrel Thermal Structural Model," under X.O. 512211-5007, by Mr. Darrel Thomsen, Dr. C.C. Chu, and Dr. W.J. Leech.

²Letter from G.I. Anderson, Hercules, Inc., to CG WECOM, ATTN: SWERR-W-A, Tom Redling, dated 14 Jun 72.

³Adams, D.E., et al., "Design Studies of the XM-140 Barrel," Cornell Aeronautical Laboratory, Inc., Feb 1967.

EXPERIMENTAL ANALYSIS

The 30mm AMCAWS weapon was fired for 7 rounds. The initial purpose was to fire the full capability of the gun, a 12-round burst. However, because hardware problems were encountered, only 7 rounds were fired. The barrel used has a 3-stage configuration, that is, the outside diameters are 1.57, 2.55, and 3.5 inches, with steps occurring at 31 and 63 inches, measured from the muzzle end. Therefore, only 3 axial locations indicated significant temperature rises in 7 rounds; these locations were identified at 3, 15, and 28 inches from the muzzle end, all with an O.D. of 1.57 inches.

These firing data were converted from millivolts to temperatures, °F, via computer program 1, listed in the appendix, and the output plot is given in Figure 1. On the basis of these data, effective propellant gas temperatures and convection coefficient values were obtained by the procedure outlined in the theoretical analysis section.

THEORETICAL ANALYSIS

During the firing of each round, a portion of the heat input entering into the bore is stored in the barrel, and part of this heat is removed from the outer barrel surface. An instantaneous energy balance for any axial location can be written in the following form:

$$q_{in} = q_{stored} + q_{out}$$

Semantically, heat input into the barrel must be equal to the amount of heat stored in the barrel plus the amount of heat dissipated to the surrounding environment. The q terms are defined as follows:

$$q_{in} = h_g A_b (T_g - T_b)$$

where

- h_g = mean heat transfer coefficient, BTU/hr - ft² - °F
- A_b = bore surface area, ft²
- T_g = mean gas temperature, °F
- T_b = bore temperature, °F

7 RDS, 10 April 75
 AMCAWS Barrel, 4340 Steel
 Firing Rate - 121 SPM
 AMMO - 30mm, full telescope,
 case consolidated



FIGURE 1

and

$$q_{\text{stored}} = mc \frac{dT}{d\theta}$$

where

m = mass of barrel, lb_m

c = specific heat of barrel, $\text{BTU}/\text{lb}_m - ^\circ\text{F}$

$\frac{dT}{d\theta}$ = time rate of change of temperature, $^\circ\text{F}/\text{hr.}$

and

$$q_{\text{out}} = h_o A_s (T_o - T_s) + \epsilon \sigma A_s (R_o^4 - R_s^4)$$

where

h_o = dissipation convection coefficient, $\text{BTU}/\text{hr} - \text{ft}^2 - ^\circ\text{F}$

A_s = outside barrel surface area, ft^2

T_o = outside barrel surface temperature, $^\circ\text{F}$

T_s = temperature of surrounding environment, $^\circ\text{F}$

ϵ = surface emissivity

σ = Stephan-Boltzmann constant, $\text{BTU}/\text{hr} - \text{ft}^2 - ^\circ\text{R}^4$

R_o = outside barrel surface temperature, $^\circ\text{R}$

R_s = temperature of surrounding environment, $^\circ\text{R}$

The radiation term, $\epsilon \sigma A_s (R_o^4 - R_s^4)$, can be disregarded in this analysis, since the radiation effect is insignificant at the temperature levels attained in 7 rounds of firing. The T_b term in q_{in} can be defined as

$$T_b = T_o + \Delta T$$

where ΔT = the temperature difference across the barrel wall, that is, the barrel can be treated as a mass-type calorimeter with the bore temperature being defined as the outer barrel surface temperature plus a radial temperature gradient. Looking at two distinct times in the firing schedule, one can write these equations as follows:

$$h_g A_b (T_g - T_{O1} - \Delta T_1) = mc \left. \frac{dT}{d\theta} \right|_1 + h_{O1} A_s (T_{O1} - T_s) \quad (1)$$

$$h_g A_b (T_g - T_{O2} - \Delta T_2) = mc \left. \frac{dT}{d\theta} \right|_2 + h_{O2} A_s (T_{O2} - T_s) \quad (2)$$

where the subscripts 1 and 2 refer to distinct times on the time versus temperature curve. After equation (1) has been expanded, it becomes

$$h_g (2\pi r_i \ell) (T_g - T_{O1} - \Delta T_1) = \rho \pi (r_o^2 - r_i^2) \ell c \left. \frac{dT}{d\theta} \right|_1 + h_{O1} (2\pi r_o \ell) (T_{O1} - T_s) \quad (1)$$

where

r_i , r_o , ℓ , and ρ are inside radius, outside radius, length, and density of the barrel, respectively. Regrouping yields the following equation:

$$h_g (T_g - T_{O1} - \Delta T_1) = [\rho (r_o^2 - r_i^2) c \left. \frac{dT}{d\theta} \right|_1 + 2r_o h_{O1} (T_{O1} - T_s)] / 2r_i$$

Defining $KA1$, $KB1$, and K_1 ,

$$KA1 = \rho (r_o^2 - r_i^2) c \left. \frac{dT}{d\theta} \right|_1$$

$$KA2 = 2r_o h_{O1} (T_{O1} - T_s)$$

and

$$K_1 = (KA1 + KB1) / 2r_i$$

Equation (1) now becomes

$$h_g (T_g - T_{O1} - \Delta T_1) = K_1 \quad (1)$$

Similarly,

$$h_g (T_g - T_{O2} - \Delta T_2) = K_2 \quad (2)$$

Define A as follows:

$$A = \left. \frac{dT}{d\theta} \right|_1 / \left. \frac{dT}{d\theta} \right|_2$$

and assuming that the $d\theta$'s are very nearly the same size

where

$$A = \Delta T_1 / \Delta T_2$$

then

$$\Delta T_2 \approx \Delta T_1 / A$$

Now, collecting terms and solving equations (1) and (2) simultaneously yields

$$h_g = (K_1 - K_2) / [\Delta T_1 (1/A - 1) + (T_{O2} - T_{O1})] \quad (3)$$

Substituting equation (3) into equation (1), one obtains the following:

$$T_g = \Delta T_1 + K_1 / h_g + T_{O1} \quad (4)$$

The next step is to select $\left. \frac{dT}{d\theta} \right|_1$ and $\left. \frac{dT}{d\theta} \right|_2$. If one can fit an accurate curve to the experimental temperature data, the derivatives can be evaluated analytically at two distinct points. Otherwise, a discrete set of derivatives can be determined. These two derivatives, $\left. \frac{dT}{d\theta} \right|_1$ and $\left. \frac{dT}{d\theta} \right|_2$, should reflect the changes in temperature early on the time versus temperature curve and toward the end of the curve; but, prior to the quasi, steady-state condition, respectively. The initial value of ΔT_1 is generally selected based on previous experience. Once $\left. \frac{dT}{d\theta} \right|_1$, $\left. \frac{dT}{d\theta} \right|_2$, and ΔT_1 are known, mean values of h_g and T_g can then be determined. With the computer program 2, listed in the appendix, equations (3) and (4) can be quite readily solved. These two values, $\bar{h}_g$ and $\bar{T}_g$, can be used to solve for the transient, radial temperature distribution for any particular firing schedule and firing rate by input of these values into computer program 3, listed in the appendix. This program employs an implicit, finite-difference algorithm, which is extremely efficient and accurate. Refinement on $\bar{h}_g$ and $\bar{T}_g$ can be made after the temperature output is compared with experimental data. This is accomplished by an iteration process in which ΔT_1 is varied in computer program 2 based on the calculated value obtained in computer program 3.

DISCUSSION OF RESULTS

Mean values $\bar{h}_g$ and $\bar{T}_g$ were obtained from the experimental data taken for the three axial locations, 3, 15.5, and 31 inches (measured from the muzzle end), that gave good temperature response in the 7 rounds. With the use of these values, various wall thicknesses at the three locations were investigated. The outside barrel surface temperature responses for this and a previous parametric wall ratio study are shown in Figure 2. The top center legend defines the firing schedule, and the lower right legend describes axial location, wall thickness, and $\bar{h}_g$ and $\bar{T}_g$ values. The x and y axis labels define the time and temperature in the respective units. The curves for the axial location near the breech end are based on $\bar{h}_g$ and $\bar{T}_g$ values from previous analyses ^{2,3} since the 7-round firing schedule did not produce significant temperature rise near the breech end. These particular curves in addition to several others that resulted from input values $\bar{h}_g$ and $\bar{T}_g$ taken from Hercules² and from XM-140³ studies are shown in Figure 3. The legends and captions are self-explanatory. On the basis of the temperature results and the pressure data available, an elastic thermal and pressure stress analysis was performed for the breech end location and for the 33-inch location (measured from the muzzle end). Peak total equivalent stresses were within the dynamic⁴ yield stress of 108,000 psi for CR-MO-VA steel at 1200°F.

A proposed barrel design is given in Figure 4. This was developed essentially on the basis of the 7 rounds of experimental data, except for the breech end, which is designed as explained above. However, an extended firing schedule of at least 50 rounds should be performed from which more accurate bore boundary condition data can be obtained. These data should be applied to a more optimum design of future 30mm tactical barrels for varying firing requirements.

²Letter from G.I. Anderson, Hercules, Inc., to CG WECOM, ATTN: SWERR-W-A, Tom Redling, dated 14 Jun 72.

³Adams, D.E., et al., "Design Studies of the XM-140 Barrel", Cornell Aeronautical Laboratory, Inc., Feb 1967.

⁴"Dynamic Properties of Superalloys at Elevated Temperatures," Technical Report RE-TR-71-75, Research Directorate, Weapons Laboratory, WECOM, February 1972.

FIRING SCHEDULE.

10 rd. bursts with 30 sec.
cooling between bursts,
at a rate of 240 rds/min.
for a total of 500 rds.

VARIOUS AXIAL LOCS
30MM BARREL

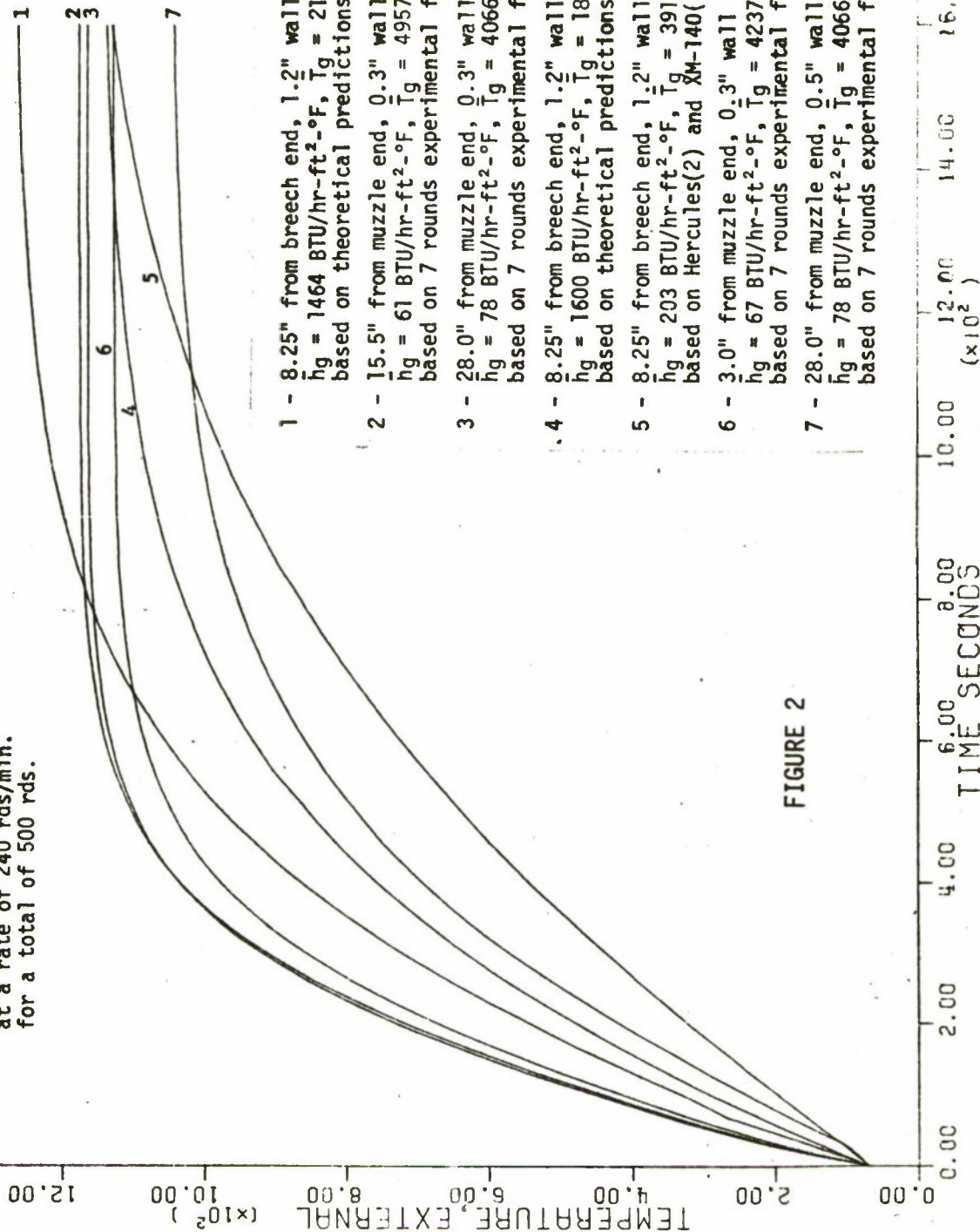


FIGURE 2

- 1 - 8.25" from breech end, 1.2" wall thickness,
 $\bar{h}_g = 1464 \text{ BTU/hr-ft}^2\text{-}^\circ\text{F}$, $\bar{T}_g = 2182^\circ\text{F}$,
based on theoretical predictions.
- 2 - 15.5" from muzzle end, 0.3" wall thickness,
 $\bar{h}_g = 61 \text{ BTU/hr-ft}^2\text{-}^\circ\text{F}$, $\bar{T}_g = 4957^\circ\text{F}$,
based on 7 rounds experimental firing.
- 3 - 28.0" from muzzle end, 0.3" wall thickness,
 $\bar{h}_g = 78 \text{ BTU/hr-ft}^2\text{-}^\circ\text{F}$, $\bar{T}_g = 4066^\circ\text{F}$,
based on 7 rounds experimental firing.
- 4 - 8.25" from breech end, 1.2" wall thickness,
 $\bar{h}_g = 1600 \text{ BTU/hr-ft}^2\text{-}^\circ\text{F}$, $\bar{T}_g = 1820^\circ\text{F}$,
based on theoretical predictions.
- 5 - 8.25" from breech end, 1.2" wall thickness,
 $\bar{h}_g = 203 \text{ BTU/hr-ft}^2\text{-}^\circ\text{F}$, $\bar{T}_g = 3910^\circ\text{F}$,
based on Hercules(2) and XM-140(3) firing data.
- 6 - 3.0" from muzzle end, 0.3" wall thickness,
 $\bar{h}_g = 67 \text{ BTU/hr-ft}^2\text{-}^\circ\text{F}$, $\bar{T}_g = 4237^\circ\text{F}$,
based on 7 rounds experimental firing data.
- 7 - 28.0" from muzzle end, 0.5" wall thickness,
 $\bar{h}_g = 78 \text{ BTU/hr-ft}^2\text{-}^\circ\text{F}$, $\bar{T}_g = 4066^\circ\text{F}$,
based on 7 rounds experimental firing data.

FIRING SCHEDULE

10 rd bursts with 30 sec
cooling between bursts,
at a rate of 240 rds/min.
for a total of 500 rds.

30MM BARREL
SECTIONS A-A, B-B, C-C

A-A: 8.25" from breech
B-B: 39.00" from breech
C-C: 83.00" from breech

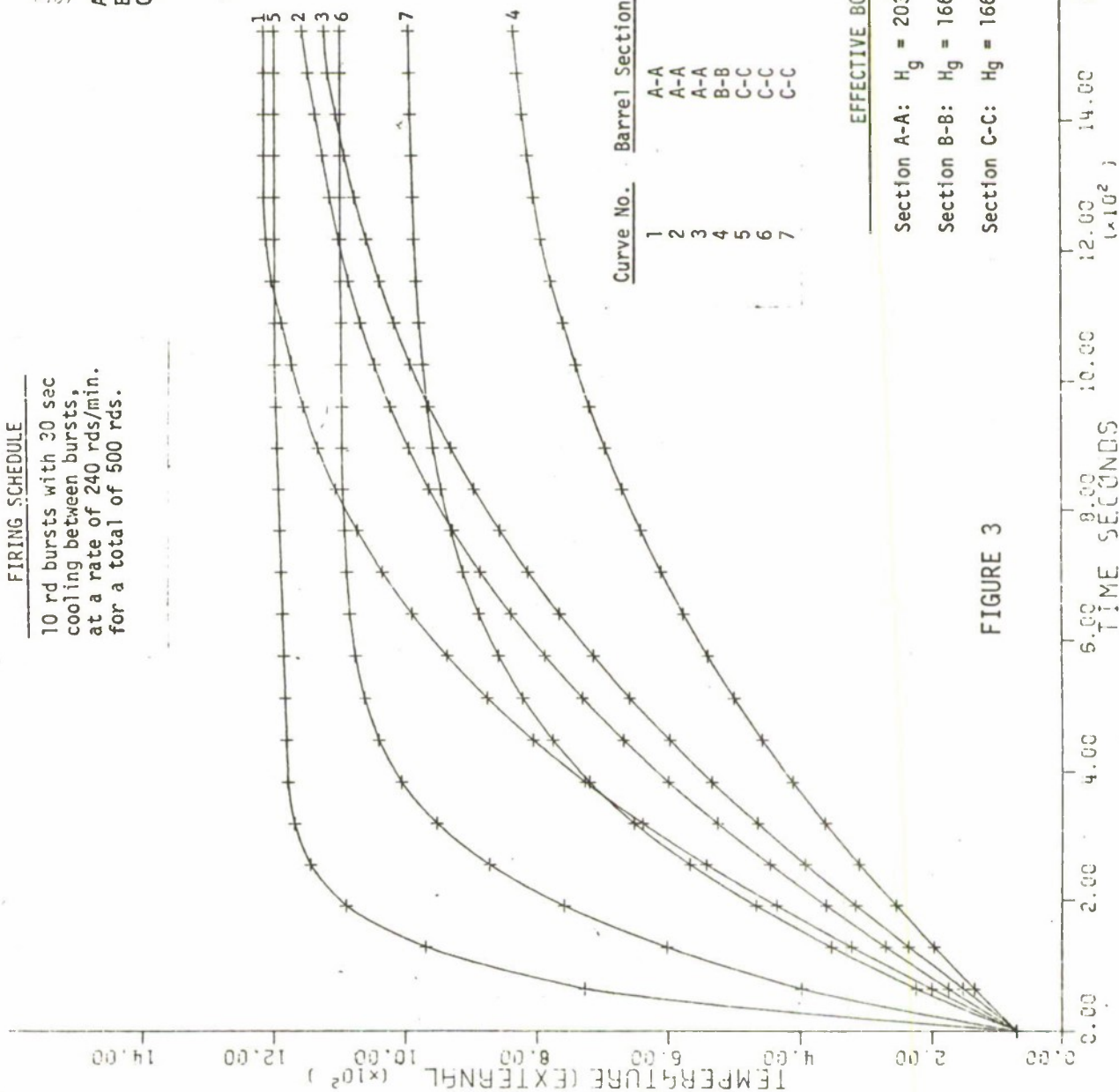


FIGURE 3

PROPOSED 30MM TACTICAL BARREL

(CR-M0-VA STEEL)

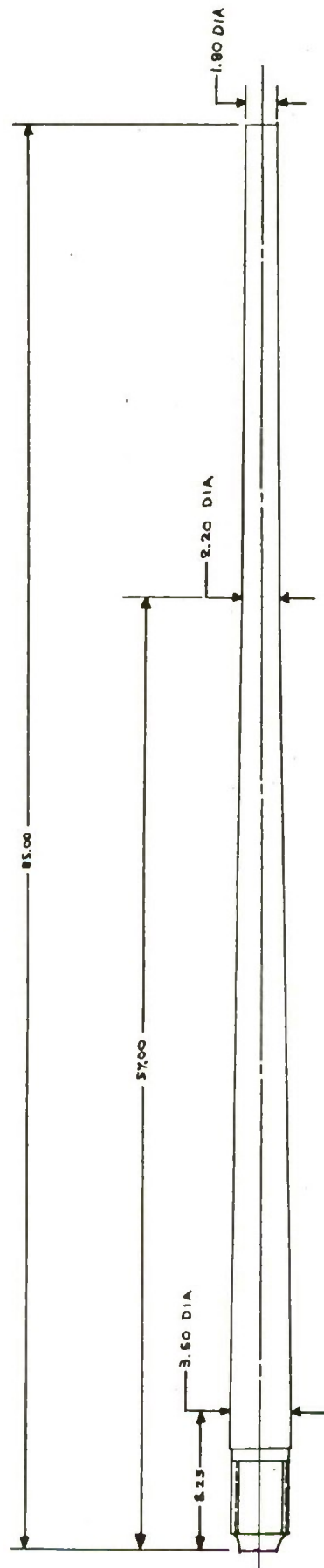


FIGURE 4

APPENDIX
Computer Program 1

```
0001 DIMENSION DATA(99),DATAY(99)
0002 COMMON/BLK1/F1,F2,F3,C1,C2,J,ITYPE
0003 COMMON/BLK2/NPTS(20)
0004 READ 1,NSETS,ITYPE
0005 1 FORMAT(2I5)
C
0006 2 ITYPE=0 MEANS DATA IS TEMPERATURE.
0007 ITYPE=1 MEANS DATA IS MILLIVOLTS.
0008 C
0009 READ 2,(NPTS(J),J=1,NSETS)
0010 2 FORMAT(16I5)
0011 READ 3,F1,F2,F3,C1,C2
0012 3 FORMAT(5F10.5)
0013 II=1
0014 J=II
0015 NPT=NPTS(J)
0016 6 READ 4,(DATA(I),DATAY(I),I=1,NPT)
0017 CALL CONVRT(DATA,DATA)
0018 II=II+1
0019 J=II
0020 NPT=NPTS(J)
0021 IF(II.GT.NSETS) GO TO 5
0022 GO TO 6
4 FORMAT(10F8.3)
5 CALL EXIT
END
```

```

0001 SURROUTINE CONVRT(OATAX,OATAY)
0002 REAL OATAX(99),OATAY(99)
0003 COMMON/BLK1/F1,F2,F3,C1,C2,J,ITYPE
0004 COMMON/BLK2/NPTS(20)
0005 NP=NPTS(J)
0006 PRINT 400
0007 400 FORMAT(1H1)
0008 IF(ITYPE.EQ.0) GO TO 403
0009 PRINT 402
0010 402 FORMAT(6X,'TIME',8X,'MILLIVOLTS',5X,'TEMPERATURE(OEG.F)')
0011 GO TO 405
0012 403 PRINT 404
0013 404 FORMAT(6X,'TIME',23X,'TEMPERATURE(OEG.F)')
0014 GO 11 I=1,NP
0015 PRINT 12,OATAX(I),DATAY(I)
0016 12 FORMAT(1F10.1,15X,1F20.1)
0017 11 CONTINUE
0018 GO TO 99
0019 405 GO 10 I=1,NP
0020 IF(OATAY(I).GT.C1) GO TO 5
0021 IF(OATAY(I).GT.C2) GO TO 6
0022 FACTOR=F3
0023 GO TO 7
0024 5 FACTOR=F1
0025 GO TO 7
0026 6 FACTOR=F2
0027 7 TEMP=OATAY(I)
0028 OATAY(I)=OATAY(I)*FACTOR+32.
0029 PRINT 401,OATAX(I),TEMP,OATAY(I)
0030 401 FORMAT(1F10.1,1F15.3,1F20.1)
0031 10 CONTINUE
0032 99 IF(J.EQ.1) GO TO 100
0033 GO TO 200
0034 100 CALL GRAPH(NP,OATAX,OATAY,0,1,9,0,7,0,200.,0.0,
200.,0.0,'TIME SECONDS','TEMPERATURE,EXTERNAL',
3,VARIOUS AXIAL LOCS','30MM BARREL')
GO TO 300
0035 200 CALL GRAPH(NP,OATAX,OATAY,0,1,0,0,7,0,200.,0.0,
0036 200.,0.0,'TIME SECONDS','TEMPERATURE,EXTERNAL',
3,VARIOUS AXIAL LOCS','30MM BARREL')
0037 300 RETURN
0038 ENO

```

APPENDIX
Computer Program 2

16/18/08

DATE = 75128

MAIN

FORTRAN IV 6 LEVEL 21

```

0001 IMPLICIT REAL*(A-Z)
0002 HEAD 1,RHO,TA,TW1,TW2,OTDT1,OTDT2,H01,H02,M1,R0,CP,DT2
0003 PRINT 1,RHO,TA,TW1,TW2,OTDT1,OTDT2,H01,H02,M1,R0,CP,DT2
0004 1 FORMAT (F10.5/6F10.5)
0005 CC=H0*CP*(R0**2-RI**2)
0006 KA1=CC*OTDT1*3600.
0007 KA2=CC*OTDT2*3600.
0008 KA1=H01*2.*R0*(TW1-TA)
0009 KA2=H02*2.*R0*(TW2-TA)
0010 K1=(KA1+KA2)/(2.*RI)
0011 K2=(KA2+KA2)/(2.*RI)
0012 A=OTDT1/OTDT2
0013 C3=TW2-TW1
0014 HG=(K1-K2)/(C3*OT2*(1./A-1.))
0015 TG = 1./HG*((KA2 + KA2)/(2.*RI)) + TW2 * OT2
0016 HDYR=15.0/HG
0017 PRINT 2,HG,TG,HDYR
0018 PRINT 3,KA1,KA2
0019 PRINT 3,KA1,KA2
0020 PRINT 3,K1,K2
0021 PRINT 3,C3
0022 3 FORMAT(10X,3F20.10)
0023 2 FORMAT(10X,HG=,F10.5,10X,TG=,F10.5,10X,HDYR=,F10.5)
0024 CALL EXIT
0025 END

```

APPENDIX
Computer Program 3

```

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
C
C DIMENSION ANS(199),NPLOT(11),TT(150)
C**DEFINITION OF LABELED COMMON -- BLK1,BLK2, AND BLK3
COMMON /BLK1/ T(150),C(150),CX(150),H(150),HX(150),IBODY(10,2)
COMMON /BLK2/ RADII(11),NODES(10),XKZ(99),BETA(10),CP(10),RHD(10),
2EMISS,RHOZ,CPZ,XKRZ,BDYR(11),RI(150),RII(150),DR(10),A(9),ITR(11)
COMMON /BLK3/ ISYM,XMIN,XMAX,YMIN,YMAX,
2IPLOT(11),TIM(150),TTR(150),TTO(150)
C
C**INITIALIZATION OF VARIABLES NOT LOCATED IN LABELED COMMON
DATA ANS,TNUM,TDENOM,DZ,DTIMEX,DDTX,IX,NBODY/.2,.4,1.0,2.0,
2195,.0,.0,1.,1.,.0005,.25,3,1/
C
C**READ CHARACTERISTICS OF PROBLEM -- RAW INPUT DATA
C
C**DEFINITION OF NAME AND NAME1
NAMELIST /NAME/ T,ISYM,YMAX,YMIN,XMAX,XMIN,TNUM,TDENOM,ANS,
2NODES,XKZ,BETA,CP,RHO,BDYR,EMISS,DZ,DTIMEX,DDTX,IX,NBODY,CPZ,
3RHOZ,XKRZ,PAV11,A,ITR
4/NAME1/DTIMEX,DDTX,DZ,II,NBODY,IX,XKRZ,RHOZ,CPZ,EMISS,TNUM,TDENOM,
5ISYM,XMAX,XMIN,YMAX,YMIN,NODES,ANS,A,ITR,IPLOT
C DIMENSION TIMEF(250),F(250)
C READ 100,4
100 FORMAT(15)
C READ 200, (TIMEF(I),F(I),I=1,N)
200 FORMAT (BF10.5)
C PRINT 202
202 FORMAT (IX,TIMEF,.25X,.F')
C PRINT 203, (TIMEF(I),F(I),I=1,N)
203 FORMAT (5X,F10.5,16X,F10.5)
26 READ(5,NAME)
C
C**CALCULATE DIMENSIONLESS LUMPED PARAMETERS, MX(I) AND C(I)
CALL LUMP (II,NBODY,DZ)
C
C**WRITE PROBLEM PARAMETERS
WRITE(6,3)
3 FORMAT(29H1HEAT TRANSFER PROGRAM HT-2A /27M PROGRAMMED BY A.M.CLAU
25ING/30H CRANK-NICOLSON ALGORITHM
3 /26H VERSION = 1 JULY 1970 ///25H THE INPUT PARAMETERS ARE)
WRITE(6,NAME1)
WRITE(6,5)
5 FORMAT(7H0REGION,3X5H1R00Y,3X 9HRADII(FT),5X6HDR(FT),5X8HBODYR(FT),
26X2HCP,8X3HRHO,8X2HKZ,6X4HBETA )
WRITE(6,7) (J,140DY(J,1),IBODY(J,2),RADII(J),DR(J),BDYR(J),CP(J),
28H(J),XKZ(J),BETA(J),J=1,NBODY)
7 FORMAT(13,14,14,3E12.3, F10.3,2F10.1,F11.0)
1 = JBODY + 1

```

```

0026 WRITE(6, 9) I, RADII(I), RQYR(I)
0027 FORMAT(13, 12X, E12.3, 12X, E12.3//)
0028 WRITE(6, 11)
0029 FORMAT(3F14.1, 7X5H H(I), 12X4HC(I), 12X4MT(I), 7X6HRADIUS )
0030 WRITE(6, 13) (I, H(I), C(I), T(I), RI(I), I=1, II)
0031 FORMAT(14, 2E16.4, F13.2, F13.5)
C
C**CALCULATE OR INITIALIZE VARIOUS QUANTITIES ---- SAVE T(I) AND DTIMEX
TSEC = 07*2*PI*CPZ*1600./XKRZ
IIP1 = II - 1
IIP2 = II - 2
IIP1 = IIP1 + 1
IF(ANS(I).GT.0) GO TO 131
C 133 I=1, 198
133 ANS(I) = ANS(I)/TSEC
ANS(I) = -ANS(I)
131 DO 15 I=1, IIP1
15 TT(I) = T(I)
ATTIME = ATIMEX
DOOTX=DOTX
N=0
IANS=1
TAUT = 0
IIP1=9
C
C**START OF SOLUTION OF PROBLEM
C POINT OF MAJOR LOOP ENTRY -- SN25(N0 NEW DTIMEX), SN24(NEW DTIMEX)
19 DO 19 I=2, IIP1
24 CX(I) = C(I)/DTIMEX*2.
25 CALL CHANGE(NBODY, TSEC, TAUT, II, IX, II)
TIME=TAUT*TSEC
HX(I)=-AXIT(1)/RQYR(1)
CALL LINEAR(TIME, TIMEF, F, FACTOR)
HX(I)=-HX(I)*FACTOR
CALL SOLVE (IIP1, IIP2, II, NBODY, BETA)
N = I + 1
TAUT = TAUT + DTIMEX
C**END OF TIME STEP
C**IF TIME=DOOTX DOUBLE TIME INCREMENT
C 21 IF(TAUT+1., DOOTX) GO TO 29
C 19CT = 1
C DTIMEX = DTIMEX*2.
C DOOTX = 2.*DOOTX
C WRITE(6, 31) DTIMEX, TAUT
C 31 FORMAT(7/57+ TIME INCREMENT DOUBLED, NEW DIMENSIONLESS INCREMENT 1
C 25 = .57, 4/36+ THE CURRENT DIMENSIONLESS TIME IS =, F7.4)
IF(FACTOR .LT. .5) GO TO 260
IF(FACTOR .GT. .5) GO TO 280
260 DTIMEX = .005
GO TO 320
280 DTIMEX = .005
300 19CT = 1
GO TO 33
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0065      29      IRET = 2
C
0066      C**IF TAUT,ST,ANS(IANS) PRINT TEMPERATURE DISTRIBUTIONS ETC.
0067      33      IF(TAUT,LT,ANS(IANS)) GO TO (24,25),IPET
0068      IANS = IANS + 1
0069      CALL RESULT(TAUT,IIM1,IIM2,TNUM,TDENOM,DZ,NBODY,ANS,IANS,
0070      IDTIME,ITP1,IIM2,ITIM)
0071      IF(ANS(IANS).NE.0) GO TO (24,25),IRET
C
0072      C**RESET INITIAL CONDITION AND TIME INCREMENT -- READ NEXT CASE -- SN26
0073      35      DTIMEX = ATIME
0074      00 37  I=1,ITP1
0075      T(1) = TT(1)
0076      GO TO 26
0077      END
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0001 SUBROUTINE LUMP(II,NBODY,DZ) 01270
0002 COMMON /RLK1/ T(150),C(150),CX(150),H(150),HX(150),IBODY(10,2) 01280
0003 COMMON /RLK2/ RADII(11),NODES(10),XKZ(99),BETA(10),CP(10),RHO(10), 00100
PEWISS,RHOZ,CPZ,XKZ2,HVPR(11),RI(150),RII(150),OR(10),A(9),ITB(11) 01300
01310
C 01320
C**THIS SUBROUTINE CALCULATES THE DIMENSIONLESS LUMPED PARAMETERS 01330
AZ=XKZ2*CPZ*DZ**2 01340
CI = .6 01350
C(1) = .0 01360
IF (HVP(1),EQ..0) GO TO 3 01370
HX(1) = RADII(1)/BODY(1) 01380
H(1) = HX(1) 01390
IBODY(1,1) = 2 01400
GO TO 5 01410
3 IBODY(1,1) = 1 01420
5 HI(1) = RADII(1) 01430
C 01440
C**BEGINNING OF LOOP TO CALCULATE C(I) AND H(I) FOR NBODY REGIONS(J) 01450
DO 4 J=1,NBODY 01460
HRC = RADII(J,1) - RADII(J) 01470
OR(J) = HRC/FLCAT(NODES(J)-1) 01480
IBODY(J,2) = IBODY(J,1) + NODES(J) - 1 01490
IA = IBODY(J,1) 01500
IE = IBODY(J,2) - 1 01510
HI(IA) = RADII(J) 01520
C 01530
C**CALCULATION OF C(I) AND H(I) FOR REGION J 01540
AJ = HRC(J)*CP(J)*OR(J)/AZ 01550
C(IA) = AJ*(HI(IA) + OR(J)/4.)/2. + CI 01560
HJ = XKZ(J)/(XKZ2*OR(J)) 01570
DO 1 I=IA,IE 01580
H(I) = HJ*(RI(I)*OR(J)/2.) 01590
HI(I+1) = HI(I) + OR(J) 01600
C(I+1) = AJ*PI(I+1) 01610
C(IE+1) = AJ*(PI(IE+1)-OR(J)/4.)/2. 01620
C 01630
C**CHECK TO SEE IF INTERFACIAL RESISTANCE IS ZERO AND PROCEED ACCORDINGLY 01640
IF (BODY(J,1).EQ..0) GO TO 2 01650
CI = .0 01660
IBODY(J+1,1) = IBODY(J,2) + 1 01670
HX(IE+1) = HI(IE+1)/BODY(J+1) 01680
H(IE+1) = HX(IE+1) 01690
GO TO 3 01700
2 CI = C(IE+1) 01710
IBODY(J+1,1) = IBODY(J,2) 01720
CONTINUE 01730
IF (BODY(NBODY+1).NE..0) GO TO 11 01740
II = IE + 1 01750
GO TO 13 01760
11 II = IE + 2 01770
C(II) = .0 01780
HI(II) = .0 01790
HI(II) = RADII(NBODY + 1)

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0045      C**CALCULATE THE DIMENSIONLESS RADIUS RII
0046      DO 16 I=1,II
0047      RII(I) = (CI(I) - RADI(I))/(RADI(NBOOY+1) - RADI(1))
0048      RETURN
0049      END
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0001 SURROUTINE LINEAR(A,X,Y,VV)
0002 DIMENSION X(1),Y(1)
0003 I=1
0004 C 1 IF (Y(I+1) .LT. Y(I)) GO TO 100
0005 C USE FOLLOWING IF AS Y INCREASES X INCREASES
0006 10 IF (A-X(I))3,2,2
0007 C USE FOLLOWING IF AS Y INCREASES X DECREASES
0008 C 100 IF (A-X(I))2,2,3
0009 2 I=I+1
0010 GO TO 10
0011 3 I=I-1
0012 VV=Y(I)*(A-X(I+1))/(X(I)-X(I+1))+Y(I+1)*(A-X(I))/(X(I+1)-X(I))
0013 RETURN
0014 EN10
0015

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0001 SUBROUTINE SOLVE (IIM1,IIM2,II,NBODY,BETA) 01860
0002 DIMENSION GE(150),FE(150),DE(150),BETA(10),BE(150),BI(150) 01870
0003 COMMON /ALB1/ T(150),C(150),CX(150),H(150),HX(150),IBODY(10,2) 01880
01890
01900 C**CORRECT THE BODY CONDUCTANCES FOR VARIABLE CONDUCTIVITIES 01900
01910 DO 3 J=1,NBODY 01910
01920 IR = IBODY(J,1) 01920
01930 IE= IBODY(J,2) - 1 01930
01940 DO 3 I=IR,IE 01940
01950 HX(I) = H(I)*(1. + BETA(J)*(T(I) + T(I+1))/2.) 01950
01960 C 01960
01970 C**START OF ELIMINATION -- CRANK-NICOLSON ALGORITHM 01970
01980 DO 9 I=2,IIM1 01980
01990 C1 = -HX(I) + HX(I-1) 01990
02000 BE(I) = CX(I) + C1 02000
02010 HI(I) = CX(I) - C1 02010
02020 GE(2) = BE(2) 02020
02030 FE(2) = (BI(2)*T(2) + HX(2)*T(3) + HX(1)*T(1)*2.)/GE(2) 02030
02040 DO 5 I=3,IIM1 02040
02050 DE(I) = -HX(I-1)/GE(I-1) 02050
02060 GE(I) = BE(I) + HX(I-1)*DE(I) 02060
02070 FE(I) = (HX(I)*T(I+1) + HX(I-1)*T(I-1) + BI(I)*T(I) + HX(I-1)* 02070
02080 2*FE(I-1))/GE(I) 02080
02090 FE(IIM1) = FE(IIM1) + HX(IIM1)*T(IIM1)/GE(IIM1) 02090
02100 C 02100
02110 C**BACK SUBSTITUTION 02110
02120 T(IIM1) = FE(IIM1) 02120
02130 DO 7 I=2,II-2 02130
02140 J = I - 1 02140
02150 T(J) = FE(J) - DE(J+1)*T(J+1) 02150
02160 RETURN 02160
02170 END 02170

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09/07/30

DATE = 75024

RESULT

FORTMAN IV G LEVEL 21

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0001 SUBROUTINE RESULT(TAUT,IIM1,II,INUM,TDENOM,DZ,NBODY,ANS,IAN, 02180
0002 20TITEX,IIP1,IIM2,IIM)
0003 DIMENSION TSTAR(150),XM(10),ANS(199),NPLT(11),Y(500),TT(150)
0004 COMON /PLX1/ T(150),CX(150),H(150),HX(150),IBODY(10,2)
0005 COMON /PLX2/ RAD1(11),NOOES(10),XKZ(99),ETA(10),CP(10),RMO(10),
0006 2EMISS,RHOZ,CPZ,XKZ,40YR(11),RI(150),RII(150),DR(10),A(9),ITR(11)
0007 COMON /PLX3/ ISYM,XMIN,XMAX,YMIN,YMAX,
0008 2IPLOT(11),TIM(150),TTR(150),TTO(150)
0009
0010 C**CALCULATE DIMENSIONAL TIME,HEAT FLOWS PER UNIT DEPTH, TSTAR, M'S
0011 C**AND FIGHTER AVERAGE TEMPERATURE. PRINT THESE QUANTITIES.
0012 CALL TAVF(II,IIP1)
0013 TSEC = DZ**2 * RHOZ * CPZ * 3600./ XKZ
0014 TIME = TAUT * TSEC
0015 JIN = HX(11)*XKZ*6.2832*(T(1) - T(2))
0016 GOUT = HX(11)*XKZ*6.2832*(T(IIM1) - T(II))
0017 HOUT=HX(11)*XKZ/R1(IIM1)
0018 HCON=XKZ/R2YR(NBODY+1)
0019 HRA=HOUT-HCON
0020 HIN=HX(11)*XKZ/RAD1(1)
0021 DO 1 I=1,IIP1
0022 TSTAR(I) = (T(I) - INUM)/TDENOM
0023 DO 3 J=1,NBODY
0024 XM(J) = PR(J)**2/(OTIME*DZ**2)
0025 WRITE(6,5) TAUT
0026 FORMAT(///22H0 DIMENSIONLESS TIME =,F7.3,10X2HHEAT FLOW PER FT (
0027 2RTI/HR-FT),10X4HCOMBINEO CONVECTION COEFFICIENT (BTU/HR-FT**2-F)
0028 WRITE(6,7) TIME,JIN,GOUT,HOUT,HRA
0029 FORMAT(22H REAL TIME (SECONDS)=,F11.3,3X4HJIN=E12.3,7H GOUT=,E12
0030 2.3,3X7H HRA=C=E12.3,3X3HHRA=E12.3)
0031 WRITE(6,9) (X(1),I=1,NBODY)
0032 FORMAT(30H M VALUES FOR REGIONS 1 THRU NBODY ARE,10F6.2)
0033 WRITE(6,9) HIN
0034 FORMAT(25H HIN (BTU/HR-FT**2-F)=,10F8.2)
0035
0036 C**PRINT THE DIMENSIONAL TEMPERATURES
0037 WRITE(6,11) T(1),IIM1,T(1),I=2,IIM1)
0038 FOR AT( /35H0THE DIMENSIONAL TEMPERATURES ARE /6H T(1)=,F10.2/
0039 213H T(2) T=0 T(13,9H) FOLLOW/(5F10.2,5X,5F10.2)
0040 WRITE(6,13)I1, T(11), T(11P1)
0041 FOR AT(3H T(13,2H)=,F12.2,6X,7HT(AVE)=,F12.2)
0042
0043 C**IF ANS(30).NE.0, PRINT THE DIMENSIONLESS TEMPERATURES
0044 WRITE(6,15)TSTAR(1),IIM1,(TSTAR(1),I=2,IIM1)
0045 C WRITE(6,13) I1,TSTAR(11), TSTAR(IIP1)
0046 C15 FOR AT( /35H0THE DIMENSIONLESS TEMPERATURES ARE/6H T(1)=,F10.2/
0047 213H T(2) T=0 T(13,9H) FOLLOW/(5F10.3,5X,5F10.3)
0048 C13 PLOT OF AVG TEMP. VS TIME
0049 C REAL DATA(150), OATAY(150)
0050 IITM = IYIM + 1
0051 TAVE = T(IIP1)
0052 TT(IITM) = T(IIP1)
0053 TTR(IITM) = T(2)
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0035      TIO(ITIM) = T(IIM1)
0036      TIM(ITIM) = TAU*ITSEC
0037      IF (IPLOT(11).EQ.0) GO TO 18
0038      IF (ANS(IANS).NE.0) GO TO 18
0039      DO 17 J = 1, ITIM
0040      DATAA(J) = TT(J)
0041      DATAA(J) = TIM(J)
0042      CALL GRAPH (ITIM, DATAA, DATAA, 3, 1, 8.0, 8.0, 0.0, 0.0, 0.0,
0043      20.0, 0.0, 'TIME SECONDS', 'TEMPERATURE (AVE) F',
0044      2, 'TRANSIENT TEMP.', 'VARIOUS RADII',)
0045      CONTINUE
0046      C PLOT CORE TEMP. VS TIME
0047      IF (IPLOT(10).EQ.0) GO TO 19
0048      IF (ANS(IANS).NE.0) GO TO 19
0049      REAL DATAA(150), DATAA(150)
0050      DO 21 J = 1, ITIM
0051      DATAA(J) = TTR(J)
0052      DATAA(J) = TIM(J)
0053      CALL GRAPH (ITIM, DATAA, DATAA, 3, 1, 8.0, 8.0, 0.0, 0.0, 0.0,
0054      20.0, 'TIME SECONDS', 'TEMPERATURE (CORE) F',
0055      2, 'TRANSIENT CORE TEMP.', 'CALCULATED DATA',)
0056      CONTINUE
0057      C PLOT HARDEL EXTERNAL TEMP. VS TIME
0058      IF (IPLOT(9).EQ.0) GO TO 25
0059      IF (ANS(IANS).NE.0) GO TO 25
0060      REAL DATAIX(150), DATAIX(150)
0061      DO 23 J = 1, ITIM
0062      DATAIX(J) = TTR(J)
0063      DATAIX(J) = TIM(J)
0064      CALL GRAPH (ITIM, DATAIX, DATAIX, 3, 1, 8.0, 8.0, 0.0, 0.0, 0.0,
0065      20.0, 'TIME SECONDS', 'TEMPERATURE (EXTERNAL) F',
0066      2, 'TRANSIENT EXTERNAL TEMP.', 'CALCULATED DATA',)
0067      CONTINUE
0068      C PLOT TEMP VS RADII
0069      REAL DATAA(50), DATAA(50)
0070      IF (ANS(IANS).NE.0) RETURN
0071      DO 15 I = 2, II+1
0072      DATAA(I-1) = T(I)
0073      DATAA(I-1) = RI(I)
0074      CALL GRAPH (IIM2, DATAA, DATAA, 3, 1, 8.0, 8.0, 0.0, 0.0, 0.0, 0.0,
0075      2, 'RADIUS FT.', 'TEMPERATURE F', 'THERMAL DATA ', 'L.P. CHAMBER',)
0076      CONTINUE
0077      C RETURN
0078      END

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TAVE

FORTRAN IV 6 LEVEL 21

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0001      SURROUTINE TAVE(II,IIP1)
0002      COMMON /RLK1/ T(150),C(150),CX(150),H(150),HX(150),IBODY(10,2)
C
C**CALCULATE WEIGHTED AVERAGED TEMPERATURE AND STORE IT IN T(IIP1)
      SUM = .0
      SUM2 = .0
      DO 39 I=1,II
      SUM = SUM + C(I)*T(I)
      SUM2 = SUM2 + C(I)
39      T(IIP1) = SUM/SUM2
      RETURN
      END
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0001 SURROUTINE CHANGE (NBODY,TSEC,TAUT,II,IX,NNN)
0002 DIMENSION MZ(11),N1(11),N2(11)
0003 COMMON /PLK1/ T(150),C(150),CA(150),M(150),MX(150),IBODY(10,2)
0004 COMMON /PLK2/ ADII(11),NODES(10),XKZ(99),BETA(10),CP(10),PHO(10),
      ZEMISS,PHOZ,CPZ,XKRZ,ADVR(11),RI(150),RII(150),RH(10),A(9),ITR(11)
      C
      C J = NUMBER OF R'S WHICH ARE TEMP. OR TIME DEPENDENT
      C N1(J) = RESISTOR NUMBER -- N1(J) = J1
      C N2(J) = RESISTOR TYPE
      C MZ(J) = RESISTOR'S INITIAL VALUE
      C A = ARRAY CONTAINING COEFFICIENTS FOR FUNCTIONS, EXPONENTS ETC.
      C TSEC = CONVERSION FACTOR (REAL TIME IN SECONDS = TIME*TSEC)
      C EXPOL = EXPONENT N WHERE M = MZ*ABS(T(J1) - T(J1+1))*EXPOL
      C ITR = ARRAY CONTAINING TYPE KEY FOR ALL BOUNDARY RESISTORS
      C TYPE = 1 M = CONSTANT
      C TYPE = 2 M = MZ*F3(TIME)
      C TYPE = 3 M = MZ*(OT)**EXPOL
      C TYPE = 4 M = MK + HC
      C TYPE = 5 M = MZ*F5(TIME) -- F5 IS A PERIODIC RECTANGULAR WAVE
      C
      C STORE INITIAL VALUES AND DETERMINE WHICH RESISTORS ARE NOT OF TYPE 1
      C IF(TAUT.GT..5) GO TO 1
      C
      C
      C N8 = IFIX( A(4) )
      C N9 = IFIX( A(9) )
      C T1 = T(1)
      C T11 = T(11)
      C M = EMISS*.1714E-8/XKRZ
      C EXC01 = A(7)
      C J = J
      C IF(ITR(1).EQ.1) GO TO 7
      C J = 1
      C M(1) = 1
      C N2(1) = ITR(1)
      C MZ(1) = M(1)
      C DO 5 I=1,NBODY
      C IF(ITR(I+1).EQ.1) GO TO 5
      C J = J + 1
      C M(J) = IBODY(I+2)
      C N2(J) = ITR(I+1)
      C J1 = N1(J)
      C MZ(J) = M(J)
      C CONTINUE
      C
      C COMPUT OF ENTRY FOR TIME.GT.ZERO -- CALCULATE NEW ROY TEMPERATURES
      C
      C 1 TIME = TAUT*TSEC
      C T(1) = T1*(1. + A(1)*SIN(A(2)*TIME))
      C T(11) = T11*(1. + TIME*A(3) + A(4)*TIME**2)
      C
      C **IF ALL R'S ARE CONSTANTS RETURN OTHERWISE RECALCULATE THOSE CHANGING
      C IF(J.EQ.0) RETURN
      C DO 11 I=1,J
      C J1 = N1(I)

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0033 DTEMP = ABS(T(J1))-T(J1+1)
0034 IF(DTEMP.EQ.0) DTEMP=1.
0035 M = N2(I)
0036 GO TO (11,12,13,14,15,16,17),M
0037 -X(J1) = HZ(I) * (1. + A(5)*SIN(A(6)*TIME))
0038 GO TO 11
0039 HX(J1) = HZ(I) * DTEMP **EXP01
0040 GO TO 11
0041 TA = T(J1) + 450.
0042 TH = T(J1+1) + 460.
0043 HX(J1) = HZ(I) * DTEMP ** EXP01 * (TA**2 + TH**2)*(TA + TH)
0044 GO TO 11
0045 IF(1.EQ.0) HX(J1) = HZ(I) * A(5)
0046 IF(1.EQ.NR) HX(J1) = HZ(I)
0047 IF(1.EQ.NR) N = -1
0048 N = N + 1
0049 GO TO 11
0050 GO TO 11
0051 GO TO 11
0052 GO TO 11
0053 NR = NR + 1
0054 IF((MOD(NR,14).NE.0).OR.(J.EQ.0)) RETURN
0055 NO 21 T=1,J
0056 J = J+1
0057 T(I1+1) = HX(J1) * XNR2 / RI(J1)
0058 RETURN
0059 END

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0001      BLOCK DATA
C
C**INITIALIZATION OF LABELED COMMON TO DEFAULT VALUES
0002      COMMON /HLK1/ T(150),C(150),CX(150),H(150),HX(150),IBODY(10,2)
0003      COMMON /HLK2/ RADII(11),NODES(10),XKZ(99),BETA(10),CP(10),RHO(10),
0004      2EMISS,ICZ,CPZ,XKRZ,HDYR(11),RI(150),RII(150),DR(10),A(9),ITR(11)
0005      COMMON /HLK3/ ISYM,XMIN,YMAX,YMIN,
0006      2IPLOT(11),TIM(150),ITP(150),TTO(150)
      DATA ISYM,XMIN,XMAX,YMIN,YMAX,EMISS,RHOZ,CPZ,XKRZ,XKZ,BETA,CP,RHO/
      2 0.,0.,1.,0.,1.,0.,1.,0.,490.,11.,10.,99*10.,10*0.10*11,10*490
      3./,NODES,T,RODYR/10*5, 1.,149*0.11*0.0/A,ITB/6*0.25*2*0.11*1/
      4,IPLOT/3*0.1,1,1/
      END
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A Theoretical and Experimental Thermal Analysis To Determine Wall Ratios For A 30MM Tactical Barrel

Prepared by: Philip D. Benzkofer

Technical Report: R-TR-75-023

34 pages, Including Figures

A combined theoretical-experimental analysis procedure is presented in the determination of wall ratios for a 30mm tactical barrel. Preliminary efforts for this task were devoted to the design of a single-shot barrel fixture; whereas, the current effort addresses the task of designing a barrel capable of withstanding prolonged automatic fire. The final result of this study is a recommended 30mm tactical barrel configuration based on thermal and pressure stress analyses for a prescribed firing schedule.

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Technical Report: R-TR-75-D23

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