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

PHILIP D. BENZKOFER

SEPTEMBER 1975

RESEARCH DIRECTORATE

Approved for public release, distribution unlimited.

GENERAL THOMAS J. RODMAN LABORATORY
ROCK ISLAND ARSENAL
ROCK ISLAND, ILLINOIS 61201
DISPOSITION INSTRUCTIONS:

Destroy this report when it is no longer needed. Do not return it to the originator.

DISCLAIMER:

The findings of this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.
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.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>DD Form 1473</td>
<td>i</td>
</tr>
<tr>
<td>TABLE OF CONTENTS</td>
<td>iii</td>
</tr>
<tr>
<td>ILLUSTRATIONS</td>
<td>iv</td>
</tr>
<tr>
<td>INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>OBJECTIVE</td>
<td>1</td>
</tr>
<tr>
<td>EXPERIMENTAL ANALYSIS</td>
<td>2</td>
</tr>
<tr>
<td>THEORETICAL ANALYSIS</td>
<td>2</td>
</tr>
<tr>
<td>DISCUSSION OF RESULTS</td>
<td>7</td>
</tr>
<tr>
<td>APPENDICES</td>
<td></td>
</tr>
<tr>
<td>Computer Program 1</td>
<td>11</td>
</tr>
<tr>
<td>Computer Program 2</td>
<td>14</td>
</tr>
<tr>
<td>Computer Program 3</td>
<td>16</td>
</tr>
<tr>
<td>DISTRIBUTION</td>
<td>S1</td>
</tr>
<tr>
<td>FIGURE</td>
<td>Illustration/Configuration</td>
</tr>
<tr>
<td>--------</td>
<td>-----------------------------</td>
</tr>
<tr>
<td>1</td>
<td>Experimental Firing Data</td>
</tr>
<tr>
<td>2</td>
<td>Computer Prediction of Temperatures for Several Axial Locations</td>
</tr>
<tr>
<td>3</td>
<td>Computer Prediction of Temperatures for 3 Axial Locations</td>
</tr>
<tr>
<td>4</td>
<td>Proposed 30mm Barrel Configuration</td>
</tr>
</tbody>
</table>
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 performed\(^1\) on the AMC30 on the basis of propellant data from Hercules\(^2\) and gas convection coefficients from XM-140\(^3\) 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.

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


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:

\[ q_{\text{in}} = q_{\text{stored}} + q_{\text{out}} \]

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:

\[ q_{\text{in}} = h_g A_b (T_g - T_b) \]

where

- \( h_g \) = mean heat transfer coefficient, BTU/hr - ft \(^2\) - °F
- \( A_b \) = bore surface area, ft \(^2\)
- \( T_g \) = 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

(Distances measured from muzzle end)
1 - 3.0", 1.57" O.D.
2 - 15.5", 1.57" O.D.
3 - 28.0", 1.57" O.D.
4 - 34.0", 2.55" O.D.
5 - 47.4", 2.55" O.D.
6 - 60.0", 2.55" O.D.
7 - 64.4", 3.50" O.D.
8 - 73.1", 3.50" O.D.
and

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

where

- \( m \) = mass of barrel, lb
- \( c \) = specific heat of barrel, BTU/lb - °F
- \( \frac{dT}{d\theta} \) = time rate of change of temperature, °F/hr.

and

\[ q_{\text{out}} = h_0 A_S (T_0 - T_S) + \varepsilon \sigma A_S (R_0^4 - R_S^4) \]

where

- \( h_0 \) = dissipation convection coefficient, BTU/hr - ft\(^2\) - °F
- \( A_S \) = outside barrel surface area, ft\(^2\)
- \( T_0 \) = outside barrel surface temperature, °F
- \( T_S \) = temperature of surrounding environment, °F
- \( \varepsilon \) = surface emissivity
- \( \sigma \) = Stephan-Boltzmann constant, BTU/hr - ft\(^2\) - °R\(^4\)
- \( R_0 \) = outside barrel surface temperature, °R
- \( R_S \) = temperature of surrounding environment, °R

The radiation term, \( \varepsilon \sigma A_S (R_0^4 - R_S^4) \), 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 \( q_{\text{in}} \) can be defined as

\[ T_b = T_0 + \Delta T \]

where \( \Delta T \) = 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:
\[ h_g A_b (T_g - T_{01} - \Delta T_1) = mc \frac{dT}{d\theta} \bigg|_1 + h_{o1} A_s (T_{01} - T_s) \] (1)

\[ h_g A_b (T_g - T_{02} - \Delta T_2) = mc \frac{dT}{d\theta} \bigg|_2 + h_{o2} A_s (T_{02} - T_s) \] (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

\[ h_g (2\pi r_i \ell) (T_g - T_{01} - \Delta T_1) = \rho \pi (r_o^2 - r_i^2) \ell c \frac{dT}{d\theta} \bigg|_1 + h_{o1} (2\pi r_o \ell) (T_{01} - T_s) \] (1)

where

\[ r_i, r_o, \ell, \text{ and } \rho \text{ are inside radius, outside radius, length, and density of the barrel, respectively.} \]

Regrouping yields the following equation:

\[ h_g (T_g - T_{01} - \Delta T_1) = \left[ \rho (r_o^2 - r_i^2) c \frac{dT}{d\theta} \bigg|_1 + 2\rho r_o h_{o1} (T_{01} - T_s) \right]/2r_i \]

Defining \( K_{A1}, K_{B1}, \) and \( K_i, \)

\[ K_{A1} = \rho (r_o^2 - r_i^2) c \frac{dT}{d\theta} \bigg|_1 \]

\[ K_{A2} = 2\rho r_o h_{o1} (T_{01} - T_s) \]

and

\[ K_i = (K_{A1} + K_{B1})/2r_i \]

Equation (1) now becomes

\[ h_g (T_g - T_{01} - \Delta T_1) = K_i \] (1)

Similarly,

\[ h_g (T_g - T_{02} - \Delta T_2) = K_2 \] (2)

Define \( A \) as follows:

\[ A = \frac{dT}{d\theta} \bigg|_1 / \frac{dT}{d\theta} \bigg|_2 \]
and assuming that the dθ's are very nearly the same size

where

\[ A = \frac{\Delta T_1}{\Delta T_2} \]

then

\[ \Delta T_2 \approx \Delta T_1 / A \]

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

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

(3)

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

\[ T_g = \Delta T_1 + \frac{K_1}{h_g} + T_{O1} \]  

(4)

The next step is to select \( \frac{dT}{d\theta} \bigg|_1 \) and \( \frac{dT}{d\theta} \bigg|_2 \). 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, \( \frac{dT}{d\theta} \bigg|_1 \) and \( \frac{dT}{d\theta} \bigg|_2 \), 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 \( \Delta T_1 \) is generally selected based on previous experience. Once \( \frac{dT}{d\theta} \bigg|_1 \), \( \frac{dT}{d\theta} \bigg|_2 \), and \( \Delta T_1 \) 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, \( h_g \) and \( T_g \), 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 \( h_g \) and \( T_g \) can be made after the temperature output is compared with experimental data. This is accomplished by an iteration process in which \( \Delta T_1 \) is varied in computer program 2 based on the calculated value obtained in computer program 3.
DISCUSSION OF RESULTS

Mean values $\tilde{h}_g$ and $\tilde{T}_g$ 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 $\tilde{h}_g$ and $\tilde{T}_g$ 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 $\tilde{h}_g$ and $\tilde{T}_g$ 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 $\tilde{h}_g$ and $\tilde{T}_g$ taken from Hercules$^2$ and from XM-140$^3$ 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 dynamic$^4$ 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.

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

FIGURE 2

| 1 | 8.25" from breech end, 1.2" wall thickness, $h_g = 1464$ BTU/hr-ft²-°F, $T_g = 2182°F$, based on theoretical predictions. |
| 2 | 15.5" from muzzle end, 0.3" wall thickness, $h_g = 61$ BTU/hr-ft²-°F, $T_g = 4957°F$, based on 7 rounds experimental firing. |
| 3 | 28.0" from muzzle end, 0.3" wall thickness, $h_g = 78$ BTU/hr-ft²-°F, $T_g = 4066°F$, based on 7 rounds experimental firing. |
| 4 | 8.25" from breech end, 1.2" wall thickness, $h_g = 1600$ BTU/hr-ft²-°F, $T_g = 1820°F$, based on theoretical predictions. |
| 5 | 8.25" from breech end, 1.2" wall thickness, $h_g = 203$ BTU/hr-ft²-°F, $T_g = 3910°F$, based on Hercules(2) and XM-140(3) firing data. |
| 6 | 3.0" from muzzle end, 0.3" wall thickness, $h_g = 67$ BTU/hr-ft²-°F, $T_g = 4237°F$, based on 7 rounds experimental firing data. |
| 7 | 28.0" from muzzle end, 0.5" wall thickness, $h_g = 78$ BTU/hr-ft²-°F, $T_g = 4066°F$, 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.

**Arm Barrel Sections**

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

**Effective Bore Conditions**

Section A-A: \[ H_g = 203 \text{ BTU/hr-FT} \] \( T_g = 3910 \text{ °F} \)

Section B-B: \[ H_g = 166 \text{ BTU/hr-FT} \] \( T_g = 2371 \text{ °F} \)

Section C-C: \[ H_g = 166 \text{ BTU/hr-FT} \] \( T_g = 2371 \text{ °F} \)

**Figure 3**
PROPOSED 30MM TACTICAL BARREL
(CR-MO-VA STEEL)
APPENDIX

Computer Program 1
DIMENSION DATA(99),DATAY(99)
COMMON/HLK1/F1,F2,F3,C1,C2,J,IYPE
COMMON/HLK2/NPTS(20)
READ 1,NSETS,ITYPE
   1 FORMAT(2I5)
      C ITYPE=0 MEANS DATA IS TEMPERATURE.
      C ITYPE=1 MEANS DATA IS MILLIVOLTS.
READ 2,(NPTS(J)*J=1,NSETS)
READ 3,F1,F2,F3,C1,C2
READ 4,(DATA(I),I=1,NPTS(J),DATAY(I),I=1,NPTS(J))
CALL CONVERT(DATAX,DATAY)
II=II+1
J=II
NPT=NPTS(J)
IF(II.GT.NSETS) GO TO 5
GO TO 4
FORMAT(10F8,3)
CALL EXIT
END
0001      SUBROUTINE CONVRT(QDATA, I, DATA)
0002      REAL QDATA(99), DlATA(99)
0003      COMMON/BLK1/F1,F2,F3,C1,C2,J,ITYPE
0004      COMMON/BLK2/NPTS(20)
0005      600      NPTS(J)
0006      PRINT 400
0007      FORMAT(1,11)
0008      IF(IIYPE,EQ,0) GO TO 403
0009      PRINT 402
0010      402      FORMAT(6X,'TIME',8X,'MILLIVOLTS',5X,'TEMPERATURE(0EG,F)')
0011      GO TO 405
0012      403      PRINT 404
0013      404      FORMAT(6X,'TIME',23X,'TEMPERATURE(0EG,F)')
0014      00 11 I=1,NP
0015      12      PRINT(I) QDATA(I),DlATA(I)
0016      11      CONTINUE
0017      10      GO TO 99
0018      405      00 10 I=1,NP
0019      IF(QDATA(I),GT,C1) GO TO 5
0020      IF(QDATA(I),GT,C2) GO TO 6
0021      6      FACTOR=F1
0022      FACTOR=F3
0023      GO TO 7
0024      5      FACTOR=F1
0025      GO TO 7
0026      6      FACTOR=F2
0027      TEMP=QDATA(I)
0028      7      OATA(I),QDATA(I),FACTO,+32.
0029      PRINT 401;QDATA(I),TEMP;QDATA(I)
0030      401      FORMAT(1F10,1,1F15,3,1F20,1)
0031      10      CONTINUE
0032      99      IF(J,EE,1) GO TO 100
0033      100      CALL GRAPH(NP, QDATA, DATA, 0.1, 9.0, 7.0, 200.0, 0.0, 2200.0, 0.0, 'TIME SECONOS', 'TEMPERATURE', 'EXTERNAL', 'VARIABLE AXIAL OCST', '30 MM BARREL')
0034      GO TO 300
0035      200      CALL GRAPH(NP, QDATA, DATA, 0.1, 0.0, 7.0, 200.0, 0.0, 2200.0, 0.0, 'TIME SECONOS', 'TEMPERATURE', 'EXTERNAL', 'VARIABLE AXIAL OCST', '30 MM BARREL')
0036      300      RETURN
0037      EN0
APPENDIX

Computer Program 2
IMPLICIT REAL*(A-Z)
HEAU 1.RHO,T0,T1,TW2,DTDT1+DTDT2+HO1+HO2+KI,RO+CP+DT2
PRINT 1.RHO,T0,T1, TW2, DTDT1+DTDT2+HO1+HO2+RI,RO+CP+OT2
1 FORMAT(AF17.5,6F10.5)
CC=HO*CP*(RO**2-RI**2)
KA1=CC*DTDT1*3600.
KA2=CC*DTDT2*3600.
KH1=HO*RI*(T=1-TA)
KH2=HO*RI*(T=2-RA)
K=KA1*KI/(T,RI)
K2=KA2*KH2/(2,RI)
A=DTDT1/DTDT2
C3=TA2-TW1
HG=(K1-K2)/(C3+DT2*(1./A-1))
TG=1./HG*((KA2+KA2)/(2.*RI)) + TW2 + OT2
HG=15.0/HG
PRINT 2*HG,TG,HOGYR
PRINT 1*KA1+KA2
PRINT 3*RA+KA2
PRINT 3*K1+K2
PRINT 3*C3
3 FORMAT(1X,3F20.10)
2 FORMAT(1X,**HG=**,F10.5,**TG=**,F10.5,**BOY=**,F10.5)
CALL EXIT
END
APPENDIX

Computer Program 3
ONE-DIMENSIONAL TRANSIENT HEAT CONDUCTION PROGRAM (HT-2A)
PROGRAMMED BY A.M. CLAUSSING, VERSION = 1 JULY 1970
THIS PROGRAM IS A GENERAL PROGRAM FOR THE SOLUTION OF CONDUCTION
PROBLEMS WITH TEN OR LESS REGIONS INCLUDING INTERFACIAL RESISTANCES
HETEFORE REGIONS

DIMENSION ANS(199), NPLT(11), T1(150)

**DEFINITION OF LABELED COMMON -- BLK1, BLK2, AND BLK3
COMMON /BLK1/ T1(150), C1(150), C2(150), R1(150), R2(150), U1(150), U2(150), IBODY(10), ITX(10), ITY(10), ITZ(10)
COMMON /BLK2/ RHO1(11), RE1(11), R2(11), R3(11), R4(11), R5(11), R6(11), R7(11), R8(11), R9(11), R10(11), R11(11)
COMMON /BLK3/ NW1(11), NW2(11), NW3(11), NW4(11), NW5(11), NW6(11), NW7(11), NW8(11), NW9(11), NW10(11), NW11(11)

**INITIALIZATION OF VARIABLES NOT LOCATED IN LABELED COMMON
DATA ANS,TNUM,TDENOM,DX,DTX,DTY,DTZ,IBODY,NBODY,2,1,1,1,0,2,0

**READ CHARACTERISTICS OF PROBLEM -- RAW INPUT DATA
C
**DEFINITION OF NAME AND NAME
NAME1 /NAME/ T1SYM,YMAX,YMIN,XMAX,XMIN,TNUM,TDENOM,ANS
NAME2 /NAME/ T1SYM,YMAX,YMIN,XMAX,XMIN,TNUM,TDENOM,ANS
NAME3 /NAME/ T1SYM,YMAX,YMIN,XMAX,XMIN,TNUM,TDENOM,ANS
NAME4 /NAME/ T1SYM,YMAX,YMIN,XMAX,XMIN,TNUM,TDENOM,ANS
NAME5 /NAME/ T1SYM,YMAX,YMIN,XMAX,XMIN,TNUM,TDENOM,ANS
NAME6 /NAME/ T1SYM,YMAX,YMIN,XMAX,XMIN,TNUM,TDENOM,ANS
NAME7 /NAME/ T1SYM,YMAX,YMIN,XMAX,XMIN,TNUM,TDENOM,ANS
NAME8 /NAME/ T1SYM,YMAX,YMIN,XMAX,XMIN,TNUM,TDENOM,ANS
NAME9 /NAME/ T1SYM,YMAX,YMIN,XMAX,XMIN,TNUM,TDENOM,ANS
NAME10 /NAME/ T1SYM,YMAX,YMIN,XMAX,XMIN,TNUM,TDENOM,ANS
NAME11 /NAME/ T1SYM,YMAX,YMIN,XMAX,XMIN,TNUM,TDENOM,ANS
NAME12 /NAME/ T1SYM,YMAX,YMIN,XMAX,XMIN,TNUM,TDENOM,ANS
NAME13 /NAME/ T1SYM,YMAX,YMIN,XMAX,XMIN,TNUM,TDENOM,ANS
NAME14 /NAME/ T1SYM,YMAX,YMIN,XMAX,XMIN,TNUM,TDENOM,ANS
NAME15 /NAME/ T1SYM,YMAX,YMIN,XMAX,XMIN,TNUM,TDENOM,ANS
NAME16 /NAME/ T1SYM,YMAX,YMIN,XMAX,XMIN,TNUM,TDENOM,ANS
NAME17 /NAME/ T1SYM,YMAX,YMIN,XMAX,XMIN,TNUM,TDENOM,ANS
NAME18 /NAME/ T1SYM,YMAX,YMIN,XMAX,XMIN,TNUM,TDENOM,ANS
NAME19 /NAME/ T1SYM,YMAX,YMIN,XMAX,XMIN,TNUM,TDENOM,ANS
NAME20 /NAME/ T1SYM,YMAX,YMIN,XMAX,XMIN,TNUM,TDENOM,ANS
NAME21 /NAME/ T1SYM,YMAX,YMIN,XMAX,XMIN,TNUM,TDENOM,ANS
NAME22 /NAME/ T1SYM,YMAX,YMIN,XMAX,XMIN,TNUM,TDENOM,ANS
NAME23 /NAME/ T1SYM,YMAX,YMIN,XMAX,XMIN,TNUM,TDENOM,ANS
NAME24 /NAME/ T1SYM,YMAX,YMIN,XMAX,XMIN,TNUM,TDENOM,ANS
NAME25 /NAME/ T1SYM,YMAX,YMIN,XMAX,XMIN,TNUM,TDENOM,ANS

**CALCULATE DIMENSIONLESS LUMPED PARAMETERS, HA(I) AND C(I)
CALL LUMP (II, NBODY, DX)

**WRITE PROBLEM PARAMETERS
WRITE(A+3)

FORTRAN IV G LEVEL 21                MAIN               DATE = 75024                09/07/30               PAGE 0001
FORTRAN IV G LEVEL 21

MA IN

DATE = 75024  09/07/30  PAGE 0002

0026 9  WRITE(6, 9)I, RADI(1), RDYR(1)
0027 2  WRITE(T(3), 12, 12*10, 3*12*E1, 3/12*E1, 3/12)
0028 1  WRITE(4, 11)
0029 0 11  IF (AT(3) > AT(1) + 7.5M H(I), 12*AT(1), 12*AT(1), 7.5M RADIUS )
0030 1  WRITE(H(1), C(I), T(I), RI(I), I=1, I=11)
0031 0 13  IF (AT(I) > 1E4, AT(4) + F13, AT(4) + F13)
0032 0  C 00500
0033 0  C**CALCULATE OR INITIALIZE VARIOUS QUANTITIES --- SAVE T(I) AND DTIMEX
0034 0  TSEC = 07*2*2*HZCPZ*7600, /KHz
0035 0  II*1 = II - 1
0036 0  II*2 = II - 2
0037 0  II*3 = II + 1
0038 0  IF (I+4) T=ST  10 TO 131
0039 0  LD 133 I=1, I=19
0040 0  133 A=S(1) = ANS(I) / TSEC
0041 0  ANS(1) = -4*S(1)
0042 0  131 DT=15 I=1, I=I1
0043 0  15  TT(I) = TI
0044 0  ATIME = UTIMEX
0045 0  043 DONT]=T
0046 0  044 N=I
0047 0  045 IM=5=1
0048 0  046 IT = "n"
0049 0  047 IF I=50
0050 0  C
0051 0  C**START OF SOLUTION OF PROBLEM
0052 0  C POINT OF 'A40P' LOOP ENTRY -- SN25(NO NEW DTIMEX), SN24(NEW DTIMEX)
0053 0  24  ON 19 IN=2, I=M
0054 0  19  Call CHASHCF(NHODY, TSEC, TAUTII, INX")
0055 0  26  CALL CHASHCF(NHODY, TSEC, TAUTII, INX")
0056 0  052  ATIME = UTIMEX
0057 0  051  HX(I) = ANDT(I) / RDYR(1)
0058 0  050  IF (I+4) T=ST  10 TO 29
0059 0  053  CALL LINEAR(I, I/I+1, I/I+1, I/I+1, I/I+1, I/I+1,...)
0060 0  054  CALL SOLVE(I, I/I+1, I/I+1, NHODY, BETA)
0061 0  055  N = 5 = 1
0062 0  056  TAU = TAT - UTIMEX
0063 0  055
0064 0  054
0065 0  053
0066 0  052
0067 0  051
0068 0  050
0069 0  049
0070 0  048
0071 0  047
0072 0  046
0073 0  045
0074 0  044
0075 0  043
0076 0  042
0077 0  041
0078 0  040
0079 0  039
0080 0  038
0081 0  037
0082 0  036
0083 0  035
0084 0  034
0085 0  033
0086 0  032
0087 0  031
0088 0  030
0089 0  029
0090 0  028
0091 0  027
0092 0  026
0093 0  025
0094 0  024
0095 0  023
0096 0  022
0097 0  021
0098 0  020
0099 0  019
0100 0  018
0101 0  017
0102 0  016
0103 0  015
0104 0  014
0105 0  013
0106 0  012
0107 0  011
0108 0  010
0109 0  009
0110 0  008
29 IF TAU=3,T,ANS(IANS) PRINT TEMPERATURE DISTRIBUTIONS ETC.
33 IF (TAU=3,T,ANS(IANS)) GO TO (2+25)*IPET
37 IANS = IANS + 1
1011 = EX, IM1, I2, ITIM) 
   IF (ANS(IANS),NE,0) GO TO (2+25)*IPET
C**SET INITIAL CONDITION AND TIME INCREMENT -- READ NEXT CASE -- SN26
35 OTT = EX = ATIME
37 DO 37 IM1, ITIM)
37 T(1) = TT(1)
   GO TO 2A
SUBROUTINE LUMP(I,MBODY,DT)

COMMON /H/(T(150),C(150),CA(150),A(150),H(150),I(150),IBODY(10),2)
COMMON /X/(X(10),XZ(99),XE(10),CP(10),RD(10),RC(10),RH(10),

DATE = 75024  09/07/30  PAGE 0001

C THIS SUBROUTINE CALCULATES THE DIMENSIONLESS LUMPED PARAMETERS
C
C Z = -H1Z*P*Z*DT**2
C
C T = C1*0
C
C IF (IHY Y(J)=0) GO TO 3
C
C T = T + (HY Y(J)/BDY(J))
C
C IN = I + HY Y(J)*NODS(J)
C
C IE = I + (HY Y(J)+1)
C
C I = T + I
C
C 3 M = M + 1
C
C 5 H(I) = RAP(1)
C
C C**BEGINNING OF LOOP TO CALCULATE C(I) AND M(I) FOR MBODY REGIONS(J)
C
C DO = J=1,MBODY
C
C 12 = HAD(J)*(J+1) - HADI(J)
C
C C(J+1) = CP(J)*BDY(J)/AC
C
C N(J) = (X(J))/X(J)*Z*(I)
C
C DC = (J+1)*J/2
C
C H(I) = A*H(J)+1*(J+1)/BDY(J)
C
C M(J) = M(J)+1
C
C C(J+1) = ((J+1)+1)-BDY(J)/Z*
C
C C**CHECK TO SEE IF I-FACIAL RESISTANCE IS ZERO AND PROCEED ACCORDINGLY
C
C IF (IHY Y(J+1)+1)+1 = J I HY Y(J+2) + 1
C
C X((E+1)) = E((E+1))/H(Y(J+1))
C
C H((E+1)+1) = (X+(E+1))
C
C 6034 DO TO 3
C
C 6035 CI = -C1*1
C
C 6036 HY Y(J+1)+1 = HY Y(J+2) + 1
C
C 6037 CONTINUE
C
C IF (IHY Y(J+1)+1)-NE(0) GO TO 11
C
C 6039 M = I + 1
C
C 6040 M = M + 1
C
C 6041 I = I + 1
C
C 6042 C(I) = 0
C
C 6043 M(I) = 1
C
C 6044 M(I) = M(I)-HAD(J)-HAD(J+1)
C**CALCULATE THE DIMENSIONLESS RADIUS RII

0045  DO 16 I=1,II
0046  16  RII(I) = (RI(I) - RADII(I))/RADII(NBODY+1) - RADII(1)
0047  RETURN
0048  END
SUBROUTINE LINEAR (A, X, Y, W, V)
DIMENSION X(1), Y(1)
I=1
C 1 IF (Y(I+1) .LT. Y(I)) GO TO 100
C USE FOLLOWING IF AS Y INCREASES X INCREASES
C 1) IF (A - X(I)) .LT. 0.5
C USE FOLLOWING IF AS Y INCREASES X DECREASES
C 100 IF (A - X(I)) .GT. 2.5
2 I=I+1
GO TO 10
C 3 I=I-1
C W = Y(I) * (A - X(I+1)) / (X(I+1) - X(I)) * Y(I+1) * (A - X(I)) / (X(I+1) - X(I))
RETURN
END
SUBROUTINE SOLVE (IIH1,IIH2,II,NBOD,Y,BETA)

DIMENSION GE(150),FE(150),DE(150),BETA(10),BE(150),BI(150)

COMMON /RLX1/T(150),C(150),CX(150),H(150),hx(150),IBODY(10,?)

C**CORRECT THE RODY CONDUCTANCES FOR VARIABLE CONDUCTIVITIES

1 DO 3 J=1,NBODY

I= IBODY(J+1)

IE= IBODY(J,2) = 1

DO 3 I=IA*IE

3 MX(1) = H(I)*((1. + BETA(J)*(T(I) + T(I+1)))/2.)

C**START OF ELIMINATION -- CRANK-NICOLSON ALGORITHM

DO 9 I=2,IIH1

CI = MX(I) + MX(I-1)

BE(I) = CX(I) * CI

HI(I) = CX(I) - CI

GE(2) = RF(?)

FE(2) = (RT(2)*T(2) + MX(2)*T(3) + MX(1)*T(1)*T(2))/GE(2)

DO 5 I=3,IIH1

DE(I) = -MX(I-1)/GE(I-1)

GE(I) = FE(I) + MX(I-1)*DE(I)

FE(I) = (MX(I)*T(I+1) + MX(I-1)*T(I-1) + BI(I)*T(I) + MX(I-1)*T(I-1) + 2*FE(I-1))/GE(I)

FE(IIH1) = FE(IIH1) + MX(IIH1)*T(II)/GE(IIH1)

C**BACK SUBSTITUTION

T(IIH1) = FF(IIH1)

DO 7 I=IIH1,2

J = I - 1

T(J) = FF(J) - BE(J+1)*T(J+1)

RETURN

END
SUBROUTINE TAVE(I1*IIPI1)
COMMON /RLK1/ T(150),C(150),CX(150),H(150),MX(150),IBODY(10,2)

C
C**CALCULATE WEIGHTED AVERAGED TEMPERATURE AND STORE IT IN T(I1IP1)

SU2 = 0
SU = 0
0005 DO 39 I=1,II
0006 SUM = SUM + C(I)*T(I)
0007 39 SU=2 = SUM2 + C(I)
0008 T(I1+1) = SUM/SUM2
0009 RETURN
0010 END
0001  SUBROUTINE CHANGE (NBODY*TSFC*TAUT*II+I*X+NNN)
0002   DIMENSION HZ(11),N1(11),N2(11)
0003       COMMON /PLYS/ T(150),C(150),CC(150),X(150),XX(150),1BODY(150,2)
0004  
0005       COMMON /KZ/ -ADII(11),NODES(10),XXZ(99),PETA(10),CP(10),PHOS(10),
0006       2EZ0,IZ,CPZ,CPXX+ADYR(11),H1(150),R1(150),HR(10),A(9),ITR(11)
0007   
0008   C J = NUMBER OF RTS WHICH ARE TEMP. OR TIME DEPENDENT
0009   C N1(J) = RESISTOR NUMBER = N1(J) = J1
0010   C N2(J) = RESISTOR TYPE
0011   C N3(J) = RESISTOR'S INITIAL VALUE
0012   C X = ARRAY CONTAINING COEFFICIENTS FOR FUNCTIONS, EXPONENTS ETC.
0013   C TSFC = CONVERSION FACTOR (HEAT TIME IN SECONDS = TIME*TSFC)
0014   C EXPOL = EXPONENT IN WHERE H = HZ*AD(S(T(J) - T(J+1)))**EXPOL
0015   C IT3 = ARRAY CONTAINING TYPE KEY FOR ALL BOUNDARY RESISTORS
0016   C TYPE = 1 = CONSTANT
0017   C TYPE = 2 = HZ*FJ(T1+F)
0018   C TYPE = 3 = HZ*FJ(T1)*EXPOL
0019   C IT3 = 4 = H = HZ*F5(TIME) -- FS IS A PERIODIC RECTANGULAR WAVE
0020   C STORE INITIAL VALUES AND DETERMINE WHICH RESISTORS ARE NOT OF TYPE 1
0021   IF(TAUT,TG,91) GO TO 1
0022   IF(TAUT,TG,91) GO TO 1
0023   1 J = 0
0024   2 J = 1
0025   3 J = J + 1
0026   4 S(J) = S1(J)
0027   5 RETURN
0028   6 CONTINUE
0029   
0030   **BEGIN OF ENTRY FOR TIME,G,0 -- CALCULATE NEW BODY TEMPERATURES
0031   7 TIME = TAUT*TSFC
0032   8 T(1) = T1*(1 + A1)*S1(A2*TIME)
0033   9 T(1) = T1*(1 + A1)*S1(A2*TIME)
0034   10 CONTINUE
0035   11 IF(J,F=.1) RETURN
0036   12 J = J + 1
0037   13 RETURN
0038   14 CONTINUE
0039   
0040   **IF ALL W1 = F1 ARE CONSTANTS RETURN OTHERWISE RECALCULATE THOSE CHANGING
```
0033  DTEMP = ABS(T(J1)-T(J1+1))        03540
0034  IF(TEMP.EQ.0.2) DTEMP=1.
0035  M = N2(I)
0036  GO TO (11,12,13,14,15,16,17)*M
0037  12 A(J1) = 0.2(I) * (1. + A(5)*SIN(A(6)*TIME))    03580
0038  GO TO 11
0039  13 H(J1) = HZ(I) * DTEMP  **EXP01  03600
0040  GO TO 11
0041  14 TA = T(J1) + 60.
0042  Td = T(J1+1) + 60.
0043  HX(J1) = HD2(J1)    *(TD**2 + TB**2)*(TA + TB)   03640
0044  Z = HZ(I) * DTEMP ** EXP01  03650
0045  GO TO 11
0046  15 IF(1.EQ.N) -X(J1) = HZ(I) * A(5)  03670
0047  IF(1.EQ.N)  HX(J1) = HZ(I)  03680
0048  IF(1.EQ.N) N = 1  03690
0049  GO TO 11
0050  16 GO TO 11
0051  17 GO TO 11
0052  11 CONTINUE
0053  NIN = NIN + 1  03700
0054  IF((MOD(NIN,K),WE,0).OR.(J,EQ.0)) RETURN  03750
0055  GO TO 11
0056  J = J(I)
0057  21 T(I)(I+1) = HX(J1) * XWZ / RI(J1)  03790
0058  RETURN
0059  END
```
DISTRIBUTION

A. Department of Defense

Office of the Director of Defense
Research & Engineering
ATTN: Mr. J. C. Barrett
Room 3D-1085, The Pentagon
Washington, DC 20301

Defense Documentation Center
ATTN: TIPIR
Cameron Station
Alexandria, VA 22314

B. Department of the Army

Commander
U. S. Army Materiel Development & Readiness Command
ATTN: DRCRD-TO
DRCRD-R, Mr. H. Cohen
5001 Eisenhower Avenue
Alexandria, VA 22333

Commander
U. S. Army Armament Command
ATTN: DRSAR-RDP
DRSAR-PP
DRSAR-PPT
DRSAR-TDC
Rock Island, IL 61201

Commander
U. S. Army Electronics Command
ATTN: DRSEL-TE-TE
Fort Monmouth, NJ 07703

Commander
Rock Island Arsenal
ATTN: SARRI-LA
SARRI-LE
SARRI-LS
SARRI-LW
SARRI-LPL
SARRI-LR
SARRI-LT
Rock Island, IL 61201

Commander
U. S. Army Missile Command
ATTN: DRSMI-RP
DRSMD-RRS Mr. R. E. Ely
DRSMD-RSM Mr. Whellahan
Redstone Arsenal, AL 35809
<table>
<thead>
<tr>
<th>Distribution</th>
<th>Copies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commander U. S. Army MERDC</td>
<td>1</td>
</tr>
<tr>
<td>ATTN: STSFB-GL</td>
<td></td>
</tr>
<tr>
<td>Fort Belvoir, VA 22060</td>
<td></td>
</tr>
<tr>
<td>Commander U. S. Army Environmental Hygiene Agency</td>
<td>1</td>
</tr>
<tr>
<td>Edgewood Arsenal, MD 21010</td>
<td></td>
</tr>
<tr>
<td>Commander U. S. Army Medical Biomechanical Research Laboratory</td>
<td>1</td>
</tr>
<tr>
<td>ATTN: Library</td>
<td></td>
</tr>
<tr>
<td>Fort Detrick Bldg. 568</td>
<td></td>
</tr>
<tr>
<td>Frederick, MD 21701</td>
<td></td>
</tr>
<tr>
<td>Commander Natick Laboratories</td>
<td>1</td>
</tr>
<tr>
<td>Natick, MA 01760</td>
<td></td>
</tr>
<tr>
<td>Commander U. S. Army Aviation School</td>
<td>1</td>
</tr>
<tr>
<td>ATTN: Office of the Librarian</td>
<td></td>
</tr>
<tr>
<td>Fort Rucker, AL 36362</td>
<td></td>
</tr>
<tr>
<td>Director Joint Military Packaging Training Center</td>
<td>1</td>
</tr>
<tr>
<td>ATTN: AMXPT-PT</td>
<td></td>
</tr>
<tr>
<td>Aberdeen Proving Ground, MD 21005</td>
<td></td>
</tr>
<tr>
<td>Commander U. S. Army Tropic Test Center</td>
<td>1</td>
</tr>
<tr>
<td>ATTN: STETC-M0-A Technical Library</td>
<td></td>
</tr>
<tr>
<td>Drawer 942</td>
<td></td>
</tr>
<tr>
<td>Fort Clayton, Canal Zone 09827</td>
<td></td>
</tr>
<tr>
<td>Commander Tobyhanna Army Depot</td>
<td>1</td>
</tr>
<tr>
<td>ATTN: AMC Packaging, Storage &amp; Containerization Center</td>
<td></td>
</tr>
<tr>
<td>Tobyhanna, PA 18466</td>
<td></td>
</tr>
<tr>
<td>Commander U. S. Army Production Equipment Agency</td>
<td>2</td>
</tr>
<tr>
<td>Rock Island Arsenal</td>
<td></td>
</tr>
<tr>
<td>Rock Island, IL 61201</td>
<td></td>
</tr>
</tbody>
</table>
DISTRIBUTION

C. Department of Navy

Office of Naval Research
ATTN: OHR-471
Room 928, Ballston Tower No. 1
Arlington, VA 22217

Commander
Naval Sea Systems Command
ATTN: SEA-03
ATTN: RRM-54
ATTN: SP-271
Washington, DC 20362

Commander
Naval Supply Systems Command
ATTN: NSUP-048
Washington, DC 20376

Commander
U. S. Naval Surface Weapons Center
ATTN: NDL-211
Silver Springs, MD 20910

Commander
U. S. Naval Research Laboratory
ATTN: NRL-2600
Washington, DC 20375

Commander
U. S. Naval Ordnance Test Station
ATTN: Code 753 Technical Library
China Lake, CA 93555

Commander
Mare Island Naval Shipyard
ATTN: Rubber Laboratory
Vallejo, CA 94592

Copies
D. Department of the Air Force

HQ USAF RDP
Room 4D-313, The Pentagon
Washington, DC 20330

AFML/LTM
Wright-Patterson AFB, OH 45433

AFML/MB
Wright-Patterson AFB, OH 45433

AFFTC
Edwards AFB, CA 93523

E. Other Government Agencies

Energy Research and Development Agency
Division of Reactor Development and Technology
Washington, DC 20545

George C. Marshall Space Flight Center, NASA
ATTN: M-S&E
M-A&PS
Huntsville, AL 35812
DISTRIBUTION LIST UPDATE

- - - FOR YOUR CONVENIENCE - - -

Government regulations require the maintenance of up-to-date distribution lists for technical reports. This form is provided for your convenience to indicate necessary changes or corrections.

If a change in our mailing lists should be made, please check the appropriate boxes below. For changes or corrections, show old address exactly as it appeared on the mailing label. Fold on dotted lines, tape or staple the lower edge together, and mail.

☐ Remove Name From List

Old Address:

☐ Change or Correct Address

Corrected or New Address:

COMMENTS

____________________________________________________________________

____________________________________________________________________

____________________________________________________________________

____________________________________________________________________

Date: ____________________ Signature: ____________________

Technical Report #

SARRI Form 900-643 (One-Time) (1 Feb 75)
Commander
Rock Island Arsenal
Attn: SARRI-LR
Rock Island, Illinois 61201
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.