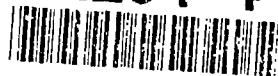


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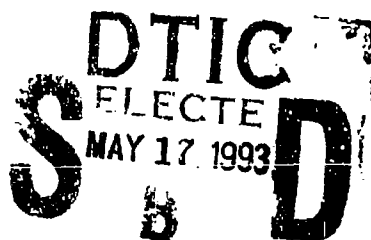


Vivacity Calculation, Rolled Ball, and
Rosette Grain Form Function and Editing
Capability Update to the Closed-Chamber
Data Analysis Program BRLCB

William F. Oberle

ARL-MR-61

April 1993



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1. INTRODUCTION

Although the Closed-Chamber Data Analysis Program BRLCB (Oberle and Kooker 1993)[†] was originally developed to support the work of the High Pressure Combustion Research Team of the Propulsion and Flight Division of the U.S. Army Research Laboratory, its use throughout the combustion community has resulted in the identification of additional features which if incorporated would enhance the programs utility. The requested features were: (1) calculations to determine vivacity, (2) inclusion of additional propellant grain form functions for rolled ball and rosette geometries, and (3) editing capabilities when dealing with multi-layered propellant grains (specifically, the ability to edit the input thermochemical information). The objective of this report is to document the inclusion of these options into the BRLCB program and provide the user with details on their use.

2. VIVACITY CALCULATION

In addition to the measurement of a propellant's burn rate, a comparison of the closed-chamber pressure-time curve with the pressure-time curve of a "standard" or baseline propellant is often used to characterize a propellant's combustion behavior. Some of the more common measurements/comparisons are dynamic vivacity, regular vivacity, relative force, and relative quickness. Generally, these comparisons or measurements involve the time derivative of the pressure (dP/dt), maximum pressure (P_{max}), and instantaneous pressure (P). For example, dynamic vivacity is defined by

$$\text{Dynamic Vivacity} = \frac{dP/dt}{(P * P_{max})} \quad (1)$$

In order to facilitate the calculation of these quantities, an additional sub-option has been added to BRLCB. This sub-option is provided to the user just prior to exiting Option 5, Smooth Pressure/Time Data, of the Main Menu. Before exiting Option 5, the user is offered the option of performing the vivacity calculation. If the vivacity calculation is selected, the user is asked to provide a file name for the vivacity information. The BRLCB program places no restrictions on the file name format; however, a file extension of .VIV is recommended to prevent duplicating file names automatically generated by BRLCB. The format of the vivacity file is given in Table 1 and consists of five columns, as shown in the table. Although the dynamic vivacity is the only above mentioned quantity calculated, all the other

[†] Oberle, W. F., and D. E. Kooker. "BRLCB: A Closed-Chamber Data Analysis Program Part I and II- Theory and User's Manual." ARL-TR-36, U.S. Army Research Laboratory, Aberdeen Proving Ground, MD, January 1993.

quantities can be computed using the information supplied in the table, provided the "reference propellant" information required for relative force and quickness is known.

Table 1. Format of Vivacity File

Column	1	2	3	4	5
Quantity	Time	Pressure	Pressure/Pmax	dP/dt	Dynamic Vivacity
Units	s	MPa	(-)	MMPa/s ^a	1/(MPa-s)

^a MMPa = Million MPa

To validate the computer coding of the vivacity sub-option, the interior ballistic code IBHVG2 (Anderson and Fickie 1987)[†] was used to simulate a pressure history (see Table 2 for specific input data utilized in the simulation).

Table 2. Input Parameters Utilized in IBHVG2 to Generate a Pressure History Used to Validate the BRLCB Vivacity Calculation

Chamber Volume (cm ³)	300
Propellant:	
Geometry	Spherical
Diameter (cm)	0.5
Mass (g)	91
Impetus (J/g)	1,140
Flame Temperature (K)	3,410
Molecular Weight (-)	24.87
Covolume (cm ³ /g)	0.996
Ratio of Specific Heats (-)	1.225
Density (g/cm ³)	1.58

The pressure history generated by IBHVG2 was then used in BRLCB with the vivacity calculation option selected. Results from the BRLCB vivacity calculations were then compared with results obtained from directly computing the quantities listed in Table 1 from the pressure history. The percentage

[†] Anderson, R. D., and K. D. Fickie. "IBHVG2- A User's Guide." BRL TR-2829, U.S. Army Research Laboratory, Aberdeen Proving Ground, MD, July 1987.

difference between the two calculations is shown in Figure 1. As seen in the figure, the maximum percent error is approximately 0.02%. Considering that dp/dt was numerically calculated for both the BRLCB and the direct calculation the results are considered virtually identical. Thus, the vivacity routine included in BRLCB is correctly performing the desired calculations. Appendix A contains the code listing for the vivacity calculation added to BRLCB.

3. ROLLED BALL AND ROSETTE PROPELLANT GRAIN FORM FUNCTION

Two additional propellant grain form functions have been added to BRLCB—the rolled or squashed ball and a general rosette form function.

The geometry of the rolled ball is shown in Figure 2. Required dimensions are the overall grain diameter, D in Figure 2, and the thickness between the flat surfaces of the grain, T in Figure 2. The equations utilized to compute grain volume and surface area are those used in the interior ballistic code IBHVG2.

As described in the User's Manual (Oberle and Kooker 1993),[†] to verify the coding for a grain form function, IBHVG2 is used to generate a pressure history for a simulated closed-chamber firing. Input values utilized in IBHVG2 for the rolled ball grain geometry are given in Table 3.

The percent difference between the BRLCB derived burn rate and the assumed burn rate used in IBHVG2 (see Table 3) is shown in Figure 3. Due to the decimal accuracy of the input data from IBHVG2 and roundoff/truncation, errors associated with the numerical routines utilized in the program the maximum percent difference of less than 2% is considered insignificant (see User's Manual [Oberle and Kooker 1993][†] for details). Thus, the coding for the rolled ball propellant is correct.

The geometry of the rosette form function is shown in Figure 4. The required dimensions are outer diameter; length; perforation diameter; inner, middle, and outer web. However, for the equations used to determine volume and surface area (identical to those used in IBHVG2), the inner and middle webs must be equal. In addition, the form function is generalized for 7, 19, 37, etc., perforations which are determined by entering the number of perforation rings. The relation between rings and the most common number of perforations is given in Table 4. The generalized relationship (n is number of rings and P

[†] Oberle, W. F., and D. E. Kooker. "BRLCB: A Closed-Chamber Data Analysis Program Part I and II - Theory and User's Manual." ARL/TR 36, U.S. Army Research Laboratory, Aberdeen Proving Ground, MD, January 1993.

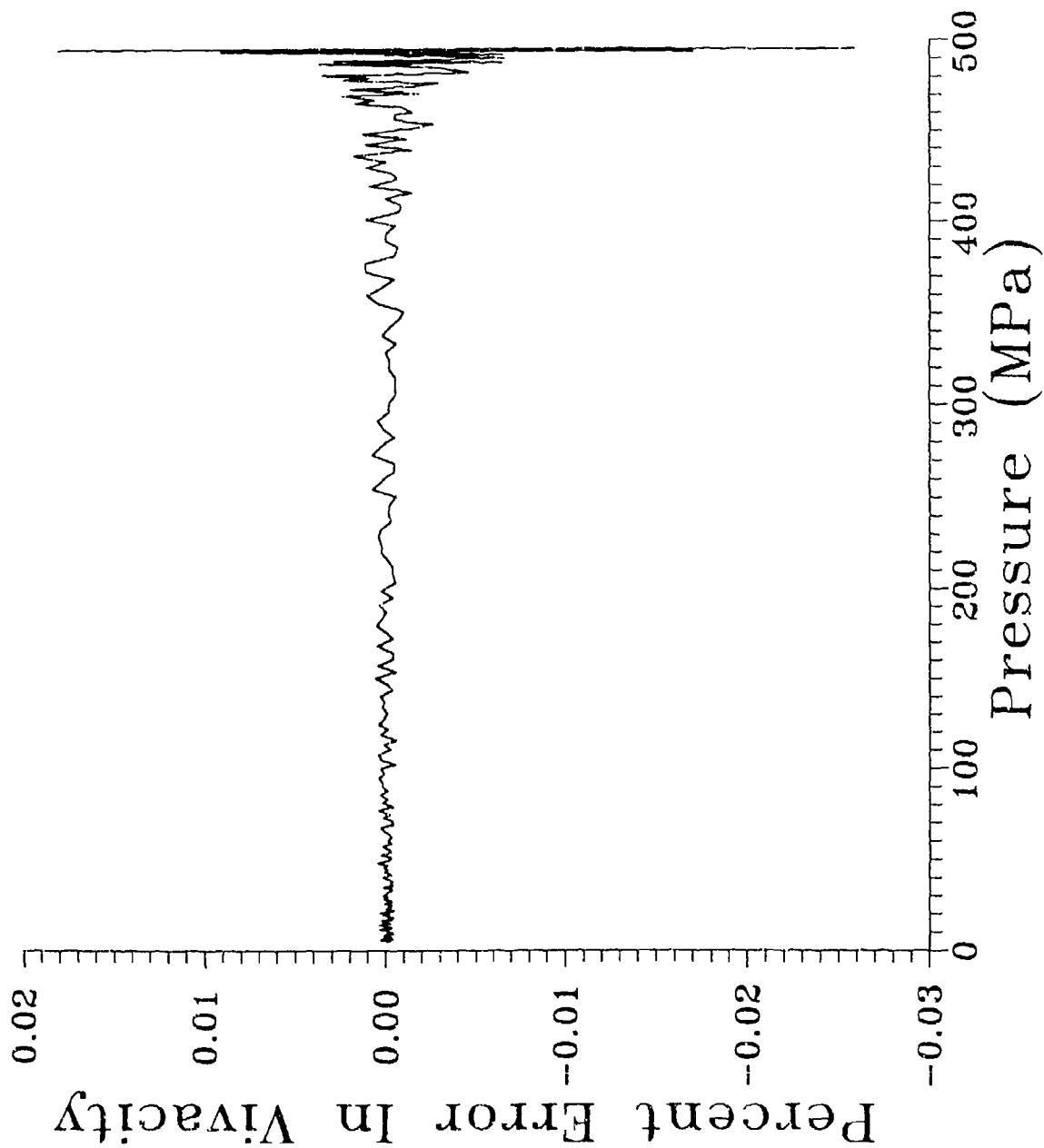


Figure 1. Percent difference between BRLCB dynamic vivacity calculation and direct calculation of the dynamic vivacity from the pressure-time data.

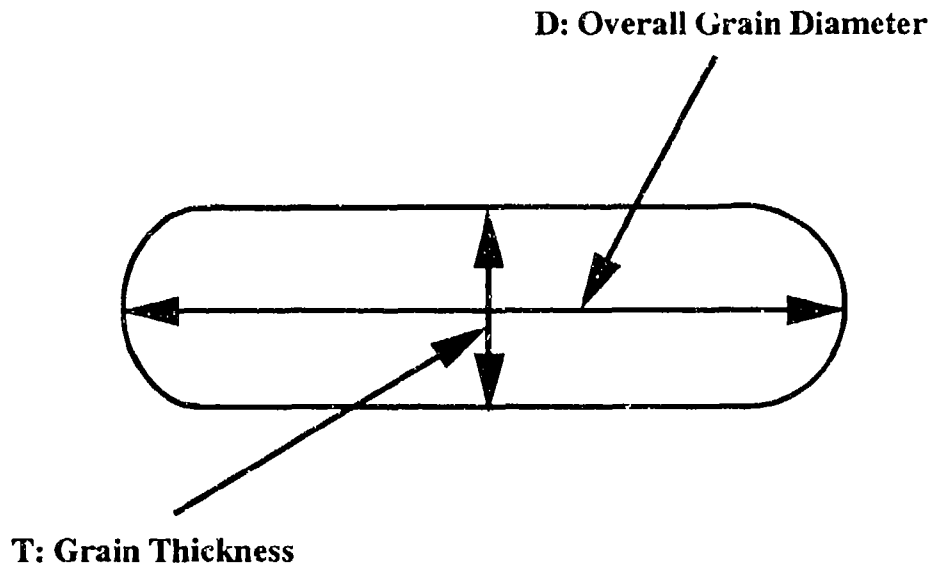


Figure 2. Schematic of rolled ball grain geometry.

Table 3. Input Parameters Used in IBHVG2 to Generate a Pressure History for Rolled Ball Grain Geometry

Chamber Volume (cm ³)	300
Propellant:	
Geometry	Rolled Ball
Overall Diameter (cm)	0.01
Thickness (cm)	0.005
Mass (g)	91
Impetus (J/g)	1,140
Flame Temperature (K)	3,410
Molecular Weight (g/g-mol)	24.87
Covolume (cm ³ /g)	0.996
Ratio of Specific Heats (-)	1.225
Density (g/cm ³)	1.58
Burn Rate Law	
Coefficient (cm/s-MPa ⁿ)	0.16
Exponent (-)	0.908

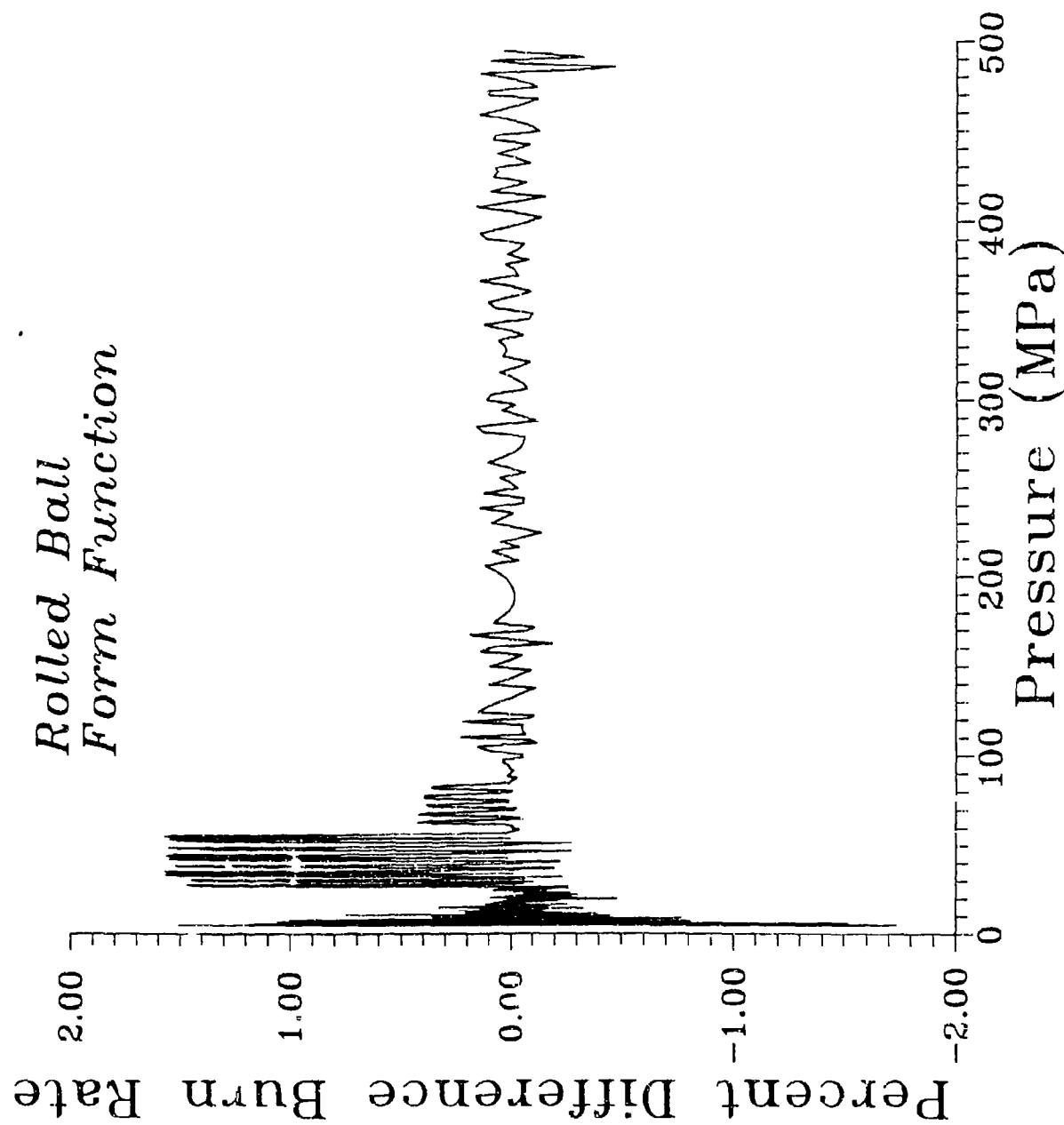


Figure 3. Percent difference between BRLCB derived burn rates and assured burn rate, rolled ball form function.

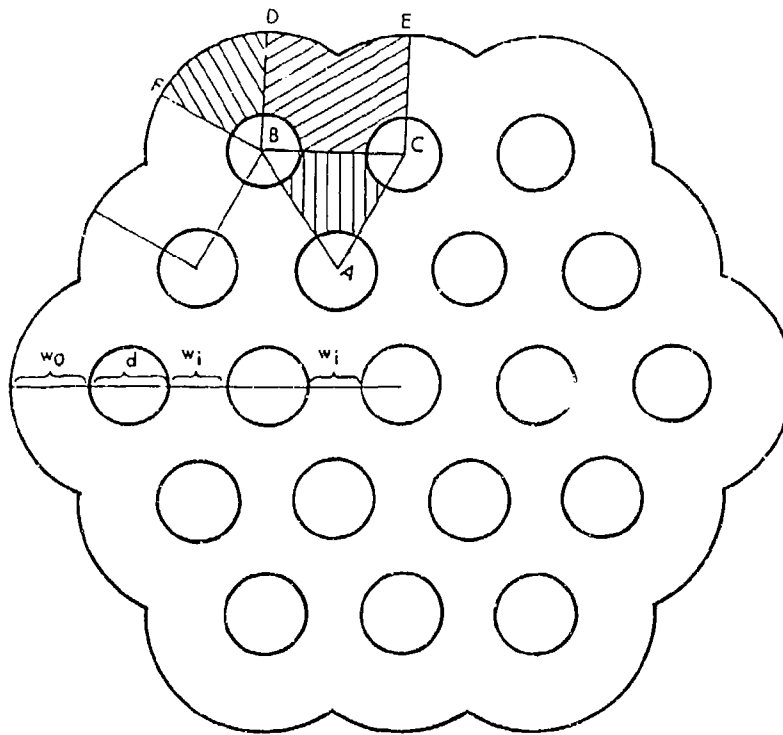


Figure 4. Schematic of rosette grain geometry.

Table 4. Relation Between Number of Rings and Perforations

No. Rings	No. Perforations
1	7
2	19
3	37

number of perforations) is

$$P = 3 * n^2 + 3 * n + 1 . \quad (2)$$

A similar procedure to that used to validate the coding for the rolled ball form function was used for the rosette form function. Input values for the IBHVG2 simulation are given in Table 5. The percent differences between derived (BRLCB) and assumed burn rates are shown in Figure 5. Although the

maximum percent difference is slightly higher than for the rolled ball the results are felt to be acceptable. Thus, the rosette form function appears to be correctly coded.

Table 5. Input Parameters Used in IBHVG2 to Generate a Pressure History for Rosette Grain Geometry

Chamber Volume (cm ³)	300
Propellant:	
Geometry	Rosette
Diameter (cm)	2.9
Length (cm)	3.5
Perf Diameter (cm)	0.3
Inner & Middle Webs (cm)	0.2
Outer Web (cm)	0.3
Mass (g)	91
Impetus (J/g)	1,140
Flame Temperature (K)	3,410
Molecular Weight (-)	24.87
Covolume (cm ³ /g)	0.996
Ratio of Specific Heats (-)	1.225
Density (g/cm ³)	1.58
Burn Rate Law	
Coefficient (cm/s-MPa ⁿ)	0.16
Exponent (-)	0.908

4. EDITING CAPABILITY

For multi-layered propellant grains, 12 different values (propellant density and thermochemical information) are required by the code for each layer. Such a process is extremely susceptible to error (typing, transposing digits, etc.). Unfortunately, to correct an error, the original version of BRLCB required the user to re-enter all 12 values for each layer, again creating a situation which is extremely error prone. To alleviate this difficulty, an additional option (Option 0) has been incorporated into the BRLCB program. This option will allow the user to edit the physical properties (density and thermochemistry) of the propellant.

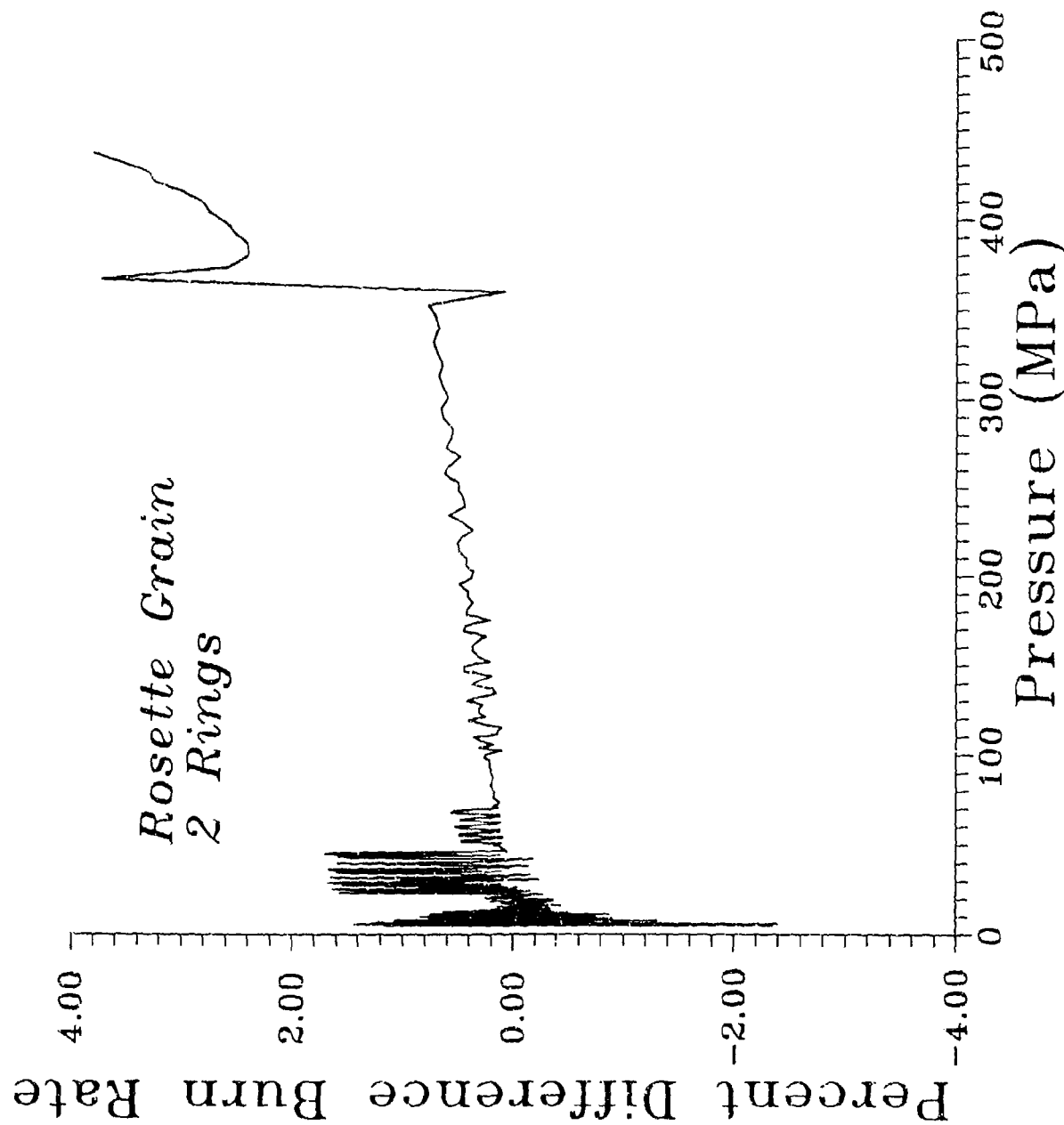


Figure 5. Percent difference between BRLCB derived burn rates and assumed burn rate, rosette form function.

The option is accessed from the Main Menu by typing a zero. The user is then requested to supply the name of the Master Information File (.MAS extension) containing the propellant data to be corrected. After entering the file name, the user will be allowed to edit the physical properties of each layer of the propellant material. In operation, the program reads the indicated Master Information File, creates a file named EDITFL with the format shown in Table 6 (example is a three-layer grain) and then invokes the EMACS editor JOVE (program EDITIN.FOR, see Appendix B). After the user completes editing (JOVE is exited by typing ESC-Z, escape key followed by the letter z), the Master Information File is rewritten (program EDOUT.FOR, see Appendix C). *THE NEW INFORMATION WILL OVERWRITE THE ORIGINAL MASTER INFORMATION INDICATED BY THE USER. THIS OPTION SIMPLY EDITS AN EXISTING MASTER INFORMATION FILE AND DOES NOT CREATE A NEW FILE.*

Table 6. Example of EDITFL File

Number of Layers: 3		
LAYER #: 1		
Property	Beginning Layer	End of Layer
Impetus (J/g)	1,100.00	1,200.00
Flame Temp. (K)	3,100.00	3,200.00
Density (g/cm ³)	1.500000	1.600000
Mol. Wt.	24.000000	25.000000
Covolume (cm ³ /g)	1.000000	14.100000
Gamma	1.200000	1.210000
LAYER #: 2		
Property	Beginning Layer	End of Layer
Impetus (J/g)	1,200.00	1,250.00
Flame Temp. (K)	3,200.00	3,300.00
Density (g/cm ³)	1.400000	1.450000
Mol. Wt.	25.000000	27.000000
Covolume (cm ³ /g)	1.200000	1.210000
Gamma	1.300000	1.310000
LAYER #: 3		
Property	Beginning Layer	End of Layer
Impetus (J/g)	1,300.00	1,400.00
Flame Temp. (K)	3,400.00	3,450.00
Density (g/cm ³)	1.400000	1.500000
Mol. Wt.	22.000000	21.000000
Covolume (cm ³ /g)	1.300000	1.400000
Gamma	1.220000	1.250000

APPENDIX A:
LISTING OF CODE ADDED TO BRLCB FOR VIVACITY CALCULATION

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```

C*****
C***** VIVACITY CALCULATION CAN BE ADDED HERE *****
C*****
353  CALL CLEAR
      WRITE(*,2781)
2781  FORMAT(///,' Do you wish to compute vivacity information?',
1/, '      (1=Yes, 2=No)')
      WRITE(*,*)'Enter your choice.'
      READ(*,*)IKLB
      IF (IKLB .EQ. 1) THEN
        WRITE(*,*)'Enter a file name for the vivacity information.'
        READ(*,2782)VIVFIL
2782  FORMAT(A20)
        OPEN(UNIT=8,FILE=VIVFIL)
        WRITE(8,2783)
2783  FORMAT(' Time (sec)   Pressure (MPa)   P/PMAX           DP/DT
1    Dynamic Vivacity',
2/, ' DP/DT has units of million MPa/sec',
3/, ' Dynamic Vivacity has units 1/(MPa*sec)',
4/, '*****',
5//)
      ENDIF
      OPEN(UNIT=3,FILE = A1(14), STATUS = 'NEW',ERR=86)
      REWIND(3)
      IST=1
      IF (NP .GT. 999) THEN
        IST=NP-990
      ENDIF
      DO 60 I =IST, NP
        TX=(I-IST)*A3(42)/1000.
C      TX=T(I)
        IF (ITYPE .EQ. 5) THEN
          WRITE(3,*)TX,PR(I),PDOT(I),EE(I)
        ELSE
          WRITE(3,*) TX,PR(I),PDOT(I)
        ENDIF
        IF (IKLB .EQ. 1) THEN
          POPMAX=PR(I)/A3(43)
          VIVY=1.E6*PDOT(I)/(PR(I)*A3(43))
          WRITE(8,2784)TX,PR(I),POPMAX,PDOT(I),VIVY
2784  FORMAT(5F16.6)
        ENDIF
60    CONTINUE
      CLOSE(UNIT=3)
      CLOSE(UNIT=8)

```

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APPENDIX B:
LISTING - PROGRAM EDITIN.FOR

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```

PROGRAM EDITIN
CHARACTER*20 FNAME1, A2 (6)*80, A1 (20), EDITFL
DIMENSION A3 (100), P (11, 15, 5)
WRITE (*, *) 'This option only applies to editing the'
WRITE (*, *) 'thermochemistry of a multi-layered grain.'
WRITE (*, *) 'Other editing can be achieved by selecting'
WRITE (*, *) 'Option 1, Create Master Information File.'
WRITE (*, *)
1000 CONTINUE
WRITE (*, *) 'Enter the file name of the master file '
WRITE (*, *) 'which is to be edited. '
WRITE (*, *) 'Include drive and file extension if necessary.'
IFGZ = 1
READ (*, 5000) FNAME1
5000 FORMAT(A20)
OPEN (UNIT = 9, FILE = FNAME1, STATUS = 'OLD', ERR = 1010)
REWIND (UNIT = 9)
GO TO 1020
1010 CONTINUE
WRITE (*, 6000)
6000 FORMAT(20X, 'The indicated master file does not exist, try again.'
1)
PAUSE
GO TO 1000
C*****
C***** READING OLD MASTER FILE TO BUILD FROM *****
C*****
1020 CONTINUE
DO 1030 I = 1, 6
    READ (9, 5010) A2 (I)
1030 CONTINUE
5010 FORMAT(A80)
DO 1040 I = 1, 20
    READ (9, 5000) A1 (I)
1040 CONTINUE
DO 1050 I = 1, 100
    READ (9, *) A3 (I)
1050 CONTINUE
DO 1060 I = 1, 11
    DO 1070 J = 1, 15
        DO 1080 K = 1, 5
            READ (9, *) P (I, J, K)
1080 CONTINUE
1070 CONTINUE
1060 CONTINUE
CLOSE (UNIT = 9)
C*****
C***** CREATING FILE WHICH WILL BE EDITED *****
C*****
OPEN (UNIT = 9, FILE = 'EDITFL')
REWIND (UNIT = 9)
C*****
C***** NOW INFORMTATION FOR EACH LAYER *****
C*****

```

```

        NUMLAY = INT (A3 (4) + .5)
        WRITE (9, 6010) FNAME1, NUMLAY
6010  FORMAT(A20,T30,'Number of Layers:',T47,I2)
        DO 1090 I = 1, NUMLAY
            WRITE (9, *)
            WRITE (9, 6020) I
6020  FORMAT(' LAYER #:',I2)
            WRITE (9, 6030)
6030  FORMAT(' Property',T20,' Beginning Layer',T40,' End of Layer')
            WRITE (9, 6040) P (2, I, 1), P (2, I, 2)
6040  FORMAT(' Impetus (J/g)',T20,F10.2,T40,F10.2)
            WRITE (9, 6050) P (3, I, 1), P (3, I, 2)
6050  FORMAT(' Flame Temp. (K)',T20,F10.2,T40,F10.2)
            WRITE (9, 6060) P (4, I, 1), P (4, I, 2)
6060  FORMAT(' Density (g/cc)',T20,F10.6,T40,F10.6)
            WRITE (9, 6070) P (5, I, 1), P (5, I, 2)
6070  FORMAT(' Mol. Wt.',T20,F10.6,T40,F10.6)
            WRITE (9, 6080) P (6, I, 1), P (6, I, 2)
6080  FORMAT(' Covolume (cc/g)',T20,F10.6,T40,F10.6)
            WRITE (9, 6090) P (7, I, 1), P (7, I, 2)
6090  FORMAT(' Gamma',T20,F10.6,T40,F10.6)
1090  CONTINUE
        CLOSE (UNIT = 9)
        END

```

APPENDIX C:
LISTING - PROGRAM EDOUT.FOR

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```

PROGRAM EDOUT
COMMON A3 (100), P (11, 15, 5)
CHARACTER*20 FNAME1, A2 (6)*80, A1 (20), LINE*80
C*****
C***** READING EDITED FILE: EDITFL *****
C*****
OPEN (UNIT = 9, FILE = 'EDITFL')
REWIND (UNIT = 9)
READ (9, 5000) FNAME1, NUMLAY
5000 FORMAT(A20,T47,I2)
OPEN (UNIT = 10, FILE = FNAME1)
REWIND (UNIT = 10)
C*****
C***** READING MASTER FILE TO REBUILD *****
C*****
1000 CONTINUE
DO 1010 I = 1, 6
READ (10, 5010) A2 (I)
1010 CONTINUE
5010 FORMAT(A80)
DO 1020 I = 1, 20
READ (10, 5020) A1 (I)
1020 CONTINUE
5020 FORMAT(A20)
DO 1030 I = 1, 100
READ (10, *) A3 (I)
1030 CONTINUE
DO 1040 I = 1, 11
DO 1050 J = 1, 15
DO 1060 K = 1, 5
READ (10, *) P (I, J, K)
1060 CONTINUE
1050 CONTINUE
1040 CONTINUE
CLOSE (UNIT = 10)
C*****
C***** NOW INFORMTAION FOR EACH LAYER IS READ FROM FILE*****
C*****
DO 1070 I = , NUMLAY
READ (9, 5030) LINE
5030 FORMAT(A80)
READ (9, 5030)
READ (9, 5030)
READ (9, 5040) P (2, I, 1), P (2, I, 2)
5040 FORMAT(T20,F10.2,T40,F10.2)
READ (9, 5050) P (3, I, 1), P (3, I, 2)
5050 FORMAT(T20,F10.2,T40,F10.2)
READ (9, 5060) P (4, I, 1), P (4, I, 2)
5060 FORMAT(T20,F10.6,T40,F10.6)
READ (9, 5070) P (5, I, 1), P (5, I, 2)
5070 FORMAT(T20,F10.6,T40,F10.6)
READ (9, 5080) P (6, I, 1), P (6, I, 2)
5080 FORMAT(T20,F10.6,T40,F10.6)
READ (9, 5090) P (7, I, 1), P (7, I, 2)

```

```

5090  FORMAT(T20,F10.6,T40,F10.6)
      P (9, I, 1) = 1.98717/P (5, I, 1)
      P (9, I, 2) = 1.98717/P (5, I, 2)
      P (10, I, 1) = P (9, I, 1)/(P (7, I, 1) - 1.)
      P (10, I, 2) = P (9, I, 2)/(P (7, I, 2) - 1.)
      P (11, I, 1) = P (10, I, 1)*P (3, I, 1)
      P (11, I, 2) = P (10, I, 2)*P (3, I, 2)
1070  CONTINUE
      CLOSE (UNIT = 9)
C*****
C***** INTEGRALS ARE UPDATED *****
C*****
      CALL COMMASS
C*****
C***** MASTER FILE IS REWRITTEN *****
C*****
      OPEN (UNIT = 7, FILE = FNAME1)
1030  CONTINUE
      DO 1090 I = 1, 6
        WRITE (7, 6000) A2 (I)
6000  FORMAT(A80)
1090  CONTINUE
      DO 1100 I = 1, 20
        WRITE (7, 6010) A1 (I)
6010  FORMAT(A20)
1100  CONTINUE
      DO 1110 I = 1, 100
        WRITE (7, *) A3 (I)
1110  CONTINUE
      DO 1120 I = 1, 11
        DO 1130 J = 1, 15
          DO 1140 K = 1, 5
            WRITE (7, *) P (I, J, K)
1140    CONTINUE
1130    CONTINUE
1120  CONTINUE
      CLOSE (UNIT = 7)
      END
C*****
C*****SUBROUTINE COMMASS*****
C*****
      SUBROUTINE COMMASS
C*****
C  Version 3.0, January 1992
C
C  THIS SUBROUTINE WILL COMPUTE THE INITIAL MASS PER LAYER AS WELL AS
C  THE INTEGRALS OF EACH PROPERTY
C
C*****
      COMMON A3 (100), P (11, 15, 5)
      ICTYPE = INT (A3 (45) + .5)
      IF (ICTYPE .GT. 14) THEN
        ICTYPE = 15
      END IF

```

```

      NL = INT (A3 (4) + .5)
      IGQR = INT (A3 (31) + .5)
C*****
C***** STORAGE LOCATION FOR INTEGRAL ARE ZEROED *****
C*****
      DO 1000 I = 2, 11
        DO 1000 J = 1, 15
          P (I, J, 3) = 0.0
1000  CONTINUE
      IF (IGQR .EQ. 1) THEN
        XI = 0.0
        CALL FORMT (IGTYPE, ASURF, VOLUNB, XI)
        P (8, 1, 3) = VOLUNB
        DO 1010 I = 2, 11
          P (I, 1, 3) = P (I, 1, 1)*P (8, 1, 3)
1010  CONTINUE
        A3 (3) = P (4, 1, 3)
        RETURN
      END IF
      DO 1020 J = 1, NL
C*****
C***** DETERMINE X VALUES FOR INTEGRATION *****
C*****
        IF (J .EQ. NL) THEN
          XS = P (1, J, 1)
          XL = A3 (1)
        ELSE
          XS = P (1, J, 1)
          XL = P (1, J + 1, 1)
        END IF
C*****
C***** ALWAYS 300 SUBDIVISIONS *****
C*****
        XDEL = XL - XS
        XSTEP = XDEL/300.
        DO 1030 I = 1, 301
          XI = XS + (I - 1)*XSTEP
C*****
          CALL FORMT (IGTYPE, ASURF, VOLUNB, XI)
C*****
          DO 1040 K = 2, 11
            PDEL = P (K, J, 2) - P (K, J, 1)
C*****
C***** INTEGRATION IS PERFORMED *****
C*****
            FCN = ((PDEL/XDEL)*(XI - XS) + P (K, J, 1))*ASURF
            IF ((I .EQ. 1) .OR. (I .EQ. 301)) THEN
              P (K, J, 3) = P (K, J, 3) + FCN
            ELSE
              P (K, J, 3) = P (K, J, 3) + 2.*FCN
            END IF
1040  CONTINUE
1030  CONTINUE
        DO 1050 K = 2, 11

```

```

      P (K, J, 3) = P (K, J, 3)*(XDEL/600.)
1050  CONTINUE
1020  CONTINUE
C*****
C***** MASS OF SINGLE GRAIN *****
C*****
      DO 1060 I = 1, NL
        A3 (3) = A3 (3) + P (4, I, 3)
1060  CONTINUE
      RETURN
      END
C*****
C*
C***** SUBROUTINE FORMT *****
C*
C*****
C*
C      ICODE: code for type of grain
C      R : burn depth
C      GL: unburned grain length
C      D : unburned outer diameter
C      PD: unburned perforation diameter
C      WI, WM, WO: inner, middle and outer webs respectively
C
C      Output:
C      SFAREA: surface area
C      FRCSFA: surface area/initial surface area
C      VOLUNB: unburned volume
C      VOLBRN: burned volume
C      FRCBRN: burned volume/initial volume
C      VOLMAO: unburned volume of outer layer
C      VOLMBO: unburned volume of inner layer
C      VOLABR: burned volume of outer layer
C      VOLBBR: burned volume of inner layer
C
C*****
      SUBROUTINE FORMT (ICODE, SFAREA, VOLUNB, R)
      COMMON A3 (100), P (11, 15, 5)
      DIMENSION S7 (4), S19 (3, 4)
      DATA RT/1.732050808/, PI3/1.047197551/, PI/3.141592654/
C*****
C***** SET GRAIN GEOMETRY *****
C*****
      GL = A3 (7)
      D = A3 (8)
      PD = A3 (9)
      WI = A3 (10)
      WM = A3 (11)
      WO = A3 (12)
C*****
C***** Set U = 2*(depth burned) and branch to grain type *****
C*****
      U = 2.0*R
C*****

```

```

C***** FINDING NUMBER OF RIGNS FOR ROSETTE GRAIN AND VALUES *****
C*****
C*****
C***** FINDING NUMBER OF RIGNS FOR ROSETTE GRAIN *****
C*****
      IF (ICODE .EQ. 15) THEN
        NRGS = INT (A3 (45) - 150. + .5)
        NIZ = 6*NRGS*NRGS
        NOZ = 6*NRGS
        NCZ = 6
C*****
C***** TEST TO DETERMINE IF METHOD APPLICABLE *****
C*****
      TOPP = WO*(PD + WO)
      BOTT = .5*WI*(PD + WI)
      IF (BOTT .GT. TOPP) THEN
        WRITE (*, *)
1        'The grain geometry does not satisfy the assumption'
        WRITE (*, *)
1        'made in determining the surface area and unburned'
        WRITE (*, *)
1        'volume of a grain. Use any results with caution.'
      END IF
      DPRIME = PD + U
C*****
C***** OUTER SLIVER IS COMPUTED *****
C*****
      THETA = 2.*ACOS (AMIN1 (1., (WI + PD)/DPRIME))
      TOPP = WI/2. + PD/2.
      BOTT = WO + PD/2.
      ALPHA = ACOS (TOPP/BOTT)
      IF (U .LE. WO) THEN
        AREA1 = .5*(PI/2. - ALPHA)*((PD - U + 2.*WO)/2. )**2
        AREA2 = .5*((WI + PD)/2.)*(PD/2. + WO)*SIN (ALPHA)
        AREA3 = .5*(PI/2. - ALPHA)*(U/2. )**2
        AREA4 = .5*(PI/2. - (THETA/2.))*(DPRIME/2. )**2
        AREA5 = .5*((WI + PD)/2.)*(DPRIME/2.)*SIN (THETA/2.)
        EOZ = 2.*(AREA1 + AREA2 - AREA3 - AREA4 - AREA5)
        XLEN1 = (PI/2. - ALPHA)*((PD - U + 2.*WO)/2.)
        XLEN2 = (PI/2. - ALPHA)*(U/2.)
        XLEN3 = (PI/2. - (THETA/2.))*(DPRIME/2.)
        SOZ = 2.*(GL - U)*(XLEN1 + XLEN2 + XLEN3)
      ELSE
        TOPP = 2.*WO*(PD + WO)
        BOTT = PD + SQRT ((2.*WO - WI)*(2.*PD + 2.*WO + WI))
        IF (U .LE. (TOPP/BOTT)) THEN
          TOPP = PD*DPRIME + 2.*WO*(PD + WO)
          BOTT = DPRIME*(PD + 2.*WO)
          BETA = ACOS (TOPP/BOTT)
          TOPP = 2.*WO*(PD + WO) - (PD*U)
          BOTT = U*(PD + 2.*WO)
          GAMMA = ACOS (TOPP/BOTT)
          AREA1 = .5*(PD/2. + WO)*(DPRIME/2.)*
1          SIN (ALPHA - THETA/2.)

```

```

        AREA2 = .5*(PD/2. + WO)*(DPRIME/2.)*SIN (BETA)
        AREA3 = .5*(ALPHA - BETA - THETA/2.)*(DPRIME/2.)*2
        AREA4 = .5*(PI/2. - ALPHA - GAMMA)*(U/2.)*2
        EOZ = 2.*(AREA1 - AREA2 - AREA3 - AREA4)
        XLEN1 = (PI/2. - ALPHA - GAMMA)*(U/2.)
        XLEN2 = (ALPHA - BETA - THETA/2.)*(DPRIME/2.)
        SOZ = 2.*(GL - U)*(XLEN1 + XLEN2)
    ELSE
        EOZ = 0.0
        SOZ = 0.0
    END IF
END IF
C*****
C***** NOW CORNER IS COMPUTED *****
C*****
    IF (U .LE. WO) THEN
        AREA1 = .5*PI/3.*((PD + 2.*WO - U)/2.)*2
        AREA2 = .5*PI/3.*(DPRIME/2.)*2
        ECZ = AREA1 - AREA2
        XLEN1 = PI/3.*((PD + 2.*WO - U)/2.)
        XLEN2 = PI/3.*(DPRIME/2.)
        SCZ = (GL - U)*(XLEN1 + XLEN2)
    ELSE
        ECZ = 0.0
        SCZ = 0.0
    END IF
C*****
C***** FINALLY THE INNER SLIVERS *****
C*****
    SQRT3 = SQRT (3.)/2.
    TOPP = (WI + PD)/SQRT3 - PD
    IF (U .LE. TOPP) THEN
        AREA1 = .5*SQRT3*(WI + PD)*2
        AREA2 = .5*(WI + PD)*(DPRIME/2.)*SIN (THETA/2.)
        AREA3 = .5*(PI/3. - THETA)*(DPRIME/2.)*2
        EIZ = AREA1 - 3.*(AREA2 + AREA3)
        XLEN1 = (PI/3 - THETA)*(DPRIME/2.)
        SIZ = 3.*(GL - U)*XLEN1
    ELSE
        EIZ = 0.0
        SIZ = 0.0
    END IF
C*****
C***** SURFACE AREA AND UNBURNED VOLUME COMPUTED *****
C*****
    E = NIZ*EIZ + NOZ*EOZ + NCZ*ECZ
    SFAREA = 2.*E + NIZ*SIZ + NOZ*SOZ + NCZ*SCZ
    VOLUME = E*(GL - U)
    RETURN
END IF
C*****
C***** ROLLED BALL GRAIN *****
C*****
    IF (ICODE .EQ. 14) THEN

```

```

      DD = A3 (8) - A3 (7)
      TT = A3 (7) - U
      SFAREA = PI/2.*(DD**2 + 2.*TT**2 + PI*DD*TT)
      VOLUNB = TT*PI/2.*((DD**2)/2. + (TT**2)/3. + (PI*DD*TT)/4.)
      RETURN
    END IF
C*****
C***** CIGARETTE GRAIN *****
C*****
      IF (ICODE .EQ. 13) THEN
        SFAREA = PI*D*D/4
        VOLUNB = (GL - R)*SFAREA
        RETURN
      END IF
C*****
C***** ALL OTHER GRAINS ARE HANDLED *****
C*****
      GO TO ( 1000, 1010, 1020, 1030, 1040, 1050, 1060, 1070,
      1 1080, 1090, 1100, 1110), ICODE
C*****
C***** CODE 1: 7-PERF GRAIN *****
C*****
C*** This part calculates the conditions before the grain burns.
C*****
1050 CONTINUE
      D = 3.0*PD + 2.0*(WI + WO)
      E0 = PI*(D**2 - 7.0*PD**2)/4.0
      S0 = PI*(D + 7.0*PD)*GL + 2.0*E0
      V0 = E0*GL
      WW = WI + PD
      DO 1120 K = 1, 3
        S7 (K) = WW
1120 CONTINUE
      WEBC = AMIN1 (WO, WI, GL)
C*****
C*** This part does the calculations for the burning grain.
C*****
      GRL = AMAX1 (GL - U, 0.0)
      OD = D - U
      PRFD = PD + U
      IF (U .GT. WEBC) GO TO 1130
      E = PI*(OD**2 - 7.0*PRFD**2)/4.0
      SFAREA = PI*(OD + 7.0*PRFD)*GRL + 2.0*E
      FRCSFA = SFAREA/S0
      VOLUNB = E*GRL
      VOLBRN = V0 - VOLUNB
      FRCBRN = VOLBRN/V0
      RETURN
C*****
C*** This part does the calculations for when the grain slivers. *****
C*****
1130 CONTINUE
      CALL GENIS (S7, PRFD, GRL, SF1, GV1)
      CALL GENOS (S7, PRFD, GRL, 0.5*OD, SF2, GV2)

```

```

SFAREA = 6.0*(SF1 + SF2)
FRCSFA = SFAREA/S0
VOLUNB = 6.0*(GV1 + GV2)
VOLBRN = V0 - VOLUNB
FRCBRN = VOLBRN/V0
RETURN
C*****
C***** CODE 2: 1-PERF GRAIN *****
C*****
C*** This part calculates the conditions before the grain burns.
C*****
1030 CONTINUE
D = PD + 2.0*WI
E0 = PI*(D**2 - PD**2)/4.0
S0 = PI*(D + PD)*GL + 2.0*E0
V0 = E0*GL
WEBC = AMIN1 (GL, WI)
C*****
C***** This part does the calculations for the burning grain. *****
C*****
IF (U .GE. WEBC) THEN
    GRL = 0.0
    E = 0.0
    GO TO 1140
END IF
GRL = GL - U
OD = D - U
PRFD = PD + U
E = PI*(OD**2 - PRFD**2)/4.0
1140 CONTINUE
SFAREA = PI*(OD + PRFD)*GRL + 2.0*E
FRCSFA = SFAREA/S0
VOLUNB = E*GRL
VOLBRN = V0 - VOLUNB
FRCBRN = VOLBRN/V0
RETURN
C*****
C***** CODE 3: CORD GRAIN *****
C*****
C*** This part calculates the conditions before the grain burns. *****
C*****
1010 CONTINUE
S0 = GL*PI*D + PI*D**2/2.0
V0 = GL*PI*D**2/4.0
C*** This part does the calculations for the burning grain.
GRL = AMAX1 (GL - U, 0.0)
OD = AMAX1 (D - U, 0.0)
E = PI*OD**2/4.0
SFAREA = PI*OD*GRL + 2.0*E
FRCSFA = SFAREA/S0
VOLUNB = GRL*PI*OD**2/4.0
VOLBRN = V0 - VOLUNB
FRCBRN = VOLBRN/V0
RETURN

```

```

C*****
C***** CODE 4: RECTANGULAR STRIP GRAIN *****
C*****
1020 CONTINUE
  S0 = 2.0*(GL*D + D*WI + GL*WI)
  V0 = GL*D*WI
  GRL = AMAX1 (GL - U, 0.0)
  DS = AMAX1 (D - U, 0.0)
  WIS = AMAX1 (WI - U, 0.0)
  SFAREA = 2.0*(GRL*DS + DS*WIS + WIS*GRL)
  FRCSFA = SFAREA/S0
  VOLUNB = GRL*DS*WIS
  VOLBRN = V0 - VOLUNB
  FRCBRN = VOLBRN/V0
  RETURN
C*****
C***** CODE 5: SPHERICAL GRAIN *****
C*****
1000 CONTINUE
  S0 = PI*D**2
  V0 = PI*D**3/6.0
  OD = AMAX1 (D - U, 0.0)
  SFAREA = PI*OD**2
  FRCSFA = SFAREA/S0
  VOLUNB = PI*OD**3/6.0
  VOLBRN = V0 - VOLUNB
  FRCBRN = VOLBRN/V0
  RETURN
C*****
C***** CODE 6: SLOTTED-TUBE GRAIN *****
C*****
C*** This part does the calculations before the grain burns. *****
C*****
1040 CONTINUE
  SLOT = 0.5*WM
  SO = 0.5*D
  SI = 0.5*PD
  THETA = ASIN (SLOT/SO)
  ALPHA = ASIN (SLOT/SI)
  E0 = (PI - ALPHA)*(SO**2 - SI**2) + (SO - SI)**2*ALPHA
  S0 = 2.0*((PI - ALPHA)*SI + (PI - THETA)*SO + (SO*COS (THETA)
1 - SI*COS (ALPHA)))*GL + 2.0*E0
  V0 = GL*E0
  WI = SO - SI
  WEBC = AMIN1 (GL, WI)
C*****
C*** This part does the calculations for the burning grain. *****
C*****
  IF (U .GE. WEBC) THEN
    GRL = 0.0
    E = 0.0
    GO TO 1150
  END IF
  SLOT = 0.5*(WM + U)

```

```

SO = 0.5*(D - U)
SI = 0.5*(PD + U)
GRL = GL - U
THETA = ASIN (SLOT/SO)
ALPHA = ASIN (SLOT/SI)
E = (PI - ALPHA)*(SO**2 - SI**2) + (SO - SI)**2*ALPHA
1150 CONTINUE
SFAREA = 2.0*((PI - ALPHA)*SI + (PI - THETA)*SO + (SO*COS (THETA)
1 - SI*COS (ALPHA)))*GRL + 2.0*E
FRCSFA = SFAREA/SO
VOLUNB = E*GRL
VOLBRN = V0 - VOLUNB
FRCBRN = VOLBRN/V0
RETURN
C*****
C***** CODE 7: ROUND-HEX 37-PERF GRAIN *****
C*****
1090 CONTINUE
SO = 18.
SI = 54.
NPERF = 37
D = 7.0*PD + 6.0*WI + 2.0*WO
GO TO 1160
C*****
C***** CODE 8: ROUND-HEX 19-PERF GRAIN *****
C*****
1080 CONTINUE
SO = 12.0
SI = 24.0
NPERF = 19
D = 5.0*PD + 4.0*WI + 2.0*WO
C*****
C***** CALCULATIONS FOR CODES 7,8,10 *****
C*****
1160 CONTINUE
WW = WI + PD
WW2 = WW**2
PRFD = PD + U
PRFD2 = PRFD**2
GRL = AMAX1 (GL - U, 0.0)
E = 0.0
THETA = 2.0*ACOS (AMIN1 (WW/PRFD, 1.0))
ALPHA = ACOS (AMIN1 ((2.0*WO + PD - U)/PRFD, 1.0))
IF (U .LT. WO) E = 0.25*PI*((2.0*WO + PD - U)**2 - PRFD2)
IF (THETA .GE. PI3) GO TO 1170
E = E + SI*0.25*(WW2*RT - 1.5*PRFD2*(SIN (THETA) + PI3 - THETA))
1170 CONTINUE
IF (ALPHA .GE. 0.5*(PI - THETA)) GO TO 1180
E = E + SO*0.125*(2.0*(2.0*WO + PD - U)*(2.0*
1 WW - PRFD*SIN (ALPHA))
2 - PRFD2*(SIN (THETA) + PI - 2.0*ALPHA - THETA))
1180 CONTINUE
IF (2.0*WO + PD .LT. WI) THEN
WRITE (*, *) ' *FORMT* BAD HEX PROP'

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```

        PAUSE
        GO TO 1190
    END IF
    VOLUNB = E*GRL
C***** TEST TO SEE IF GRAIN CONSUMED *****
    IF (VOLUNB .LE. 0.0) THEN
        SFAREA = 0.0
        VOLUNB = 0.0
        GO TO 1190
    END IF
C*****NOW THE SURFACE AREA*****
    PH = D/2. - WO - PD/2.
    IF (U .EQ. 0.0) THEN
        SFAREA = 2.*E + GRL*PH*6. + NPERF*PI*PD*
1        GRL + PI*GRL*(2*WO + PD)
        GO TO 1190
    END IF
C*****NO SLIVERING YET*****
    IF ((WO .GT. U) .AND. (WI .GT. U)) THEN
        SFAREA = 2.*E + NPERF*(PD + U)*GRL*PI + 6.*PH*
1        GRL + PI*(2.*WO + PD - U)*GRL
        GO TO 1190
    END IF
C***** NOW SLIVERING *****
    SFAREA = 2.*E
C***** FIRST THE INNER SLIVERS *****
    IF (THETA .GE. PI/3) THEN
        GO TO 1200
    ELSE
        SFAREA = SFAREA + 1.5*PRFD*GRL*(PI/3 - THETA)*SI
    END IF
1200 CONTINUE
C***** NOW THE OUTER SLIVERS & CORNERS *****
C***** CORNERS NOT CONSUMED *****
    IF (WO .GT. U) THEN
        SFAREA = SFAREA + PI*(PD + 2.*WO - U + PRFD)*GRL
    END IF
C*****NOW OUTER SLIVERS*****
    IF (ALPHA .LT. .5*(PI - THETA)) THEN
        SFAREA = SFAREA + (WW - PRFD*SIN (ALPHA))*GRL*SO +
1        PRFD*GRL*(PI/2. - ALPHA - THETA/2.)*SO
    END IF
1190 CONTINUE
    RETURN
C*****
C***** CODE 9: 19-PERF GRAIN *****
C*****
C*** This part calculates the conditions before the grain burns *****
C*****
1070 CONTINUE
    D = 5.0*PD + 2.0*(WI + WM + WO)
    E0 = PI*(D**2 - 19.0*PD**2)/4.0
    S0 = PI*(D + 19.0*PD)*GL + 2.0*E0
    V0 = E0*GL

```

```

S19 (1, 1) = WI + PD
S19 (2, 1) = S19 (1, 1)
S19 (3, 1) = S19 (1, 1)
S19 (1, 2) = 0.5*SQRT (3.0*(WM + PD)**2 + (WI + PD)**2)
S19 (2, 2) = S19 (1, 2)
S19 (3, 2) = S19 (1, 1)
S19 (1, 3) = PD + 0.5*(WI + WM)
S19 (2, 3) = S19 (1, 2)
S19 (3, 3) = WM + PD
S19 (1, 4) = S19 (1, 3)
S19 (2, 4) = 2.0*S19 (1, 3)
S19 (3, 4) = S19 (1, 3)*RT
WEBC = AMIN1 (WO, WM, WI, S19 (1, 3) - PD, S19 (1, 2) - PD, GL)
C*****
C*** This part does the calculations for the burning grain. *****
C*****
GRL = AMAX1 (GL - U, 0.0)
C*****
OD = D - U
PRFD = PD + U
IF (U .GE. WEBC) GO TO 1210
E = 0.25*PI*(OD**2 - 19.0*PRFD**2)
SFAREA = PI*(OD + 19.0*PRFD)*GRL + 2.0*E
FRCSFA = SFAREA/S0
VOLUNB = E*GRL
VOLBRN = V0 - VOLUNB
FRCBRN = VOLBRN/V0
RETURN
1210 CONTINUE
SUMSA = 0.0
SUMGV = 0.0
DO 1220 K = 1, 2
CALL GENIS (S19 (1, K), PRFD, GRL, SA, GV)
SUMSA = SUMSA + 6.0*SA
SUMGV = SUMGV + 6.0*GV
1220 CONTINUE
CALL GENIS (S19 (1, 3), PRFD, GRL, SA, GV)
SUMSA = SUMSA + 12.0*SA
SUMGV = SUMGV + 12.0*GV
CALL GENOS (S19 (1, 4), PRFD, GRL, .5*OD, SA, GV)
SUMSA = SUMSA + 12.0*SA
SUMGV = SUMGV + 12.0*GV
SFAREA = SUMSA
FRCSFA = SFAREA/S0
VOLUNB = SUMGV
VOLBRN = V0 - VOLUNB
FRCBRN = VOLBRN/V0
RETURN
C*****
C***** CODE 10: ROUND-HEX 7-PERF GRAIN *****
C*****
1060 CONTINUE
SO = 6.0
SI = 6.0

```

```

      NPERF = 7
      GO TO 1160
C*****
C***** CODE 11: CORD WITH INHIBITED ENDS *****
C*****
C This routine will only calculate the surface area of the lateral surface.
C It will not calculate the surface area of the inhibited ends. *****
C*****
1100 CONTINUE
      SO = GL*PI*D
      VO = GL*PI*D**2/4.0
C **** This part does the calculations for the burning grain
      OD = AMAX1 (D - U, 0.0)
      SFAREA = PI*OD*GL
      FRCSFA = SFAREA/SO
      VOLUME = GL*PI*OD**2/4.0
      VOLBRN = VO - VOLUME
      FRCBRN = VOLBRN/VO
      RETURN
C*****
C***** CODE 12: RECTANGULAR STRIP GRAIN WITH INHIBITED SIDES *****
C*****
C This routine will only calculate the surface area of the two burning sides.
C It will not calculate the surface area of the inhibited sides.
C*****
1110 CONTINUE
      SO = 2.0*GL*WI
      VO = GL*D*WI
      VOLMAO = (D - WI)*GL*WO
      VOLMBO = WI*GL*WO
C*****
C **** This part does the calculations for the burning grain
      DS = AMAX1 (D - U, 0.0)
      SFAREA = 2.0*GL*WI
      FRCSFA = SFAREA/SO
      VOLUME = GL*DS*WI
      VOLBRN = VO - VOLUME
      FRCBRN = VOLBRN/VO
      IF (DS .GE. WI) THEN
        VOLABR = VOLBRN
        VOLBBR = 0.
      ELSE
        VOLABR = VOLMAO
        VOLBBR = VOLBRN - VOLABR
      END IF
      RETURN
      END
C*****
C*****
C
C SUBROUTINE *GENIS*: calculate surface area and volume for a
C                      general inner sliver of a burning grain

```

```

C                                     with length = GRL & perforation dia. = PRFD.
C
C      SUBROUTINE GENIS (S, PRFD, GRL, SURF, VOL)
C      DIMENSION S (3), A (4)
C      DATA PI2/1.5707963/
C
C      ***** : Store angles A1,A2,A3 and area of triangle
C                with sides S(1),S(2),S(3) into A(1)...A(4)
C
C      A (1) = ACOS ((S (2)**2 + S (3)**2 - S (1)**2)/(2.0*S (2)*S (3)))
C      A (2) = ACOS ((S (1)**2 + S (3)**2 - S (2)**2)/(2.0*S (1)*S (3)))
C      A (3) = ACOS ((S (1)**2 + S (2)**2 - S (3)**2)/(2.0*S (1)*S (2)))
C      A (4) = 0.5*S (1)*S (3)*SIN (A (2))
C
C      ...check for error condition: find if triangle acceptable...
C
C      J = 0
C      DO 1000 I = 1, 3
C        IF (A (I) .LT. 0.5*PI2) J = J + 1
C      1000 CONTINUE
C      IF (J .GT. 1) STOP ' GENIS ERROR'
C
C      succeeding passes until burnout: find auxiliary angles
C
C      TAU12 = ACOS (AMIN1 (1.0, S (3)/PRFD))
C      TAU13 = ACOS (AMIN1 (1.0, S (2)/PRFD))
C      TAU23 = ACOS (AMIN1 (1.0, S (1)/PRFD))
C
C      ...and branch to 25 if sliver fails burnout criteria. If not
C      then sliver is burned and go to 30.
C
C      IF (TAU12 + TAU13 + TAU23 .LT. PI2 .AND. GRL .GT. 0.0) THEN
C        GO TO 1010
C      ELSE
C        GO TO 1020
C      END IF
C
C      sliver not burned out: determine end area, volume and surface area
C
C      1010 CONTINUE
C      E = A (4) - 0.25*PRFD*(S (1)*SIN (TAU23) + S (2)*SIN (TAU13)
C      1 + S (3)*SIN (TAU12) + PRFD*(PI2 - TAU12 - TAU13 - TAU23))
C
C      VOL = E*GRL
C
C      SURF = 2.0*E + GRL*PRFD*(PI2 - TAU12 - TAU13 - TAU23)
C
C      ...and RETURN
C
C      RETURN
C

```

```

C  sliver is burned out: return with zero volume and surface area.
C
1020 CONTINUE
      VOL = 0.0
      SURF = 0.0
      RETURN
      END
C*****
C  SUBROUTINE "GENOS" : Calculates surface area and volume for a
C                      general outer sliver of a burning grain
C                      with length = GRL, radius = RAD, and
C                      perforation diameter = PRFD
C
      SUBROUTINE GENOS (S, PRFD, GRL, RAD, SURF, VOL)
      DIMENSION S (3), A (4)
C
C *****      Store angles A1,A2,A3 and area of triangle
C                      with sides S(1),S(2),S(3) into A(1) ...A(4)
C
      A (1) = ACOS ((S (2)**2 + S (3)**2 - S (1)**2)/(2.0*S (2)*S (3)))
      A (2) = ACOS ((S (1)**2 + S (3)**2 - S (2)**2)/(2.0*S (1)*S (3)))
      A (3) = ACOS ((S (1)**2 + S (2)**2 - S (3)**2)/(2.0*S (1)*S (2)))
      A (4) = 0.5*S (1)*S (3)*SIN (A (2))
C
C
C  succeeding passes until burnout: determine auxiliary angles
C
      TAU1 = ACOS (AMIN1 (1., (S (2)**2 + RAD**2 - 0.25*
1  PRFD**2)/(2.*S (2)*RAD)))
      TAU2 = ACOS (AMIN1 (1., (S (3)**2 + RAD**2 - 0.25*
1  PRFD**2)/(2.*S (3)*RAD)))
      TAU3 = ACOS (AMAX1 (-1.0, (S (2)**2 - RAD**2 + 0.25*
1  PRFD**2)/(S (2)*PRFD)))
      TAU4 = ACOS (AMAX1 (-1.0, (S (3)**2 - RAD**2 + 0.25*
1  PRFD**2)/(S (3)*PRFD)))
C
      SIG = ACOS (AMIN1 (1.0, S (1)/PRFD))
C
C ...then check error conditions...
C
      IF (TAU3 .LT. A (3) .OR. TAU4 .LT. A (2)) STOP ' *GENOS* ERROR'
C
C ...IF ok, check if sliver burned out. If not burned out go to 25.
C  If burned out go to 30.
C
      IF (TAU1 + TAU2 .LT. A (1) .AND. GRL .GT. 0.0) THEN
        GO TO 1000
      ELSE
        GO TO 1010
      END IF
C
C
C  sliver not burned out: determine end area, volume and surface area.
C

```

```

1000 CONTINUE
      E = 0.5*RAD*(S (2)*SIN (TAU1) + RAD*(A (1) - TAU1 - TAU2)
1      + S (3)*SIN (TAU2)) - A (4) - 0.25*PRFD*(S (1)*SIN (SIG)
2      + 0.5*PRFD*(TAU3 + TAU4 - 2.0*SIG - A (2) - A (3)))
C
      VOL = E*GRL
C
      SURF = 2.0*E + GRL*(RAD*(A (1) - TAU1 - TAU2) + 0.5*PRFD*(TAU3
1      + TAU4 - 2.0*SIG - A (2) - A (3)))
C
C ...and RETURN.
C
      RETURN
C
C sliver is burned out: return with zero volume and surface area.
C
1010 CONTINUE
      VOL = 0.0
      SURF = 0.0
      RETURN
      END

```

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