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MEMORANDUM REPORT ARBRL-MR-03361

THE COMPETITION BETWEEN TUBE HEATING AND MUZZLE VELOCITY IN STICK PROPELLANT GUN CHARGES

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July 1984

US ARMY ARMAMENT RESEARCH AND DEVELOPMENT CENTER
BALLISTIC RESEARCH LABORATORY
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In this report, NOVA, a one-dimensional, two-phase-flow, interior ballistic code, is used to examine in detail the trade-offs between one- and multi-bundle stick configurations and between calculated heating of the chamber and tube walls and calculated muzzle velocity. The system chosen for these calculations is a Navy 5-inch, 54-caliber gun firing the HIFRAG projectile and using a charge made up of nominal M31 propellant. The results provide the charge designer an appreciation of the tradeoffs between the hydrodynamic

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effects which on one hand increase muzzle velocity and on the other hand may seriously alter heat transfer processes.

The tradeoffs between using a single bundle of slotted stick propellant compared with several (two through five) bundles were studied. It was anticipated that more bundles might lead to more movement of the propellant down the gun tube, in the manner of granular propellant. That would dissipate the anticipated heat over more of the chamber and gun tube. Thus, heating of the chamber at the origin of rifling would be reduced, and that would reduce critical barrel erosion. NOVA predicts that the sticks will move away from the breech as they burn, and that the multiple-bundle charges will spread out well past the origin of rifling before burnout. Nonetheless, as one goes from one long bundle of sticks to 5 short bundles, the maximum gun bore surface temperature at the origin of rifling is predicted to drop only 20 K. If one adds a bit more propellant to the five-bundle charge in order to regain the ballistic performance of the one-bundle charge the heating at the origin of rifling rises. In the end, going from one long bundle to five reduces the predicted peak temperature at the origin of rifling only 11 K.

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I. INTRODUCTION

The solution to several of the problems associated with the use of conventional solid propellants seems to lie with the use of stick propellants. Sticks lead to much lower flow resistance, so that possible pressure waves are minimized. Sticks permit tighter packing, which should permit the use of more, cooler-burning propellant, retaining ballistic performance even in volume-limited guns. There is some evidence that sticks are more forgiving of igniter variability. Finally, muzzle velocities achieved with sticks are somewhat higher than those predicted by interior-ballistic models, for reasons that are only beginning to be understood. On the other hand, it has been shown that the lower gas flow resistance associated with stick propellants can lead to their staying in the chamber while they are burning, so that the heat from the combustion process is preferentially deposited in the chamber walls, perhaps leading to decreased tube life.

The concern pointed out by Horst in his recent report[1] is that heating of the origin of rifling could be greater for stick propellants than for conventional granular propellant charges of the same composition. Such localized heating could make up for, or even more than make up for, the reduced heating expected to result from using cooler stick propellants. In this report, we seek to find out if the use of multiple propellant bundles of shorter sticks could distribute the tube heating enough to reduce the heating at the origin of rifling appreciably.

II. NOVA CALCULATIONS

The point of departure for these calculations was a Navy 5-inch, 54-caliber gun with a HIFRAG projectile and one bundle of 9.53 kg (21 lb) of nominal M31 slotted stick propellant with a perf diameter of 2.54 mm (0.1 in.), a web thickness of 2.03 mm (0.08 in.), and a length of 762 mm (30 in.). We used our work-horse single-precision NOVA[2] with its new solution method. We recognize that the peak chamber pressure that was predicted for this calculation was a bit higher than is desired for this weapon system. The other calculations of the set were for 2, 3, 4, and 5 bundles of propellant, for which all the grain dimensions were maintained except the length; and the total initial length of the end-to-end bundles remained 762 mm (30 in.).

Heat loss to the walls and the resulting wall temperature were calculated as described by Horst.[1] First, convective heat transfer to the tube was calculated using a simple turbulent pipe flow correlation[3] based on a hydraulic Reynolds Number to account for the presence of the solid phase. Then the local temperature at the inside surface of the tube was determined, using an approximate cubic profile integral solution to the one-dimensional

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1. A. W. Horst, "A Comparison of Barrel-Heating Processes for Granular and Stick Propellant Charges," ARBRL-MR-03193, USA ARRADCOM, Ballistic Research Laboratory, Aberdeen Proving Ground, MD, August 1982 (AD A118 394).

2. P. S. Gough, "Extensions to NOVA Flamespread Modeling Capacity," PGA-TR-81-2, Paul Gough Associates, Inc., Portsmouth, NH, April 1981.

3. J. P. Holman, <u>Heat Transfer</u>, McGraw-Hill, 1968.

heat conduction equation. This approximation has previously been shown[4] to produce a 2% error in predicting temperature change for a constant heat flux and 6% for a linearly increasing flux.

These calculated wall temperatures are not presented to be correct in an absolute sense; for that, we must wait for a much better representation of the processes that lead to gun tube wall heating. However, the calculated temperatures should be relatively correct, so that relative increases or decreases in calculated tube wall temperatures should be meaningful.

A. Charge Motion and Ballistics

The big change that one expects when going from one bundle of long sticks to many bundles of shorter sticks is that the charge will spread out in the chamber and the gun tube, after the manner of granular charges, so that the heating of the gun tube is distributed over more surface area. Figure 1 illustrates the NOVA calculations for charge positions for 0%-, 25%-, 50%-, 75%-, and (nearly) fully-burned propellant. Note how quickly the several propellant bundles spread out, moving out to the origin of rifling by the time the propellant was half burned and extending well into the tube by the time all the propellant has burned. The spreading was driven by the difference in the pressure difference which was working on the front bundle versus that applied to the rear bundle. For example, for five bundles, at the time when about 50% of the propellant had burned, the end-to-end pressure difference across the front bundle was 15.2 MPa, while that across the rear bundle was only 1.76 MPa. Thus, the front bundle was accelerated forward faster than the rear bundle, leaving the rear bundle behind.

The calculations showed that a principal effect of adding multiple bundles was a decrease in the peak chamber pressure and the muzzle velocity, apparently because the spreading out of the bundles permits the propellant to burn in a larger effective free volume. We used an earlier version of NOVA[5] to perform a test to examine this effect. In this earlier version of NOVA, the amount of interphase friction which contributes to interphase drag could be independently set. By using several values for the amount of friction, ranging from one that was the right order of magnitude for sticks to one that was about right for granular propellant - greater by two orders of magnitude - we could influence the amount of the spreading of the bundles. While we could not use slotted sticks for these calculational experiments, we did use five bundles of 152.4-mm-long single-perforated grains. As expected, as the drag increased, the spreading of the bundles increased. More importantly, as the spreading of the bundles increased, the predicted peak pressure declined modestly.

During these calculations, a question arose about whether the tapers at the ends of the chamber of the 5-inch, 54-caliber gun significantly affected the predicted pressure differences and therefore stick motions as well. Thus,

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4. C. W. Nelson, "On Calculating Ignition of a Propellant Bed," ARBRL-MR-02864, USA ARRADCOM, Ballistic Research Laboratory, Aberdeen Proving Ground, MD, September 1978 (AD A062 266).

5. P. S. Gough, "The NOVA Code: A User's Manual. Volume I. Description and Use," IHCR 80-8, Naval Ordnance Station, Indian Head, MD, December 1980.

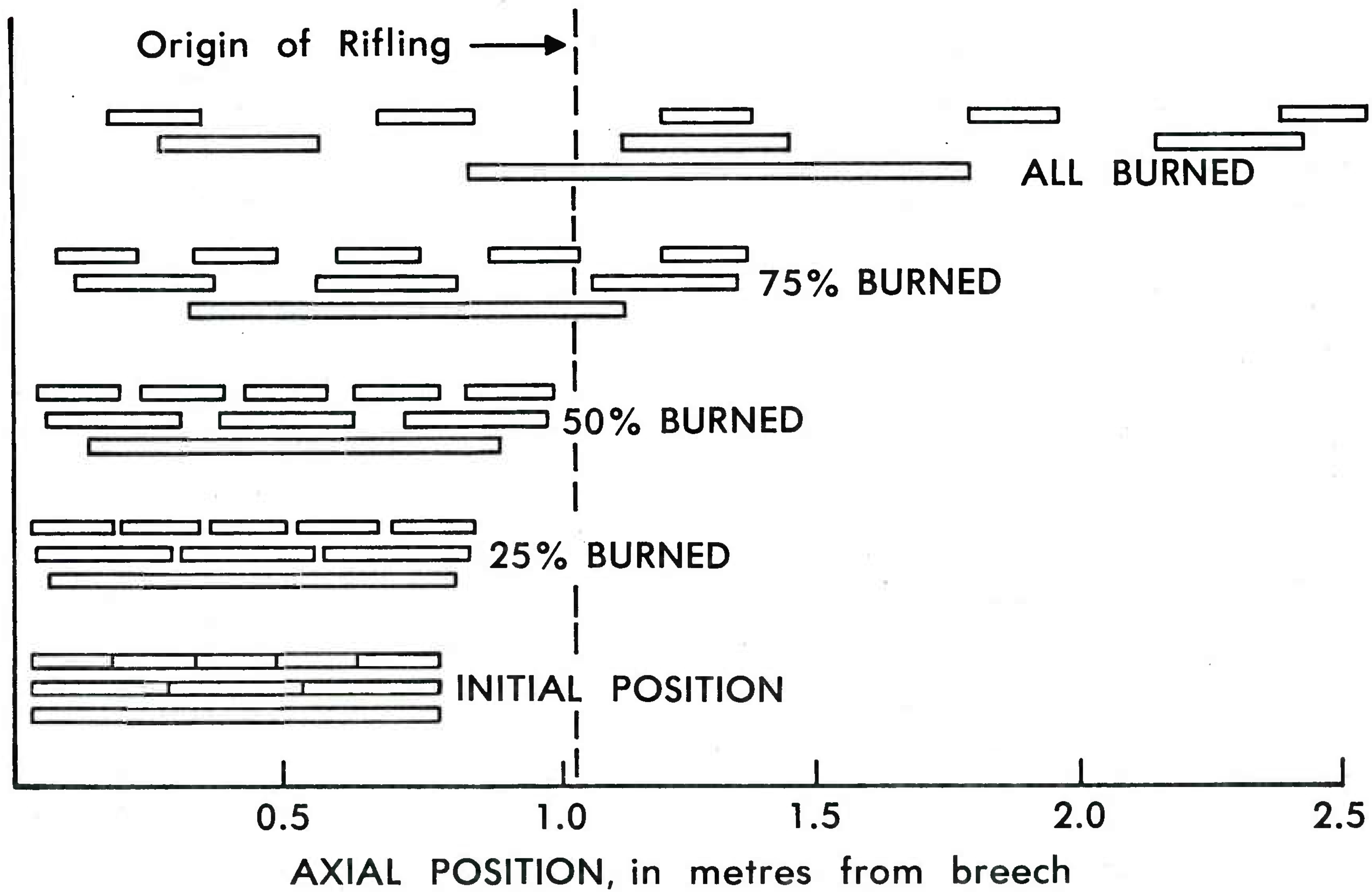

Figure 1. Stick Motion Down the Gun Tube. For One, Three, and Five Bundles of Propellant, at Several Times in the Ballistic Cycle.

separate calculations were performed with a straight chamber (just the same diameter as the gun tube, in fact), and the pressure differences which cause the front bundle to move more rapidly than the rear one were still evident and operative.

Table 1 charts the loss of peak pressure and muzzle velocity that was obtained for an increase in the number of propellant bundles. For the calculation marked with a "+," the charge was increased to 9.64 kg (21.24 lb), an amount selected to restore the maximum chamber pressure to that predicted for one bundle. The job control language (JCL) and data for each of these six cases are included as Appendices A through F. For the last case, the NOVA input echo is also included, so one can see how NOVA uses the input data.

TABLE 1. THE TRADE-OFFS BETWEEN THE NUMBER OF STICK PROPELLANT BUNDLES, WALL HEATING, AND BALLISTIC PERFORMANCE

Bundles	Peak Pressure (MPa)	Maximum Wall Temperature (K)	Muzzle Velocity (m/s)
1	384	1212	857
2	381	1187	859
3	378	1178	856
4	377	1170	852
5	375	1165	847
5+	384	1172	856

Note that the maximum temperature at any location along the wall was predicted to decline only 47 K as one goes from one bundle to five. However, the peak chamber pressure also declined slowly, so that if one were to use multiple bundles, one could increase the charge weight somewhat. Under those circumstances, a predicted reduction of 40 K is achieved, at a cost of only 1 m/s muzzle velocity.

The fact that the muzzle velocity increases as one goes from one bundle to two is a real feature of the calculations, but it is not explained. Close examination of the calculations shows that the projectile in the two-bundle case "catches up and passes" the projectile in the one-bundle case rather late in the ballistic cycle.

B. Heating at the Origin of Rifling

The heating of the tube at the origin of rifling is perhaps even more important. Figure 2 examines the temperature versus time at the origin of rifling. Each curve starts at the time at which the front ends of the burning sticks passed the origin of rifling (and the calculated temperature jumps up into the range displayed on the figure). We see that there is a modest decline in the peak temperature as the number of bundles increases, and that only a 20 K decrease results from changing from one bundle of propellant sticks to five bundles. Worse, only a 11 K decrease results once one has increased the weight of the five-bundle charge to recoup ballistic performance. It appears that there is "no free lunch;" if performance is desired, these calculations suggest that heating is inevitable.

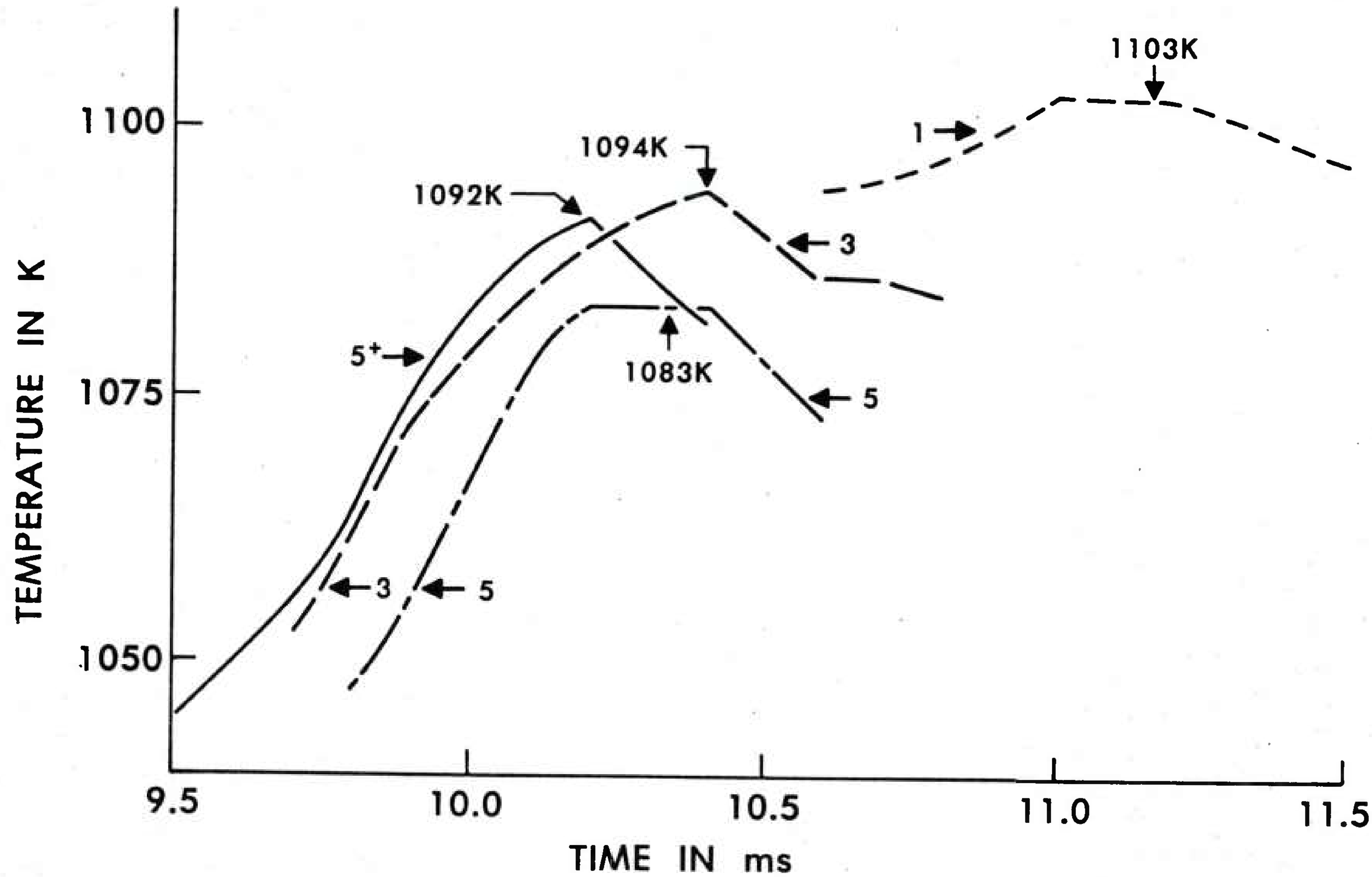

Figure 2. The Temperature at the Origin of Rifling. For One, Three, and Five Bundles of Propellant. The Maximum Temperature for Each Situation is Noted.

III. PREVIOUS CALCULATIONS

We had previously reported to the Navy[6] that increasing the number of bundles would increase the maximum chamber pressure. Those results were an artifact of the calculations peculiar to multiple bundles of sticks. For sticks, regions of ullage smaller than some user-definable threshold at the ends of the sticks are neglected in the calculation; the parameter that defines this threshold length for the ullage that may be neglected was too large. For multiple bundles, the total neglected ullage was non-negligible. The free volume in the calculation thus decreased significantly (several percent), and the chamber volume (predictably, in hindsight) increased. The calculations in this report supercede those earlier results.

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6. Letter to NOS/IH dated 10 June 1983, subject: Stick Propellant Technology for Naval Guns.

ACKNOWLEDGMENTS

This work has benefited from helpful conversations with and suggestions from A. W. Horst, P. S. Gough, F. W. Robbins, J. A. Birkett, S. E. Mitchell, and colleagues in the Interior Ballistics Division of the BRL.

REFERENCES

1. A. W. Horst, "A Comparison of Barrel-Heating Processes for Granular and Stick Propellant Charges," ARBRL-MR-03193, USA ARRADCOM, Ballistic Research Laboratory, Aberdeen Proving Ground, MD, August 1982 (AD A118 394).

2. P. S. Gough, "Extensions to NOVA Flamespread Modeling Capacity," PGA-TR-81-2, Paul Gough Associates, Inc., Portsmouth, NH, April 1981.

3. J. P. Holman, Heat Transfer, McGraw-Hill, 1968.

4. C. W. Nelson, "On Calculating Ignition of a Propellant Bed," ARBRL-MR-02864, USA ARRADCOM, Ballistic Research Laboratory, Aberdeen Proving Ground, MD, September 1978 (AD A062 266).

5. P. S. Gough, "The NOVA Code: A User's Manual. Volume I. Description and Use," IHCR 80-8, Naval Ordnance Station, Indian Head, MD, December 1980.

6. Letter to NOS/IH dated 10 June 1983, subject: Stick Propellant Technology for Naval Guns.

APPENDIX A

JCL AND DATA FOR ONE BUNDLE OF STICK PROPELLANT

```
GEK,STMFZ,T119,P1,MS300000.      N554ONE, INCREMENTAL STUDY
ACCOUNT,XXXXXX.                  1 INCREMENT, 30" LONG, 21.0# WT.
RFL(300000)
ATTACH,N,NUCPTSB,ID=GEK.
N,PL=20000.
*EOR
5/54 SLOTTED STICK CHARGE, 21.0# TOTAL CHARGE WT, ONE BUNDLE
TFFFTTT  1      1 1       01
   25  200    0 3000                      0.
1.0         234.75    0.0001    2.0       0.20      0.1       0.0002    0.0002
    6    2    2    5    0    2    1    1    0    0    0    5    0    0    0    0
550.        14.7      28.896    1.4
550.
M31A1E1,RADPE472129B1.0         31.0      21.0      0.060
    3 .260      .100      30.0      1.0       .01
50000.      1.0       50000.              0.5
100000.     .00290    .70       0.0       783.      0.0277    .0001345  .6
15446095. 22.187      1.2566    31.28
6303000.  36.13       1.25
0.          0.01
0.          0.99
10.         10.
10.         10.
0.0         2.552     1.754     2.688     5.80      2.742     32.52     2.61
 35.09      2.53      300.      2.53
35.09       1000.     37.17     1700.     39.12     3250.     40.09     1000.
300.        300.
4.102       0.0086    0.7       550.
35.09       70.       14.0      7.163
31.27       1.179     0.0                 9
34.52       0.0
0.0         0.0       .05       530.      .09       735.      .2        850.
0.312       870.      .4        970.      .504      1210.     .617      1870.
0.8         100000.
2.          17.       23.5      27.       35.
```

APPENDIX B
JCL AND DATA FOR TWO BUNDLES OF STICK PROPELLANT

```
GEK,STMFZ,T119,P1,MS300000.       N554TWO, INCREMENTAL STUDY
ACCOUNT,XXXXXX.                   2 INCREMENTS, 15" LONG, 10.5# EA
RFL(300000)
ATTACH,N,NUCPTSB,ID=GEK.
N,PL=20000.
*EOR
 5/54 SLOTTED STICK CHARGE, 21.0# TOTAL CHARGE WT, TWO BUNDLES
TFFFTTT  1     1 1      01
   25    5    0 3000           .0001
1.0        234.75    0.0001    2.0       0.20      0.01      0.0002    0.0002
    6    2    2    5    0    2    1    1    0    0    0    5    0    0    0    1
550.       14.7      28.896    1.4
550.
M31A1E1,RADPE472129B1.0        16.0      10.5      0.060
16.0       31.0      10.5
    3 .260     .100      15.0      1.0       .01
50000.     1.0       50000.              0.5
100000.    .00290    .70       0.0       783.      0.0277    .0001345  .6
15446095.  22.187    1.2566    31.28
6303000.   36.13     1.25
0.         0.01
0.         0.99
10.        10.
10.        10.
0.0        2.552     1.754     2.688     5.80      2.742     32.52     2.61
 35.09     2.53      300.      2.53
35.09      1000.     37.17     1700.     39.12     3250.     40.09     1000.
300.       300.
4.102      0.0086    0.7       550.
35.09      70.       14.0      7.163
31.27      1.179     0.0                 9
34.52      0.0
0.0        0.0       .05       530.      .09       735.      .2        850.
0.312      870.      .4        970.      .504      1210.     .617      1870.
0.8        100000.
2.         17.       23.5      27.       35.
```

APPENDIX C

JCL AND DATA FOR THREE BUNDLES OF STICK PROPELLANT

```
GEK,STMFZ,T119,P1,MS300000.      N554THR, INCREMENTAL STUDY
ACCOUNT,XXXXXX.                  3 INCREMENTS, 10" LONG, 7.0# EA
RFL(300000)
ATTACH,N,NUCPTSB,ID=GEK.
N,PL=20000.
*EOR
 5/54 SLOTTED STICK CHARGE, 21.0# TOTAL CHARGE WT, THREE BUNDLES
TFFFTTT  1     1 1      01
   25  200    0 3000           .0001
1.0       234.75    0.0001    2.0       0.20      0.01      0.0002    0.0002
    6    2    2    5    0    2    1    1    0    0    0    5    0    0    0    2
550.      14.7      28.896    1.4
550.
M31A1E1,RADPE472129B1.0       11.0      7.00      0.060
11.0      21.0      7.00
21.0      31.0      7.00
    3 .260     .100      10.0      1.0       .01
50000.    1.0       50000.              0.5
100000.   .00290    .70       0.0       783.      0.0277    .0001345  .6
15446095. 22.187    1.2566    31.28
6303000.  36.13     1.25
0.        0.01
0.        0.99
10.       10.
10.       10.
0.0        2.552     1.754     2.688     5.80      2.742     32.52     2.61
 35.09     2.53      300.       2.53
35.09      1000.     37.17     1700.     39.12     3250.     40.09     1000.
300.       300.
4.102     0.0086    0.7       550.
35.09     70.       14.0      7.163
31.27     1.179     0.0                 9
34.52     0.0
0.0        0.0       .05       530.      .09       735.      .2        850.
0.312      870.      .4        970.      .504      1210.     .617      1870.
0.8        100000.
2.         17.       23.5      27.       35.
```

APPENDIX D

JCL AND DATA FOR FOUR BUNDLES OF STICK PROPELLANT

```
GEK,STMFZ,T119,P1,MS300000.      N554FOU, INCREMENTAL STUDY
ACCOUNT,XXXXXX.                  4 INCREMENTS, 7.5" LONG, 5.25# EA
RFL(300000)
ATTACH,N,NUCPTSB,ID=GEK.
N,PL=20000.
*EOR
 5/54 SLOTTED STICK CHARGE, 21.0# TOTAL CHARGE WT, FOUR BUNDLES
TFFFTTT  1     1 1       01
   30    5    0 3000
1.0        234.75    0.0001    2.0       0.20      0.1       0.0002    0.0002
    6    2    2    5    0    2    1    1    0    0    0    5    0    0    0    3
550.       14.7      28.896    1.4
550.
M31A1E1,RADPE472129B1.0        8.50      5.25      0.060
8.50       16.0      5.25
16.0       23.5      5.25
23.5       31.0      5.25
    3 .260      .100      7.50      1.0       .01
50000.     1.0       50000.              0.5
100000.    .00290    .70       0.0       783.      0.0277    .0001345  .6
15446095.  22.187    1.2566    31.28
6303000.   36.13     1.25
0.         0.01
0.         0.99
10.        10.
10.        10.
0.0        2.552     1.754     2.688     5.80      2.742     32.52     2.61
 35.09     2.53      300.      2.53
35.09      1000.     37.17     1700.     39.12     3250.     40.09     1000.
300.       300.
4.102      0.0086    0.7       550.
35.09      70.       14.0      7.163
31.27      1.179     0.0                 9
34.52      0.0
0.0        0.0       .05       530.      .09       735.      .2        850.
0.312      870.      .4        970.      .504      1210.     .617      1870.
0.8        100000.
2.         17.       23.5      27.       35.
```

APPENDIX E

JCL AND DATA FOR FIVE BUNDLES OF STICK PROPELLANT

```
GEK,STMFZ,T119,P1,MS300000.       N554FIV, INCREMENTAL STUDY
ACCOUNT,XXXXXX.                   5 INCREMENTS, 6" LONG, 4.2# EA
RFL(300000)
ATTACH,N,NUCPTSB,ID=GEK.
N,PL=20000.
*EOR
 5/54 SLOTTED STICK CHARGE, 21.0# TOTAL CHARGE WT, FIVE BUNDLES
TFFFTTT  1     1 1      01
   25  200    0 3000
1.0        234.75    0.0001    2.0       0.20      0.1       0.0002    0.0002
    6    2    2    5    0    2    1    1    0    0    0    5    0    0    0    4
550.       14.7      28.896    1.4
550.
M31A1E1,RADPE472129B1.0        7.00      4.20      0.060
7.0        13.0      4.20
13.0       19.0      4.20
19.0       25.0      4.20
25.0       31.0      4.20
    3 .260     .100      6.0       1.0       .01
50000.     1.0       50000.              0.5
100000.    .00290    .70       0.0       783.      0.0277    .0001345  .6
15446095.  22.187    1.2566    31.28
6303000.   36.13     1.25
0.         0.01
0.         0.99
10.        10.
10.        10.
0.0        2.552     1.754     2.688     5.80      2.742     32.52     2.61
 35.09     2.53      300.      2.53
35.09      1000.     37.17     1700.     39.12     3250.     40.09     1000.
300.       300.
4.102      0.0086    0.7       550.
35.09      70.       14.0      7.163
31.27      1.179     0.0                 9
34.52      0.0
0.0        0.0       .05       530.      .09       735.      .2        850.
0.312      870.      .4        970.      .504      1210.     .617      1870.
0.8        100000.
2.         17.       23.5      27.       35.
```

APPENDIX F

JCL AND DATA FOR FIVE BUNDLES OF STICK PROPELLANT WITH PROPELLANT WEIGHT INCREASED TO MATCH BALLISTICS OF ONE-BUNDLE CASE

```
GEK,STMFZ,T119,P1,MS300000.       N554FIX, INCREMENTAL STUDY
ACCOUNT,XXXXXX.                   5 INCREMENTS, 4" LONG, 4.2485# EA
RFL(300000)
ATTACH,N,NUCPTSB,ID=GEK.
N,PL=20000.
*EOR
 5/54 SLOTTED STICKS, 21.2425# TOTAL, 5 BUNDLES, 4" LONG
TFFFTTT  1      1 1      01
   25  200    0 5000          .001
1.0       234.75    0.0001    2.0       0.20      0.01      0.0002    0.0002
    6    2    2    5    0    2    1    1    0    0    0    5    0    0    0    4
550.      14.7      28.896    1.4
550.
M31A1E1,RADPE472129B1.0       5.00      4.2485    0.060
5.0       9.0       4.2485
9.0       13.0      4.2485
13.0      17.0      4.2485
17.0      21.0      4.2485
    3 .260     .100      4.0       1.0       .01
50000.    1.0       50000.              0.5
100000.   .00290    .70       0.0       783.      0.0277    .0001345  .6
15446095. 22.187    1.2566    31.28
6303000.  36.13     1.25
0.        0.01
0.        0.99
10.       10.
10.       10.
0.0        2.552     1.754     2.688     5.80      2.742     32.52     2.61
 35.09     2.53      300.      2.53
35.09      1000.     37.17     1700.     39.12     3250.     40.09     1000.
300.       300.
4.102     0.0086    0.7       550.
35.09     70.       14.0      7.163
31.27     1.179     0.0                 9
34.52     0.0
0.0        0.0       .05       530.      .09       735.      .2        850.
0.312      870.      .4        970.      .504      1210.     .617      1870.
0.8        100000.
2.         17.       23.5      27.       35.
```

5/54 SLOTTED STICKS, 21.2425# TOTAL, 5 BUNDLES, 4" LONG

NUCPTS VERSION NUMBER 2.25

CONTROL DATA

LOGICAL VARIABLES:
PRINT T   GRAPH F   DISK WRITE F   DISK READ F
I.B. TABLE T   FLAME TABLE T   PRESSURE TABLE(S) T
EROSIVE EFFECT 0   DYNAMIC EFFECT 0   WALL TEMPERATURE CALCULATION 1
LEFT HAND BOUNDARY CONDITION 0   RIGHT HAND BOUNDARY CONDITION 0   LEFT HAND RESERVOIR 0
RIGHT HAND RESERVOIR 0   BED PRECOMPRESSED 0
HEAT LOSS CALCULATION 1   INSULATING LAYER 0

BORE RESISTANCE FUNCTION 1
EXPLICIT COMPACTION WAVE 0 MUZZLE BLOWDOWN ANALYSIS 0

CALCOMP PLOTS, OPTION 0

SOLUTION METHOD 1

INTEGRATION PARAMETERS

NUMBER OF STATIONS AT WHICH DATA ARE STORED	25
NUMBER OF STEPS BEFORE LOGOUT	1
TIME STEP FOR DISK START	0
NUMBER OF STEPS FOR TERMINATION	5000
TIME BEFORE PRINTOUT	.1000E-02
PRESSURE RATIO FOR LP ANALYSIS OF LARGE ULLAGE REGION (N.B., DEFAULT IS 0.2, TEST SUPPRESSED FOR VALUES LARGER THAN 10)	.2000
TIME FOR TERMINATION (SEC)	1.000
PROJECTILE TRAVEL FOR TERMINATION (INS)	234.75
MAXIMUM TIME STEP (SEC)	.1000E-03
STABILITY SAFETY FACTOR	2.00
SOURCE STABILITY FACTOR	.2000
SPATIAL RESOLUTION FACTOR	.0100
TIME INTERVAL FOR I.B. TABLE STORAGE(SEC)	.2000E-03
TIME INTERVAL FOR PRESSURE TABLE STORAGE (SEC)	.2000E-03

FILE COUNTERS

NUMBER OF STATIONS TO SPECIFY TUBE RADIUS	6		
NUMBER OF TIMES TO SPECIFY PRIMER DISCHARGE	2		
NUMBER OF POSITIONS TO SPECIFY PRIMER DISCHARGE	2		
NUMBER OF ENTRIES IN BORE RESISTANCE TABLE	5		
NUMBER OF ENTRIES IN WALL TEMPERATURE TABLE	0		
NUMBER OF ENTRIES IN FILLER ELEMENT TABLE	2		
NUMBER OF TYPES OF PROPELLANTS	1		
NUMBER OF BURN RATE DATA SETS	1		
NUMBER OF ENTRIES IN VOID FRACTION TABLE(S)	0	0	0
NUMBER OF ENTRIES IN PRESSURE HISTORY TABLES	5		
NUMBER OF ENTRIES IN LEFT BOUNDARY SOURCE TABLE	0		
NUMBER OF ENTRIES IN RIGHT BOUNDARY SOURCE TABLE	0		
NUMBER OF WALL STATIONS FOR INVARIANT EMBEDDING	0		
NUMBER OF BED STATIONS FOR INVARIANT EMBEDDING	0		

GENERAL PROPERTIES OF INITIAL AMBIENT GAS

INITIAL TEMPERATURE (DEG.R)	550.0
INITIAL PRESSURE (PSI)	14.7
MOLECULAR WEIGHT (LBM/LBMOL)	28.896
RATIO OF SPECIFIC HEATS	1.4000

```
              GENERAL PROPERTIES OF PROPELLANT BEO

INITIAL TEMPERATURE (DEG.R)                                  550.0
VIRTUAL MASS COEFFICIENT FOR MOMENTUM TRANSFER (-)           0.000
VIRTUAL MASS COEFFICIENT FOR ENERGY DISSIPATION              0.000
VOID FRACTION PACKING COEFFICIENTS                          0.0000      0.0000      0.0000
MINIMUM IMPACT VELOCITY FOR EXPLICIT COMPACTION
                              WAVE (IN/SEC)            100000000.
```

PROPERTIES OF PROPELLANT 1

PROPELLANT TYPE	M31A1E1,RADPE472129B
MASS OF PROPELLANT (LBM)	21.2425
DENSITY OF PROPELLANT (LBM/IN**3)	.0600
FORM FUNCTION INDICATOR	3
OUTSIDE DIAMETER (INS)	.2600
INSIDE DIAMETER (INS)	.1000
LENGTH (INS)	4.0000
NUMBER OF PERFORATIONS	1.
SLOT WIDTH(IN)	.01000

RHEOLOGICAL PROPERTIES

SPEED OF COMPRESSION WAVE IN SETTLED BED (IN/SEC)	50000.
SETTLING POROSITY	1.0000
SPEED OF EXPANSION WAVE (IN/SEC)	50000.
POISSON RATIO (-)	.5000

SOLID PHASE THERMOCHEMISTRY

MAXIMUM PRESSURE FOR BURN RATE DATA (LBF/IN**2)	100000.
BURNING RATE PRE-EXPONENTIAL FACTOR (IN/SEC/PSI**BN)	.2900E-02
BURNING RATE EXPONENT	.7000
BURNING RATE CONSTANT (IN/SEC)	0.0000
IGNITION TEMPERATURE (DEG.R)	783.0
ARRHENIUS ACTIVATION ENERGY (LBF-IN/LBMOL)	.0
FREQUENCY FACTOR (SEC**-1)	.0
THERMAL CONDUCTIVITY (LBF/SEC/DEG.R)	.2770E-01
THERMAL DIFFUSIVITY (IN**2/SEC)	.1345E-03
EMISSIVITY FACTOR	.600

GAS PHASE THERMOCHEMISTRY

CHEMICAL ENERGY RELEASED IN BURNING(LBF-IN/LBM)	.15446E+08
MOLECULAR WEIGHT (LBM/LBMOL)	22.1870
RATIO OF SPECIFIC HEATS	1.2566
COVOLUME	31.2800
FLAME TEMPERATURE [BACK-CALCULATED]	2640.
IMPETUS [FT-LB/LB]	330289.

LOCATION OF PACKAGE(S)

PACKAGE	LEFT BODY(INS)	RIGHT BODY(INS)	MASS(LBM)
1	1.000	5.000	4.249
2	5.000	9.000	4.249
3	9.000	13.000	4.249
4	13.000	17.000	4.249
5	17.000	21.000	4.249

PROPERTIES OF PRIMER

CHEMICAL ENERGY RELEASED IN BURNING(LBF-IN/LBM)	.6303E+07
MOLECULAR WEIGHT (LBM/LBMOL)	36.1300
RATIO OF SPECIFIC HEATS	1.2500
SPECIFIC VOLUME OF SOLID(IN**3/LBM)	0.0000
FLAME TEMPERATURE [BACK-CALCULATED]	1709.
IMPETUS [FT-LB/LB]	131313.

PRIMER DISCHARGE FUNCTION (LBM/IN/SEC)

POS.(INS)	0.00	.99
TIME(SEC)		
0.	10.00	10.00
.100E-01	10.00	10.00

PARAMETERS TO SPECIFY TUBE GEOMETRY

ISTANCE(IN)	RADIUS(IN)
0.000	2.552
1.754	2.688
5.800	2.742
32.520	2.610
35.090	2.530
300.000	2.530

CHAMBER VOLUME (IN**3) 786.101

BORE RESISTANCE TABLE

POSITION (INS)		RESISTANCE (PSI)
REL TO BREECH	REL TO TRAVEL	
35.090	0.000	1000.
37.170	2.080	1700.
39.120	4.030	3250.
40.090	5.000	1000.
300.000	264.910	300.

THERMAL PROPERTIES OF TUBE

THERMAL CONDUCTIVITY (LBF/SEC/DEG.R)	4.102
THERMAL DIFFUSIVITY (IN**2/SEC)	.8600E-02
EMISSIVITY FACTOR	.700
INITIAL TEMPERATURE (DEG.R)	550.00

PROJECTILE AND RIFLING DATA

INITIAL POSITION OF BASE OF PROJECTILE(INS)	35.090
MASS OF PROJECTILE (LBM)	70.000
POLAR MOMENT OF INERTIA (LBM-IN**2)	14.000
ANGLE OF RIFLING (DEG)	7.163

FILLER ELEMENT DATA

ELEMENT	POSITION INS	MASS LBM	RESISTANCE LBF	TYPE	NO.DATA
1	31.270	1.179	0.000	0	9
2	34.520	0.000	0.000	0	0

STRESS-STRAIN DATA FOR ELEMENT NO. 1

STRAIN IN/IN	PRESSURE LBF/IN**2
0.000	0.000
.050	530.000
.090	735.000
.200	850.000
.312	870.000
.400	970.000
.504	1210.000
.617	1870.000
.800	100000.000

POSITIONS FOR PRESSURE TABLE STORAGE

2.0000 17.0000 23.5000 27.0000 35.0000

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