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TECHNICAL REPORT BRL-TR-2829

IBHVG2 -- A USER'S GUIDE

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JULY 1987

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## Errata Sheet for BRL-TR-2829, "IBHVG2 -- A USER'S GUIDE"

- | Page | Description  |
|------|--|
| 41   | After equation (A.14), reference to 'Figure 6' should be 'Figure 7'  |
| 43   | Section C, first paragraph, last sentence: "...tube-based frame of reference (Figure 6), where $z_p \approx x_p + x_r$ , is as follows."                           |
| 49   | Equation (D.18) should be:<br>$A_w = \left[ \frac{V_c}{A_b} \right] \pi D_b + 2A_b + \pi D_b [z_p - z_p(0)]$   |
|      | Equation (D.21) should be:<br>$\bar{v} = \frac{\dot{z}_p}{2}$  |
| 50   | Section E, third paragraph, second sentence: "These codes solve for surface area and unburned volume for the different grain types..."                             |
| 55   | Subscript definitions, last line should have " 0 " (zero) instead of " $\phi$ " (phi)  |
| 58   | Graph at bottom of page should have following axis labels:<br>Horizontal axis      "Depth Burned (in)"<br>Vertical axis          "Surface Area (in <sup>2</sup> )" |
| 61   | Appendix D, first paragraph, end of third sentence: "...integration step size (DELT in the \$INFO deck)."  |
| 62   | Appendix E, third paragraph, second sentence: "...case 5 took more time to compute on the Cray and the PC than..."   |
| 73   | Test Case 2, second paragraph, end of fourth sentence: "...\$TRAJ, and \$INFO decks, and the graph at the end of Appendix B.)"                                     |

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19. ABSTRACT (Continue on reverse if necessary and identify by block number) <p>IBHVG2, which stands for "Interior Ballistics of High Velocity Guns, version 2," is a lumped-parameter, interior ballistic computer code. The code, which was developed at the BRL, is an updated version of the classic Baer-Frankle interior ballistic code. IBHVG2 is used for calculation of interior ballistic trajectories, including gas pressure, projectile displacement and projectile velocity as a function of time. The code treats both regular and dented propellants. It contains powerful variational and searching capabilities, so that it can, for example, search and find the "best" propellant dimensions, given the maximum allowable gas pressure.</p> <p>This report thoroughly documents IBHVG2, so that all of its many features can be used effectively. The report contains a detailed description of the range of possible user input and a description of both the algorithms embodied along with the FORTRAN subroutines which implement them. There are also complete examples of input and output from the code. Although the code has been written to be as generally applicable as possible, the report has a short section describing modifications that are necessary to enable the code to run on various computers and compiler combinations. A machine-readable copy of the code can be obtained by contacting the authors of this report.</p>			
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## I. INTRODUCTION

The efficient design of large caliber guns and their corresponding charges requires an accurate simulation of the interior ballistic cycle. Simple lumped-parameter models are usually sufficient to predict the gross ballistic variables such as chamber pressure and projectile velocity to precision rivaling experimental capabilities. This accomplishment allows ballisticians to focus on experiments which either validate the models or are used to extend the modeling effort. Since computer simulation is very inexpensive in relation to experimental testing, once it has been established that the model corresponds to actual firings, the designer can try out many different ideas under a variety of circumstances. The net result is a superior round at minimum cost.

This report describes one such code which is widely used in the interior ballistics community. IBHVG2, which stands for "Interior Ballistics of High Velocity Guns, version 2", was developed by describing the ballistic events as a set of ordinary differential equations which are solved by marching forward in time. One feature which has helped to popularize the code is its flexible method of inputting user options, allowing the designer to focus his energies on the ballistics instead of the computer programming aspects. Past experience suggests that IBHVG2 is general enough to investigate most gun/charge scenarios without any modifications to the computer algorithms.

Most useful computer codes are the product of evolution and IBHVG2 is no exception. The basic principles are described in the well-known Baer-Frankle report[1]. IBHVG1, which was written by Robert Deas of BRL, is essentially the Baer-Frankle methodology written in FORTRAN with an improved user-interface. Some ideas were also borrowed from MPRGUN written by Paul Baer, also of BRL. In 1981, mission requirements dictated that a new code be written which would properly model deterred propellants and provide a better description of heat transfer to the gun tube. Franz Lynn was the sole author of the coding efforts, although numerous discussions among the scientists in the Interior Ballistic Division of BRL helped shape the final form and goals. Development ceased after his untimely death in 1983.

The basic operation of the code is quite simple. From a sufficient description of the gun system and its propelling charge, IBHVG2 can simulate the burning of the primer and propellant while computing the time trace of a variety of variables to include: mean gas pressure and temperature of the gun chamber, acceleration and velocity of the projectile, and the mass fraction of each unburned propellant. One of the advanced features of the code is the ability to automatically vary its inputs for a new simulation in an iterative fashion. This is very useful for charge design work. As an illustration, the ballisticians could fix the maximum allowable gun tube pressure and require the code to vary some characteristic of a specific propellant (say, the grain web size) until the goal is attained. Such iterations can, in turn, be nested. Extending our example, one may desire to meet the target pressure while optimizing on the exit velocity of the projectile by varying another propellant characteristic. Detailed examples are included in Appendix E to serve as a guide to the reader and to demonstrate the versatility of the code.

Figures 1 and 2 are included to demonstrate the correspondence between range firing data and IBHVG2 simulations. The data come from a series of experiments investigating short, slotted sticks (25-mm) fired in a 155-mm howitzer (see reference [2]). They are representative of results one would expect for granular charges in a large caliber weapon. The input for computer simulation is based on propellant data obtained from closed-bomb experiments and

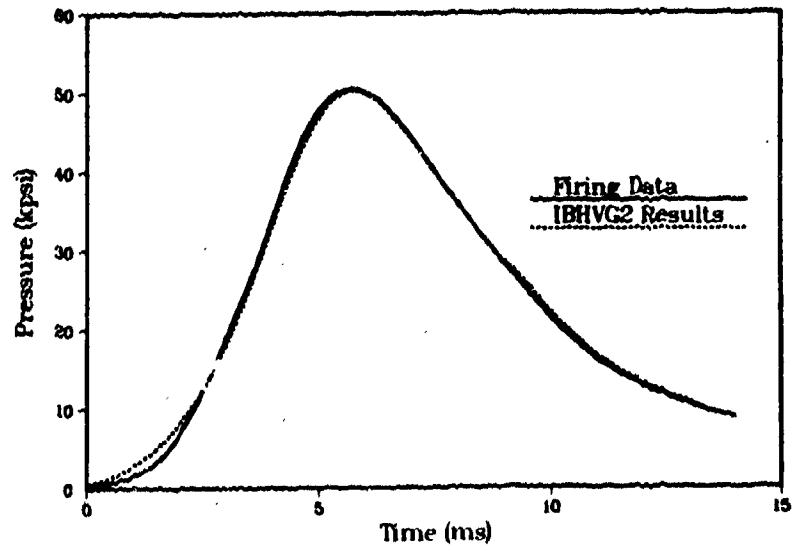


Figure 1. Comparison of Pressure Histories

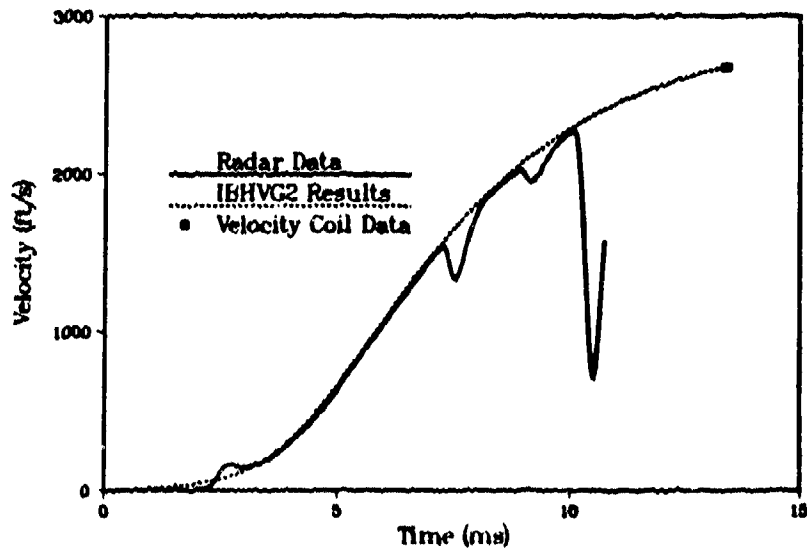


Figure 2. Comparison of Velocity Histories

the projectile resistance profile corresponds to previously recorded measurements for a M101 projectile. That is to say, there was no curve fitting since there are no free parameters; all input data either involved direct physical measurements or were obtained by independent experiments.

As one can see, the comparison of range data with an IBHVG2 simulation is reasonably good. Both the pressure and velocity histories appear to be within the experimental error of the measurements. This point is worth some elaboration. In these firings there are two sets of measurement records to estimate variance. One consists of time traces from redundant transducers of the same event such as two pressure gages at the same axial distance of the gun tube. The other involves measurements from repeated, but equivalent, firings. Both sets are useful for different reasons. The former gives quantitative information about transducer and measurement error, while the latter provides insight about reproducibility of the experiment.

One should note that the time origin for the firing data is arbitrary; therefore, to aid in the comparison, the origin of the data is adjusted such that the maximum pressure occurs at the same time as the simulation. Using this technique, the pressure simulation falls within the experimental uncertainty of the range data (pooled standard deviation of about 0.4 kpsi) with the exception of the first 2.5 ms. This region is of interest because it describes the portion of the interior ballistic event least understood.

There is a strong temptation to explain the disparity to the fact that IBHVG2 simulates the propellant burning uniformly, whereas, experiments have demonstrated that flamespreading is neither complete nor instantaneous immediately after ignition. Presumably, this would cause the pressure to initially lag behind the computed result. Examination of various transducer channels suggest another factor to be considered. It is common to observe two separate channels with results in excellent agreement everywhere except the first millisecond or so. This behavior could be attributed to slight variations in the individual pressure ports (sometimes described as "plugging") or it could be a manifestation of the finite dynamic response of the transducers. Pressure transducers for the study of ballistics are calibrated and chosen based on accuracy from static tests and linearity over the range; frequency response is of secondary importance. In summary, it is not clear which plays the most significant role, but it is obvious that this region contains the most uncertainty. The key point is that for early times IBHVG2 pressures tend to exceed those recorded on the firing range.

The velocity comparison shows two independent measurements from the range. The solid curve is obtained from Doppler radar where the time origin is the same as obtained for the pressure comparison described above. The oscillation exhibited prior to projectile exit is an artifact of the technique. The signal appears to have been severely attenuated, probably because this round had some blow-by gases which were absorbing the radiation. The bump at 2.5 ms should also be disregarded. This is typical of Doppler measurements due to the difficulty of discerning a velocity of a slow moving object. The star marks the velocity recorded independently via velocity coils near the gun muzzle. The time coordinate is arbitrary, but the velocity value is precise to within 0.2 percent (based on the pooled variance of 12 shots). The IBHVG2 estimate for muzzle velocity falls inside this bound.

While writing this report, we expected just to include a comparison from any former experiment. To our surprise, it appears that experimental curves are seldom compared to IBHVG2 simulations, although virtually all gun firings are preceded by some lumped-parameter calculation. Most investigations just compare the maximum pressure and the muzzle velocity. In the hands of an experienced ballisticians this may be sufficient. However, the primary reason for not comparing the curves is due to the difficulty of getting the range data and the



simulation results in a suitable format and on the same computer. It is the sincere hope of the authors that this will no longer be an obstacle. The code is now sufficiently portable to be run on most any computer with a FORTRAN compiler. As demonstrated in Appendix E, a single simulation can be executed on a microcomputer on the order of a minute. Therefore, it would be reasonable to run the code on the same computer which does the data acquisition. Then a comparison can be established immediately after the firing. It is clear that the best time to reconcile or verify a discrepancy is soon after the experiment when all the details are fresh.

Such an arrangement could have advantages beyond convenience. If the curves match as well as the one shown in this report over a wide range of ammunition, the simulation could almost be used as a quality control mechanism. Any significant deviations would signal a serious problem with either the experiment or what the user perceives as correct input. If, on the other hand, the curves do not match as well with some rounds as others, then we will have identified some new research issues. Documenting problem cases would, at the very minimum, aid future simulation efforts. Regardless, we predict a synergistic effect if some modeling is shifted to those who actually do the firing.

This report is designed to be both an introduction and a user's guide to IBHVG2. The first section is a complete reference manual for the construction of the user input decks. It is followed by a short description of each FORTRAN subroutine found in the code. The third section describes the ordinary differential equations and the constitutive relations used to create the code. Both the physics and the mathematical assumptions are briefly discussed. The remainder of the report describes issues about executing the code to include some examples.

This documentation is essentially an attempt to pull together much of the information known about the IBHVG2 code and put it in one place for the convenience of the user. The fact that both authors are novices at using the code probably served as an advantage. More times than we care to recount, one of us had to seek out an advanced user to understand something about the folklore or discover some fact which was "common knowledge" in using the code. Undoubtedly, in the process we have absorbed some information which now makes sense to us, but is not clearly stated in this report. Familiarity has a tendency to obscure subtle understandings. When the reader uncovers such failures, we would appreciate hearing from you so it can be corrected for a future guide. Comments about useful additions or omissions are also encouraged.

## II. DESCRIPTION OF INPUT DECKS

### A. Syntax Rules

Input data stream for IBHVG2 consists of a series of "decks." The start of each deck is demarcated by a line starting with a "\$" in the first column and followed by a four letter mnemonic. All lines of input data between decks should in principle be closely related ballistic parameters.

Inputs are free format in that more than one can be included per line. Comments may be incorporated by preceding them with a "\$" in any column other than the first. The formats are

$$\text{variable} = \text{value}$$

for ordinary unsubscripted variables and

$$\text{variable} (\text{sub}) = \text{value}_1, \dots, \text{value}_n$$

for subscripted variables, with commas and/or blanks between consecutive variable/value constructs. Integer and real formats are legal for all numerical values. Character strings must be delimited with either apostrophes or quotes. All keywords, to include deck cards and variable names, must be in uppercase.

The first blank between consecutive variable/value fields is the legal delimiter; any additional ones are ignored. Blanks embedded in variable names, subscripts, or numeric values are significant but illegal. Leading blanks in character strings are squeezed out.

An omitted "(sub)" in a subscripted variable is taken to be 1. Consecutive values fill locations sub, sub+1, sub+2, etc., while pairs of commas with nothing or blanks between them advance to the next subscript (i.e., a subscript is skipped over). All character variables default to blank strings while numerical variables default to either zero or a convenient value listed below. If a variable is multiply-defined, the last input overrides all previous ones. All syntax errors are flagged. A list of all valid deck names follows as well as descriptions of all variables within each deck.

## B. Decks

### SCOMM

All cards between a \$COMM and the next deck card are ignored to allow the tagging of a data input file with user comments.

### SEND

This control card signifies end-of-input for the current case. IBHVG2 will then execute. Afterwards, it will start reading the next card, if any. This is to allow the processing of other runs or for the code itself to generate runs internally. An end-of-input condition for a user's input deck is processed as if the \$END card was read in. *A frequent mistake by novice users is to include the \$END and follow it by a blank line. The code assumes this is another run and proceeds to produce errors due to insufficient information.*

### \$FIND

For inputs to a general variation-and-search utilizing function minimization techniques (see reference [6] for algorithm). Up to six \$FIND decks may be submitted in one run allowing a variation in six dimensions. A list of additional option variables for outputting is found at the end of this section.

VARY	name of parameter including any subscript
DECK	name of deck containing parameter; 4 characters max; may not be PARA, PDIS, FIND, PMAX, or TDIS
NTH	number of deck if there are several with same name (default = 1)
FROM	initial value of parameter in proper units
EPS	error tolerance
OUTV	name of desired output variable from run completion variables (see end of this section)
CODE	0 to achieve desired value of OUTV variable 1 to maximize OUTV variable
VAL	desired value if CODE is 0, else ignored
MULT	multiplier for function-minimizer residual (default = 1.0)
MIN	min allowable value of VARY parameter (default = 0.0)
MAX	max allowable value of VARY parameter (default = 1.0E+10)

## \$GUN

For variables related to gun-tube geometry, namely:

NAME TYPE	name of gun; 28 characters max
CHAM CV CVOL	chamber volume [ <i>in</i> <sup>3</sup> ]
GRVE	groove diameter [ <i>in</i> ]
LAND	land diameter [ <i>in</i> ]
TRAV LENG	travel to shot-exit [ <i>in</i> ]
G/L	ratio of groove to land surface area; smooth-bore if G/L=0 (default)
TWST	rifling twist [ <i>calibers /turn</i> ]
LOPT	0 [default] to ignore LDEN 1 to calculate CHAM from total charge weight and LDEN 2 to calculate total charge weight from CHAM and LDEN; primer & charge weights must be specified; they are scaled proportionally to sum to required total charge weight
LDEN	ratio total charge weight/chamber volume [ <i>g /cm</i> <sup>3</sup> ]; used when LOPT = 1 or 2 (default = 0.2) <i>CAUTION: LDEN calculations are done after C/M (which may have altered charge weights) used.</i>
CLEN	effective chamber length [ <i>in</i> ] for scaling in-chamber pressure gauge locations (default = CV/bore area)
NGAG	number of gauge locations (default = 0 max = 30)
GLOC	gauge location array of size NGAG [ <i>in</i> ] (default = 0.0). Dis- tance is measured (+) downtube from the breech or (-) into chamber from the initial position of the projectile base. <i>CAUTION: IBHVG2 will discard duplicate or out-of-range values and will rearrange distances in ascending order, if neces- sary. This should be kept in mind when using, for example, a \$SAVE deck--the position you reference may not be the one the computer code decided upon.</i>

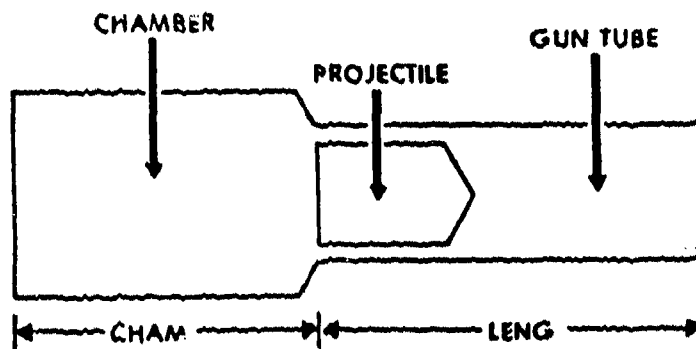
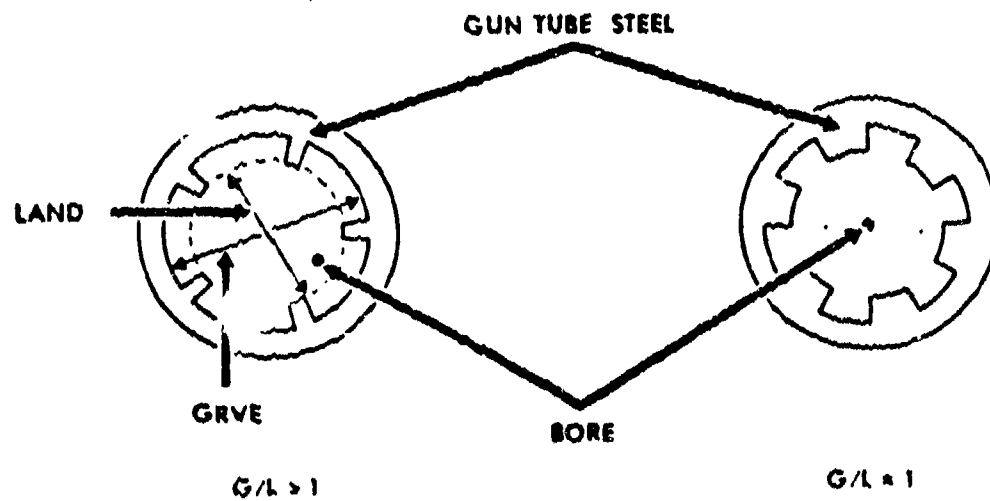


Figure 3 Gun Parameters

## SHEAT

For heat-loss-related variables, namely:

TSHL	tube shell thickness for heat sink [in] [default = 0.004]
CSHL	shell specific heat [ $in-lb_f/lb_m-K$ ] covering a broad range of steels [default = 1848.0]
RSHL	shell material density [ $lb_m/in^3$ ] [default = 0.284]
TWAL	initial wall temperature [K] [default = 293.0]
H0	free convective heat transfer coefficient for air in the tube [ $in-lb_f/in^2-sec-K$ ] [default = 0.0648]
HL	0 to ignore heat losses in energy balance 1 [default] to include heat losses

## SINFO

For run-related inputs. The variables are:

DELT	max integration time step [sec] [default = 0.0001]
DLPF	1 [default] for DELP in units of time [sec] 2 for DELP in units of projectile travel [in]
DELP	integrator logout & print step [sec] or [in]; reset to DELT if DLPF = 1 and DELP < DELT
SOFT	0 to suppress file storage of run output [default] 1 to write trajectory data for each run into output file STORE for post-processing 2 to write only single-line summaries for each parametric run into file STORE; ignored if non-parametric runs are being conducted
GRAD	1 for Lagrange gradient [default] 2 for Pidduck-Kent gradient
UNIT	unit system for output; not implemented yet, but will be a choice between 0 for SI and 1 for English

<b>POPT</b>	print option array of size 6 [all defaults = 1]. Detailed descriptions given below between the double bars:
<b>POPT(1)</b>	0 to suppress 1 to print input echo
<b>POPT(2)</b>	0 to suppress trajectory print 1 to print default trajectory variables 2 to print user-specified \$TDIS variables
<b>POPT(3)</b>	0 to suppress 1 to print IB summary
<b>POPT(4)</b>	0 to suppress blowdown calculation 1 to print blowdown phase (see reference [5], chapter 9) to include tube recoil when the recoil option is in effect (see \$RECO)
<b>POPT(5)</b>	0 to honor above print options for every run of parametric variation 1 to honor above print options for first run of parametric variation and print a single-line summary thereafter 2 like 1, but summary print variables supplied via \$PDIS specifications
<b>POPT(6)</b>	is currently unused
<b>RUN TITL</b>	run title on output pages; 48 character* max
<b>EPS</b>	max error for integrator time-step adjustment and transition tolerances [default = 0.002]
<b>CONP</b>	0 for usual non-constant-pressure run [default] 1 for run with constant pressure maintained by varying the burning rate of the single charge 2 for run with constant pressure maintained by varying the surface area of the single charge
<b>PRES</b>	desired constant breach pressure [psi] when CONP option is 1 or 2
<b>TOL</b>	error tolerance [psi] for PRES [default = 1.0]

## SPARA

For parametric variations; up to four \$PARA decks per run permit a four dimensional matrix to be systematically tried. The DECK must contain a nominal value of the variable to be VARY'd.

VARY	name of parametric variable including any subscript
DECK	name of deck containing variable; 4 chars max; may not be PARA, PDIS, FIND, PMAX, or TDIS
NTH	deck number if there is more than one (default = 1)
FROM	initial value of variable
TO	final value of variable
BY	increment/decrement value

## \$PDIS

Each deck defines one variable to be printed in lieu of the default set for each line of the parametric summary print. There can be up to 11 \$PDIS decks in effect: one for each variable printed for the interior ballistic cycle. Be sure to include the line POPT(5)=2 (print option) in the \$INFO deck. To write the summary information to a file attached to UNIT=7, include the line SOPT=2 in the \$INFO deck. (\$PDIS is similar to the \$TDIS deck). A list of additional option variables for outputting is found at the end of this section.

SHOW	name of variable to print; 4 chars max
DECK	name of deck containing the desired variable; any deck may be named except PARA, PDIS, FIND, and PMAX
NTH	number of deck if more than one (default = 1)
MULT	number to multiply data value by (default = 1.0)
DIV	number to divide data value by (default = 1.0)
REMI REMK	20 character remark string for titles and file STORE



## SPMAX

For variation of charge weight or web to achieve a desired maximum breech pressure. If web is varied, grain ratios rather than gr. in dimensions may be the better choices in the \$PROP deck concerned. The \$PROP deck must contain a nominal value of charge weight and web, even though one or the other will be varied in the \$PMAx operation. Note that a DECK='PROP' card is not needed in a \$PMAx; the program knows that it must be varying some propellant characteristic. If you include DECK='PROP', the program will complain but will still do the proper things.

VARY	variable name in a \$PROP deck including any subscript
NTH	number of \$PROP deck (default = 1)
TRY1	first value of VARY to try
TRY2	second value of VARY to try; third and subsequent guesses are based on interpolation. NOTE: the last two guesses from the previous run are employed as the first two guesses in second and subsequent \$PARA runs
PMAx	maximum breech pressure [psi] sought
EPS	error tolerance [psi] for PMAx; (default = 1.0)
LOOP	max number of tries before quitting (default = 20)
MIN	minimum allowable value of VARY parameter (default = 0.0)
MAX	maximum allowable value of VARY parameter (default = 1.0E+10)
NPMX	0 (default) if PMAx refers to the max breech pressure ever achieved during the run n where $n \in (1, 2, \dots, 5)$ if PMAx refers to the NPMX-th local breech pressure maximum achieved

## SPRIM

For primer data. The "primer" is considered completely burned at the start of integration. For this reason, it is considered wise to include only enough primer to reach sufficient pressurization to ignite the propelling charge. Real primers are usually modelled with IBHVG2 by simulating the function with both a \$PRIM and a \$PROP deck. A typical correspondence is 10% by weight for the \$PRIM and 90% as a \$PROP. Constant-pressure runs may include or exclude a primer. A primer is mandatory for conventional simulations.

NAME	name of primer; 28 characters max
TYPE	
GAMA	specific heat ratio
FORC	force [ $ft \cdot lb_f / lb_m$ ]
COV	covolume [ $in^3 / lb_m$ ]
TEMP	flame temperature [K]
CHWT	weight [ $lb_m$ ]
WT	
CHGW	
C	
CW	

**SPROJ**

For projectile-related variables.

<b>NAME TYPE</b>	projectile designation; 28 characters max
<b>PRWT WT</b>	projectile weight [ <i>lb<sub>m</sub></i> ]
<b>COPT</b>	0 [default] to ignore C/M 1 to calculate PRWT from total charge weight & C/M 2 to calculate total charge weight from PRWT & C/M; primer and all charge weights must be specified, but they will be scaled proportionally to sum to the required total charge weight
<b>C/M</b>	used when COPT=1 or 2; ratio of total charge weight and projectile weight [default = 1.0]
<b>SOPT</b>	0 [default] bypass PRWT calculation based on subprojectile parameters and sabot formula 1 find PRWT based on projectile weight estimation formula of Burns (see Reference [3]) 2 find PRWT based on same weight estimation formula using coefficients yielding 15% lighter sabot
<b>WTSP</b>	subprojectile weight [ <i>lb<sub>m</sub></i> ]
<b>LSP</b>	subprojectile length [ <i>in</i> ]
<b>DSP</b>	subprojectile diameter [ <i>in</i> ]
<b>PDES</b>	max design pressure [ <i>psi</i> ] for sabot projectile
<b>SABO</b>	sabot weight [ <i>lb<sub>m</sub></i> ]; not input—set by IBHVG2

**SPROP**

Defines a main propelling charge element. IBHVG2 will recognize up to five such decks and considers them independently (i.e., order is unimportant). The following are basic input variables most useful for describing homogeneous, undeterred grains:

NAME TYPE	name of propellant; 28 chars max
RHO DENS	density [ $lb_m/in^3$ ]
GAMA	specific heat ratio
FORC	force [ $ft-lb_f/lb_m$ ]
COV	covolume [ $in^3/lb_m$ ]
TEMP	flame temperature [K]
CHWT WT CHGW C CW	weight [ $lb_m$ ]
ALPH	burning rate $\approx \beta P^\alpha$ [ $in/s$ ] where $P$ is mean pressure [psi]
BETA	burning rate exponent, $\alpha$
EROS	erosive burning coefficient, empirical factor multiplied by projectile velocity [ $in/s$ ] to add to burning rate [default = 0.0]
GRAN FORM	granulation code chosen from 7PF (or 7P), 1PF (1P), CORD, RECT (SLAB), SPHR (BALL), SLOT, 37HX (37H), 19HX (19H), 19PF (19P), GEN, PIE (STAR), GHEX (HEX), MONO (see Appendix B)

WI WIN	inner web for cylindrical/hexagonal grains [ <i>in</i> ]
WO WOUT	outer web for cylindrical/hexagonal grains [ <i>in</i> ]
WM WMID	middle web for cylindrical/hexagonal grains [ <i>in</i> ]
WEB WB	common value of all inner, middle, and outer webs [ <i>in</i> ]; also resets WI/O
D DIAM GDIA	grain diameter, if applicable [ <i>in</i> ]
PD DP PDIA	perf diameter, if applicable [ <i>in</i> ] [default = 0]
SLOT	slot width in SLOT and PIE grains [ <i>in</i> ]
NSLT	number of diametral slots in PIE grain $\geq 2$
NRNG	number of concentric rings of perfs around central perf in HEX grains; $\geq 0$ [default = 2]
L GL LEN GLEN	grain length, if applicable [ <i>in</i> ]
WIDTH	grain width in RECT grains [ <i>in</i> ]
THCK	grain thickness in RECT grains [ <i>in</i> ]
NSUR	number of depth/surface pairs for GEN grain [default = 1, max = 10]
DEPB	depths-burned array [ <i>in</i> ] for GEN grains; ignored if NSUR = 1
SURF	surface area array [ <i>in</i> <sup>2</sup> ] for GEN grains
IGNC	code specifying charge ignition: 0 to ignite at start of integration [default] 1 to ignite at some time [ <i>s</i> ] 2 to ignite at some projectile travel [ <i>in</i> ] 3 to ignite at some mean pressure [ <i>psi</i> ] 4 to ignite at some Z (mass fraction burned) of the charge described by the previous SPROP deck

THRC	threshold value for ignition if IGNC > 0
IGNS	array of size 3 specifying ignition codes for the perf, end, and lateral grain surfaces, respectively; same codes as IGNC; ignored if IGNC > 0.0
THRS	array of threshold values for surface ignition
PA-B	0 [default] for standard treatment of charge; set automatically if grain has no perfs or if run has either constant-pressure option set 1 for perf-augmented burning of charge until grain fracture
DSCF	Robbins-Horst discharge coefficient in weight flux computation for perf-augmented burning model [default = 1.0] (see Reference [4])
FRAC	0 [default] for no user-defined grain fracture criterion of charge with PA-B = 1. <i>NOTE: web burn-through turns off perf-augmented burning.</i> 1 to specify pressure-difference grain fracture threshold for charge with PA-B = 1. <i>NOTE: web burn-through triggers fracture.</i>
NFRG	number of fragments when 1PF grain fractures $\geq 1$
THRF	absolute value of difference between chamber and perf pressures for grain fracture [psi]; ignored if FRAC = 0 [default = 0.0]

IBHVG2 will calculate grain dimensions if given either actual measurements, or alternatively, a single measurement combined with ratio specifications. This latter technique is quite useful when the code is used to optimize a charge design. For example, a CORD grain can be defined by D and L, or by L and the ratio L/D. For a 7-perforated grain, WI and DP together with WI/O, D/DP, and L/D will completely specify the grain geometry. The slot width of a SLOT or PIE grain will be calculated given SW/D and D. Care must be taken to avoid over-specified or inconsistent information since the computer program may make arbitrary or poor decisions. IBHVG2 prints the grain dimensions prior to ballistic calculations; experienced users of the code always scrutinize this portion of the output for any surprises.

L/D	grain length/grain diameter
L/DP L/PD	grain length/perf diameter
D/DP D/PD	grain diameter/perf diameter

L/WD	grain length/grain width
WD/T	grain width/grain thickness
SW/D	slot width/grain diameter
WI/O	inner web/outer web for multiperforated grains; web eccentricity for single perf grains [default = 1.0]

For dettered grains, further (or replacement) inputs to handle variable thermochemistry and burning rates are necessary. Visualize each grain having, in general, three disjoint surfaces:

Surface	Description
P	perf (includes the slot, if any)
E	end
L	lateral

Extending inward from each surface are layers 1, 2, 3, and 4 (the innermost or "core"), and any or all of the first three may be of zero thickness (nonexistent) on one or more of the P, E, or L surfaces. The core layer is always present and its properties, unlike those of the outer layers, are independent of depth. As there is only one common 4th layer, L-specifications for the core override all others to prevent conflicts. All depth-varying properties are consecutively defined at the outer surface of each layer from the outside in so each of the following is an array of size 4. Linear interpolation is performed by IBHVG2 when intermediate values are required.

RHOP	density [ $lb_m/in^3$ ]	on P surfaces
RHOE		on E surfaces
RHOL		on L surfaces
GAMP	specific heat ratio	on P surfaces
GAME		on E surfaces
GAML		on L surfaces
FRCP	force [ $ft-lb_f/lb_m$ ]	on P surfaces
FRCE		on E surfaces
FRCL		on L surfaces
COVP	covolume [ $in^3/lb_m$ ]	on P surfaces
COVE		on E surfaces
COVL		on L surfaces
TMPP	flame temperature [K]	on P surfaces
TMPE		on E surfaces
TMPL		on L surfaces

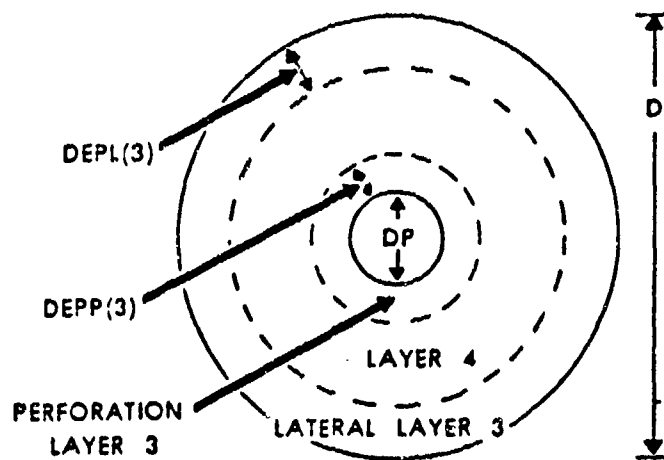


Figure 4. Two-Layer, Single-Perf Grain (end-view)

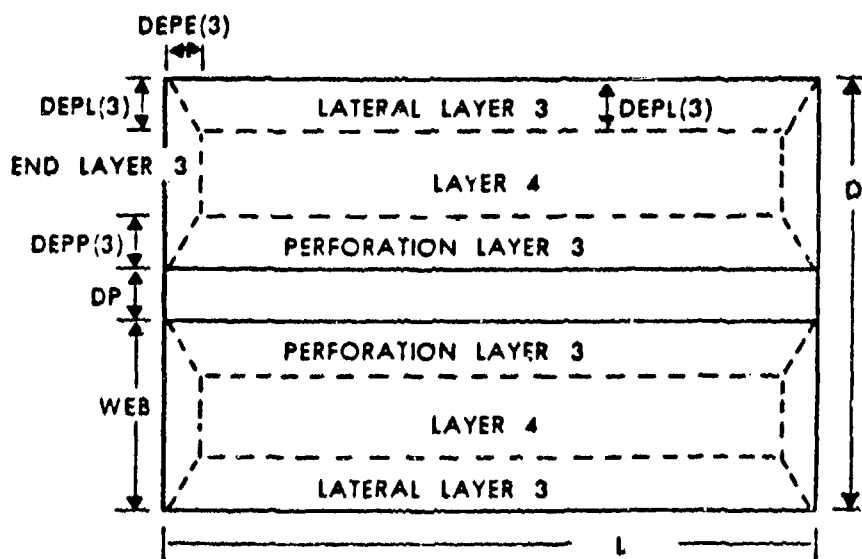


Figure 5. Two-Layer, Single-Perf Grain (lateral-view)



Arrays of size 3 specify the transition depths [*in*] between the first and second, the second and third, and the third and fourth layers, respectively, for each surface.

DEPP	transition depths	on P surfaces
DEPE		on E surfaces
DEPL		on L surfaces
	[defaults = 0.0]	

Transition depths will be calculated by IBHVG2 if positive ratios specifying transition depths as fractions of surface-to-surface distance are input. Arrays of size 3 store the ratios [the default for all values is 0.0].

DP/S	ratios of transition depths on P surfaces to WI; used for perforated grains only
DE/S	ratios of transition depths on E surfaces to: <ul style="list-style-type: none"> <li>• min(GL,WIDTH) for RECT</li> <li>• GL for perforated &amp; CORD grains</li> </ul>
DL/S	ratios of transition depths on L surfaces to: <ul style="list-style-type: none"> <li>• D for CORD &amp; SPHR grains</li> <li>• THCK for RECT grains</li> <li>• WI for perforated grains</li> </ul>
FP/L	ratios of DP/S to DL/S; DP/S values will be found given FP/L and DL/S; useful for defining a relation between transition depths on P and L surfaces

Finally, burning rate data for the outer surface of each layer may be incorporated via several alternative methods. It should be noted that interpolation is linear for depths and betas, but logarithmic for alphas and tables of pressure versus burning rates.

NTBL	method of specifying burning rate inputs ... absolute value is number of table entries on every surface layer; range of values: -10 to +10 <ul style="list-style-type: none"> <li>&lt; 0 to specify betas and alphas as tabular functions of mean pressure [<i>psi</i>], NTBL triples in all</li> <li>= 0 to define one beta/alpha pair [default]</li> <li>&gt; 0 to specify burning rates [<i>in/sec</i>] as tabular functions of mean pressure [<i>psi</i>], NTBL pairs in all. <i>NOTE: if NTBL = 1, burning rate is constant so corresponding pressure value, if any, is ignored.</i></li> </ul>
PR1L	pressures [ <i>psi</i> ] on outside of layer 1, L surface. PR2L, PR3L, PR4L, PR1E, PR2E, PR3E, PR4E, PR1P, PR2P, PR3P, PR4P are defined similarly.

BR1L	burning rates ( <i>in/sec</i> ) on outside of layer 1, L surface. BR2L, BR3L, BR4L, BR1E, BR2E, BR3E, BR4E, BR1P, BR2P, BR3P, BR4P are defined similarly.
CF1L	burning rate coefficients (betas) on outside of layer 1, L surface. CF2L, CF3L, CF4L, CF1P, CF2P, CF3P, CF4P are defined similarly.
EX1L	burning rate exponents (alphas) on outside of layer 1, L surface. EX2L, EX3L, EX4L, EX1E, EX2E, EX3E, EX4E, EX1P, EX2P, EX3P, EX4P are defined similarly.

### \$RECO

For recoil data. In the model currently available, the gun tube freely recoils under the influence of breech pressure less resistance pressure. In IBHVG2 Version 400, this option has not been fully tested and should not be considered reliable.

RECO	0 for fixed tube, no recoil (default) 1 to employ recoil option
RCWT WT	weight ( <i>lb</i> ) of tube and recoiling parts
NAME TYPE	name of recoil system; 28 characters max

### \$RESI

This precedes resistance pressure inputs. The variables are:

NPTS	number of travel/pressure pairs (min = 0, max = 20)
TRAV	projectile travel array of size 20 ( <i>in</i> )
PRES	resistance pressure array of size 20 ( <i>psi</i> )
AIR	0 to suppress adding in air resistance 1 to include air resistance (default)
HTFR	fraction of work done to overcome barrel resistance which is used to pre-heat tube wall; $0.0 \leq \text{HTFR} \leq 1.0$ (default = 0.0)

## SSAVE

Actually, not a deck card, but a control card. If it is the first card in a run after an \$END card, the values of all input variables are retained, so that succeeding decks need only update selected variables. If an \$END card is not followed by a SSAVE card, all input variables must be reinitialized. See test cases 3, 4, and 5 in Appendix B for examples.

## STDIS

Each deck defines one variable to be printed in lieu of the default set for each line of the trajectory print. There can be up to 11 \$TDIS decks in effect: one for each variable printed for the interior ballistic cycle. Be sure to include the line POPT(2)=2 (print option) in the \$INFO deck. To write the trajectory information to a file attached to UNIT=7, include the line SOPT=2 in the \$INFO deck. (\$TDIS is similar to the \$PDIS deck). The list of option variables available for use is found at the end of this section.

SHOW	name of variable to print from deck TRAJ; 4 characters max
MULT	number to multiply data value by [default = 1.0]
DIV	number to divide data value by [default = 1.0]
REMI REMK	20 character remark string for titles and file STORE

## Trajectory Variables

Below is a list of keyword variables which can be used in conjunction with the \$TDIS, \$FIND, and \$PDIS decks to reference quantities other than the default set. To use them with \$PDIS and \$FIND, one must include the line DECK="TRAJ"; a reference within \$TDIS assumes the keyword will come from the following list. Test cases 3 demonstrates the use of \$TDIS to change the trajectory display printed during the ballistic cycle.

MEAN	mean gas pressure in chamber [psi]
PRFP	array of size 5 of mean gas pressure in perfs [psi] of each charge; equal to MEAN if no perf-augmented burning in that charge at current time step
GAGE	array of size 30 of gage pressures [psi]
BRCH	breech pressure [psi]
BASE	pressure at projectile base [psi]
PDOT	$d(\text{mean chamber pressure})/dt$ [kpsi/ms]

<b>PDTP</b>	array of size 5 of $d(\text{mean perf pressure})/dt$ [ $kpsi/ms$ ], one for each charge
<b>TBAR</b>	mean gas temperature in chamber [ $K$ ]
<b>PRFT</b>	array of size 5 of mean gas temperature in perfs [ $K$ ] of each charge; equal to TBAR if no perf-augmented burning in that charge at current time step
<b>FRCR</b>	bore-friction resistance pressure [ $psi$ ]
<b>AIRR</b>	air resistance pressure [ $psi$ ]
<b>TOTR</b>	sum of FRCR and AIRR
<b>TWAL</b>	temperature of tube wall shell [ $K$ ]
<b>WTB</b>	array of size 5 of weight burned of each charge [ $lb_m$ ]; reference by subscript
<b>WTBR</b>	array of size 5 of weight-burning rate of each charge [ $lb_m/sec$ ]; reference by subscript
<b>WTBT</b>	total weight of gas in chamber [ $lb_m$ ]
<b>PRJE</b>	projectile translational kinetic energy [ $in-lb_f$ ]
<b>PRJ%</b>	$PRJE * 100 / TOTE$
<b>PRPE</b>	propellant and gas kinetic energy [ $in-lb_f$ ]
<b>PRP%</b>	$PRPE * 100 / TOTE$
<b>ROTE</b>	projectile rotational kinetic energy [ $in-lb_f$ ]
<b>ROT%</b>	$ROTE * 100 / TOTE$
<b>FRTE</b>	barrel-frictional work to tube [ $in-lb_f$ ]
<b>FRT%</b>	$FRCE * 100 / TOTE$
<b>FREE</b>	barrel-frictional work not absorbed as heat to the tube wall [ $in-lb_f$ ]
<b>FRE%</b>	$FREE * 100 / TOTE$
<b>DRGE</b>	work done against air in barrel [ $in-lb_f$ ]
<b>DRG%</b>	$DRGE * 100 / TOTE$
<b>RECE</b>	kinetic energy of recoiling tube [ $in-lb_f$ ]

REC%	$RECE * 100 / TOTE$
HETE	energy lost as heat convected to tube wall [ <i>in-lb<sub>f</sub></i> ]
HET%	$HETE * 100 / TOTE$
LOSE	sum of all energy losses [ <i>in-lb<sub>f</sub></i> ]
LOS%	$LOSE * 100 / TOTE$
TOTE	total chemical energy released by combustion [ <i>in-lb<sub>f</sub></i> ]
EDOT	$d(TOTE)/dt$ [ <i>in-lb<sub>f</sub>/sec</i> ]
GASE	internal energy of gas [ <i>in-lb<sub>f</sub></i> ], i.e., $TOTE - LOSE$
GAS%	$GASE * 100 / TOTE$
SRF	array of size 5 of burning-surface area of each charge [ <i>in<sup>2</sup></i> ]; reference by subscript
SRFT	total surface area of all ignited charges [ <i>in<sup>2</sup></i> ]
TIME	time [ <i>ms</i> ]
TRAV	projectile displacement from initial position [ <i>in</i> ]
VEL	ground-based projectile velocity [ <i>ft/sec</i> ]
ACCL	projectile acceleration [ <i>G's</i> ]
Z	array of size 5 of charge weight fractions burned; reference by subscript
DB-P	array of size 5 of depth burned into P surface of each charge [ <i>in</i> ]; reference by subscript
DB-E	same as above for E surfaces
DB-L	same as above for L surfaces
DB-F	same as above for F (fracture) surfaces
BR-P	array of size 5 of burning rate on P surface of each charge [ <i>in/sec</i> ]; reference by subscript
BR-E	same as above for E surfaces
BR-L	same as above for L surfaces
BR-F	same as above for F (fracture) surfaces

### Run Completion Variables

These are output variables defined after a complete IBHVG2 run. Typically they represent some global extrema which can only be ascertained at the conclusion of ballistic computation. For example, a maximum pressure is determined after shot ejection, while there could be several local maxima during the pressure history. The variables may be referenced by name using \$PDIS (with DECK='OUT') as in test case 6, or by \$FIND as the value inserted for OUTV as shown in test case 5.

PMAX	max breech pressure [psi]
HUMP	array of size 5 of local breech pressure maxima [psi]
GMAX	array of size 30 of gauge pressure maxima [psi]
VMUZ	muzzle velocity [ft/s]
AMAX	max acceleration [g's]
BMAX	max base pressure [psi]
X@BO	array of size 5 of projectile position [in] at charge burnouts; reference by subscript
PMUZ	base pressure at shot exit [psi]
ZMUZ	array of size 5 of charge weight fractions burned at shot exit; reference by subscript
IMPL	final impulse (momentum) [lb <sub>f</sub> -s]
LDEN	calculated loading density [g/cm <sup>3</sup> ]

### III. SUBROUTINE DESCRIPTIONS

- AUXGEN** check consistency of charge weight and densities specified for FRMGEN charge
- AUXHEX** add to weight of core of nth grain the contributions from P, E, and L layers with linearly-varying density ... used for hexagonal or cylindrical grains with NPERFS(NTH) number of perfs
- AUXMON** add to weight of core of nth grain the contributions from P, E, and L layers with linearly-varying density ... used for monolithic grains only
- AUXSLT** add to weight of core of nth grain the contributions from P, E, and L layers with linearly-varying density ... used for slot grains only
- AUXSTR** add to weight of core of nth grain the contributions from layers with linearly-varying density on IASUB-th surface ... used for rectangular grains only
- BADBN** determine if grain surfaces in 01p, slot, 07p, 19p, 19h, or 37h have burned beyond core of grain
- BLDATA** define static parameters, including I/O device numbers, alphanumeric characters set, and version number of IBHVG2
- BRNCMP** return a burning rate through BRNCMP
- BRNRAT** lookup burning rates as function of pressure and interpolate linearly as function of depth burned
- BULDEK** define input variables for projectile
- CALPEJ** calculate projectile weight, if required, based on projectile weight estimation formula cited in ARBRL-TR-02364, p. 24, by Burns (See Reference (3))

**COMDEK** read through comment deck

**CPRCHK** error check input if constant pressure run

**CPREDA** store current values before and restore values after tentative integration step for constant pressure run

**CRITIG** return value of ignition-criterion variable for nth charge based on ignition code for comparison with threshold value

**CRKLN** parse input line, crack and classify fields as numeric, string, or variable name, and flag syntax errors

**CRKNUM** stash numeric value in field number, NFIELD, or flag error

**CRKSUB** stash integer subscript in field number, NFIELD, or flag error

**CRKTT** stash start and stop columns of string in field number, NFIELD

**CRKVAR** stash variable name and subscript, if any, in field number, NFIELD, or flag error

**DATINP** initialize input variables and call appropriate input routines

**DEFPAG** define number of lines/output page

**DERIV1** calculate derivatives for ODE solver during 1B cycle



**DERIV3** calculate derivatives for ODE solver during evacuation phase (treatment drawn from Corner, Chapter 9 of Reference [5])

**DFQSET** set up eqns for solver KUTMER

**DODPDT** calculate  $d(\text{mean pressure})/dt$

**DRIVER** drive IB solver in selected modes

**ECHOIN** echo inputs

**ECHOPR** echo propellant input data

**ENEQST** calculate mean temperatures and pressures

**EVPREP** initialization and setup for evacuation cycle

**FILLCB** fill common blocks as input cards are interpreted

**FINDEK** define input variables driving automatic program search for desired conditions

**FNEVAL** compute residual as function value FBAR for FUNMIN

**FORMFN** calculate instantaneous grain surface areas and fractions burned for the grains in each charge

**FRM01P** find surface areas for 01-perf cylindrical grain geometry

**FRM07P** find surface areas for 07-perf cylindrical grain geometry

**FRM19H** find surface areas for 19-perf hexagonal grain geometry

**FRM19P** find surface areas for 19-perf cylindrical grain geometry

**FRM37H** find surface areas for 37-perf hexagonal grain geometry

**FRMADJ** return trial value of surface area in constant pressure run

**FRMCRD** find surface areas for cord grain geometry

**FRMGEN** find surface area for charge with user-specified values of surface area as function of depth burned

**FRMHEX** find surface areas for general hexagonal grain geometry

**FRMMON** find surface areas for monolithic, perforated, cylindrical grain geometry

**FRMPIE** find surface areas for pie grain geometry

**FRMSLT** find surface areas for slotted grain geometry

**FRMSPH** find surface areas for spherical grain geometry

**FRMSTR** find surface areas for strip (rectangular) grain geometry

**FSTORE** store parameter values determined by FUNMIN

**FUNMIN** finds the minimum of function of n variables based on method in BRL-TN-1677 by J.D. Wortman (See Reference [6])

**GAGSET** find and sort gage positions

**GENISL** finds the surface area-contributions due to inner slivers for a multiperforated propellant grain

**GENOSL** finds the surface area-contributions due to outer slivers for a multiperforated propellant grain

**GRADNT** calculate pressure at breech, projectile base, & gages

**GUNDEK** define input variables for gun tube

**HDRSTO** store descriptive information in file for post-run processing of detailed IB and evacuation cycles

**HELPPR** format and build output lines for ECHOPR

**HETDEK** define input variables used in heat loss calculations

**HEXCOR**

find surface area contribution from rounded corners of multiperforated hexagonal propellant grain

**HEXOSL**

find surface area contribution for outer slivers in multiperforated hexagonal propellant grain

**HLRATE**

calculate heat-loss rate from treatment of Black and Comenetz in Chap. 5, vol. 1 of NDRC hypervelocity report (See Reference [7])

**IBHVG2**

Interior Ballistics of High-Velocity Guns, 2nd version (main program unit)

**IBPREP**

initialization and setup for ballistic cycle

**INFDEK**

define miscellaneous input run variables

**INITCP**

calculate initial conditions for constant-pressure run

**INITPR**

define properties of air in chamber and initialize some integrals with primer information

**INTBAL**

initiate and control calculations for IB cycle and bore-evacuation phase

**KMPAUX**

print user-requested values in trajectory print form

**KMPRN1**

print details at current time step in interior ballistic cycle

**KMPRN2**

print details at current time step in evacuation phase

**KMTRM1** establish values of variables representing the transition conditions checked by KUTMER in IB cycle

**KMTRM2** establish values of variables representing the transition conditions checked by KUTMER in evacuation cycle

**KUTMER** 5-step Runge-Kutta ODE integrator with auto-adjustment of step size to achieve accumulation tolerances as well as transition and print conditions

**LCHECK** check layer depths for consistency and find initial current-layer-exposed for each surface of nth grain

**LDEFIN** calculate layer-transition depths bases on ratios

**LIMITF** check whether any values set by FUNMIN are out-of-range

**MAXDER** define input variables for maximum pressure search

**MGRATE** calculate mass-generation rates, energy-generation rate, and related derivatives in chamber and perfs

**MINAUX** print user-requested values in parametric print form

**MINPET** compressed print parametric runs

**MXBRPR** adjust single input variable to achieve desired maximum pressure

**NEWEPS** reset double-sided integrator tolerance EPSL

- NEWFLG** update flags and clean up after each print step
- OUTDEK** define program-accessible output variables
- PACKER** encode utility for input parsing routines
- PAGCHK** begin new output page with appropriate headings when necessary
- PARDEK** define input variables dealing with automatic parametric variation of desired run variables
- PDSDEK** define input variables dealing with user-selected printing on parametric compressed print summary
- PICKDT** compute maximum integration step size
- POLYIN** compute the integral for mass of an object with a density changing linearly in coordinate  $x$ . For example, if the object had two dimensions  $L$  and  $W$  for planes 1 and 2 which are perpendicular to  $x$ , then the integral would be:
- $$\text{Mass} = \int_{x_1}^{x_2} \left[ L_1 + \frac{L_2 - L_1}{x_2 - x_1} (x - x_1) \right] \left[ W_1 + \frac{W_2 - W_1}{x_2 - x_1} (x - x_1) \right] \left[ \rho_1 + \frac{\rho_2 - \rho_1}{x_2 - x_1} (x - x_1) \right] dx.$$
- PRIDEK** define input variables for primer
- PRPDEK** define input variables for propellant description
- PSTORE** store parameter values from matrix

**RATIOS** recalculate charge weights, projectile weight, or chamber volume based on input options and ratios

**RDLINE** read input card-image

**RECDEK** define input variables for gun recoil

**REDOTT** accept last integration step for constant pressure run or prepare for restart of last step

**RESDEK** define input variables for resistance profile

**RESIST** compute resistance pressure to projectile motion

**RUNDAT** define the machine precision limit; return a current date through DAYR and time thru TIMR (TIMR is highly system-dependent and has been commented out)

**SAVDEK** process \$SAVE control cards

**SETVAR** set a variable VNAME to number in VALUE for parametric variation and search routines or retrieves current contents

**SHOTGO** set a shot-start flag based on initial chamber pressures and prepares for first search for maximum pressure

**SPECIN** same purpose as POLYIN, but modified to accommodate a SLOT geometry

**STASHD**            move double precision number

**STASHI**            convert double precision to integer

**STDPRP**            set default propellant properties

**STRTRD**            define control cards, initialize page control, and common blocks

**TDSDEK**            define user-selectable trajectory print variables

**THERMI**            return thermodynamic information interpolated linearly on depth burned

**TRJDEK**            define program-accessible output variables

**TRJSUM**            print run summary through projectile exit

**UPDATE**            post-print-step update

**UPDAUX**            find current layer exposed for jth surface of ith grain

**VENTPF**            find  $dm/dt$  from perforations based on method of Robbins & Horst in  
ARBRL-MR-03295 (See Reference [4])

**WRAPUP**            is merely a program stub. Users may desire to include their own system  
clean-up commands, etc.



## IV. ALGORITHM DESCRIPTIONS

### A. Calculation of Mean Temperature and Pressure

By the First Law of Thermodynamics, we state the energy balance for the closed interior ballistic system at time  $t$  as

$$\text{initial energy of gases} = \text{internal energy of gases} + \text{losses}$$

where the loss term includes work done by and heat transferred from the system. In addition, we will assume the gaseous components always retain their identity and that they undergo no further reactions after being generated. Using average values of specific heats over the temperatures considered, we express this balance as

$$\sum_{i,j} m_{ij} c_{vj} T_{ij} + m_o c_o T_o = \left[ \sum_{i,j} m_{ij} c_{vj} + m_o c_o \right] T_{\text{mean}} + L \quad (\text{A.01})$$

which we solve for mean temperature

$$T_{\text{mean}} = \frac{\sum_{i,j} m_{ij} c_{vj} T_{ij} + m_o c_o T_o - L}{\sum_{i,j} m_{ij} c_{vj} + m_o c_o} \quad (\text{A.02})$$

where the summations are taken over each surface  $j$  of every charge element  $i$  with the addition of a primer considered all burned at  $t = 0$ . From the definitions

$$\gamma \equiv c_p / c_o \quad (\text{A.03})$$

$$c_p - c_o = R \quad (\text{A.04})$$

$$F = RT_f \quad (\text{A.05})$$

it follows that

$$c_o = \frac{F}{(\gamma - 1)T_f} \quad (\text{A.06})$$

Substituting this result into (A.02) and simplifying our notation somewhat we get

$$T_{\text{mean}} = \frac{\sum_b \frac{F_b m_b}{\gamma_b - 1} + \frac{F_o m_o}{\gamma_o - 1} - L}{\sum_b \frac{F_b m_b}{(\gamma_b - 1) T_{f_b}} + \frac{F_o m_o}{(\gamma_o - 1) T_{f_o}}} \quad (\text{A.07})$$

which, in the limit, becomes

$$T_{\text{mean}} = \frac{\sum_b \int \frac{F_b}{\gamma_b - 1} dm_b + \frac{F_o m_o}{\gamma_o - 1} - L}{\sum_b \int \frac{F_b}{(\gamma_b - 1) T_{f_b}} dm_b + \frac{F_o m_o}{(\gamma_o - 1) T_{f_o}}} \quad (\text{A.08})$$

for differential weights burned, or

$$T_{\text{mean}}(t) = \frac{\sum_b \int \frac{F_b \dot{m}_b}{\gamma_b - 1} dt + \frac{F_o m_o}{\gamma_o - 1} - L(t)}{\sum_b \int \frac{F_b \dot{m}_b}{(\gamma_b - 1) T_{f_b}} dt + \frac{F_o m_o}{(\gamma_o - 1) T_{f_o}}} \quad (\text{A.09})$$

for instantaneous values of  $F$ ,  $\dot{m}$ ,  $\gamma$ , and  $T_f$ . The derivation of  $L$  is discussed in section III.D.

We assume Noble-Abel gases and mixtures, that is, a covolume correction applied to the ideal gas law so, at time  $t$ ,

$$P_{\text{mean}} \left[ V_{\text{free}} - \sum_b m_b \eta_b - m_o \eta_o \right] = \left[ \sum_b m_b R_b + m_o R_o \right] T_{\text{mean}} \quad (\text{A.10})$$

which, with the aid of (A.05), we solve for mean pressure,

$$P_{\text{mean}} = \frac{T_{\text{mean}} \left[ \sum_b \frac{F_b m_b}{T_{f_b}} + \frac{F_o m_o}{T_{f_o}} \right]}{V_{\text{free}} - \sum_b m_b \eta_b - m_o \eta_o} \quad (\text{A.11})$$

which becomes

$$P_{\text{mean}} = \frac{T_{\text{mean}} \left[ \sum_b \int \frac{F_b}{T_{f_b}} dm_b + \frac{F_o m_o}{T_{f_o}} \right]}{V_{\text{free}} - \sum_b \int \eta_b dm_b - \eta_o m_o} \quad (\text{A.12})$$

in the limit for differential weights burned. The free volume of the system is the volume behind the projectile less that occupied by unburned propellant, or

$$V_{free} = V_c + A_b [x_p + x_r] - \sum_i n_i V_i \quad (\text{A.13})$$

so

$$P_{mean}(t) = \frac{T_{mean}(t) \left[ \sum_h \int \frac{F_h \dot{m}_h}{T_{jh}} dt + \frac{F_o m_o}{T_{jo}} \right]}{V_c + A_b [x_p + x_r] - \sum_i n_i V_i - \sum_h \int \eta_h \dot{m}_h dt - \eta_o m_o} \quad (\text{A.14})$$

for instantaneous values of  $x_p$ ,  $x_r$ ,  $\eta$ ,  $F$ ,  $\dot{m}$ ,  $\gamma$ , and  $T_j$ . The gun coordinate system defining the displacements  $x_p$  and  $x_r$  is shown in Figure 6. How they are computed is taken up in section III.B.

The rate at which the weight of propellant  $i$  is converted into gas on its  $j$ th surface is given by

$$\dot{m}_{ij} = n_i \rho_{ij} S_{ij} r_{ij} \quad (\text{A.15})$$

for instantaneous values of  $\rho$  and  $S$  where the burning rates are either tabulated experimental values or empirical functions of the form

$$r_{ij} = \beta_{ij} [P_{mean}]^{\alpha_{ij}} + \zeta_{ij} v_p \quad (\text{A.16})$$

for known  $\alpha$ ,  $\beta$ , and  $\zeta$ . The determination of the geometrical properties of individual propellant grains,  $V_i$ ,  $S_{ij}$ , and  $n_i$  is taken up in section III.E.

## B. Dynamic Relations

By Newton's Second Law, we express the acceleration of the projectile at any time  $t$  by

$$\text{projectile acceleration} = \frac{\text{net force on projectile}}{\text{projectile mass}}$$

where the propulsive force is supplied by the pressure of the propellant combustion gases on the base of the projectile and the retarding forces are provided by barrel resistance against the rotating band as well as air resistance against the nose as the air is compressed ahead of the projectile during its flight downtube. Hence we express projectile acceleration as

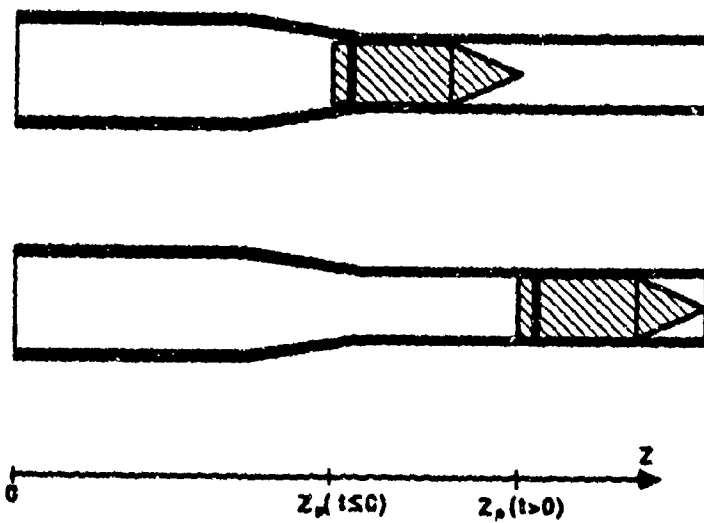


Figure 6. Gun Tube Reference Frame

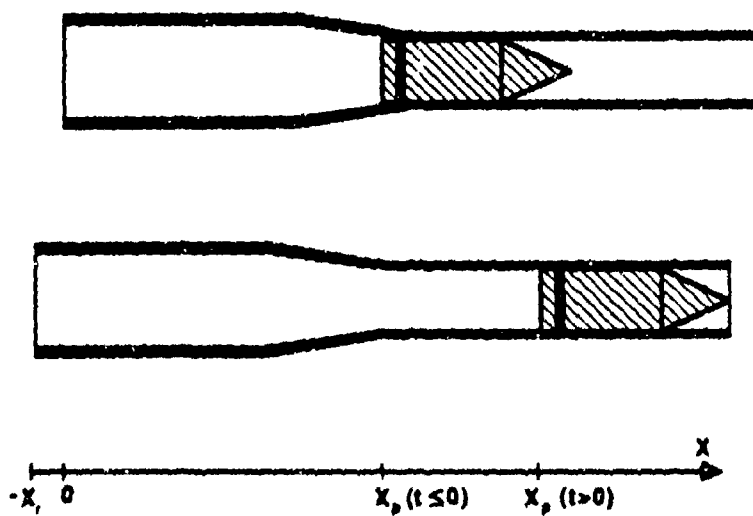


Figure 7. Ground Reference Frame

$$\ddot{x}_p = \frac{[P_{base} - P_{res} - P_{air}] A_b}{m_p/g} \quad (B.01)$$

for instantaneous values of  $P_{base}$ ,  $P_{res}$ , and  $P_{air}$ . Similarly, the acceleration of the freely-recoiling barrel is

$$\ddot{x}_r = \frac{[P_{breach} - P_{res}] A_b}{m_r/g} \quad (B.02)$$

for instantaneous values of  $P_{breach}$  and  $P_{res}$ . One integration produces the ground-referenced projectile and recoil velocities  $\dot{x}_p$  and  $\dot{x}_r$ . A second integration yields the projectile and barrel displacements,  $x_p$  and  $x_r$ , measured from their respective initial positions. Calculations of breach and base pressure are taken up in section III.C. Resistance pressure due to engraving of the rotating band is interpolated from tabular resistance pressures as a function of the tube-referenced projectile displacement  $x_p + x_r$ .

### C. Calculation of the Pressure Gradient

We will consider two ways of calculating the pressure gradient in the system from the breach to the projectile base. The first is the so-called Lagrange approximation with the added assumption that the introduction of recoil does not appreciably disturb the gradient so derived. The central assumptions of this model are that the entire charge may at any time be treated as gaseous—that is, all burned—and that the density of the gas is uniformly distributed along the gun tube at any given time. The derivation in a tube-based frame of reference is as follows ( $z \equiv x_p + x_r$ ).

We use the one-dimensional, inviscid equations of continuity and momentum

$$0 = \frac{\partial \rho}{\partial t} + \frac{\partial}{\partial z}(\rho v), \quad 0 \leq z \leq z_p \quad (C.01)$$

$$-\frac{1}{\rho} \frac{\partial P}{\partial z} = \frac{\partial v}{\partial t} + v \frac{\partial v}{\partial z}, \quad 0 \leq z \leq z_p \quad (C.02)$$

together with the uniformity assumption

$$\frac{\partial \rho}{\partial z} = 0. \quad (C.03)$$

Then (C.01) and (C.03) imply

$$\frac{\partial v}{\partial z} = -\frac{1}{\rho} \frac{d\rho}{dt} \quad (C.04)$$

with the boundary conditions of

$$\begin{aligned} v(0, t) &= 0 \\ v(z_p, t) &= v_p \equiv \dot{z}_p \end{aligned} \quad (\text{C.05})$$

where  $z_p$  and  $v_p$  denote position of the projectile base and projectile velocity, respectively. Integrating over  $z$ , produces the gas velocity distribution

$$v(z, t) = z \frac{\dot{z}_p(t)}{z_p(t)} \quad (\text{C.06})$$

indicating a linear distribution from breech to base. Substituting (C.06) into (C.02) we find

$$-\frac{1}{\rho} \frac{\partial p}{\partial z} = z \frac{z_p \ddot{z}_p - \dot{z}_p \dot{z}_p}{z_p^2} + \left[ z \frac{\dot{z}_p}{z_p} \right] \left[ \frac{\dot{z}_p}{z_p} \right] \quad (\text{C.07})$$

or

$$\frac{\partial p}{\partial z} = -\rho \frac{z}{z_p} \ddot{z}_p \quad (\text{C.08})$$

Now the all-burnt assumption implies the (spatially uniform) density

$$\rho = \frac{\sum C_i / g}{A_b z_p} \quad (\text{C.09})$$

Substituting both (C.09) and (B.01) rewritten in tube-based coordinates into (C.08), we find

$$\frac{\partial p}{\partial z} = -\frac{z}{z_p} \left[ \frac{\sum C_i / g}{A_b z_p} \right] \frac{[P_{base} - P_{res} - P_{air}] A_b}{m_p / g} \quad (\text{C.10})$$

so that

$$P(z, t) = \psi(t) - \frac{[P_{base} - P_{res} - P_{air}] \sum C_i}{2 m_p z_p^2} z^2 \quad (\text{C.11})$$

The condition  $P(0, t) = P_{breech}$  implies

$$\psi(t) = P_{breech} \quad (\text{C.12})$$

so the requirement  $P(z_p, t) = P_{base}$  forces

$$P_{breech} = P_{base} + \frac{1}{2} \frac{\sum C_i}{m_p} [P_{base} - P_{res} - P_{air}]. \quad (C.13)$$

Into the definition

$$P_{mean} = \frac{1}{z_p} \int_0^{z_p} P(z, t) dz \quad (C.14)$$

we substitute (C.11) and (C.12) and integrate, yielding

$$P_{mean} = P_{breech} - \frac{1}{6} \frac{\sum C_i}{m_p} [P_{base} - P_{res} - P_{air}]. \quad (C.15)$$

Then substituting for  $P_{breech}$  from (C.13) into (C.15) and rearranging, we find

$$P_{base} = \frac{3P_{mean} + \frac{\sum C_i}{m_p} [P_{res} + P_{air}]}{3 + \frac{\sum C_i}{m_p}}. \quad (C.16)$$

Thus, according to the Lagrange model, knowledge of the charge-to-projectile weight ratio, the mean pressure, and the resistance pressures is sufficient to calculate the entire pressure gradient down the tube and, in particular, the desired base and breech pressures. Alternatively, the Pidduck-Kent gradient model may be employed.

The Pidduck-Kent model, as described by Corner[5], employs charge-to-mass ratio,  $\Theta$ , specific heat ratio,  $\gamma$ , and space-mean pressure,  $P_{mean}$ , to estimate base and breech pressures in the ballistic gun system. The base pressure is scaled by the following:

$$\Theta \equiv \frac{\sum C_i}{m_p} \quad (C.17)$$

$$P_{base} = \frac{P_{mean}}{1 + \frac{\Theta}{\Delta}} \quad (C.18)$$

where  $\Delta$  is the Pidduck-Kent constant. Breech pressure is related to the base pressure estimate. Let

$$p \equiv \frac{1}{\gamma - 1} \quad (C.19)$$

$$\frac{1}{a_0} \equiv \frac{2p + 3}{\Delta} + 2 \frac{p + 1}{\Theta}. \quad (C.20)$$

$$P_{\text{breach}} = P_{\text{base}} (1 - a_0)^{p+1} \quad (\text{C.27})$$

The reader is encouraged to examine the classical derivation and its implicit assumptions for more information. The purpose here is to merely illustrate how IBHVG2 performs the calculations.

The Pidduck-Kent constant has been correlated with  $\Theta$  and  $\gamma$  by a linear least squares fit described by Grollman and Baer[9]. No explanation was given for the formulation, but it is a fifth-order polynomial in charge-to-mass ratio and scaled with the specific heat ratio:

$$\Delta(\Theta) = 3 + a\Theta + b\Theta^2 + c\Theta^3 + d\Theta^4 + e\Theta^5 \quad (\text{C.21})$$

where

$$a = a_1 + \frac{a_2}{\gamma}, \quad b = b_1 + \frac{b_2}{\gamma}, \quad \dots, \quad e = e_1 + \frac{e_2}{\gamma} \quad (\text{C.18})$$

Values for the fitted parameters ( $a_1, a_2, b_1, b_2, \dots$ ) are given in the above reference. Not surprisingly with ten parameters, the regression error is quite small. The report states that the maximum error was 0.21% over the rectangular domain of  $\gamma \in [1.2, 1.3]$  and  $\Theta \in [0, 26]$ . This is more than adequate for modeling considerations.

#### D. Work and Losses

The term  $L(t)$  in (A.09) comprises the total work done by the interior ballistic system less the energy transferred from the system at time  $t$ . In IBHVG2,  $L(t)$  includes contributions from: the translational kinetic energy of the projectile, the translational kinetic energy of the propellants and gases, the rotational kinetic energy of the projectile, the kinetic energy of the recoiling barrel, work done against barrel friction, work done against the resistance of the air in the tube opposing projectile motion, and heat lost to the gun tube. We neglect the amount of energy expended in the deformation of the gun barrel and any work done in overcoming the frictional resistance of the propellant bed or the combustion gases moving against the tube wall.

The translational kinetic energy of the projectile in a tube reference frame is

$$E_{\text{trans}} = \frac{1}{2} \frac{m_p}{g} \dot{z}_p^2 \quad (\text{D.01})$$

To find the translational energy of the propellants and gases, we first consider the Lagrange model developed in section C. In this case, all the propellant was assumed to be burned, an assumption which implies there is no work expended in moving any solid propellant, only work done moving gases. Alternatively, we may reinterpret the assumption as requiring the solid propellant remaining at any instant to have the same linear velocity profile as the gases and be distributed throughout the system so that the overall density is uniform.



Either view is consistent with the expression for energy in a differential volume of the system

$$dE_{prop} = \frac{1}{2} \rho v^2(z) dV, \quad 0 \leq z \leq z_p \quad (D.02)$$

But the velocity at any point was found by (C.06), so

$$E_{prop} = \frac{1}{2} \rho A_b \int_0^{z_p} \left[ z \frac{\dot{z}_p}{z_p} \right]^2 dz \quad (D.03)$$

Integrating yields

$$E_{prop} = \frac{1}{6} \rho A_b z_p \dot{z}_p^2 \quad (D.04)$$

or, by substituting for  $\rho$  from (C.09) we have, with respect to the ground,

$$E_{prop} = \frac{1}{6} \frac{\sum C_i}{g} \dot{z}_p^2 \quad (D.05)$$

Similarly, it can be shown that for the Pidduck-Kent gradient model,

$$E_{prop} = \frac{1}{2} \frac{\sum \int \dot{m}_b dt + m_b}{\Delta g \dot{z}_p^2} \quad (D.06)$$

The rotational kinetic energy of the projectile in a tube frame of reference is

$$E_{rotat} = \frac{1}{2} I_p \omega^2 \quad (D.07)$$

where the moment of inertia of the projectile is taken to be that of a solid cylinder of bore diameter and uniform density, that is

$$I_p = \frac{1}{8} \frac{m_p}{g} D_b^2 \quad (D.08)$$

Because of varying weight distribution, sabot projectiles have a smaller  $I_p$  than this while artillery shells have a larger  $I_p$ , but the fraction of overall energy embodied in  $E_{rotat}$  is so small that IBHVG2 currently assumes (D.08) for all projectiles. The twist for rifled barrels,  $\tau$ , is commonly expressed as the number of "calibers" (barrel diameters) of downtube travel required for one complete revolution of the projectile. Thus,  $2\pi$  radians are turned in  $\tau D_b$  inches of travel, so the definition

$$\theta_p = \omega_p t \quad (D.09)$$

implies

$$2\pi = \omega_p \left[ \frac{rD_b}{\dot{x}_p} \right] \quad (D.10)$$

or, finally,

$$\omega_p(t) = \frac{2\pi \dot{x}_p}{rD_b} \quad (D.11)$$

The translational energy of the recoiling barrel in a ground-based reference frame is

$$E_r = \frac{1}{2} \frac{m_r}{g} \dot{x}_r^2 \quad (D.12)$$

Currently, IBHVG2 requires tabular input of barrel frictional resistance pressure as a function of projectile displacement to compute the work done. These resistance profiles have been experimentally determined from measurements of force required to push projectiles through gun tubes or, perhaps more realistically, via instrumented projectiles used in actual firings which transmit data from onboard accelerometers and pressure gages. Given such tabular data,  $P_{res}(z)$ , the work required to overcome the frictional resistance of the gun tube is

$$E_{frict} = A_b \int_{x_p(0)}^{x_p^*} P_{res}(z) dz \quad (D.13)$$

where displacement is measured with respect to the barrel, or

$$E_{frict} = A_b \int [\dot{x}_p + \dot{x}_r] P_{res}(x_p + x_r) dt. \quad (D.14)$$

Similarly, the work done against air resistance is

$$E_{drag} = A_b \int \dot{x}_p P_{air} dt. \quad (D.15)$$

The last energy loss considered is that due to heat transfer to the gun barrel. The model employs a metal shell of thickness  $\delta$  which is initially at temperature  $T_0$  surrounding the interior ballistic system. As heat is transferred to the shell via convection from the combustion gases, it is assumed to come to thermal equilibrium instantaneously not only radially, but axially as the motion of the projectile exposes greater portions of the shell to heating. The rate of heat transfer is taken to be proportional to the difference between the mean temperature of the system,  $T_{mean}$ , and the average temperature of the shell,  $T_w$ , by Newton's Law of Cooling. That is,

$$E_{\text{heat}} = \int \dot{Q} dt \quad (\text{D.16})$$

with

$$\dot{Q} = A_w h [T_{\text{mean}} - T_w] \quad (\text{D.17})$$

where the wall area of the shell exposed to the system is that of the chamber plus that which has been exposed by the motion of the projectile, or

$$A_w = \left[ \frac{V_o}{A_b} \right] \pi D_b + 2A_b + \pi D_b [z_p + z_r] \quad (\text{D.18})$$

and the heat transfer coefficient

$$h = \lambda \bar{c}_p \bar{\rho} \bar{v} + h_n \quad (\text{D.19})$$

is that of Nordheim, Soodak, and Nordheim[8] with the addition of a natural convective term,  $h_n$ , to allow heat transfer in the absence of projectile motion. In the work cited, the authors selected a friction factor of

$$\lambda = \left[ 13.2 + 4 \log_{10} [2.54 D_b] \right]^{-2} \quad (\text{D.20})$$

based on studies with rifled and unrifled tubes. The mean gas velocity is

$$\bar{v} = \frac{1}{2} [z_p + z_r] \quad (\text{D.21})$$

from the linear gas velocity distribution in the Lagrange model (C.06). The mean gas density is the total weight of propellant burned divided by the volume of the system, or

$$\bar{\rho} = \frac{\sum_b \int \dot{m}_b dt + m_o}{V_o} \quad (\text{D.22})$$

Now (A.03) and (A.06) imply

$$c_p = \frac{F \gamma}{(\gamma - 1) T_f} \quad (\text{D.23})$$

so we take the charge-weight-burned weighted average

$$\bar{c}_p = \frac{\sum_b \int \frac{F_b \gamma_b \dot{m}_b}{(\gamma_b - 1) T_{fb}} dt + \frac{F_s \gamma_s m_s}{(\gamma_s - 1) T_{fs}}}{\sum_b \int \dot{m}_b dt + m_s} \quad (D.24)$$

At any instant, the heat already transferred to the shell is

$$Q + f E_{frict} = c_{pw} m_w [T_w - T_0] \quad (D.25)$$

or

$$Q + f F_{frict} = c_{pw} \rho_w A_w \delta [T_w - T_0] \quad (D.26)$$

where  $f$  is that fraction of work done against bore friction which pre-heats the shell. Knowledge of the heat capacity, density, and thickness of the shell permit calculation of the temperature of the shell

$$T_w = \frac{Q + f E_{frict}}{c_{pw} \rho_w A_w \delta} + T_0. \quad (D.27)$$

## E. Propellant Grain Geometry

The calculation of instantaneous surface area and burning rates allows us to approximate burned propellant volume during the current time step at any point during deflagration. Thus the mass generation rate of propellant gases may be obtained for subsequent calculations of pressurization behind the projectile. (See Equation A.15)

Up to five different propellants may be described by as many \$PROP input decks. Each may have a different grain geometry, charge weight, burning rate characteristics, and other physical properties; each deck must be self-sufficient in describing its propellant. Later references use the parameter NTH to point to an individual deck (first propellant deck is NTH=1, etc.).

In IBHVG2, we include many of the conventional propellant grain geometries in the "form function" subroutines. These codes solve for current surface area (burned) volume for the different grain types shown in Table 1. Forms CORD, STAR, PF, SLOT, 7PF, 19PF, and MONO are all variations on a right circular cylinder. The special form functions (HEX, MONO, and GEN) will be described later in this section. Descriptions and drawings of the grain types are in Appendix B.

Table 1. Grain Types

cord	CORD
sphere	BALL or SPHR
slab	SLAB or RECT
pie-shaped	STAR or PIE
single-perf	1PF or 1P
sloped single-perf	SLOT
seven-perf	7PF or 7P
nineteen-perf cord	19PF or 19P
hexagonal	GHEX or HEX
nineteen-perf hexagonal	19HX or 19H
thirty-seven perf hex	37HX or 37H
monolithic n-perf	MONO
general undefined	GEN

Each geometry described to IBHVG2 requires a minimum of information: either absolute measurements, or one exact measurement and a combination of ratios to other surfaces. Incompatible measurements of perf diameters, grain diameter, and web distances will, in general, show up as a change in grain diameter. Using the geometry and density, we calculate a unit weight for one grain, then we find the number of grains for the charge by dividing the unit weight into the charge weight.

As an example, for a  $i^{\text{th}}$  propellant of cord-type grains, each of initial length  $l_i$ , density  $\rho_i$ , and initial diameter  $D_i$ , we compute the initial volume  $V_i$  and number of grains  $n_i$  by

$$V_i = \pi l_i \left( \frac{D_i}{2} \right)^2 \quad (\text{E.01})$$

and

$$n_i = \frac{C_i}{V_i \rho_i} \quad (\text{E.02})$$

Total initial surface area  $S_i$  as the sum of lateral and end areas is

$$S_i = \pi n_i \left[ D_i l_i + 2 \left( \frac{D_i}{2} \right)^2 \right] \quad (\text{E.03})$$

We assume all propellant burns in a direction perpendicular to the grain surface. During the current time step, a laminar layer is consumed which has total volume  $V_i^*$  approximated by

$$V_i^* = n_i S_i \epsilon_i \quad (\text{E.04})$$

where  $\epsilon_i$  is the depth burned during the step. As long as the time increment is small and no gross change of grain geometry occurs during the step, then we may use  $V_i^*$  to calculate pressure increase. Each physical dimension affected by the loss of solid propellant is updated before the next time step, when surface and remaining volume are recalculated. For generality, we may define the lateral surfaces with a specific burning rate function, the end surfaces with a second burning rate, and a third function for any perforation surfaces.

If a major change occurs in the propellant geometry, as in this case when current grain diameter is  $D_i^*$  and

$$D_i^* \leq 2\epsilon_i \quad (\text{E.05})$$

then the grain has extinguished and all remaining volume has burned. IBHVG2 checks for this and similar cases on different grain types; the appropriate time step is decreased to find the exact time where geometry is flagged, and an output line is printed to notify the user.

All multiperforated grains develop fragments when depth burned reaches one-half web distance. The method of calculation differentiates between inner and outer slivers, as described in Reference [10].

HEX is a general form for right hexagonal grains. The geometry assumes at least one central perforation; additional perforations are described by a value for NRNG. NRNG=1 will provide a seven-perforated hexagonal grain; NRNG=2 will be a nineteen-perf hexagonal grain. The number of perforations possible is theoretically unlimited. Web distance is a required input; perforation diameter and grain length may be described directly or as ratios to given dimensions. Major diameter is computed from a combination of web distances and perforation diameters.

We attempt to generalize the right circular cylindrical grain for more than nineteen perforations to the type MONO. This is an experimental grain type currently under consideration. The idea is based on the catalytic monoliths currently found in automobile mufflers to reduce air pollution. It is hoped that recent advances in extrusion technology used to make the ceramic catalytic monoliths can be transferred to propellant manufacture. The concept is novel because the dimensions are on the order of the diameter of the gun tube. Conceptually, there is no difference in modeling this type of grain than a standard multi-perfed grain. The grain length, web distance, and diameters (perforation and grain) are required inputs. The routine will calculate the number of perforations consistent with the given dimensions.

We have a user-definable form function, GEN, in the guise of two input arrays containing data pairs describing depth burned versus total surface area of propellant grains. This allows use of irregularly shaped grain forms as long as the user can describe the surface function. Test case 2 found in Appendix C demonstrates the use of a general form function approximating a 7-perf geometry.

Often real propellants are made in a series of layers. For example, an outer layer may consist of a thin, slow-burning layer applied over a fast-burning central propellant core. Each propellant geometry must have a core layer (designated as layer 4), and may have up to three more layers. The depth of the transitions between layers is order-dependent in the input deck description, with associated burning rates, densities, and other physical properties similarly defined. IBHVG2 keeps track of these layers during the deflagration process and signals to the user when each transition has been accomplished. Variation of density in grain layers affect grain weight so that for the  $i^{\text{th}}$  propellant having  $j$  distinct layers, Equation (E.02) becomes

$$m_i = \frac{C_i}{\sum_j V_{ij} \rho_{ij}} \quad (\text{E.06})$$

## V. APPENDICES

### A. Nomenclature

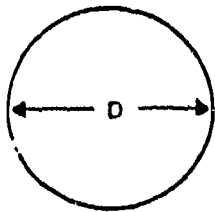
Symbol	Definition	Units
$\alpha$	exponent in burning-rate expression	varies
$\beta$	coefficient in burning-rate expression	varies
$\gamma$	specific heat ratio, $c_p/c_v$	—
$\delta$	wall shell thickness	in
$\Delta$	Pidduck-Kent constant	—
$e$	distance burned into propellant	in
$\eta$	propellant covolume	$\text{in}^3/\text{lb}_m$
$\lambda$	friction factor	—
$\omega$	rotational distance	radians
$\rho$	density	$\text{lb}_m/\text{in}^3$
$r$	gun tube rifling	calibers / $2\pi$
$\theta$	angle of rotation	radians
$\Theta$	charge/projectile mass ratio	—
$\zeta$	burning rate augmentation factor	—
$a, b, c, d, e$	Pidduck-Kent coefficients	—
$c_p$	specific heat at constant pressure	in $\text{lb}_f, \text{lb}_m^{-1} \cdot \text{K}^{-1}$
$c_v$	specific heat at constant volume	in $\text{lb}_f, \text{lb}_m^{-1} \cdot \text{K}^{-1}$
$f$	fraction of friction work converted to heating the tube	—
$g$	acceleration due to gravity	$\text{in}/\text{sec}^2$
$h$	heat transfer coefficient	$\text{lb}_f, \text{ft}^{-2} \cdot \text{K}^{-1}$
$l$	length	in
$m$	charge weight	$\text{lb}_m$
$n$	number of propellant grains	—
$p$	Pidduck-Kent parameter	—
$r$	propellant regression rate	in / sec
$t$	time	sec
$v$	velocity	in / sec
$x$	travel coordinate, ground reference frame	in
$z$	travel coordinate, tube reference frame	in
$A$	area	$\text{in}^2$
$C$	unburnt propellant	$\text{lb}_m$
$D$	diameter	in
$E$	energy	$\text{ft lb}_f$



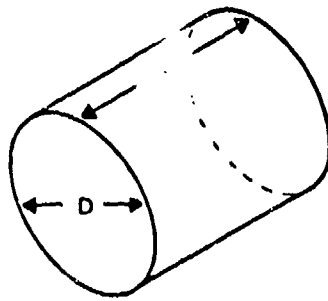
Symbol	Definition	Units
<i>F</i>	propellant "force"	$ft\ lb_f / lb_m$
<i>I</i>	moment of inertia	$lb_m\ in^2$
<i>L</i>	energy losses	$ft\ lb_f$
<i>P</i>	pressure	$lb_f / in^2$
<i>Q</i>	heat loss	$ft-lb_f$
<i>R</i>	universal gas constant	$ft\ lb_f\ mole^{-1}\ ^\circ K^{-1}$
<i>T</i>	temperature	$^\circ K$
<i>V</i>	volume	$in^3$

Subscript	Definition
<i>air</i>	property due to air in gun tube
<i>b</i>	bore
<i>base</i>	base of projectile
<i>breech</i>	breech of gun chamber
<i>c</i>	chamber
<i>drag</i>	resistance to motion
<i>f</i>	flame property
<i>free</i>	available space for propellant gases
<i>frict</i>	frictional property
<i>heat</i>	heat-induced property
<i>i</i>	propellant charge number
<i>j</i>	propellant grain surface
<i>k</i>	propellant type w.r.t. chemical/energetic properties
<i>mean</i>	averaged property
<i>p</i>	projectile
<i>prop</i>	propellant
<i>r</i>	recoil
<i>res</i>	frictional resistance
<i>rotat</i>	rotational property
<i>s</i>	primer property
<i>trans</i>	translational
<i>v</i>	free volume
<i>w</i>	wall property
$\phi$	initial

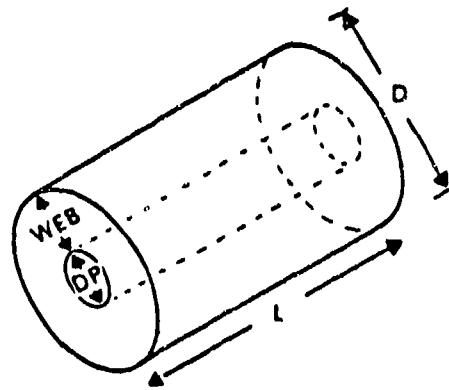
## B. Propellant Grain Configurations



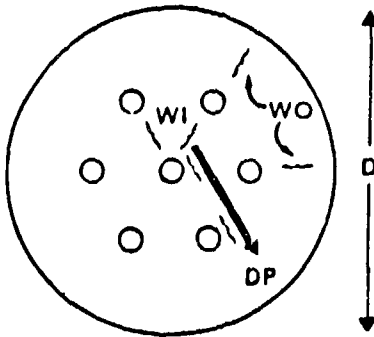
Ball



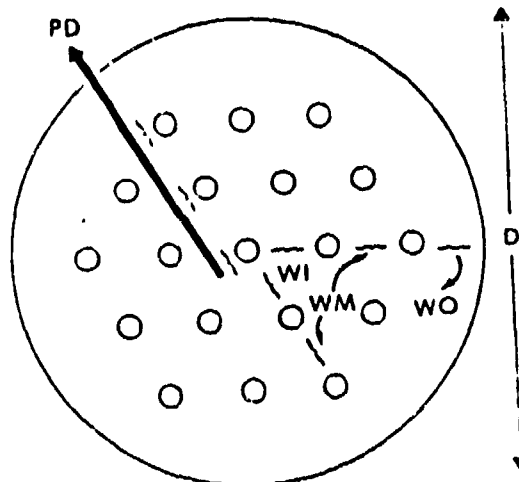
Cord



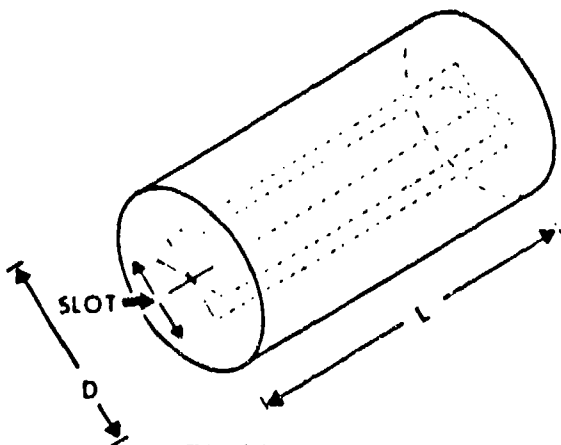
Single-Perf



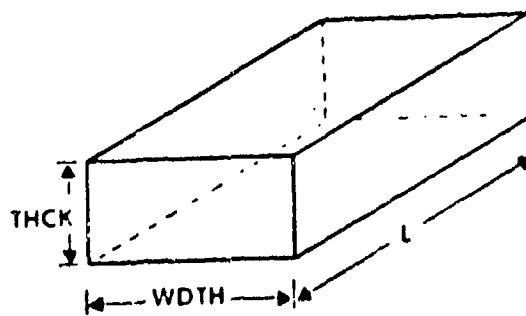
7-Perf



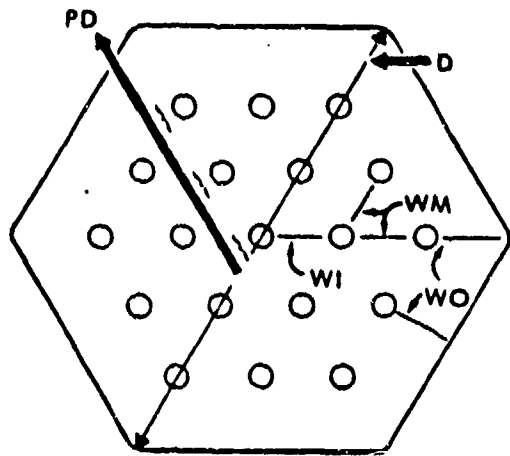
19-Perf



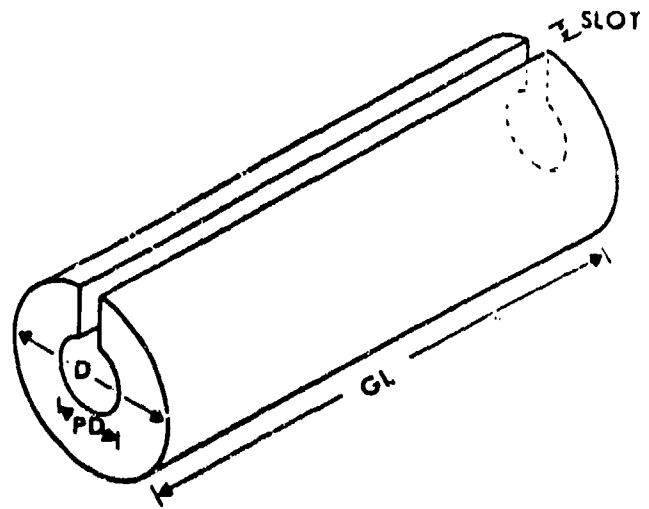
Pie (showing NSLT=3)



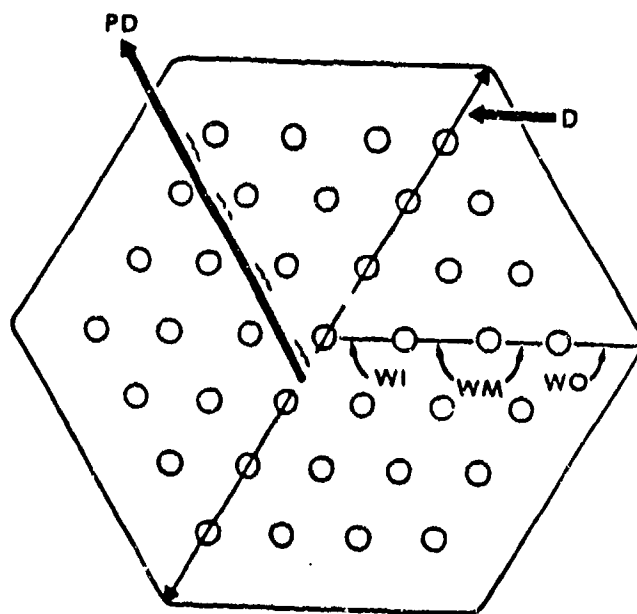
Strip (Rectangular)



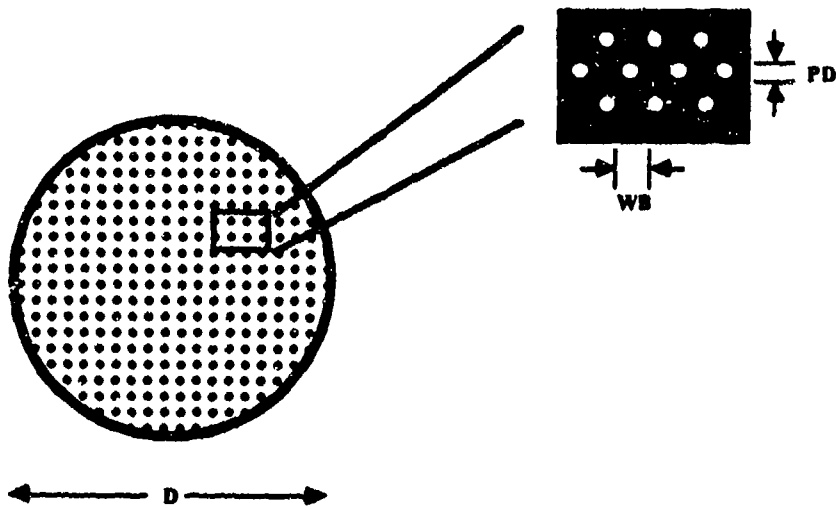
10-Perf, Hexagonal



Slotted Stick

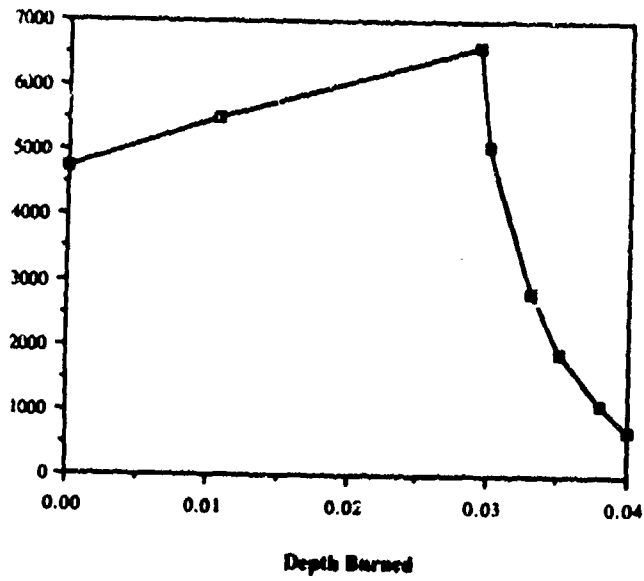


37-Perf, Hexagonal



Monolithic

Surface Function used in Test Case 2



General

### C. Installation

IBHVG2 (Version 400 and higher) has been re-designed for use with computers having no less than a 32-bit word length. Although the software may run on a shorter word-length machine, the precision of the output and ease of use will suffer greatly since the default tolerances require at least five significant digits. For example, the default pressure tolerance on a PMAX calculation is 1 psi, and normal pressure ranges are 10 kpsi and higher for most calculations. Therefore, a computer which does not have five decimal digit accuracy cannot reliably solve for pressure within default tolerance.

The first line of output from IBHVG2.400 is a CPU-dependent indicator of the attainable accuracy of a floating-point computation. The code computes the "machine epsilon" as commonly defined in numerical analysis. The pseudo-code shown below illustrates both the definition and the implementation.

```
i ← 0
repeat
  i ← i+1
  ε ← 2-i
until ( 1.0 ≥ 1.0 + ε )
```

The value of  $\epsilon$  which terminates the loop is printed and saved in variable ERRTOL. It is typically on the order of  $10^{-7}$  on 32-bit computers and  $10^{-15}$  on 64-bit systems. ERRTOL is used for deciding when iterative solutions have converged to within the precision of a given machine.

IBHVG2.400 has been benchmarked and tested on computers using the FORTRAN66 and FORTRAN77 compilers. Some non-portable FORTRAN exists in the code and a description follows:

#### Main Program IBHVG

The PROGRAM statement is required to define I/O parameters in certain systems, while others only need to define the entry point. For the former, I/O devices are:

#	Unit Name	Description
5	NDEVI	Standard Input device
6	NDEVO	Standard Output device
7	NDEVS	When \$INFO deck option SOPT=1 or 2, this device saves output copy for user-supplied post-processing
9	NDEVT	Temporary character-manipulation device

All are formatted I/O devices, as opposed to unformatted binary files. NOTE: On many systems, more than one run may execute at any given time. Be sure that the separate runs do not overlap on I/O devices.

### Subroutine CRKNUM

IBHVG2 writes characters, integers, and floating-point numbers to NDEVT and reads them back later for format conversion; CRKNUM handles the character-to-number conversion process. Since some operating systems use only upper-case alphabetic characters, and others may use lower-case letters, a provision has been made to interpret 'e' and 'd' as 'E' and 'D' during the conversion. Variables SMALLE and SMALLD should contain the lower-case letters. While transferring source code between systems, these characters often are converted to upper-case unintentionally.

### Subroutine HELPPR

Array HOLD is used for run-time format development. Many FORTRAN77 compilers require that HOLD be declared as a CHARACTER array; FORTRAN66 does not recognize the CHARACTER statement.

### Subroutine RDLINE

Reads input line and prints copy to standard output device. RDLINE must recognize the situation when end-of-input is reached. FORTRAN66 and FORTRAN77 use different end-of-file routines; use one of the given examples or re-write to suit the compiler.

### Subroutine RUNDAT

Contains most of the machine-dependent coding, including a section which can be used to insert current date and time (if available from the CPU). Array DAYR holds the date; array TIMR holds the time. The original program opted for a 'DD-MMM-YY' and 'HH:MM:SS' format, but can be put in any format which will fit in the 12-character arrays. The arrays will be printed at the top of each page, along with the current run title. This feature has been commented out in the distribution deck in order to obtain maximum compiler flexibility. A section of interactive control statements concerning availability of input/output files has been added for IBM/PC-AT users.

When compiling, non-fatal warnings may occur in FORTRAN77 because non-character arrays are being filled with alphanumeric information. Ignore them if possible. After compilation, link the object code with standard FORTRAN libraries (including SIN, COS, MOD, SQRT, etc.).

## D. Bugs

Sometimes, a particular calculation will not converge due to the integration algorithm. This has not been fully explored, but an eject mechanism has been installed in the KUTMER subroutine to indicate an error whenever ballistic time does not advance in twenty integration steps. A common action to relieve the thrashing is to change the integration step size (DT in the \$INFO deck). Because of this weakness in IBHVG2, one should monitor the calculations closely, observing that the solution is progressing, or one should use "time" cards or other time-limiting features of one's computer operating system to minimize endless computations. The integration routine is known to be suspect, and will be replaced in a future version.

IBHVG2 occasionally has serious problems with 37-perf propellant. The symptom is a sudden change in peak pressure and muzzle velocity with a tiny change in web dimension. It's almost as if, at the time of slivering, propellant gases come together to reform solid propellant. We are checking on this one; in the meantime, trust 37-perf simulations only after varying webs over a range around your final solution.

Due to the accuracy limitations of the integration routines, IBHVG2 will often seem to find successive pressure maximums and minimums when they do not co-exist in real situations. The overall maximums will be correctly reported in the end-of-trajectory summary. Extreme care must be taken if the user attempts to find values for the second (or later) pressure peaks (i.e.,  $NPMX > 1$  in the \$PMAX deck) since the numeric fluctuations will be treated as actual pressure peaks.

Some users have had trouble with using the \$FIND option. The problem can usually be traced to a poor initial guess to start off the optimization. The algorithm encoded is relatively weak and requires a better guess than perhaps more modern techniques. Therefore, we suggest that \$FIND be used with knowledge of its limitations and to apply some caution. It would not be unreasonable to perform a \$PARA iteration around the answer obtained with the \$FIND just to make sure. If the option converges correctly for your particular problem, it has proven to be quite useful in charge design.

## E. Sample Input Decks and Outputs

Sample input decks follow. The corresponding outputs are among the files on the distribution media. These were run on a Perkin-Elmer 3252 (32-bit word) running AT&T UNIX System V, Release 2.0 and compiled using the 'f77' compiler. The calculations match closely with those of a CDC 7600 running NOS (64-bit word). Other machines checked were: DEC VAX/780 running VMS, IBM PC/AT running MSDOS with floating point, DEC VAX/780 running UNIX 4.2 BSD, and Cray X/MP-48 running COS (64-bit word).

Below is a table showing some execution times of the different inputs on some representative hardware. We are trying to give an approximate feel for performance on a mainframe computer, a minicomputer, and a microcomputer. As one can readily see, the most appropriate environment depends on what type of problem you are involved with. If the code was to estimate the behavior of a given input (few iterations), then the microcomputer will deliver the answer in a minute or two. On the other hand, complex optimization problems can require minutes of mainframe time.

Case	CPU Time (seconds)		
	Cray X/MP-48	VAX 780	IBM PC/AT
1	0.4	26.4	93
2	0.7	38.5	122
3	4.7	267.4	1054
4	2.8	115.9	868
5	14.9	526.7	4912
6	13.5	634.8	3895

One interesting quirk which might be noticed by the reader is that the ordering of the run times is not consistent among the different machines. For example, case 5 took less time to compute on the Cyber and the PC than case 6, while the order is reverse on the VAX. This is caused by the precision of the arithmetic with the intermediate results. The Cray has a 64-bit word at single-precision and the PC's floating point processor computes to 80 bits; the VAX is using only 32 bits of precision. We speculate that there are some convergence problems for these cases which are causing more difficulty for the VAX than the other two machines. Ideally, the integration routine should recognize this and compensate accordingly, but this remains a future project.



## Test Case 1

This input deck represents a minimum IBHVG2 run. The two methods of commenting input decks are shown (\$COMM and after \$ on any input card). Note that all the primer in the \$PRIM deck is considered burnt at the start of calculation. A good practice for primer/igniter definition is to separate the igniter into two pieces so that a large amount of energetic material is not suddenly introduced into the gun chamber. One piece should be a \$PRIM deck including just enough to ignite the rest of the primer as a \$PROP deck. (Usually about 10 percent of the igniter in \$PRIM seems to work well.) Also notice that the second propellant geometry input does not include a main diameter since it is calculated in the form function subroutine. Blank lines and other white space between input deck sections allow easy readability, but are not necessary.

---

```
$COMM      IBHVG2 BENCHMARK TEST CASE 1
           HARP GUN WITH M30 PROP 7P

$INFO     POPT=1,1,1,0 $ ECHO INPUT LINES, PRINT TRAJECTORY + SUMMARY
           RUN='M30 7-PERF - LOT UNKNOWN'

$GUN      NAME='HARP GUN'
           CHAM=4378 GRVE=7.292  LAND=7.292 $ SMOOTH BORE
           TRAV=570.5 TWST=99

$COMMENT  PRIMER IS ASSUMED ALL BURNED AT TIME=0.0
           IGNITER CHARGE IS PROPELLANT 1
           MAIN CHARGE IS PROPELLANT 2

$PRIM     NAME='BLK POWDER'  CHWT=0.0154
           GAMA=1.25  FORC=96000  COV=30  TEMP=2000

$PROP     NAME='BLK POWDER'  CHWT=1.5  GRAN='CORD'
           LEN=0.198  DIAM=0.098  RHO=0.06
           GAMA=1.25  FORC=96000  COV=35  TEMP=2000
           ALPH=0.0  BETA=20

$PROP     NAME='M30 LOT UNKNOWN'  CHWT=55  GRAN='7PF'
           LEN=0.672  PD=0.026  WEB=0.0457  RHO=0.0607
           GAMA=1.2441  FORC=359876  COV=28.441  TEMP=3012
           NTBL=4  PR4L=6000,10000,12000,40000  BR4L=2.0,2.56,2.75,5.94

$COMMENT  NOMINAL PROJECTILE AND RESISTANCE PROFILE

$PROJ     NAME='PLASTIC LAB SABOT' PRWT=52

$RESI     NPTS=4
           TRAV=0, 0.3, 3, 600
           PRES=100, 4000, 1800, 800

$END
```

---

*Producing the following output:*

ERRTOL= 4.768372E-07

```
CARD 1 --> $COMM
CARD 2 --> IBMVG2 BENCHMARK TEST CASE 1
CARD 3 -->
CARD 4 --> HARP GUN WITH M30 PROP 7P
CARD 5 -->
CARD 6 --> $INFO $ ECHO INPUT LINES, PRINT TRAJECTORY + SUMMARY
CARD 7 --> POPT=1,1,1,0
CARD 8 --> RUN='M30 7-PERF - LOT UNKNOWN'
CARD 9 -->
CARD 10 --> $GUN
CARD 11 --> NAME='HARP GUN'
CARD 12 --> CHAM=4378 GRVE=7.292 LAND=7.292 $ SMOOTH BORE
CARD 13 --> TRAV=570.5 TWST=99
CARD 14 -->
CARD 15 --> $COMMENT
CARD 16 --> PRIMER IS ASSUMED ALL BURNED AT TIME=0.0
CARD 17 --> IGNITER CHARGE IS PROPELLANT 1
CARD 18 --> MAIN CHARGE IS PROPELLANT 2
CARD 19 --> $PRIM
CARD 20 --> NAME='BLK POWDER' CHWT=.0154
CARD 21 --> GAMA=1.25 FORC=96000 COV=30 TEMP=2000
CARD 22 --> $PROP
CARD 23 --> NAME='BLK POWDER' CHWT=1.5 GRAN='COPD'
CARD 24 --> LEN=.198 DIAM=.098 RHO=0.06
CARD 25 --> GAMA=1.25 FORC=96000 COV=35 TEMP=2000
CARD 26 --> ALPH=0.0 BETA=20
CARD 27 --> $PROP
CARD 28 --> NAME='M30 LOT UNKNOWN' CHWT=55 GRAN='7PF'
CARD 29 --> LEN=.672 FU=.026 WEB=.0457 RHO=0.0607
CARD 30 --> GAMA=1.2441 OPC=359876 COV=28.441 TEMP=3012
CARD 31 --> NTBL=4 PR4L=6000,10000,12000,40000 BR4L=2.0,2.56,2.75,5.94
CARD 32 -->
CARD 33 --> $COMMENT
CARD 34 --> NOMINAL PROJECTILE AND RESISTANCE PROFILE
CARD 35 --> $PROJ
CARD 36 --> NAME='PLASTIC LAB SABOT' PRWT=52
CARD 37 --> $RESI
CARD 38 --> NPYS=4
CARD 39 --> TRAV=0 .3 3 600
CARD 40 --> PRES=100, 4000, 1800, 800
CARD 41 --> $END
```

-----  
 - GUN TUBE -  
 -----

TYPE: MARP GUN  
 GROOVE DIAMETER (IN): 7.292  
 TWIST (CAL/S/TURN): 99.0  
 SHELL THICKNESS (IN): 0.004000  
 INITIAL SHELL TEMP (K): 293.  
 CHAMBER VOLUME (IN3): 4378.00  
 LAND DIAMETER (IN): 7.292  
 BORE AREA (IN2): 41.7622  
 SHELL CP (IN-LB/LB-K): 1648.0  
 AIR NO (IN-LB/IN2-S-K): 0.06480  
 TRAVEL (IN): 570.50  
 GROOVE/LAND RATIO (-): 0.000  
 HEAT-LOSS OPTION: 1  
 SHELL DENSITY (LB/IN3): 0.2840

-----  
 - PROJECTILE -  
 -----

TYPE: PLASTIC LAB SABOT  
 TOTAL WEIGHT (LB): 52.000  
 WEIGHT PREDICTOR OPTION: 0

-----  
 - RESISTANCE -  
 -----

AIR RESISTANCE OPTION: 1  
 WALL HEATING FRACTION: 0.000  
 FRICTION TABLE LENGTH: 4  
 1 TRAVEL (IN) PRESSURE (PSI) 1 TRAVEL (IN) PRESSURE (PSI)  
 1 0.00 100. 4 600.00 800.  
 2 0.50 4000.

-----  
 - GENERAL -  
 -----

MAX TIME STEP (S): 0.000100  
 PRINT OPTIONS: 1 1 1 0 1 1  
 GRADIENT MODEL: LAGRANGIAN  
 PRINT STEP (S): 0.000000  
 STORE OPTION: 0  
 MAX RELATIVE ERROR (-): 0.00200  
 CONSTANT-PRESSURE OPTION: 0

-----  
 - RECOIL -  
 -----

RECOIL OPTION: 0  
 TYPE: 0  
 RECOILING WEIGHT (LB): 0.

-----  
 - PRIMER -  
 -----

TYPE: BLK POWDER  
 COVOLUME (IN3/LB): 50.000  
 GAMMA (-): 1.2500  
 FLAME TEMP (K): 2000.0  
 FORCE (FT-LB/LB): 96000.  
 WEIGHT (LB): 0.015400

- CHARGE 1 -

TYPE: BLK POWDER  
 EROSION COEFF (-):  
 GRAIN LENGTH (IN):

0.000000  
 0.198000

GRAINS:  
 CHARGE ICM CODE:  
 GRAIN DIAMETER (IN):

16739.  
 0.098000

CORR  
 0

WEIGHT (LB):  
 CHARGE ICM AT (\$):

1.5000  
 0.000000E+00

PROPERTIES AT LAYER BOUNDARIES OF END SURFACES  
 1ST 2ND 3RD 4TH

PROPERTIES AT LAYER BOUNDARIES OF LAT SURFACES  
 1ST 2ND 3RD 4TH

AT DEPTH (IN):  
 ADJACENT LAYER WT %:  
 DENSITY (LB/IN<sup>3</sup>):  
 GAMMA (-):  
 FORCE (FT-LB/LB):  
 CONVOLUME (IN<sup>3</sup>/LB):  
 FLAME TEMP (K):  
 BURNING RATE EXPS:  
 BURNING RATE COEFFS:

0.000000  
 100.0000  
 0.060000  
 1.2500  
 960000.  
 35.0000  
 2000.0  
 0.00000  
 20.00000000

0.000000  
 100.0000  
 0.060000  
 1.2500  
 960000.  
 35.0000  
 2000.0  
 0.00000  
 20.00000000

- CHARGE 2 -

TYPE: 100 LOT UNKNOWN	GRAINS: 27128.	79F	0	55.0000
EROSIVE COEFF (-):	CHARGE IGM CODE:	0	0	0.00000E+00
GRAIN LENGTH (IN):	GRAIN DIAMETER (IN):	0.26080	0.26080	0.022600
INNER WEB (IN):	OUTER WEB (IN):	0.04570	0.04570	

	PROPERTIES AT LAYER BOUNDARIES OF PERF SURFACES			
	1ST	2ND	3RD	4TH
AT DEPTH (IN):	0.00000			0.00000
ADJACENT LAYER WT %:				100.000
DENSITY (LB/IN3):	0.06070			0.06070
GAMMA (-):	1.2441			1.2441
FORCE (FT-LB/LB):	359876.			359876.
COVOLUME (IN3/LB):	28.441			28.441
FLAME TEMP (K):	3012.0			3012.0
MEAN PRESSURES (PSI):	6000.0			6000.0
MEAN PRESSURES (PSI):	10000.0			10000.0
MEAN PRESSURES (PSI):	12000.0			12000.0
MEAN PRESSURES (PSI):	40000.0			40000.0
BURNING RATES (IN/S):	2.00			2.00
BURNING RATES (IN/S):	2.56			2.56
BURNING RATES (IN/S):	2.75			2.75
BURNING RATES (IN/S):	5.94			5.94

	PROPERTIES AT LAYER BOUNDARIES OF LAT SURFACES			
	1ST	2ND	3RD	4TH
AT DEPTH (IN):	0.00000			0.00000
ADJACENT LAYER WT %:				100.000
DENSITY (LB/IN3):	0.06070			0.06070
GAMMA (-):	1.2441			1.2441
FORCE (FT-LB/LB):	359876.			359876.
COVOLUME (IN3/LB):	28.441			28.441
FLAME TEMP (K):	3012.0			3012.0
MEAN PRESSURES (PSI):	6000.0			6000.0
MEAN PRESSURES (PSI):	10000.0			10000.0
MEAN PRESSURES (PSI):	12000.0			12000.0
MEAN PRESSURES (PSI):	40000.0			40000.0
BURNING RATES (IN/S):	2.00			2.00
BURNING RATES (IN/S):	2.56			2.56
BURNING RATES (IN/S):	2.75			2.75
BURNING RATES (IN/S):	5.94			5.94

TIME (MS)	TRAV (IN)	VEL (FT/S)	ACC (G)	BREECH PRESS (PSI)	MEAN PRESS (PSI)	BASE PRESS (PSI)	MEAN TEMP (K)	FRAC BURN 1	FRAC BURN 2
0.000	0.00	0.	0.	5.	5.	5.	2000.	0.000	0.000
0.100	0.00	0.	0.	94.	94.	94.	2329.	0.099	0.001
0.106	0.00	0.	0.	100.	100.	100.	2337.	0.104	0.001
SHOT-START PRESSURE ACHIEVED									
0.200	0.00	0.	66.	227.	212.	182.	2432.	0.191	0.002
0.300	0.00	0.	147.	386.	353.	287.	2501.	0.277	0.003
0.400	0.00	1.	235.	567.	514.	408.	2554.	0.356	0.005
0.500	0.00	2.	327.	768.	694.	546.	2597.	0.431	0.007
0.600	0.01	3.	420.	986.	891.	702.	2634.	0.499	0.009
0.700	0.01	5.	511.	1221.	1106.	875.	2665.	0.562	0.012
0.800	0.02	6.	597.	1471.	1337.	1068.	2693.	0.620	0.015
0.900	0.03	8.	674.	1757.	1585.	1280.	2717.	0.673	0.018
1.000	0.04	11.	741.	2016.	1848.	1514.	2739.	0.720	0.021
1.100	0.	13.	796.	2308.	2128.	1769.	2759.	0.764	0.025
1.200	0.	16.	837.	2613.	2425.	2047.	2777.	0.803	0.029
1.300	0.09	19.	862.	2931.	2737.	2348.	2793.	0.838	0.033
1.400	0.11	21.	872.	3262.	3065.	2672.	2808.	0.868	0.037
1.500	0.14	24.	865.	3505.	3410.	3020.	2822.	0.895	0.042
1.600	0.17	27.	842.	3961.	3771.	3391.	2834.	0.919	0.047
1.700	0.21	30.	804.	4330.	4149.	3786.	2846.	0.938	0.052
1.800	0.24	32.	753.	4713.	4543.	4203.	2857.	0.955	0.058
1.900	0.28	34.	689.	5110.	4954.	4643.	2867.	0.969	0.064
2.000	0.33	37.	827.	5569.	5383.	5009.	2876.	0.980	0.070
2.100	0.37	40.	1112.	6079.	5828.	5327.	2884.	0.988	0.076
2.200	0.42	44.	1409.	6610.	6292.	5656.	2892.	0.994	0.082
2.300	0.48	49.	1719.	7160.	6773.	5997.	2899.	0.998	0.089
2.400	0.54	55.	2043.	7732.	7271.	6350.	2906.	1.000	0.096
2.450	0.57	58.	2211.	8026.	7527.	6530.	2909.	1.000	0.100
PROPELLANT 1 BURNED OUT									
2.500	0.61	62.	2382.	8325.	7788.	6714.	2911.	1.000	0.103
2.600	0.69	70.	2735.	8940.	8323.	7090.	2917.	1.000	0.111
2.700	0.78	80.	3105.	9578.	8877.	7477.	2922.	1.000	0.119
2.800	0.88	90.	3491.	10237.	9450.	7875.	2926.	1.000	0.127
2.900	1.00	102.	3895.	10919.	10041.	8284.	2929.	1.000	0.135
3.000	1.13	115.	4315.	11621.	10648.	8701.	2932.	1.000	0.144
3.100	1.27	130.	4752.	12340.	11268.	9125.	2935.	1.000	0.153
3.200	1.44	146.	5205.	13076.	11902.	9555.	2937.	1.000	0.162
3.300	1.63	164.	5677.	13833.	12552.	9991.	2939.	1.000	0.172
3.400	1.83	183.	6172.	14615.	13223.	10439.	2940.	1.000	0.181
3.500	2.07	203.	6690.	15423.	13914.	10896.	2941.	1.000	0.192
3.600	2.32	226.	7233.	16257.	14626.	11363.	2941.	1.000	0.202
3.700	2.61	250.	7801.	17116.	15356.	11838.	2941.	1.000	0.213
3.800	2.92	276.	8394.	17999.	16106.	12319.	2941.	1.000	0.225
3.900	3.27	304.	8882.	18876.	16873.	12866.	2940.	1.000	0.236
4.000	3.65	333.	9344.	19763.	17656.	13441.	2939.	1.000	0.249
4.100	4.07	364.	9815.	20658.	18454.	14027.	2938.	1.000	0.261
4.200	4.53	396.	10294.	21589.	19267.	14624.	2936.	1.000	0.274
4.300	5.02	430.	10780.	22523.	20092.	15229.	2934.	1.000	0.288
4.400	5.56	466.	11273.	23471.	20928.	15843.	2931.	1.000	0.302
4.500	6.14	503.	11771.	24428.	21773.	16463.	2928.	1.000	0.316
4.600	6.77	542.	12274.	25394.	22626.	17089.	2925.	1.000	0.331
4.700	7.44	582.	12779.	26366.	23483.	17719.	2921.	1.000	0.346
4.800	8.17	624.	13287.	27341.	24344.	18351.	2917.	1.000	0.362
4.900	8.94	668.	13795.	28318.	25207.	18984.	2917.	1.000	0.378
5.000	9.77	713.	14302.	29293.	26067.	19616.	2907.	1.000	0.395

TIME (MS)	TRAV (IN)	VEL. (FT/S)	ACC (G)	BREECH PRESS (PSI)	MEAN PRESS (PSI)	BASE PRESS (PSI)	MEAN TEMP (K)	FRAC BURN 1	FRAC BURN 2
5.100	10.65	760.	14808.	30264.	26925.	20245.	2902.	1.000	0.412
5.200	11.59	808.	15309.	31229.	27776.	20870.	2897.	1.000	0.429
5.300	12.59	858.	15806.	32184.	28619.	21489.	2891.	1.000	0.447
5.400	13.65	910.	16296.	33126.	29450.	22099.	2885.	1.000	0.466
5.500	14.78	963.	16779.	34053.	30269.	22700.	2879.	1.000	0.485
5.600	15.97	1018.	17252.	34963.	31072.	23290.	2872.	1.000	0.504
5.700	17.22	1074.	17714.	35852.	31857.	23866.	2865.	1.000	0.524
5.800	18.55	1132.	18164.	36718.	32621.	24427.	2858.	1.000	0.544
5.900	19.94	1191.	18601.	37558.	33363.	24972.	2851.	1.000	0.565
6.000	21.41	1252.	19024.	38371.	34080.	25499.	2843.	1.000	0.586
6.100	22.94	1314.	19431.	39154.	34771.	26006.	2836.	1.000	0.607
6.200	24.56	1377.	19821.	39905.	35434.	26493.	2828.	1.000	0.629
6.300	26.25	1441.	20194.	40622.	36067.	26958.	2820.	1.000	0.652
6.400	28.02	1507.	20548.	41303.	36669.	27400.	2812.	1.000	0.674
6.500	29.87	1574.	20883.	41948.	37238.	27818.	2803.	1.000	0.698
6.600	31.80	1641.	21198.	42555.	37774.	28211.	2795.	1.000	0.721
6.700	33.81	1710.	21493.	43123.	38275.	28580.	2786.	1.000	0.745
6.800	35.90	1780.	21767.	43651.	38741.	28922.	2778.	1.000	0.769
6.900	38.08	1850.	22020.	44139.	39172.	29239.	2769.	1.000	0.794
7.000	40.34	1922.	22252.	44586.	39567.	29529.	2761.	1.000	0.819
7.100	42.69	1994.	22463.	44992.	39926.	29793.	2752.	1.000	0.844
7.191	44.89	2059.	22539.	45141.	40057.	29890.	2743.	1.000	0.864
LOCAL PRESSURE MAX DETECTED									
7.191	44.89	2059.	22539.	45141.	40057.	29890.	2743.	1.000	0.864
LOCAL PRESSURE MIN DETECTED									
7.200	45.13	2066.	22539.	45140.	4005	29889.	2742.	1.000	0.866
LOCAL PRESSURE MAX DETECTED									
7.300	47.65	2139.	22465.	45001.	39934.	29800.	2731.	1.000	0.884
7.400	50.26	2211.	22298.	44680.	39651.	29593.	2720.	1.000	0.900
7.500	52.95	2282.	22058.	44221.	39246.	29296.	2708.	1.000	0.913
7.600	55.74	2353.	21759.	43649.	38742.	28926.	2695.	1.000	0.926
7.700	58.60	2422.	21413.	42986.	38156.	28497.	2682.	1.000	0.936
7.800	61.55	2491.	21028.	42247.	37504.	28019.	2669.	1.000	0.945
7.900	64.58	2558.	20611.	41447.	36798.	27501.	2655.	1.000	0.954
8.000	67.69	2623.	20168.	40597.	36048.	26951.	2641.	1.000	0.960
8.100	70.87	2687.	19706.	39710.	35265.	26376.	2627.	1.000	0.966
8.200	74.14	2750.	19234.	38805.	34467.	25790.	2613.	1.000	0.972
8.300	77.47	2811.	18759.	37893.	33662.	25200.	2599.	1.000	0.976
8.400	80.88	2871.	18283.	36979.	32856.	24608.	2585.	1.000	0.980
8.500	84.36	2929.	17808.	36067.	32051.	24018.	2571.	1.000	0.984
8.600	87.91	2986.	17337.	35161.	31251.	23430.	2557.	1.000	0.987
8.700	91.53	3041.	16869.	34263.	30458.	22849.	2542.	1.000	0.990
8.800	95.21	3094.	16407.	33375.	29675.	22274.	2528.	1.000	0.993
8.900	98.95	3146.	15952.	32501.	28903.	21707.	2514.	1.000	0.996
9.000	102.76	3197.	15505.	31641.	28144.	21150.	2500.	1.000	0.998
9.100	106.63	3246.	15065.	30796.	27398.	20603.	2486.	1.000	0.997
9.200	110.55	3294.	14635.	29969.	26668.	20066.	2472.	1.000	0.998
9.300	114.53	3341.	14215.	29160.	25954.	19542.	2458.	1.000	0.999
9.400	118.57	3386.	13804.	28369.	25256.	19029.	2444.	1.000	1.000
9.500	122.66	3429.	13403.	27598.	24575.	18529.	2430.	1.000	1.000
9.537	124.18	3445.	13257.	27317.	24327.	18347.	2425.	1.000	1.000
PROPELLANT 2 BURNED OUT									
9.600	126.79	3472.	13013.	26848.	23913.	18042.	2417.	1.000	1.000
9.700	130.99	3513.	12637.	26124.	23273.	17573.	2403.	1.000	1.000
9.800	135.23	3553.	12275.	25426.	22657.	17120.	2390.	1.000	1.000

TIME (MS)	TRAV (IN)	VEL (FT/S)	ACC (G)	BREECH PRESS (PSI)	MEAN PRESS (PSI)	BASE PRESS (PSI)	MEAN TEMP (K)	FRAC BURN 1	FRAC BURN 2
9.900	139.51	3592.	11926.	24753.	22063.	16683.	2377.	1.000	1.000
10.000	143.85	3630.	11589.	24104.	21490.	16263.	2364.	1.000	1.000
10.100	148.23	3667.	11265.	23479.	20938.	15857.	2351.	1.000	1.000
10.200	152.65	3703.	10952.	22876.	20406.	15465.	2339.	1.000	1.000
10.300	157.11	3737.	10651.	22294.	19892.	15087.	2326.	1.000	1.000
10.400	161.62	3771.	10361.	21733.	19397.	14723.	2314.	1.000	1.000
10.500	166.16	3804.	10081.	21192.	18919.	14372.	2302.	1.000	1.000
10.600	170.75	3836.	9811.	20670.	18458.	14032.	2291.	1.000	1.000
10.700	175.37	3867.	9550.	20167.	18013.	13705.	2279.	1.000	1.000
10.800	180.03	3898.	9299.	19680.	17583.	13389.	2267.	1.000	1.000
10.900	184.72	3927.	9056.	19211.	17168.	13083.	2256.	1.000	1.000
11.000	189.45	3956.	8822.	18757.	16768.	12788.	2245.	1.000	1.000
11.100	194.22	3984.	8596.	18320.	16381.	12503.	2234.	1.000	1.000
11.200	199.02	4011.	8378.	17897.	16007.	12228.	2223.	1.000	1.000
11.300	203.85	4038.	8167.	17488.	15646.	11961.	2213.	1.000	1.000
11.400	208.71	4064.	7964.	17093.	15296.	11704.	2202.	1.000	1.000
11.500	213.60	4089.	7767.	16710.	14959.	11455.	2192.	1.000	1.000
11.600	218.52	4114.	7577.	16341.	14632.	11214.	2182.	1.000	1.000
11.700	223.47	4138.	7394.	15984.	14316.	10981.	2172.	1.000	1.000
11.800	228.45	4162.	7216.	15638.	14010.	10755.	2162.	1.000	1.000
11.900	233.46	4185.	7044.	15303.	13714.	10536.	2152.	1.000	1.000
12.000	238.50	4207.	6878.	14979.	13428.	10325.	2143.	1.000	1.000
12.100	243.56	4229.	6717.	14665.	13150.	10120.	2133.	1.000	1.000
12.200	248.64	4250.	6562.	14361.	12881.	9921.	2124.	1.000	1.000
12.300	253.76	4271.	6411.	14067.	12621.	9728.	2115.	1.000	1.000
12.400	258.90	4292.	6266.	13781.	12368.	9542.	2106.	1.000	1.000
12.500	264.06	4312.	6124.	13504.	12123.	9360.	2097.	1.000	1.000
12.600	269.24	4331.	5988.	13236.	11886.	9185.	2088.	1.000	1.000
12.700	274.45	4350.	5855.	12976.	11655.	9014.	2080.	1.000	1.000
12.800	279.68	4369.	5727.	12724.	11432.	8849.	2071.	1.000	1.000
12.900	284.94	4387.	5602.	12479.	11215.	8688.	2063.	1.000	1.000
13.000	290.21	4405.	5482.	12241.	11004.	8532.	2054.	1.000	1.000
13.100	295.51	4422.	5365.	12010.	10800.	8380.	2046.	1.000	1.000
13.200	300.83	4439.	5251.	11786.	10601.	8233.	2038.	1.000	1.000
13.300	306.16	4456.	5141.	11568.	10408.	8090.	2030.	1.000	1.000
13.400	311.52	4473.	5034.	11356.	10221.	7950.	2022.	1.000	1.000
13.500	316.90	4489.	4930.	11151.	10039.	7815.	2014.	1.000	1.000
13.600	322.29	4504.	4829.	10951.	9862.	7683.	2007.	1.000	1.000
13.700	327.71	4520.	4732.	10756.	9689.	7555.	1999.	1.000	1.000
13.800	333.14	4535.	4637.	10567.	9522.	7430.	1992.	1.000	1.000
13.900	338.59	4550.	4544.	10384.	9359.	7309.	1984.	1.000	1.000
14.000	344.06	4564.	4455.	10205.	9200.	7190.	1977.	1.000	1.000
14.100	349.54	4578.	4368.	10030.	9045.	7075.	1970.	1.000	1.000
14.200	355.05	4592.	4283.	9861.	8895.	6963.	1963.	1.000	1.000
14.300	360.57	4606.	4201.	9696.	8748.	6854.	1956.	1.000	1.000
14.400	366.10	4619.	4120.	9535.	8606.	6747.	1949.	1.000	1.000
14.500	371.65	4632.	4043.	9378.	8467.	6643.	1942.	1.000	1.000
14.600	377.22	4645.	3967.	9226.	8331.	6542.	1935.	1.000	1.000
14.700	382.80	4658.	3893.	9077.	8199.	6443.	1928.	1.000	1.000
14.800	388.40	4670.	3822.	8932.	8070.	6347.	1922.	1.000	1.000
14.900	394.01	4683.	3752.	8791.	7945.	6252.	1915.	1.000	1.000
15.000	399.64	4695.	3684.	8653.	7822.	6161.	1909.	1.000	1.000
15.100	405.28	4706.	3618.	8519.	7703.	6071.	1902.	1.000	1.000
15.200	410.93	4718.	3553.	8388.	7586.	5983.	1896.	1.000	1.000
15.300	416.60	4729.	3491.	8260.	7472.	5896.	1890.	1.000	1.000



TIME (MS)	TRAV (IN)	VEL (FT/S)	ACC (G)	BREECH PRESS (PSI)	MEAN PRESS (PSI)	BASE PRESS (PSI)	MEAN TEMP (K)	FRAC BURN 1	FRAC BURN 2
15.400	422.28	4740.	3430.	8135.	7361.	5814.	1884.	1.000	1.000
15.500	427.97	4751.	3370.	8013.	7253.	5733.	1877.	1.000	1.000
15.600	433.68	4762.	3312.	7894.	7147.	5653.	1871.	1.000	1.000
15.700	439.40	4773.	3256.	7778.	7044.	5575.	1865.	1.000	1.000
15.800	445.14	4783.	3201.	7664.	6943.	5499.	1860.	1.000	1.000
15.900	450.88	4793.	3147.	7554.	6844.	5424.	1854.	1.000	1.000
16.000	456.64	4803.	3095.	7445.	6747.	5351.	1848.	1.000	1.000
16.100	462.41	4813.	3044.	7340.	6653.	5280.	1842.	1.000	1.000
16.200	468.19	4823.	2994.	7236.	6561.	5210.	1837.	1.000	1.000
16.300	473.98	4832.	2946.	7135.	6471.	5142.	1831.	1.000	1.000
16.400	479.79	4842.	2898.	7036.	6382.	5075.	1825.	1.000	1.000
16.500	485.60	4851.	2852.	6940.	6296.	5010.	1820.	1.000	1.000
16.600	491.43	4860.	2807.	6845.	6212.	4946.	1815.	1.000	1.000
16.700	497.27	4869.	2763.	6753.	6129.	4883.	1809.	1.000	1.000
16.800	503.12	4878.	2720.	6662.	6048.	4821.	1804.	1.000	1.000
16.900	508.98	4887.	2679.	6574.	5969.	4761.	1799.	1.000	1.000
17.000	514.85	4895.	2638.	6487.	5892.	4702.	1793.	1.000	1.000
17.100	520.72	4904.	2598.	6402.	5816.	4644.	1788.	1.000	1.000
17.200	526.61	4912.	2559.	6319.	5742.	4587.	1783.	1.000	1.000
17.300	532.51	4920.	2521.	6238.	5669.	4532.	1778.	1.000	1.000
17.400	538.42	4928.	2484.	6158.	5598.	4477.	1773.	1.000	1.000
17.500	544.34	4936.	2448.	6080.	5528.	4424.	1768.	1.000	1.000
17.600	550.27	4944.	2413.	6004.	5460.	4371.	1763.	1.000	1.000
17.700	556.21	4952.	2378.	5929.	5393.	4320.	1758.	1.000	1.000
17.800	562.15	4959.	2344.	5856.	5327.	4270.	1753.	1.000	1.000
17.900	568.11	4967.	2311.	5784.	5263.	4220.	1749.	1.000	1.000
17.960	570.50	4970.	2298.	5756.	5237.	4200.	1747.	1.000	1.000

PROJECTILE EXIT

CONDITIONS AT:	P <sub>MAX</sub>	MUZZLE
TIME (MS):	7.191	17.940
TRAVEL (IN):	44.89	570.50
VELOCITY (FT/S):	2059.	4970.
ACCELERATION (G):	22539.	2248.
BREECH PRESS (PSI):	45141.	5756.
MEAN PRESS (PSI):	40057.	5237.
BASE PRESS (PSI):	29890.	4200.
MEAN TEM <sup>o</sup> (K):	2743.	1747.
Z CHARGE 1 (-):	1.000	1.000
Z CHARGE 2 (-):	0.864	1.000

ENERGY BALANCE SUMMARY	IN-LB	%
TOTAL CHEMICAL:	979802624.	100.00
(1) INTERNAL GAS:	570262272.	58.20
(2) WORK AND LOSSES:	409540352.	41.80
(A) PROJECTILE KINETIC:	239312960.	24.42
(B) GAS KINETIC:	86697888.	8.85
(C) PROJECTILE ROTATIONAL:	120494.	0.01
(D) FRICTIONAL WORK TO TUBE:	0.	0.00
(E) OTHER FRICTIONAL WORK:	31748304.	3.24
(F) WORK DONE AGAINST AIR:	8165177.	0.83
(G) HEAT CONVECTED TO BORE:	43515312.	4.44
(H) RECOIL ENERGY:	0.	0.00
LOADING DENSITY (G/CM <sup>3</sup> ):	0.357	
CHARGE WT/PROJECTILE WT:	1.087	
PIEZOMETRIC EFFICIENCY:	0.225	
EXPANSION RATIO:	6.442	

## Test Case 2

This case demonstrates how to include two successive, but independent, runs as a single input file. The input descriptions do not overlap because the program will reset all parameters after an \$END card unless specifically told not to do so. The main propellant in the first sub-case is divided into three layers: outer layer (2) is a deterred propellant with a low burning rate, middle layer (3) is a thin transition zone, and the inner layer (4) is a fast-burning propellant. The transition zone is used to avoid an abrupt change in burning rates. Though all surfaces (lateral, end, and perforation) are defined for layers 2 and 3, the core layer has its end and perforation parameters overridden by the lateral inputs. Gun chamber length is defined as 5 inches, and pressure gages are specified at the breech end (position at -5.0 inches with respect to the base of projectile) and at the projectile end (position 0.0 inches) of the chamber. The default equations for finding internal pressures are Lagrangian, but Pidduck-Kent is used in this case.

The second data set also uses the Pidduck-Kent gradient to solve for internal pressures. A prominent feature here is the form function 'GEN' instead of the standard '7PF' granulation. The data for the depth-burned versus surface array came from a similar run where DB-P and SRF(2) were printed as part of the trajectory information. (See input descriptions for \$TDIS, \$TRAJ, and \$INFO decks.) Again, the igniter has been split into two parts with a small portion as \$PRIM and the rest as the first \$PROP deck. Blank lines and liberal indents allow easy readability, but are not necessary.

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### SCOMMENT

IBHVG2 BENCHMARK TEST CASE 2

TWO INDEPENDENT DATA SETS IN ONE IBHVG2 RUN

FIRST SET : Laterally Deterred Propellant  
(Very thin transition zone between outer and inner  
propellant types, resulting in three layers)  
1 - Deterrent, .0007 thick, low B/R exponent  
2 - Transition zone, .0001 thick, from low to hi exp  
3 - Core propellant, hi burning rate

SECOND SET : STANDARD 105MM CANNON  
PIDDUCK-KENT INTERNAL PRESSURE GRADIENT EQUATION  
USE GENERAL GRAIN FORM F/ANCTION

### SheAT

TSWL = 0.00450      CSHL = 1848      RSHL = 0.284  
TWAL = 293          HO = 0.0648      HL = 1

### SGUN

NAME='X4881 25MM APFSDS-T'    CHAN=5.86    GRVE=0.988    LAND=0.980  
G/L=1.    TRAV=74    TWST=25  
CLEN=5    NGAG=2    GLOC=-5,0

### SPROJ

NAME = 'APFSDS-T'    PRWT = 0.170

### SRESI

NPTS = 4                    AIR = 1  
TRAV =    0,    0.2,    1.0,    74  
PRES =    200,    2000,    400,    400

### SINFO

RUN = '120MATCH-1824881'    DELT = 5E-5    DELP = 5E-5  
GRAD = 2                    POPT = 1,1,0,2    SOPT = 0  
EPS = 0.002                COMP = 0

SRECO  
NAME = 'NONE' RECO = 0 RCWT = 0

SPRIM  
NAME='U/KNO3' CHWT=0.00022  
GAMA = 1.25 FORC = 212500  
COV = 30 TEMP = 2000

SROP  
NAME='M10 7P' CHWT=0.2071 GRAN='7PF'  
RHO=0.06 GAMA=1.2385 FORC=330000  
COV=27.04 TEMP=3073 EROS=0  
NTBL=-1  
PR2P=100000 PR2E=100000 PR2L=100000  
PR3P=100000 PR3E=100000 PR3L=100000  
PR4L=100000  
CF2P=.00289 CF2E=0.00289 CF2L=0.00289  
EX2P=0.678 EX2E=0.678 EX2L=0.678  
CF3P=0.00289 CF3E=0.00289 CF3L=0.00289  
EX3P=0.678 EX3E=0.678 EX3L=0.678  
CF4L=0.004656 EX4L=0.7061  
DEPP=,0.0007,0.0008 DEPE=,0.0007,0.0008 DEPL=,0.0007,0.0008  
LEN=0.0972 DIAM=0.0928 PD=0.0058  
WI=0.0175 WD=0.0202

SEND

SHEAT  
TSHL = 0.00450 CSHL = 1848 RSHL = 0.284  
TVAL = 293 HD = 0.0648 HL = 1

SGUM  
NAME = '105-MM GUM M68' CHAM = 375 GRVE = 4.224  
LAND = 4.134 G/L = 2. TRAV = 187  
TWST = 99

SPROJ  
NAME = 'M456A2' PRUT = 23.2

SRESI  
NPTS = 4 AIR = 1  
TRAV = 0, 0.5, 8.0, 187  
PRES = 100, 2100, 500, 200

SINFO  
RUN = '105MATCH-1105' DELT = 5E-5 DELP = 5E-5  
GRAD = 2 POPT = 1,1,1,0,2 SOPT = 0  
EPS = 0.002 COMP = 0

SRECO  
NAME = 'NONE' RECO = 0 RCWT = 0

SPRIM  
NAME = 'BENITE' CHWT = 0.001  
GAMA = 1.25 FORC = 212500  
COV = 30 TEMP = 2000

SROP  
NAME = 'BENITE' CHWT = 0.072 GRAN = 'CORD'  
RHO = 0.06 GAMA = 1.25 FORC = 212500  
COV = 30 TEMP = 2000 EROS = 0.00000  
ALPH = 0 BETA = 10 IGNC = 0  
LEN = 10. DIAM = 0.08

SROP  
NAME = 'M30 7P' CHWT = 11.9 GRAN='GEN'  
RHO = 0.0607 GAMA = 1.241 FORC = 360000  
COV = 29.11 TEMP = 3010 EROS = 0.000000  
NTBL=0 ALPH=0.8 BETA=0.001320  
\$ THE FOLLOWING PARAMETERS REPLACED BY DEPTH-BURNED/SURFACE ARRAY  
\$ LEN =0.63 DIAM = 0.3087 PD = 0.0245  
\$ WEB=0.0588 GRAN = '7PF'  
NSUR=8  
DEPB=0. 0.0106, 0.02925, 0.0300, 0.0330, 0.0351, 0.038, 0.040  
SURF=4756., 5517., 6589., 5067., 2823., 1900., 1100., 710.

SEND

Producing the following output:

ERRTOL= 4.768372E-07

```
CARD 1 --- $COMMENT
CARD 2 --- IBHVG2 BENCHMARK TEST CASE 2
CARD 3 ---
CARD 4 --- TWO INDEPENDENT DATA SETS IN ONE IBHVG2 RUN
CARD 5 ---
CARD 6 --- FIRST SET : LATERALLY DETERRED PROPELLANT
CARD 7 --- (VERY THIN TRANSITION ZONE BETWEEN OUTER AND INNER
CARD 8 --- PROPELLANT TYPES, RESULTING IN THREE LAYERS)
CARD 9 --- 1 - DETERRENT, .0007 THICK, LOW B/R EXPONENT
CARD 10 --- 2 - TRANSITION ZONE, .0001 THICK, FROM LOW TO HI EXP
CARD 11 --- 3 - CORE PROPELLANT, HI BURNING RATE
CARD 12 ---
CARD 13 --- SECOND SET : STANDARD 105MM CANNON
CARD 14 --- PIDDUCK-KENT INTERNAL PRESSURE GRADIENT EQUATION
CARD 15 --- USE GENERAL GRAIN FORM FUNCTION
CARD 16 ---
CARD 17 --- $SHEAT
CARD 18 --- TSHL = 0.00450 CSHL = 1848 RSHL = 0.284
CARD 19 --- TWAL = 293 NO = 0.0648 NL = 1
CARD 20 ---
CARD 21 --- $SGUN
CARD 22 --- NAME='XMB81 25MM APFSDS-T' CHAM=5.86 GRVE=0.988 LAND=0.960
CARD 23 --- G/L=1 TRAV=74 TWST=25
CARD 24 --- CLEN=5 NGAG=2 GLOC=-5,0
CARD 25 ---
CARD 26 --- $PROJ
CARD 27 --- NAME = 'APFSDS-T' PRVT = 0.170
CARD 28 ---
CARD 29 --- $RESI
CARD 30 --- NPTS = 4 AIR = 1
CARD 31 --- TRAV = 0, 0.2, 1.0, 74
CARD 32 --- PRES = 200, 2000, 400, 400
CARD 33 ---
CARD 34 --- $SINFO
CARD 35 --- RUN = '120MATCH-102M881' DELT = 5E-5 DELP = 5E-5
CARD 36 --- GRAD = 2 POPT = 1,1,1,0,2 SOPT = 0
CARD 37 --- EPS = 0.002 COMP = 0
CARD 38 ---
CARD 39 --- $RECO
CARD 40 --- NAME = 'NONE' RECO = 0 RCWT = 0
CARD 41 ---
CARD 42 --- $SPRIM
CARD 43 --- NAME='B/KNO3' CHWT=0.00022
CARD 44 --- GAMA = 1.25 FORC = 212500
CARD 45 --- COV = 30 TEMP = 2000
CARD 46 ---
CARD 47 --- $SPROP
CARD 48 --- NAME='M10 7P' CHWT=0.2071 GRAN='7PF'
CARD 49 --- RHO=0.06 GAMA=1.2385 FORC=330000
CARD 50 --- COV=27.04 TEMP=3073 EROS=0
CARD 51 --- NTBL=-1
CARD 52 --- PR2P=100000 PR2E=100000 PR2L=100000
CARD 53 --- PR3P=100000 PR3E=100000 PR3L=100000
CARD 54 --- PR4L=100000
CARD 55 --- CF2P=.00289 CF2E=0.00289 CF2L=0.00289
```

CARD 56 --> EX2P=0.678 EX2E=0.678 EX2L=0.678  
CARD 57 --> CF3P=0.00289 CF3E=0.00289 CF3L=0.00289  
CARD 58 --> EX3P=0.678 EX3E=0.678 EX3L=0.678  
CARD 59 --> CF4L=0.004656 EX4L=0.7061  
CARD 60 --> DEPP=,0.0007,0.0008 DEPE=,0.0007,0.0008 DCPL=,0.0007,0.0008  
CARD 61 --> LEN=0.0972 DIAM=0.0928 PD=0.0058  
CARD 62 --> W1=0.0175 W0=0.0202  
CARD 63 --> SEND

-----  
 - GUN TUNE -  
 -----  
 TYPE: M0801 25MM APFS08-T  
 GROOVE DIAMETER (IN): 0.988  
 TWIST (CALS/TURN): 25.0  
 SHELL THICKNESS (IN): 0.004500  
 INITIAL SHELL TEMP (K): 293.  
 NO. GAGES: 2  
 CHAMBER VOLUME (IN3): 5.86  
 LAND DIAMETER (IN): 0.980  
 BORE AREA (IN2): 0.7605  
 SHELL CP (IN-LB/LB-K): 1048.0  
 AIR NO (IN-LB/IN2-S-K): 0.06680  
 CHAMBER LENGTH (IN): 5.00  
 TRAVEL (IN): 74.00  
 GROOVE/LAND RATIO (-): 1.000  
 HEAT-LOSS OPTION: 1  
 SHELL DENSITY (LB/IN3): 0.2840

1 LOCATION (IN) 1 LOCATION (IN)  
 1 -5.00 2 0.00

-----  
- PROJECTILE -  
-----

TYPE: APFS08-T TOTAL WEIGHT (LB): 0.170 WEIGHT PREDICTOR OPTION: 0

-----  
- RESISTANCE -  
-----

AIR RESISTANCE OPTION: 1 WALL HEATING FRACTION: 0.000 FRICTION TABLE LENGTH: 4  
 1 TRAVEL (IN) PRESSURE (PSI) 1 TRAVEL (IN) PRESSURE (PSI)  
 1 0.00 200. 3 1.00 400. 4 74.00 400.  
 2 0.20 2000.

-----  
- GENERAL -  
-----

MAX TIME STEP (S): 0.000050 PRINT STEP (S): 0.000050 MAX RELATIVE ERROR (-): 0.00200  
 PRINT OPTIONS: 1 1 1 0 2 1 STORE OPTION: 0 CONSTANT-PRESSURE OPTION: 0  
 GRADIENT MODEL: PIDDUCK-KENT

-----  
- RECOIL -  
-----

RECOIL OPTION: 0 TYPE: NONE RECOILING WEIGHT (LB): 0.

-----  
- PRIMER -  
-----

TYPE: B/KM03 GAMMA (-): 1.2500 FORCE (FT-LB/LB): 212500.  
 COMVOLUME (IN3/LB): 30.000 FLAME TEMP (K): 2000.0 WEIGHT (LB): 0.000220

- CHARGE 1 -

TYPE: M10 7P  
 EROSIIVE COEFF (-):  
 GRAIN LENGTH (IN):  
 INNER WEB (16):

0.000000  
 0.09720  
 0.01750

GRAINS:  
 CHARGE IGM CODE:  
 GRAIN DIAMETER (IN):  
 OUTER WEB (IN):

0.00000  
 0.09720  
 0.01750

WEIGHT (LB):  
 CHARGE IGM AT (S):  
 PERF DIAMETER (IN):

0.2071  
 0.00000E+00  
 0.00580

7PF  
 0  
 0.09280  
 0.02020

PROPERTIES AT LAYER BOUNDARIES OF PERF SURFACES  
 1ST 2ND 3RD 4TH

AT DEPTH (IN):  
 ADJACENT LAYER WT %:  
 DENSITY (LB/IN3):  
 GAMMA (-):  
 FORCE (FT-LB/LB):  
 COVOLUME (IN3/LB):  
 FLAME TEMP (K):  
 MEAN PRESSURES (PSI):  
 BURNING RATE EXPS:  
 BURNING RATE COEFFS:

0.00000  
 1.510  
 0.06000  
 1.2385  
 330000.  
 27.040  
 3073.0  
 100000.0  
 0.6780  
 0.0028900

0.00070  
 0.240  
 0.06000  
 1.2385  
 330000.  
 27.040  
 3073.0  
 100000.0  
 0.6780  
 0.0028900

0.00080  
 93.16  
 0.06000  
 1.2385  
 330000.  
 27.040  
 3073.0  
 100000.0  
 0.6780  
 0.0046560

PROPERTIES AT LAYER BOUNDARIES OF END SURFACES  
 1ST 2ND 3RD 4TH

0.00000  
 1.408  
 0.06000  
 1.2385  
 330000.  
 27.040  
 3073.0  
 100000.0  
 0.6780  
 0.0028900

0.00070  
 0.196  
 0.06000  
 1.2385  
 330000.  
 27.040  
 5073.0  
 100000.0  
 0.6780  
 0.0028900

0.00080  
 93.161  
 0.06000  
 1.2385  
 330000.  
 27.040  
 3073.0  
 100000.0  
 0.6780  
 0.0046560

PROPERTIES AT LAYER BOUNDARIES OF LAT SURFACES  
 1ST 2ND 3RD 4TH

0.00000  
 3.057  
 0.06000  
 1.2385  
 330000.  
 27.040  
 3073.0  
 100000.0  
 0.6780  
 0.0028900

0.00070  
 0.429  
 0.06000  
 1.2385  
 330000.  
 27.040  
 3073.0  
 100000.0  
 0.6780  
 0.0028900

0.00080  
 93.161  
 0.06000  
 1.2385  
 330000.  
 27.040  
 3073.0  
 100000.0  
 0.6780  
 0.0046560



TIME (MS)	TRAV (IN)	VEL (FT/S)	ACC (G)	BREECH PRESS (PSI)	MEAN PRESS (PSI)	BASE PRESS (PSI)	MEAN TEMP (K)	FRAC BURN 1
0.000	0.00	0.	0.	234.	234.	234.	2000.	0.000
0.050	0.00	0.	570.	516.	449.	328.	2411.	0.001
0.100	0.00	2.	1586.	882.	768.	561.	2651.	0.002
0.150	0.00	6.	2950.	1393.	1212.	885.	2793.	0.003
0.200	0.01	12.	4677.	2073.	1803.	1317.	2878.	0.005
0.250	0.02	21.	6765.	2944.	2561.	1871.	2932.	0.007
0.300	0.03	34.	9183.	4024.	3500.	2557.	2965.	0.010
0.350	0.06	51.	11867.	5324.	4431.	3383.	2985.	0.013
0.400	0.10	72.	14714.	6843.	5953.	4349.	2995.	0.017
0.450	0.15	98.	17574.	8569.	7454.	5445.	2999.	0.022
0.500	0.21	129.	20933.	10472.	9109.	6654.	2996.	0.027
0.550	0.30	168.	27484.	12499.	10873.	7943.	2988.	0.034
0.600	0.42	217.	34389.	14569.	12673.	9258.	2974.	0.041
0.650	0.57	278.	41401.	16571.	14415.	10530.	2954.	0.049
0.700	0.75	351.	48241.	18388.	15995.	11685.	2927.	0.057
0.714	0.81	372.	50010.	18825.	16375.	11963.	2918.	0.060
LAYER TRANSITION 2 TO 3 ON PERF SURFACE OF PROPELLANT 1								
LAYER TRANSITION 2 TO 3 ON END SURFACE OF PROPELLANT 1								
LAYER TRANSITION 2 TO 3 ON LAT SURFACE OF PROPELLANT 1								
SHOT-START PRESSURE ACHIEVED								
0.745	0.96	426.	56718.	20715.	18019.	13163.	2906.	0.068
LAYER TRANSITION 3 TO 4 ON PERF SURFACE OF PROPELLANT 1								
LAYER TRANSITION 3 TO 4 ON END SURFACE OF PROPELLANT 1								
LAYER TRANSITION 3 TO 4 ON LAT SURFACE OF PROPELLANT 1								
0.750	0.99	435.	58346.	21208.	18448.	13477.	2903.	0.070
0.800	1.28	540.	72675.	26216.	22804.	16659.	2885.	0.093
0.850	1.64	668.	86257.	31000.	26966.	19699.	2857.	0.119
0.900	2.09	817.	98072.	35165.	30589.	22346.	2821.	0.146
0.950	2.62	983.	107234.	38399.	33402.	24401.	2777.	0.180
1.000	3.27	1161.	113276.	40537.	35262.	25760.	2729.	0.213
1.050	4.02	1346.	116206.	41582.	36171.	26424.	2678.	0.248
1.079	4.51	1456.	116611.	41735.	36304.	26521.	2647.	0.269
LOCAL PRESSURE MAX DETECTED								
1.100	4.88	1533.	116389.	41665.	36243.	26476.	2626.	0.284
1.150	5.86	1719.	114406.	40986.	35653.	26045.	2573.	0.319
1.200	6.95	1901.	110871.	39763.	34588.	25268.	2522.	0.355
1.250	8.14	2076.	106336.	38189.	33220.	24268.	2473.	0.389
1.300	9.44	2243.	101247.	36421.	31682.	23144.	2426.	0.423
1.350	10.83	2402.	95931.	34574.	30075.	21970.	2382.	0.456
1.400	12.32	2552.	90614.	32726.	28467.	20796.	2340.	0.488
1.450	13.89	2694.	85441.	30929.	26904.	19654.	2301.	0.518
1.500	15.55	2827.	80500.	29713.	25411.	18564.	2264.	0.548
1.550	17.28	2953.	75837.	27595.	24004.	17535.	2229.	0.576
1.600	19.09	3072.	71472.	26081.	22687.	16573.	2196.	0.604
1.650	20.97	3183.	67406.	24672.	21461.	15678.	2165.	0.630
1.700	22.91	3289.	63631.	23365.	20324.	14847.	2136.	0.655
1.750	24.91	3388.	60133.	22154.	19271.	14078.	2108.	0.680
1.800	26.97	3483.	56892.	21033.	18296.	13366.	2082.	0.704
1.850	29.09	3572.	53891.	19997.	17394.	12707.	2057.	0.726
1.900	31.26	3656.	51110.	19037.	16559.	12097.	2033.	0.749
1.950	33.48	3736.	48531.	18147.	15786.	11532.	2011.	0.770
2.000	35.74	3813.	46136.	17322.	15068.	11008.	1989.	0.791
2.050	38.05	3885.	43910.	16556.	14402.	10521.	1968.	0.811
2.100	40.40	3954.	41744.	15811.	13753.	10047.	1946.	0.829
2.150	42.79	4019.	39598.	15072.	13110.	9577.	1924.	0.845

TIME (MS)	TRAV (IN)	VEL (FT/S)	ACC (G)	BRECH PRESS (PSI)	MEAN PRESS (PSI)	BASE PRESS (PSI)	MEAN TEMP (K)	FRAC BURN 1
2.200	45.22	4082.	37540.	14362.	12493.	9127.	1901.	0.860
2.250	47.69	4140.	35585.	13689.	11908.	8699.	1878.	0.873
2.300	50.19	4196.	33737.	13054.	11355.	8295.	1855.	0.886
2.350	52.73	4249.	31996.	12454.	10834.	7914.	1833.	0.897
2.400	55.29	4299.	30358.	11891.	10344.	7556.	1812.	0.908
2.450	57.88	4347.	28817.	11361.	9883.	7220.	1790.	0.918
2.500	60.51	4392.	27312.	10844.	9433.	6891.	1768.	0.927
2.550	63.15	4435.	25853.	10342.	8996.	6572.	1745.	0.934
2.600	65.83	4475.	24462.	9864.	8580.	6268.	1723.	0.940
2.650	68.52	4514.	23144.	9410.	8186.	5980.	1700.	0.946
2.700	71.24	4550.	21903.	8984.	7815.	5709.	1678.	0.951
2.750	73.98	4584.	20735.	8582.	7465.	5454.	1656.	0.955
2.750	74.00	4584.	20729.	8580.	7464.	5452.	1656.	0.955
PROJECTILE EXIT								

CONDITIONS AT:	PMAX	MUZZLE
TIME (MS):	1.079	2.750
TRAVEL (IN):	4.51	74.00
VELOCITY (FT/S)	1456.	4584.
ACCELERATION (G):	116611.	20729.
BREECH PRESS (PSI):	41735.	8580.
MEAN PRESS (PSI):	36304.	7464.
BASE PRESS (PSI):	26521.	5452.
MEAN TEMP (K):	2647.	1656.
Z CHARGE 1 (-):	0.269	0.955

GAGE	AT (IN)	PMAX (PSI)
	WRT SON	
1	-5.00	41735.
2	0.00	35559.

ENERGY BALANCE SUMMARY	IN-LB	%
TOTAL CHEMICAL:	3286882.	100.00
(1) INTERNAL GAS:	1771932.	53.91
(2) WORK AND LOSSES:	1514950.	46.09
(A) PROJECTILE KINETIC:	665761.	20.26
(B) GAS KINETIC:	245588.	7.47
(C) PROJECTILE ROTATIONAL:	5257.	0.16
(D) FRICTIONAL WORK TO TUBE:	0.	0.00
(E) OTHER FRICTIONAL WORK:	23103.	0.70
(F) WORK DONE AGAINST AIR:	15303.	0.47
(G) HEAT CONVECTED TO BORE:	559936.	17.04
(H) RECOIL ENERGY:	0.	0.00

LOADING DENSITY (G/CM3):	0.979
CHARGE WT/PROJECTILE WT:	1.220
PIEZOMETRIC EFFICIENCY:	0.283
EXPANSION RATIO:	10.603

CARD 64 -->  
 CARD 65 -->  
 CARD 66 --> SHEAT  
 CARD 67 --> TSHL = 0.00450      CSHL = 1848      RSHL = 0.284  
 CARD 68 --> TWAL = 293      NO = 0.0648      NL = 1  
 CARD 69 -->  
 CARD 70 --> \$GUN  
 CARD 71 --> NAME = '105-MM GUN M68'      CHAM = 375      GRVE = 4.224  
 CARD 72 --> LAND = 4.134      G/L = 2.      TRAV = 187  
 CARD 73 --> TWST = 99  
 CARD 74 -->  
 CARD 75 --> \$PROJ  
 CARD 76 --> NAME = 'M456A2'      PRVT = 23.2  
 CARD 77 -->  
 CARD 78 --> \$RESI  
 CARD 79 --> NPTS = 4      AIR = 1  
 CARD 80 --> TRAV = 0,      0.5,      8.0,      187  
 CARD 81 --> PRES = 100,      2100,      500,      200  
 CARD 82 -->  
 CARD 83 --> \$INFO  
 CARD 84 --> RUN = '10SMATCH-1105'      DELT = 5E-5      DELP = 5E-5  
 CARD 85 --> GRAD = 2      POPT = 1,1,1,0,2      SOPT = 0  
 CARD 86 --> EPS = 0.002      COMP = 0  
 CARD 87 -->  
 CARD 88 --> \$RECO  
 CARD 89 --> NAME = 'NONE'      RECO = 0      RCWT = 0  
 CARD 90 -->  
 CARD 91 --> \$PRIN  
 CARD 92 --> NAME = 'BENITE'      CHWT = 0.001  
 CARD 93 --> GAMA = 1.25      FORC = 212500  
 CARD 94 --> COV = 30      TEMP = 2000  
 CARD 95 -->  
 CARD 96 --> \$PROP  
 CARD 97 --> NAME = 'BENITE'      CHWT = 0.072      GRAN = 'CORD'  
 CARD 98 --> RHO = 0.06      GAMA = 1.25      FCRC = 212500  
 CARD 99 --> COV = 30      TEMP = 2000      EROS = 0.00000  
 CARD 100 --> ALPH = 0      BETA = 10      IGNC = 0  
 CARD 101 --> LEN = 10.      DIAM = 0.68  
 CARD 102 -->  
 CARD 103 --> \$PROP  
 CARD 104 --> NAME = 'M30 7P'      CHWT = 11.9      GRAN='GEN'  
 CARD 105 --> RHO = 0.0607      GAMA = 1.241      FORC = 360000  
 CARD 106 --> COV = 29.11      TEMP = 3010      EROS = 0.0000000  
 CARD 107 --> NTBL=0 ALPH=0.8 BETA=0.001320  
 CARD 108 --> \$ THE FOLLOWING PARAMETERS REPLACED BY DEPTH-BURNED/SURFACE ARRAY  
 CARD 109 --> \$ LEN =0.63      DIAM = 0.3087      PD = 0.0245  
 CARD 110 --> \$ WEB=0.0588      GRAN = '7PF'  
 CARD 111 --> NSUR=8  
 CARD 112 --> DEPB=0.      0.0106, 0.02925, 0.0300, 0.0330, 0.0351, 0.038, 0.040  
 CARD 113 --> SURF=4756.,5517., 6589., 5067., 2823., 1900., 1100., 710.  
 CARD 114 -->  
 CARD 115 --> \$END

- GUN TUBE -

TYPE: 105-MM GUN M68  
 GROOVE DIAMETER (IN): 4.224  
 TWIST (CAL./TURN): 99.0  
 SHELL THICKNESS (IN): 0.004500  
 INITIAL SHELL TEMP (K): 293.

CHAMBER VOLUME (IN3): 375.00  
 LAND DIAMETER (IN): 4.134  
 BORE AREA (IN2): 13.8163  
 SHELL CP (IN-LB/LB-K): 1848.0  
 AIR MO (IN-LB/IN2-S-K): 0.06480

TRAVEL (IN): 187.00  
 GROOVE/LAND RATIO (-): 2.000  
 HEAT-LOSS OPTION: 1  
 SHELL DENSITY (LB/IN3): 0.2840

- PROJECTILE -

TYPE: M56A2  
 - RESISTANCE -

TOTAL WEIGHT (LB): 23.200

WEIGHT PREDICTOR OPTION: 0

AIR RESISTANCE OPTION: 1

?	TRAVEL (IN)	PRESSURE (PSI)
1	0.00	100.
2	0.50	2100.

WALL HEATING FRACTION: 0.000

?	TRAVEL (IN)	PRESSURE (PSI)
1	8.00	500.
3	8.00	500.
4	187.00	200.

- GENERAL -

MAX TIME STEP (S): 0.000050  
 PRINT OPTIONS: 1 1 0 2 1  
 GRADIENT MODEL: PIDDUCK-KERT

PRINT STEP (S): 0.000050  
 STORE OPTION: 0

MAX RELATIVE ERROR (-): 0.00200  
 CONSTANT-PRESSURE OPTION: 0

- RECOIL -

RECOIL OPTION: 0

TYPE: NONE

RECOILING WEIGHT (LB): 0.

- PRIMER -

TYPE: BENITE  
 COVOLUME (IN3/LB): 30.000

GAMMA (-): 1.2500  
 FLAME TEMP (K): 2000.0

FORCE (FT-LB/LB): 212500.  
 WEIGHT (LB): 0.001000

-----  
 - CHARGE 1 -  
 -----

TYPE: DEWITE  
 EROSIIVE COEFF (-): 0.000000  
 GRAIN LENGTH (IN): 10.000000

GRAINS:  
 CHARGE IGM CODE: 23.873  
 CORO: 0  
 GEN: 0  
 GRAIN DIAMETER (IN): 0.080000

WEIGHT (LB): 0.0720  
 CHARGE IGM AT (\$): 0.000000E+00

PROPERTIES AT LAYER BOUNDARIES OF END SURFACES

	1ST	2ND	3RD	4TH
AT DEPTH (IN):	0.000000	0.000000	0.000000	0.000000
ADJACENT LAYER WT %:	100.0000	100.0000	100.0000	100.0000
DENSITY (LB/IN3):	0.060000	0.060000	0.060000	0.060000
GAMMA (-):	1.2500	1.2500	1.2500	1.2500
FORCE (FT-LB/LB):	212500.	212500.	212500.	212500.
COVOLUME (IN3/LB):	30.0000	30.0000	30.0000	30.0000
FLAME TEMP (K):	2000.0	2000.0	2000.0	2000.0
BURNING RATE EXPS:	0.0000	0.0000	0.0000	0.0000
BURNING RATE COEFFS:	10.00000000	10.00000000	10.00000000	10.00000000

PROPERTIES AT LAYER BOUNDARIES OF LAT SURFACES

	1ST	2ND	3RD	4TH
AT DEPTH (IN):	0.000000	0.000000	0.000000	0.000000
ADJACENT LAYER WT %:	100.0000	100.0000	100.0000	100.0000
DENSITY (LB/IN3):	0.060000	0.060000	0.060000	0.060000
GAMMA (-):	1.2500	1.2500	1.2500	1.2500
FORCE (FT-LB/LB):	212500.	212500.	212500.	212500.
COVOLUME (IN3/LB):	30.0000	30.0000	30.0000	30.0000
FLAME TEMP (K):	2000.0	2000.0	2000.0	2000.0
BURNING RATE EXPS:	0.0000	0.0000	0.0000	0.0000
BURNING RATE COEFFS:	10.00000000	10.00000000	10.00000000	10.00000000

-----  
 - CHARGE 2 -  
 -----

TYPE: MSO 7P  
 EROSIIVE COEFF (-): 0.000000

GRAINS:  
 CHARGE IGM CODE: 1.0000  
 CORO: 0  
 GEN: 0  
 GRAIN DIAMETER (IN): 0.080000

WEIGHT (LB): 11.9000  
 CHARGE IGM AT (\$): 0.000000E+00

PROPERTIES AT LAYER BOUNDARIES OF END SURFACES

	1ST	2ND	3RD	4TH
AT DEPTH (IN):	0.000000	0.000000	0.000000	0.000000
ADJACENT LAYER WT %:	100.0000	100.0000	100.0000	100.0000
DENSITY (LB/IN3):	0.060000	0.060000	0.060000	0.060000
GAMMA (-):	1.2500	1.2500	1.2500	1.2500
FORCE (FT-LB/LB):	212500.	212500.	212500.	212500.
COVOLUME (IN3/LB):	30.0000	30.0000	30.0000	30.0000
FLAME TEMP (K):	2000.0	2000.0	2000.0	2000.0
BURNING RATE EXPS:	0.0000	0.0000	0.0000	0.0000
BURNING RATE COEFFS:	10.00000000	10.00000000	10.00000000	10.00000000

PROPERTIES AT LAYER BOUNDARIES OF LAT SURFACES

	1ST	2ND	3RD	4TH
AT DEPTH (IN):	0.000000	0.000000	0.000000	0.000000
ADJACENT LAYER WT %:	100.0000	100.0000	100.0000	100.0000
DENSITY (LB/IN3):	0.060000	0.060000	0.060000	0.060000
GAMMA (-):	1.2500	1.2500	1.2500	1.2500
FORCE (FT-LB/LB):	212500.	212500.	212500.	212500.
COVOLUME (IN3/LB):	30.0000	30.0000	30.0000	30.0000
FLAME TEMP (K):	2000.0	2000.0	2000.0	2000.0
BURNING RATE EXPS:	0.0000	0.0000	0.0000	0.0000
BURNING RATE COEFFS:	10.00000000	10.00000000	10.00000000	10.00000000

TIME (MS)	TRAV (IN)	VEL (FT/S)	ACC (G)	BREECH PRESS (PSI)	MEAN PRESS (PSI)	BASE PRESS (PSI)	MEAN TEMP (K)	FRAC BURN 1	FRAC BURN 2
0.000	0.00	0.	0.	14.	14.	14.	2000.	0.000	0.000
0.050	0.00	0.	0.	47.	47.	47.	2109.	0.025	0.000
0.100	0.00	0.	0.	86.	86.	86.	2177.	0.050	0.000
0.116	0.00	0.	0.	100.	100.	100.	2197.	0.058	0.000
SHOT-START PRESSURE ACHIEVED									
0.150	0.00	0.	7.	141.	131.	112.	2235.	0.074	0.000
0.200	0.00	0.	34.	196.	182.	157.	2286.	0.098	0.000
0.250	0.00	0.	63.	258.	241.	207.	2332.	0.122	0.000
0.300	0.00	0.	97.	329.	306.	263.	2375.	0.145	0.000
0.350	0.00	0.	134.	408.	380.	326.	2415.	0.168	0.001
0.400	0.00	1.	175.	496.	462.	397.	2452.	0.191	0.001
0.450	0.00	1.	221.	594.	553.	475.	2486.	0.213	0.001
0.500	0.00	1.	271.	703.	655.	562.	2518.	0.235	0.001
0.550	0.00	2.	326.	823.	766.	658.	2548.	0.257	0.002
0.600	0.00	2.	386.	955.	890.	764.	2576.	0.278	0.002
0.650	0.01	3.	451.	1101.	1025.	880.	2602.	0.300	0.002
0.700	0.01	4.	522.	1260.	1173.	1007.	2627.	0.320	0.003
0.750	0.01	5.	598.	1434.	1335.	1147.	2649.	0.341	0.003
0.800	0.01	6.	681.	1624.	1512.	1299.	2671.	0.361	0.004
0.850	0.02	7.	771.	1830.	1705.	1464.	2691.	0.381	0.004
0.900	0.02	8.	867.	2055.	1914.	1644.	2709.	0.400	0.005
0.950	0.03	10.	970.	2299.	2141.	1839.	2727.	0.420	0.006
1.000	0.03	11.	1080.	2563.	2387.	2050.	2743.	0.439	0.007
1.050	0.04	13.	1199.	2848.	2652.	2278.	2758.	0.457	0.007
1.100	0.05	15.	1325.	3157.	2939.	2525.	2772.	0.476	0.008
1.150	0.06	18.	1460.	3489.	3249.	2790.	2786.	0.494	0.009
1.200	0.07	20.	1603.	3846.	3581.	3076.	2798.	0.511	0.010
1.250	0.08	23.	1755.	4230.	3939.	3383.	2809.	0.529	0.012
1.300	0.10	26.	1917.	4642.	4322.	3712.	2820.	0.546	0.013
1.350	0.11	29.	2088.	5083.	4733.	4065.	2830.	0.562	0.014
1.400	0.13	32.	2269.	5555.	5173.	4443.	2839.	0.579	0.016
1.450	0.15	36.	2460.	6059.	5642.	4846.	2847.	0.595	0.017
1.500	0.18	40.	2662.	6597.	6143.	5276.	2855.	0.611	0.019
1.550	0.20	45.	2874.	7170.	6676.	5734.	2862.	0.626	0.021
1.600	0.23	50.	3097.	7779.	7244.	6222.	2869.	0.641	0.023
1.650	0.26	55.	3330.	8426.	7847.	6739.	2875.	0.656	0.025
1.700	0.30	60.	3575.	9113.	8486.	7288.	2880.	0.670	0.027
1.750	0.33	66.	3831.	9840.	9163.	7870.	2885.	0.685	0.029
1.800	0.38	73.	4098.	10609.	9879.	8485.	2890.	0.699	0.032
1.850	0.42	79.	4375.	11420.	10635.	9134.	2894.	0.712	0.034
1.900	0.47	87.	4665.	12276.	11432.	9818.	2897.	0.725	0.037
1.950	0.53	95.	5028.	13177.	12271.	10539.	2900.	0.738	0.040
2.000	0.58	103.	5486.	14124.	13152.	11296.	2902.	0.751	0.043
2.050	0.65	112.	5967.	15117.	14077.	12090.	2904.	0.763	0.047
2.100	0.72	122.	6471.	16156.	15044.	12921.	2906.	0.772	0.050
2.150	0.80	133.	6997.	17241.	16055.	13789.	2907.	0.787	0.054
2.200	0.88	145.	7547.	18373.	17108.	14694.	2907.	0.798	0.058
2.250	0.97	157.	8118.	19549.	18204.	15635.	2908.	0.809	0.062
2.300	1.07	171.	8712.	20769.	19340.	16611.	2907.	0.820	0.066
2.350	1.18	185.	9326.	22031.	20515.	17620.	2906.	0.831	0.071
2.400	1.29	201.	9961.	23333.	21728.	18661.	2905.	0.841	0.076
2.450	1.42	217.	10615.	24673.	22975.	19733.	2903.	0.851	0.081
2.500	1.55	235.	11286.	26044.	24254.	20832.	2901.	0.860	0.086
2.550	1.70	254.	11973.	27451.	25562.	21955.	2898.	0.869	0.092
2.600	1.86	274.	12674.	28881.	26894.	23099.	2894.	0.878	0.097

TIME (MS)	TRAV (IN)	VEL (FT/S)	ACC (G)	BREECH PRESS (PSI)	MEAN PRESS (PSI)	BASE PRESS (PSI)	MEAN TEMP (K)	FRAC BURN 1	FRAC BURN 2
2.650	2.03	295.	13387.	30333.	28246.	24260.	2891.	0.887	0.103
2.700	2.21	317.	14110.	31802.	29614.	25435.	2886.	0.895	0.110
2.750	2.41	340.	14839.	33281.	30991.	26618.	2881.	0.903	0.116
2.800	2.62	365.	15572.	34764.	32372.	27804.	2876.	0.911	0.123
2.850	2.85	390.	16306.	36245.	33751.	28988.	2870.	0.918	0.130
2.900	3.09	417.	17037.	37717.	35122.	30165.	2864.	0.925	0.138
2.950	3.35	445.	17763.	39172.	36477.	31329.	2857.	0.931	0.145
3.000	3.62	474.	18479.	40604.	37810.	32474.	2850.	0.938	0.153
3.050	3.92	505.	19183.	42004.	39114.	33595.	2842.	0.944	0.161
3.100	4.23	536.	19871.	43366.	40383.	34684.	2834.	0.950	0.170
3.150	4.56	569.	20539.	44683.	41609.	35737.	2825.	0.955	0.178
3.200	4.91	602.	21186.	45947.	42786.	36748.	2816.	0.960	0.187
3.250	5.28	637.	21806.	47153.	43909.	37712.	2807.	0.965	0.196
3.300	5.67	672.	22399.	48294.	44971.	38625.	2797.	0.970	0.206
3.350	6.09	709.	22961.	49364.	45968.	39481.	2787.	0.974	0.215
3.400	6.53	746.	23490.	50360.	46395.	40278.	2776.	0.978	0.225
3.450	6.98	784.	23984.	51277.	47749.	41011.	2766.	0.981	0.235
3.500	7.47	823.	24442.	52113.	48527.	41679.	2755.	0.984	0.245
3.550	7.97	863.	24863.	52863.	49226.	42280.	2743.	0.987	0.256
3.600	8.50	903.	25183.	53528.	49846.	42811.	2732.	0.990	0.266
3.650	9.06	944.	25458.	54107.	50385.	43274.	2720.	0.992	0.277
3.700	9.64	985.	25692.	54599.	50842.	43648.	2709.	0.994	0.288
3.750	10.24	1027.	25884.	55003.	51219.	43991.	2697.	0.996	0.299
3.800	10.87	1069.	26035.	55321.	51515.	44246.	2685.	0.998	0.310
3.850	11.52	1111.	26146.	55556.	51734.	44433.	2673.	0.999	0.321
3.900	12.20	1153.	26219.	55711.	51878.	44557.	2661.	0.999	0.332
3.950	12.91	1195.	26256.	55789.	51950.	44619.	2649.	1.000	0.343
4.000	13.64	1237.	26257.	55793.	51954.	44623.	2637.	1.000	0.354
PROPELLANT 1 BURNED OUT									
4.050	14.39	1280.	26226.	55729.	51894.	44571.	2625.	1.000	0.366
LOCAL PRESSURE MAX DETECTED									
4.100	15.17	1322.	26164.	55599.	51774.	44468.	2613.	1.000	0.377
4.150	15.98	1364.	26073.	55410.	51598.	44316.	2601.	1.000	0.388
4.200	16.81	1406.	25956.	55165.	51370.	44121.	2590.	1.000	0.400
4.250	17.66	1448.	25814.	54869.	51094.	43884.	2578.	1.000	0.411
4.300	18.54	1489.	25651.	54527.	50775.	43610.	2566.	1.000	0.423
4.350	19.45	1530.	25447.	54142.	50417.	43302.	2555.	1.000	0.434
4.400	20.38	1571.	25265.	53719.	50023.	42964.	2544.	1.000	0.445
4.450	21.34	1611.	25047.	53263.	49598.	42599.	2533.	1.000	0.457
4.500	22.31	1652.	24815.	52776.	49145.	42210.	2522.	1.000	0.468
4.550	23.32	1691.	24570.	52263.	48668.	41800.	2511.	1.000	0.479
4.600	24.34	1731.	24314.	51728.	48169.	41371.	2501.	1.000	0.490
4.650	25.39	1770.	24049.	51173.	47652.	40928.	2490.	1.000	0.501
4.700	26.47	1808.	23777.	50601.	47120.	40470.	2480.	1.000	0.512
4.750	27.56	1846.	23497.	50016.	46575.	40003.	2470.	1.000	0.523
4.800	28.68	1884.	23213.	49420.	46020.	39526.	2460.	1.000	0.534
4.850	29.82	1921.	22924.	48816.	45457.	39042.	2451.	1.000	0.545
4.900	30.99	1958.	22633.	48204.	44888.	38553.	2441.	1.000	0.556
4.950	32.17	1994.	22339.	47589.	44315.	38061.	2432.	1.000	0.567
5.000	33.38	2030.	22044.	46971.	43739.	37567.	2423.	1.000	0.577
5.050	34.61	2065.	21749.	46351.	43162.	37071.	2414.	1.000	0.588
5.100	35.86	2100.	21453.	45732.	42586.	36576.	2405.	1.000	0.598
5.150	37.13	2134.	21159.	45115.	42011.	36082.	2396.	1.000	0.609
5.200	38.42	2168.	20866.	44500.	41439.	35591.	2388.	1.000	0.619
5.250	39.73	2201.	20575.	43890.	40870.	35103.	2380.	1.000	0.629



TIME (MS)	TRAV (IN)	VEL (FT/S)	ACC (G)	BREECH PRESS (PSI)	MEAN PRESS (PSI)	BASE PRESS (PSI)	MEAN TEMP (K)	FRAC BURN 1	FRAC BURN 2
5.300	41.06	2234.	20286.	43284.	40306.	34618.	2372.	1.000	0.639
5.350	42.41	2266.	19999.	42683.	39747.	34138.	2364.	1.000	0.649
5.400	43.78	2298.	19716.	42089.	39193.	33662.	2356.	1.000	0.659
5.450	45.17	2330.	19436.	41501.	38646.	33192.	2348.	1.000	0.669
5.500	46.57	2361.	19159.	40921.	38106.	32728.	2341.	1.000	0.679
5.550	48.00	2392.	18886.	40348.	37572.	32270.	2333.	1.000	0.689
5.600	49.44	2422.	18617.	39784.	37047.	31819.	2326.	1.000	0.698
5.650	50.91	2451.	18352.	39228.	36529.	31374.	2319.	1.000	0.708
5.700	52.39	2481.	18091.	38680.	36019.	30936.	2312.	1.000	0.718
5.750	53.88	2510.	17834.	38141.	35517.	30505.	2305.	1.030	0.727
5.800	55.40	2538.	17581.	37611.	35023.	30081.	2299.	1.000	0.736
5.850	56.93	2566.	17333.	37090.	34538.	29664.	2292.	1.000	0.746
5.900	58.48	2594.	17089.	36578.	34061.	29255.	2286.	1.000	0.755
5.950	60.04	2621.	16849.	36075.	33593.	28852.	2280.	1.000	0.764
6.000	61.62	2648.	16614.	35581.	33133.	28457.	2273.	1.000	0.773
6.050	63.22	2675.	16383.	35096.	32682.	28070.	2267.	1.000	0.782
6.100	64.83	2701.	16156.	34621.	32239.	27689.	2261.	1.000	0.791
6.150	66.46	2727.	15934.	34154.	31804.	27316.	2256.	1.000	0.799
6.200	68.11	2752.	15716.	33696.	31377.	26949.	2250.	1.000	0.808
6.250	69.76	2778.	15502.	33247.	30959.	26590.	2244.	1.000	0.817
6.300	71.44	2802.	15292.	32806.	30549.	26238.	2239.	1.000	0.825
6.350	73.13	2827.	15087.	32374.	30147.	25893.	2233.	1.000	0.834
6.400	74.83	2851.	14885.	31951.	29752.	25554.	2228.	1.000	0.842
6.450	76.55	2875.	14688.	31536.	29366.	25222.	2223.	1.000	0.851
6.500	78.28	2898.	14491.	31122.	28981.	24891.	2217.	1.000	0.859
6.550	80.03	2921.	14283.	30686.	28574.	24542.	2212.	1.000	0.866
6.600	81.79	2944.	14065.	30227.	28148.	24175.	2205.	1.000	0.873
6.650	83.56	2967.	13839.	29752.	27705.	23795.	2199.	1.000	0.879
6.700	85.35	2989.	13613.	29276.	27262.	23415.	2192.	1.000	0.885
6.750	87.15	3010.	13387.	28803.	26821.	23036.	2185.	1.000	0.891
6.800	88.96	3032.	13163.	28331.	26382.	22659.	2179.	1.000	0.896
6.850	90.78	3053.	12940.	27863.	25946.	22284.	2172.	1.000	0.901
6.900	92.62	3074.	12719.	27398.	25513.	21913.	2165.	1.000	0.906
6.950	94.47	3094.	12500.	26937.	25084.	21544.	2158.	1.000	0.910
7.000	96.33	3114.	12283.	26481.	24659.	21179.	2151.	1.000	0.914
7.050	98.21	3133.	12069.	26029.	24239.	20818.	2144.	1.000	0.918
7.100	100.09	3153.	11857.	25583.	23823.	20461.	2136.	1.000	0.922
7.150	101.99	3172.	11647.	25142.	23412.	20108.	2129.	1.000	0.926
7.200	103.90	3190.	11440.	24706.	23006.	19760.	2122.	1.000	0.929
7.250	105.82	3208.	11236.	24277.	22606.	19416.	2115.	1.000	0.932
7.300	107.75	3226.	11035.	23853.	22212.	19077.	2108.	1.000	0.935
7.350	109.69	3244.	10837.	23434.	21824.	18744.	2100.	1.000	0.938
7.400	111.64	3261.	10643.	23028.	21443.	18417.	2093.	1.000	0.941
7.450	113.60	3278.	10453.	22628.	21071.	18097.	2086.	1.000	0.944
7.500	115.58	3295.	10267.	22236.	20706.	17784.	2079.	1.000	0.946
7.550	117.56	3311.	10085.	21852.	20349.	17477.	2072.	1.000	0.948
7.600	119.55	3327.	9907.	21476.	19999.	17177.	2065.	1.000	0.951
7.650	121.55	3343.	9733.	21108.	19656.	16882.	2057.	1.000	0.953
7.700	123.56	3359.	9562.	20748.	19321.	16594.	2050.	1.000	0.955
7.750	125.58	3374.	9395.	20395.	18992.	16312.	2043.	1.000	0.957
7.800	127.61	3389.	9231.	20050.	18671.	16036.	2037.	1.000	0.958
7.850	129.65	3404.	9071.	19712.	18356.	15766.	2030.	1.000	0.960
7.900	131.69	3418.	8914.	19381.	18048.	15501.	2023.	1.000	0.962
7.950	133.75	3432.	8761.	19058.	17747.	15242.	2016.	1.000	0.963
8.000	135.81	3446.	8612.	18742.	17452.	14990.	2009.	1.000	0.965

TIME (MS)	TRAV (IN)	VEL (FT/S)	ACC (G)	BREECH PRESS (PSI)	MEAN PRESS (PSI)	BASE PRESS (PSI)	MEAN TEMP (K)	FRAC BURN 1	FRAC BURN 2
8.050	137.88	3460.	8466.	18433.	17165.	14743.	2003.	1.000	0.966
8.100	139.96	3474.	8323.	18132.	16884.	14502.	1996.	1.000	0.968
8.150	142.05	3487.	8184.	17837.	16610.	14266.	1989.	1.000	0.969
8.200	144.15	3500.	8048.	17549.	16342.	14036.	1983.	1.000	0.971
8.250	146.25	3513.	7915.	17268.	16080.	13811.	1976.	1.000	0.972
8.300	148.36	3525.	7785.	16993.	15824.	13591.	1970.	1.000	0.973
8.350	150.48	3538.	7658.	16724.	15574.	13376.	1964.	1.000	0.974
8.400	152.61	3550.	7534.	16462.	15329.	13166.	1957.	1.000	0.975
8.450	154.74	3562.	7413.	16205.	15090.	12960.	1951.	1.000	0.976
8.500	156.88	3574.	7294.	15953.	14856.	12759.	1945.	1.000	0.977
8.550	159.03	3586.	7179.	15708.	14627.	12563.	1939.	1.000	0.978
8.600	161.19	3597.	7065.	15467.	14403.	12371.	1932.	1.000	0.979
8.650	163.35	3608.	6955.	15232.	14184.	12183.	1926.	1.000	0.980
8.700	165.52	3620.	6846.	15002.	13970.	11999.	1920.	1.000	0.981
8.750	167.69	3630.	6740.	14777.	13761.	11819.	1914.	1.000	0.982
8.800	169.87	3641.	6637.	14557.	13556.	11643.	1908.	1.000	0.983
8.850	172.06	3652.	6535.	14342.	13355.	11470.	1903.	1.000	0.983
8.900	174.26	3662.	6436.	14131.	13159.	11302.	1897.	1.000	0.984
8.950	176.46	3673.	6339.	13925.	12967.	11137.	1891.	1.000	0.985
9.000	178.66	3683.	6245.	13723.	12779.	10975.	1885.	1.000	0.986
9.050	180.88	3693.	6152.	13525.	12595.	10813.	1879.	1.000	0.986
9.100	183.09	3702.	6061.	13332.	12415.	10663.	1874.	1.000	0.987
9.150	185.32	3712.	5973.	13143.	12239.	10512.	1868.	1.000	0.988
9.188	187.00	3719.	5907.	13003.	12109.	10400.	1864.	1.000	0.988

PROJECTILE EXIT

CONDITIONS AT:	PMAX	MUZZLE
TIME (MS):	4.000	9.188
TRAVEL (IN):	13.64	187.00
VELOCITY (FT/S)	1237.	3719.
ACCELERATION (G):	26257.	5907.
BREECH PRESS (PSI):	55793.	13003.
MEAN PRESS (PSI):	51954.	12109.
BASE PRESS (PSI):	44623.	10400.
MEAN TEMP (K):	2637.	1864.
Z CHARGE 1 (-):	1.000	1.000
Z CHARGE 2 (-):	0.354	0.988

ENERGY BALANCE SUMMARY	IN-LB	%
TOTAL CHEMICAL:	211486528.	100.00
(1) INTERNAL GAS:	131203024.	62.04
(2) WORK AND LOSSES:	80283504.	37.96
(A) PROJECTILE KINETIC:	59803360.	28.28
(B) GAS KINETIC:	9825915.	4.65
(C) PROJECTILE ROTATIONAL:	30111.	0.01
(D) FRICTIONAL WORK TO TUBE:	0.	0.00
(E) OTHER FRICTIONAL WORK:	1007907.	0.48
(F) WORK DONE AGAINST AIR:	463070.	0.22
(G) HEAT CONVECTED TO BORE:	9153141.	4.33
(H) RECOIL ENERGY:	0.	0.00
LOADING DENSITY (G/CM3):	0.884	
CHARGE WT/PROJECTILE WT:	0.516	
PIEZOMETRIC EFFICIENCY:	0.415	
EXPANSION RATIO:	7.890	

### Test Case 3

The purpose here is to illustrate how to change the trajectory print and how to use the MULT function to alter one of the outputs. Projectile velocity, normally given in *feet/second*, has been multiplied by 12 and is now in units of *inches/second*. Three pressure gage locations have been added, one at thirty inches from projectile base (toward the breech), the second at original projectile base position, and the third at 10 inches of travel. After projectile exit, IBHVG2 also prints the blowdown phase of the shot, showing a rarefaction wave (pressure relief) moving from muzzle exit to breech.

Another complete ballistic calculation is initiated after the first solution and uses much of the previous input. The \$SAVE feature enables IBHVG2 to carry over values from the previous run except those parameters specifically given in the \$SAVE deck. Trajectory display is set back to default outputs, and blowdown phase dropped. Burning rate inputs have been changed for the second \$PROP deck from the ALPHA/BETA method to an array of pressure/rate points. The \$PARA deck is shown, where the charge weight of the second propellant (NTH=2) is varied from 25 through 27 by increments of 0.2 pounds. On the output, after the trajectory and summary information from the first iteration (CHWT=25), a table of values is printed showing iterated charge weights, maximum pressure, velocity and pressure at muzzle exit, propellant fractions burned and the point in travel where each propellant burned out (X@Z=1). Each line of output here represents an entire IBHVG2 calculation where only the charge weight input is changed from one run to the next.

---

```
SCOMM
  IBHVG2 BENCHMARK TEST CASE 3
- SHOW TRAJECTORY PRINT OPTIONS, GUN TUBE GAUGE PRINTS, BLOWDOWN PHASE
- SHOW 'SAVE' FEATURE ; CHANGE PRINT OPTION AND BURN-RATE INPUTS;
- SHOW SMALL PARAMETRIC STUDY ON CHARGE WEIGHT FOR PROPELLANT 2, AND
  USE DEFAULT OUTPUTS FOR CHARGE WEIGHT VARIATIONS (PMAZ,VMUZ,PMUZ,X@Z=1)

'TDIS' VALUES USED WITH SPECIAL PRINT OPTION - POPT(2)=2
STDIS
SHOW='TIME' REMK='TIME (MS)'
STDIS
SHOW='TRAV' REM1='TRAVEL (INCHES)'
STDIS
SHOW='VEL' REM1='VELOCITY (IN/SEC)' MULT=12.  $ IF MULT=1, THEN VEL=FT/SEC
STDIS
SHOW='ACCL' REMK='ACCEL (GRAV)'
STDIS
SHOW='FRCR' REM1='FRICTION (PSI)'
STDIS
SHOW='BRCH' REM1='BREECH PRESSURE (PSI)'
STDIS
SHOW='BASE' REM1='BASE PRESSURE (PSI)'
STDIS
SHOW='TBAR' REM1='MEAN TEMP (DEG K)'
STDIS
SHOW='WTB(1)' REM1='PROP 1 (LBS BURNED)'
STDIS
SHOW='WTB(2)' REMK='PROP 2 (LBS BURNED)'
STDIS
SHOW='WTB(3)' REM1='PROP 3 (LBS BURNED)'

SHEAT
  TSHL=0.00384
SCOMM
```

```

GET MAXIMUM PRESSURES AT GAGE LOCATIONS - BREACH,
ORIGINAL PROJECTILE BASE, AND AT 10 INCHES OF TRAVEL
$GUN
NAME='155-MM 198' CHAM=1150 GRVE=6.2 LAND=6.1
G/L=1.66 TRAV=205. TWST=20 NGAG=3 GLOC=-30.,0.,10. CLEN=30.

$PROJ
NAME='M549A1' PRWT=96
$RESI
NPTS=7 TRAV=0,0.4,1.,1.55,2.05,4.5,200
PRES=250,3350,4950,3625,3250,2500,1500

$COMM
INVOKE SPECIAL TRAJECTORY PRINT OPTION - POPT(2)=2
CALCULATE AND PRINT BLOWDOWN PHASE - POPT(4)=1
$INFO
POPT=1,2,1,1,0
RUN='NEAR-STANDARD M203/M549'

$SPRH
NAME='BLK POWDER' CHWT=0.0154
GAMA=1.25 FORC=96000 COV=30 TEMP=2000
$SPROP
NAME='BLK POWDER' CHWT=0.2976 GRAN='CORD'
LEN=0.198 DIAM=0.095
RHO=0.06 GAMA=1.25 FORC=96000 COV=30 TEMP=2000
ALPH=0.0 BETA=50 EROS=0.00000
$SPROP
NAME='M30A1' CHWT=26.2 GRAN='7PF'
LEN=0.9481 DIAM=0.4173 PD=0.0338 WI=0.078975 WO=0.078975
RHO=0.0572 GAMA=1.243 FORC=356400 COV=28.5 TEMP=3040
NTBL=0 ALPH=0.701 BETA=0.004025
$SPROP
NAME='MC TUBE' CHWT=0.5 GRAN='1PF' NTBL=0 ALPH=0 BETA=30
LEN=28 DIAM=1.5 PD=1.25 WEB=0.125
FORC=180000 COV=30 TEMP=1553 RHO=0.034 GAMA=1.25
$SEND

$SAVE $ KEEP PREVIOUS INPUTS EXCEPT FOR FOLLOWING VALUES

$COMM
CHANGE TRAJECTORY PRINT OPTION AND TITLE
$INFO
POPT=1,1,1,0,1 RUN='M203/M549 TABULAR B/R DATA'

$SPROP $ NO CHANGES IN FIRST PROPELLANT DECK
$SPROP $ CHANGE BURNING RATE SPECIFICATION METHOD
NTBL=4 PR4L=1000,5000,10000,30000 BR4L=0.5102,1.577,2.563,5.536

$COMM
ADD PARAMETRIC VARIATION ON CHARGE WEIGHT FOR SECOND PROPELLANT
$PARA
VARY='CHWT' DECK='PROP' NTH=2 FROM=25 TO=27 BY=0.2
$SEND

```

*Producing the following output:*

ERRTOL= 4.768372E-07

```
CARD 1 --> $COMM
CARD 2 --> IBHVG2 BENCHMARK TEST CASE 3
CARD 3 -->
CARD 4 --> - SHOW TRAJECTORY PRINT OPTIONS, GUN TUBE GAUGE PRINTS, BLOWDOWN PHASE
CARD 5 --> - SHOW 'SAVE' FEATURE ; CHANGE PRINT OPTION AND BURN-RATE INPUTS;
CARD 6 --> - SHOW SMALL PARAMETRIC STUDY ON CHARGE WEIGHT FOR PROPELLANT 2, AND
CARD 7 --> USE DEFAULT OUTPUTS FOR CHARGE WEIGHT VARIATIONS (PMAZ,VMU2,PMU2,XBZ=1)
CARD 8 -->
CARD 9 --> 'TDIS' VALUES USED WITH SPECIAL PRINT OPTION - POPT(2)=2
CARD 10 --> $TDIS
CARD 11 --> SHOW='TIME' REMK='TIME (MS)
CARD 12 --> $TDIS
CARD 13 --> SHOW='TRAV' REM1='TRAVEL (INCHES)'
CARD 14 --> $TDIS
CARD 15 --> SHOW='VEL' REM1='VELOCITY (IN/SEC)' MULT=12. $ IF MULT=1, THEN VEL=FT/SEC
CARD 16 --> $TDIS
CARD 17 --> SHOW='ACCL' REMK='ACCEL (GRAV)'
CARD 18 --> $TDIS
CARD 19 --> SHOW='FRCR' REM1='FRICTION (PSI)'
CARD 20 --> $TDIS
CARD 21 --> SHOW='BRCH' REM1='BREECH PRESSURE (PSI)'
CARD 22 --> $TDIS
CARD 23 --> SHOW='BASE' REM1='BASE PRESSURE (PSI)'
CARD 24 --> $TDIS
CARD 25 --> SHOW='TBAR' REM1='MEAN TEMP (DEG K)'
CARD 26 --> $TDIS
CARD 27 --> SHOW='WTB(1)' REM1='PROP 1 (LBS BRNED)'
CARD 28 --> $TDIS
CARD 29 --> SHOW='WTB(2)' REMK='PROP 2 (LBS BRNED)'
CARD 30 --> $TDIS
CARD 31 --> SHOW='WTB(3)' REM1='PROP 3 (LBS BRNED)'
CARD 32 -->
CARD 33 --> SHEAT
CARD 34 --> TSHL=0.00384
CARD 35 -->
CARD 36 --> $COMM
CARD 37 --> GET MAXIMUM PRESSURES AT GAGE LOCATIONS - BREECH,
CARD 38 --> ORIGINAL PROJECTILE BASE, AND AT 10 INCHES OF TRAVEL
CARD 39 --> $GUN
CARD 40 --> NAME='155-MM 198' CHAM=1150 GRVE=6.2 LAND=6.1
CARD 41 --> G/L=1.66 TRAV=205. TWST=20 NGAG=3 GLOC=-30.,0.,10. CLEN=30.
CARD 42 -->
CARD 43 --> $PROJ
CARD 44 --> NAME='M549A1' PRWT=96
CARD 45 --> $RESI
CARD 46 --> NPTS=7 TRAV=0,0.4,1.,1.55,2.05,4.5,200
CARD 47 --> PRES=250,3350,4950,3625,3250,2500,1500
CARD 48 -->
CARD 49 --> $COMM
CARD 50 --> INVOKE SPECIAL TRAJECTORY PRINT OPTION - POPT(2)=2
CARD 51 --> CALCULATE AND PRINT BLOWDOWN PHASE - POPT(4)=1
CARD 52 --> $INFO
CARD 53 --> POPT=1,2,1,1,0
CARD 54 --> RUN='NEAR-STANDARD M203/M549'
CARD 55 -->
```

CARD 56 --> SPRIN  
 CARD 57 --> N# 'LK POWDER' CHWT=0.0154  
 CARD 58 --> G 25 FORC=96000 COV=30 TEMP=2000  
 CARD 59 --> SPRO  
 CARD 60 --> NA 'LK POWDER' CHWT=0.2976 GRAN='ORD'  
 CARD 61 --> LEN=0.198 DIAM=0.098  
 CARD 62 --> RHO=0.06 GAMA=1.25 FORC=96000 COV=30 TEMP=2000  
 CARD 63 --> ALPH=0.0 BETA=50 EROS=0.00000  
 CARD 64 --> SPROP  
 CARD 65 --> NAME='M30A1' CHWT=26.2 GRAN='7PF'  
 CARD 66 --> LEN=0.9481 DIAM=0.4173 PD=0.037R WI=0.078975 WO=0.078975  
 CARD 67 --> RHO=0.0572 GAMA=1.243 FORC=356400 COV=28.7 TEMP=3040  
 CARD 68 --> NTBL=0 ALPH=0.701 BETA=0.004025  
 CARD 69 --> SPROP  
 CARD 70 --> NAME='NC TUBE' CHWT=0.5 GRAN='1PF' NTBL=0 ALPH= A=30  
 CARD 71 --> LEN=28 DIAM=1.5 PD=1.25 WEB=0.125  
 CARD 72 --> FORC=180000 COV=30 TEMP=1553 RHO=0.034 GAMA=1.25  
 CARD 73 --> SEND

-----  
 - GUN TUBE -  
 -----

TYPE: 155-MM 198  
 GROOVE DIAMETER (IN): 6.200  
 TWIST (CALS/TURN): 20.0  
 SHELL THICKNESS (IN): 0.003840  
 INITIAL SHELL TEMP (K): 293.  
 CHAMBER VOLUME (IN3): 1150.00  
 LAND DIAMETER (IN): 6.100  
 BORE AREA (IN2): 29.8275  
 SHELL CP (IN-LB/LB-K): 1948.0  
 AIR HD (IN-LB/IN2-S-K): 0.06480  
 TRAVEL (IN): 205.00  
 GROOVE/LAND RATIO (-): 1.660  
 HEAT-LOSS OPTION: 1  
 SHELL DENSITY (LB/IN3): 0.2840

NO. GAGES:

NO.	LOCATION (IN)	CHAMBER LENGTH (IN)	LOCATION (IN)	LOCATION (IN)
1	-30.00	3	1	10.00

-----  
 - PROJECTILE -  
 -----

TYPE: \*649A1  
 TOTAL WEIGHT (LB): 96.000  
 WEIGHT PREDICTOR OPTION: 0

-----  
 - RESISTANCE -  
 -----

AIR RESISTANCE OPTION: 1

TRAVEL (IN)	PRESSURE (PSI)	WALL HEATING FRACTION:	FRICITION TABLE LENGTH:
1	250.	1	7
2	3350.	4	6
3	4950.	5	7
			TRAVEL (IN) PRESSURE (PSI)
			4.50 2500.
			200.00 1500.

-----  
 - GENERAL -  
 -----

MAX TIME STEP (S): 0.000100  
 PRINT OPTIONS: 1 2 1 1 0 1  
 GRADIENT MODEL: LAGRANGIAN  
 PRINT STEP (S): 0.000000  
 STORE OPTION: 0  
 MAX RELATIVE ERROR (-): 0.00200  
 CONSTANT-PRESSURE OPTION: 0

-----  
 - RECOIL -  
 -----

RECOIL OPTION: 0  
 TYPE: 0  
 RECOILING WEIGHT (LB): 0.

-----  
 - PRIMER -  
 -----

TYPE: BLK POWDER  
 COVOLUME (IN3/LB): 30.000  
 GAMMA (-): 1.2500  
 FLAME TEMP (K): 2000.0  
 FORCE (FT-LB/LB): 96000.  
 WEIGHT (LB): 0.015400



-----  
 - CHARGE 1 -  
 -----

TYPE: BLK POWDER	GRAINS:	3321.0	CORO	0	WEIGHT (LB):	0.2976
EROSIVE COEFF (-):	CHARGE IGM CODE:				CHANGE IGM AT (\$):	0.00000E+00
GRAIN LENGTH (IN):	GRAIN DIAMETER (IN):	0.09800				

	PROPERTIES AT LAYER BOUNDARIES OF END SURFACES	PROPERTIES AT LAYER BOUNDARIES OF LAT SURFACES
	1ST 2ND 3RD 4TH	1ST 2ND 3RD 4TH
AT DEPTH (IN):	0.00000	0.00000
ADJACENT LAYER WT X:	100.000	100.000
DENSITY (LB/INS):	0.06300	0.06000
GAMMA (-):	1.2500	1.2500
FORCE (FT-LB/LB):	96000.	96000.
COVOLUME (INS/LB):	30.000	30.000
FLAME TEMP (K):	2000.0	2000.0
BURNING RATE EXPS:	0.0000	0.0000
BURNING RATE COEFFS:	50.0000000	50.0000000

-----  
 - CHARGE 2 -  
 -----

TYPE: M30M1  
 EROSION COEFF (-):  
 GRAIN LENGTH (IN):  
 INNER WEB (IN):

0.000000  
 0.94810  
 0.07898

GRAINS:  
 CHARGE IGM CODE:  
 GRAIN DIAMETER (IN):  
 OUTER WEB (IN):

3702.4  
 0  
 0.41730  
 0.07898

WEIGHT (LB):  
 CHARGE IGM AT (\$):  
 PERF DIAMETER (IN):

26.2000  
 0.00000E+00  
 0.03380

PROPERTIES AT LAYER BOUNDARIES OF PERF SURFACES

	1ST	2ND	3RD	4TH
AT DEPTH (IN):	---	---	---	---
ADJACENT LAYER WT %:	---	---	---	---
DENSITY (LB/INS):	---	---	---	---
GAMMA (-):	---	---	---	---
FORCE (FT-LB/LB):	---	---	---	---
COVOLUME (INS/LB):	---	---	---	---
FLAME TEMP (K):	---	---	---	---
BURNING RATE EXPS:	---	---	---	---
BURNING RATE COEFFS:	---	---	---	---

PROPERTIES AT LAYER BOUNDARIES OF END SURFACES

	1ST	2ND	3RD	4TH
AT DEPTH (IN):	---	---	---	---
ADJACENT LAYER WT %:	---	---	---	---
DENSITY (LB/INS):	---	---	---	---
GAMMA (-):	---	---	---	---
FORCE (FT-LB/LB):	---	---	---	---
COVOLUME (INS/LB):	---	---	---	---
FLAME TEMP (K):	---	---	---	---
BURNING RATE EXPS:	---	---	---	---
BURNING RATE COEFFS:	---	---	---	---

PROPERTIES AT LAYER BOUNDARIES OF LAT SURFACES

	1ST	2ND	3RD	4TH
AT DEPTH (IN):	---	---	---	---
ADJACENT LAYER WT %:	---	---	---	---
DENSITY (LB/INS):	---	---	---	---
GAMMA (-):	---	---	---	---
FORCE (FT-LB/LB):	---	---	---	---
COVOLUME (INS/LB):	---	---	---	---
FLAME TEMP (K):	---	---	---	---
BURNING RATE EXPS:	---	---	---	---
BURNING RATE COEFFS:	---	---	---	---

- CHARGE 3 -

TYPE: MC TUBE  
 EXPLOSIVE COEFF (-):  
 GRAIN LENGTH (IN):  
 INNER WEB (IN):

0.000000  
 28.000000  
 0.125000

GRAINS:  
 CHARGE IGM CODE:  
 GRAIN DIAMETER (IN):  
 WEB RATIO:

0.97268  
 0  
 1.50000  
 1.00000

WEIGHT (LB):  
 CHARGE IGM AT (S):  
 PERF DIAMETER (IN):

0.5000  
 0.00000E+00  
 1.25000

1PF

PROPERTIES AT LAYER BOUNDARIES OF PERF SURFACES

	1ST	2ND	3RD	4TH
AT DEPTH (IN):	---	---	---	---
ADJACENT LAYER WT %:	---	---	---	---
DENSITY (LB/INS):	---	---	---	---
GAMMA (-):	---	---	---	---
FORCE (FT-LB/LB):	---	---	---	---
COVOLUME (INS/LB):	---	---	---	---
FLAME TEMP (K):	---	---	---	---
BURNING RATE EXPS:	---	---	---	---
BURNING RATE COEFFS:	---	---	---	---

PROPERTIES AT LAYER BOUNDARIES OF END SURFACES

	1ST	2ND	3RD	4TH
AT DEPTH (IN):	---	---	---	---
ADJACENT LAYER WT %:	---	---	---	---
DENSITY (LB/INS):	---	---	---	---
GAMMA (-):	---	---	---	---
FORCE (FT-LB/LB):	---	---	---	---
COVOLUME (INS/LB):	---	---	---	---
FLAME TEMP (K):	---	---	---	---
BURNING RATE EXPS:	---	---	---	---
BURNING RATE COEFFS:	---	---	---	---

PROPERTIES AT LAYER BOUNDARIES OF LAT SURFACES

	1ST	2ND	3RD	4TH
AT DEPTH (IN):	---	---	---	---
ADJACENT LAYER WT %:	---	---	---	---
DENSITY (LB/INS):	---	---	---	---
GAMMA (-):	---	---	---	---
FORCE (FT-LB/LB):	---	---	---	---
COVOLUME (INS/LB):	---	---	---	---
FLAME TEMP (K):	---	---	---	---
BURNING RATE EXPS:	---	---	---	---
BURNING RATE COEFFS:	---	---	---	---

TRAJECTORY VARIABLES:												TIME (MS)																				
/ 1/	/ 2/	/ 3/	/ 4/	/ 5/	/ 6/	/ 7/	/ 8/	/ 9/	/ 10/	/ 11/	TRAVEL (INCHES)	VELOCITY (IN/SEC)	ACCEL (GRAV)	FRICTION (PSI)	BREECH PRESSURE (PSI)	MEAN TEMP (DEG K)	PROP 1 (LBS BRINED)	PROP 2 (LBS BRINED)	PROP 3 (LBS BRINED)	TRAVEL (INCHES)	VELOCITY (IN/SEC)	ACCEL (GRAV)	FRICTION (PSI)	BREECH PRESSURE (PSI)	MEAN TEMP (DEG K)	PROP 1 (LBS BRINED)	PROP 2 (LBS BRINED)	PROP 3 (LBS BRINED)				
0.95191E-01	0.45392E-09	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.66669E-01	0.54050E-02	0.22943E-01	0.	0.	0.	0.	0.	0.	0.69755E-01	0.59065E-02	0.24102E-01	0.18176E-01	0.48194E-01	0.35912E-01	0.72275E-01	0.96344E-01	0.12041	0.14446	0.16850	0.19253	0.23576
0.10000	0.71886E-08	0.31346E-02	3.3780	250.00	26.407	26.407	26.407	26.407	26.407	26.407	1933.1	1985.2	2034.7	2081.2	2125.2	2167.1	2207.1	2245.3	2309.4	1930.6	1933.1	1985.2	2034.7	2081.2	2125.2	2167.1	2207.1	2245.3	2309.4			
0.20000	0.50371E-04	1.5284	76.405	250.41	530.92	817.09	1122.4	1444.9	1786.1	1924.1	260.87	496.32	748.23	1016.1	1300.6	1602.7	1924.1	2266.5	2942.5	260.87	260.87	496.32	748.23	1016.1	1300.6	1602.7	1924.1	2266.5	2942.5			
0.30000	0.40276E-03	5.9640	153.83	253.12	412.6	558.51	717.0	891.8	1066.6	1231.7	3022.9	3444.7	3900.4	4391.6	4919.5	5485.5	6061.5	6713.9	7406.9	2316.2	2316.2	3444.7	3900.4	4391.6	4919.5	5485.5	6061.5	6713.9	7406.9			
0.40000	0.13490E-02	13.462	234.78	260.45	412.6	558.51	717.0	891.8	1066.6	1231.7	3444.7	3900.4	4391.6	4919.5	5485.5	6061.5	6713.9	7406.9	8156.0	2348.6	2348.6	3444.7	3900.4	4391.6	4919.5	5485.5	6061.5	6713.9	7406.9			
0.50000	0.32013E-02	24.146	318.69	274.81	438.8	582.1	740.6	903.1	1073.6	1251.1	3865.4	4382.1	4959.2	5580.0	6251.6	6959.2	7706.8	8500.0	9331.2	2407.2	2407.2	3444.7	3900.4	4391.6	4919.5	5485.5	6061.5	6713.9	7406.9			
0.60000	0.62869E-02	38.123	405.13	298.72	493.77	653.77	824.77	1000.0	1183.6	1373.6	4282.1	4959.2	5706.8	6500.0	7331.2	8200.0	9116.4	10080.0	11096.0	2453.6	2453.6	3444.7	3900.4	4391.6	4919.5	5485.5	6061.5	6713.9	7406.9			
0.70000	0.10959E-01	55.483	493.77	334.77	534.77	706.77	891.8	1088.3	1296.7	1511.1	4706.8	5485.5	6331.2	7251.1	8251.1	9331.2	10500.0	11751.1	13080.0	2503.6	2503.6	3444.7	3900.4	4391.6	4919.5	5485.5	6061.5	6713.9	7406.9			
0.80000	0.17499E-01	76.306	584.35	385.62	584.35	788.62	1000.0	1227.0	1483.6	1751.1	5127.0	5996.7	6959.2	8000.0	9116.4	10311.2	11580.0	12916.4	14331.2	2543.2	2543.2	3444.7	3900.4	4391.6	4919.5	5485.5	6061.5	6713.9	7406.9			
0.90000	0.35238E-01	122.74	751.66	523.10	751.66	1000.0	1227.0	1483.6	1751.1	2046.0	5546.0	6460.0	7451.1	8500.0	9616.4	10800.0	12051.1	13380.0	14796.0	2581.2	2581.2	3444.7	3900.4	4391.6	4919.5	5485.5	6061.5	6713.9	7406.9			
PROPELLANT 1 BURNED OUT																																
1.0000	0.37751E-01	128.62	770.58	542.57	770.58	1000.0	1227.0	1483.6	1751.1	2046.0																						
1.1000	0.52164E-01	160.25	866.91	654.27	866.91	1100.0	1483.6	1751.1	2046.0	2316.2																						
1.2000	0.69264E-01	195.65	965.73	791.93	965.73	1200.0	1751.1	2046.0	2316.2	2608.7																						
1.3000	0.91421E-01	234.90	1066.6	958.51	1066.6	1300.0	2046.0	2316.2	2608.7	2916.4																						
1.4000	0.11704	278.09	1168.9	1157.0	1168.9	1400.0	2316.2	2608.7	2916.4	3227.0																						
1.5000	0.14717	325.25	1272.1	1390.6	1272.1	1500.0	2608.7	2916.4	3227.0	3538.6																						
1.6000	0.18222	376.40	1375.8	1642.2	1375.8	1600.0	2916.4	3227.0	3538.6	3850.0																						
1.7000	0.22259	431.57	1479.3	1975.0	1479.3	1700.0	3227.0	3538.6	3850.0	4161.4																						
1.8000	0.26867	490.72	1582.1	2332.2	1582.1	1800.0	3538.6	3850.0	4161.4	4473.6																						
1.9000	0.32066	553.82	1683.5	2736.7	1683.5	1900.0	3850.0	4161.4	4473.6	4785.8																						
2.0000	0.37956	620.80	1783.0	3191.6	1783.0	2000.0	4161.4	4473.6	4785.8	5097.0																						
2.0833	0.43373	680.01	1912.0	3440.0	1912.0	2083.3	4473.6	4785.8	5097.0	5409.2																						
PROPELLANT 3 BURNED OUT																																
2.1000	0.44517	692.42	1940.7	3470.4	1940.7	2100.0	4785.8	5097.0	5409.2	5721.4																						
2.2000	0.51827	770.78	2116.2	3665.4	2116.2	2200.0	5097.0	5409.2	5721.4	6033.6																						
2.3000	0.59955	856.03	2297.1	3882.1	2297.1	2300.0	5409.2	5721.4	6033.6	6345.8																						
2.4000	0.68971	948.36	2483.0	4122.6	2483.0	2400.0	5721.4	6033.6	6345.8	6658.0																						
2.5000	0.78947	1048.0	2673.3	4388.6	2673.3	2500.0	6033.6	6345.8	6658.0	6970.2																						
2.6000	0.89956	1155.0	2867.4	4682.1	2867.4	2600.0	6345.8	6658.0	6970.2	7282.4																						
2.7000	1.0207	1269.8	3094.4	4900.1	3094.4	2700.0	6658.0	6970.2	7282.4	7594.6																						
2.8000	1.1539	1396.9	3485.6	5179.2	3485.6	2800.0	6970.2	7282.4	7594.6	7906.8																						
2.9000	1.3006	1529.4	3896.7	5425.6	3896.7	2900.0	7282.4	7594.6	7906.8	8219.0																						
3.0000	1.4624	1698.3	4327.9	5636.9	4327.9	3000.0	7594.6	7906.8	8219.0	8531.2																						
3.1000	1.6408	1873.9	4736.9	5856.9	4736.9	3100.0	7906.8	8219.0	8531.2	8843.4																						
3.2000	1.8376	2064.2	5116.4	6093.3	5116.4	3200.0	8219.0	8531.2	8843.4	9155.6																						
3.3000	2.0542	2269.4	5506.4	6348.7	5506.4	3300.0	8531.2	8843.4	9155.6	9467.8																						
3.4000	2.2920	2469.3	5877.0	6587.0	5877.0	3400.0	8843.4	9155.6	9467.8	9780.0																						
3.5000	2.5525	2723.7	6253.6	6809.2	6253.6	3500.0	9155.6	9467.8	9780.0	10092.2																						
3.6000	2.8372	2972.6	6634.9	7019.1	6634.9	3600.0	9467.8	9780.0	10092.2	10404.4																						
3.7000	3.1475	3236.4	7019.1	7210.0	7019.1	3700.0	9780.0	10092.2	10404.4	10716.6																						
3.8000	3.4850	3515.1	7404.7	7404.7	7404.7	3800.0	10092.2	10404.4	10716.6	11028.8																						

TRAJECTORY VARIABLES:										
/ 1/	/ 2/	/ 3/	/ 4/	/ 5/	/ 6/	/ 7/	/ 8/	/ 9/	/ 10/	/ 11/
3.9000	3.8510	3808.7	7789.8	2698.7	31304.	27777.	2802.2	0.29764	4.9419	0.49934
4.0000	4.2472	4117.1	8172.6	2577.4	32589.	28886.	2801.7	0.29764	5.2376	0.49934
4.1000	4.6750	4440.1	8536.2	2499.1	33647.	29981.	2800.3	0.29764	5.5431	0.49934
4.2000	5.1357	4776.4	8869.4	2496.7	35068.	31052.	2797.8	0.29764	5.8585	0.49934
4.3000	5.6307	5125.4	9191.7	2494.2	36250.	32087.	2794.5	0.29764	6.1834	0.49934
4.4000	6.1612	5486.6	9501.5	2491.5	37365.	33082.	2790.3	0.29764	6.5176	0.49934
4.5000	6.7284	5859.5	9796.9	2488.6	38467.	34031.	2785.2	0.29764	6.8609	0.49934
4.6000	7.3334	6243.5	10076.	2485.5	39491.	34929.	2779.5	0.29764	7.2131	0.49934
4.7000	7.9774	6637.9	10339.	2482.2	40452.	35770.	2773.0	0.29764	7.5736	0.49934
4.8000	8.6613	7042.2	10582.	2478.7	41344.	36552.	2765.9	0.29764	7.9423	0.49934
4.9000	9.3861	7455.5	10807.	2475.0	42165.	37271.	2758.2	0.29764	8.3187	0.49934
4.9805	10.0000	7794.3	10972.	2471.9	42772.	37803.	2751.7	0.29764	8.6270	0.49934
5.0000	10.153	7877.0	11011.	2471.1	42911.	37925.	2750.0	0.29764	8.7023	0.49934
5.1000	10.962	8306.1	11194.	2466.9	43580.	38512.	2741.3	0.29764	9.0929	0.49934
5.2000	11.814	8741.8	11356.	2462.6	44172.	39030.	2732.2	0.29764	9.4899	0.49934
5.3000	12.710	9183.4	11497.	2458.0	44686.	39480.	2722.7	0.29764	9.8928	0.49934
5.4000	13.651	9638.0	11616.	2453.2	45122.	39862.	2712.9	0.29764	10.301	0.49934
5.5000	14.636	10081.	11715.	2448.2	45481.	40176.	2702.7	0.29764	10.715	0.49934
5.6000	15.667	10535.	11794.	2442.9	45766.	40425.	2692.4	0.29764	11.133	0.49934
5.7000	16.743	10992.	11852.	2437.4	45978.	40611.	2681.9	0.29764	11.555	0.49934
5.8000	17.864	11451.	11892.	2431.6	46121.	40735.	2671.2	0.29764	11.981	0.49934
5.9000	19.034	11911.	11914.	2425.7	46197.	40802.	2660.4	0.29764	12.410	0.49934
5.9715	19.897	12240.	11920.	2421.2	46212.	40815.	2652.7	0.29764	12.718	0.49934
6.0000	20.248	12371.	11919.	2419.4	46210.	40813.	2649.6	0.29764	12.842	0.49934
6.1000	21.508	12832.	11908.	2413.0	46164.	40772.	2638.7	0.29764	13.276	0.49934
6.2000	22.814	13291.	11882.	2406.3	46064.	40683.	2627.8	0.29764	13.712	0.49934
6.3000	24.166	13750.	11842.	2399.4	45912.	40550.	2616.9	0.29764	14.150	0.49934
6.4000	25.564	14206.	11789.	2392.3	45714.	40375.	2606.1	0.29764	14.589	0.49934
6.5000	27.007	14661.	11725.	2384.9	45472.	40163.	2595.3	0.29764	15.029	0.49934
6.6000	28.496	15112.	11650.	2377.3	45192.	39917.	2584.6	0.29764	15.469	0.49934
6.7000	30.029	15561.	11566.	2369.4	44877.	39640.	2574.0	0.29764	15.910	0.49934
6.8000	31.608	16006.	11474.	2361.3	44531.	39335.	2563.5	0.29764	16.351	0.49934
6.9000	33.230	16447.	11373.	2353.0	44157.	39007.	2553.2	0.29764	16.791	0.49934
7.0000	34.897	16885.	11267.	2344.5	43759.	38657.	2543.0	0.29764	17.231	0.49934
7.1000	36.607	17318.	11154.	2335.8	43339.	38288.	2532.9	0.29764	17.671	0.49934
7.2000	38.361	17747.	11037.	2326.8	42902.	37904.	2523.0	0.29764	18.109	0.49934
7.3000	40.157	18171.	10915.	2317.6	42448.	37506.	2513.2	0.29764	18.546	0.49934
7.4000	41.995	18590.	10790.	2308.2	41983.	37096.	2503.6	0.29764	18.982	0.49934
7.5000	43.874	19005.	10663.	2298.6	41506.	36678.	2494.2	0.29764	19.416	0.49934
7.6000	45.795	19414.	10533.	2288.8	41021.	36252.	2484.9	0.29764	19.849	0.49934
7.7000	47.757	19819.	10401.	2278.7	40530.	35820.	2475.8	0.29764	20.280	0.49934
7.8000	49.759	20218.	10268.	2268.5	40034.	35384.	2466.9	0.29764	20.709	0.49934

TRAJECTORY VARIABLES:

TIME (MS)  
 TRAVEL (INCHES)  
 VELOCITY (IN/SEC)  
 ACCEL (GRAV)  
 FRICTION (PSI)  
 BRECHN PRESSURE (PSI)  
 BASE PRESSURE (PSI)  
 MEAN TEMP (DEG K)  
 PROP 1 (LBS BRNED)  
 PROP 2 (LBS BRNED)  
 PROP 3 (LBS BRNED)

	/ 1/	/ 2/	/ 3/	/ 4/	/ 5/	/ 6/	/ 7/	/ 8/	/ 9/	/ 10/	/ 11/
7.9000	51.801	20612.	10134.	2258.1	39535.	34946.	2458.1	0.29764	21.136	0.49934	
8.0000	53.881	21001.	10000.	2247.4	39034.	34506.	2449.5	0.29764	21.561	0.49934	
8.1000	56.001	21385.	9865.2	2236.6	38533.	34066.	2441.1	0.29764	21.984	0.49934	
8.2000	58.158	21764.	9732.3	2225.5	38033.	33626.	2432.8	0.29764	22.405	0.49934	
8.3000	60.353	22137.	9574.7	2214.3	37445.	33110.	2423.7	0.29764	22.783	0.49934	
8.4000	62.585	22503.	9386.9	2202.9	36747.	32496.	2413.3	0.29764	23.103	0.49934	
8.5000	64.854	22862.	9134.7	2191.3	35995.	31836.	2402.3	0.29764	23.386	0.49934	
8.6000	67.157	23213.	8974.1	2179.5	35212.	31148.	2390.9	0.29764	23.640	0.49934	
8.7000	69.496	23556.	8758.7	2167.5	34412.	30445.	2379.2	0.29764	23.871	0.49934	
8.8000	71.848	23890.	8541.0	2155.4	33602.	29735.	2367.4	0.29764	24.080	0.49934	
8.9000	74.273	24216.	8322.8	2143.1	32791.	29022.	2355.4	0.29764	24.271	0.49934	
9.0001	76.711	24533.	8105.5	2130.6	31983.	28313.	2343.3	0.29764	24.444	0.49934	
9.1001	79.180	24842.	7890.2	2118.0	31182.	27609.	2331.1	0.29764	24.603	0.49934	
9.2001	81.679	25143.	7677.6	2105.2	30391.	26914.	2318.9	0.29764	24.747	0.49934	
9.3001	84.208	25435.	7468.4	2092.3	29612.	26230.	2306.7	0.29764	24.879	0.49934	
9.4001	86.766	25720.	7263.1	2079.2	28847.	25558.	2294.5	0.29764	24.998	0.49934	
9.5001	89.352	25997.	7062.1	2066.0	28098.	24900.	2282.4	0.29764	25.107	0.49934	
9.6001	91.965	26266.	6865.6	2052.6	27365.	24256.	2270.2	0.29764	25.205	0.49934	
9.7001	94.605	26527.	6673.9	2039.1	26649.	23627.	2258.1	0.29764	25.294	0.49934	
9.8001	97.270	26782.	6487.1	2025.5	25952.	23014.	2246.1	0.29764	25.375	0.49934	
9.9001	99.961	27029.	6306.0	2011.7	25275.	22419.	2234.1	0.29764	25.448	0.49934	
10.000	102.68	27269.	6130.8	1997.8	24620.	21843.	2222.4	0.29764	25.517	0.49934	
10.100	105.41	27503.	5961.4	1983.8	23985.	21286.	2210.7	0.29764	25.581	0.49934	
10.200	108.18	27730.	5797.5	1969.7	23371.	20746.	2199.2	0.29764	25.640	0.49934	
10.300	110.96	27951.	5639.2	1955.4	22777.	20224.	2187.8	0.29764	25.695	0.49934	
10.400	113.77	28166.	5486.1	1941.1	22203.	19719.	2176.6	0.29764	25.746	0.49934	
10.500	116.59	28375.	5338.3	1926.6	21647.	19230.	2165.5	0.29764	25.793	0.49934	
10.600	119.44	28578.	5195.4	1912.1	21109.	18757.	2154.5	0.29764	25.836	0.49934	
10.700	122.31	28776.	5057.3	1897.4	20589.	18299.	2143.7	0.29764	25.876	0.49934	
10.800	125.20	28969.	4923.9	1882.6	20086.	17857.	2133.0	0.29764	25.913	0.49934	
10.900	128.10	29157.	4795.0	1867.8	19600.	17429.	2122.4	0.29764	25.947	0.49934	
11.000	131.03	29340.	4670.5	1852.8	19129.	17014.	2111.9	0.29764	25.979	0.49934	
11.100	133.97	29518.	4550.2	1837.8	18674.	16613.	2101.6	0.29764	26.007	0.49934	
11.200	136.93	29691.	4433.9	1822.6	18233.	16225.	2091.4	0.29764	26.033	0.49934	
11.300	139.91	29861.	4321.6	1807.4	17807.	15850.	2081.3	0.29764	26.057	0.49934	
11.400	142.90	30025.	4213.0	1792.1	17394.	15486.	2071.3	0.29764	26.078	0.49934	
11.500	145.91	30186.	4108.0	1776.7	16995.	15134.	2061.5	0.29764	26.097	0.49934	
11.600	148.94	30343.	4006.5	1761.2	16608.	14794.	2051.8	0.29764	26.114	0.49934	
11.700	151.98	30496.	3908.4	1745.6	16233.	14463.	2042.1	0.29764	26.129	0.49934	
11.800	155.04	30645.	3813.5	1730.0	15870.	14144.	2032.6	0.29764	26.143	0.49934	
11.900	158.11	30791.	3721.7	1714.3	15519.	13834.	2023.2	0.29764	26.155	0.49934	
12.000	161.20	30933.	3632.9	1698.5	15178.	13533.	2013.9	0.29764	26.167	0.49934	
12.100	164.30	31071.	3547.1	1682.6	14849.	13242.	2004.7	0.29764	26.173	0.49934	
12.200	167.41	31207.	3464.0	1666.7	14529.	12960.	1995.6	0.29764	26.180	0.49934	

TRAJECTORY VARIABLES:											
TIME (MS)	TRAVEL (INCHES)	VELOCITY (IN/SEC)	ACCEL (GRAV)	FRICTION (PSI)	BREECH PRESSURE (PSI)	BASE PRESSURE (PSI)	MEAN TEMP (DEG K)	PROP 1 (LBS BRNED)	PROP 2 (LBS BRNED)	PROP 3 (LBS BRNED)	TIME
/ 1/	/ 2/	/ 3/	/ 4/	/ 5/	/ 6/	/ 7/	/ 8/	/ 9/	/ 10/	/ 11/	TIME
12.300	170.54	31339.	3383.6	1650.7	14219.	12686.	1986.7	0.29764	26.186	0.49934	0.49934
12.400	173.68	31468.	3305.7	1634.6	13918.	12421.	1977.8	0.29764	26.190	0.49934	0.49934
12.500	176.83	31595.	3230.4	1618.5	13626.	12163.	1969.0	0.29764	26.193	0.49934	0.49934
12.600	180.00	31718.	3157.4	1602.3	13343.	11913.	1960.3	0.29764	26.195	0.49934	0.49934
12.700	183.18	31839.	3086.8	1586.1	13069.	11671.	1951.7	0.29764	26.196	0.49934	0.49934
12.717	183.71	31859.	3075.2	1583.3	13023.	11631.	1950.2	0.29764	26.196	0.49934	0.49934
PROPELLANT 2 BURNED OUT											
12.800	186.36	31956.	3018.5	1569.8	12803.	11436.	1943.2	0.29764	26.196	0.49934	0.49934
12.900	189.56	32072.	2922.5	1553.4	12545.	11208.	1934.8	0.29764	26.196	0.49934	0.49934
13.000	192.78	32185.	2868.7	1537.0	12295.	10987.	1926.6	0.29764	26.196	0.49934	0.49934
13.100	196.00	32295.	2827.1	1520.5	12054.	10773.	1918.5	0.29764	26.196	0.49934	0.49934
13.200	199.23	32403.	2767.6	1503.9	11820.	10566.	1910.5	0.29764	26.196	0.49934	0.49934
13.300	202.48	32509.	2706.5	1500.0	11592.	10366.	1902.6	0.29764	26.196	0.49934	0.49934
13.377	205.00	32589.	2659.6	1500.0	11421.	10216.	1896.6	0.29764	26.196	0.49934	0.49934
PROJECTILE EXIT											

CONDITIONS AT:	PMAX	MUZZLE
TIME (MS):	5.972	13.377
TRAVEL (IN):	19.90	205.00
VELOCITY (FT/S):	1020.	2716.
ACCELERATION (G):	11920.	2660.
BREECH PRESS (PSI):	46212.	11421.
MEAN PRESS (PSI):	44413.	11019.
BASE PRESS (PSI):	40815.	10216.
MEAN TEMP (K):	2653.	1897.
Z CHARGE 1 (-):	1.000	1.000
Z CHARGE 2 (-):	0.485	1.000
Z CHARGE 3 (-):	1.000	1.000

GAGE AT (IN)	PMAX (PSI)	WRT SOM
1	-30.00	46212.
2	0.00	43943.
3	10.00	42699.

ENERGY BALANCE SUMMARY	IN-LB	%
TOTAL CHEMICAL:	466804736.	100.00
(1) INTERNAL GAS:	294272512.	63.04
(2) WORK AND LOSSES:	172532304.	36.96
(A) PROJECTILE KINETIC:	131932192.	28.26
(B) GAS KINETIC:	12374597.	2.65
(C) PROJECTILE ROTATIONAL:	1627647.	0.35
(D) FRICTIONAL WORK TO TUBE:	0.	0.00
(E) OTHER FRICTIONAL WORK:	12313598.	2.64
(F) WORK DONE AGAINST AIR:	621945.	0.13
(G) HEAT CONVECTED TO BORE:	13662321.	2.93
(H) RECOIL ENERGY:	0.	0.00

LOADING DENSITY (G/CM <sup>3</sup> ):	0.650
CHARGE WT/PROJECTILE WT:	0.281
PIEZOMETRIC EFFICIENCY:	0.467
EXPANSION RATIO:	6.317



TIME (MS)	RAREFACTION WAVE LOC'N (IN)	BREECH PRESS (PSI)	MOMENTUM (LB-SEC)	RECOIL TRAVEL (IN)	RECOIL VEL (FT/S)
13.377	243.55	11421.	9236.	0.00	0.00
13.500	242.66	11166.	9277.	0.00	0.00
14.000	238.57	10217.	9436.	0.00	0.00
14.500	233.78	9392.	9582.	0.00	0.00
15.000	228.29	8670.	9717.	0.00	0.00
15.500	222.13	8034.	9842.	0.00	0.00
16.000	215.30	7470.	9957.	0.00	0.00
16.500	207.84	6967.	10065.	0.00	0.00
17.000	199.75	6517.	10165.	0.00	0.00
17.500	191.05	6113.	10259.	0.00	0.00
18.000	181.75	5747.	10348.	0.00	0.00
18.500	171.88	5416.	10431.	0.00	0.00
19.000	161.45	5115.	10509.	0.00	0.00
19.500	150.48	4839.	10584.	0.00	0.00
20.000	138.97	4587.	10654.	0.00	0.00
20.500	126.95	4356.	10720.	0.00	0.00
21.000	114.42	4143.	10784.	0.00	0.00
21.500	101.41	3946.	10844.	0.00	0.00
22.000	87.91	3764.	10902.	0.00	0.00
22.500	73.95	3595.	10956.	0.00	0.00
23.000	59.53	3438.	11009.	0.00	0.00
23.500	44.66	3291.	11059.	0.00	0.00
24.000	29.36	3155.	11107.	0.00	0.00
24.500	13.63	3027.	11153.	0.00	0.00
24.923	0.00	2926.	11191.	0.00	0.00

CARD 74 -->  
CARD 75 --> \$SAVE           \$ KEEP PREVIOUS INPUTS EXCEPT FOR FOLLOWING VALUES  
CARD 76 -->  
CARD 77 --> \$COMM  
CARD 78 -->           CHANGE TRAJECTORY PRINT OPTION AND TITLE  
CARD 79 --> \$INFO  
CARD 80 -->   POPT=1,1,1,0,1   RUN='M203/M549   TABULAR B/R DATA'  
CARD 81 -->  
CARD 82 --> \$PROP           \$ NO CHANGES IN FIRST PROPELLANT DECK  
CARD 83 --> \$PROP           \$ CHANGE BURNING RATE SPECIFICATION METHOD  
CARD 84 -->   NTBL=4 PR4L=1000,5000,10000,30000 BR4L=0.5102,1.577,2.563,5.536  
CARD 85 -->  
CARD 86 --> \$COMM  
CARD 87 -->   ADD PARAMETRIC VARIATION ON CHARGE WEIGHT FOR SECOND PROPELLANT  
CARD 88 --> \$PARA  
CARD 89 -->   VARY='CHWT' DECK='PROP' NTH=2 FROM=25 TO=27 BY=0.2  
CARD 90 --> \$END

--- GUN TUBE ---

TYPE: 155-MM 198  
 GROOVE DIAMETER (IN): 6.100  
 TWIST (CAL/S/TURN): 20.0  
 SHELL THICKNESS (IN): 0.003040  
 INITIAL SHELL TEMP (K): 293.  
 NO. GAGES: 3  
 CHAMBER VOLUME (IN3): 1150.00  
 LAND DIAMETER (IN): 6.100  
 BORE AREA (IN2): 29.8275  
 SHELL CP (IN-LB/LB-K): 1848.0  
 AIR NO (IN-LB/IN2-S-K): 0.06480  
 TRAVEL (IN): 205.00  
 GROOVE/LAND RATIO (-): 1.660  
 HEAT-LOSS OPTION: 1  
 SHELL DENSITY (LB/IN3): 0.2840

I	LOCATION (IN)	CHAMBER LENGTH (IN)
1	-30.00	30.00

I	LOCATION (IN)
3	10.00

--- PROJECTILE ---

TYPE: M549A1  
 TOTAL WEIGHT (LB): 96.000  
 WEIGHT PREDICTOR OPTION: 0

AIR RESISTANCE OPTION: 1  
 WALL HEATING FRACTION: 0.000  
 FRICTION TABLE LENGTH: 7

I	TRAVEL (IN)	PRESSURE (PSI)	TRAVEL (IN)	PRESSURE (PSI)
1	0.00	250.	6	4.50
2	0.40	3350.	7	200.00
3	1.00	4950.		

--- GENERAL ---

MAX TIME STEP (S): 0.000100  
 PRINT OPTIONS: 1 1 1 0 1 1  
 GRADIENT MODEL: LAGRANGIAN  
 PRINT STEP (S): 0.000000  
 STORE OPTION: 0  
 MAX RELATIVE ERROR (-): 0.00200  
 CONSTANT-PRESSURE OPTION: 0

--- RECOIL ---

RECOIL OPTION: 0  
 TYPE: 0  
 RECOILING WEIGHT (LB): 0.

--- PRIMER ---

TYPE: BLK POWDER  
 COVOLUME (IN3/LB): 30.000  
 GAMMA (-): 1.2500  
 FLAME TEMP (K): 2000.0  
 FORCE (FT-LB/LB): 96000.  
 WEIGHT (LB): 0.015600

-----  
 - CHARGE 1 -  
 -----

TYPE: BLK POWDER  
 EROSION COEFF (-):  
 GRAIN LENGTH (IN):

0.000000  
 0.190000

GRAINS:  
 CHARGE ICM CODE:  
 GRAIN DIAMETER (IN):

3321.0  
 0  
 0.098000

WEIGHT (LB):  
 CHARGE ICM AT (S):

0.2976  
 0.000000E+00

PROPERTIES AT LAYER BOUNDARIES OF END SURFACES		PROPERTIES AT LAYER BOUNDARIES OF LAT SURFACES						
	1ST	2ND	3RD	4TH	1ST	2ND	3RD	4TH
AT DEPTH (IN):	-----	-----	-----	-----	-----	-----	-----	-----
ADJACENT LAYER WT %:	-----	-----	-----	-----	-----	-----	-----	-----
DENSITY (LB/IN3):	-----	-----	-----	-----	0.000000	-----	-----	0.000000
GAMMA (-):	-----	-----	-----	-----	100.0000	-----	-----	100.0000
FORCE (FT-LB/LB):	-----	-----	-----	-----	0.060000	-----	-----	0.060000
COVOLUME (IN3/LB):	-----	-----	-----	-----	1.250000	-----	-----	1.250000
FLAME TEMP (K):	-----	-----	-----	-----	960000	-----	-----	960000
BURNING RATE EXPS:	-----	-----	-----	-----	30.0000	-----	-----	30.0000
BURNING RATE COEFFS:	-----	-----	-----	-----	2000.0	-----	-----	2000.0
	-----	-----	-----	-----	0.000000	-----	-----	0.000000
	-----	-----	-----	-----	50.00000000	-----	-----	50.00000000

- CHARGE 2 -

TYPE: M50A1  
 EROSION COEFF (-): 0.000000  
 GRAIN LENGTH (IN): 0.94810  
 INNER WEB (IN): 0.07898

GRAINS:  
 CHARGE IGM CODE: 3532.8  
 GRAIN DIAMETER (IN): 0.41730  
 OUTER WEB (IN): 0.07898

WEIGHT (LB): 25.0000  
 CHARGE IGM AT (S): 0.00000E+00  
 PERF DIAMETER (IN): 0.03390

7PF: 0

PROPERTIES AT LAYER BOUNDARIES OF PERF SURFACES

	1ST	2ND	3RD	4TH
AT DEPTH (IN):	---	---	---	---
ADJACENT LAYER WT %:	---	---	---	---
DENSITY (LB/IN3):	---	---	---	---
GAMMA (-):	---	---	---	---
FORCE (FT-LB/LB):	---	---	---	---
COVOLUME (IN3/LB):	---	---	---	---
FLAME TEMP (K):	---	---	---	---
MEAN PRESSURES (PSI):	---	---	---	---
MEAN PRESSURES (PSI):	---	---	---	---
MEAN PRESSURES (PSI):	---	---	---	---
BURNING RATES (IN/S):	---	---	---	---
BURNING RATES (IN/S):	---	---	---	---
BURNING RATES (IN/S):	---	---	---	---

PROPERTIES AT LAYER BOUNDARIES OF END SURFACES

	1ST	2ND	3RD	4TH
AT DEPTH (IN):	---	---	---	---
ADJACENT LAYER WT %:	---	---	---	---
DENSITY (LB/IN3):	---	---	---	---
GAMMA (-):	---	---	---	---
FORCE (FT-LB/LB):	---	---	---	---
COVOLUME (IN3/LB):	---	---	---	---
FLAME TEMP (K):	---	---	---	---
MEAN PRESSURES (PSI):	---	---	---	---
MEAN PRESSURES (PSI):	---	---	---	---
MEAN PRESSURES (PSI):	---	---	---	---
BURNING RATES (IN/S):	---	---	---	---
BURNING RATES (IN/S):	---	---	---	---
BURNING RATES (IN/S):	---	---	---	---

PROPERTIES AT LAYER BOUNDARIES OF LAT SURFACES

	1ST	2ND	3RD	4TH
AT DEPTH (IN):	---	---	---	---
ADJACENT LAYER WT %:	---	---	---	---
DENSITY (LB/IN3):	---	---	---	---
GAMMA (-):	---	---	---	---
FORCE (FT-LB/LB):	---	---	---	---
COVOLUME (IN3/LB):	---	---	---	---
FLAME TEMP (K):	---	---	---	---
MEAN PRESSURES (PSI):	---	---	---	---
MEAN PRESSURES (PSI):	---	---	---	---
MEAN PRESSURES (PSI):	---	---	---	---
BURNING RATES (IN/S):	---	---	---	---
BURNING RATES (IN/S):	---	---	---	---
BURNING RATES (IN/S):	---	---	---	---

-----  
 - CHARGE 3 -  
 -----

TYPE: MC TUBE  
 EROSIIVE COEFF (-): 0.5000  
 GRAIN LENGTH (IN): 28.00000  
 INNER WEB (IN): 0.12500

GRAINS:  
 CHARGE ICM CODE: 0.97268  
 GRAIN DIAMETER (IN): 1.50000  
 WEB RATIO: 1.00000

WEIGHT (LB): 0.5000  
 CHARGE ICM AT (S): 0.00000E+00  
 PERF DIAMETER (IN): 1.2500

1PF 0  
 1.50000  
 1.00000

PROPERTIES AT LAYER BOUNDARIES OF PERF SURFACES

	1ST	2ND	3RD	4TH
AT DEPTH (IN):	0.000000	0.000000	0.000000	0.000000
ADJACENT LAYER WT %:	28.00000	100.000	100.000	100.000
DENSITY (LB/IN3):	0.12500	0.03400	0.03400	0.03400
GAMMA (-):		1.2500	1.2500	1.2500
FORCE (FT-LB/LB):		180000.	180000.	180000.
COVOLUME (IN3/LB):		30.000	30.000	30.000
FLAME TEMP (K):		1553.0	1553.0	1553.0
BURNING RATE EXPS:		0.0000	0.0000	0.0000
BURNING RATE COEFFS:			30.0000000	30.0000000

PROPERTIES AT LAYER BOUNDARIES OF END SURFACES

	1ST	2ND	3RD	4TH
AT DEPTH (IN):				
ADJACENT LAYER WT %:				
DENSITY (LB/IN3):				
GAMMA (-):				
FORCE (FT-LB/LB):				
COVOLUME (IN3/LB):				
FLAME TEMP (K):				
BURNING RATE EXPS:				
BURNING RATE COEFFS:				

PROPERTIES AT LAYER BOUNDARIES OF LAT SURFACES

	1ST	2ND	3RD	4TH
AT DEPTH (IN):				
ADJACENT LAYER WT %:				
DENSITY (LB/IN3):				
GAMMA (-):				
FORCE (FT-LB/LB):				
COVOLUME (IN3/LB):				
FLAME TEMP (K):				
BURNING RATE EXPS:				
BURNING RATE COEFFS:				

TIME (MS)	TRAV (IN)	VEL (FT/S)	ACC (G)	BREECH PRESS (PSI)	MEAN PRESS (PSI)	BASE PRESS (PSI)	MEAN TEMP (K)	FRAC BURN 1	FRAC BURN 2	FRAC BURN 3
0.000	0.00	0.	0.	26.	26.	26.	2000.	0.000	0.000	0.000
0.099	0.00	0.	0.	250.	250.	250.	1925.	0.233	0.000	0.048
SHOT-START PRESSURE ACHIEVED										
0.100	0.00	0.	0.	251.	251.	251.	1926.	0.234	0.000	0.048
0.200	0.00	0.	70.	505.	495.	475.	1973.	0.431	0.001	0.096
0.300	0.00	0.	143.	774.	753.	712.	2019.	0.591	0.031	0.145
0.400	0.00	1.	218.	1056.	1025.	962.	2062.	0.720	0.002	0.193
0.500	0.00	2.	296.	1353.	1310.	1225.	2104.	0.821	0.003	0.241
0.600	0.01	3.	375.	1664.	1610.	1502.	2143.	0.895	0.004	0.289
0.700	0.01	4.	455.	1991.	1926.	1794.	2181.	0.947	0.006	0.337
0.800	0.02	6.	537.	2334.	2258.	2104.	2217.	0.980	0.007	0.385
0.980	0.03	9.	686.	3006.	2907.	2709.	2278.	1.000	0.010	0.472
PROPELLANT 1 BURNED OUT										
1.000	0.03	10.	702.	3085.	2983.	2781.	2285.	1.000	0.011	0.481
1.100	0.05	12.	787.	3496.	3383.	3156.	2316.	1.000	0.013	0.529
1.200	0.06	15.	873.	3937.	3811.	3559.	2345.	1.000	0.015	0.577
1.300	0.08	18.	960.	4409.	4270.	3991.	2373.	1.000	0.018	0.625
1.400	0.11	21.	1048.	4911.	4760.	4457.	2399.	1.000	0.020	0.673
1.500	0.13	25.	1137.	5445.	5281.	4953.	2423.	1.000	0.023	0.721
1.600	0.17	28.	1224.	6012.	5836.	5483.	2446.	1.000	0.026	0.769
1.700	0.20	33.	1311.	6613.	6424.	6046.	2468.	1.000	0.030	0.817
1.800	0.24	37.	1397.	7248.	7047.	6644.	2488.	1.000	0.033	0.865
1.900	0.29	42.	1481.	7918.	7705.	7278.	2507.	1.000	0.037	0.912
2.000	0.34	46.	1562.	8624.	8399.	7948.	2526.	1.000	0.041	0.960
2.083	0.39	51.	1627.	9238.	9003.	8534.	2540.	1.000	0.044	1.000
PROPELLANT 3 BURNED OUT										
2.100	0.40	52.	1641.	9351.	9115.	8641.	2545.	1.000	0.045	1.000
2.200	0.47	57.	1788.	10061.	9804.	9288.	2574.	1.000	0.050	1.000
2.300	0.54	63.	1939.	10806.	10526.	9967.	2600.	1.000	0.055	1.000
2.400	0.62	70.	2094.	11585.	11283.	10679.	2624.	1.000	0.060	1.000
2.500	0.71	77.	2253.	12399.	12074.	11424.	2646.	1.000	0.065	1.000
2.600	0.80	84.	2415.	13247.	12898.	12202.	2666.	1.000	0.070	1.000
2.700	0.91	92.	2579.	14129.	13757.	13013.	2684.	1.000	0.076	1.000
2.800	1.03	101.	2782.	15050.	14648.	13846.	2701.	1.000	0.083	1.000
2.900	1.15	110.	3133.	16024.	15572.	14669.	2716.	1.000	0.089	1.000
3.000	1.29	121.	3500.	17032.	16527.	15518.	2730.	1.000	0.096	1.000
3.100	1.44	133.	3885.	18072.	17512.	16391.	2742.	1.000	0.103	1.000
3.200	1.61	146.	4260.	19137.	18522.	17293.	2753.	1.000	0.110	1.000
3.300	1.79	160.	4594.	20219.	19557.	18232.	2763.	1.000	0.118	1.000
3.400	1.99	176.	4938.	21324.	20612.	19188.	2771.	1.000	0.126	1.000
3.500	2.22	192.	5270.	22444.	21684.	20164.	2778.	1.000	0.134	1.000
3.600	2.46	209.	5600.	23578.	22770.	21154.	2784.	1.000	0.143	1.000
3.700	2.72	228.	5935.	24720.	23864.	22152.	2789.	1.000	0.152	1.000
3.800	3.00	248.	6273.	25868.	24963.	23154.	2793.	1.000	0.162	1.000
3.900	3.31	268.	6613.	27016.	26062.	24154.	2795.	1.000	0.171	1.000
4.000	3.65	290.	6954.	28157.	27154.	25148.	2797.	1.000	0.181	1.000
4.100	4.01	313.	7294.	29288.	28236.	26132.	2797.	1.000	0.192	1.000
4.200	4.40	337.	7631.	30402.	29301.	27100.	2797.	1.000	0.203	1.000
4.300	4.82	362.	7938.	31489.	30344.	28054.	2796.	1.000	0.214	1.000
4.400	5.27	388.	8228.	32546.	31359.	28986.	2794.	1.000	0.225	1.000
4.500	5.75	415.	8508.	33569.	32342.	29887.	2791.	1.000	0.237	1.000
4.600	6.27	443.	8778.	34552.	33286.	30754.	2787.	1.000	0.249	1.000
4.700	6.82	472.	9036.	35492.	34188.	31582.	2782.	1.000	0.262	1.000
4.800	7.40	501.	9281.	36382.	35044.	32367.	2777.	1.000	0.274	1.000
4.900	8.02	532.	9511.	37220.	35849.	33105.	2771.	1.000	0.287	1.000

TIME (MS)	TRAV (IN)	VEL (FT/S)	ACC (G)	BREECH PRESS (PSI)	MEAN PRESS (PSI)	BASE PRESS (PSI)	MEAN TEMP (K)	FRAC BURN 1	FRAC BURN 2	FRAC BURN 3
5.000	8.68	563.	9726.	38002.	36599.	33794.	2765.	1.000	0.301	1.000
5.100	9.37	594.	9924.	38725.	37294.	34431.	2758.	1.000	0.314	1.000
5.186	10.00	622.	10082.	39299.	37845.	34937.	2752.	1.000	0.326	1.000
PRESSURE GAGE 3 EXPOSED										
5.200	10.10	626.	10106.	39387.	37929.	35014.	2751.	1.000	0.328	1.000
5.300	10.87	659.	10271.	39985.	38504.	35541.	2743.	1.000	0.342	1.000
5.400	11.69	693.	10418.	40520.	39017.	36012.	2734.	1.000	0.356	1.000
5.500	12.54	726.	10548.	40990.	39469.	36426.	2726.	1.000	0.371	1.000
5.600	13.43	760.	10660.	41396.	39858.	36703.	2717.	1.000	0.385	1.000
5.700	14.36	795.	10755.	41738.	40187.	37085.	2707.	1.000	0.400	1.000
5.800	15.34	830.	10832.	42018.	40456.	37331.	2698.	1.000	0.415	1.000
5.900	16.35	865.	10893.	42237.	40666.	37523.	2688.	1.000	0.430	1.000
6.000	17.41	900.	10938.	42397.	40819.	37664.	2678.	1.000	0.445	1.000
6.100	18.51	935.	10968.	42501.	40919.	37755.	2668.	1.000	0.461	1.000
6.200	19.66	970.	10983.	42551.	40967.	37799.	2658.	1.000	0.476	1.000
6.248	20.21	987.	10985.	42556.	40972.	37803.	2653.	1.000	0.484	1.000
LOCAL PRESSURE MAX DETECTED										
6.300	20.84	1006.	10984.	42550.	40966.	37797.	2648.	1.000	0.492	1.000
6.400	22.07	1041.	10971.	42501.	40918.	37754.	2637.	1.000	0.508	1.000
6.500	23.34	1076.	10947.	42407.	40828.	37670.	2627.	1.000	0.523	1.000
6.600	24.65	1112.	10912.	42272.	40698.	37551.	2617.	1.000	0.539	1.000
6.700	26.01	1147.	10865.	42099.	40531.	37397.	2607.	1.000	0.555	1.000
6.800	27.41	1182.	10810.	41890.	40331.	37212.	2597.	1.000	0.571	1.000
6.900	28.84	1216.	10745.	41649.	40099.	36999.	2586.	1.000	0.587	1.000
7.000	30.33	1251.	10673.	41379.	39839.	36760.	2576.	1.000	0.603	1.000
7.100	31.85	1285.	10593.	41082.	39554.	36499.	2567.	1.000	0.618	1.000
7.200	33.41	1319.	10507.	40763.	39247.	36216.	2557.	1.000	0.634	1.000
7.300	35.01	1353.	10416.	40422.	38920.	35915.	2547.	1.000	0.650	1.000
7.400	36.66	1386.	10320.	40064.	38575.	35598.	2538.	1.000	0.666	1.000
7.500	38.34	1419.	10219.	39689.	38215.	35268.	2528.	1.000	0.682	1.000
7.600	40.06	1452.	10114.	39301.	37842.	34925.	2519.	1.000	0.698	1.000
7.700	41.82	1484.	10007.	38902.	37458.	34572.	2510.	1.000	0.713	1.000
7.800	43.62	1516.	9897.	38492.	37065.	34210.	2501.	1.000	0.729	1.000
7.900	45.46	1548.	9785.	38075.	36664.	33841.	2492.	1.000	0.745	1.000
8.000	47.34	1579.	9671.	37652.	36257.	33467.	2483.	1.000	0.760	1.000
8.100	49.25	1610.	9556.	37223.	35845.	33088.	2475.	1.000	0.776	1.000
8.200	51.20	1641.	9439.	36791.	35430.	32707.	2466.	1.000	0.791	1.000
8.300	53.19	1671.	9323.	36357.	35013.	32323.	2458.	1.000	0.807	1.000
8.400	55.21	1701.	9206.	35922.	34594.	31938.	2450.	1.000	0.822	1.000
8.500	57.27	1730.	9089.	35486.	34175.	31554.	2442.	1.000	0.837	1.000
8.600	59.37	1759.	8972.	35051.	33757.	31169.	2434.	1.000	0.852	1.000
8.700	61.50	1788.	8847.	34584.	33303.	30756.	2426.	1.000	0.867	1.000
8.800	63.66	1816.	8688.	33996.	32743.	30237.	2416.	1.000	0.879	1.000
8.900	65.86	1844.	8515.	33356.	32128.	29671.	2406.	1.000	0.889	1.000
9.000	68.08	1871.	8334.	32686.	31484.	29080.	2395.	1.000	0.899	1.000
9.100	70.35	1898.	8148.	31998.	30823.	28472.	2384.	1.000	0.908	1.000
9.200	72.64	1924.	7960.	31300.	30152.	27856.	2373.	1.000	0.915	1.000
9.300	74.96	1949.	7770.	30598.	29477.	27235.	2362.	1.000	0.923	1.000
9.400	77.32	1974.	7581.	29896.	28802.	26615.	2351.	1.000	0.929	1.000
9.500	79.70	1998.	7392.	29197.	28131.	25999.	2339.	1.000	0.935	1.000
9.600	82.11	2021.	7206.	28506.	27466.	25388.	2328.	1.000	0.941	1.000
9.700	84.55	2044.	7022.	27823.	26810.	24784.	2316.	1.000	0.946	1.000
9.800	87.02	2067.	6840.	27150.	26163.	24190.	2305.	1.000	0.951	1.000
9.900	89.51	2088.	6662.	26489.	25528.	23606.	2293.	1.000	0.955	1.000
10.000	92.03	2110.	6488.	25840.	24905.	23033.	2282.	1.000	0.959	1.000



TIME (MS)	TRAV (IN)	VEL (FT/S)	ACC (G)	BREECH PRESS (PSI)	MEAN PRESS (PSI)	BASE PRESS (PSI)	MEAN TEMP (K)	FRAC BURN 1	FRAC BURN 2	FRAC BURN 3
10.190	94.57	2130.	6317.	25206.	24294.	22472.	2270.	1.000	0.962	1.000
10.200	97.14	2150.	6150.	24585.	23698.	21924.	2259.	1.000	0.966	1.000
10.300	99.73	2170.	5987.	23979.	23115.	21388.	2247.	1.000	0.968	1.000
10.400	102.35	2189.	5829.	23389.	22548.	20867.	2236.	1.000	0.971	1.000
10.500	104.99	2207.	5676.	22817.	21998.	20361.	2225.	1.000	0.974	1.000
10.600	107.65	2225.	5527.	22262.	21465.	19870.	2214.	1.000	0.976	1.000
10.700	110.33	2243.	5383.	21724.	20947.	19395.	2203.	1.000	0.978	1.000
10.800	113.03	2260.	5243.	21202.	20446.	18933.	2192.	1.000	0.980	1.000
10.900	115.75	2277.	5108.	20697.	19960.	18486.	2181.	1.000	0.982	1.000
11.000	118.49	2293.	4978.	20206.	19488.	18053.	2171.	1.000	0.984	1.000
11.100	121.25	2309.	4851.	19731.	19032.	17632.	2160.	1.000	0.985	1.000
11.200	124.03	2324.	4728.	19271.	18589.	17225.	2150.	1.000	0.987	1.000
11.300	126.83	2339.	4610.	18825.	18160.	16830.	2140.	1.000	0.988	1.000
11.400	129.65	2354.	4495.	18392.	17744.	16447.	2130.	1.000	0.990	1.000
11.500	132.48	2368.	4384.	17973.	17341.	16076.	2120.	1.000	0.991	1.000
11.600	135.33	2382.	4276.	17567.	16950.	15717.	2110.	1.000	0.992	1.000
11.700	138.20	2396.	4172.	17173.	16571.	15368.	2100.	1.000	0.993	1.000
11.800	141.08	2409.	4071.	16791.	16204.	15030.	2090.	1.000	0.994	1.000
11.900	143.98	2422.	3973.	16421.	15848.	14702.	2081.	1.000	0.995	1.000
12.000	146.89	2435.	3879.	16062.	15502.	14383.	2071.	1.000	0.996	1.000
12.100	149.82	2447.	3787.	15713.	15167.	14075.	2062.	1.000	0.996	1.000
12.200	152.76	2459.	3698.	15376.	14842.	13775.	2053.	1.000	0.997	1.000
12.300	155.72	2471.	3612.	15048.	14527.	13485.	2044.	1.000	0.997	1.000
12.400	158.69	2482.	3529.	14730.	14221.	13203.	2035.	1.000	0.998	1.000
12.500	161.68	2493.	3449.	14421.	13924.	12929.	2026.	1.000	0.998	1.000
12.600	164.68	2504.	3370.	14122.	13636.	12663.	2017.	1.000	0.999	1.000
12.700	167.69	2515.	3295.	13831.	13356.	12405.	2008.	1.000	0.999	1.000
12.800	170.71	2526.	3221.	13549.	13084.	12155.	1999.	1.000	0.999	1.000
12.900	173.75	2536.	3150.	13274.	12820.	11911.	1991.	1.000	1.000	1.000
13.000	176.80	2546.	3081.	13008.	12564.	11675.	1982.	1.000	1.000	1.000
13.100	179.86	2556.	3014.	12749.	12314.	11445.	1974.	1.000	1.000	1.000
13.200	182.93	2565.	2950.	12498.	12072.	11221.	1966.	1.000	1.000	1.000
13.300	186.02	2575.	2887.	12253.	11837.	11004.	1957.	1.000	1.000	1.000
13.395	188.96	2583.	2829.	12027.	11619.	10803.	1950.	1.000	1.000	1.000
PROPELLANT 2 BURNED OUT										
13.400	189.11	2584.	2826.	12016.	11608.	10793.	1949.	1.000	1.000	1.000
13.500	192.21	2593.	2767.	11785.	11386.	10588.	1941.	1.000	1.000	1.000
13.600	195.33	2602.	2710.	11562.	11171.	10389.	1933.	1.000	1.000	1.000
13.700	198.46	2610.	2654.	11345.	10962.	10196.	1926.	1.000	1.000	1.000
13.800	201.60	2619.	2598.	11134.	10759.	10009.	1918.	1.000	1.000	1.000
13.900	204.74	2627.	2542.	10929.	10562.	9829.	1910.	1.000	1.000	1.000
13.908	205.00	2628.	2537.	10912.	10546.	9814.	1910.	1.000	1.000	1.000
PROJECTILE EXIT										

CONDITIONS AT:	PHAX	MUZZLE
TIME (MS):	6.248	13.908
TRAVEL (IN):	20.21	205.00
VELOCITY (FT/S):	987.	2628.
ACCELERATION (G):	16985.	2537.
BREECH PRESS (PSI):	42556.	10912.
MEAN PRESS (PSI):	40972.	10546.
BASE PRESS (PSI):	37803.	9814.
MEAN TEMP (K):	2653.	1910.
Z CHARGE 1 (-):	1.000	1.000
Z CHARGE 2 (-):	0.484	1.000
Z CHARGE 3 (-):	1.000	1.000

GAGE	AT (IN) WRT SCM	PHAX (PSI)
1	-30.00	42556.
2	0.00	40581.
3	10.00	39492.

ENERGY BALANCE SUMMARY

	IN-LB	%
TOTAL CHEMICAL:	445809920.	100.00
(1) INTERNAL GAS:	283111168.	63.50
(2) WORK AND LOSSES:	162698832.	36.50
(A) PROJECTILE KINETIC:	123518720.	27.71
(B) GAS KINETIC:	11070795.	2.48
(C) PROJECTILE ROTATIONAL:	1523850.	0.34
(D) FRICTIONAL WORK TO TUBE:	0.	0.00
(E) OTHER FRICTIONAL WORK:	12313684.	2.76
(F) WORK DONE AGAINST AIR:	584053.	0.13
(G) HEAT CONVECTED TO BORE:	13687733.	3.07
(H) RECOIL ENERGY:	0.	0.00
LOADING DENSITY (G/CM3):	0.621	
CHARGE WT/PROJECTILE WT:	0.269	
PIEZOMETRIC EFFICIENCY:	0.475	
EXPANSION RATIO:	6.317	

PARAMETRIC VARIABLES: / 1/ PROP 2 CHWT

/1/	PMAX	VMUZ	PMUZ	Z(1)	XQZ=1	Z(2)	XQZ=1	Z(3)	XQZ=1
25.00	42556.	2628.	9814.	1.000	0.02	1.000	186.02	1.000	0.34
25.20	43147.	2642.	9881.	1.000	0.02	1.000	185.62	1.000	0.35
25.40	43745.	2657.	9949.	1.000	0.02	1.000	185.19	1.000	0.36
25.60	44349.	2672.	10015.	1.000	0.02	1.000	184.72	1.000	0.36
25.80	44961.	2687.	10086.	1.000	0.02	1.000	184.25	1.000	0.37
26.00	45582.	2701.	10151.	1.000	0.02	1.000	183.72	1.000	0.37
26.20	46208.	2716.	10217.	1.000	0.02	1.000	183.17	1.000	0.38
26.40	46845.	2731.	10288.	1.000	0.02	1.000	182.60	1.000	0.39
26.60	47491.	2745.	10350.	1.000	0.02	1.000	181.98	1.000	0.39
26.80	48142.	2760.	10415.	1.000	0.02	1.000	178.12	1.000	0.40
27.00	48802.	2775.	10485.	1.000	0.02	1.000	177.45	1.000	0.41

## Test Case 4

This run was used in a case study for a design of an incremental charge concept. It is included because it illustrates the utility of a well-documented input deck. All keywords are in uppercase, but the comments are in lowercase and spaced appropriately. The propelling charge is quite involved, requiring five different propellant decks. It should be noted that the combustible and non-combustible tubes were modeled as a propellant in IBHVG2.

```
SCOMM
  IBHVG2 BENCHMARK TEST 4
  Showing acceptable uses of lower-case characters
  Showing five propellants, including two non-burning charges
  Shows iteration on f.fth charge web to find PMAX=45kpsi

  Changing Burning Data   M30/M9   Zone 5

  -----
  This run is to determine nominal parameter values
  by comparing the results with the "BARE INCREMENT"
  baseline.
  -----

  ** DECK as of 14 Mar, 1630 hours

  -----

SHEAT
  TSHL=0.00384

SGUN
  NAME='155-MM 198'   CHAM=1150   GRVE=6.2   LAND=6.1
  G/L=1.66 TRAV=205. TWST=20

SPROJ
  NAME='M549A1'   PRWT=96

SRESI
  NPYS=8
  TRAV= 0, 0.4, 1., 1.55, 2.05, 4.5, 20, 200
  PRES=250, 2000, 3500, 2000, 1000, 500, 500, 500

SINFO
  POPT=1,1,1,0,1
  RUN="Incremental Charge Design   M30-M9"

SPRIM           $ Primer
  NAME='BLK POWDER'   $ Class 5 Black Powder
  CHWT=0.0154
  GAMA=1.25   FORC=96000   COV=30   TEMP=2000

SPROP           $ Igniter Function
  NAME='BLACK POWDER' $ Bag of black powder with each increment
  CHWT=0.3125         $ 5 ozs, 1 oz per increment
  GRAN='CORD'
  LEN=0.198   DIAM=0.098   RHO=0.06   GAMA=1.25   FORC=96000
  COV=30   TEMP=2000   ALPH=0.0   BETA=50.0   EROS=0.0

SPROP           $ Inner Tube
  NAME='NC TUBE'     $ Nitrocellulose Tube (Non-Combustible)
  GRAN='1PF'
  FORC=180000   COV=30   TEMP=1553   RHO=0.034   GAMA=1.25
```

NTBL=0 ALPH=0.00001 BETA=0.00001  
LEN=5.75  
PD=1.6875  
DIAM=2.0  
WEB=0.15625  
CW=0.3125

SPROP       \$ Outer Tube -- does not really exist

NAME='MC TUBE'   \$ Nitrocellulose Tube (Non-Combustible)  
GRAN='1PF'  
FORC=180000 COV=30 TEMP=1553 RHO=0.034 GAMA=1.25  
NTBL=0 ALPH=0.00001 BETA=0.00001  
LEN=5.75  
DIAM=5.9  
PD=5.89  
WEB=0.005  
CHWT=0.00005   \$ effectively, this tube is fictitious

SPROP       \$ M9 Propellant Charge

NAME='M9 HAIR'   \$ Lot # 6961  
GRAN='CORD'  
RHO=0.06   GAMA=1.2078   FORC=392399   COV=27.365   TEMP=3860  
LEN=4.00   DIAM=0.0337  
NTBL = 4  
PR4L = 1000, 3000, 4000, 15000  
BR4L = 0.617, 1.68, 1.90, 6.13  
EROS=0.0  
CHWT=1.5

SPROP       \$ M30 Propellant Charge

NAME='M30A1'   \$ Lot # 7022G  
GRAN='1PF'  
RHO=0.0572   GAMA=1.243   FORC=356400   COV=28.5   TEMP=3040  
NTBL=4  
PR4L = 1000, 5000, 10000, 30000  
BR4L = 0.40, 1.25, 2.25, 5.56  
LEN=5.50  
DIAM=0.2572  
WEB=0.09235  
PD=0.0725  
CHWT=22.5

SPMAX

VARY='WEB'   TRY1=0.09   TRY2=0.094   PMAX=45000.   NTH=5

SEND

---

*Producing the following output:*

ERRTOL= 4.768372E-07

```
CARD 1 --> $COMM
CARD 2 --> IBHVG2 BENCHMARK TEST 4
CARD 3 --> Showing acceptable uses of lower-case characters
CARD 4 --> Showing five propellants, including two non-burning charges
CARD 5 --> Shows iteration on fifth charge web to find PMAX=45kpsi
CARD 6 -->
CARD 7 --> Changing Burning Data M30/M9 Zone 5
CARD 8 -->
CARD 9 --> -----
CARD 10 --> This run is to determine nominal parameter values
CARD 11 --> by comparing the results with the "BARE INCREMENT"
CARD 12 --> baseline.
CARD 13 --> -----
CARD 14 -->
CARD 15 --> ** DECK as of 14 Mar, 1630 hours
CARD 16 -->
CARD 17 --> -----
CARD 18 -->
CARD 19 -->
CARD 20 --> $HEAT
CARD 21 --> TSHL=0.00384
CARD 22 -->
CARD 23 --> $GUM
CARD 24 --> NAME='155-MM 198' CNAM=1150 GRVE=6.2 LANO=6.1
CARD 25 --> G/L=1.66 TRAV=205. TWST=20
CARD 26 -->
CARD 27 --> $PROJ
CARD 28 --> NAME='M549A1' PRVT=96
CARD 29 -->
CARD 30 --> $RESI
CARD 31 --> NPTS=8
CARD 32 --> TRAV= 0, 0.4, 1., 1.55, 2.05, 4.5, 20, 200
CARD 33 --> PRES=250, 2000, 3500, 2000, 1000, 500, 500, 500
CARD 34 -->
CARD 35 --> $INFO
CARD 36 --> POPT=1,1,1,0,1
CARD 37 --> RUN="Incremental Charge Design M30-M9"
CARD 38 -->
CARD 39 -->
CARD 40 -->
CARD 41 --> $PRIM $ Primer
CARD 42 -->
CARD 43 --> NAME='BLK POWDER' $ Class 5 Black Powder
CARD 44 --> CHWT=0.0154
CARD 45 --> GAMA=1.25 FORC=96000 COV=30 TEMP=2000
CARD 46 -->
CARD 47 -->
CARD 48 -->
CARD 49 --> $PROP $ Igniter Function
CARD 50 -->
CARD 51 --> NAME='BLACK POWDER' $ Bag of black powder with each increment
CARD 52 --> CHWT=0.3125 $ 5 ozs, 1 oz per increment
CARD 53 --> GRAN='CORD'
CARD 54 --> LEN=0.198 DIAM=0.098 RHO=0.06 GAMA=1.25 FORC=96000
CARD 55 --> COV=30 TEMP=2000 ALPH=0.0 BETA=50.0 EROS=0.0
```

```

CARD 56 -->
CARD 57 -->
CARD 58 -->
CARD 59 --> $PROP          $ Inner Tube
CARD 60 -->
CARD 61 --> NAME='NC TUBE'  $ Nitrocellulose Tube (Non-Combustible)
CARD 62 --> GRAN='1PF'
CARD 63 --> FORC=180000 COV=30 TEMP=1553 RHO=0.034 GAMA=1.25
CARD 64 --> NTBL=0 ALPH=0.00001 BETA=0.00001
CARD 65 --> LEN=5.75
CARD 66 --> PD=1.6875
CARD 67 --> DIAM=2.0
CARD 68 --> WEB=0.15625
CARD 69 --> CV=0.3125
CARD 70 -->
CARD 71 -->
CARD 72 -->
CARD 73 -->
CARD 74 --> $PROP          $ Outer Tube -- does not really exist
CARD 75 -->
CARD 76 --> NAME='NC TUBE'  $ Nitrocellulose Tube (Non-Combustible)
CARD 77 --> GRAN='1PF'
CARD 78 --> FORC=180000 COV=30 TEMP=1553 RHO=0.034 GAMA=1.25
CARD 79 --> NTBL=0 ALPH=0.00001 BETA=0.00001
CARD 80 --> LEN=5.75
CARD 81 --> DIAM=5.9
CARD 82 --> PD=5.09
CARD 83 --> WEB=0.005
CARD 84 --> CHWT=0.00005 $ effectively, this tube is fictitious
CARD 85 -->
CARD 86 -->
CARD 87 -->
CARD 88 --> $PROP          $ W9 Propellant Charge
CARD 89 --> NAME='W9 HAIR'    $ Lot # 6961
CARD 90 --> GRAN='CORD'
CARD 91 --> RHO=0.06 GAMA=1.2078 FORC=392399 COV=27.365 TEMP=3860
CARD 92 --> LEN=4.00 DIAM=0.0337
CARD 93 --> NTBL = 4
CARD 94 --> PR4L = 1000, 3000, 4000, 15000
CARD 95 --> BR4L = 0.617, 1.68, 1.90, 6.13
CARD 96 --> EROS=0.0
CARD 97 --> CHWT=1.5
CARD 98 -->
CARD 99 -->
CARD 100 --> $PROP          $ M30 Propellant Charge
CARD 101 --> NAME='M30A1'      $ Lot # 70226
CARD 102 --> GRAN='1PF'
CARD 103 --> RHO=0.0572 GAMA=1.243 FORC=356400 COV=28.5 TEMP=3040
CARD 104 --> NTBL=4
CARD 105 --> PR4L = 1000, 5000, 10000, 30000
CARD 106 --> BR4L = 0.40, 1.35, 2.25, 5.56
CARD 107 --> LEN=5.50
CARD 108 --> DIAM=0.2572
CARD 109 --> WEB=0.09235
CARD 110 --> PD=0.0725

```

CARD 111 --> CHWT=22.5  
CARD 112 -->  
CARD 113 --> SPMAX  
CARD 114 -->  
CARD 115 --> VARY='WEB' TRY1=0.09 TRY2=0.094 PMAX=45000. NTN=5  
CARD 116 -->  
CARD 117 --> SEND



- GUN TUBE -  
 TYPE: 155-MM 190  
 GROOVE DIAMETER (IN): 6.200  
 TWIST (CAL/S/TURR): 20.0  
 SHELL THICKNESS (IN): 0.003040  
 INITIAL SWELL TEMP (K): 293.

- PROJECTILE -  
 TYPE: M549A1  
 - RESISTANCE -

AIR RESISTANCE OPTION: 1  

I	TRAVEL (IN)	PRESSURE (PSI)
1	0.00	250.
2	0.40	2000.
3	1.00	3500.

CHAMBER VOLUME (IN3): 1150.00  
 LAND DIAMETER (IN): 6.100  
 BORE AREA (IN2): 29.8275  
 SHELL CP (IN-LB/LB-K): 1845.0  
 AIR NO (IN-LB/IN2-S-K): 0.06480

TOTAL WEIGHT (LB): 96.000  
 WEIGHT PREDICTOR OPTION: 0

- GENERAL -  
 MAX TIME STEP (S): 0.000100  
 PRINT OPTIONS: 1 1 0 1 1  
 GRADIENT MODEL: LAGRANGIAN

- RECOIL -  
 RECOIL OPTION: 0  
 TYPE: 0

TYPE: BLK POWDER  
 COVOLUME (IN3/LB): 30.000  
 GAMMA (-): 1.2500  
 FLAME TEMP (K): 2000.0

TRAVEL (IN): 205.00  
 GROOVE/LAND RATIO (-): 1.660  
 HEAT-LOSS OPTION: 1  
 SHELL DENSITY (LB/IN3): 0.2840

MAX RELATIVE ERROR (-): 0.00700  
 CONSTANT-PRESSURE OPTION: 0

RECOILING WEIGHT (LB): 0.

FORCE (FT-LB/LB): 96000.  
 WEIGHT (LB): 0.015400

WALL HEATING FRACTION: 0.000  

I	TRAVEL (IN)	PRESSURE (PSI)
4	1.55	2000.
5	2.05	1000.
6	4.50	500.

FRICTION TABLE LENGTH: 8  

I	TRAVEL (IN)	PRESSURE (PSI)
7	20.00	500.
8	200.00	500.

----- CHARGE 1 -----

TYPE: BLACK POWDER  
 EROSION COEFF (-): 0.000000  
 GRAIN LENGTH (IN): 0.19800

GRAINS:  
 CHARGE IGM CODE: 3487.3  
 GRAIN DIAMETER (IN): 0.09800

CORD 0  
 0.09800

WEIGHT (LB): 0.3125  
 CHARGE IGM AT (S): 0.00000E+00

PROPERTIES AT LAYER BOUNDARIES OF LAT SURFACES

	1ST	2ND	3RD	4TH
AT DEPTH (IN):				
ADJACENT LAYER WT %:				
DENSITY (LB/IN3):				
GAMMA (-):				
FORCE (FT-LB/LB):				
COVOLUME (IN3/LB):				
FLAME TEMP (K):				
BURNING RATE EXPS:				
BURNING RATE COEFFS:				

----- CHARGE 2 -----

TYPE: MC TUNE  
 EROSION COEFF (-): 0.000000  
 GRAIN LENGTH (IN): 5.75000  
 INNER WEB (IN): 0.15625

GRAINS:  
 CHARGE IGM CODE: 1.7662  
 GRAIN DIAMETER (IN): 2.00000  
 WEB RATIO: 1.0000

1PF 0  
 2.00000  
 1.0000

WEIGHT (LB): 0.3125  
 CHARGE IGM AT (S): 0.00000E+00  
 PERF DIAMETER (IN): 1.68750

PROPERTIES AT LAYER BOUNDARIES OF PERF SURFACES

	1ST	2ND	3RD	4TH
AT DEPTH (IN):				
ADJACENT LAYER WT %:				
DENSITY (LB/IN3):				
GAMMA (-):				
FORCE (FT-LB/LB):				
COVOLUME (IN3/LB):				
FLAME TEMP (K):				
BURNING RATE EXPS:				
BURNING RATE COEFFS:				

----- CHARGE 3 -----

TYPE: BLACK POWDER  
 EROSION COEFF (-): 0.000000  
 GRAIN LENGTH (IN): 0.19800

GRAINS:  
 CHARGE IGM CODE: 3487.3  
 GRAIN DIAMETER (IN): 0.09800

CORD 0  
 0.09800

WEIGHT (LB): 0.3125  
 CHARGE IGM AT (S): 0.00000E+00

PROPERTIES AT LAYER BOUNDARIES OF LAT SURFACES

	1ST	2ND	3RD	4TH
AT DEPTH (IN):				
ADJACENT LAYER WT %:				
DENSITY (LB/IN3):				
GAMMA (-):				
FORCE (FT-LB/LB):				
COVOLUME (IN3/LB):				
FLAME TEMP (K):				
BURNING RATE EXPS:				
BURNING RATE COEFFS:				

----- CHARGE 3 -----

TYPE: NC TUBE	GRAINS:	0.27619E-02	1PF	0	WEIGHT (LB):	0.0001
EROSIVE COEFF (-):	CHARGE IGM CODE:				CHARGE IGM AT (S):	0.00000E+00
GRAIN LENGTH (IN):	GRAIN DIAMETER (IN):	5.90000			PERF DIAMETER (IN):	5.89000
INNER WEB (IN):	WEB RATIO:	1.0000				

	PROPERTIES AT LAYER BOUNDARIES OF PERF SURFACES	PROPERTIES AT LAYER BOUNDARIES OF END SURFACES
	1ST 2ND 3RD 4TH	1ST 2ND 3RD 4TH
AT DEPTH (IN):	0.00000	0.00000
ADJACENT LAYER VT %:	100.000	100.000
DENSITY (LB/IN3):	0.03400	0.03400
GAMMA (-):	1.2500	1.2500
FORCE (FT-LB/LB):	180000.	180000.
COVOLUME (IN3/LB):	30.000	30.000
FLAME TEMP (K):	1553.0	1553.0
BURNING RATE EXPS:	0.0000	0.0000
BURNING RATE COEFFS:	0.0000100	0.0000100

	PROPERTIES AT LAYER BOUNDARIES OF LAT SURFACES
	1ST 2ND 3RD 4TH
AT DEPTH (IN):	0.00000
ADJACENT LAYER VT %:	100.000
DENSITY (LB/IN3):	0.03400
GAMMA (-):	1.2500
FORCE (FT-LB/LB):	180000.
COVOLUME (IN3/LB):	30.000
FLAME TEMP (K):	1553.0
BURNING RATE EXPS:	0.0000
BURNING RATE COEFFS:	0.0000100

- CHARGE 4 -

TYPE: M9 NAIR	GRAINS: CHARGE IGM CODE: 7007.0	COORD	WEIGHT (LB):	1.5000
EROSIVE COEFF (-):	GRAIN DIAMETER (IN):	0.03370	CHARGE IGM AT (S):	0.00000E+00
GRAIN LENGTH (IN):	0.000000			
	4.00000			

AT DEPTH (IN):	PROPERTIES AT LAYER BOUNDARIES OF END SURFACES	PROPERTIES AT LAYER BOUNDARIES OF LAT SURFACES
ADJACENT LAYER WT %:	1ST 2ND 3RD 4TH	1ST 2ND 3RD 4TH
DENSITY (LB/IN <sup>3</sup> ):	0.00000	0.00000
GAMMA (-):	100.000	100.000
FORCE (FT-LB/LB):	0.06000	0.06000
COVOLUME (IN <sup>3</sup> /LB):	1.2078	1.2078
FLAME TEMP (K):	392399.	392399.
MEAN PRESSURES (PSI):	27.365	27.365
MEAN PRESSURES (PSI):	3660.0	3660.0
MEAN PRESSURES (PSI):	1000.0	1000.0
MEAN PRESSURES (PSI):	3000.0	3000.0
MEAN PRESSURES (PSI):	4000.0	4000.0
BURNING RATES (IN/S):	15000.0	15000.0
BURNING RATES (IN/S):	0.62	0.62
BURNING RATES (IN/S):	1.68	1.68
BURNING RATES (IN/S):	1.90	1.90
BURNING RATES (IN/S):	6.13	6.13

- CHARGE 5 -

TYPE: W30A1  
 EROSIVE COEFF (-): 0.000000  
 GRAIN LENGTH (IN): 5.50000  
 INNER WEB (IN): 0.09144

GRAINS: 1518.6  
 CHARGE IGM CODE: 0  
 GRAIN DIAMETER (IN): 0.25338  
 WEB RATIO: 1.0000

WEIGHT (LB): 22.5000  
 CHARGE IGM AT (S): 0.00000E+00  
 PERF DIAMETER (IN): 0.07250

PROPERTIES AT LAYER BOUNDARIES OF PERF SURFACES

	1ST	2ND	3RD	4TH
AT DEPTH (IN):	0.00000	0.00000	0.00000	0.00000
ADJACENT LAYER WT %:	100.000	100.000	100.000	100.000
DENSITY (LB/IN <sup>3</sup> ):	0.05720	0.05720	0.05720	0.05720
GAMMA (-):	1.2430	1.2430	1.2430	1.2430
FORCE (FT-LB/LB):	356400.	356400.	356400.	356400.
COVOLUME (IN <sup>3</sup> /LB):	28.500	28.500	28.500	28.500
FLAME TEMP (K):	3040.0	3040.0	3040.0	3040.0
MEAN PRESSURES (PSI):	1000.0	1000.0	1000.0	1000.0
MEAN PRESSURES (PSI):	5000.0	5000.0	5000.0	5000.0
MEAN PRESSURES (PSI):	10000.0	10000.0	10000.0	10000.0
BURNING RATES (IN/S):	30000.0	30000.0	30000.0	30000.0
BURNING RATES (IN/S):	0.40	0.40	0.40	0.40
BURNING RATES (IN/S):	1.35	1.35	1.35	1.35
BURNING RATES (IN/S):	2.25	2.25	2.25	2.25
BURNING RATES (IN/S):	5.56	5.56	5.56	5.56

PROPERTIES AT LAYER BOUNDARIES OF END SURFACES

	1ST	2ND	3RD	4TH
AT DEPTH (IN):	0.00000	0.00000	0.00000	0.00000
ADJACENT LAYER WT %:	100.000	100.000	100.000	100.000
DENSITY (LB/IN <sup>3</sup> ):	0.05720	0.05720	0.05720	0.05720
GAMMA (-):	1.2430	1.2430	1.2430	1.2430
FORCE (FT-LB/LB):	356400.	356400.	356400.	356400.
COVOLUME (IN <sup>3</sup> /LB):	28.500	28.500	28.500	28.500
FLAME TEMP (K):	3040.0	3040.0	3040.0	3040.0
MEAN PRESSURES (PSI):	1000.0	1000.0	1000.0	1000.0
MEAN PRESSURES (PSI):	5000.0	5000.0	5000.0	5000.0
MEAN PRESSURES (PSI):	10000.0	10000.0	10000.0	10000.0
BURNING RATES (IN/S):	30000.0	30000.0	30000.0	30000.0
BURNING RATES (IN/S):	0.40	0.40	0.40	0.40
BURNING RATES (IN/S):	1.35	1.35	1.35	1.35
BURNING RATES (IN/S):	2.25	2.25	2.25	2.25
BURNING RATES (IN/S):	5.56	5.56	5.56	5.56

PROPERTIES AT LAYER BOUNDARIES OF LAT SURFACES

	1ST	2ND	3RD	4TH
AT DEPTH (IN):	0.00000	0.00000	0.00000	0.00000
ADJACENT LAYER WT %:	100.000	100.000	100.000	100.000
DENSITY (LB/IN <sup>3</sup> ):	0.05720	0.05720	0.05720	0.05720
GAMMA (-):	1.2430	1.2430	1.2430	1.2430
FORCE (FT-LB/LB):	356400.	356400.	356400.	356400.
COVOLUME (IN <sup>3</sup> /LB):	28.500	28.500	28.500	28.500
FLAME TEMP (K):	3040.0	3040.0	3040.0	3040.0
MEAN PRESSURES (PSI):	1000.0	1000.0	1000.0	1000.0
MEAN PRESSURES (PSI):	5000.0	5000.0	5000.0	5000.0
MEAN PRESSURES (PSI):	10000.0	10000.0	10000.0	10000.0
BURNING RATES (IN/S):	30000.0	30000.0	30000.0	30000.0
BURNING RATES (IN/S):	0.40	0.40	0.40	0.40
BURNING RATES (IN/S):	1.35	1.35	1.35	1.35
BURNING RATES (IN/S):	2.25	2.25	2.25	2.25
BURNING RATES (IN/S):	5.56	5.56	5.56	5.56

TIME (MS)	TRAV (IN)	VEL (FT/S)	ACC (G)	BREECH PRESS (PSI)	MEAN PRESS (PSI)	BASE PRESS (PSI)	MEAN TEMP (K)	FRAC BURN 1	FRAC BURN 2	FRAC BURN 3	FRAC BURN 4	FRAC BURN 5
0.000	0.00	0.	0.	25.	25.	25.	2000.	0.000	0.000	0.000	0.000	0.000
0.100	0.00	0.	0.	172.	172.	172.	2149.	0.234	0.000	0.000	0.001	0.000
0.149	0.00	0.	0.	250.	250.	250.	2203.	0.334	0.000	0.000	0.002	0.000
SHOT-START PRESSURE ACHIEVED												
0.200	0.00	0.	25.	340.	336.	329.	2258.	0.431	0.000	0.000	0.003	0.000
0.300	0.00	0.	76.	527.	517.	496.	2359.	0.591	0.000	0.000	0.006	0.001
0.400	0.00	1.	132.	733.	715.	679.	2457.	0.720	0.000	0.000	0.011	0.002
0.500	0.00	1.	194.	961.	934.	881.	2550.	0.821	0.000	0.000	0.017	0.002
0.600	0.00	2.	262.	1214.	1178.	1106.	2639.	0.895	0.000	0.000	0.025	0.003
0.700	0.01	3.	336.	1496.	1449.	1357.	2723.	0.947	0.000	0.000	0.034	0.004
0.800	0.01	4.	418.	1810.	1753.	1638.	2801.	0.980	0.000	0.000	0.045	0.006
0.980	0.02	7.	587.	2476.	2395.	2234.	2925.	1.000	0.000	0.000	0.070	0.008
PROPELLANT 1 BURNED OUT												
1.000	0.02	7.	608.	2559.	2476.	2308.	2938.	1.000	0.000	0.000	0.073	0.009
1.100	0.03	9.	720.	3008.	2909.	2711.	2994.	1.000	0.000	0.000	0.090	0.011
1.200	0.05	12.	843.	3512.	3396.	3163.	3041.	1.000	0.000	0.000	0.110	0.013
1.300	0.06	15.	976.	4062.	3928.	3659.	3078.	1.000	0.000	0.000	0.130	0.015
1.400	0.08	18.	1118.	4666.	4512.	4205.	3109.	1.000	0.000	0.000	0.152	0.018
1.500	0.11	22.	1274.	5336.	5161.	4810.	3135.	1.000	0.000	0.000	0.177	0.021
1.600	0.13	26.	1442.	6076.	5877.	5480.	3158.	1.000	0.000	0.000	0.204	0.024
1.700	0.17	31.	1624.	6887.	6664.	6216.	3177.	1.000	0.000	0.000	0.234	0.027
1.800	0.21	37.	1819.	7774.	7523.	7023.	3193.	1.000	0.000	0.000	0.266	0.031
1.900	0.26	43.	2027.	8738.	8459.	7901.	3207.	1.000	0.000	0.000	0.301	0.036
2.000	0.31	50.	2247.	9781.	9471.	8853.	3218.	1.000	0.000	0.000	0.339	0.040
2.100	0.38	58.	2478.	10903.	10562.	9880.	3227.	1.000	0.000	0.000	0.380	0.045
2.200	0.45	66.	2749.	12115.	11737.	10980.	3234.	1.000	0.000	0.000	0.424	0.051
2.300	0.54	75.	3049.	13416.	12996.	12156.	3239.	1.000	0.000	0.000	0.469	0.057
2.400	0.63	86.	3364.	14800.	14337.	13411.	3243.	1.000	0.000	0.000	0.517	0.063
2.500	0.74	97.	3692.	16265.	15757.	14740.	3245.	1.000	0.000	0.000	0.566	0.070
2.600	0.87	109.	4031.	17805.	17250.	16140.	3245.	1.000	0.000	0.000	0.617	0.077
2.700	1.01	123.	4384.	19411.	18807.	17600.	3243.	1.000	0.000	0.000	0.668	0.086
2.800	1.16	138.	4968.	21104.	20420.	19052.	3240.	1.000	0.000	0.000	0.719	0.094
2.900	1.34	155.	5578.	22840.	22072.	20536.	3235.	1.000	0.000	0.000	0.769	0.104
3.000	1.53	174.	6211.	24604.	23749.	22038.	3229.	1.000	0.000	0.000	0.817	0.113
3.100	1.76	195.	6822.	26367.	25428.	23550.	3221.	1.000	0.000	0.000	0.862	0.124
3.200	2.00	218.	7439.	28113.	27089.	25040.	3211.	1.000	0.000	0.000	0.903	0.135
3.300	2.28	243.	7942.	29799.	28705.	26519.	3199.	1.000	0.000	0.000	0.938	0.147
3.400	2.59	269.	8402.	31410.	30253.	27939.	3186.	1.000	0.000	0.000	0.967	0.159
3.500	2.92	297.	8838.	32922.	31705.	29272.	3170.	1.000	0.000	0.000	0.987	0.171
3.600	3.30	326.	9241.	34310.	33038.	30493.	3153.	1.000	0.000	0.000	0.998	0.184
3.657	3.53	343.	9451.	35029.	33727.	31125.	3142.	1.000	0.000	0.000	1.000	0.192
PROPELLANT 4 BURNED OUT												
3.700	3.71	356.	9607.	35557.	34234.	31589.	3134.	1.000	0.000	0.000	1.000	0.198
3.800	4.15	388.	9957.	36740.	35369.	32628.	3115.	1.000	0.000	0.000	1.000	0.212
3.900	4.64	420.	10287.	37867.	36450.	33618.	3096.	1.000	0.000	0.000	1.000	0.226
4.000	5.16	454.	10578.	38925.	37469.	34556.	3077.	1.000	0.000	0.000	1.000	0.241
4.100	5.73	488.	10850.	39912.	38419.	35431.	3058.	1.000	0.000	0.000	1.000	0.255
4.200	6.34	524.	11100.	40821.	39293.	36237.	3039.	1.000	0.000	0.000	1.000	0.271
4.300	6.99	560.	11327.	41647.	40087.	36968.	3020.	1.000	0.000	0.000	1.000	0.286
4.400	7.68	597.	11530.	42385.	40797.	37622.	3001.	1.000	0.000	0.000	1.000	0.302
4.500	8.42	634.	11707.	43032.	41420.	38196.	2982.	1.000	0.000	0.000	1.000	0.318
4.600	9.20	672.	11860.	43586.	41953.	38687.	2963.	1.000	0.000	0.000	1.000	0.334
4.700	10.03	710.	11986.	44047.	42397.	39096.	2944.	1.000	0.000	0.000	1.000	0.350
4.800	10.91	749.	12087.	44415.	42751.	39422.	2926.	1.000	0.000	0.000	1.000	0.366
4.900	11.83	788.	12163.	44691.	43016.	39667.	2907.	1.000	0.000	0.000	1.000	0.382

TIME (MS)	TRAV (IN)	VEL (FT/S)	ACC (G)	BREECH PRESS (PSI)	MEAN PRESS (PSI)	BASE PRESS (PSI)	MEAN TEMP (K)	FRAC BURN 1	FRAC BURN 2	FRAC BURN 3	FRAC BURN 4	FRAC BURN 5
5.000	12.80	827.	12214.	44878.	43196.	39833.	2889.	1.000	0.000	0.000	1.000	0.399
5.100	13.81	867.	12241.	44979.	43293.	39922.	2870.	1.000	0.000	0.000	1.000	0.415
5.173	14.59	896.	12247.	45000.	43314.	39942.	2857.	1.000	0.000	0.000	1.000	0.427
LOCAL PRESSURE MAX DETECTED												
5.200	14.88	906.	12246.	44997.	43311.	39939.	2852.	1.000	0.000	0.000	1.000	0.432
5.300	15.99	946.	12229.	44938.	43254.	39887.	2834.	1.000	0.000	0.000	1.000	0.448
5.400	17.15	985.	12192.	44806.	43127.	39770.	2817.	1.000	0.000	0.000	1.000	0.465
5.500	18.35	1024.	12137.	44607.	42936.	39593.	2799.	1.000	0.000	0.000	1.000	0.481
5.600	19.61	1063.	12064.	44345.	42684.	39362.	2782.	1.000	0.000	0.000	1.000	0.498
5.700	20.91	1102.	11976.	44027.	42378.	39080.	2765.	1.000	0.000	0.000	1.000	0.514
5.800	22.25	1140.	11874.	43658.	42024.	38754.	2748.	1.000	0.000	0.000	1.000	0.530
5.900	23.64	1178.	11760.	43244.	41625.	38387.	2732.	1.000	0.000	0.000	1.000	0.546
6.000	25.08	1216.	11634.	42790.	41188.	37984.	2716.	1.000	0.000	0.000	1.000	0.562
6.100	26.56	1253.	11499.	42300.	40717.	37551.	2700.	1.000	0.000	0.000	1.000	0.577
6.200	28.09	1290.	11355.	41781.	40217.	37091.	2684.	1.000	0.000	0.000	1.000	0.593
6.300	29.66	1326.	11204.	41236.	39693.	36608.	2669.	1.000	0.000	0.000	1.000	0.608
6.400	31.27	1362.	11048.	40669.	39148.	36106.	2654.	1.000	0.000	0.000	1.000	0.623
6.500	32.92	1398.	10886.	40085.	38586.	35588.	2640.	1.000	0.000	0.000	1.000	0.638
6.600	34.62	1432.	10721.	39487.	38010.	35058.	2625.	1.000	0.000	0.000	1.000	0.653
6.700	36.36	1467.	10553.	38878.	37425.	34519.	2611.	1.000	0.000	0.000	1.000	0.668
6.800	38.14	1500.	10383.	38262.	36832.	33973.	2597.	1.000	0.000	0.000	1.000	0.682
6.900	39.96	1533.	10211.	37640.	36234.	33423.	2584.	1.000	0.000	0.000	1.000	0.696
7.000	41.82	1566.	10039.	37017.	35634.	32873.	2571.	1.000	0.000	0.000	1.000	0.710
7.100	43.72	1598.	9866.	36392.	35034.	32317.	2558.	1.000	0.000	0.000	1.000	0.724
7.200	45.66	1630.	9694.	35770.	34435.	31765.	2545.	1.000	0.000	0.000	1.000	0.738
7.300	47.63	1660.	9523.	35150.	33839.	31217.	2533.	1.000	0.000	0.000	1.000	0.751
7.400	49.64	1691.	9353.	34535.	33247.	30672.	2521.	1.000	0.000	0.000	1.000	0.764
7.500	51.69	1721.	9185.	33926.	32661.	30132.	2509.	1.000	0.000	0.000	1.000	0.777
7.600	53.77	1750.	9018.	33323.	32082.	29598.	2497.	1.000	0.000	0.000	1.000	0.790
7.700	55.89	1779.	8854.	32729.	31510.	29071.	2486.	1.000	0.000	0.000	1.000	0.803
7.800	58.04	1807.	8692.	32143.	30946.	28552.	2475.	1.000	0.000	0.000	1.000	0.815
7.900	60.23	1835.	8533.	31566.	30391.	28041.	2464.	1.000	0.000	0.000	1.000	0.828
8.000	62.44	1862.	8376.	30998.	29845.	27539.	2453.	1.000	0.000	0.000	1.000	0.840
8.100	64.69	1889.	8222.	30441.	29309.	27045.	2443.	1.000	0.000	0.000	1.000	0.852
8.200	66.98	1915.	8071.	29895.	28783.	26561.	2433.	1.000	0.000	0.000	1.000	0.863
8.300	69.29	1941.	7923.	29358.	28268.	26086.	2423.	1.000	0.000	0.000	1.000	0.875
8.400	71.63	1966.	7778.	28833.	27762.	25621.	2413.	1.000	0.000	0.000	1.000	0.886
8.500	74.01	1991.	7635.	28319.	27267.	25165.	2404.	1.000	0.000	0.000	1.000	0.897
8.600	76.41	2015.	7496.	27815.	26783.	24719.	2394.	1.000	0.000	0.000	1.000	0.908
8.700	78.84	2039.	7360.	27323.	26310.	24283.	2385.	1.000	0.000	0.000	1.000	0.919
8.800	81.31	2063.	7227.	26842.	25847.	23856.	2376.	1.000	0.000	0.000	1.000	0.930
8.900	83.79	2086.	7097.	26371.	25394.	23440.	2367.	1.000	0.000	0.000	1.000	0.940
9.000	86.31	2108.	6970.	25911.	24952.	23032.	2358.	1.000	0.000	0.000	1.000	0.951
9.100	88.85	2131.	6846.	25462.	24520.	22635.	2350.	1.000	0.000	0.000	1.000	0.961
9.200	91.42	2152.	6725.	25024.	24098.	22246.	2342.	1.000	0.000	0.000	1.000	0.971
9.300	94.02	2174.	6606.	24596.	23686.	21867.	2333.	1.000	0.000	0.000	1.000	0.981
9.400	96.64	2195.	6491.	24178.	23284.	21497.	2325.	1.000	0.000	0.000	1.000	0.991
9.496	99.18	2215.	6371.	23746.	22869.	21114.	2317.	1.000	0.000	0.000	1.000	1.000
PROPELLANT 5 BURNED OUT												
9.500	99.29	2216.	6363.	23717.	22841.	21089.	2316.	1.000	0.000	0.000	1.000	1.000
9.600	101.96	2236.	6175.	23034.	22184.	20484.	2302.	1.000	0.000	0.000	1.000	1.000
9.700	104.65	2255.	5994.	22380.	21555.	19904.	2288.	1.000	0.000	0.000	1.000	1.000
9.800	107.37	2274.	5821.	21753.	20952.	19349.	2275.	1.000	0.000	0.000	1.000	1.000
9.900	110.11	2293.	5655.	21152.	20373.	18816.	2262.	1.000	0.000	0.000	1.000	1.000
10.000	112.87	2311.	5496.	20575.	19819.	18305.	2249.	1.000	0.000	0.000	1.000	1.000

TIME (MS)	TRAV (IN)	VEL (FT/S)	ACC (G)	BREECH PRESS (PSI)	MEAN PRESS (PSI)	BASE PRESS (PSI)	MEAN TEMP (K)	FRAC BURN 1	FRAC BURN 2	FRAC BURN 3	FRAC BURN 4	FRAC BURN 5
10.100	115.66	2328.	5343.	20022.	19287.	17815.	2236.	1.000	0.000	0.000	1.000	1.000
10.200	118.46	2345.	5196.	19491.	18776.	17345.	2223.	1.000	0.000	0.000	1.000	1.000
10.300	121.28	2362.	5056.	18982.	18285.	16893.	2211.	1.000	0.000	0.000	1.000	1.000
10.400	124.13	2378.	4920.	18492.	17814.	16459.	2199.	1.000	0.000	0.000	1.000	1.000
10.500	126.99	2393.	4790.	18021.	17361.	16042.	2187.	1.000	0.000	0.000	1.000	1.000
10.600	129.87	2409.	4665.	17563.	16926.	15641.	2176.	1.000	0.000	0.000	1.000	1.000
10.700	132.77	2424.	4545.	17133.	16507.	15255.	2164.	1.000	0.000	0.000	1.000	1.000
10.800	135.69	2438.	4429.	16714.	16104.	14884.	2153.	1.000	0.000	0.000	1.000	1.000
10.900	138.62	2452.	4318.	16310.	15716.	14527.	2142.	1.000	0.000	0.000	1.000	1.000
11.000	141.57	2466.	4210.	15921.	15342.	14182.	2131.	1.000	0.000	0.000	1.000	1.000
11.100	144.54	2479.	4107.	15547.	14981.	13850.	2121.	1.000	0.000	0.000	1.000	1.000
11.200	147.52	2492.	4007.	15186.	14634.	13531.	2110.	1.000	0.000	0.000	1.000	1.000
11.300	150.52	2505.	3911.	14838.	14299.	13222.	2100.	1.000	0.000	0.000	1.000	1.000
11.400	153.53	2517.	3818.	14502.	13976.	12925.	2090.	1.000	0.000	0.000	1.000	1.000
11.500	156.56	2530.	3728.	14178.	13664.	12638.	2080.	1.000	0.000	0.000	1.000	1.000
11.600	159.61	2541.	3642.	13865.	13363.	12360.	2070.	1.000	0.000	0.000	1.000	1.000
11.700	162.66	2553.	3558.	13562.	13072.	12093.	2060.	1.000	0.000	0.000	1.000	1.000
11.800	165.73	2564.	3478.	13270.	12791.	11834.	2051.	1.000	0.000	0.000	1.000	1.000
11.900	168.82	2575.	3400.	12988.	12520.	11584.	2042.	1.000	0.000	0.000	1.000	1.000
12.000	171.91	2586.	3324.	12715.	12257.	11342.	2032.	1.000	0.000	0.000	1.000	1.000
12.100	175.02	2597.	3251.	12451.	12003.	11103.	2023.	1.000	0.000	0.000	1.000	1.000
12.200	178.15	2607.	3180.	12195.	11758.	10882.	2015.	1.000	0.000	0.000	1.000	1.000
12.300	181.28	2617.	3112.	11948.	11520.	10663.	2006.	1.000	0.000	0.000	1.000	1.000
12.400	184.43	2627.	3046.	11709.	11289.	10451.	1997.	1.000	0.000	0.000	1.000	1.000
12.500	187.59	2637.	2982.	11477.	11066.	10245.	1989.	1.000	0.000	0.000	1.000	1.000
12.600	190.76	2646.	2920.	11252.	10850.	10046.	1980.	1.000	0.000	0.000	1.000	1.000
12.700	193.94	2656.	2859.	11034.	10640.	9853.	1972.	1.000	0.000	0.000	1.000	1.000
12.800	197.13	2665.	2801.	10823.	10437.	9656.	1964.	1.000	0.000	0.000	1.000	1.000
12.900	200.33	2674.	2744.	10618.	10240.	9484.	1956.	1.000	0.000	0.000	1.000	1.000
13.000	203.55	2683.	2689.	10419.	10049.	9308.	1948.	1.000	0.000	0.000	1.000	1.000
13.045	205.00	2666.	2665.	10331.	9964.	9231.	1945.	1.000	0.000	0.000	1.000	1.000

PROJECTILE EXIT



CONDITIONS AT:	PMAX	MUZZLE
TIME (MS):	5.173	13.045
TRAVEL (IN):	14.59	205.00
VELOCITY (FT/S):	896.	2686.
ACCELERATION (G):	12247.	2665.
BREECH PRESS (PSI):	45000.	10331.
MEAN PRESS (PSI):	43314.	9964.
BASE PRESS (PSI):	39942.	9231.
MEAN TEMP (K):	2857.	1945.
Z CHARGE 1 (-):	1.000	1.000
Z CHARGE 2 (-):	0.000	0.000
Z CHARGE 3 (-):	0.000	0.000
Z CHARGE 4 (-):	1.000	1.000
Z CHARGE 5 (-):	0.427	1.000

ENERGY BALANCE SUMMARY	IN-LB	%
TOTAL CHEMICAL:	431019520.	100.00
(1) INTERNAL GAS:	271604224.	63.01
(2) WORK AND LOSSES:	159415406.	36.99
(A) PROJECTILE KINETIC:	12905072.	29.95
(B) GAS KINETIC:	11045006.	2.56
(C) PROJECTILE ROTATIONAL:	1592645.	0.37
(D) FRICTIONAL WORK TO TUBE:	0.	0.00
(E) OTHER FRICTIONAL WORK:	3175198.	0.74
(F) WORK DONE AGAINST AIR:	612820.	0.14
(G) HEAT CONVECTED TO BORE:	13894672.	3.22
(H) RECOIL ENERGY:	0.	0.00
LOADING DENSITY (G/CM3):	0.593	
CHARGE WT/PROJECTILE WT:	0.257	
PIEZOMETRIC EFFICIENCY:	0.469	
EXPANSION RATIO:	6.317	

## Test Case 5

This is another another example of detherred propellant grains for the second \$PROJ deck. A transition zone of 0.001 thickness is added to gain a smooth transition from the outer shell to the inner propellant. An obvious correction by the program is shown where the second propellant grain diameter is input as five inches, then corrected to 0.4837 in the form function subroutine when the web distances and perforation diameters are added.

Using the \$FIND deck, the program is directed to search for a solution where peak breech pressure is 63000 *psi* and muzzle velocity of the projectile is maximized. The searching method employed is a function minimization routine developed at BRL many years ago, and will be replaced by another technique in the future. The current code does find solutions when possible, but actual 'best case' may elude the algorithm. In the run output, a table of trial values follows the input card echoes where each line represents a full ballistic calculation by IBHVG2.

```
SCOMM
  IBHVG2 BENCHMARK TEST CASE 5

  SHOW DETERRED PROPELLANT EXAMPLE
  USE 'FIND' FUNCTION TO SEARCH FOR SPECIFIC SOLUTION

SHEAT
  TSHL = 0.00450      CSHL = 1848      RSHL = 0.284
  TWAL = 293          HO = 0.0648      HL = 1

SGUN
  NAME = '120MM GUN'  CHAM = 525      GRVE = 4.724
  LAND = 4.724        G/L = 1.        TRAV = 187.11
  TWST = 99

SPROJ
  NAME = 'APFSDS'     PRWT = 21.1

SRESI
  NPTS = 4            AIR = 1
  TRAV = 0, 0.8, 3.0, 187
  PRES = 100, 2500, 100, 100

SINFO
  RUN = '120 MM GUN DETERRED-120DEY' DELT = 5E-5      DELP = 5E-5
  GRAD = 2              POPT = 1,1,1,0,2      SOPT = 0
  EPS = 0.05           COMP = 0

SRECO
  NAME = 'NONE'       RECO = 0      RCWT = 0

SPRIM
  NAME = 'BENITE'     CHWT = 0.00347
  GAMA = 1.25         FORC = 212500
  COV = 30            TEMP = 2000

SPROP
  NAME = 'BENITE'     CHWT = 0.06653      GRAN = 'CORD'
  RHO = 0.06          GAMA = 1.25      FORC = 212500
  COV = 30            TEMP = 2000      EROS = 0.00000
  ALPH = 0            BETA = 27        IGNC = 0
  LEN = 9.998         DIAM = 0.078

SCOMM
  VARY WEB AND CHARGE WEIGHT OF SECOND PROPELLANT TO FIND
  A SOLUTION AT APPROX 63KPSI AND MAXIMUM MUZZLE VELOCITY

SFIND
  VARY='WEB' FROM=.070 VAL=63000 NTH=2 QUTV='PMAX' CODE=0
  MIN=0.063 DECK='PROP' EPS=0.0001

SFIND
```

VARY='CHWT' DECK='PROP' NTH=2 FROM=20.0 EPS=0.01 OUTV='VMUZ'  
CODE=1 MULT=0.5 MIN=18. MAX=22.

SCOMM

OUTER LAYER HAS LOW BURNING RATE (DETERRED), NEXT LAYER IS A THIN  
TRANSITION ZONE, AND CORE LAYER (4) IS THE MAIN PROPELLANT

SPROP

NAME = 'JA2-G54 0.85-0.15 19P' CHWT = 20.5 GRAN = '19PF'  
RHO=0.05732 EROS = 0.0000000  
LEN = 3 DIAM = 5 PD = 0.020 WEB=0.0625

GJMP=,1.2725,1.2725,1.2257 GAME=,1.2725,1.2725,1.2257  
GANL=,1.2725,1.2725,1.2257

COVP=,31.17,31.17,27.48 COVE=,31.17,31.17,27.48  
COVL=,31.17,31.17,27.48

TMPL=,2248,2248,3400 TMPE=,2248,2248,3400 TMPP=,2248,2248,3400

FRCL=,300417,300417,382152 FRCE=,300417,300417,382152  
FRCP=,300417,300417,382152

DEPP=,0.03,0.031 DEPE=,0.03,0.031 DEPL=,0.03,0.031

NTBL=4 PR4L=2000,4000,10000,25000

BR4L=1.05,1.52,2.93,6.56

PR3L=2000,4000,10000,25000 PR2L=2000,4000,10000,25000

BR3L=0.694,1.01,1.94,4.34 BR2L=0.694,1.01,1.94,4.34

PR4P=2000,4000,10000,25000 BR4P=1.05,1.52,2.93,6.56

PR3P=2000,4000,10000,25000 BR3P=0.694,1.01,1.94,4.34

PR2P=2000,4000,10000,25000 BR2P=0.694,1.01,1.94,4.34

PR4E=2000,4000,10000,25000 BR4E=1.05,1.52,2.93,6.56

PR3E=2000,4000,10000,25000 BR3E=0.694,1.01,1.94,4.34

PR2E=2000,4000,10000,25000 BR2E=0.694,1.01,1.94,4.34

SCOMM

THIRD AND FOURTH PROPELLANTS MAKE UP A COMBUSTIBLE CARTRIDGE CASE  
OF FELTED NITRO-CELLULOSE AND KRAFT PAPER

SPROP

NAME = 'FNC CASE' CHWT = 1.41 GRAN = '1PF'

RHO = 0.04 GAMA = 1.258

FRCP = ,150000,150000 FRCE = ,150000,150000 FRCL(4)=200000

COV = 27.927 TEMP = 1610 EROS = 0.00

IGNS(3)=2 THRS(3)=200 DEPP = , 0.015 , 0.0155 DEPE = , 0.015 , 0.0155

NTBL=2

PR2P=1000,10000 BR2P=0.5,2.4 PR3P=1000,10000 BR3P=0.5,2.4

PR2E=1000,10000 BR2E=0.5,2.4 PR3E=1000,10000 BR3E=0.5,2.4

PR4L=1000,10000 BR4L=0.5,10

LEN = 18 DIAM = 6.17 PD = 6.01

WI = 0.08

SPROP

NAME = 'KRAFT CASE' CHWT = .21 GRAN = '1PF'

RHO = 0.04 GAMA = 1.2734 FOMC = 95726

COV = 9.883 TEMP = 1054 EROS = 0.00

ALPH = 1 BETA = 0.00001 IGNC = 0

LEN = 3.4 DIAM = 6.17 PD = 6.01

WI = 0.08

SEND

Producing the following output:

ERRTOL = 4.768372E-07

CARD 1 --> \$COMM  
CARD 2 --> IBHVG2 BENCHMARK TEST CASE 5  
CARD 3 -->  
CARD 4 --> SHOW DETERRED PROPELLANT EXAMPLE  
CARD 5 --> USE 'FIND' FUNCTION TO SEARCH FOR SPECIFIC SOLUTION  
CARD 6 -->  
CARD 7 --> \$HEAT  
CARD 8 --> TSHL = 0.00450            CSHL = 1848            RSHL = 0.284  
CARD 9 --> TWAL = 293                HO = 0.0648            HL = 1  
CARD 10 -->  
CARD 11 --> \$GUN  
CARD 12 --> NAME = '120MM GUN'    CHAM = 525            GRVE = 4.724  
CARD 13 --> LAND = 4.724            G/L = 1.            TRAV = 187.11  
CARD 14 --> TWST = 99  
CARD 15 -->  
CARD 16 --> \$PROJ  
CARD 17 --> NAME = 'APFSDS'    PRWT = 21.1  
CARD 18 -->  
CARD 19 --> \$RESI  
CARD 20 --> NPTS = 4                AIR = 1  
CARD 21 --> TRAV = 0, 0.8, 3.0, 187  
CARD 22 --> PRES = 100, 2500, 100, 100  
CARD 23 -->  
CARD 24 --> \$INFO  
CARD 25 --> RUN = '120 MM GUN DETERRED-120DET'    DELT = 5E-5            DELP = 5E-5  
CARD 26 --> GRAD = 2                POPT = 1,1,1,0,2    SOPT = 0  
CARD 27 --> EPS = 0.05              COMP = 0  
CARD 28 -->  
CARD 29 --> \$RECO  
CARD 30 --> NAME = 'NONE'            RECO = 0            RCWT = 0  
CARD 31 -->  
CARD 32 --> \$SPRM  
CARD 33 --> NAME = 'BENITE'            CHWT = 0.00347  
CARD 34 --> GAMA = 1.25            FORC = 212500  
CARD 35 --> COV = 30                TEMP = 2000  
CARD 36 --> \$SPROP  
CARD 37 --> NAME = 'BENITE'            CHWT = 0.06653    GRAN = 'CORD'  
CARD 38 --> RHO = 0.06            GAMA = 1.25            FORC = 212500  
CARD 39 --> COV = 30                TEMP = 2000            EROS = 0.00000  
CARD 40 --> ALPH = 0                BETA = 27            IGNC = 0  
CARD 41 --> LEW = 9.998            DIAM = 0.078  
CARD 42 -->  
CARD 43 --> \$COMM  
CARD 44 --> VARY WEB AND CHARGE WEIGHT OF SECOND PROPELLANT TO FIND  
CARD 45 --> A SOLUTION AT APPROX 63KPSI AND MAXIMUM MUZZLE VELOCITY  
CARD 46 --> \$FIND  
CARD 47 --> VARY='WEB' FROM=.070 VAL=63000 NTH=2 OUTV='PMAX' CODE=0  
CARD 48 --> MIN=0.063 DECK='PROP' EPS=0.0001  
CARD 49 --> \$FIND  
CARD 50 --> VARY='CHWT' DECK='PROP' NTH=2 FROM=20.0 EPS=0.01 OUTV='VMUZ'  
CARD 51 --> CODE=1 MULT=0.5 MIN=18. MAX=22.  
CARD 52 -->  
CARD 53 --> \$COMM  
CARD 54 --> OUTER LAYER HAS LOW BURNING RATE (DETERRED), NEXT LAYER IS A THIN  
CARD 55 --> TRANSITION ZONE, AND CORE LAYER (4) IS THE MAIN PROPELLANT

```

CARD 56 --> $PROP
CARD 57 --> NAME = 'JA2-G54 .85-.15 19P' CHWT = 20.5 GRAM = '19PF'
CARD 58 --> RHO=0.05732 EROS = 0.0000000
CARD 59 --> LEN = 3 DIAM = 5 PD = 0.020 WEB=0.0625
CARD 60 -->
CARD 61 --> GAMP=,1.2725,1.2725,1.2257 GAME=,1.2725,1.2725,1.2257
CARD 62 --> GAHL=,1.2725,1.2725,1.2257
CARD 63 -->
CARD 64 --> COVP=,31.17,31.17,27.48 COVE=,31.17,31.17,27.48
CARD 65 --> COVL=,31.17,31.17,27.48
CARD 66 -->
CARD 67 --> TMPL=,2248,2248,3400 TMPE=,2248,2248,3400 TMPP=,2248,2248,3400
CARD 68 -->
CARD 69 --> FRCL=,300417,300417,382152 FRCE=,300417,300417, 2152
CARD 70 --> FRCP=,300417,300417,382152
CARD 71 -->
CARD 72 --> DEPP=,0.03,0.031 DEPE=,0.03,0.031 DEPL=,0.03,0.031
CARD 73 -->
CARD 74 --> NTBL=4 PR4L=2000,4000,10000,25000
CARD 75 --> BR4L=1.05,1.52,2.93,6.56
CARD 76 --> PR3L=2000,4000,10000,25000 PR2L=2000,4000,10000,25000
CARD 77 --> BR3L=0.694,1.01,1.94,4.34 BR2L=0.694,1.01,1.94,4.34
CARD 78 --> PR4P=2000,4000,10000,25000 BR4P=1.05,1.52,2.93,6.56
CARD 79 --> PR3P=2000,4000,10000,25000 BR3P=0.694,1.01,1.94,4.34
CARD 80 --> PR2P=2000,4000,10000,25000 BR2P=0.694,1.01,1.94,4.34
CARD 81 --> PR4E=2000,4000,10000,25000 BR4E=1.05,1.52,2.93,6.56
CARD 82 --> PR3E=2000,4000,10000,25000 BR3E=0.694,1.01,1.94,4.34
CARD 83 --> PR2E=2000,4000,10000,25000 BR2E=0.694,1.01,1.94,4.34
CARD 84 -->
CARD 85 --> $COMM
CARD 86 --> THIRD AND FOURTH PROPELLANTS MAKE UP A COMBUSTIBLE CARTRIDGE CASE
CARD 87 --> OF FELTED NITRO-CELLULOSE AND KRAFT PAPER
CARD 88 --> $PROP
CARD 89 --> NAME = 'FNC CASE' CHWT = 1.41 GRAM = '1PF'
CARD 90 --> RHO = 0.04 GAMA = 1.258
CARD 91 --> FRCP=,150000,150000 FRCE=,150000,150000 FRCL(4)=200000
CARD 92 --> COV = 27.927 TEMP = 1610 EROS = 0.00
CARD 93 --> IGNS(3)=2 THRS(3)=200 DEPP=,0.015,0.0155 DEPE=,0.015,0.0155
CARD 94 --> NTBL=2
CARD 95 --> PR2P=1000,10000 BR2P=0.5,2.4 PR3P=1000,10000 BR3P=0.5,2.4
CARD 96 --> PR2E=1000,10000 BR2E=0.5,2.4 PR3E=1000,10000 BR3E=0.5,2.4
CARD 97 --> PR4L=1000,10000 BR4L=0.5,10
CARD 98 --> LEN = 18 DIAM = 6.17 PD = 6.01
CARD 99 --> WI = 0.08
CARD 100 --> $PROP
CARD 101 --> NAME = 'KRAFT CASE' CHWT = .21 GRAM = '1PF'
CARD 102 --> RHO = 0.04 GAMA = 1.2734 FORC = 95726
CARD 103 --> COV = 9.803 TEMP = 1054 EROS = 0.00
CARD 104 --> ALPH = 1 BETA = 0.00001 IGHC = 0
CARD 105 --> LEN = 3.4 DIAM = 6.17 PD = 6.01
CARD 106 --> WI = 0.03
CARD 107 --> $END

```

VARY / 1/ WEB		2 PROP TO HIT < 1>		PMAX
VARY / 2/ CHWT		2 PROP TO MAX < 2>		VMUZ
/ 1/	< 1>	/ 2/	< 2>	
0.7000E-01	0.4430E+05	20.00	3520.	
0.7011E-01	0.4414E+05	20.00	3513.	
0.6989E-01	0.4445E+05	20.00	3528.	
0.6945E-01	0.4508E+05	20.00	3555.	
0.6945E-01	0.4519E+05	20.01	3561.	
0.6945E-01	0.4530E+05	20.02	3564.	
0.6945E-01	0.4562E+05	20.05	3573.	
0.6890E-01	0.4701E+05	20.11	3627.	
0.6395E-01	0.6323E+05	20.60	4224.	
0.6395E-01	0.6412E+05	20.66	4019.	
0.6395E-01	0.6236E+05	20.55	4202.	
0.6395E-01	0.6299E+05	20.59	4217.	
0.6340E-01	0.6533E+05	20.64	4287.	
0.6450E-01	0.6078E+05	20.53	4157.	
0.6395E-01	0.6275E+05	20.57	4214.	
0.6395E-01	0.6323E+05	20.60	4224.	
0.6395E-01	0.6275E+05	20.57	4214.	
0.6385E-01	0.6341E+05	20.60	4231.	
0.6405E-01	0.6258E+05	20.58	4201.	

= 0.6300E+05

- GUN TUBE -  
 TYPE: 120MM GUN  
 GROOVE DIAMETER (IN): 4.724  
 TWIST (CALS/TURN): 99.0  
 SHELL THICKNESS (IN): 0.004500  
 INITIAL SHELL TEMP (K): 293.  
 CHAMBER VOLUME (IN3): 525.00  
 LAND DIAMETER (IN): 4.724  
 BORE AREA (IN2): 17.5271  
 SHELL CP (IN-LB/LB-K): 1848.0  
 AIR W0 (IN-LB/IN2-S-K): 0.06480  
 TRAVEL (IN): 187.11  
 GROOVE/LAND RATIO (-): 1.000  
 HEAT-LOSS OPTION: 1  
 SHELL DENSITY (LB/IN3): 0.2840

- PROJECTILE -  
 TYPE: APFSDS  
 TOTAL WEIGHT (LB): 21.100  
 WEIGHT PREDICTOR OPTION: 0

AIR RESISTANCE OPTION: 1  
 I TRAVEL (IN) PRESSURE (PSI) 1 WALL HEATING FRACTION: 0.000  
 1 0.00 100. 3 3.00 100.  
 2 0.80 2500. 4 187.00 100.

- GENERAL -  
 MAX TIME STEP (S): 0.000050  
 PRINT OPTIONS: 1 1 1 0 2 1  
 GRADIENT MODEL: P100AUX-KENT  
 PRINT STEP (S): 0.000050  
 STORE OPTION: 0  
 MAX RELATIVE ERROR (-): 0.05000  
 CONSTANT-PRESSURE OPTION: 0

- RECOIL -  
 RECOIL OPTION: 0  
 TYPE: NONE  
 RECOILING WEIGHT (LB): 0.

TYPE: BEHITE  
 CONVOLUME (IN3/LB): 30.000  
 GAMMA (-): 1.2500  
 FLAME TEMP (K): 2000.0  
 FORCE (FT-LB/LB): 212500.  
 WEIGHT (LB): 0.003470

-----  
 - CHARGE 1 -  
 -----

TYPE: BENITE	GRAINS:	23.210	CORD	0	WEIGHT (LB):	0.0665
EROSIVE COEFF (-):	CHARGE IGM CODE:				CHARGE IGM AT (\$):	0.00000E+00
GRAIN LENGTH (IN):	GRAIN DIAMETER (IN):	0.07800				

	PROPERTIES AT LAYER BOUNDARIES OF END SURFACES	PROPERTIES AT LAYER BOUNDARIES OF LAT SURFACES
	1ST 2ND 3RD 4TH	1ST 2ND 3RD 4TH
AT DEPTH (IN):	0.00000	0.00000
ADJACENT LAYER VT %:	100.000	100.000
DENSITY (LB/IN3):	0.000	0.04000
GAMMA (-):	0.000	1.2500
FORCE (FT-LB/LB):	212500	212500
COVOLUME (IN3/LB):	0.000	30.000
FLAME TEMP (K):	1000.0	2000.0
BURNING RATE EXPS:	0.0000	0.0000
BURNING RATE COEFFS:	27.0000000	27.0000000



----- CHARGE 2 -----

TYPE: JAZ-G54 .85-.15 19P 0.000000 673.47 19PF 20.5897  
 EROSION COEFF (-): 3.00000 CHARGE IGM CODE: 0.03000 CHARGE IGM AT (\$): 0.00000E+00  
 GRAIN LENGTH (IN): 0.06395 GRAIN DIAMETER (IN): 0.48370 PERF DIAMETER (IN): 0.02000  
 INNER WEB (IN): 0.06395 MIDDLE WEB (IN): 0.06395 OUTER WEB (IN): 0.06395

	PROPERTIES AT LAYER BOUNDARIES OF PERF SURFACES			PROPERTIES AT LAYER BOUNDARIES OF END SURFACES		
	1ST	2ND	3RD	4TH	5TH	6TH
AT DEPTH (IN):	-----	0.00000	0.03000	0.03100	0.03000	0.03100
ADJACENT LAYER WT %:	-----	49.756	2.664	21.665	0.016	21.665
DENSITY (LB/IN3):	-----	0.05732	0.05732	0.05732	0.05732	0.05732
GAMMA (-):	-----	1.2725	1.2725	1.2257	1.2725	1.2257
FORCE (FT-LB/LB):	-----	300417.	300417.	392152.	300417.	392152.
COVOLUME (IN3/LB):	-----	31.170	31.170	27.480	31.170	27.480
FLAME TEMP (K):	-----	2248.	2248.	3400.0	2248.	3400.0
MEAN PRESSURES (PSI):	-----	2000.0	2000.0	2000.0	2000.0	2000.0
MEAN PRESSURES (PSI):	-----	4000.0	4000.0	4000.0	4000.0	4000.0
MEAN PRESSURES (PSI):	-----	10000.0	10000.0	10000.0	10000.0	10000.0
MEAN PRESSURES (PSI):	-----	25000.0	25000.0	25000.0	25000.0	25000.0
BURNING RATES (IN/S):	-----	0.69	0.69	1.05	0.69	1.05
BURNING RATES (IN/S):	-----	1.01	1.01	1.52	1.01	1.52
BURNING RATES (IN/S):	-----	1.94	1.94	2.93	1.94	2.93
BURNING RATES (IN/S):	-----	4.34	4.34	6.56	4.34	6.56

PROPERTIES AT LAYER BOUNDARIES OF LAT SURFACES

	PROPERTIES AT LAYER BOUNDARIES OF LAT SURFACES			PROPERTIES AT LAYER BOUNDARIES OF LAT SURFACES		
	1ST	2ND	3RD	4TH	5TH	6TH
AT DEPTH (IN):	-----	0.00000	0.03000	0.03100	0.03000	0.03100
ADJACENT LAYER WT %:	-----	23.816	0.732	21.665	0.732	21.665
DENSITY (LB/IN3):	-----	0.05732	0.05732	0.05732	0.05732	0.05732
GAMMA (-):	-----	1.2725	1.2725	1.2257	1.2725	1.2257
FORCE (FT-LB/LB):	-----	300417.	300417.	392152.	300417.	392152.
COVOLUME (IN3/LB):	-----	31.170	31.170	27.480	31.170	27.480
FLAME TEMP (K):	-----	2248.	2248.	3400.0	2248.	3400.0
MEAN PRESSURES (PSI):	-----	2000.0	2000.0	2000.0	2000.0	2000.0
MEAN PRESSURES (PSI):	-----	4000.0	4000.0	4000.0	4000.0	4000.0
MEAN PRESSURES (PSI):	-----	10000.0	10000.0	10000.0	10000.0	10000.0
MEAN PRESSURES (PSI):	-----	25000.0	25000.0	25000.0	25000.0	25000.0
BURNING RATES (IN/S):	-----	0.69	0.69	1.05	0.69	1.05
BURNING RATES (IN/S):	-----	1.01	1.01	1.52	1.01	1.52
BURNING RATES (IN/S):	-----	1.94	1.94	2.93	1.94	2.93
BURNING RATES (IN/S):	-----	4.34	4.34	6.56	4.34	6.56

-----  
 - CHARGE 3 -  
 -----

TYPE: FNC CASE	1.2795	1PF	WEIGHT (LB):	1.4100
EROSIVE COEFF (-):	0.000000	0	CHARGE IGM AT (S):	0.00000E+00
P-SURF IGM CODE:	0	0	L-SURF IGM CODE:	2
P-SURF IGM AT (S):	0.00000E+00	0.00000E+00	L-SURF IGM AT (IN):	0.20000E+03
GRAIN LENGTH (IN):	16.00000	6.17000	PERF DIAMETER (IN):	6.01000
INNER WEB (IN):	0.08000	1.0000		

GRAINS:	1ST	2ND	3RD	4TH
CHARGE IGM CODE:	0.01500	0.01500	0.01500	0.01550
E-SURF IGM CODE:	18.535	80.690	80.690	80.690
E-SURF IGM AT (S):	0.04000	0.04000	0.04000	0.04000
GRAIN DIAMETER (IN):	1.2580	1.2580	1.2580	1.2580
WEB RATIO:	150000.	200000.	150000.	200000.
	27.927	27.927	27.927	27.927
	1610.0	1610.0	1610.0	1610.0
	1000.0	1000.0	1000.0	1000.0
	10000.0	10000.0	10000.0	10000.0
	0.50	0.50	0.50	0.50
	2.40	2.40	2.40	2.40

AT DEPTH (IN):	0.01550
ADJACENT LAYER WT %:	80.690
DENSITY (LB/IN3):	0.04000
GAMMA (-):	1.2580
FORCE (FT-LB/LB):	200000.
COVOLUME (IN3/LB):	27.927
FLAME TEMP (K):	1610.0
MEAN PRESSURES (PSI):	1000.0
MEAN PRESSURES (PSI):	1000.0
BURNING RATES (IN/S):	0.50
BURNING RATES (IN/S):	2.40

AT DEPTH (IN):	0.00000
ADJACENT LAYER WT %:	80.690
DENSITY (LB/IN3):	0.04000
GAMMA (-):	1.2580
FORCE (FT-LB/LB):	200000.
COVOLUME (IN3/LB):	27.927
FLAME TEMP (K):	1610.0
MEAN PRESSURES (PSI):	1000.0
MEAN PRESSURES (PSI):	1000.0
BURNING RATES (IN/S):	0.50
BURNING RATES (IN/S):	10.00

- CHARGE 4 -

TYPE: KRAFT CASE  
EROSIVE COEFF (-):  
GRAIN LENGTH (IN):  
INNER WEB (IN):

0.000000  
3.40000  
0.080000

GRAINS:  
CHARGE ICM CODE:  
GRAIN DIAMETER (IN):  
WEB RATIO:

1.0088  
0  
6.17000  
1.0000

WEIGHT (LB):  
CHARGE ICM AT (S):  
PERF DIAMETER (IN):

0.2100  
0.00000E+00  
6.01000

PROPERTIES AT LAYER BOUNDARIES OF PERF SURFACES

	1ST	2ND	3RD	4TH	5TH
AT DEPTH (IN):	-----	-----	-----	-----	-----
ADJACENT LAYER WT %:	-----	-----	-----	-----	-----
DENSITY (LB/IN <sup>3</sup> ):	-----	-----	-----	-----	-----
GAMMA (-):	-----	-----	-----	-----	-----
FORCE (FT-LB/LB):	-----	-----	-----	-----	-----
COVOLUME (IN <sup>3</sup> /LB):	-----	-----	-----	-----	-----
FLAME TEMP (K):	-----	-----	-----	-----	-----
BURNING RATE EXPS:	-----	-----	-----	-----	-----
BURNING RATE COEFFS:	-----	-----	-----	-----	-----

PROPERTIES AT LAYER BOUNDARIES OF LAT SURFACES

	1ST	2ND	3RD	4TH	5TH
AT DEPTH (IN):	-----	-----	-----	-----	-----
ADJACENT LAYER WT %:	-----	-----	-----	-----	-----
DENSITY (LB/IN <sup>3</sup> ):	-----	-----	-----	-----	-----
GAMMA (-):	-----	-----	-----	-----	-----
FORCE (FT-LB/LB):	-----	-----	-----	-----	-----
COVOLUME (IN <sup>3</sup> /LB):	-----	-----	-----	-----	-----
FLAME TEMP (K):	-----	-----	-----	-----	-----
BURNING RATE EXPS:	-----	-----	-----	-----	-----
BURNING RATE COEFFS:	-----	-----	-----	-----	-----

TIME (MS)	TRAV (IN)	VEL (F1/S)	ACC (G)	BREECH PRESS (PSI)	MEAN PRESS (PSI)	MEAN PRESS (PSI)	MEAN TEMP (K)	FRAC BURN 1	FRAC BURN 2	FRAC BURN 3	FRAC BURN 4
0.000	0.00	0.	0.	71.	71.	71.	2000.	0.000	0.000	0.000	0.000
0.010	0.00	0.	0.	101.	101.	101.	2023.	0.013	0.000	0.000	0.000
SHOT-START PRESSURE ACHIEVED											
0.050	0.00	0.	73.	281.	248.	187.	2067.	0.063	0.000	0.000	0.000
0.100	0.00	0.	212.	533.	470.	355.	2093.	0.134	0.000	0.000	0.000
0.150	0.00	1.	377.	832.	734.	555.	2110.	0.198	0.001	0.000	0.000
0.200	0.00	1.	565.	1176.	1037.	784.	2122.	0.259	0.001	0.001	0.000
0.250	0.00	3.	777.	1563.	1378.	1042.	2131.	0.317	0.001	0.001	0.000
0.300	0.00	4.	1010.	1993.	1758.	1328.	2139.	0.373	0.002	0.002	0.000
0.350	0.01	6.	1264.	2465.	2174.	1643.	2145.	0.427	0.002	0.002	0.000
0.400	0.01	8.	1539.	2980.	2629.	1986.	2151.	0.478	0.003	0.003	0.000
0.450	0.02	11.	1833.	3537.	3120.	2357.	2155.	0.527	0.004	0.003	0.000
0.500	0.02	14.	2146.	4137.	3649.	2757.	2159.	0.574	0.004	0.004	0.000
0.550	0.03	18.	2478.	4779.	4215.	3185.	2162.	0.618	0.005	0.005	0.000
0.600	0.05	22.	2834.	5475.	4829.	3649.	2165.	0.659	0.006	0.006	0.000
0.650	0.06	27.	3215.	6230.	5495.	4152.	2167.	0.699	0.007	0.007	0.000
0.700	0.08	32.	3623.	7045.	6215.	4696.	2169.	0.735	0.008	0.008	0.000
0.750	0.10	39.	4056.	7924.	6989.	5281.	2171.	0.770	0.009	0.009	0.001
0.800	0.12	45.	4515.	8866.	7821.	5909.	2172.	0.802	0.011	0.010	0.001
0.850	0.15	53.	4999.	9874.	8710.	6581.	2173.	0.831	0.012	0.011	0.001
0.900	0.19	62.	5508.	10948.	9657.	7296.	2173.	0.859	0.014	0.013	0.001
0.950	0.23	71.	6042.	12092.	10666.	8059.	2173.	0.883	0.015	0.014	0.001
1.000	0.27	81.	6610.	13322.	11752.	8879.	2173.	0.906	0.017	0.016	0.001
1.050	0.33	92.	7211.	14643.	12916.	9759.	2172.	0.926	0.019	0.017	0.001
1.100	0.38	104.	7847.	16057.	14164.	10701.	2171.	0.943	0.021	0.019	0.001
1.150	0.45	117.	8517.	17566.	15495.	11707.	2169.	0.959	0.023	0.021	0.002
1.200	0.53	132.	9220.	19172.	16912.	12777.	2167.	0.972	0.026	0.023	0.002
1.250	0.61	147.	9954.	20876.	18414.	13912.	2164.	0.982	0.029	0.026	0.002
1.300	0.70	164.	10718.	22675.	20002.	15112.	2161.	0.990	0.031	0.028	0.002
1.350	0.81	182.	11527.	24570.	21673.	16375.	2157.	0.996	0.035	0.030	0.003
1.400	0.92	201.	12730.	26556.	23425.	17698.	2153.	0.999	0.038	0.033	0.003
1.444	1.03	220.	13848.	28392.	25045.	18922.	2148.	1.000	0.041	0.035	0.003
PROPELLANT 1 BURNED OUT											
1.450	1.05	223.	13991.	28626.	25251.	19078.	2148.	1.000	0.042	0.036	0.003
1.500	1.19	246.	15307.	30774.	27146.	20509.	2142.	1.000	0.046	0.039	0.004
1.550	1.34	272.	16674.	32991.	29101.	21986.	2136.	1.000	0.050	0.042	0.004
1.600	1.51	300.	19086.	35261.	31103.	23499.	2129.	1.000	0.054	0.045	0.004
1.650	1.70	330.	19534.	37569.	33139.	25037.	2121.	1.000	0.059	0.048	0.005
1.700	1.91	363.	21010.	39895.	35191.	26588.	2113.	1.000	0.065	0.052	0.005
1.750	2.14	398.	22502.	42220.	37241.	28137.	2104.	1.000	0.070	0.055	0.006
1.800	2.39	435.	24000.	44518.	39269.	29668.	2094.	1.000	0.076	0.059	0.006
1.850	2.66	475.	25491.	46766.	41252.	31167.	2083.	1.000	0.082	0.063	0.007
1.900	2.96	517.	26963.	48939.	43168.	32614.	2072.	1.000	0.089	0.067	0.007
1.950	3.28	562.	28145.	51012.	44997.	33996.	2060.	1.000	0.095	0.071	0.008
2.000	3.63	608.	29224.	52963.	46718.	35296.	2048.	1.000	0.103	0.075	0.008
2.050	4.01	656.	30224.	54772.	48314.	36502.	2035.	1.000	0.110	0.079	0.009
2.100	4.42	705.	31137.	56423.	49771.	37602.	2021.	1.000	0.118	0.084	0.010
2.150	4.86	756.	31953.	57901.	51074.	38587.	2008.	1.000	0.126	0.088	0.010
2.200	5.33	808.	32668.	59196.	52216.	39450.	1994.	1.000	0.134	0.093	0.011
2.250	5.83	861.	33278.	60300.	53190.	40186.	1979.	1.000	0.143	0.097	0.011
2.300	6.36	915.	33780.	61210.	53993.	40792.	1965.	1.000	0.152	0.102	0.012
2.350	6.93	970.	34175.	61927.	54625.	41270.	1951.	1.000	0.161	0.107	0.013
2.400	7.53	1025.	34464.	62454.	55090.	41621.	1936.	1.000	0.170	0.112	0.014
2.450	8.16	1081.	34653.	62798.	55393.	41850.	1922.	1.000	0.179	0.116	0.014
2.500	8.82	1137.	34745.	62968.	55544.	41964.	1908.	1.000	0.189	0.121	0.015

TIME (MS)	TRAV (IN)	VEL (FT/S)	ACC (G)	BREECH PRESS (PSI)	MEAN PRESS (PSI)	BASE PRESS (PSI)	MEAN TEMP (K)	FRAC BURN 1	FRAC BURN 2	FRAC BURN 3	FRAC BURN 4
2.527	9.20	1167.	34756.	62991.	55564.	41979.	1900.	1.000	0.194	0.124	0.015
LOCAL PRESSURE MAX DETECTED											
2.550	9.52	1193.	34746.	62975.	55550.	41969.	1894.	1.000	0.199	0.126	0.016
2.600	10.26	1249.	34665.	62832.	55424.	41873.	1880.	1.000	0.208	0.131	0.016
2.650	11.02	1304.	34507.	62552.	55176.	41686.	1866.	1.000	0.218	0.136	0.017
2.700	11.82	1360.	34281.	62148.	54821.	41418.	1853.	1.000	0.228	0.140	0.018
2.750	12.65	1415.	33995.	61636.	54368.	41076.	1840.	1.000	0.238	0.145	0.019
2.800	13.52	1469.	33656.	61028.	53832.	40671.	1827.	1.000	0.248	0.150	0.019
2.850	14.42	1523.	33271.	60338.	53223.	40211.	1815.	1.000	0.258	0.155	0.020
2.900	15.35	1576.	32848.	59578.	52553.	39704.	1803.	1.000	0.268	0.159	0.021
2.950	16.31	1629.	32392.	58760.	51832.	39160.	1791.	1.000	0.278	0.164	0.021
3.000	17.30	1680.	31910.	57895.	51069.	38583.	1780.	1.000	0.288	0.168	0.022
3.050	18.32	1731.	31408.	56993.	50273.	37982.	1768.	1.000	0.298	0.173	0.023
3.100	19.38	1782.	30890.	56062.	49452.	37361.	1758.	1.000	0.308	0.177	0.023
3.150	20.46	1831.	30360.	55110.	48612.	36727.	1747.	1.000	0.318	0.182	0.024
3.200	21.57	1879.	29823.	54145.	47761.	36084.	1737.	1.000	0.328	0.186	0.024
3.221	22.05	1900.	29586.	53719.	47385.	35800.	1733.	1.000	0.332	0.187	0.025
LAYER TRANSITION 2 TO 3 ON PERF SURFACE OF PROPELLANT 3											
LAYER TRANSITION 2 TO 3 ON END SURFACE OF PROPELLANT 3											
3.239	22.45	1916.	29419.	53420.	47121.	35601.	1730.	1.000	0.335	0.193	0.025
LAYER TRANSITION 3 TO 4 ON PERF SURFACE OF PROPELLANT 3											
LAYER TRANSITION 3 TO 4 ON END SURFACE OF PROPELLANT 3											
3.250	22.72	1927.	29348.	53292.	47009.	35516.	1727.	1.000	0.338	0.204	0.025
3.300	23.89	1974.	29024.	52712.	46497.	35129.	1717.	1.000	0.347	0.250	0.026
3.350	25.08	2020.	28684.	52105.	45961.	34724.	1707.	1.000	0.357	0.296	0.026
3.400	26.31	2066.	28332.	51474.	45405.	34304.	1698.	1.000	0.367	0.341	0.027
3.450	27.56	2112.	27970.	50826.	44833.	33872.	1689.	1.000	0.376	0.385	0.027
3.500	28.84	2156.	27601.	50163.	44249.	33431.	1680.	1.000	0.386	0.429	0.028
3.550	30.15	2200.	27225.	49490.	43654.	32982.	1672.	1.000	0.396	0.472	0.029
3.600	31.48	2244.	26844.	48809.	43054.	32528.	1664.	1.000	0.405	0.514	0.029
3.650	32.84	2287.	26461.	48123.	42448.	32071.	1656.	1.000	0.415	0.555	0.030
3.700	34.23	2329.	26077.	47434.	41841.	31612.	1648.	1.000	0.424	0.596	0.030
3.750	35.64	2371.	25693.	46746.	41234.	31153.	1641.	1.000	0.434	0.636	0.031
3.800	37.07	2412.	25310.	46059.	40628.	30695.	1634.	1.000	0.443	0.675	0.031
3.850	38.53	2452.	24928.	45375.	40025.	30240.	1627.	1.000	0.452	0.713	0.032
3.900	40.02	2492.	24549.	44697.	39426.	29787.	1621.	1.000	0.461	0.751	0.032
3.950	41.52	2531.	24174.	44024.	38833.	29339.	1615.	1.000	0.471	0.788	0.033
4.000	43.05	2570.	23802.	43359.	38246.	28896.	1609.	1.000	0.480	0.824	0.033
4.050	44.61	2608.	23435.	42701.	37666.	28458.	1603.	1.000	0.489	0.860	0.034
4.100	46.18	2646.	23073.	42053.	37094.	28025.	1597.	1.000	0.498	0.895	0.034
4.150	47.78	2682.	22716.	41413.	36530.	27599.	1591.	1.000	0.507	0.929	0.035
4.200	49.40	2719.	22364.	40784.	35975.	27180.	1586.	1.000	0.516	0.962	0.035
4.257	51.29	2760.	21975.	40084.	35357.	26713.	1580.	1.000	0.526	1.000	0.036
PROPELLANT 3 BURNED OUT											
4.300	52.71	2790.	21615.	39443.	34792.	26286.	1576.	1.000	0.533	1.000	0.036
4.350	54.39	2824.	21206.	38709.	34145.	25797.	1571.	1.000	0.542	1.000	0.036
4.400	56.10	2858.	20808.	37996.	33516.	25322.	1566.	1.000	0.550	1.000	0.037
4.450	57.82	2891.	20422.	37303.	32905.	24860.	1561.	1.000	0.559	1.000	0.037
4.500	59.57	2924.	20046.	36629.	32310.	24411.	1556.	1.000	0.567	1.000	0.038
4.550	61.33	2956.	19680.	35975.	31733.	23975.	1551.	1.000	0.575	1.000	0.038
4.600	63.11	2987.	19325.	35338.	31172.	23551.	1547.	1.000	0.583	1.000	0.039
4.650	64.91	3018.	18980.	34720.	30626.	23139.	1543.	1.000	0.592	1.000	0.039
4.700	66.73	3048.	18644.	34119.	30096.	22738.	1538.	1.000	0.600	1.000	0.039
4.750	68.57	3078.	18318.	33535.	29581.	22349.	1534.	1.000	0.607	1.000	0.040
4.800	70.43	3107.	18001.	32968.	29080.	21971.	1530.	1.000	0.615	1.000	0.040

TIME (MS)	TRAV (IN)	VEL (FT/S)	ACC (G)	BREECH PRESS (PSI)	MEAN PRESS (PSI)	BASE PRESS (PSI)	MEAN TEMP (K)	FRAC BURN 1	FRAC BURN 2	FRAC BURN 3	FRAC BURN 4
4.850	72.30	3136.	17693.	32416.	28594.	21603.	1526.	1.000	0.623	1.000	0.040
4.900	74.19	3164.	17393.	31879.	28120.	21246.	1522.	1.000	0.631	1.000	0.041
4.950	76.10	3192.	17101.	31358.	27660.	20898.	1519.	1.000	0.638	1.000	0.041
5.000	78.02	3219.	16818.	30851.	27213.	20560.	1515.	1.000	0.646	1.000	0.042
5.050	79.96	3246.	16542.	30357.	26778.	20231.	1511.	1.000	0.653	1.000	0.042
5.100	81.92	3272.	16274.	29878.	26355.	19912.	1508.	1.000	0.661	1.000	0.042
5.150	83.89	3298.	16012.	29411.	25943.	19601.	1504.	1.000	0.668	1.000	0.043
5.200	85.87	3324.	15758.	28957.	25543.	19298.	1501.	1.000	0.675	1.000	0.043
5.250	87.88	3349.	15511.	28515.	25153.	19003.	1497.	1.000	0.682	1.000	0.043
5.300	89.89	3374.	15270.	28085.	24773.	18717.	1494.	1.000	0.689	1.000	0.043
5.350	91.92	3398.	15036.	27666.	24404.	18437.	1491.	1.000	0.696	1.000	0.044
5.400	93.97	3422.	14807.	27258.	24044.	18166.	1488.	1.000	0.703	1.000	0.044
5.450	96.03	3446.	14585.	26861.	23694.	17901.	1485.	1.000	0.710	1.000	0.044
5.500	98.11	3469.	14368.	26474.	23352.	17643.	1482.	1.000	0.717	1.000	0.045
5.550	100.19	3492.	14157.	26097.	23020.	17392.	1479.	1.000	0.724	1.000	0.045
5.600	102.30	3515.	13951.	25729.	22695.	17147.	1475.	1.000	0.731	1.000	0.045
5.650	104.41	3537.	13750.	25371.	22379.	16908.	1473.	1.000	0.737	1.000	0.046
5.700	106.54	3559.	13554.	25022.	22071.	16675.	1470.	1.000	0.744	1.000	0.046
5.741	108.28	3577.	13399.	24745.	21827.	16491.	1468.	1.000	0.749	1.000	0.046
LAYER TRANSITION 2 TO 3 ON PERF SURFACE OF PROPELLANT 2											
LAYER TRANSITION 2 TO 3 ON END SURFACE OF PROPELLANT 2											
LAYER TRANSITION 2 TO 3 ON LAT SURFACE OF PROPELLANT 2											
5.750	108.68	3581.	13364.	24683.	21773.	16450.	1468.	1.000	0.750	1.000	0.046
5.800	110.84	3602.	13198.	24387.	21512.	16252.	1467.	1.000	0.757	1.000	0.046
5.850	113.00	3623.	13069.	24159.	21310.	16100.	1469.	1.000	0.765	1.000	0.047
5.900	115.18	3644.	12983.	24009.	21178.	16000.	1474.	1.000	0.773	1.000	0.047
5.954	117.37	3667.	12949.	23951.	21127.	15962.	1486.	1.000	0.783	1.000	0.047
LAYER TRANSITION 3 TO 4 ON PERF SURFACE OF PROPELLANT 2											
LAYER TRANSITION 3 TO 4 ON END SURFACE OF PROPELLANT 2											
LAYER TRANSITION 3 TO 4 ON LAT SURFACE OF PROPELLANT 2											
6.000	119.58	3686.	12949.	23954.	21130.	15964.	1498.	1.000	0.792	1.000	0.047
LOCAL PRESSURE MIN DETECTED											
6.050	121.80	3707.	12947.	23956.	21131.	15965.	1511.	1.000	0.802	1.000	0.048
6.061	122.39	3711.	12947.	23956.	21131.	15966.	1514.	1.000	0.804	1.000	0.048
LOCAL PRESSURE MAX DETECTED											
6.100	124.03	3728.	12945.	23955.	21131.	15965.	1524.	1.000	0.812	1.000	0.048
6.150	126.27	3749.	12931.	23935.	21113.	15952.	1536.	1.000	0.821	1.000	0.048
6.200	128.53	3769.	12878.	23843.	21032.	15891.	1545.	1.000	0.830	1.000	0.049
6.250	130.80	3790.	12804.	23714.	20918.	15805.	1553.	1.000	0.838	1.000	0.049
6.300	133.08	3811.	12715.	23559.	20781.	15701.	1559.	1.000	0.845	1.000	0.049
6.350	135.37	3831.	12616.	23383.	20626.	15584.	1564.	1.000	0.852	1.000	0.049
6.400	137.67	3851.	12507.	23192.	20457.	15457.	1569.	1.000	0.858	1.000	0.050
6.450	139.99	3871.	12391.	22987.	20276.	15320.	1573.	1.000	0.864	1.000	0.050
6.500	142.32	3891.	12269.	22771.	20086.	15176.	1576.	1.000	0.870	1.000	0.050
6.550	144.66	3911.	12142.	22546.	19887.	15026.	1579.	1.000	0.875	1.000	0.050
6.600	147.01	3930.	12011.	22313.	19682.	14871.	1581.	1.000	0.881	1.000	0.051
6.650	149.38	3949.	11877.	22074.	19471.	14712.	1583.	1.000	0.886	1.000	0.051
6.700	151.75	3968.	11739.	21831.	19256.	14550.	1584.	1.000	0.890	1.000	0.051
6.750	154.14	3987.	11600.	21583.	19038.	14385.	1585.	1.000	0.895	1.000	0.051
6.800	156.54	4006.	11459.	21332.	18817.	14218.	1585.	1.000	0.899	1.000	0.052
6.850	158.95	4024.	11316.	21079.	18593.	14049.	1585.	1.000	0.903	1.000	0.052
6.900	161.37	4042.	11173.	20824.	18368.	13879.	1585.	1.000	0.907	1.000	0.052
6.950	163.80	4060.	11028.	20567.	18142.	13708.	1585.	1.000	0.911	1.000	0.052
7.000	166.24	4078.	10884.	20310.	17915.	13537.	1584.	1.000	0.914	1.000	0.053
7.050	168.69	4095.	10739.	20053.	17689.	13366.	1583.	1.000	0.918	1.000	0.053

TIME (MS)	TRAV (IN)	VEL (FT/E)	ACC (G)	BREECH PRESS (PSI)	NEAR PRESS (PSI)	BASE PRESS (PSI)	NEAR TEMP (K)	FRAC BURN 1	FRAC BURN 2	FRAC BURN 3	FRAC BURN 4
7.100	171.15	4112.	10595.	19797.	17462.	13195.	1582.	1.000	0.921	1.000	0.053
7.150	173.63	4129.	10431.	19541.	17236.	13024.	1580.	1.000	0.924	1.000	0.053
7.200	176.11	4146.	10307.	19285.	17011.	12854.	1579.	1.000	0.927	1.000	0.054
7.250	178.60	4162.	10165.	19031.	16787.	12685.	1577.	1.000	0.930	1.000	0.054
7.300	181.10	4179.	10023.	18779.	16564.	12516.	1575.	1.000	0.932	1.000	0.054
7.350	183.62	4195.	9862.	18528.	16343.	12349.	1573.	1.000	0.935	1.000	0.054
7.400	186.14	4211.	9742.	18279.	16124.	12183.	1570.	1.000	0.937	1.000	0.054
7.419	187.11	4217.	9689.	18185.	16040.	12120.	1569.	1.000	0.938	1.000	0.054

PROJECTILE EXIT

CONDITIONS AT:	P MAX	MUZZLE
TIME (MS):	2.527	7.419
TRAVEL (IN):	9.20	187.11
VELOCITY (FT/S):	1167.	4217.
ACCELERATION (G):	34756.	9689.
BREECH PRESS (PSI):	62991.	18185.
MEAN PRESS (PSI):	55564.	16040.
BASE PRESS (PSI):	41979.	12120.
MEAN TEMP (K):	1900.	1569.
Z CHARGE 1 (-):	1.000	1.000
Z CHARGE 2 (-):	0.194	0.938
Z CHARGE 3 (-):	0.124	1.000
Z CHARGE 4 (-):	0.015	0.054

ENERGY BALANCE SUMMARY	IN-L6	%
TOTAL CHEMICAL:	293665792.	100.00
(1) INTERNAL GAS:	191603776.	65.25
(2) WORK AND LOSSES:	102062016.	34.75
(A) PROJECTILE KINETIC:	69901328.	23.80
(B) GAS KINETIC:	22608000.	7.70
(C) PROJECTILE ROTATIONAL:	35195.	0.01
(D) FRICTIONAL WORK TO TUBE:	0.	0.00
(E) OTHER FRICTIONAL WORK:	391065.	0.13
(F) WORK DONE AGAINST AIR:	725224.	0.25
(G) HEAT CONVECTED TO BORE:	8401203.	2.86
(N) RECOIL ENERGY:	0.	0.00
LOADING DENSITY (G/CM3):	1.175	
CHARGE WT/PROJECTILE WT:	1.056	
PIEZOMETRIC EFFICIENCY:	0.338	
EXPANSION RATIO:	7.247	



## Test Case 6

Test case 6 is a two-part run with a \$PMAX calculation in the first portion. The inputs are saved and re-used for a \$PARA study on charge weight (second propellant deck) as a further set of calculations.

The \$PMAX deck attempts to vary the web distance of the second propellant to reach a maximum breech pressure of 75 kpsi. Initial tries for the iterative solution are WEB=0.070 and WEB=0.075; these values establish a direction of search (WEB to increase or decrease). During execution, no output (other than input deck echoes) is printed until a solution has been found.

Ignition variations are in effect on propellant 2. The perforation surfaces are considered ignited at the start of calculation, end surfaces ignite at 0.2 milliseconds, and lateral surface when mean pressure reaches 2000 psi.

After the first solution has been found, IBHVG2 saves inputs to use for the second series of runs; namely, a \$PARA study on charge weight for the second propellant. Values to be printed in the table at the end of the trajectory output have been specified in the first deck, and the \$PMAX is still in effect to search for 75 kpsi maximum breech pressure by varying web distance.

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SCOMM
  IBHVG2 BENCHMARK TEST CASE 6
  SHOW IGNITION CODE VARIATIONS - PMAX .VS. PARA,PMAX

SHEAT
  TSHL = 0.00450      CSHL = 1848      RSHL = 0.284
  TWAL = 293         HO   = 0.0648     HL   = 1

SGLN
  NAME = '120MM GUN TEST CASE'  CHAM = 607      GRVE = 4.724
  LAND = 4.724                 G/L  = 1.      TRAV = 187.11
  TWST = 99

SPROJ
  NAME = 'APFSOR'  PRVT = 15.65

SCOMM
  'PDIS' VALUES USED WITH PARAMETRIC PRINT OPTION POPT(5)=2
SPDIS
  SHOW='PMAX' DECK='OUT'
SPDIS
  SHOW='CHWT' DECK='PROP' NTH=2
SPDIS
  SHOW='DIAM' DECK='PROP' NTH=2
SPDIS
  SHOW='PD' DECK='PROP' NTH=2
SPDIS
  SHOW='WEB' DECK='PROP' NTH=2
SPDIS
  SHOW='VMUZ' DECK='OUT'
SPDIS
  SHOW='ZMUZ(2)' DECK='OUT'
SPDIS
  SHOW='LDEN' DECK='OUT'

SRESI
  NPTS = 4      AIR = 1
  TRAY = 0, 0.8, 3.0, 187
  PRES = 100, 2500, 100, 100

SINFO
  RUN = '120MM IGNITION DELAY EXPERIMENT'  DELT = 5E-5  DELP = 5E-5
  GRAD = 2      POPT = 1,1,1,0,2  SOPT = 0
```

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EPS = 0.05
SRECO
NAME = 'NONE'      RECO = 0      RCWT = 0
SPRIN
NAME = 'BENITE'    CHWT = 0.00347
                  GAMA = 1.25    FORC = 212500
COV = 30          TEMP = 2000
SPROP
NAME = 'JA2 7P'    CHWT = 10.00    GRAN = '7PF'
RHO = 0.05732     GAMA = 1.2257   FORC = 382152
COV = 27.48       TEMP = 3400    EROS = 0.0000000
NTBL=4 PR4L= 2000,4000,10000,25000 BR4L= 1.05,1.52,2.93,6.56
LEN = 0.643       DIAM = 0.420    PD = 0.020
WI = 0.076        WO = 0.074
SCOMM
PROPELLANT IGNITION CODES:
PERF  IGNITES AT START OF CALCULATION
END   IGNITES AT TIME=.2 MILLISECONDS
LATERAL IGNITES WHEN MEAN PRESSURE REACHES 2KPSI
SPROP
NAME = 'JA2 7P'    CHWT = 7.5      GRAN = '7PF'
RHO = 0.05732     GAMA = 1.2257   FORC = 382152
COV = 27.48       TEMP = 3400    EROS = 0.0000000
NTBL=4 PR4L= 2000,4000,10000,25000 BR4L= 1.05,1.52,2.93,6.56
LEN = 0.643       DIAM = 0.420    PD = 0.020
WEB = 0.075
IGNS=0,1,3 THRS=0.,.0002,2000.
SCOMM
PROGRAM ITERATES WEB OF SECOND PROPELLANT UNTIL PMAX=75000 REACHED
INITIAL GUESSES OF WEB ARE .070 AND .075 INCHES
SPMAX
VARY='WEB' NTH=2 PMAX=75000 TRY1=0.070 TRY2=0.075
SEND
SSAVE
SCOMM
VARY CHARGE WEIGHT OF SECOND PROPELLANT FROM 6 TO 8 POUNDS
BY INCREMENTS OF .5 POUNDS
ALL OTHER OPTIONS STILL IN FORCE AS IN PREVIOUS DECK
SPARA
VARY='CW' NTH=2 FROM=6 TO=8 BY=0.5 DECK='PROP'
SEND

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*Producing the following output:*

ERRTOL= 4.768372E-07

CARD 1 --> SCONH  
CARD 2 --> IBHVQ2 BENCHMARK TEST CASE 6  
CARD 3 -->  
CARD 4 --> SHOW IGNITION CODE VARIATIONS - PMAX .VS. PARA,PMAX  
CARD 5 -->  
CARD 6 --> SHEAT  
CARD 7 --> TSHL = 0.00450 CSHL = 1848 RSHL = 0.284  
CARD 8 --> THAL = 293 NO = 0.0648 NL = 1  
CARD 9 --> SGUM  
CARD 10 --> NAME = '120MM GUN TEST CASE' CKAM = 607 GRVE = 4.724  
CARD 11 --> LAND = 4.724 G/L = 1. TRAV = 187.11  
CARD 12 --> TWST = 99  
CARD 13 --> SPROJ  
CARD 14 --> NAME = 'APFSDS' PRWT = 15.65  
CARD 15 --> SCONH  
CARD 16 --> 'POIS' VALUES USED WITH PARAMETRIC PRINT OPTION POPT(5)=2  
CARD 17 --> SPDIS  
CARD 18 --> SHOW='PMAX' DECK='OUT'  
CARD 19 --> SPDIS  
CARD 20 --> SHOW='CHWT' DECK='PROP' NTH=2  
CARD 21 --> SPDIS  
CARD 22 --> SHOW='DIAM' DECK='PROP' NTH=2  
CARD 23 --> SPDIS  
CARD 24 --> SHOW='PD' DECK='PROP' NTH=2  
CARD 25 --> SPDIS  
CARD 26 --> SHOW='WEB' DECK='PROP' NTH=2  
CARD 27 --> SPDIS  
CARD 28 --> SHOW='MUZ' DECK='OUT'  
CARD 29 --> SPDIS  
CARD 30 --> SHOW='ZMUZ(2)' DECK='OUT'  
CARD 31 --> SPDIS  
CARD 32 --> SHOW='LDEN' DECK='OUT'  
CARD 33 -->  
CARD 34 --> SRESI  
CARD 35 --> NPTS = 4 AIR = 1  
CARD 36 --> TRAV = 0, 0.8, 3.0, 187  
CARD 37 --> PRES = 100, 2500, 100, 100  
CARD 38 -->  
CARD 39 --> SINFO  
CARD 40 --> RUN = '120MM IGNITION DELAY EXPERIMENT' DELT = 5E-5 DELP = 5E-5  
CARD 41 --> GRAD = 2 POPT = 1,1,1,0,2 SOPT = 0  
CARD 42 --> EPS = 0.05  
CARD 43 -->  
CARD 44 --> SRECO  
CARD 45 --> NAME = 'NONE' RECO = 0 RCUT = 0  
CARD 46 -->  
CARD 47 --> SPRIM  
CARD 48 --> NAME = 'BENITE' CHWT = 0.00347  
CARD 49 --> GAMA = 1.25 FORC = 212500  
CARD 50 --> COV = 30 TEMP = 2000  
CARD 51 --> SPROP  
CARD 52 --> NAME = 'JA2 7P' CHWT = 10.00 GRAN = '7PF'  
CARD 53 --> RHO = 0.05732 GAMA = 1.2257 FORC = 382152  
CARD 54 --> COV = 27.48 TEMP = 3400 EROS = 0.0000000  
CARD 55 --> NYBL=4 PR4L= 2000,4000,10000,25000 BR4L= 1.05,1.52,2.93,6.56

CARD 56 --> LEN = 0.643 DIAM = 0.420 PD = 0.020  
 CARD 57 --> WI = 0.076 WO = 0.074  
 CARD 58 -->  
 CARD 59 --> \$CONN  
 CARD 60 --> PROPELLANT IGNITION CODES:  
 CARD 61 --> PERF IGNITES AT START OF CALCULATION  
 CARD 62 --> ENO IGNITES AT TIME=.2 MILLISECONDS  
 CARD 63 --> LATERAL IGNITES WHEN MEAN PRESSURE REACHES 2KPSI  
 CARD 64 -->  
 CARD 65 --> \$PROP  
 CARD 66 --> NAME = 'JA2 7P' CHWT = 7.5 GRAN = '7PF'  
 CARD 67 --> RHO = 0.05732 GAMA = 1.2257 FORC = 382152  
 CARD 68 --> COV = 27.48 TEMP = 3400 EROS = 0.0000000  
 CARD 69 --> NTBL=4 PR4L= 2000,4000,10000,25000 BR4L= 1.05,1.52,2.93,6.56  
 CARD 70 --> LEN = 0.643 DIAM = 0.420 PD = 0.020  
 CARD 71 --> WEB = 0.075  
 CARD 72 --> IGNS=0,1,3 THRS=0.,.0002,2000.  
 CARD 73 -->  
 CARD 74 --> \$CONN  
 CARD 75 --> PROGRAM ITERATES WEB OF SECOND PROPELLANT UNTIL PMAX=75000 REACHED  
 CARD 76 --> INITIAL GUESSES OF WEB ARE .070 AND .075 INCHES  
 CARD 77 --> \$PMAX  
 CARD 78 --> VARY='WEB' NTH=2 PMAX=75000 TRY1=0.070 TRY2=0.075  
 CARD 79 --> \$END

----- GUN TUBE -----  
 TYPE: 120MM GUN TEST CASE  
 GROOVE DIAMETER (IN): 4.724  
 THRU GROOVE (IN): 4.724  
 SHELL WEIGHT (LB): 99.0  
 INIT. SHELL TEMP (K): 0.004500  
 293.  
 CHAMBER VOLUME (IN3): 607.00  
 LAUD DIAMETER (IN): 4.724  
 BORE AREA (IN2): 17.5271  
 SHELL CP (IN-LB/LB-K): 1848.0  
 AIR MO (IN-LB/IN2-S-K): 0.06480  
 TRAVEL (IN): 187.11  
 GROOVE/LAID RATIO: 1.000  
 HEAT-LOSS OPTION: 1  
 SHELL DENSITY (LB/IN3): 0.2840  
 TOTAL WEIGHT (LB): 15.650  
 WEIGHT PREDICTOR OPTION: 0  
 TYPE: APFSDS  
 ----- RESISTANCE -----  
 AIR RESISTANCE OPTION: 1  
 1 TRAVEL (IN) PRESSURE (PSI) 100. 2500.  
 2 0.00 0.00  
 WALL HEATING FRACTION: 0.000  
 1 TRAVEL (IN) PRESSURE (PSI) 100.  
 3 3.00 100.  
 4 187.00 120.  
 FRICTION TABLE LENGTH: 4  
 1 TRAVEL (IN) PRESSURE (PSI)  
 4 187.00 120.  
 ----- GENERAL -----  
 MAX TIME STEP (S): 0.000050  
 PRINT OPTIONS: 1 1 1 0 2 1  
 GRADIENT MODEL: PIDDUCK-KENT  
 PRINT STEP (S): 0.000050  
 STORE OPTION: 0  
 MAX RELATIVE ERROR (-): 0.05000  
 CONSTANT-PRESSURE OPTION: 0  
 ----- RECOIL -----  
 RECOIL OPTION: 0  
 TYPE: NONE  
 RECOILING WEIGHT (LB): 0.  
 TYPE: BENITE  
 COVOLUME (IN3/LB): 30.000  
 GAMMA (-): 1.2500  
 FLAME TEMP (K): 2000.0  
 FORCE (FT-LB/LB): 212500.  
 WEIGHT (LB): 0.003470

-----  
 - CHARGE 1 -  
 -----

TYPE: JAZ 7P  
 EROSION COEFF (-):  
 GRAIN LENGTH (IN):  
 INNER WEB (IN):

0.000000  
 0.64300  
 0.07600

GRAINS:  
 CHARGE IGM CODE:  
 GRAIN DIAMETER (IN):  
 OUTER WEB (IN):

2724.4  
 0.36000  
 0.07400

WEIGHT (LB):  
 CHARGE IGM AT (S):  
 PERFOR DIAMETER (IN):

10.0000  
 0.00000E+00  
 0.02000

PROPERTIES AT LAYER BOUNDARIES OF PERF SURFACES  
 2ND 3RD 4TH  
 1ST 2ND 3RD 4TH

AT DEPTH (IN):  
 ADJACENT LAYER WT %:  
 DENSITY (LB/IN3):  
 GAMMA (-):  
 FORCE (FT-LB/LB):  
 COVOLUME (IN3/LB):  
 FLAME TEMP (K):  
 MEAN PRESSURES (PSI):  
 MEAN PRESSURES (PSI):  
 MEAN PRESSURES (PSI):  
 BURNING RATES (IN/S):  
 BURNING RATES (IN/S):  
 BURNING RATES (IN/S):

0.00000  
 100.000  
 0.05732  
 1.2257  
 382152.  
 27.480  
 3400.0  
 2000.0  
 4000.0  
 10000.0  
 25000.0  
 1.05  
 1.52  
 2.93  
 6.56

PROPERTIES AT LAYER BOUNDARIES OF END SURFACES  
 1ST 2ND 3RD 4TH

0.00000  
 100.000  
 0.05732  
 1.2257  
 382152.  
 27.480  
 3400.0  
 2000.0  
 4000.0  
 10000.0  
 25000.0  
 1.05  
 1.52  
 2.93  
 6.56

PROPERTIES AT LAYER BOUNDARIES OF LAT SURFACES  
 1ST 2ND 3RD 4TH

0.00000  
 100.000  
 0.05732  
 1.2257  
 382152.  
 27.480  
 3400.0  
 2000.0  
 4000.0  
 10000.0  
 25000.0  
 1.05  
 1.52  
 2.93  
 6.56

AT DEPTH (IN):  
 ADJACENT LAYER WT %:  
 DENSITY (LB/IN3):  
 GAMMA (-):  
 FORCE (FT-LB/LB):  
 COVOLUME (IN3/LB):  
 FLAME TEMP (K):  
 MEAN PRESSURES (PSI):  
 MEAN PRESSURES (PSI):  
 MEAN PRESSURES (PSI):  
 BURNING RATES (IN/S):  
 BURNING RATES (IN/S):  
 BURNING RATES (IN/S):

0.00000  
 100.000  
 0.05732  
 1.2257  
 382152.  
 27.480  
 3400.0  
 2000.0  
 4000.0  
 10000.0  
 25000.0  
 1.05  
 1.52  
 2.93  
 6.56

-----  
 - CHARGE 2 -  
 -----

TYPE: JA2 7	3203.5	7PF	0	7.5000
EROSIVE COEFF (-):	0.000000		0	0.00000E+00
P-SURFACE IGM CODE:	0		1	3
E-SURF IGM AT (S):	0.00000E+00	0.20000E-03		0.20000E+04
GRAIN LENGTH (IN):	0.64300	0.28585		0.02000
INNER WEB (IN):	0.05646	0.05646		

GRAINS:				
CHARGE IGM CODE:				
E-SURF IGM CODE:				
E-SURF IGM AT (S):				
GRAIN DIAMETER (IN):				
OUTER WEB (IN):				

WEIGHT (LB):				
CHARGE IGM AT (S):				
L-SURF IGM CODE:				
L-SURF IGM AT (PST):				
PERF DIAMETER (IN):				

AT DEPTH (IN):	1ST	2ND	3RD	4TH
ADJACENT LAYER WT %:	0.00000	0.00000	0.00000	0.00000
DENSITY (LB/IN3):	100.000	100.000	100.000	100.000
GAMMA (-):	0.05732	0.05732	0.05732	0.05732
FORCE (FT-LB/LB):	1.2257	1.2257	1.2257	1.2257
COVOLUME (IN3/LB):	382152.	382152.	382152.	382152.
FLAME TEMP (K):	27.480	27.480	27.480	27.480
MEAN PRESSURES (PSI):	3400.0	3400.0	3400.0	3400.0
MEAN PRESSURES (PSI):	2000.0	2000.0	2000.0	2000.0
MEAN PRESSURES (PSI):	4000.0	4000.0	4000.0	4000.0
MEAN PRESSURES (PSI):	10000.0	10000.0	10000.0	10000.0
BURNING RATES (IN/S):	25000.0	25000.0	25000.0	25000.0
BURNING RATES (IN/S):	1.05	1.05	1.05	1.05
BURNING RATES (IN/S):	1.52	1.52	1.52	1.52
BURNING RATES (IN/S):	2.93	2.93	2.93	2.93
BURNING RATES (IN/S):	6.56	6.56	6.56	6.56

PROPERTIES AT LAYER BOUNDARIES OF LAT SURFACES	1ST	2ND	3RD	4TH
AT DEPTH (IN):	0.00000	0.00000	0.00000	0.00000
ADJACENT LAYER WT %:	100.000	100.000	100.000	100.000
DENSITY (LB/IN3):	0.05732	0.05732	0.05732	0.05732
GAMMA (-):	1.2257	1.2257	1.2257	1.2257
FORCE (FT-LB/LB):	382152.	382152.	382152.	382152.
COVOLUME (IN3/LB):	27.480	27.480	27.480	27.480
FLAME TEMP (K):	3400.0	3400.0	3400.0	3400.0
MEAN PRESSURES (PSI):	2000.0	2000.0	2000.0	2000.0
MEAN PRESSURES (PSI):	4000.0	4000.0	4000.0	4000.0
MEAN PRESSURES (PSI):	10000.0	10000.0	10000.0	10000.0
BURNING RATES (IN/S):	25000.0	25000.0	25000.0	25000.0
BURNING RATES (IN/S):	1.05	1.05	1.05	1.05
BURNING RATES (IN/S):	1.52	1.52	1.52	1.52
BURNING RATES (IN/S):	2.93	2.93	2.93	2.93
BURNING RATES (IN/S):	6.56	6.56	6.56	6.56

TIME (MS)	TRAV (IN)	VEL (FT/S)	ACC (G)	BREECH PRESS (PSI)	MEAN PRESS (PSI)	BASE PRESS (PSI)	MEAN TEMP (K)	FRAC BURN 1	FRAC BURN 2
0.000	0.00	0.	0.	29.	29.	29.	2000.	0.000	0.000
0.050	0.00	0.	0.	54.	54.	54.	2490.	0.000	0.000
0.100	0.00	0.	0.	87.	87.	87.	2779.	0.000	0.000
0.120	0.00	0.	0.	102.	102.	102.	2859.	0.000	0.000
SHOT-START PRESSURE ACHIEVED									
0.150	0.00	0.	-6.	145.	127.	95.	2954.	0.000	0.000
0.202	0.00	0.	37.	203.	178.	133.	3072.	0.001	0.000
PROPELLANT 2 IGNITED ON END SURFACE									
0.250	0.00	0.	88.	273.	240.	179.	3151.	0.001	0.000
0.300	0.00	0.	149.	357.	313.	234.	3207.	0.001	0.001
0.350	0.00	1.	219.	454.	398.	297.	3247.	0.002	0.001
0.400	0.00	1.	297.	562.	493.	368.	3275.	0.002	0.001
0.450	0.00	2.	384.	684.	600.	448.	3297.	0.003	0.001
0.500	0.00	2.	478.	818.	718.	535.	3313.	0.003	0.002
0.550	0.00	3.	581.	966.	847.	632.	3326.	0.004	0.002
0.600	0.01	4.	691.	1126.	988.	737.	3337.	0.005	0.002
0.650	0.01	5.	809.	1300.	1141.	851.	3345.	0.005	0.003
0.700	0.01	7.	935.	1488.	1305.	974.	3351.	0.006	0.003
0.750	0.02	8.	1067.	1690.	1482.	1106.	3357.	0.007	0.004
0.800	0.02	10.	1207.	1905.	1671.	1247.	3362.	0.008	0.004
0.850	0.03	12.	1352.	2135.	1873.	1397.	3365.	0.009	0.005
0.880	0.03	14.	1442.	2278.	1998.	1491.	3367.	0.009	0.005
PROPELLANT 2 IGNITED ON LAT SURFACE									
0.900	0.04	15.	1534.	2420.	2123.	1584.	3369.	0.010	0.005
0.950	0.05	17.	1773.	2790.	2447.	1826.	3373.	0.011	0.007
1.000	0.06	20.	2028.	3188.	2797.	2087.	3375.	0.012	0.008
1.050	0.07	24.	2297.	3615.	3172.	2366.	3378.	0.013	0.010
1.100	0.09	28.	2579.	4071.	3572.	2665.	3379.	0.014	0.012
1.150	0.11	32.	2874.	4556.	3997.	2982.	3381.	0.016	0.014
1.200	0.13	37.	3185.	5075.	4452.	3322.	3382.	0.017	0.016
1.250	0.15	42.	3516.	5635.	4944.	3689.	3382.	0.019	0.018
1.300	0.18	48.	3866.	6238.	5472.	4083.	3382.	0.021	0.020
1.350	0.21	55.	4236.	6884.	6039.	4506.	3383.	0.023	0.023
1.400	0.24	62.	4626.	7576.	6646.	4959.	3382.	0.025	0.025
1.450	0.28	70.	5035.	8316.	7295.	5443.	3382.	0.027	0.028
1.500	0.33	78.	5463.	9103.	7986.	5958.	3381.	0.029	0.031
1.550	0.38	87.	5910.	9941.	8720.	6507.	3380.	0.032	0.034
1.600	0.43	97.	6375.	10829.	9499.	7088.	3379.	0.034	0.038
1.650	0.49	108.	6858.	11769.	10324.	7703.	3378.	0.037	0.042
1.700	0.56	119.	7366.	12775.	11206.	8361.	3376.	0.040	0.046
1.750	0.64	132.	7901.	13850.	12149.	9065.	3374.	0.043	0.050
1.800	0.72	145.	8464.	14998.	13157.	9817.	3372.	0.047	0.055
1.850	0.81	159.	9101.	16223.	14231.	10618.	3370.	0.051	0.060
1.900	0.91	174.	10178.	17526.	15375.	11472.	3367.	0.055	0.065
1.950	1.02	192.	11326.	18911.	16589.	12378.	3364.	0.059	0.071
2.000	1.14	211.	12549.	20378.	17876.	13338.	3361.	0.064	0.077
2.050	1.27	232.	13848.	21929.	19237.	14353.	3358.	0.069	0.084
2.100	1.42	255.	15224.	23565.	20671.	15424.	3354.	0.074	0.091
2.150	1.58	281.	16680.	25283.	22179.	16549.	3349.	0.080	0.098
2.200	1.76	309.	18215.	27084.	23758.	17727.	3344.	0.086	0.107
2.250	1.95	340.	19830.	28963.	25407.	18957.	3339.	0.092	0.115
2.300	2.17	373.	21523.	30919.	27123.	20237.	3333.	0.099	0.125
2.350	2.40	409.	23294.	32944.	28900.	21563.	3326.	0.107	0.134
2.400	2.66	448.	25138.	35033.	30732.	22930.	3319.	0.115	0.145
2.450	2.94	490.	27053.	37178.	32614.	24334.	3312.	0.123	0.156



TIME (MS)	TRAV (IN)	VEL (FT/S)	ACC (G)	BREECH PRESS (PSI)	MEAN PRESS (PSI)	BASE PRESS (PSI)	MEAN TEMP (K)	FRAC BURN 1	FRAC BURN 2
2.500	3.25	535.	28732.	39369.	34535.	25768.	3304.	0.132	0.168
2.550	3.58	583.	30363.	41595.	36488.	27225.	3295.	0.141	0.180
2.600	3.95	633.	32011.	43846.	38463.	28699.	3285.	0.151	0.193
2.650	4.34	686.	33668.	46110.	40449.	30180.	3276.	0.161	0.207
2.700	4.77	741.	35324.	48372.	42433.	31661.	3265.	0.172	0.222
2.750	5.23	800.	36969.	50619.	44404.	33132.	3254.	0.183	0.237
2.800	5.73	860.	38592.	52837.	46350.	34583.	3243.	0.195	0.253
2.850	6.26	924.	40182.	55010.	48256.	36006.	3231.	0.207	0.270
2.900	6.84	990.	41729.	57125.	50111.	37390.	3218.	0.220	0.288
2.950	7.45	1058.	43222.	59166.	51902.	38726.	3205.	0.233	0.306
3.000	8.11	1129.	44651.	61121.	53617.	40005.	3192.	0.247	0.325
3.050	8.81	1202.	46007.	62976.	55244.	41220.	3178.	0.262	0.344
3.100	9.55	1277.	47281.	64720.	56774.	42361.	3165.	0.277	0.365
3.150	10.34	1354.	48466.	66343.	58198.	43423.	3150.	0.292	0.386
3.200	11.18	1433.	49556.	67836.	59508.	44401.	3136.	0.308	0.407
3.250	12.06	1514.	50545.	69193.	60698.	45289.	3121.	0.324	0.429
3.300	12.99	1596.	51430.	70409.	61764.	46084.	3107.	0.340	0.452
3.350	13.97	1679.	52209.	71479.	62703.	46785.	3092.	0.357	0.476
3.400	15.01	1764.	52880.	72404.	63514.	47390.	3077.	0.374	0.499
3.450	16.09	1849.	53444.	73182.	64197.	47900.	3062.	0.392	0.524
3.500	17.23	1936.	53901.	73816.	64753.	48315.	3048.	0.410	0.548
3.550	18.41	2023.	54255.	74309.	65186.	48638.	3033.	0.428	0.573
3.600	19.65	2110.	54509.	74666.	65499.	48871.	3018.	0.446	0.599
3.650	20.95	2198.	54666.	74891.	65697.	49019.	3004.	0.464	0.624
3.700	22.29	2286.	54731.	74992.	65785.	49085.	2989.	0.483	0.650
3.718	22.78	2310.	54734.	75000.	65792.	49090.	2984.	0.489	0.659
LOCAL PRESSURE MAX DETECTED									
3.718	22.78	2318.	54734.	75000.	65792.	49090.	2984.	0.489	0.659
LOCAL PRESSURE MIN DETECTED									
3.718	22.78	2318.	54734.	75000.	65792.	49090.	2984.	0.489	0.659
LOCAL PRESSURE MAX DETECTED									
3.750	23.69	2375.	54711.	74976.	65771.	49074.	2975.	0.501	0.676
3.800	25.14	2463.	54609.	74850.	65660.	48991.	2961.	0.520	0.703
3.850	26.65	2550.	54432.	74622.	65460.	48842.	2947.	0.539	0.729
3.900	28.20	2638.	54186.	74300.	65177.	48631.	2934.	0.558	0.756
3.950	29.81	2725.	53777.	73892.	64820.	48364.	2920.	0.577	0.782
4.000	31.47	2811.	53111.	73406.	64394.	48047.	2907.	0.596	0.809
4.050	33.18	2897.	53093.	72851.	63907.	47683.	2894.	0.615	0.836
4.100	34.95	2982.	52620.	72220.	63353.	47270.	2881.	0.634	0.862
4.150	36.76	3066.	51925.	71287.	62535.	46660.	2868.	0.652	0.884
4.200	38.63	3149.	51047.	70104.	61697.	45885.	2853.	0.671	0.902
4.250	40.54	3231.	50062.	68770.	60832.	45016.	2838.	0.690	0.917
4.300	42.50	3310.	49000.	67350.	59081.	44082.	2822.	0.708	0.930
4.350	44.51	3388.	47900.	65858.	57772.	43106.	2807.	0.726	0.941
4.400	46.57	3465.	46765.	64324.	56426.	42102.	2791.	0.744	0.950
4.450	48.67	3539.	45611.	62766.	55060.	41082.	2776.	0.761	0.958
4.500	50.82	3611.	44451.	61199.	53685.	40056.	2760.	0.778	0.965
4.550	53.00	3682.	43295.	59636.	52314.	39033.	2745.	0.795	0.970
4.600	55.23	3751.	42155.	58097.	50964.	38026.	2730.	0.811	0.975
4.650	57.51	3818.	41038.	56587.	49639.	37038.	2715.	0.827	0.980
4.700	59.82	3883.	39944.	55109.	48343.	36071.	2701.	0.843	0.983
4.750	62.16	3947.	38876.	53667.	47078.	35127.	2686.	0.859	0.987
4.800	64.55	4008.	37808.	52224.	45812.	34182.	2672.	0.873	0.990
4.850	66.97	4068.	36739.	50780.	44545.	33237.	2657.	0.886	0.992
4.900	69.43	4127.	35653.	49313.	43258.	32276.	2642.	0.897	0.994

TIME (MS)	TRAV (IN)	VEL (FT/S)	ACC (G)	BREECH PRESS (PSI)	MEAN PRESS (PSI)	BASE PRESS (PSI)	MEAN TEMP (K)	FRAC BURN 1	FRAC BURN 2
4.950	71.93	4183.	34508.	47846.	41972.	31317.	2627.	0.907	0.996
5.000	74.45	4238.	33499.	46401.	40705.	30371.	2611.	0.916	0.997
5.050	77.01	4291.	32452.	44987.	39464.	29445.	2596.	0.923	0.998
5.100	79.60	4342.	31432.	43608.	38254.	28543.	2581.	0.930	0.999
5.150	82.22	4392.	30440.	42268.	37079.	27666.	2565.	0.936	0.999
5.200	84.87	4440.	29479.	40969.	35939.	26816.	2550.	0.942	1.000
5.250	87.55	4487.	28549.	39713.	34837.	25901.	2535.	0.947	1.000
5.251	87.61	4488.	28528.	39684.	34812.	25901.	2535.	0.947	1.000
PROPELLANT 2 BURNED OUT									
5.300	90.25	4532.	27652.	38501.	33774.	25200.	2520.	0.952	1.000
5.350	92.99	4576.	26789.	37335.	32751.	24437.	2505.	0.956	1.000
5.400	95.75	4619.	25956.	36214.	31768.	23703.	2491.	0.960	1.000
5.450	98.53	4660.	25161.	35137.	30823.	22978.	2476.	0.963	1.000
5.500	101.34	4700.	24394.	34102.	29915.	22321.	2462.	0.966	1.000
5.550	104.17	4738.	23657.	33107.	29042.	21670.	2448.	0.969	1.000
5.600	107.02	4776.	22949.	32152.	28204.	21044.	2434.	0.972	1.000
5.650	109.90	4812.	22269.	31234.	27399.	20444.	2421.	0.974	1.000
5.700	112.80	4848.	21615.	30352.	26626.	19867.	2407.	0.976	1.000
5.750	115.72	4882.	20988.	29506.	25884.	19313.	2394.	0.978	1.000
5.800	118.65	4915.	20386.	28695.	25172.	18781.	2381.	0.980	1.000
5.850	121.61	4947.	19808.	27916.	24488.	18272.	2369.	0.982	1.000
5.900	124.59	4979.	19253.	27168.	23832.	17782.	2356.	0.983	1.000
5.950	127.59	5009.	18720.	26450.	23202.	17312.	2344.	0.985	1.000
6.000	130.60	5039.	18208.	25760.	22597.	16861.	2332.	0.986	1.000
6.050	133.64	5068.	17716.	25097.	22015.	16427.	2320.	0.987	1.000
6.100	136.68	5096.	17242.	24459.	21456.	16009.	2309.	0.988	1.000
6.150	139.75	5124.	16787.	23846.	20918.	15608.	2297.	0.989	1.000
6.200	142.83	5150.	16348.	23256.	20400.	15222.	2286.	0.990	1.000
6.250	145.93	5176.	15926.	22688.	19902.	14850.	2275.	0.991	1.000
6.300	149.04	5202.	15519.	22141.	19422.	14492.	2264.	0.992	1.000
6.350	152.17	5226.	15128.	21613.	18960.	14147.	2253.	0.993	1.000
6.400	155.32	5250.	14750.	21105.	18514.	13814.	2243.	0.994	1.000
6.450	158.47	5274.	14385.	20616.	18085.	13494.	2232.	0.994	1.000
6.500	161.64	5297.	14034.	20143.	17670.	13184.	2222.	0.995	1.000
6.550	164.83	5319.	13695.	19687.	17270.	12886.	2212.	0.996	1.000
6.600	168.03	5341.	13367.	19247.	16884.	12598.	2202.	0.996	1.000
6.650	171.24	5362.	13051.	18822.	16512.	12320.	2192.	0.997	1.000
6.700	174.46	5383.	12745.	18412.	16151.	12051.	2182.	0.997	1.000
6.750	177.70	5403.	12450.	18015.	15803.	11792.	2173.	0.997	1.000
6.800	180.94	5423.	12164.	17632.	15467.	11541.	2164.	0.998	1.000
6.850	184.20	5442.	11888.	17261.	15142.	11298.	2154.	0.998	1.000
6.894	187.11	5459.	11650.	16942.	14862.	11089.	2146.	0.998	1.000
PROJECTILE EXIT									

CONDITIONS AT:	P MAX	MUZZLE
TIME (MS):	3.718	6.894
TRAVEL (IN):	22.78	187.11
VELOCITY (FT/S):	2318.	5459.
ACCELERATION (G):	54734.	11650.
BREECH PRESS (PSI):	75000.	16942.
MEAN PRESS (PSI):	65792.	14862.
BASE PRESS (PSI):	49090.	11089.
MEAN TEMP (K):	2984.	2146.
Z CHARGE 1 (-):	0.489	0.998
Z CHARGE 2 (-):	0.659	1.000

ENERGY BALANCE SUMMARY	IN-LB	%
TOTAL CHEMICAL:	355233280.	100.00
(1) INTERNAL GAS:	224251200.	63.13
(2) WORK AND LOSSES:	130982080.	36.87
(A) PROJECTILE KINETIC:	86906272.	24.46
(B) GAS KINETIC:	29568784.	8.32
(C) PROJECTILE ROTATIONAL:	43757.	0.01
(D) FRICTIONAL WORK TO TUBE:	0.	0.00
(E) OTHER FRICTIONAL WORK:	391060.	0.11
(F) WORK DONE AGAINST AIR:	1221806.	0.34
(G) HEAT CONVECTED TO BORE:	12850402.	3.62
(H) RECOIL ENERGY:	0.	0.00
LOADING DENSITY (G/CM3):	0.798	
CHARGE WT/PROJECTILE WT:	1.118	
PEZOMETRIC EFFICIENCY:	0.353	
EXPANSION RATIO:	6.403	

CARD 80 -->  
CARD 81 --> \$SAVE  
CARD 82 -->  
CARD 83 --> \$COMM  
CARD 84 --> VARY CHARGE WEIGHT OF SECOND PROPELLANT FROM 6 TO 8 POUNDS  
CARD 85 --> BY INCREMENTS OF .5 POUNDS  
CARD 86 --> ALL OTHER OPTIONS STILL IN FORCE AS IN PREVIOUS DECK  
CARD 87 --> \$PARA  
CARD 88 --> VARY='CW' NTH=2 FROM=6 TO=8 BY=0.5 DECK='PROP'  
CARD 89 --> SEND

-----  
 - GUN TUBE -  
 -----

TYPE: 120MM GUN TEST CASE  
 GROOVE DIAMETER (IN): 4.724  
 TWIST (CAL/S/TURN): 99.0  
 SHELL THICKNESS (IN): 0.004500  
 INITIAL SHELL TEMP (K): 293.  
 CHAMBER VOLUME (IN3): 607.00  
 LAND DIAMETER (IN): 4.724  
 BORE AREA (IN2): 17.5271  
 SHELL CP (IN-LB/LB-K): 1848.0  
 AIR HO (IN-LB/IN2-S-K): 0.06480  
 TRAVEL (IN): 187.11  
 GROOVE/LAND RATIO (-): 1.000  
 HEAT-LOSS OPTION: 1  
 SHELL DENSITY (LB/IN3): 0.2840

-----  
 - PROJECTILE -  
 -----

TYPE: APFSDS  
 TOTAL WEIGHT (LB): 15.650  
 WEIGHT PREDICTOR OPTION: 0

-----  
 - RESISTANCE -  
 -----

AIR RESISTANCE OPTION: 1  
 WALL HEATING FRACTION: 0.000  
 FRICTION TABLE LENGTH: 4  

I	TRAVEL (IN)	PRESSURE (PSI)	I	TRAVEL (IN)	PRESSURE (PSI)
1	0.00	100.	4	187.00	100.
2	0.80	2500.			

-----  
 - GENERAL -  
 -----

MAX TIME STEP (\$): 0.000050  
 PRINT OPTIONS: 1 1 1 0 2 1  
 GRADIENT MODEL: PIDDUCK-KENT  
 MAX RELATIVE ERROR (-): 0.05000  
 CONSTANT-PRESSURE OPTION: 0

-----  
 - RECOIL -  
 -----

RECOIL OPTION: 0  
 TYPE: NONE  
 RECOILING WEIGHT (LB): 0.

-----  
 - PRIMER -  
 -----

TYPE: BENITE  
 COVOLUME (IN3/LB): 30.000  
 GAMMA (-): 1.2500  
 FLAME TEMP (K): 2000.0  
 FORCE (FT-LB/LB): 212500.  
 WEIGHT (LB): 0.003470

-----  
 - CHARGE 1 -  
 -----

TYPE: JAZ 7P  
 EROSION COEFF (-):  
 GRAIN LENGTH (IN):  
 INNER WEB (IN):

0.000000  
 0.64300  
 0.07600

GRAINS:  
 CHARGE IGM CODE:  
 GRAIN DIAMETER (IN):  
 OUTER WEB (IN):

2724.4  
 0.34000  
 0.07400

WEIGHT (LB):  
 CHARGE IGM AT (S):  
 PERF DIAMETER (IN):

10.0000  
 0.00000E+00  
 0.02000

	PROPERTIES AT LAYER BOUNDARIES OF PERF SURFACES				PROPERTIES AT LAYER BOUNDARIES OF END SURFACES			
	1ST	2ND	3RD	4TH	1ST	2ND	3RD	4TH
AT DEPTH (IN):	-----	-----	-----	-----	-----	-----	-----	-----
ADJACENT LAYER WT X:	-----	-----	-----	-----	-----	-----	-----	-----
DENSITY (LB/IN3):	-----	-----	-----	-----	-----	-----	-----	-----
GAMMA (-):	-----	-----	-----	-----	-----	-----	-----	-----
FORCE (FT-LB/LB):	-----	-----	-----	-----	-----	-----	-----	-----
COVOLUME (IN3/LB):	-----	-----	-----	-----	-----	-----	-----	-----
FLAME TEMP (K):	-----	-----	-----	-----	-----	-----	-----	-----
MEAN PRESSURES (PSI):	-----	-----	-----	-----	-----	-----	-----	-----
MEAN PRESSURES (PSI):	-----	-----	-----	-----	-----	-----	-----	-----
MEAN PRESSURES (PSI):	-----	-----	-----	-----	-----	-----	-----	-----
BURNING RATES (IN/S):	-----	-----	-----	-----	-----	-----	-----	-----
BURNING RATES (IN/S):	-----	-----	-----	-----	-----	-----	-----	-----
BURNING RATES (IN/S):	-----	-----	-----	-----	-----	-----	-----	-----

	PROPERTIES AT LAYER BOUNDARIES OF LAT SURFACES				PROPERTIES AT LAYER BOUNDARIES OF END SURFACES			
	1ST	2ND	3RD	4TH	1ST	2ND	3RD	4TH
AT DEPTH (IN):	-----	-----	-----	-----	-----	-----	-----	-----
ADJACENT LAYER WT X:	-----	-----	-----	-----	-----	-----	-----	-----
DENSITY (LB/IN3):	-----	-----	-----	-----	-----	-----	-----	-----
GAMMA (-):	-----	-----	-----	-----	-----	-----	-----	-----
FORCE (FT-LB/LB):	-----	-----	-----	-----	-----	-----	-----	-----
COVOLUME (IN3/LB):	-----	-----	-----	-----	-----	-----	-----	-----
FLAME TEMP (K):	-----	-----	-----	-----	-----	-----	-----	-----
MEAN PRESSURES (PSI):	-----	-----	-----	-----	-----	-----	-----	-----
MEAN PRESSURES (PSI):	-----	-----	-----	-----	-----	-----	-----	-----
MEAN PRESSURES (PSI):	-----	-----	-----	-----	-----	-----	-----	-----
BURNING RATES (IN/S):	-----	-----	-----	-----	-----	-----	-----	-----
BURNING RATES (IN/S):	-----	-----	-----	-----	-----	-----	-----	-----
BURNING RATES (IN/S):	-----	-----	-----	-----	-----	-----	-----	-----

- CHARGE 2 -

TYPE: JAZ 7P	GRAINS:	4241.2	7PF	WEIGHT (LB):	6.0000
EROSIVE COEFF (-):	CHARGE IGM CODE:		0	CHARGE IGM AT (\$):	0.00000E+00
P-SURF IGM CODE:	E-SURF IGM CODE:		1	L-SURF IGM CODE:	3
P-SURF IGM AT (\$):	E-SURF IGM AT (\$):	0.20000E-03	0.22731	L-SURF IGM AT (PSI):	0.2000E+04
GRAIN LENGTH (IN):	GRAIN DIAMETER (IN):	0.04183	0.04183	PERF DIAMETER (IN):	0.02000
INNER WEB (IN):	OUTER WEB (IN):				

AT DEPTH (IN):	PROPERTIES AT LAYER BOUNDARIES OF PERF SURFACES	PROPERTIES AT LAYER BOUNDARIES OF END SURFACES
ADJACENT LAYER WT %:	1ST 2ND 3RD 4TH	1ST 2ND 3RD 4TH
DENSITY (LB/IN3):	0.00000	0.00000
GAMMA (-):	100.000	100.000
FORCE (FT-LB/LB):	0.05732	0.05732
CONVOLUME (IN3/LB):	1.2257	1.2257
FLAME TEMP (K):	382152	382152
MEAN PRESSURES (PSI):	27.480	27.480
MEAN PRESSURES (PSI):	3400.0	3400.0
MEAN PRESSURES (PSI):	2000.0	2000.0
MEAN PRESSURES (PSI):	4000.0	4000.0
BURNING RATES (IN/S):	10000.0	10000.0
BURNING RATES (IN/S):	25000.0	25000.0
BURNING RATES (IN/S):	1.05	1.05
BURNING RATES (IN/S):	1.52	1.52
BURNING RATES (IN/S):	2.93	2.93
BURNING RATES (IN/S):	6.56	6.56

AT DEPTH (IN):	PROPERTIES AT LAYER BOUNDARIES OF LAT SURFACES
ADJACENT LAYER WT %:	1ST 2ND 3RD 4TH
DENSITY (LB/IN3):	0.00000
GAMMA (-):	100.000
FORCE (FT-LB/LB):	0.05732
CONVOLUME (IN3/LB):	1.2257
FLAME TEMP (K):	382152
MEAN PRESSURES (PSI):	27.480
MEAN PRESSURES (PSI):	3400.0
MEAN PRESSURES (PSI):	2000.0
MEAN PRESSURES (PSI):	4000.0
BURNING RATES (IN/S):	10000.0
BURNING RATES (IN/S):	25000.0
BURNING RATES (IN/S):	1.05
BURNING RATES (IN/S):	1.52
BURNING RATES (IN/S):	2.93
BURNING RATES (IN/S):	6.56

TIME (MS)	TRAV (IN)	VEL (FT/S)	ACC (G)	BREECH PRESS (PSI)	MEAN PRESS (PSI)	BASE PRESS (PSI)	MEAN TEMP (K)	FRAC BURN 1	FRAC BURN 2
0.000	0.00	0.	0.	27.	27.	27.	2000.	0.000	0.000
0.050	0.00	0.	0.	50.	50.	50.	2496.	0.000	0.000
0.100	0.00	0.	0.	81.	81.	81.	2786.	0.000	0.000
0.126	0.00	0.	0.	100.	100.	100.	2837.	0.000	0.000
SHOT-START PRESSURE ACHIEVED									
0.149	0.00	0.	-11.	134.	119.	90.	2960.	0.000	0.000
0.201	0.00	0.	30.	189.	167.	127.	3078.	0.001	0.000
PROPELLANT 2 IGNITED ON END SURFACE									
0.250	0.00	0.	79.	254.	224.	171.	3155.	0.001	0.001
0.300	0.00	0.	137.	331.	293.	223.	3210.	0.001	0.001
0.350	0.00	1.	203.	419.	371.	282.	3248.	0.002	0.001
0.400	0.00	1.	276.	518.	459.	349.	3277.	0.002	0.002
0.450	0.00	1.	358.	629.	557.	424.	3298.	0.003	0.002
0.500	0.00	2.	447.	752.	665.	507.	3314.	0.003	0.002
0.550	0.00	3.	543.	886.	784.	597.	3327.	0.004	0.003
0.600	0.01	4.	647.	1033.	914.	696.	3337.	0.004	0.003
0.650	0.01	5.	758.	1192.	1054.	803.	3345.	0.005	0.004
0.700	0.01	6.	875.	1363.	1205.	918.	3352.	0.006	0.004
0.750	0.02	8.	1000.	1546.	1368.	1042.	3357.	0.007	0.005
0.800	0.02	10.	1130.	1743.	1542.	1174.	3362.	0.007	0.006
0.850	0.03	11.	1267.	1952.	1727.	1315.	3365.	0.008	0.006
0.900	0.04	14.	1409.	2174.	1923.	1464.	3369.	0.009	0.007
0.919	0.04	14.	1463.	2259.	1999.	1522.	3370.	0.010	0.007
PROPELLANT 2 IGNITED ON LAT SURFACE									
0.950	0.04	16.	1603.	2470.	2185.	1664.	3372.	0.010	0.009
1.000	0.05	19.	1836.	2826.	2499.	1903.	3375.	0.011	0.010
1.050	0.07	22.	2083.	3207.	2837.	2160.	3377.	0.013	0.013
1.100	0.08	25.	2343.	3614.	3197.	2435.	3379.	0.014	0.015
1.150	0.10	29.	2614.	4048.	3581.	2727.	3381.	0.015	0.017
1.200	0.12	34.	2897.	4508.	3988.	3037.	3382.	0.016	0.020
1.250	0.14	39.	3195.	4999.	4422.	3368.	3383.	0.018	0.022
1.300	0.16	44.	3509.	5527.	4889.	3723.	3383.	0.020	0.025
1.350	0.19	50.	3842.	6094.	5390.	4105.	3383.	0.021	0.028
1.400	0.22	57.	4192.	6700.	5927.	4514.	3383.	0.023	0.032
1.450	0.26	64.	4559.	7349.	6500.	4950.	3383.	0.025	0.035
1.500	0.30	71.	4944.	8039.	7111.	5415.	3383.	0.027	0.039
1.550	0.34	80.	5346.	8773.	7761.	5910.	3382.	0.030	0.043
1.600	0.40	88.	5765.	9553.	8451.	6435.	3381.	0.032	0.047
1.650	0.45	98.	6200.	10379.	9181.	6992.	3380.	0.035	0.052
1.700	0.51	108.	6650.	11252.	9953.	7580.	3379.	0.037	0.057
1.750	0.58	120.	7120.	12179.	10773.	8204.	3377.	0.040	0.062
1.800	0.66	131.	7613.	13168.	11649.	8871.	3376.	0.044	0.068
1.850	0.74	144.	8132.	14224.	12583.	9582.	3374.	0.047	0.074
1.900	0.83	158.	8813.	15348.	13577.	10340.	3372.	0.051	0.081
1.950	0.93	173.	9836.	16544.	14635.	11145.	3369.	0.054	0.088
2.000	1.04	189.	10926.	17813.	15758.	12000.	3366.	0.059	0.095
2.050	1.16	208.	12085.	19158.	16947.	12906.	3364.	0.063	0.103
2.100	1.29	228.	13317.	20580.	18205.	13864.	3360.	0.068	0.112
2.150	1.43	251.	14622.	22078.	19531.	14873.	3357.	0.073	0.121
2.200	1.59	275.	16004.	23655.	20925.	15936.	3353.	0.078	0.131
2.250	1.76	302.	17463.	25309.	22388.	17050.	3348.	0.084	0.142
2.300	1.95	332.	18999.	27039.	23919.	18215.	3343.	0.090	0.153
2.350	2.16	364.	20613.	28842.	25514.	19430.	3338.	0.097	0.165
2.400	2.39	398.	22305.	30715.	27171.	20692.	3332.	0.104	0.178
2.450	2.64	435.	24072.	32654.	28886.	21998.	3326.	0.111	0.191



TIME (MS)	TRAV (IN)	VEL (FT/S)	ACC (G)	BREECH PRESS (PSI)	MEAN PRESS (PSI)	BASE PRESS (PSI)	MEAN TEMP (K)	FRAC BURN 1	FRAC BURN 2
2.500	2.91	476.	25912.	34653.	30654.	23345.	3319.	0.119	0.206
2.550	3.21	519.	27567.	36705.	32469.	24727.	3311.	0.127	0.22
2.600	3.53	564.	29147.	38802.	34324.	26139.	3303.	0.136	0.237
2.650	3.89	613.	30756.	40936.	36212.	27577.	3295.	0.145	0.254
2.700	4.27	663.	32384.	43097.	38124.	29033.	3286.	0.155	0.273
2.750	4.68	717.	34025.	45275.	40051.	30500.	3276.	0.165	0.292
2.800	5.13	773.	35671.	47459.	41982.	31971.	3266.	0.176	0.312
2.850	5.61	832.	37311.	49636.	43908.	33438.	3256.	0.187	0.333
2.900	6.13	893.	38936.	51795.	45818.	34892.	3245.	0.199	0.355
2.950	6.69	957.	40538.	53921.	47699.	36325.	3233.	0.211	0.378
3.000	7.28	1024.	42106.	56003.	49541.	37727.	3222.	0.224	0.403
3.050	7.91	1093.	43630.	58028.	51332.	39091.	3209.	0.237	0.428
3.100	8.59	1164.	45101.	59984.	53062.	40409.	3197.	0.251	0.454
3.150	9.31	1238.	46511.	61858.	54719.	41671.	3184.	0.265	0.482
3.200	10.08	1314.	47850.	63639.	56296.	42871.	3171.	0.280	0.510
3.250	10.89	1392.	49113.	65319.	57781.	44003.	3157.	0.295	0.540
3.300	11.75	1472.	50291.	66888.	59169.	45059.	3144.	0.311	0.570
3.350	12.66	1554.	51380.	68338.	60452.	46037.	3130.	0.327	0.602
3.400	13.61	1637.	52374.	69664.	61625.	46930.	3116.	0.343	0.634
3.450	14.62	1722.	53271.	70862.	62685.	47737.	3102.	0.360	0.667
3.500	15.68	1809.	54069.	71928.	63627.	48455.	3088.	0.377	0.701
3.550	16.79	1896.	54765.	72860.	64453.	49083.	3074.	0.395	0.735
3.600	17.96	1985.	55361.	73660.	65160.	49622.	3059.	0.413	0.771
3.650	19.17	2075.	55856.	74327.	65750.	50071.	3045.	0.431	0.807
3.700	20.45	2165.	56253.	74864.	66225.	50433.	3031.	0.449	0.844
3.729	21.21	2218.	56351.	75000.	66345.	50525.	3023.	0.460	0.863
LOCAL PRESSURE MAX DETECTED									
3.729	21.21	2218.	56351.	75000.	66345.	50525.	3023.	0.460	0.863
LOCAL PRESSURE MIN DETECTED									
3.729	21.21	2218.	56351.	75000.	66345.	50525.	3023.	0.460	0.863
LOCAL PRESSURE MAX DETECTED									
3.750	21.77	2256.	56305.	74944.	66296.	50487.	3016.	0.468	0.875
3.800	23.15	2346.	55943.	74476.	65882.	50172.	3000.	0.487	0.900
3.850	24.59	2436.	55323.	73668.	65167.	49627.	2982.	0.505	0.920
3.900	26.07	2524.	54512.	72605.	64227.	48911.	2964.	0.524	0.936
3.950	27.62	2611.	53552.	71345.	63112.	48062.	2946.	0.542	0.949
4.000	29.21	2696.	52476.	69932.	61862.	47110.	2927.	0.561	0.960
4.050	30.85	2780.	51317.	68409.	60515.	46084.	2909.	0.579	0.969
4.100	32.54	2862.	50116.	66830.	59118.	45021.	2890.	0.596	0.976
4.150	34.28	2941.	48889.	65218.	57692.	43935.	2872.	0.614	0.982
4.200	36.07	3019.	47649.	63586.	56249.	42836.	2854.	0.631	0.987
4.250	37.91	3095.	46404.	61950.	54801.	41733.	2836.	0.648	0.991
4.300	39.79	3168.	45163.	60318.	53358.	40634.	2819.	0.664	0.994
4.350	41.71	3240.	43933.	58701.	51927.	39545.	2801.	0.680	0.997
4.400	43.67	3310.	42719.	57105.	50516.	38470.	2784.	0.696	0.998
4.450	45.68	3378.	41526.	55537.	49128.	37413.	2768.	0.712	0.999
4.500	47.73	3444.	40357.	54000.	47769.	36378.	2751.	0.727	1.000
4.511	48.19	3458.	40096.	53658.	47466.	36147.	2748.	0.731	1.000
PROPELLANT 2 BURNED OUT									
4.549	49.76	3506.	39245.	52539.	46476.	35393.	2736.	0.742	1.000
4.599	51.88	3569.	38145.	51094.	45198.	34420.	2720.	0.756	1.000
4.649	54.04	3629.	37085.	49700.	43965.	33481.	2705.	0.771	1.000
4.699	56.24	3688.	36062.	48357.	42777.	32576.	2690.	0.785	1.000
4.749	58.47	3745.	35077.	47064.	41633.	31705.	2675.	0.798	1.000
4.799	60.73	3801.	34128.	45818.	40531.	30866.	2661.	0.812	1.000

TIME (MS)	TRAV (IN)	VEL (FT/S)	ACC (G)	BREECH PRESS (PSI)	MEAN PRESS (PSI)	BASE PRESS (PSI)	MEAN TEMP (K)	FRAC BURN 1	FRAC BURN 2
4.849	63.03	3855.	33214.	44618.	39469.	30058.	2647.	0.825	1.000
4.899	65.36	3908.	32334.	43463.	38448.	29280.	2634.	0.838	1.000
4.949	67.72	3959.	31486.	42351.	37464.	28530.	2621.	0.851	1.000
4.999	70.11	4009.	30668.	41278.	36514.	27807.	2608.	0.863	1.000
5.049	72.53	4058.	29856.	40213.	35573.	27090.	2595.	0.874	1.000
5.099	74.98	4105.	29061.	39171.	34450.	26388.	2583.	0.885	1.000
5.149	77.46	4152.	28268.	38130.	33730.	25687.	2570.	0.894	1.000
5.199	79.96	4196.	27481.	37098.	32817.	24991.	2556.	0.902	1.000
5.249	82.49	4240.	26710.	36086.	31922.	24310.	2543.	0.910	1.000
5.299	85.05	4282.	25959.	35101.	31050.	23646.	2530.	0.916	1.000
5.349	87.63	4324.	25228.	34142.	30202.	23000.	2516.	0.922	1.000
5.399	90.24	4364.	24519.	33213.	29380.	22374.	2503.	0.928	1.000
5.449	92.87	4403.	23833.	32312.	28584.	21768.	2490.	0.933	1.000
5.499	95.52	4440.	23168.	31441.	27813.	21180.	2477.	0.938	1.000
5.549	98.20	4477.	22525.	30598.	27067.	20613.	2465.	0.942	1.000
5.599	100.89	4513.	21904.	29784.	26347.	20064.	2452.	0.946	1.000
5.649	103.61	4548.	21304.	28998.	25651.	19535.	2439.	0.950	1.000
5.699	106.35	4582.	20724.	28238.	24980.	19023.	2427.	0.953	1.000
5.749	109.11	4615.	20165.	27505.	24331.	18529.	2415.	0.956	1.000
5.799	111.89	4647.	19624.	26797.	23705.	18052.	2403.	0.959	1.000
5.849	114.68	4678.	19103.	26114.	23101.	17592.	2391.	0.962	1.000
5.899	117.50	4708.	18599.	25455.	22517.	17148.	2379.	0.965	1.000
5.949	120.33	4738.	18113.	24818.	21955.	16719.	2368.	0.967	1.000
5.999	123.19	4766.	17644.	24204.	21411.	16305.	2356.	0.969	1.000
6.049	126.05	4794.	17191.	23611.	20887.	15906.	2345.	0.971	1.000
6.099	128.94	4822.	16753.	23039.	20380.	15520.	2334.	0.973	1.000
6.149	131.84	4848.	16330.	22486.	19891.	15148.	2323.	0.975	1.000
6.199	134.76	4874.	15922.	21952.	19419.	14788.	2312.	0.976	1.000
6.249	137.69	4900.	15528.	21436.	18963.	14441.	2301.	0.978	1.000
6.299	140.64	4924.	15148.	20939.	18523.	14106.	2291.	0.979	1.000
6.349	143.60	4948.	14780.	20459.	18098.	13782.	2280.	0.980	1.000
6.399	146.57	4972.	14426.	19996.	17688.	13470.	2270.	0.982	1.000
6.449	149.56	4995.	14083.	19548.	17292.	13169.	2260.	0.983	1.000
6.499	152.57	5017.	13752.	19116.	16910.	12877.	2250.	0.984	1.000
6.549	155.58	5039.	13432.	18698.	16540.	12596.	2240.	0.985	1.000
6.599	158.61	5061.	13123.	18294.	16183.	12324.	2230.	0.986	1.000
6.649	161.66	5082.	12823.	17903.	15837.	12060.	2221.	0.987	1.000
6.699	164.71	5102.	12534.	17525.	15503.	11806.	2211.	0.988	1.000
6.749	167.78	5122.	12253.	17159.	15179.	11559.	2202.	0.989	1.000
6.799	170.86	5141.	11982.	16805.	14866.	11321.	2193.	0.989	1.000
6.849	173.95	5160.	11719.	16462.	14562.	11090.	2184.	0.990	1.000
6.899	177.05	5179.	11464.	16130.	14269.	10866.	2175.	0.991	1.000
6.949	180.16	5197.	11217.	15808.	13984.	10649.	2166.	0.992	1.000
6.999	183.29	5215.	10978.	15496.	13708.	10439.	2158.	0.992	1.000
7.049	186.42	5233.	10746.	15194.	13440.	10235.	2149.	0.993	1.000
7.060	187.11	5236.	10696.	15129.	13383.	10192.	2147.	0.993	1.000

PROJECTILE EXIT

CONDITIONS AT:	PMAX	MUZZLE
TIME (MS):	3.729	7.060
TRAVEL (IN):	21.21	187.11
VELOCITY (FT/S):	2218.	5236.
ACCELERATION (G):	56351.	10696.
BREECH PRESS (PSI):	75000.	15129.
MEAN PRESS (PSI):	66345.	13383.
BASE PRESS (PSI):	50525.	10192.
MEAN TEMP (K):	3023.	2147.
Z CHARGE 1 (-):	0.460	0.993
Z CHARGE 2 (-):	0.863	1.000

ENERGY BALANCE SUMMARY	IN-LB	%
TOTAL CHEMICAL:	323663104.	100.00
(1) INTERNAL GAS:	204413888.	63.16
(2) WORK AND LOSSES:	119249216.	36.84
(A) PROJECTILE KINETIC:	79963376.	24.71
(B) GAS KINETIC:	25038928.	7.74
(C) PROJECTILE ROTATIONAL:	40262.	0.01
(D) FRICTIONAL WORK TO TUBE:	0.	0.00
(E) OTHER FRICTIONAL WORK:	391050.	0.12
(F) WORK DONE AGAINST AIR:	1140127.	0.35
(G) HEAT CONVECTED TO BORE:	12675466.	3.92
(H) RECOIL ENERGY:	0.	0.00

LOADING DENSITY (G/CM3):	0.730
CHARGE WT/PROJECTILE WT:	1.023
PIEZOMETRIC EFFICIENCY:	0.325
EXPANSION RATIO:	6.403

PARAMETRIC VARIABLES: / 1/ OUT 1 PMAX  
 / 2/ PROP 2 CHWT  
 / 3/ PROP 2 DIAM  
 / 4/ PROP 2 PO  
 / 5/ PROP 2 WEB  
 / 6/ OUT 1 VMUZ  
 / 7/ OUT 1 ZMUZ(2)  
 / 8/ OUT 1 LDEN

/ 1/	/ 2/	/ 3/	/ 4/	/ 5/	/ 6/	/ 7/	/ 8/
75000.	6.0000	0.22731	0.20000E-01	0.41828E-01	5236.5	1.0000	0.72978
75000.	6.5000	0.24653	0.20000E-01	0.46632E-01	5320.0	1.0000	0.75258
75000.	7.0000	0.26551	0.20000E-01	0.51377E-01	5396.4	1.0000	0.77538
75000.	7.5000	0.28584	0.20000E-01	0.56461E-01	545	1.0000	0.79818
75000.	8.0000	0.30781	0.20000E-01	0.61953E-01	550	1.0000	0.82099

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## VII. ACKNOWLEDGEMENTS

As stated in the introduction, the intention of this report is to instruct and clarify how to use the IBHVG2 computer code. Although we have worked to improve the computer code in regards to portability and efficiency, Franz Lynn deserves the credit for the creation of IBHVG2. The widespread use of the computer algorithm is a testament to his skill and abilities. His death represents a loss to the interior ballistics community. To be sure, he was sorely missed during the documentation phase of IBHVG2.

We gave considerable thought about including Franz's name on this report. Much of the writing about the input cards and the algorithm comes from his original notes. We decided against it to avoid confusing the readers. Any errors or omissions are solely our own. We are certain that a report with Franz's participation would have been better since he was obviously more knowledgeable about what the code could and could not do.

To thank all the people who helped in writing this documentation or in developing the code would be rather pointless, since it would entail most of the professional staff of Interior Ballistic Division at BRL. However, a few names stand out in particular. A special thanks goes to Fred Robbins for serving as our sublime authority about how to use the code, and to Bob Deas and Paul Baer for motivation about the what and why parts. Stumping these three with a question usually meant some extensive computer experimentation was required. Fortunately, this was an infrequent occurrence.

As a final comment, it is worth mentioning that much of the progress in computer simulations can be directly attributed to experimental developments. From a mathematical standpoint, the equations solved by IBHVG2 are neither original nor particularly complicated. What is new is the data being used to drive these simulations. In-bore measurements, accurate burning rate correlations, and instrumented projectiles have reduced the number of unknowns so that modelers can focus their energies on design and optimization. In this vein, we would like to thank the respective staffs under the direction of Arpad Juhasz for closed bomb firings and Jim Evans for range operations at Sandy Point (Range 18).