AN ATTEMPT TO MODEL THE GUN
INTERNAL BALLISTICS PROBLEM

THESIS

AM/ME/72-2 James Frederick Setchell
Captain USAF

SCHOOL OF ENGINEERING

WRIGHT-PATTERSON AIR FORCE BASE, OHIO
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Gun Internal Ballistics
AN ATTEMPT TO MODEL THE GUN INTERNAL BALLISTICS PROBLEM

THESIS

Presented to the Faculty of the School of Engineering of the Air Force Institute of Technology, Air University, in Partial Fulfillment of the Requirements for the Degree of Master of Science

by

James Frederick Setchell, Jr., B.S.A.E.

Captain USAF

Graduate Aerospace-Mechanical Engineering

March 1972

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Preface

In this work I have made an effort to model the complex power-burning, chambered-gun internal ballistics process with an artificial sequence of fundamental processes. Although I was unable to obtain acceptable results from the model in the time allotted for this work, I feel that the partial results attained to date indicate that the model shows good promise. At the very least I have learned a great deal about the gun business, the application of engineering principles to physical problems, the value and results of simplifying assumptions, and the frustrations involved in creating and perfecting a lengthy and involved computer program.

I now take this opportunity to express my gratitude to my thesis advisor, Dr. James Hitchcock, both for posing this most challenging problem as well as for his knowledgable advice on analyzing the gun problem. I am also grateful for the timely suggestions made by the other gentlemen on my thesis committee, Dr. Andrew Shine and Capt (Dr.) Stephen Koob. And I thank my lovely wife Judy, whose patient understanding during this difficult time has been truly remarkable.

James F. Setchell
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<td>$v$ Velocity</td>
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<tr>
<td>$V$ Volume</td>
<td>$\eta$ Burn Rate Exponent</td>
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<td>$\gamma$ Ratio of Specific Heats</td>
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<td>$\rho$ Density</td>
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$ft/sec$  
$cub in$  
$in/sec$  
$lbm/in^3$
Abstract

An attempt is made to model the internal ballistics process of a powder-burning gun by replacing the actual internal ballistics process with an incremental sequence of phases. These phases are a constant-volume energy transfer phase, a shell motion and finite-amplitude wave propagation phase, a propellant motion phase, and a gas expansion and mass transfer phase. The model permits consideration of a chambered, powder-burning gun problem with unspecified pressure, density, velocity, temperature, and propellant distributions. The method of solution shows promise, but useful results have not been attained to date.
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I. Introduction

Background

Gun internal ballistics is the study of the conversion of latent chemical energy of a propellant to kinetic energy of a projectile. It is only concerned with the period of time that begins with propellant ignition and ends with the projectile leaving the barrel. The primary purpose of a gun internal ballistics study is to predict the gas property and shell motion history of a gun.

The formal study of gun internal ballistics began during the eighteenth century with the work of Benjamin Robins in 1742 and Count Joseph-Louis Lagrange in 1793. C. K. Thornhill includes a summary of early gun internal ballistics work in "A New Special Solution to the Complete Problem of the Internal Ballistics of Guns", and suggests that, since the time of Robins and Lagrange, analyses of the gun problem have generally followed one of three methods. The first method involves a solution to the complete fluid dynamic equations of flow using the theory of finite-amplitude waves in gases. The second method involves a reduction of the problem to the solution of ordinary differential equations. Solutions employing this second method are known as "mixed solutions", and do not involve the complete fluid dynamic equations of flow. Solutions involving the third method are
known as "special solutions". Such solutions do involve the complete fluid dynamic equations of flow, are self-similar in nature, and require that the initial conditions be precisely those which insure \( \text{se}'\text{-}\text{similarity} \) (Ref 7:1).

The conversion of chemical energy of the propellant to kinetic energy of the shell is a complex process, and an exact analytical description of this process does not exist. Every gun internal ballistics analysis employs a number of simplifying assumptions which reduce the problem to a model which can be more readily analyzed. In order to provide a basis of comparison between the present work and other studies the most commonly-used assumptions found in other gun ballistics studies will now be discussed.

One of the first simplifications applied to the gun problem was that the propellant was completely burned before the shell motion was permitted to begin. This assumption was used by Robins and Lagrange in the eighteenth century, then by Love and Pidduck during the early part of the twentieth century (Ref 3:347), and finally in a more modern work by Seigel (Ref 7). A second assumption includes the presence of burning propellant in the analysis, but requires that the propellant velocity be the same as the gas velocity. The works of Baer and Hitchcock are examples of studies which employ this assumption (Refs 1, 2, and 5). A third assumption is that the chamber may be represented by an "effective chamber" which has the same volume as the actual chamber but a diameter equal to that of the bore. Seigel
states that the "effective chamber" assumption is invalid, however, in that an analysis incorporating this assumption neglects certain significant compression effects which occur as a result of the area change in the chamber (Ref 7:28).

A final assumption is that the gas density is only a function of time. The works of Heiney (Ref 4:5) and Hitchcock (Ref 5:4) illustrate that this assumption is a sufficient condition for a linear gas velocity distribution.

Such assumptions as the ones discussed above do serve to reduce the gun problem to a more amenable form, but in doing so they tend to form models which deviate somewhat from physical reality. One might well question the validity of a model which represents a chambered, propellant-burning gun with a non-chambered, non-propellant burning tube, yet the results of many such simplified analyses agree quite satisfactorily with experimental results (Refs 1, 2, 4, 5, 6 and 7). Recently, however, evidence has appeared which indicates that conventional theory is not always providing acceptable results, particularly for power-burning guns with muzzle velocities in excess of 5000 feet per second (fps). Baer points out that as muzzle velocities increase beyond 5000 fps conventional internal ballistic theory is unable to predict detailed gun performance (Ref 1:535). Further, Hitchcock noted an increased deviation between theory and experiment for muzzle velocities in the 5500 - 6500 fps range (Ref 5:25-26).
The Present Work

The present work has two objectives. The first is to model the gun internal ballistics process in such a manner as to be independent of the four commonly-used assumptions described above. The second objective is to use the results of this model to explain the deviations between theory and experiment for high-speed guns noted by Baer and Hitchcock.

Section II is a two-part section devoted to a discussion of the analytical model used in this work. The first part contains a discussion of the fundamental assumptions used as a basis for the model, while the second part contains a word description of the operation of the model. Section III contains the working equations, the derivation of these equations, and a detailed list of the assumptions used in deriving them. Section IV contains a discussion of the results. The conclusion reached as a result of this work and some recommendations for future work are contained in Section V.

A Fortran Extended computer program was created to perform the numerous storing, searching, and computational routines involved in the solution. Pertinent information about the type of computer used, storage requirements, program run time, as well as a simplified logic diagram, a program listing, and a sample output are contained in the appendices. A brief glossary of terms peculiar to the gun internal ballistics field is provided in Appendix E.
II. The Analytical Model

Fundamental Assumptions

The analytical model is based upon two fundamental assumptions. The first is that for small but finite increments of time the actual internal ballistics process may be represented by an artificial sequence of four separate "phases". This sequence consists of a constant volume energy transfer phase, a shell motion and wave propagation phase, a propellant motion phase, and a gas expansion and mass transfer phase. The implication of the assumption is that for small but finite increments of time the net result of this artificial sequence of phases is approximately the same as if all the phases had occurred simultaneously. This sequence bears a general resemblance to a thermodynamic cycle in that a system is changed from an initial set of conditions to a final set of conditions by an orderly progression of events; for this reason an individual sequence will hereafter be referred to as a "cycle".

The second fundamental assumption is that the column of gas and propellant between the breech and the shell may be represented by a fixed number of individual gas "subvolumes". At any instant of time the gas properties within an individual subvolume are considered to be constant. These property values may, however, vary from one subvolume to another. Gas and propellant mass transfer may occur between subvolumes, but only at separate and specified times during the cycle.
The purpose of these two assumptions is to simplify the internal ballistics process into one that is more readily analyzed. The first assumption separates the complex internal ballistics process into more fundamental processes: constant volume combustion, one-dimensional motion and mass transfer, and finite-amplitude wave propagation. The second assumption simplifies the analysis of the gas and propellant column by separating it into a number of small constant-property-value subvolumes. These subvolumes are then analyzed using the theory of finite-amplitude waves in gases, a basic energy equation, and simple equations of mass motion and mass transfer.

**Word Description of the Model**

**Overall Physical Description.** The diameter change from the chamber to the bore normally occurs over a finite length of the gun barrel. For this analysis this area change is considered to occur at a single location. No other changes in the physical description of the gun barrel are made. In this work the region between the breech and the area-change location will be referred to as the "chamber", while the remainder of the gun barrel will be referred to as the "bore".

The projectile is initially positioned at the location of the area change and the chamber is divided into a fixed number of cylindrical segments. The axis of rotation of each segment is the same as the axis of rotation of the chamber. All segments initially contain the same quantity
of gas mass, the same number of propellant grains, and have the same volume. Further, all segments initially have identical gas property values.

The Gas Subvolumes. The gas which occupies the available space between the boundaries of a single segment forms the gas subvolume. Gas subvolume properties change as a result of expansion (wave propagation) and mass change. Gas mass change occurs as a result of mass transfer across the gas boundaries and as a result of a propellant burn.

The Propellant Segments. The amount of mass released by a given mass of burning propellant during a finite increment of time is dependent upon the surface area of the propellant, the relative flow of gas past the propellant, and the pressure of the gas surrounding the propellant. In order to account for the surface area of the propellant as it burns, the number of propellant grains in each propellant segment is fixed at the initial value. Also, all grains within a single propellant segment are considered to burn at the same rate. Hence all the grains within a single propellant segment are kept identical with one another, and the mass released by a single propellant segment during a single burn time increment is simply the mass released by a single grain times the number of grains in the segment. Since the number of grains in a single segment is fixed, it can be seen that the mass of propellant in a single segment can only decrease. Location of the various propellant segments is
accomplished by fixing the length of each segment at the original value.

There is no requirement that a propellant segment be located entirely within a gas subvolume; therefore if a single propellant segment happens to be located such that its length is divided by a gas boundary the burning rate of that segment should actually be influenced by the two different velocities and pressures of the two subvolumes. When this situation occurs the burning rate of the entire propellant segment is determined by the average pressure and relative velocity of the two subvolumes.

The Gas Boundaries. The gas boundaries have three functions. The first is to serve as solid, fixed boundaries during the constant-volume energy transfer phase of the cycle. The second function is to act as planes of mass transfer during the gas expansion and propellant-motion phases of the cycle. The third function is to serve as locations for the finite-amplitude waves which are used to change the gas property values following an incremental shell motion. If a wave travelling toward the breech is designated an "upstream" (against the gas flow) wave and a wave travelling toward the shell is designated a "downstream" wave, then it can be seen that there will be four possible types of waves: an upstream expansion wave, an upstream compression wave, a downstream expansion wave, and a downstream compression wave. Gas properties are changed whenever one of these waves travels across a gas subvolume. Since the gas
properties within each subvolume are required to be constant at any instant of time, a wave is not permitted to be located between two gas boundaries. A wave is propagated to the next boundary only if it is determined that there is sufficient time remaining in the time increment for this motion to occur. If the wave cannot cross at least half-way across the subvolume it is fixed at its current location.

Gas Subvolume Containing the Area Change. The gas subvolume which contains the area change from the chamber to the bore is an exception to the normal constant-diameter gas subvolumes, and is therefore treated somewhat differently. A "property discontinuity" is considered to exist at the location of the area change, and the gas property values on the chamber side of the subvolume are not necessarily the same as the gas property values on the bore side. Further, unlike other subvolumes, internal gas mass transfer does occur from the chamber side to the bore side. This process is described in the Word Description of the Model Operation section below.

Word Description of the Model Operation. In order to illustrate the operation of the model as well as clarify the functions of the previously-described features a brief description of a typical cycle will now be given.

The first phase of the cycle is the constant-volume energy transfer phase. All motion is frozen, then each propellant segment is burned for a single time increment. This burning process changes the pressure, density,
temperature, and gas volume in each subvolume. The mass of each propellant segment is, of course, reduced. After this increment of burning is completed and the appropriate adjustments have been made in the subvolume property values the cycle proceeds to the second phase.

The second phase is the projectile motion and wave propagation phase. The average of the pressure before the burn and the pressure after the burn in the subvolume adjacent to the projectile is considered to act upon the shell for one time increment. This force changes the projectile acceleration and velocity and moves the shell to a new location. The change in projectile velocity is considered to be impulsive and to generate a finite expansion wave which, later in the cycle, will propagate toward the breech. The model first propagates expansion waves from earlier projectile motion, then proceeds to other types of waves which may be present, including the recently-generated expansion wave from the current projectile motion. If a compression wave "catches up" with another wave of like kind and direction the wave strengths are combined prior to further propagation. Different types of waves or like waves travelling in opposite directions are not combined. Waves which encounter the projectile or breech are reflected in like kind, and a wave which crosses the gas subvolume containing the area change is reflected as two waves of appropriate strength and direction (Ref 7:28). When all present waves have been propagated as
far as possible during a single time increment the cycle proceeds to the third phase.

The third phase of the cycle is the propellant motion phase. The pressure drop across the length of the segment is determined, then an estimated drag coefficient and an estimated effective area are used in a simplified equation of motion to determine the new velocity and position of the propellant segment. When all the segments have been moved the cycle proceeds to the fourth and final phase.

The last phase of the cycle is the gas expansion and mass transfer phase. The net effect of each wave that has crossed a single gas boundary is used to determine the new velocity of that boundary. Once the new velocity is determined the boundary is moved at that velocity for a single time increment. The boundary velocity, barrel cross-sectional area, and the gas density of the next downstream subvolume are used to determine the gas mass transfer across the boundary during this motion. After all boundaries have been relocated the total propellant mass within each subvolume is redetermined. With the subvolume pressure held at the value determined during the wave propagation phase, the remainder of the gas property values are then determined from an equation of state. This final property determination marks the end of the cycle.

The cycle just described is repeated until it is determined that the projectile position exceeds the length of the barrel, at which time the analysis ends. Provisions are made
in the model to check for propellant burn-out prior to projectile exit in order that the propellant-burning and motion parts of the cycle may be deleted. Figure 1 illustrates the physical appearance of the model prior to projectile motion and at some later time.
1: Shell
2: Gas Subvolume
3: Gas Boundary
4: Propellant Segment
5: Compression Wave
6: Expansion Wave

Fig. 1. Physical Setup of Model.
III. Analysis

Analytical Assumptions

The two fundamental assumptions which form the basis for the analytical model have been previously discussed in the first part of Section II. The following analytical assumptions have also been used:

(a) All motion is one-dimensional.
(b) Propellant burning takes place under constant-volume conditions.
(c) The propellant burning rate is a function of gas pressure and relative gas-to-propellant velocity.
(d) The propellant grains burn uniformly over their entire surface.
(e) The gas obeys the Nobel-Abel equation of state with a constant covolume.
(f) The gas has a constant ratio of specific heats.
(g) The gas subvolume boundaries are adiabatic.
(h) The drag coefficient for the propellant segments is constant.
(i) The drag on the projectile consists of a variable aerodynamic drag and a constant friction drag.
(j) The diameter change from the chamber to the bore occurs at a single location.
(k) A normal shock forms ahead of the projectile as soon as the projectile motion begins.
(1) The presence of the propellant exerts no influence on the wave propagation process.

The following are considered to be negligible:

(a) Heat transfer to the gun walls and to the projectile.
(b) Friction losses between the gas and the gun walls.
(c) Friction losses between the propellant and the gun walls.
(d) Drag due to projectile rotation (rolling drag).
(e) Losses due to propellant gas leaking past the projectile.
(f) The pressure gradient between the front of the projectile and the downstream side of the normal shock.
(g) Effects due to gun recoil.
(h) Effects due to variations in the initial temperature of the propellant.

The Working Equations

The Energy Equation. The first law of thermodynamics for a constant volume subvolume with no mass flow is

\[ Q = \Delta U \]  \hspace{1cm} (1)

where, for the constant volume adiabatic combustion used in this work

\[ q = \frac{F}{\gamma g - 1} \]  \hspace{1cm} (Ref 3:175)  \hspace{1cm} (2)

and
\[ \Delta u = C_v \Delta T \]  
(3)

where \( \gamma_g \) = propellant gas ratio of specific heats

For the gun problem

\[ C_v = \frac{R}{\gamma_g - 1} \]  
(Ref 8.126)  
(4)

Since \( F \), the "force constant" is defined as

\[ F = R \frac{T}{g iso} \]  
(5)

Eq (1) becomes

\[ \frac{R \frac{T}{g iso}}{\gamma_g - 1} = \frac{R}{\gamma_g - 1} \]  
(6)

For a finite quantity of Eqs (2) and (3) may be expressed

\[ Q = \frac{R \frac{T}{g iso}}{\gamma_g - 1} \Delta M_g \]

\[ \Delta U = \frac{R}{\gamma_g - 1} (M_f T_f - M_i T_i) \]  
(8)

where \( M_f \) = final mass of gas

\( M_i \) = initial mass of gas

\( T_f \) = final gas temperature

\( T_i \) = initial gas temperature

Equating (7) and (8)

\[ \frac{R \frac{T}{g iso}}{\gamma_g - 1} (M_f - M_i) = \frac{R}{\gamma_g - 1} (M_f T_f - M_i T_i) \]  
(9)
\[ T_f = T_{iso} \left( 1 - \frac{M_f}{M_i} \right) + T_i \frac{M_i}{M_f} \]  \hspace{1cm} (10)

**Equation of State.** The equation of state used is the "Nobel-Abel" equation of state with a constant covolume

\[ P(V - M_b) = M g T \]  \hspace{1cm} (11)

where \( b \) = covolume

**Mass Change Due to Propellant Burn.** The change in mass for a single propellant segment during a single time increment is

\[ \Delta M_g = -\Delta M_p = -(\Delta V_p \rho_p) (N_p) \]  \hspace{1cm} (12)

where \( \Delta V_p \) = change in a single grain volume
\( \rho_p \) = propellant density
\( N_p \) = number of grains per segment
\( M_p \) = propellant mass
\( M_g \) = gas mass

The propellant burn rate is taken to be

\[ \dot{R} = B(P/1000)^n + K_c v_T \]  \hspace{1cm} (Ref 5:9)  \hspace{1cm} (13)

where \( \dot{R} \) = propellant burn rate (length/time)
\( B \) = burn rate at 1000 psia and \( v_T = 0 \)
\( P \) = gas pressure
\( n \) = burn rate exponent
\( K_c \) = erosive burn constant
\( v_T \) = relative gas-to-propellant velocity
The volume change of a single grain is

\[ \Delta V_g = \left| (A_p R_p) - (A_p R_p)' \right| \]  

where \( A_p \) = grain surface area

\[ R_p \] = grain radius

\(( \ )'\) = value after propellant burn

The absolute value in Eq (14) is necessary because some grains are designed such that the surface area increases during the initial burn process. The surface area vs. grain radius for the particular problem studied was obtained from tabular data (Ref 5:38-41). Equations (12), (13), and (14) are used to determine \( M_i \) vs. \( M_f \) in Eq (10).

**Wave Propagation.** The pressure change induced by a finite-amplitude wave of strength \( \Delta V \) is given by

\[ \Delta P = -\rho a (\Delta v) \]  

(Ref 7:10-12)  

where \( \Delta P \) = finite pressure change

\( \rho \) = gas density ahead of wave

\( a \) = sonic velocity ahead of wave

\( \Delta v \) = finite velocity change

Wave velocity is given by

\[ V_w = a + v_g \]  

(Ref 7:11)  

where \( V_w \) = wave velocity

\( v_g \) = gas velocity

\( a \) = gas sonic velocity
As mentioned previously in Section II, a wave which encounters the gas subvolume containing the chamber-bore area change is split into two waves. For example, a bore-side upstream-travelling expansion wave is split into a compression wave which travels back toward the shell and an expansion wave which continues on toward the breech. The strengths and directions of the split waves are determined in the following manner.

Consider an upstream-travelling rarefraction (expansion) wave $\Delta v_1$ which has just reached the bore side of the gas subvolume containing the chamber-bore area change (Fig. 2a). The change in pressure on the bore side of the subvolume is determined with Eq (15)

$$\Delta P_1 = -\rho_b a_b \Delta v_1$$

where $\rho_b =$ bore-side density

$a_b =$ bore-side sonic velocity

The wave is advanced to the point of area change and the new bore-side pressure and velocity values are determined (Fig. 2b)

$$P_{b_1} = P_b + \Delta P_1 \quad (17)$$

$$v_{b_1} = v_b + \Delta v_1 \quad (18)$$

The decreased pressure on the bore side induces an increased mass flow from the chamber side. The amount of mass
Fig. 2a: Expansion Wave Approaching Δa

Fig. 2b: Wave at Δa

Note: $P_{b1} < P_b$

Fig. 2c: Internal Mass Transfer

Note: $P_{c1} < P_c; P_{b2} > P_{b1}$

Fig. 2d: Resultant Wave Split

Fig. 2. Chamber Subvolume "Wave Split".
transferred from the chamber side to the bore side is

$$\Delta M_1 = \rho_{ch} A_b v_b \Delta t$$  \hspace{1cm} (19)

where \(\rho_{ch}\) = chamber side density

\(A_b\) = bore side area

\(\Delta t\) = time increment

The amount of gas mass on the bore side is therefore increased by an amount \(\Delta M_1\) while the gas mass on the chamber side is decreased by the same amount (Fig. 2c). If temperature is assumed to be constant during this process the new bore-side pressure becomes

$$P_{b_2} = \frac{(M_b + \Delta M_1) R T_b}{V_b - b(M_b + \Delta M_1)}$$  \hspace{1cm} (20)

while the new chamber-side pressure is

$$P_{c_1} = \frac{(M_b - \Delta M_1) R T_c}{V_c - b(M_c - \Delta M_1)}$$  \hspace{1cm} (21)

where \(T_b\) = bore-side temperature

\(T_c\) = chamber-side temperature

It can be seen from Eqs (20) and (21) that \(P_{b_2}\) will be greater than \(P_{b_1}\) (but still less than \(P_b\)) while \(P_{c_1}\) will be less than \(P_c\). Hence the net effect is to produce a downstream-travelling compression wave of strength \(\Delta P_2 = P_{b_2} - P_{b_1}\) (positive) at \(A\) (Fig. 2a) and an upstream-travelling expansion wave of strength \(\Delta P_3 = P_{c_1} - P_c\) (negative) at \(B\) in
in Fig. 1d. A similar analysis holds for the other types of waves.

**Propellant Segment Motion.** Propellant segment motion is determined from a simplified equation of motion. It is assumed that the sum of the forces $\Sigma f_p$ acting on a single propellant segment for a single time increment is

$$\Sigma f_p = (\Delta P)A_e + D_p$$

where $\Delta P$ = pressure difference across the segment length

$A_e$ = estimated "effective area"

$D_p$ = estimated aerodynamic drag

The estimated effective area of the segment is taken to be

$$A_e = \frac{V_p}{L_p}$$

where $V_p$ = volume of the propellant segment

$L_p$ = fixed length of the propellant segment

The estimated aerodynamic drag on the propellant segment is taken to be

$$D_p = \frac{1}{2} \rho g v_r^2 A_e C_d$$

where $\rho_g$ = gas density

$v_r$ = relative velocity of gas past the propellant

$C_d$ = estimated drag coefficient (constant)

If the acceleration of the segment $a_p$ is approximated by
then Newton's second law applied to the propellant segment is

\[-(ΔP)A_t + 1/2 \rho g \int v_r^2 A_c d = \frac{Δv_p}{Δt}\] (26)

where \(m_p\) = propellant segment mass
\(v_p\) = propellant segment velocity
\(v_r\) = relative velocity of gas past propellant
(assumed to be positive at all times)

If \(Δv_p\) is taken to be

\[Δv_p = v_p' - v_p\] (27)

where \(v_p'\) = the velocity at the end of \(Δt\)
\(v_p\) = the velocity at the beginning of \(Δt\)

then Eq (26) may be solved for \(v_p'\)

\[v_p' = v_p + \frac{Δt}{m_p} [(ΔP)A_t + 1/2 \rho g \int v_r^2 A_c d]\] (28)

Aerodynamic Drag. The aerodynamic drag pressure \(P_d\) exerted on the projectile on the muzzle side of the projectile is given by

\[P_d = Pa \left\{1 + \frac{γa v_{pr}}{2a} \left(\frac{γa + 1}{2}\right) \frac{v_{pr}}{a} + \sqrt{\left(\frac{γa + 1}{2}\right) \frac{v_{pr}}{a}^2 + 4}\right\}\] (Ref S:44) (29)
where $P_d = \text{aerodynamic drag pressure}$

$P_a = \text{ambient (upstream of shock) pressure}$

$\gamma_a = \text{ambient ratio of specific heats}$

$v_{pr} = \text{projectile velocity}$

$a = \text{ambient sonic velocity}$

**Projectile Equation of Motion.** The equation of motion for the projectile is taken to be

$$
(P_{pr} - P_f - P_{ad}) A_b = (M_{pr})(a_{pr})
$$

(30)

where $P_{pr} = \text{pressure on the breech side of the projectile}$

$P_f = \text{estimated constant friction pressure}$

$P_{ad} = \text{aerodynamic drag pressure}$

$M_{pr} = \text{projectile mass}$

$a_{pr} = \text{projectile acceleration}$
IV. Discussion of Results

Of the two objectives stated in the introduction to this work only the first has been met, and that with extremely limited results. The model has performed acceptably for only one complete cycle following the initial motion of the shell. Results obtained from the second cycle indicate that the model is failing to combine gas and propellant motion in such a manner as to obtain a realistic pressure distribution. Specifically, an unrealistically low pressure in the gas subvolume adjacent to the shell is established early during the second cycle. This low pressure in turn sets up wave reflections from the chamber subvolume with unrealistically high velocity strength values. These erroneous waves are then propagated for the remainder of the time increment, and the resulting model bears little resemblance to the actual physical situation. The excessively low pressure is a direct result of the separation of gas motion from propellant motion. The sudden expansion of the subvolume adjacent to the shell caused by the shell motion increases the volume available to the gas in that subvolume. Because there is no motion of propellant into that subvolume at that point in the cycle, the space that should be occupied by some portion of propellant mass is not; hence the gas expands to fill an unrealistically large volume and the pressure drops.
V. Conclusion and Recommendations

Conclusion

The conclusion reached as a result of the work to date is:

The basic model concept shows promise, but at present the model is failing to realistically represent the combined flow of gas and propellant.

Recommendations

The following recommendations are made concerning this analysis:

1. The basic model concept should be revised to realistically represent the combined flow of gas and propellant in order to preserve a realistic pressure gradient.

2. The propellant segment drag coefficient should be computed from Reynold's number considerations instead of the present constant value.

3. A more accurate representation of the shell sliding friction should be attempted.

4. An allowance for energy loss due to heat transfer should be introduced.

5. Propellant burning rate values should be obtained from tabular data rather than the conventional pressure and erosive burn scheme used in this work.
Bibliography


Appendix A

Computer Program Features and Requirements
Computer Program Features

Debug Mode of Operation. A self-debugging feature is built into the program to enable automatic debugging during future program modifications. The self-debugging feature is activated by replacing the "FTN." control card at the beginning of the deck with an "FTN(D)" control card, and increasing the memory requirement by 12K. The debug feature causes the following to occur automatically:

a. Automatic bounds check on all arrays.
b. Printout of certain key program variables whenever these values change, along with the program location of the change.

Logic tracing is available by adding a

```
C$ TRACE
col: 12 7
```
card immediately after the "C$ DEBUG" card in the deck.

Further information on the debug mode of operation is contained in Chapter 11 of the Control Data 6400/6500/6600 Computer Systems Fortran Extended Reference Manual.

Solution of the Preburned Propellant Problem. The preburned propellant problem may be considered with this program by:

a. Entering all propellant data as if the propellant were going to be burned.
b. Setting the value of the variable "NOCH" to "2" on the appropriate data card.
# Computer Program Requirements

<table>
<thead>
<tr>
<th>Language</th>
<th>Fortran Extended.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Computer</td>
<td>Control Data 6600 (Digital)</td>
</tr>
<tr>
<td>Storage</td>
<td>36K (Binary)</td>
</tr>
<tr>
<td></td>
<td>45K (Compile/no debug)</td>
</tr>
<tr>
<td></td>
<td>60K (Debug)</td>
</tr>
<tr>
<td>Run time</td>
<td>Undetermined.</td>
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</tbody>
</table>
Appendix B

Computer Program Symbols
**NOTE:** The term "bore-side" refers to the bore side of the subvolume containing the chamber-bore area change. "Chamber-side" refers to the chamber side of the same subvolume.

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Area</td>
</tr>
<tr>
<td>ADP</td>
<td>Aerodynamic drag pressure</td>
</tr>
<tr>
<td>AGRO</td>
<td>Average gas density</td>
</tr>
<tr>
<td>AGV</td>
<td>Average gas velocity</td>
</tr>
<tr>
<td>A1</td>
<td>Multipurpose variable</td>
</tr>
<tr>
<td>BA</td>
<td>Bore area</td>
</tr>
<tr>
<td>BD</td>
<td>Bore diameter (input)</td>
</tr>
<tr>
<td>BETA</td>
<td>Pressure burn coefficient (input)</td>
</tr>
<tr>
<td>BGMAS</td>
<td>Bore-side gas mass</td>
</tr>
<tr>
<td>BP</td>
<td>Bore-side pressure</td>
</tr>
<tr>
<td>BRO</td>
<td>Bore-side gas density</td>
</tr>
<tr>
<td>BT</td>
<td>Bore-side temperature</td>
</tr>
<tr>
<td>BURNA</td>
<td>Propellant burn area (tabular input)</td>
</tr>
<tr>
<td>BV</td>
<td>Bore-side gas velocity</td>
</tr>
<tr>
<td>BXP</td>
<td>Pressure burn exponent (input)</td>
</tr>
<tr>
<td>CA</td>
<td>Chamber area</td>
</tr>
<tr>
<td>CD</td>
<td>Propellant drag coefficient (input)</td>
</tr>
<tr>
<td>CGMAS</td>
<td>Chamber-side gas mass</td>
</tr>
<tr>
<td>CHD</td>
<td>Chamber diameter (input)</td>
</tr>
<tr>
<td>CHL</td>
<td>Chamber length (input)</td>
</tr>
<tr>
<td>CHRO</td>
<td>Chamber-side gas density</td>
</tr>
<tr>
<td>Symbol</td>
<td>Definition</td>
</tr>
<tr>
<td>--------</td>
<td>------------</td>
</tr>
<tr>
<td>CHV</td>
<td>Chamber-side gas velocity</td>
</tr>
<tr>
<td>CL</td>
<td>Fixed length of propellant segments</td>
</tr>
<tr>
<td>CMAS</td>
<td>Propellant segment mass</td>
</tr>
<tr>
<td>CMASS</td>
<td>Total propellant mass in subvolume (output only)</td>
</tr>
<tr>
<td>CMIG</td>
<td>Igniter charge mass (input)</td>
</tr>
<tr>
<td>COVOL</td>
<td>Covolume (input)</td>
</tr>
<tr>
<td>CP</td>
<td>Chamber-side pressure</td>
</tr>
<tr>
<td>CRO</td>
<td>Propellant density (input)</td>
</tr>
<tr>
<td>CT</td>
<td>Chamber-side temperature</td>
</tr>
<tr>
<td>CV</td>
<td>Propellant segment velocity</td>
</tr>
<tr>
<td>CX</td>
<td>Propellant segment position</td>
</tr>
<tr>
<td>DCM</td>
<td>Mass Change due to burn</td>
</tr>
<tr>
<td>DIST</td>
<td>Distance (various uses)</td>
</tr>
<tr>
<td>DM</td>
<td>Incremental mass change (various uses)</td>
</tr>
<tr>
<td>DMC</td>
<td>Center section of DCM for KTYP = 10 and KTYP = 11 (Ref to Fig. 3).</td>
</tr>
<tr>
<td>DML</td>
<td>Left side of DCM (Refer to Fig. 3).</td>
</tr>
<tr>
<td>DMR</td>
<td>Right side of DCM (Refer to Fig. 3).</td>
</tr>
<tr>
<td>DP</td>
<td>Pressure change</td>
</tr>
<tr>
<td>DT</td>
<td>Time increment</td>
</tr>
<tr>
<td>DV</td>
<td>Velocity change</td>
</tr>
<tr>
<td>DVB</td>
<td>Bore-side velocity change</td>
</tr>
<tr>
<td>DVC</td>
<td>Chamber-side velocity change</td>
</tr>
<tr>
<td>DVSUM</td>
<td>Sum of velocity changes at an individual gas boundary</td>
</tr>
<tr>
<td>EBK</td>
<td>Erosive burn constant (input)</td>
</tr>
<tr>
<td>F</td>
<td>Gun constant (also known as &quot;force constant&quot;) (input)</td>
</tr>
<tr>
<td>Symbol</td>
<td>Definition</td>
</tr>
<tr>
<td>--------</td>
<td>------------</td>
</tr>
<tr>
<td>FP</td>
<td>Friction pressure (input)</td>
</tr>
<tr>
<td>GAMA</td>
<td>Ambient ratio of specific heats (input)</td>
</tr>
<tr>
<td>GAMG</td>
<td>Propellant gas ratio of specific heats (input)</td>
</tr>
<tr>
<td>GMAS</td>
<td>Subvolume gas mass</td>
</tr>
<tr>
<td>GNMAS</td>
<td>Initial propellant grain mass (input)</td>
</tr>
<tr>
<td>GNS</td>
<td>Number of grains per propellant segment</td>
</tr>
<tr>
<td>GRAD</td>
<td>Grain burn radius (tabular input)</td>
</tr>
<tr>
<td>GUNL</td>
<td>Gun barrel length (input)</td>
</tr>
<tr>
<td>I</td>
<td>Counter (various uses)</td>
</tr>
<tr>
<td>IB</td>
<td>Bore gas boundary reference</td>
</tr>
<tr>
<td>ID</td>
<td>Program section identifier</td>
</tr>
<tr>
<td>IS</td>
<td>Stored gas boundary value</td>
</tr>
<tr>
<td>IWA</td>
<td>&quot;Is wave available for propagation&quot; indicator</td>
</tr>
<tr>
<td>IX</td>
<td>Index (used during wave propagation)</td>
</tr>
<tr>
<td>JB</td>
<td>Bore-side wave type</td>
</tr>
<tr>
<td>JC</td>
<td>Chamber-side wave type</td>
</tr>
<tr>
<td>JS</td>
<td>Stored wave type value</td>
</tr>
<tr>
<td>K</td>
<td>Counter (various uses)</td>
</tr>
</tbody>
</table>

**Wave type:**
- $J = 1$: Upstream expansion
- $J = 2$: Downstream expansion
- $J = 3$: Upstream compression
- $J = 4$: Downstream compression

**IWA:**
- $IWA = 0$: Wave present and ready for propagation
- $IWA = 1$: No wave present
- $IWA = 2$: Wave present but already propagated during this time increment
<table>
<thead>
<tr>
<th>Symbol</th>
<th>Definition</th>
</tr>
</thead>
</table>
| KCHW   | Index: 
KCHW = 0 Wave is not chamber reflection 
KCHW = 1 Wave is chamber reflection from area change subvolume 
KCHW = 2 Wave is bore reflection from area change subvolume |
| KTYP   | Type of propellant segment (Refer to Fig. 3) |
| L      | Counter (various uses) |
| LTYP   | Index: 
LTYP = 0 Propellant segment within subvolume 
LTYP = 1 Propellant segment divided by upstream gas boundary |
| M      | Counter (various uses) |
| N      | Propellant segment counter |
| NB     | Number of gas boundaries (input) |
| NOCH   | Index: 
NOCH = 0 Propellant segment present (input) in subvolume 
NOCH = 1 Propellant segment not present in subvolume 
NOCH = 2 No propellant in gur |
<p>| NTAB   | Number of tabular entries in the grain surface area (input) vs burn distance table |
| OBP    | Bore-side pressure before incremental burn |
| OCP    | Chamber-side pressure before incremental burn |
| OP     | Normal subvolume pressure before incremental burn |
| ORAD   | Grain burn radius before incremental burn |
| OSHV   | Shell velocity at beginning of time increment |
| OSURFA | Grain surface area before incremental burn |
| P      | Subvolume gas pressure |
| PA     | Ambient pressure (input) |</p>
<table>
<thead>
<tr>
<th>Symbol</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>PDIF</td>
<td>Pressure difference across a single propellant segment length</td>
</tr>
<tr>
<td>POS</td>
<td>Position (used in output)</td>
</tr>
<tr>
<td>PRES</td>
<td>Pressure (various uses)</td>
</tr>
<tr>
<td>PSHOT</td>
<td>Shell start pressure (also known as shot start pressure) (input)</td>
</tr>
<tr>
<td>PSTOR</td>
<td>Stored pressure value</td>
</tr>
<tr>
<td>R</td>
<td>Current grain burn radius</td>
</tr>
<tr>
<td>RDOT</td>
<td>Grain burn rate</td>
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<td>RG</td>
<td>Propellant gas constant</td>
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<tr>
<td>RO</td>
<td>Subvolume gas density</td>
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<td>ROA</td>
<td>Ambient gas density (input)</td>
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<td>ROW</td>
<td>Density (used in output)</td>
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<td>SHA</td>
<td>Shell acceleration</td>
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<td>Shell mass (input)</td>
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<td>SHV</td>
<td>Shell velocity</td>
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<td>SHX</td>
<td>Shell position</td>
</tr>
<tr>
<td>SURFA</td>
<td>Grain surface area after incremental burn</td>
</tr>
<tr>
<td>SV</td>
<td>Gas subvolume sonic velocity</td>
</tr>
<tr>
<td>SVA</td>
<td>Ambient sonic velocity</td>
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<td>SVK</td>
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<td>T</td>
<td>Subvolume gas temperature</td>
</tr>
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<td>TA</td>
<td>Ambient temperature (input)</td>
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<td>TAC</td>
<td>Time available to chamber-bore area change reflections</td>
</tr>
<tr>
<td>TAV</td>
<td>Time available (various uses)</td>
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<td>TCMAS</td>
<td>Total propellant mass in subvolume</td>
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<tr>
<td>Symbol</td>
<td>Definition</td>
</tr>
<tr>
<td>---------</td>
<td>---------------------------------------------------------------------------</td>
</tr>
<tr>
<td>TCMASB</td>
<td>Total bore-side propellant mass</td>
</tr>
<tr>
<td>TCMASC</td>
<td>Total chamber-side propellant mass</td>
</tr>
<tr>
<td>TEMP</td>
<td>Temperature (used in output)</td>
</tr>
<tr>
<td>TIME</td>
<td>Time expired</td>
</tr>
<tr>
<td>TISO</td>
<td>Isochoric flame temperature (input)</td>
</tr>
<tr>
<td>TOTCM</td>
<td>Total propellant mass (input)</td>
</tr>
<tr>
<td>TTC</td>
<td>Time to cross subvolume (used in wave propagation)</td>
</tr>
<tr>
<td>TYPGUN</td>
<td>Type of gun being analyzed (input)</td>
</tr>
<tr>
<td>TYPROP</td>
<td>Type of propellant (input)</td>
</tr>
<tr>
<td>V</td>
<td>Subvolume gas velocity</td>
</tr>
<tr>
<td>VEL</td>
<td>Velocity (used in output)</td>
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<tr>
<td>VOL</td>
<td>Volume (various uses)</td>
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<tr>
<td>W</td>
<td>Stored value of wave strength</td>
</tr>
<tr>
<td>WDIST</td>
<td>Distance (various uses)</td>
</tr>
<tr>
<td>WV</td>
<td>Wave velocity</td>
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<tr>
<td>X</td>
<td>Gas boundary position</td>
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<tr>
<td>XMR</td>
<td>Propellant mass ratio (before burn vs after burn)</td>
</tr>
<tr>
<td>XNB</td>
<td>Same as NB</td>
</tr>
<tr>
<td>XRAD</td>
<td>Grain burn radius</td>
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Appendix C

Simplified Computer Program

Logic Diagram
Simplified Computer Program Logic Diagram

**INITIALIZATION SECTION**

- READ INPUT
- PRINT INPUT
- INITIALIZE	CHAMBER SECTION VARIABLES
- IS NOCH = 2? →
  - GO TO "A" SHELL MOTION SECTION
  - IS P PSHOT? →
    - INITIALIZE ALL SEGMENTS TO PSHOT CONDITIONS
    - TO "A" OPPELLANT RN SECTION
  - GO TO "A" SHELL MOTION SECTION
PROPELLANT BURN SECTION

A

IS NOCH = 2?

GO TO "A" SHELL MOTION SECTION

GO TO "A" PROPELLANT LOCATOR SECTION

RETURN FROM PROPELLANT LOCATOR SECTION

BURN PROPELLANT SEGMENT

PROPELLANT SEGMENT PRESENT IN SUBVOLUME?

ADVANCE TO NEXT SUBVOLUME

COMPUTE NEW TEMP, GMAS CMAS, RO, P VALUES

HAVE ALL PROPELLANT SEGMENTS BEEN BURNED?

ADVANCE TO NEXT PROPELLANT SEGMENT

IS SUBVOLUME ADJACENT TO SHELL

PROPAGATE PRESSURE PULSE FOR RT
SHELL MOTION SECTION

A

DETERMINE AVERAGE PRESSURE ACTING ON SHELL

DETERMINE NEW SHX, SHV, SHA VALUES

DETERMINE EXPANSION WAVE STRENGTH

IS SHELL POSITION GUNL?

STOP

GO TO "A" WAVE PROPAGATION SECTION
BEGIN WITH J=1 & X(I)=?

HAVE ALL X(I) BEEN CHECKED FOR CURRENT J?

WAVE PRESENT?

J=J+1

ADVANCE TO NEXT X(I)

IS J=4?

GO TO "A" PROPELLANT MOTION SECTION

IS THERE TIME TO CROSS SUBVOLUME?

IS THERE TIME TO CROSS HALF-WAY?

DOES NEXT SUBVOLUME CONTAIN CHAMBER-BORE AREA CHANGE?

CROSS TO NEXT BOUNDARY

CHANGE PRESSURE AND VELOCITY

REFLECT WAVE

IS WAVE AT BREECH OR SHELL?
CHAMBER WAVE REFLECTION SECTION

A

DETERMINE STRENGTHS OF EACH WAVE

PROPAGATE CHAMBER-SIDE WAVE

PROPAGATE BORE-SIDE WAVE

RETURN TO "B" WAVE PROPAGATION SECTION
PROPELLANT MOTION SECTION

A

GO TO "A" PROPELLANT LOCATOR SECTION

RETURN FROM PROPELLANT LOCATOR SECTION

DETERMINE NEW CV, CX VALUES

ADVANCE TO NEXT PROPELLANT SEGMENT

HAVE ALL SEGMENTS BEEN RELOCATED?

GO TO "A" GAS MOTION AND MASS TRANSFER SECTION
GAS MOTION AND MASS TRANSFER SECTION

A

Determine new boundary location B

Is gas boundary immediately upstream from chamber-bore area change? Y N

Will boundary travel beyond chamber-bore area change? Y N

Compute mass transfer

Recompute total propellant mass in each subvolume

Is gas boundary immediately upstream from shell? Y N

Advance to next boundary

Establish new chamber-bore area change subvolume

Go to "B" this page

Compute final R0, T values

Go to output

Go to "B" this page

45
DETERMINE KTYP REFER TO FIG. 3

RETURN TO SENDING SECTION

IS PROPELLANT SEGMENT DIVIDED BY THE REFERENCE BOUNDARY?

IS PROPELLANT SEGMENT WITHIN REFERENCE SUBVOLUME?

SET VALUE OF VARIABLE "NOCH" TO 1 (PROPELLANT NOT PRESENT)

A
<table>
<thead>
<tr>
<th>KTYP=1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>6</td>
<td>7</td>
<td>8</td>
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<tr>
<td>9</td>
<td>10</td>
<td>11</td>
<td></td>
</tr>
</tbody>
</table>

**NOTE:**

"I" = reference boundary

---

**Fig. 3.** Types of propellant segment locations.
Appendix D

Computer Program Listing

and

Sample Output
GUN

**PROGRAM GUN(INPUT,OUTPUT,GUN=OUTPUT)**

**GUN INTERNAL BALLISTICS PROBLEM**

**DIMENSION P(50), V(50), R0(50), T(50), GMAS(50), TCMAS(50), DSVM(50)**

**DIMENSION CX(50), CMAS(50), RX(50), GMAS, TCMAS, RG, CHFO, BPO, CM**

**STORES (DM, CMAS)**

**PFAU INPUT VALUES**

**PRINT INPUT VALUES**
GAM/ME/72-2

PRINT 313,CMIG
PRINT 314,CPN
PRINT 315,TISQ
PRINT 316,F
PRINT 317,CTA
PRINT 318,XP
PRINT 319,FK
PRINT 320,COVCC
PRINT 321,GAMA
PRINT 322,GNMAS
PRINT 323,CD
PRINT 324
PRINT 325,PA
PRINT 326,TA
PRINT 327,ROA
PRINT 328,SVA
PRINT 329
PRINT 330,GT
PRINT 331,NR
PRINT 332
PRINT 333
PRINT 334
PRINT 335
PRINT 336,(GPAD(I),BURNA(I),I=1,NTAB)

************************************************************************************

* INITIALIZE VARIABLES VAR=IADLFS
* LOCATE INITIAL GAS BOUNDARIES AND CHANGE SEGMENTS

************************************************************************************

T=0.01
YN=NP
TIME=DT
RG=CAMG*32.174*RG
DA=CAMG*CHC*CHD
CM=CHL
DM=CM
CL=CM/(XNR-1.)
GM=TOC+((XNB-1.)*GNMAS)
L=HR-1
DIST=0.
ND=10
I=1,L
X(I)=DIST
Y(I)=DIST
NSUM(I)=0
DIST=DIST+CL
X(I,J)=CHL
IF 2< I=1,ND
TO 2, J=1,4
INA(I,J)=1
K(I,J)=".

************************************************************************************

* DETERMINE CONDITIONS AT PSHOT

50
GAM/ME/72-2

GUN

COC 6600 FTN V3.0 279C OPT=1 02/07/72

```
T(1)=TISO
R(I)=GRAD(I)
TCHAS(I)=TCHAS(I)
AGV=0.
ACV=0.
KTYP=2
GO TO 200
30 IF(P(1)>GF.PSHOT) GO TO 40
TTHM=TIME+CT
GO TO 200
40 L=NM-1
IF I=1,L
(I)=P(1)
V(I)=L.
RO(I)=RO(I)
T(I)=TISO
G*MAS(I)=G*MAS(I)
TCHAS(I)=TCHAS(I)
C*MAS(I)=C*MAS(I)
CV(I)=0.
50 I=I+1
O=P(1)
T=NM-1
NT=NT+15
SHA=2,174*(P(NP-1)-FP)*BA/SHM
SHV=SHA*OT
SHX=SHX+SHV*SHV/(SHA*2.)
X(NP)=SHX
CT=TTSO
BT=TTSO
DV=SHV
NV=SHV
DF=-.374*K(I)*CR(VK*TISO)*DV
PP=P(I)+NP
G*MAS=RO(I)*BA*V*GT*12.
VOL=(SHX-CHL).*RA*12.
APC=PCHAS/VOL
I*=G*MAS
VOL=(CHL-N(I))*CA*12.-CMAS(I)/CRO
C*MAS=G*MAS(I)-DH
CHRO=C*MAS/VOL
DP=-.374*CHRO*SORT(SVK*TISO)*DV
CF=P(I)+DP.
W(I,1)=-2.69*DIS/(RO(I)*SORT(SVK*TISO))
IWA(I,1)=?
CHV=W(I,1)
```
GAM/ME/72-2

GUN

GO TO 4

***********************************************************************

* 
* PROPELLANT BURN SECTION
* 

***********************************************************************

100 DIST=X(NF)-X(NF-1)
IF(X(NF-1),LT.CHLL,AND.CHLL.LT.X(NF)) GO TO 102
WV=SRT(SVX*T(NB-1)) - V(NB-1)
DT=T*DIST/WV
GO TO 104

102 WV=SRT(SVX*(T(5*ET+CT))) -5*(EV+CHV)
DT=T*DIST/WV

104 TIME = TIME+DT
I = NCH + EN 2 GO TO 301
ID=2
I=1
N=1
GO TO 1141

114 I=I+1
IF(I,FO,NF) GO TO 301
GO TO 1141

201 GO TO (21,202,213,204,205,206,207,208,209,20,210,201,202,213,214)

PRES=G*(P(I)+P(I-1))
GO TO 211

211 PRES=P(I)
GO TO 217

212 PRES=G*(P(I-1)+CP)
GO TO 219

213 PRES=G*(PF+CP)
GO TO 219

215 PRES=LP
GO TO 213

217 PRES=PP
GO TO 217

219 PRES=G*(P(I-1)+CP)
GO TO 219

220 IF(N,E0,NF-1) CF=PRESS

221 PROTETTA=(PRES/1C0,)*BXP+E9K*(AVG-ACV)
CHAS=O(N)
OSUPF=ATKN(GBPAG,ERNA,NTAR,1,GRAC)
P(N)=P(+,-) - GENT*CT
IF(P(N),EG,0,) GO TO 212
VCH=1
GO TO 118

215 X=0AN(E(N))
SUPF=ATKN(GBPAG,ERNA,NTAR,1,XPAD)
DCM=ARS((GRAD*OSURF*XRAD*SURFA)*CRC*GNS)
CHAS(N)=CHAS(N)-DCM

S2
215  \text{GO TO} (214, 22), 214, 214, 222, 224, 220, 214, 220, 216, 218, \text{KTYP}

\begin{verbatim}
2  DEF=KTYP,EQ.4
   IF(DEF,DEF.5) GO TO 920
   DML=DCM*DST/*L
   DNH=DCM*DEF
   IF(DEF,DEF.4) GO TO 215
   L=I-1
   \text{GO TO} 300

218  \text{DIST}=X(I)-CX(N)
   \text{WOIST}=CHL-X(I)
   IF(Id,EQ.5) GO TO 920
   DML=DCM*DIST/*L
   DNH=DCM*WOIST/*L
   \text{GO TO} 230

226  IF(Id,EQ.5) GO TO 920
   \text{GO TO} 230

222  IF(Id,EQ.5) GO TO 920
   \text{GO TO} 230

224  IF(Id,EQ.5) GO TO 920
   \text{GO TO} 230

230  TCMAS(L)=TCMAS(L)-DML
   XMP=GMAS(L)/(GMAS(L)+DML)
   GMAS(L)=GMAS(L)+DML
   T(L)=TISO*(1-XHR)+T(L)*XHR
   A=PM
   IF(X(L),LT,CHL1,AND,CHL1,GE,X(L+1)) A=CA
   VOL=(X(L+1)-X(L))**A**1.2=TCMAS(L)/CRC
   RC(L)=GMAS(L)/VOL
   IF(N,CQ(N-1),AND,LE,(NR-2)) FSTCR=P(I)
   P(L)=1.2*GMAS(L)*RG*T(L)/(VOL-CQ*VCL*GMAS(L))
\end{verbatim}
IF(TL,EQ.1) GO TO 30
GO TO 245
250 TCMAA=TCMAA-OM
XMR=CCMAS/(CGMAS+CM)
CMAS=GMAS+OM
CT=ITSO*(1.-XMR)+CT*XMR
VOL=CA*(CHL-E(L))/12.- (TCMAA/CRO)
CMRA=CMAS/VOL
CF=12.*CMAS*RG*CT/(VOL*CCVOL*CMAS)
GO TO 245
240 TCMAA=TCMAA-OM
XMR=GMAS/(CGMAS+NM)
DMAS=GMAS+OM
DT=ITSO*(1.-XMR)+RT*XMR
VOL=BA*(X(L+1)-CHL)/12.- (TCMAA/CFO)
RPO=CMAS/VOL
RP=12.*CMAS*RG*RT/(VOL*CCVOL*GMAS)
245 GO TO (250,270,252,254,270,250,270,256,260),KTYP
250 IF(M,EQ.2) GO TO 270
M=2
251 NM=OMR
L=I
GO TO 239
252 IF(M,EQ.2) GO TO 270
M=2
NM=OMR
L=I
GO TO 235
254 IF(M,EQ.2) GO TO 270
M=2
NM=OMR
GO TO 241
256 IF(M,EQ.3) GO TO 270
IF(M,EQ.2) GO TO 258
M=2
NM=OMC
GO TO 240
259 M=3
GO TO 251
260 IF(M,EQ.3) GO TO 270
IF(M,EQ.2) GO TO 252
M=2
NM=OMC
L=I
GO TO 235
262 M=7
NM=OMP
GO TO 240
273 IF(ID,EQ.1) GO TO 30
IF(M,EQ.(NM-1)) GO TO 275
N=NM+1
GO TO 1171
275 IF(TL,EQ.(NB-1))ANC,KTYP,EQ.3,OR,KTYP,EQ.5) GO TO 277
IF(TL,TL,(NB-1)) GO TO 280
GO TO 301
**GAM/NE/72-2**

**GUN**

```plaintext
277  IF(X(I).LT.CHXL.AND.CHXL.LT.X(I+1)) GO TO 288
    DP=P(I)-OP
280  I=I+1
    IF(I.EQ.NP) GO TO 301
    IF(X(I).LT.CHXL.AND.CHXL.LT.X(I+1)) GO TO 292

294  IF(KTYP.EQ.3.OR.KTYP.EQ.5) GO TO 290
    DP=DP-OP
297  I=I+1
    IF(KTYP.EQ.5) (GO 10 290
    GO TO 294

92  IF(I.EQ.0) (GO 10 290
    GO TO 297

**SHELL MOTION SECTION**

```plaintext
301  OSHV=SHV
    PES=P(NP-1)+OP
    IF(X(NP-1).LT.CHXL) PSES=5*(NP+OP)
    ADP=PA*(1+GAMA*CSHV/(2.*SVA))**((GAMA+1.)*OSHV/(2.*SVA)**(2.*4.)))
    SHA=32.174*(PES-ADP-FP)*PA/SHM
    OSHV+SHA+DT
    W=WSHV*(SHV*SHA**2.)
    IF(W.GE.GUNL) GO TO 500
    W(IP+1)=W(IP,1)+(SHV+OSHV)
    IVA(NP,1)=G
```

55
GAM/ME/72-2

* WAVE PROTECTION SECTION

410 T=2
J=1
TV=0

410 IF(IHA(I,J).EQ.0) GO TO 470
IF(J.EQ.2.OR.J.EQ.4) GO TO 420
IF(T.EQ.NP) GO TO 430
I=I+1
GO TO 410

420 IF(T.EQ.1) GO TO 430
I=I-1
GO TO 410

430 GO TO (440,450,460,590),J

440 J=2
I=IM-1
GO TO 410

450 J=3
I=2
GC TO 410

460 J=4
I=NP-1
GO TO 410

470 DV=W(I,J)
IF(KCHW.EQ.1.OR.KCHW.EQ.2) GO TO 471
IC=I
JC=J

471 IF(J.EQ.2.OR.J.EQ.4) GO TO 475
IF(X(I-1).LT.CHL.AND.CHL.LT.X(I)) GO TO 500
K=I-1
SV=SGPT(SVK*T(K))
VW=SV-V(X)
IF(VW.LT.0.) GO TO 496
DIST=Y(I)-X(K)
GO TO 430

475 IF(X(I).LT.CHL.AND.CHL.LT.X(I+1)) GO TO 500
K=I+1
SV=SGPT(SVK*T(I))
VW=SV-V(T)
DIST=Y(K)-X(I)

490 TTC=DST/VW
IF(TTC.0.TAV) GC TO 495

480 IHA(I,J)=1
W(I,J)=3.
TAV=TAV-TTC
IF(J.EQ.1.OR.J.EQ.3) I=I-1
DP=-1.3733*SGT(I)*SORT(SVK*T(I))*DV
P(I)=P(I)+DP
DV=SUM(I-DV)-SUM(I)+DV
IF(J.EQ.2.OR.J.EQ.4) I=I+1
IH=I,J=0.
W(I,J)=W(I,J)+DV
IF(T.EQ.1) GO TO 445

54
IF(I,EO,NA) GO TO 490
TF(IT,LO,1) GO TO 492
GO TO 471

483
Ty=0
THA(I,J)=2
W(I,J)=0V
J=JS
GO TO 410

485
THA(I,J)=1
W(I,J)=0
TF(J,FO,1) J=2
IF(J,EO,3) J=4
THA(I,J)=0
W(I,J)=W(I,J)+0V
IF(IT*EQ.1) GO TO 486
GO TO 471

486
Ty=0
THA(I,J)=2
J=JS
GO TO 410

490
THA(I,J)=1
W(I,J)=0
TF(J,EO,2) J=1
IF(J,EO,4) J=3
THA(I,J)=0
W(I,J)=W(I,J)+0V
IF(IT*EN.1) GO TO 491
GO TO 471

491
Ty=0
THA(I,J)=2
J=JS
GO TO 410

495
IF(KCHW,FO,1) GO TO 498
IF(KCHW,FO,2) GO TO 499
WDIST=KV+TAV
IF(WDIST,GT,(*5*DIST)) GO TO 497

496
THA(I,J)=2
W(I,J)=0V
J=JS
GO TO 410

497
Ty=1
GO TO 431

498
THA(I,J)=2
W(I,J)=0V
J=90

57
GO TO 470
10 KCHW=0
GO TO 496
500 IF(KCHW.EQ.1) GO TO 4'
IF(KCHW.EQ.2) GO TO 4'
IF(J.EQ.2 OR J.EQ.4) GO TO 505
K=I+1
SV=6*(SQR(SVK+CT))
WV=SV*5*(PV+CHV)
IF(WV,LT,9.) GO TO 7
DIST=X(K)-X(I)
GO TO 537
555 K=I+1
SV=5*(SQR(SVK+CT))
WV=SV*5*(BV+CHV)
IF(WV,LT,9.) GO TO 7
DIST=X(K)-X(I)
507 TTC=DIST/WV
IF(TTC.GT.TAV) GO TO 496
TAV=TAV-TTC
TA=TA
IWA(I,J)=1
W(I,J)=9.
L=I
IF(J,J.EQ.1 OR J.EQ.3) L=I-1
BV=PV+DV
DB=CHP*DA*DV*O.*12.
PGMAS=PGMAS+DM
CGMAS=CGMAS+DM
O=C=CP
OCP=CF
VOL=(X(L+1)-CHL)*FA+12.-TCMAS/C<
CT=12.*PGMAS*RG*BT/(VOL-CCVOL*PGMAS)
O=OVCVOL/VOL
V=2.*647*(3-PORF)/(|CG*SORT(SVK*BT))
VOL=(CHL-X(L))*CA+12.-TCMAS/CPD
CT=12.*PGMAS*RG*CT/(VOL-CCVOL*CGMAS)
CGV=CGMAS/VOL
OVC=-2.*687*(CP-OCEF)/(|CHRO*SRT(SVK*CT))
J=2
IF(DVH=LT,9.) JC=4
JC=1
IF(CVC,LT,9.) JC=3
IF(J,J.EQ.1 OR J.EQ.3) GO TO 581
OVSUM(I)=OVSUM(I)+DV
OVSUM(I+1)=OVSUM(I+1)+DV
I=I+1
GO TO 592
591 I=I
OVSUM(I)=OVSUM(I)+DV
OVSUM(I-1)=OVSUM(I-1)+DV
I=I-1
60 KCHW=1
J=JC
IWA(I,J)=9.
GAM/ME/72-2

GAM

\[ H(i,j) = w(i,j) + DVC \]
\[ TAV = TAG \]
\[ GC \to 477 \]
\[ 584 \] NO SAE I=1,N
\[ 595 \] IF(MA(I,J)<CG,2) JVA(T,J)=0

* * *

CHANGE MOTION SECTION

* *

* *

**CHANCE MOTION SECTION**

**CHANCE MOTION SECTION**

TF(NCH,EO,2) GO TO 991
ID=3
T=1
N=1
GO TO 1101

615 I=I+1
620 IF(T,EO,N7) GO TO 801
GC TO 1101

625 AGV=5*(V(I-1)+V(I))
GO TO 577

630 AGV=V(I)
GC TO 670

635 AGV=V(I-1)+CHV)
GO TO 670

640 AGV=5*(PV+CHV)
GO TO 670

645 AGV=CHV
GC TO 670

650 AGV=DV
GC TO 670

655 AGV=5*(PV+V(I))
GO TO 670

660 AGV=5*(CHV+V(T))
GO TO 670

665 AGV=5*(V(I-1)+PV)

670 TF(NCH,EO,2) GC TO 672
ACV=CV(N)

677 IF(AGV,LE,0.) AGV=0.

682 IF(AGV,LE,7.) AGV=0.
IF(IN,CG,2) GO TO 240
GO TO (675,691,731,705,720,725,730,735,740,745,750),KTyp

687 IF(I,EO,2) GO TO 690
TF(I,E0,MN-1)) GC TO 695

692 IP=I-1+P(I)
GO TO 755

693 IF(I,EO,2) GO TO 690
TF(I,EO,MN-1)) GC TO 695

702 IF=I-1-P(I)
GO TO 755

703 PRIF=P(N-1)-P(I)
GO TO 695

704 PRIF=P(N-1)-P(I)
GO TO 695

59
GAM/ME/72-2

```
10  PRIF=P(I-1)-CP
    AGRO=.5*(RO(I-1)+CHRO)
    GO TO 750
700 IF(J(0,1)-NP) GO TO 710
    IF=5*P(I-1)-P(I+1)
10  AGRO=.5*(CHPO+CHRO)
    GO TO 750
710 PRIF=P(T-1)-5*(AF+CP)
    GO TO 711
720 PRIF=P(I-1)-CP
    AGRO=CHPO
    GO TO 756
725 PRIF=CP-P(I)
    AGRO=RO(I)
    GO TO 755
730 PRIF=CP-P(I)
    AGRO=.5*(RO(I)+9RO)
    GO TO 755
740 IF=P(I)+P(I+1)
    AGRO=PO(I)
    GO TO 756
745 PRIF=CP-P(I)
    AGRO=.5*(CHPO+RO(I))
    GO TO 756
750 IF=P(I-1)-CP
    AGRO=.5*(PO(I-1)+PFO)
755 AIX=CMS(N)/((CMO*CL12)*
    CV(N)=CV(N)+((T/CMS(N)))*(PDIF*A1*32.174+.5*AGRO*41*CC*(ACV*AGV-2.1*
    1*CV(N))*AGV+CV(N)*CV(N))
    IF(CV(N)=(E.*)) CV(N)=0.
    CV(N)=CV(N)+CV(N)*DT
    IF(N.E.)(NP-1)) GO TO 801
    N=N+1
    GO TO 1171

GAS BOUNDARY MOTION SECTION
```

```
901 I=2
805 IF(X(I)+LT.CH.LIN.0.CH.L*LT.X(I+1)) GO TO 810
    Y(I)=-RVSU(I)
    X(I)=X(I)+Y(I)*DT
    A=FA
    IF(X(I)+LT.CH.L) A=CA
    T=12.*PO(I)*A+V(I)*DT
    GMSF(I-1)=CMS(N-1)+DH
    GMSF(I)=CMS(I)+CM
707 IF(T.E.)(NP-1)) GO TO 901
    I=I+1
    GO TO 805
910 DIST=CHL-X(I)
```
GAM/ME/72-2

COC 6600 FTN V3.0-279G OPT=1 02/07/72

03C

**TC**=DIT/CHV
TF(TC,,T,ET) GO TO 920
TAV=DT-TTC
A=AGMAS*CGMAS
X(I)=CHL*PV*OT
NSUM(I)=RV
DM=12.*CHV*CA*CHV*OT
GMAS(T)=A-OH
CG-MAS=GMAS(I-1)+OH
PM=12.*PO*OA*PV*CT
PMAS=OM
GMAS(I)=GMAS(I)-OM
GO TO 877

* * *
* CHARGE REDISTRIBUTION SECTION *
* *

913 L=N-1
L=N-1
GO TO 1311

915 L=N-1
GO TO 1311

917 TCMA=I=0.
TCMAS=O.
I=1
I=I+1
GO TO 935

920 I=I+1
GO TO 1171

925 GO TO(921,922,923,924,925,926,927,922,923,924,925,926,927,930,931),KTP

**1** TCMA(I-1)=TCMAS(I-1)+CMAS(N)*DIST/CL
TCMA(I)=TCMAS(I)+CMAS(N)*((CL-DIST)/CL)
GO TO 435

927 TCMA(I)=TCMAS(I)+CMAS(N)
GUN
CDC 6600 FTN V3.0-279C CFT=1 02/07/72

GUN

?7 TCMAS(I-1) = TCMAS(I-1) + CMAS(N) * DIST/CL
TCMAS(I) = TCMASC + CMAS(N) * (CL-DIST)/CL
GO TO 975

924 TCMAP = TCMASC + CMAS(N) * DIST/CL
TCMASA = TCMAP + CMAS(N) * (CL-DIST)/CL
GO TO 935

920 TCMAP = TCMASC + CMAS(N)
GO TO 975

929 TCMAP = TCMASC + CMAS(N) * DIST/CL
TCMAS(I) = TCMAP + CMAS(N) * (CL-DIST)/CL
GO TO 975

931 TCMASC = TCMASC + CMAS(N) * DIST/CL
TCMASA = TCMASC + CMAS(N) * WDIST/CL
TCMAS(I) = TCMAS(I) + CMAS(N) * (CL-DIST-WDIST)/CL
GO TO 935

971 TCMAS(I-1) = TCMAS(I-1) + CMAS(N) * DIST/CL
TCMAS = TCMASC + CMAS(N) * WDIEST/CL
TCMASA = TCMASC + CMAS(N) * (CL-DIST-WDIST)/CL

935 IF(N+EN, (N=1)) GO TO 1000
NEN+1

GO TO 1191

**********************************************************************

* GAS PROPERTY REALIGNMENT SECTION

**********************************************************************

1000 L = N-1
GO TO 1072; I = 1, L
IF(X(I), LT, CHL, ANC, CHL, LT, X(I+1)) GO TO 1026

A = 0.0
IF(X(I), LT, CHL, A = CA
VCL = X(I+1) - X(I) * A * 12.0 - (TCMAS(I) / CRO)
PC(I) = GMAS(I) / VOL
T(I) = P(I) * (VOL - GMAS(I) * COVOL) / (12.0 * GMAS(I) * RG)
GO TO 1131

1026 VCL = (CHL - X(I)) * CA * 12.0 - (TCMAS/CRO)
CRO = CRO + 45 / VOL
CT = L * (VOL - GMAS * COVOL) / (12.0 * GMAS * RG)
VCL = X(I+1) - (CHL * BA * 12.0 - (TCMASA/CRO)
PD = GMASVOL
AT = P * (VOL - RGMAS * COVOL) / (12.0 * GMAS * RG)

1131 CHTTNUF
GO TO 1301

**********************************************************************

* CHANGE LOCATION SECTION

**********************************************************************

1101 LTYPE=0
IF(P(N), GE, 50) GO TO 1105
NGH = 1
GO TO (100, 105, 615, 620, 918), 10

62
1105 IF (I. EQ. 4) GO TO 1115
IF (CX(N) .GE. X(I) .AND. (CX(N) .GE. X(I+1))) GO TO 1120
IF (CX(N) .LT. X(I) .AND. X(I) .LT. (CX(N) + CL)) GO TO 1115

1110 NCH=0
GO TO (1103, 105, 615, 620, 910), T
1115 L*YP=1

1130 NCH=0
IF (L*YP .EQ. 1) GO TO 1135
IF (I .LE. 2 OR I .GE. 8-1) GO TO 1135
IF (Y(I) .LT. CHL AND X(I+2) .LT. CHL) GO TO 1145
IF (I .EQ. 2) GT. CHL) GC TO 1145

1135 IF (X(I) .LT. CHL AND CHL .LT. X(I+1) AND X(I+2) .LT. (CX(N) + CL)) GO TO 1150
IF (I .EQ. 3) GO TO 1140
IF (X(I+1) .LT. CHL AND CHL .LT. X(I+2)) GC TO 1160
IF (I .EQ. 1) GO TO 1145

1140 IF (Y(I-1) .LT. CHL AND CHL .LT. X(I)) GO TO 1170

1145 K*YP=1
IF (L*YP = EQ. 1) K*YP=1
GO TO 1180

1150 IF (L*YP .EQ. 0) GO TO 1155
K*YP=7
IF (CX(N) .LT. X(I) .AND. (CX(N) + CL) .GT. CHL) K*YP=11
GO TO 1187

1155 K*YP=4
IF (NCH .EQ. 2) GO TO 1180
IF (I .EQ. 0) GO TO 1187
IF (CX(N) .LT. X(I) .AND. (CX(N) + CL) .LE. CHL) K*YP=5
IF (Y(I) .LT. CHL AND (CX(N) + CL) .LE. X(I+1)) K*YP=6
GO TO 1180

1160 IF (L*YP .EQ. 1) GO TO 1165
K*YP=7
GO TO 1180

1165 K*YP=1
GO TO 1190

1170 IF (L*YP .EQ. 1) GO TO 1175
K*YP=9
GO TO 1190

1175 K*YP=8
IF (NCH .EQ. 2) GO TO 1180
IF (CX(N) .LT. X(I) .AND. (CX(N) + CL) .GT. X(I)) K*YP=10

1190 GO TO (1125, 626, 627, 629, 213), T

**********************************************************************
* OUTPUT
**********************************************************************

1310 PRINT 35, I, TIME
PRINT 351, SHX
PRINT 352, SHY
PRINT 353, SHA
PRINT 364, SH4
PRINT 3545,
L=NR-1
GO 1320 I=1, L
IF (I .EQ. (NR-1) .AND. X(I) .LT. CHL) GC TO 1310

63
GAM/ME/72-2

GUN

CDC 6600 FTM V.3.C-279C AFT=1 02/07/72

\[ P=V(I) \]
\[ Q=RC \]
\[ VEL=V(T) \]
\[ ROW=PO \]
\[ TMAP=I \]
\[ CMAS=TCMAS(I) \]
\[ POS=X(I) \]
\[ GO TO 1320 \]

1310 \[ DSEL=IR \]
\[ DOP=PECS \]
\[ VEL=V \]
\[ ROW=RO \]
\[ TEMP=FT \]
\[ CMAS=TCMAS \]
\[ POS=X(I) \]

1320 \[ PRINT 3560, FOS, PECS, VEL, TEMP, ROW, CMAS \]

*****************************************************************************

* \[ RETURN TO PRESSURE PUMP TC RESTART CYCLE \]

*****************************************************************************

GO TO 1.0

1510 CONTINUE

*****************************************************************************

* FORMATS

*****************************************************************************

2.0 FORMAT(01, , A10)
20.1 FORMAT(4(15, , 4)
20.2 FORMAT(4, 17)
20.3 FORMAT(2(10, , 4)
3.1 FORMAT(1H1, , 'GUN DESCRIPTION' , /
3.1 FORMAT(1H, , 'TYPE OF GUN', , 'T30, A17')
3.1 FORMAT(1H, , 'GUN LENGTH', , 'T30, F13.5, T50, *FT*')
3.1 FORMAT(1H, , 'CHAMBER LENGTH', , 'T30, F13.5, T50, *FT*')
3.1 FORMAT(1H, , 'CHAMBER DIAMETER', , 'T30, F13.5, T50, *IN*')
3.1 FORMAT(1H, , 'CHAMBER DIAMETER', , 'T30, F13.5, T50, *IN*')
3.1 FORMAT(1H, , 'GUN ANG SHELL INFORMATION' , /
3.1 FORMAT(1H, , 'SHELL START PRESSURE', , 'T30, F13.5, T50, *LBF/SC IN*')
3.1 FORMAT(1H, , 'SHELL END PRESSURE', , 'T30, F13.5, T50, *LBF/SC IN*')
3.1 FORMAT(1H, , 'PROPELLANT INFORMATION' , /
3.1 FORMAT(1H, , 'TYPE OF PROPELLANT', , 'T30, A13')
3.1 FORMAT(1H, , 'PROPELLANT MASS', , 'T30, F13.5, T50, *LBM*')
3.1 FORMAT(1H, , 'PROPELLANT DENSITY', , 'T30, F13.5, T50, *LBM/SC IN*')
3.1 FORMAT(1H, , 'ISOCHORIC FLAME TEMP', , 'T30, F13.5, T50, *C*')
3.1 FORMAT(1H, , 'COEFFICIENT CONSTANT', , 'T30, F13.5, T50, *FT-LBF/SC IN*')
3.1 FORMAT(1H, , 'PRESSURE BURN RATE CCEF', , 'T30, F13.5, T50, *IN/SEC-1000 PS FT*)
3.1 FORMAT(1H, , 'PRESSURE BURN RATE EXPONENT', , 'T30, F13.5')
3.1 FORMAT(1H, , 'EROSIVE BURN RATE COEF', , 'T30, F13.5')
3.1 FORMAT(1H, , 'COVOLUME', , 'T30, F13.5, T50, *CUBIC IN/LBM*')
3.1 FORMAT(1H, , 'RATIO OF SPECIFIC HEATS', , 'T30, F13.5')
**DECK ATKN**

*FUNCTION ATKN(X,Y,N,K,XI)*

**ATKN: AITKEN INTERPOLATING FUNCTION**

**USAGE...**

**Z=ATKN(X,Y,N,K,XI)**

**WHERE...**

X - TABLE OF INDEPENDENT VARIABLE VALUES,  
(MAY BE ASCENDING OR DESCENDING).  
Y - TABLE OF DEPENDENT VARIABLE VALUES,  
N - NO. OF POINTS IN TABLES X AND Y,  
K - DEGREE OF INTERPOLATION DESIRED.  
XI - X-VALUE FOR WHICH INTERPOLATION IS DESIRED.

**THE INTERPOLATED VALUE IS RETURNED AS THE FUNCTION VALUE.**

**71 CELLS OF BLANK COMMON ARE USED.**

**DIMENSION X(N), Y(N)**

**COMMON I1, K1, LI, LL, LU**

**COMMON XX(13), YY(13)**

**DATA KMAX=.127**

**IF (K.GT. KMAX.OP. K.LE. 0) GO TO 300**

**KI=K+1**

**IF (X(N)-X(1)) 100, 10, 10**

10 **IF (XI-X(1)) 20, 20, 30**

20 **LL=NL**

**GO TO 250**

25 **IF (X(N)-XI) 40, 40, 50**

35 **LL=NL-K1**

**GO TO 250**

50 **LI=1**

**LU=NL**

60 **IF (LU-LL-1) 103, 180, 70**

70 **LI=(LL+LU)/2**

**IF (X(LI)-XI) 80, 80, 90**

80 **LL=LI**

**GO TO 250**

90 **LU=LI**

**GO TO 250**

100 **IF (XI-X(1)) 120, 20, 20**

110 **IF (X(N)-XI) 133, 40, 40**

120 **LL=1**

**LU=NL**

130 **IF (LU-LL-1) 180, 180, 150**

140 **LI=(LL+LU)/2**

**IF (X(LI)-XI) 160, 170, 170**

150 **LU=LT**

**GO TO 160**

66
ATKN

70 LL=LI
   GO TO 14
140 LL=LL-(K1+1)/P
   IF (LL) ?290, 190
190 IF (LL+K1-N) 200, 200, 40
200 GO TO 1, K1
   I=LL+1
   YY(I)=X(I1)-Y1
210 YY(I)=Y(I1)
   GO 22, I=1, K
   GO 22, J=I, K
220 YY(J+1)=(1/((XX(J+1)-XX(I)))*(YY(I)*XX(J+1)-YY(J+1)*XX(I))
   ATKN=YY(K1)
   RETURN
C
301 FORMAT (13.5, K
100 FORMAT (3HOK=, 112, 33H IS INCORRECT FOR FUNCTION ATKN)
   CALL SYSTEM(2.0, 6)
END
GAM/ME/72-2

GUN DESCRIPTION

TYPE OF GUN
GUN LENGTH 155MM HOW
CHAMBER LENGTH 18.36000 FT
CHAMBER DIAMETER 2.43000 FT
BARREL DIAMETER 5.00000 IN

GUN AND SHELL INFORMATION

SHELL START PRESSURE 4006.00000 LBF/SQ IN
GUN FRICTION PRESSURE 350.00000 LBF/SQ IN
SHELL MASS 12.77000 LAM

FUECELLENT INFORMATION

TYPE OF FUECELLENT NC 11,JE
FUECELLENT MASS 12.15000 LAM
IGNITE MASS .07260 LAM
FUECELLENT DENSITY .95750 LB/FT^3
ISOCORIC "LAMF TFPP 3.030.00000 DEG P
FORCE CONSTANT 364500.00000 FT-LBF/LAM
PRESSURE BURN RATE COEF .49100 FT-LBF/LAM-SEC
PRESSURE BURN RATE EXPONENT .67000 SEC
EFFECTIVE BURN RATE COEF .00019
CONCLUME 29.62000 CUBIC IN/LAM
RATIO OF SPECIFIC HEATS 1.40300
MASS PFR GRAIN .00214
DRAG COEF .10000

ATMOSPHERIC CONDITIONS

PRESSURE 14.70000 LBF/SQ IN
TEMPERATURE 650.00000 DEG F
DENSITY .40004 LAM/FT^3
SONIC VELOCITY 1128.55231 FT/SEC

PROBLEM VARIABLES

TIME INCREMENT .00001 SEC
NUMBER OF GAS BOUNDARIES 21
PROPELLANT GRAIN BURN DISTANCE VS SURFACE AREA

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<th>BURN DIST (IN)</th>
<th>SURFACE AREA (SQ IN)</th>
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<td>POSITION (FT)</td>
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Appendix E

Glossary
Glossary

Bore
The interior of the gun barrel. In this work the portion of the barrel from the area change at the chamber to the barrel exit.

Breech
The end of the barrel opposite from the barrel exit.

Chamber
A short length of barrel at the breech end with a larger diameter than the rest of the barrel.

Chambrage
A term referring to the presence of a chamber, as in "a gun with chambrage".

Erosive Burn
Propellant burn induced by the relative velocity of gas past the propellant surface.

Force Constant
Term used in the gun business as a measure of propellant energy potential. The force constant is the product of the propellant gas constant and the isochoric flame temperature.

Isochoric Flame Temperature
Temperature attained if a given mass of propellant is burned adiabatically in a constant-volume container.

Muzzle
The exit end of the barrel.

Propellant grain
Small geometrically-shaped mass of propellant. A commonly-used shape is a cylinder with seven holes aligned with the axis of rotation of the cylinder.

Rifling
A groove machined into the bore to induce a stabilizing spin to the projectile.

Shot Pressure
An artificial pressure used in some analyses (including this one). The projectile is not permitted to move until the shot pressure is attained; this is an approximation to the force necessary to overcome certain frictional resistances to projectile motion.
Vita

Captain James F. Setchell was born in Colorado Springs, Colorado, on 1 February 1943. He received a bachelor of science degree in aerospace engineering from Texas A&M University in May, 1964, and was commissioned a second lieutenant in the United States Air Force at that time.

Prior to entry on active duty Captain Setchell was employed as a structural repair engineer for the B-58 Hustler aircraft at the San Antonio Air Materiel Area, San Antonio, Texas. He entered active duty in September, 1964, and from that time until May, 1970, he was assigned to the Strategic Air Command in the missile operations field. Captain Setchell reported to the Air Force Institute of Technology at Wright-Patterson Air Force Base, Ohio, in June, 1970, where he was enrolled in the Graduate Aero-Mechanical School. He completed the course requirements for a master's degree in mechanical engineering in December, 1971, and is currently assigned to the Foreign Technology Division at Wright-Patterson Air Force Base. Captain Setchell is married and has one daughter.

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