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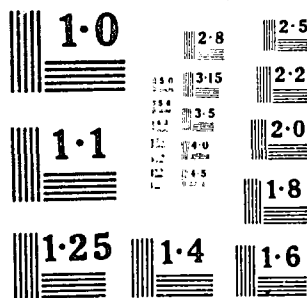
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TECHNICAL REPORT AFATL-TR-74-32

SIMPLIFIED
ANALYTIC AND EXPERIMENTAL
INTERIOR BALLISTICS OF LIGHT GAS GUNS

TERMINAL BALLISTICS BRANCH
WEAPONS EFFECTS DIVISION

JANUARY 1974

FINAL REPORT: February 1971 to June 1973

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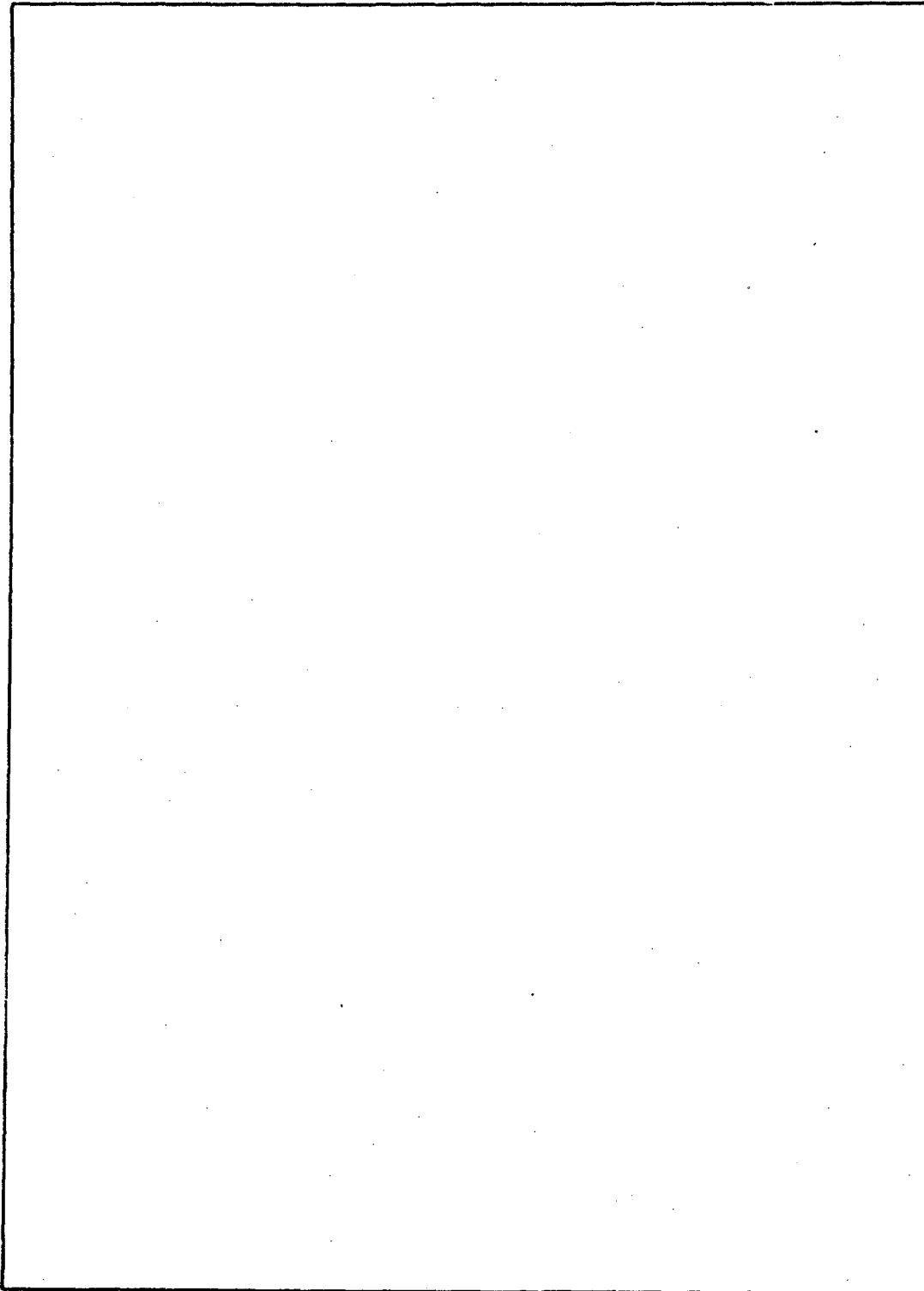
REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER AFATL-TR-74-32	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) SIMPLIFIED ANALYTIC AND EXPERIMENTAL INTERIOR BALLISTICS OF LIGHT GAS GUNS		5. TYPE OF REPORT & PERIOD COVERED Final Report February 1971 - June 1973
7. AUTHOR(s) Otto K. Heiney		6. PERFORMING ORG. REPORT NUMBER
9. PERFORMING ORGANIZATION NAME AND ADDRESS Weapons Effects Division (DLRD) Air Force Armament Laboratory Eglin Air Force Base, Florida 32542		8. CONTRACT OR GRANT NUMBER(s)
11. CONTROLLING OFFICE NAME AND ADDRESS Air Force Armament Laboratory Air Force Systems Command Eglin Air Force Base, Florida 32542		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS Project 25490313
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		12. REPORT DATE January 1974
		13. NUMBER OF PAGES
		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report) Distribution limited to U. S. Government agencies only; this report documents test and evaluation; distribution limitation applied January 1974. Other requests for this document must be referred to the Air Force Armament Laboratory (DLRD), Eglin Air Force Base, Florida 32542.		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES Available in DDC		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number)		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) A two-stage light gas gun incremental interior ballistic formalism is presented, along with a FORTRAN IV computer program that utilizes the system. Typical input and output data, both plotted and tabular, are included. A standard conventional gun ballistic analytic approach is coupled to a mathematical model of the light gas chamber. Correlations of the mathematical model and computer predictions to experimental device firings are demonstrated.		

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PREFACE

This report has been generated under the terminal ballistic analysis portion of Project 25490313. It is, in essence, an extension of a closed breech gun interior ballistic analysis reported in Air Force Armament Laboratory Technical Report AFATL-TR-69-42 (see Reference 1). The computer algorithm was developed by Otto K. Heiney, Captain, USAFR, as part of the duties associated with the Air Force Reserve mobilization program.

This technical report has been reviewed and is approved.

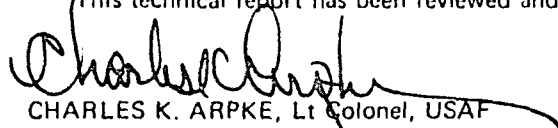

CHARLES K. ARPKE, Lt Colonel, USAF
Chief, Weapons Effects Division

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SECTION I

INTRODUCTION

This report presents a first order mathematical model of the interior ballistics of two-stage light gas guns. The model and experimental data are presented for a helium system, but conceptually, any driver gas can be used if the thermodynamic properties are known.

Section II describes the models of the combustion chamber, the pump tube, and the launch tube, as well as the mechanism of coupling between the chambers. The results of the analysis (Equations 11, 20, and 24) are in an incremental form specifically tailored for digital machine computation.

The computer program generated from the analysis is listed in Section III, along with samples of input and output data, as well as a test case.

Section IV illustrates the comparison of experimental to analytic data fit and discusses the particular experimental system utilized to verify the generated mathematical analysis. The analytic approach used is essentially heuristic. During this effort, engineering simplicity has been selected over mathematical elegance. The vague or undefined lumped parameter constant approach has been avoided as much as possible.

SECTION II

ANALYSIS

1. SYSTEM DESCRIPTION

The light gas system used to generate and calibrate this mathematical model is shown schematically in Figure 1. This system is a typical two-stage light gas gun which uses helium as the working fluid. The mechanism of operation is to burn gun propellant in the combustion chamber until a pressure is generated (around 900 psi) which, for this device, will shear the restraining ring on the piston and allow it to travel into and compress the helium gas on the pump tube stage. The gas being compressed eventually reaches a much higher pressure than the driver gas, due to the inertia of the relatively heavy piston traveling at a velocity of approximately 2,000 ft/sec. This pump tube gas is compressed until it reaches a pressure adequate to shear the restraining mechanism on the propelled payload. The projectile is then accelerated at high velocity down the evacuated launch tube, utilizing the very low pressure gradient decrement associated with the low molecular weight of the light gas. The simplified heuristic mathematical analysis of the physical phenomena occurring in the system is discussed in the following paragraphs. Table 1 defines the symbols used in the mathematic analysis. Figure 2 illustrates the experimental launcher system used, and Figure 3 shows the target area and target evacuation system.

2. COMBUSTION TUBE ANALYSIS

The solution for the combustion tube, or propellant burning side of the device, is through a standard gun ballistic approach similar to that given in Reference 1.

The energy balance for this section will be

$$E_1 = E_2 + E_3 + E_4 \quad (1)$$

Where

E_1 is the energy put into the system by combustion of the solid propellant.

E_2 is the translational energy of piston.

E_3 is the heat loss to walls.

E_4 is the energy required to accelerate unburned propellant and combustion gases.

The chemical energy generated will be

$$E_1 = m_N C_V (T'_0 - T_c) \quad (2)$$

Reference:

1. Heiney, O. K., Analytic and Experimental Interior Ballistics of Closed Breech Guns, Air Force Armament Laboratory AFATL-TR-69-42, May 1969 (Unclassified).

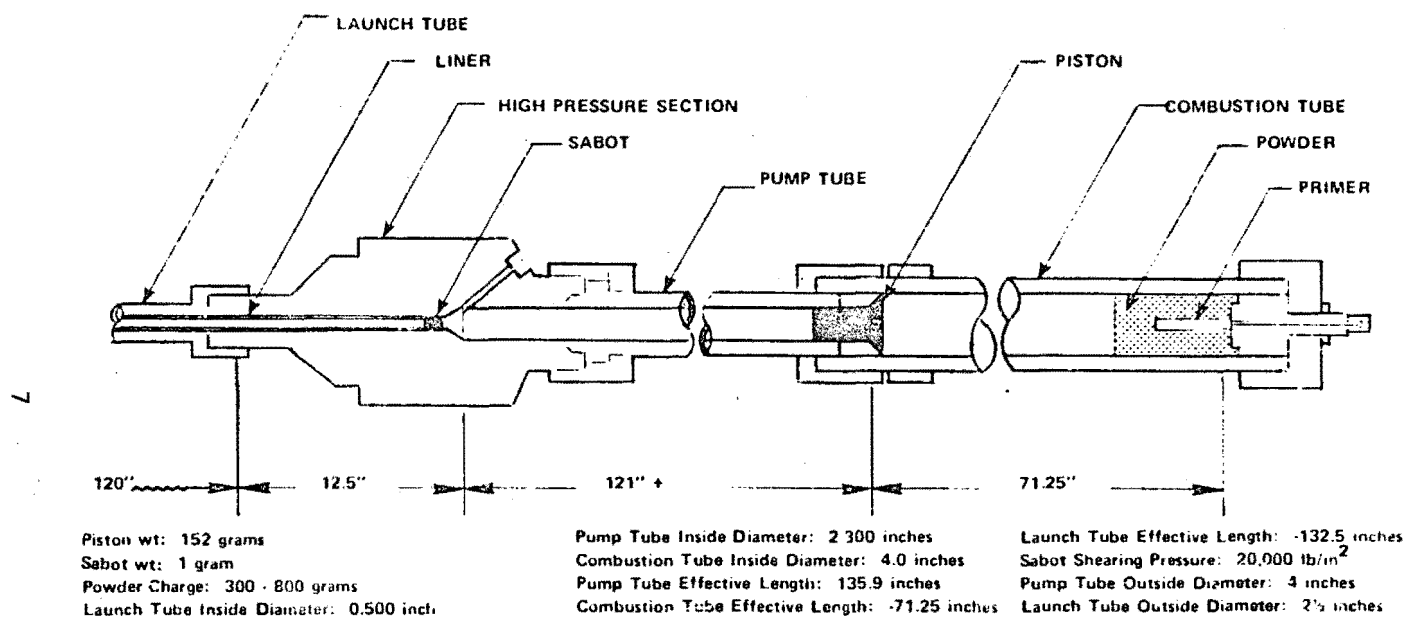


Figure 1. Light Gas System

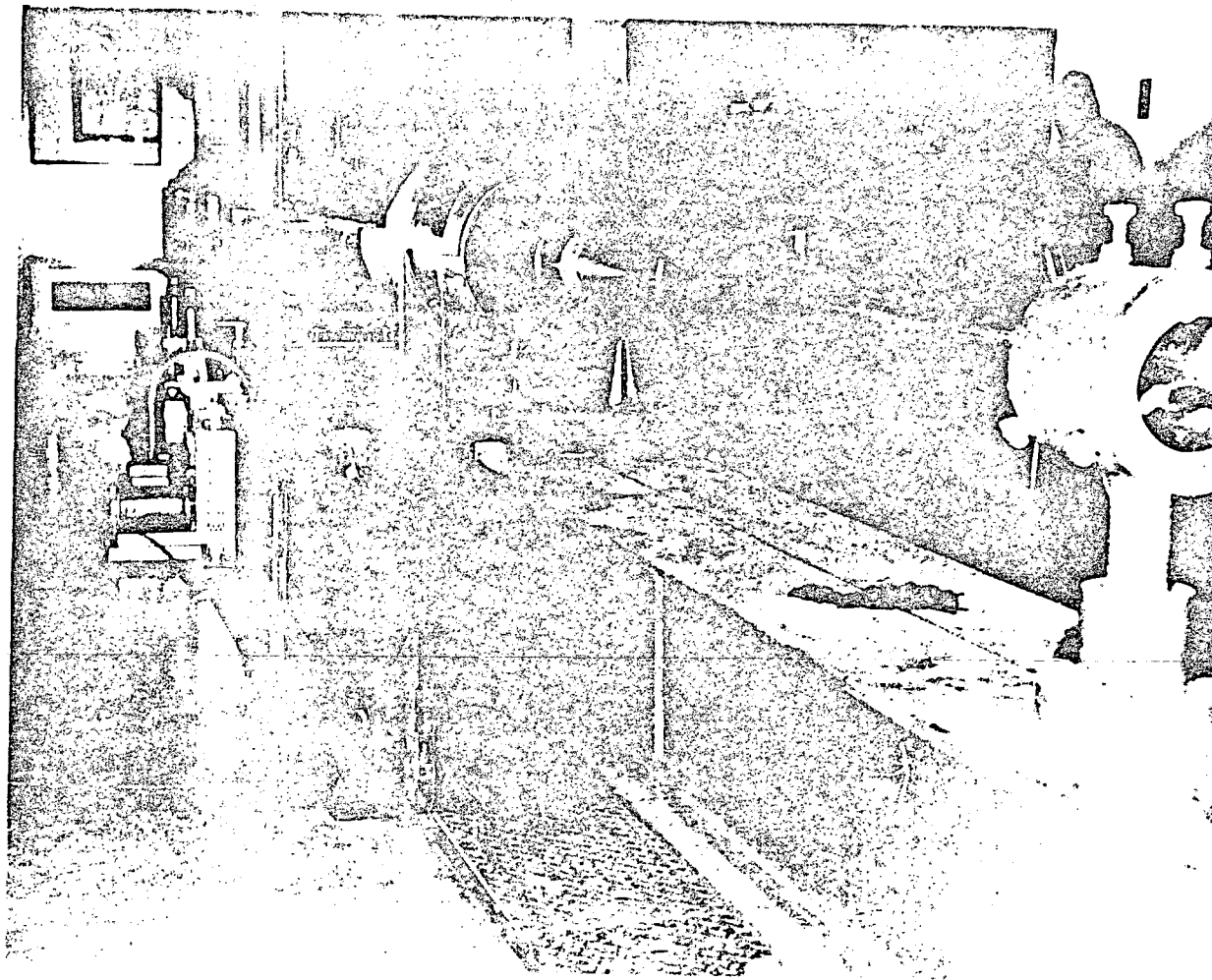


Figure 2. Experimental Launch System

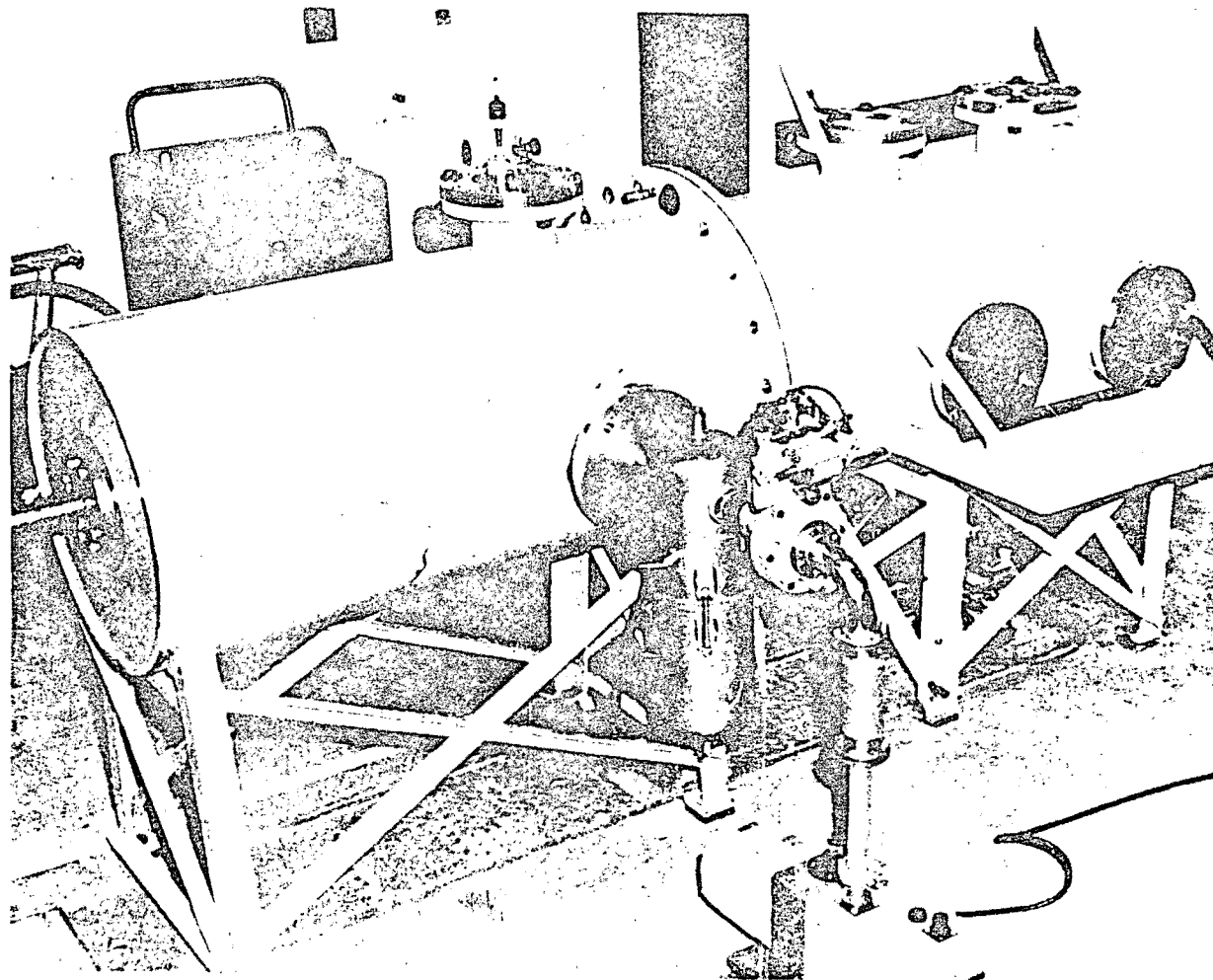


Figure 3. Target Area and Evacuation System

TABLE 1. LIST OF SYMBOLS USED FOR MATHEMATICAL ANALYSIS

A_c	Bore area of combustion chamber
a_p	Acceleration of piston
A_S	Bore area launch tube
a_S	Acceleration at payload
C_v	Specific heat of gas at constant volume
C_W	Total mass of gun propellant
F	Force
g	Acceleration value of gravity
F_B	Impetus of propellant
m_a	Pseudo-mass of compression piston
m_B	Mass of compression piston
M_N	Molecular weight of light gas
m_n	Mass of propellant burned
m_S	Mass of payload
n_L	Mass of pump tube gas charge
P_c	Pressure in combustion chamber
P_L	Pressure in pump tube chamber
P_N	Net action pressure on compression piston
P_S	Pressure at projectile base
R	Universal gas constant
r	Linear propellant burning rate
S_B	Burning surface of propellant
t	Time

TABLE 1. CONCLUDED

T_c	Gun propellant gas temperature
T_L	Gas temperature in pump tube
T_0	Isochoric flame temperature of propellant
V_A	Volume of pump tube chamber
v_c	Velocity of compression piston
V_P	Initial volume of propellant chamber
v_S	Payload velocity
X_c	Reference distance to compression piston
X_S	Payload distance reference
β_c	Heat loss factor combustion chamber
β_2	Heat loss factor pump tube
δ	Gun propellant gas density factor
ρ_P	Density of propellant
γ_c	Specific heat ratio of combustion gases
γ_L	Specific heat ratio of light gas

The translational energy of payload will be

$$E_2 = \frac{1}{2} m_B v_c^2 \quad (3)$$

The heat loss of the gases is proportional to the distance traveled, which is roughly proportional to the square of the velocity (Reference 2). This heat loss can then be approximated

$$E_3 = -\frac{1}{2} \beta_c m_a v_c^2 \quad (4)$$

Using a Kent form solution (Reference 3) with high velocity modifications for the energy contained in the accelerating gases and unburned propellant, the following approximation can be obtained:

$$E_4 = \frac{1}{2} \frac{C_W}{g \delta} v_c^2 \quad (5)$$

In this equation, δ equals 3 at low velocities but increases at high velocities because the density distribution becomes less uniform. This effect, and the variation of δ with payload velocity, is discussed in Reference 4.

An effective mass may be defined as

$$m_a = m_B + \frac{C_W}{g \delta} \quad (6)$$

Then

$$E_2 + E_3 + E_4 = (1 + \beta_c) \frac{1}{2} m_a v_c^2 + P_c A_c X_c \quad (7)$$

The term γ is defined by

$$(\gamma_c - 1) = \frac{R}{C_V} = \frac{F_B}{C_V T_0} \quad (8)$$

References:

2. Hirschfelder, Kershner, and Curtiss, Interior Ballistics, Volumes I and II. NDRC Reports A-142 and A-180, February and April 1943, (Declassified).
3. Kent, R. H.: "Some Special Solutions for the Motion of the Powder Gas," Physics 7, 1936.
4. Heiney, O. K.: "A New Computer-Oriented Formalism for Gun Ballistics," Proceedings 3rd ICRPG-AIAA Solid Propulsion Conference. Volume I, 3-5 June 1968 (Confidential).

Then, from Equations (2), (7), and (8)

$$m_N F_B \left(\frac{1 + T_c}{T_0} \right) = \frac{1}{2} (\gamma_c - 1) (1 + \beta_c) m_a v_c^2 \quad (9)$$

The temperature ratio is eliminated by the introduction of the equation of state to give the basic ballistic equation for the propellant combustion chamber.

$$P_c (V_P + A_c X_c) = m_N F_B \cdot (\gamma_c - 1) (1 + \beta_c) \frac{m_a}{2} v_c^2 \quad (10)$$

The following differential form of Equation (10) is more convenient for incremental computation:

$$\frac{dP_c}{dt} (V_P + A_c X_c) = \frac{dm_N}{dt} F_B \cdot (\gamma_c - 1) (1 + \beta_c) m_a \frac{dv_c}{dt} \frac{dX_c}{dt} + P_L A_c \frac{dX_c}{dt} \quad (11)$$

Equation (11), coupled with the expressions for propellant burning rate and those describing the motion of the projectile, provides a complete solution for the combustion chamber. The expression for gas generation is then

$$\frac{dm_N}{dt} = r S_B \rho_P \quad (12)$$

where S_B is the total exposed propellant burning surface, ρ_P is the density of the propellant, and r is the linear burning rate of the propellant. This burning rate is a non-linear function of the combustion chamber pressure; thus, the r vs. P data must be read into the computer in tabular form.

The equation of motion for the compression piston is derived from a simple force balance:



$$P_N = P_c - P_L$$

$$F = P_N A_c = m_B a_p \quad (13)$$

$$\frac{dv_c}{dt} = a_p = \frac{A_c (P_c - P_L)}{m_B}$$

The preceding discussion provides the solution for the pressure on the combustion side, while the following discussion develops the solution for the pump tube. The solutions are quasi independent and coupled only through piston motion.

3. PUMP TUBE ANALYSIS

The solution starts with an equation of state for this chamber;

$$P_L V_A = n_L R T_L \quad (14)$$

Then taking

$$R = C_V(\gamma_L - 1) \quad (15)$$

and differentiating gives

$$\frac{dP_L}{dt} \cdot \frac{V_A}{\gamma_L - 1} + \frac{P_L}{\gamma_L - 1} \frac{dV_A}{dt} = n_L C_V \frac{dT_L}{dt} \quad (16)$$

Equation (16) is a differential energy equation for this system. Collecting terms and including a term for the work performed by payload projectile acceleration gives

$$\frac{dP_L}{dt} = n_L \frac{R}{V_A} \frac{dT_L}{dt} + \frac{P_L}{V_A} \frac{dV_A}{dt} - (\gamma_L - 1) m_S' v_S \frac{dv_S}{dt} \quad (17)$$

Consider the last term with m_S' (handled as for the combustion on tube analysis) as a combination of the launched payload sabot and projectile weight plus a varying fraction of the compressed gas mass. The advantage of the use of helium for the working fluid is apparent here. Figure 4 gives the value of this variable (gas density gradient factor δ) as a function of projectile velocities, with n_L being the charge of helium on the light gas side.

$$m_S' = m_S + \frac{n_L}{\delta g} \quad (18)$$

After including β_2 , the result for this term is

$$(\gamma_L - 1) (1 + \beta_2) m_S' v_S \frac{dv_S}{dt} \quad (19)$$

This gives, finally, the basic differential pressure equation:

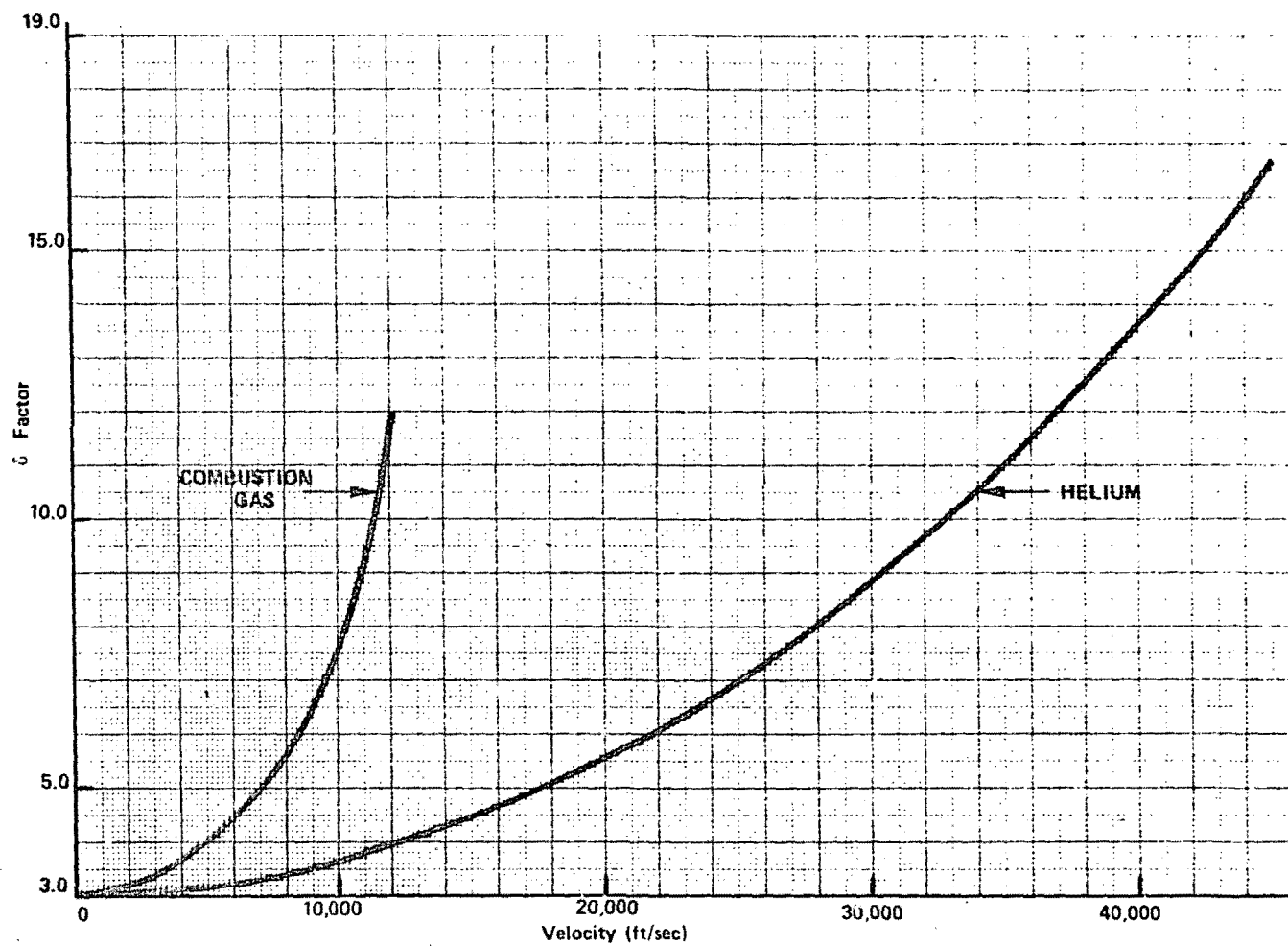


Figure 4. Gas Density Factor as a Function of Velocity

$$\frac{DP_L}{dt} = n_L \frac{R}{V_A} \frac{dt_L}{dt} + \frac{P_L A_c}{V_A} \frac{dX_c}{dt} - \frac{P_L}{V_A} A_s \frac{dX_s}{dt} - (\gamma_L - 1)(1 + \beta_2) m_S v_S \frac{dv_S}{dt} \quad (20)$$

The result of Equation (2) is then coupled with the results from the combustion chamber analysis. Also, required is the following relation from Reference 5 which is valid to the first order for the stepwise quasi-isentropic approach used;

$$\frac{P}{T} \frac{dT}{dt} = \frac{R}{c_p} \frac{dP}{dt} \quad (21)$$

Again using Equation (15) gives

$$\frac{dT_L}{dt} \cong \left(\frac{\gamma_L - 1}{\gamma_L} \right) \frac{T_L}{P_L} \frac{dP_L}{dt} \quad (22)$$

Equations (20) and (22) provide an incremental solution for the pump tube pressure as a function of time, when coupled with the solution for compression piston motion.

4. PRESSURE GRADIENT AND PAYLOAD MOTION

Equation (2) provides a time history of the space mean static pressure. An expression for payload motion, however, requires the pressure at the base of the shot to be defined. Reference 1 covers this pressure gradient computation in some detail. The results of that analysis provide

$$\frac{P_S}{P_L} = \left[1 + \left(\frac{\gamma_L - 1}{3} \right) \left(\frac{M_W v_S^2}{gRT_L} \right) \right]^{-\gamma_L/(\gamma_L - 1)} \quad (23)$$

Where P_S is pressure at the projectile and P_L is mean chamber pressure.

Equation (23) is plotted in Figure 5 and dramatically illustrates the advantage of using a low molecular weight gas as the driving medium. It is seen that at a velocity of 10,000 fps, combustion gases with a molecular weight of 24 are no longer able to deliver energy to the accelerating payload. Helium, however, with a molecular weight of 4 is seen to remain 44

Reference:

5. Liepmann, H. W., and Roshko, A.: Elements of Gas Dynamics. Wiley, 1957.

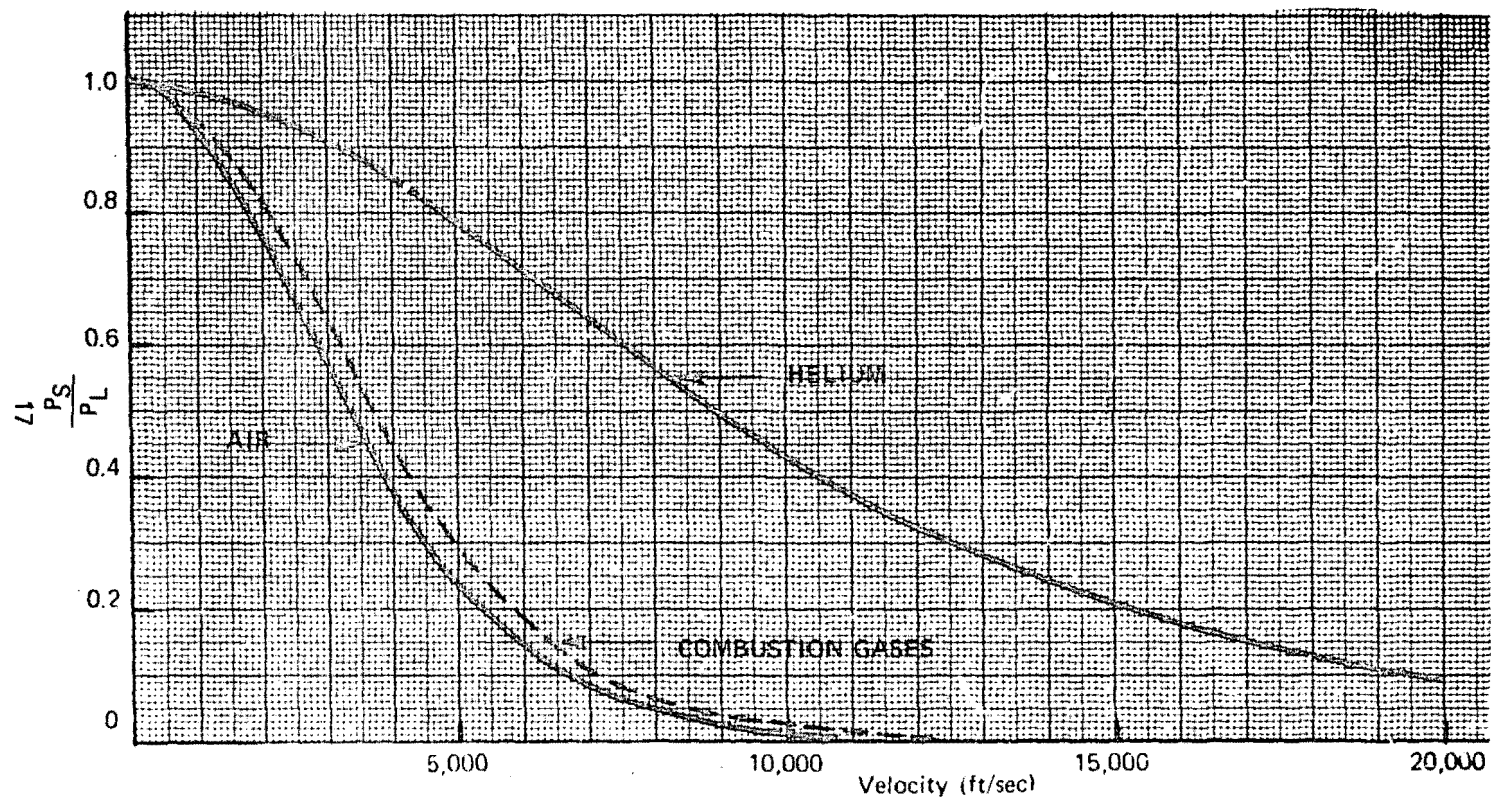


Figure 5. Pressure Gradient vs. Flow Velocity

percent efficient in its ability to deliver useful energy to the projectile. At these velocities, regardless of the breech pressure, a gas with a heavy mean molecular weight of 24 will require virtually all the generated thermal energy to acquire the necessary directed kinetic energy to reach payload velocity. The lighter molecular weight gas will require much less of the available energy to be accelerated to payload velocity. With this pressure gradient defined, the payload motion equations become, then, quite simple in an incremental form:

$$v_S = v_S + a_S \Delta t \quad (24)$$

with

$$a_S = P_S A_S / m_S \quad (25)$$

Equations (11), (20), and (24) provide solutions for pressure in the combustion tube, pump tube, and payload motion, respectively. A complete solution is possible if the following initial conditions are known: volumes, diameters, and weights of projectiles and propellants. Additionally, initial gas pressurization and sabot release pressures must be determined accurately because the system performance is extraordinarily sensitive to these two parameters.

SECTION III

USERS GUIDE

This section provides a nomenclature table (Table 2), a program listing, and sample input and output data so that this computer code can be run as it currently exists or it can be modified for other particular applications, such as those discussed in Reference 6.

An abbreviated flow chart is provided in Figure 6 and provides general comment statements that may be lacking in the program itself. The program may be run on reasonably small computers because core requirements are moderate. Table 3 provides a sample of the necessary case input data, and Table 4 is the associated output.

1. INPUT DATA

The input data for the program are in two main categories. The first goes in only once, and consists of 13 cards containing propellant and light gas data. The second set of data consists of case cards; three cards are required per case, and as many case cards may be stacked as is desired. The particular data are as follows:

a. Propellant and light gas data:

Card 1 contains propellant impetus, specific heat ratio, density, covolume, and type.

Cards 2 and 3 contain 20 reference pressures for propellant linear burning rates.

Cards 4 and 5 contain 20 burning rates at the fixed reference pressures.

Cards 6 and 7 contain 20 fixed propellant gas velocities.

Cards 8 and 9 contain 20 propellant gas density factors corresponding to mean density distribution in systems with the fixed propellant gas velocities.

Cards 10 and 11 contain 20 fixed helium gas velocities.

Cards 12 and 13 contain 20 system helium density distribution factors corresponding to the fixed helium gas velocities.

b. Case Cards:

Card 1 consists of the following system physical property data for the combustion chamber. Bore area, chamber volume, piston weight, piston travel, propellant web, heat loss factor, propellant charge, initial helium pressure, piston shot start pressure.

Reference:

6. Rynearson, R. J.: Optimization of a Two-Stage Light Gas Gun. Thesis, Texas A&M University, December 1972.

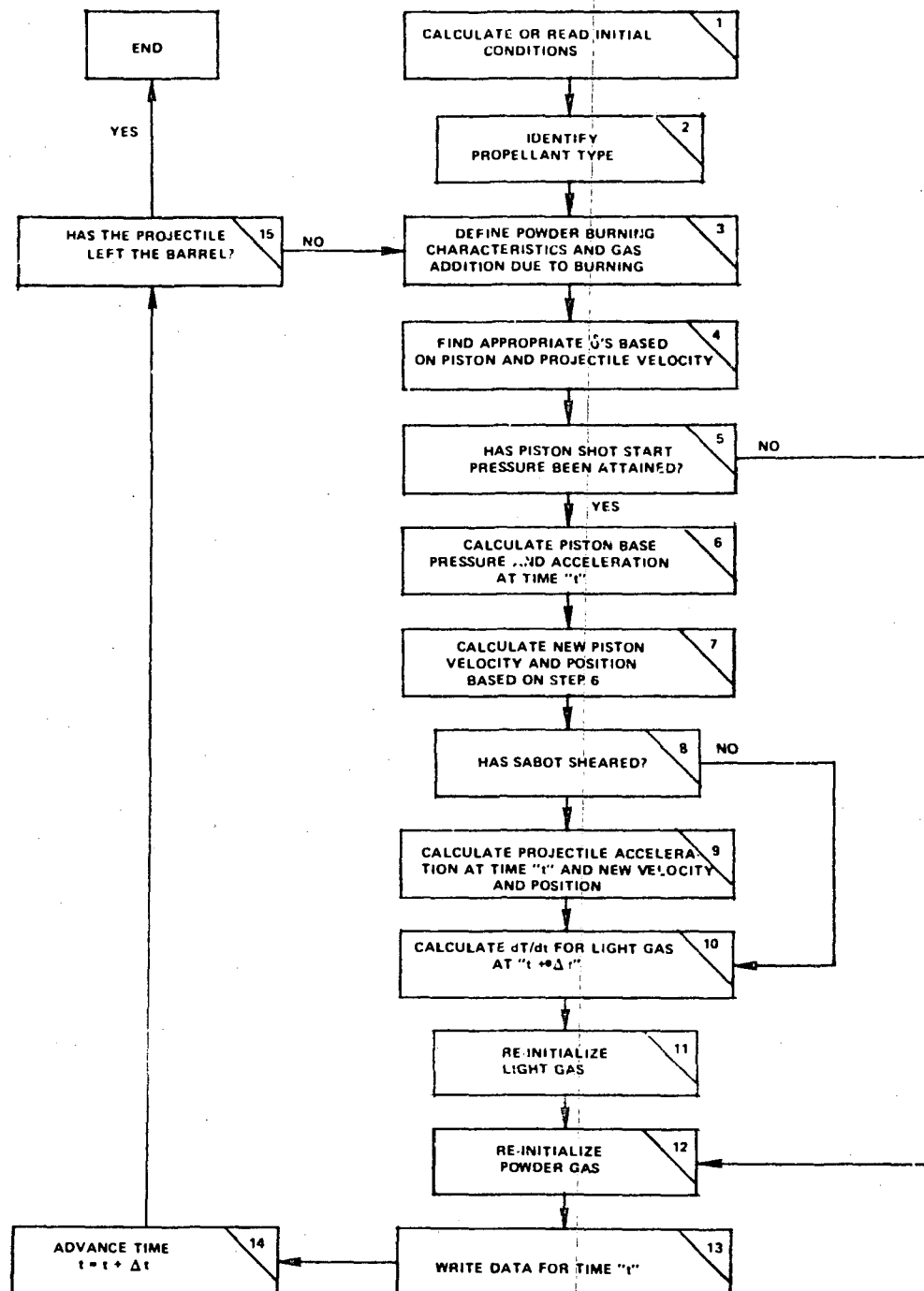


Figure 6. Code Logic Diagram

TABLE 2. PROGRAM NOMENCLATURE

ACEL	Acceleration of the piston
ALEA	Cross-sectional area of barrel
ALGT	Acceleration of the projectile
AREA	Cross-sectional area of pump tube
BARE	Burning area of propellant
BDIS	Piston travel
BETA	Heat loss coefficient for propellant gas
BLIS	Projectile travel
BLTA	Heat loss coefficient for light gas
BP	Mass of propellant burned
CHG	Initial powder charge weight
CPEG	Projectile base pressure
CPIC	Projectile muzzle velocity
CPLG	Average light gas pressure
CPRS	Average propellant gas pressure
CVL	Volume (η) for light gas
CVOL	Powder chamber volume
DAN	Diameter for ball type propellant
DELTA	Time increment
DFLG	" δ " factor for light gas
DIN	Propellant grain inside diameter
DLDT	Piston velocity
DOT	Propellant grain outside diameter
DPDT	Pressure slope in propellant gas

TABLE 2. CONTINUED

DPLG	Pressure slope in light gas
DTDT	Temperature slope in light gas
EFM	Effective or psuedo mass of piston
FIMP	Impetus of propellant
FPU	Fraction of propellant burned
FVOL	"Free" volume of propellant gas
GAMA	Specific heat ratio of propellant combustion gas
GIN	Initial powder gas density
GMLG	Specific heat ratio of light gas
GN	Propellant gas density
GRNS	Number of propellant grains
HCPP	Peak pressure in propellant gas
HGBL	Barrel length
HGID	Initial light gas density
HGIP	Initial light gas pressure
HGIT	Initial light gas temperature
HGIV	Initial light gas volume
HGM	Mass of light gas
HGSM	Weight of projectile
HLGP	Light gas peak pressure
IPT	Identifies propellant type
PIT	1.5, empirical correction factor
PFAC	" δ " factor for propellant gas
PLGR	Isentropic pressure ratio in light gas

TABLE 2. CONCLUDED

PREX	Piston base pressure
PRS	Array of powder chamber pressures
PSL	Array for light gas
PSY	Array for propellant gas
RFST	Diaphragm burst pressure or projectile release pressure
RHO	Propellant weight density
RTF	Universal gas constant (Units = $\text{ft} \cdot \text{lb}_f/\text{lb}_{\text{mole}}^{\circ}\text{K}$) value = 2780
RUN	Pump tube length
SABPR	Powder diaphragm burst pressure or piston release pressure
SCPRS	Initial powder chamber pressure
SHOT	Piston mass
TIME	Elapsed time
TF	Flame temperature of propellant
TLGS	Average light gas temperature
TYPE	Output array to write propellant name
UBW	Unburned propellant volume
VEE	Velocity array for propellant gas
VEL1	Old piston velocity
VEL2	New piston velocity
VLE	Velocity array for light gas
VLG	Projectile velocity
VLGS	List gas volume
WEB	Propellant grain thickness
WMAL	Light gas molecular weight
WMOL	Propellant gas molecular weight
XLIN	Length of propellant grain

TABLE 3. INPUT DATA

346180.	1.252	.0603	29.69	M-10					
300.	500.	700.	1000.	1500.	2000.	2500.	3000.	4000.	5000.
6000.	8000.	10000.	20000.	30000.	40000.	50000.	70000.	100000.	200000.
.13	.2	.28	.38	.52	.68	.81	.96	1.2	1.45
1.72	2.20	2.70	4.6	6.7	8.3	9.6	12.2	15.8	25.
0.	500.	1000.	1500.	2000.	2500.	3000.	3500.	4000.	4500.
5000.	5500.	6000.	6500.	7000.	7500.	8000.	8500.	9000.	12000.
3.	3.	3.05	3.1	3.18	3.35	3.38	3.50	3.70	3.85
4.05	4.3	4.55	4.85	5.2	5.55	5.95	6.40	7.00	12.0
0.	2000.	4000.	6000.	8000.	10000.	12000.	14000.	16000.	18000.
20000.	22000.	24000.	26000.	28000.	32000.	36000.	40000.	45000.	50000.
3.	3.	3.1	3.2	3.4	3.6	3.9	4.2	4.6	5.1
5.5	6.1	6.7	7.3	8.0	9.6	11.5	13.6	16.7	20.2
4.15	895.	.45	136.	.018	.3	.32	100.	900.	
5000.	132.	40.	.0033	565.	300.	.196	.2		

TABLE 4. CASE OUTPUT

SHOT WT. CHARGE WEB B. LENGTH CHB VOL BORE AREA

2.45 2.322 2.2182 135.0 895.28 4.15

LIGHT GAS GUN DATA SHOT WEIGHT B. LENGTH CHB VOL. BORE AREA HEAT LOSS
2.2332 132.97 865.22 2.194 2.22

MOLECULAR WEIGHT = 24.2 HEAT LOSS FACTOR IS 0.38 PROPELLANT USED IN SYSTEM IS M-12

PROPELLANT FORM IS SINGLE PERFORATE OR CONSTANT SURFACE

TIME	CHAMB PRES	PROPELLANT SIZE	TRAVEL	PROP. BURNED	PRES	SLOPE	VELOCITY	CHB PRES	VELOCITY	LIGHT GAS SIDE	TRAVEL	BS PRES	TEMP
0.000000	117.3	2.000	0.0116	21583.27	2.22	42.22	0.22	0.22	0.22	0.22	42.22	372.72	
0.001000	134.5	2.000	0.0231	21584.44	2.22	42.22	0.22	0.22	0.22	0.22	42.22	372.72	
0.002000	151.8	2.000	0.0347	21585.62	2.22	42.22	0.22	0.22	0.22	0.22	42.22	372.72	
0.003000	169.1	2.000	0.0462	21586.79	2.22	42.22	0.22	0.22	0.22	0.22	42.22	372.72	
0.004000	186.3	2.000	0.0578	21587.97	2.22	42.22	0.22	0.22	0.22	0.22	42.22	372.72	
0.005000	223.5	2.000	0.0693	21589.15	2.22	42.22	0.22	0.22	0.22	0.22	42.22	372.72	
0.006000	229.9	2.000	0.0809	21590.32	2.22	42.22	0.22	0.22	0.22	0.22	42.22	372.72	
0.007000	239.2	2.000	0.0924	21591.50	2.22	42.22	0.22	0.22	0.22	0.22	42.22	372.72	
0.008000	255.4	2.000	0.1040	21592.68	2.22	42.22	0.22	0.22	0.22	0.22	42.22	372.72	
0.009000	272.7	2.000	0.1156	21593.85	2.22	42.22	0.22	0.22	0.22	0.22	42.22	372.72	
0.010000	292.2	2.000	0.1271	21595.03	2.22	42.22	0.22	0.22	0.22	0.22	42.22	372.72	
0.011000	327.3	2.000	0.1387	21596.22	2.22	42.22	0.22	0.22	0.22	0.22	42.22	372.72	
0.012000	325.3	2.000	0.1502	21597.40	2.22	42.22	0.22	0.22	0.22	0.22	42.22	372.72	
0.013000	344.1	2.000	0.1613	21598.58	2.22	42.22	0.22	0.22	0.22	0.22	42.22	372.72	
0.014000	363.0	2.000	0.1755	21599.76	2.22	42.22	0.22	0.22	0.22	0.22	42.22	372.72	
0.015000	384.5	2.000	0.1903	21600.94	2.22	42.22	0.22	0.22	0.22	0.22	42.22	372.72	
0.016000	426.2	2.000	0.2048	21602.12	2.22	42.22	0.22	0.22	0.22	0.22	42.22	372.72	
0.017000	428.5	2.000	0.2200	21603.30	2.22	42.22	0.22	0.22	0.22	0.22	42.22	372.72	
0.018000	452.8	2.000	0.2352	21604.48	2.22	42.22	0.22	0.22	0.22	0.22	42.22	372.72	
0.019000	477.5	2.000	0.2505	21605.66	2.22	42.22	0.22	0.22	0.22	0.22	42.22	372.72	
0.020000	523.8	2.000	0.2658	21606.84	2.22	42.22	0.22	0.22	0.22	0.22	42.22	372.72	
0.021000	531.2	2.000	0.2813	21607.54	2.22	42.22	0.22	0.22	0.22	0.22	42.22	372.72	
0.022000	555.9	2.000	0.2968	21608.69	2.22	42.22	0.22	0.22	0.22	0.22	42.22	372.72	
0.023000	562.4	2.000	0.3125	21609.82	2.22	42.22	0.22	0.22	0.22	0.22	42.22	372.72	
0.024000	627.5	2.000	0.3282	21610.94	2.22	42.22	0.22	0.22	0.22	0.22	42.22	372.72	
0.025000	654.5	2.000	0.3440	21612.06	2.22	42.22	0.22	0.22	0.22	0.22	42.22	372.72	
0.026000	652.2	2.000	0.3598	21613.18	2.22	42.22	0.22	0.22	0.22	0.22	42.22	372.72	
0.027000	723.5	2.000	0.3756	21614.30	2.22	42.22	0.22	0.22	0.22	0.22	42.22	372.72	
0.028000	762.2	2.000	0.3914	21615.42	2.22	42.22	0.22	0.22	0.22	0.22	42.22	372.72	
0.029000	812.3	2.000	0.4072	21616.54	2.22	42.22	0.22	0.22	0.22	0.22	42.22	372.72	
0.030000	853.3	2.000	0.4230	21617.66	2.22	42.22	0.22	0.22	0.22	0.22	42.22	372.72	
0.031000	898.5	2.000	0.4388	21618.78	2.22	42.22	0.22	0.22	0.22	0.22	42.22	372.72	
0.032000	925.1	2.000	0.4546	21619.90	2.22	42.22	0.22	0.22	0.22	0.22	42.22	372.72	
0.033000	925.4	2.000	0.4704	21621.02	2.22	42.22	0.22	0.22	0.22	0.22	42.22	372.72	
0.034000	912.7	2.000	0.4862	21622.14	2.22	42.22	0.22	0.22	0.22	0.22	42.22	372.72	
0.035000	913.2	2.000	0.5020	21623.26	2.22	42.22	0.22	0.22	0.22	0.22	42.22	372.72	
0.036000	925.3	2.000	0.5178	21624.38	2.22	42.22	0.22	0.22	0.22	0.22	42.22	372.72	
0.037000	917.4	2.000	0.5336	21625.50	2.22	42.22	0.22	0.22	0.22	0.22	42.22	372.72	
0.038000	919.9	2.121	0.5518	21626.62	2.22	42.22	0.22	0.22	0.22	0.22	42.22	372.72	

TABLE 4. CONTINUED

P.0268130	922.1	0.159	0.5534	50892.96	62.08	48.11	0.00	0.00	48.11	328.33
P.0268135	924.4	0.201	0.5558	50747.88	93.36	48.14	0.00	0.00	48.14	328.42
P.0268140	926.7	0.248	0.5586	50599.17	103.87	48.17	0.00	0.00	48.17	328.52
P.0268145	928.9	0.301	0.5581	50447.18	114.40	48.21	0.00	0.00	48.21	328.63
P.0268150	931.2	0.358	0.5597	50291.59	124.96	48.25	0.00	0.00	48.25	328.76
P.0268155	933.4	0.421	0.5613	50132.68	135.54	48.30	0.00	0.00	48.30	328.89
P.0268160	935.7	0.488	0.5629	50070.36	146.15	48.35	0.00	0.00	48.35	329.04
P.0268165	937.9	0.561	0.5645	50004.67	156.78	48.40	0.00	0.00	48.40	329.19
P.0268170	940.1	0.639	0.5661	50035.63	167.43	48.46	0.00	0.00	48.46	329.37
P.0268175	942.4	0.722	0.5677	50063.25	178.12	48.52	0.00	0.00	48.52	329.55
P.0268180	944.7	0.810	0.5693	50087.55	188.82	48.58	0.00	0.00	48.58	329.74
P.0268185	946.8	0.903	0.5709	50108.56	199.55	48.65	0.00	0.00	48.65	329.95
P.0268190	949.2	1.001	0.5725	50125.31	212.39	48.72	0.00	0.00	48.72	330.16
P.0268195	951.2	1.105	0.5741	50148.88	221.88	48.80	0.00	0.00	48.80	330.39
P.0268200	953.4	1.213	0.5758	50152.09	231.88	48.88	0.00	0.00	48.88	330.63
P.0268205	955.7	1.327	0.5774	50160.18	242.70	48.96	0.00	0.00	48.96	330.88
P.0268210	957.7	1.446	0.5790	50165.11	253.55	49.05	0.00	0.00	49.05	331.14
P.0268215	959.9	1.571	0.5806	50166.90	264.42	49.15	0.00	0.00	49.15	331.42
P.0268220	962.2	1.702	0.5823	50165.59	275.31	49.24	0.00	0.00	49.24	331.71
P.0268225	964.7	1.835	0.5839	50161.21	286.25	49.34	0.00	0.00	49.34	332.01
P.0268230	966.3	1.975	0.5855	50153.78	297.18	49.45	0.00	0.00	49.45	332.32
P.0268235	968.4	2.120	0.5872	50143.35	308.12	49.56	0.00	0.00	49.56	332.64
P.0268240	970.6	2.271	0.5888	50129.94	319.10	49.67	0.00	0.00	49.67	332.98
P.0268245	972.7	2.427	0.5905	50113.58	332.19	49.79	0.00	0.00	49.79	333.32
P.0268250	974.8	2.588	0.5921	50094.32	341.12	49.92	0.00	0.00	49.92	333.66
P.0268255	976.9	2.754	0.5938	50072.18	352.16	50.04	0.00	0.00	50.04	334.01
P.0268260	979.0	2.926	0.5954	50047.22	363.23	50.18	0.00	0.00	50.18	334.36
P.0268265	981.2	3.103	0.5971	50019.45	374.31	50.31	0.00	0.00	50.31	334.74
P.0268270	983.1	3.285	0.5987	50000.95	385.41	50.45	0.00	0.00	50.45	335.15
P.0268275	985.2	3.473	0.6004	50005.69	396.53	50.58	0.00	0.00	50.58	335.58
P.0268280	987.2	3.665	0.6021	50011.76	407.68	50.73	0.00	0.00	50.73	336.02
P.0268285	989.3	3.864	0.6038	50001.21	418.84	50.91	0.00	0.00	50.91	336.47
P.0268290	991.3	4.068	0.6054	50040.85	430.02	51.07	0.00	0.00	51.07	336.93
P.0268295	993.3	4.277	0.6071	50095.34	441.22	51.23	0.00	0.00	51.23	337.41
P.0268300	995.3	4.492	0.6088	50150.13	452.43	51.41	0.00	0.00	51.41	337.90
P.0268305	997.3	4.711	0.6105	49901.45	463.67	51.58	0.00	0.00	51.58	338.40
P.0268310	999.3	4.937	0.6122	49650.34	474.92	51.76	0.00	0.00	51.76	338.92
P.0268315	1001.3	5.167	0.6138	49387.84	486.19	51.95	0.00	0.00	51.95	339.45
P.0268320	1003.3	5.403	0.6155	49114.94	497.48	52.14	0.00	0.00	52.14	340.00
P.0268325	1005.2	5.645	0.6172	48840.28	508.78	52.32	0.00	0.00	52.32	340.56
P.0268330	1007.2	5.892	0.6189	48563.88	520.11	52.54	0.00	0.00	52.54	341.13
P.0268335	1009.1	6.144	0.6206	48285.45	531.44	52.75	0.00	0.00	52.75	341.71
P.0268340	1011.0	6.402	0.6223	48005.02	542.87	52.96	0.00	0.00	52.96	342.31
P.0268345	1012.9	6.665	0.6240	47722.67	554.17	53.18	0.00	0.00	53.18	342.92
P.0268350	1014.8	6.934	0.6257	47438.43	565.55	53.41	0.00	0.00	53.41	343.55
P.0268355	1016.7	7.208	0.6274	47152.35	576.95	53.64	0.00	0.00	53.64	344.19
P.0268360	1018.6	7.488	0.6292	46864.51	588.35	53.88	0.00	0.00	53.88	344.85
P.0268365	1020.5	7.773	0.6309	46574.94	599.79	54.12	0.00	0.00	54.12	345.52
P.0268370	1022.3	8.064	0.6326	46283.71	611.24	54.37	0.00	0.00	54.37	346.20
P.0268375	1024.2	8.360	0.6343	45990.86	622.69	54.63	0.00	0.00	54.63	346.89
P.0268380	1026.0	8.662	0.6360	45696.46	634.16	54.89	0.00	0.00	54.89	347.59
P.0268385	1027.8	8.969	0.6377	45400.55	645.65	55.16	0.00	0.00	55.16	348.30
P.0268390	1029.6	9.281	0.6395	45103.20	657.15	55.44	0.00	0.00	55.44	349.02
P.0268395	1031.4	9.600	0.6412	44804.46	668.65	55.72	0.00	0.00	55.72	349.75
P.0268400	1033.2	9.923	0.6429	44504.39	680.16	56.01	0.00	0.00	56.01	350.49
P.0268405	1035.0	10.253	0.6447	44203.04	691.71	56.31	0.00	0.00	56.31	351.24
P.0268410	1036.8	10.587	0.6464	43900.48	703.25	56.61	0.00	0.00	56.61	352.00
P.0268415	1038.5	10.926	0.6481	43598.75	714.81	56.92	0.00	0.00	56.92	352.77
P.0268420	1040.2	11.274	0.6499	43291.94	726.38	57.24	0.00	0.00	57.24	353.55

1128.9	0.00	41.397	0.7537	2534.48	1414.62	91.12	4.08	0.00	91.12
1129.9	0.00	40.239	0.7538	2534.75	1403.51	88.45	0.00	0.00	88.45
1130.6	0.00	39.305	0.7502	2633.14	1392.03	87.16	0.00	0.00	87.16
1131.8	0.00	38.925	0.7483	2661.18	1380.47	85.91	0.00	0.00	85.91
1132.7	0.00	38.271	0.7465	2667.49	1368.89	84.76	0.00	0.00	84.76
1134.0	0.00	37.447	0.7446	2714.21	1357.32	83.52	0.00	0.00	83.52
1135.5	0.00	36.479	0.7428	2742.20	1345.71	82.37	0.00	0.00	82.37
1137.4	0.00	35.343	0.7410	2770.80	1334.11	81.23	0.00	0.00	81.23
1139.3	0.00	34.184	0.7392	2798.93	1322.49	80.15	0.00	0.00	80.15
1141.2	0.00	33.008	0.7373	2826.93	1310.86	79.09	0.00	0.00	79.09
1143.0	0.00	31.815	0.7355	2854.77	1299.22	78.06	0.00	0.00	78.06
1144.8	0.00	30.603	0.7337	2882.38	1287.55	77.05	0.00	0.00	77.05
1146.7	0.00	29.373	0.7319	2911.96	1275.92	75.97	0.00	0.00	75.97
1148.7	0.00	28.135	0.7301	2941.11	1264.26	74.91	0.00	0.00	74.91
1150.5	0.00	26.896	0.7282	2970.59	1252.59	73.86	0.00	0.00	73.86
1152.4	0.00	25.644	0.7264	2999.92	1240.91	72.87	0.00	0.00	72.87
1154.2	0.00	24.387	0.7246	3029.18	1229.23	71.82	0.00	0.00	71.82
1156.0	0.00	23.125	0.7228	3058.31	1217.54	70.77	0.00	0.00	70.77
1157.9	0.00	21.857	0.7210	3088.62	1205.84	69.75	0.00	0.00	69.75
1159.8	0.00	20.583	0.7192	3118.95	1194.14	68.75	0.00	0.00	68.75
1161.7	0.00	19.305	0.7174	3149.02	1182.44	67.76	0.00	0.00	67.76
1163.5	0.00	18.025	0.7155	3178.81	1170.73	66.78	0.00	0.00	66.78
1165.4	0.00	16.742	0.7137	3209.12	1159.02	65.82	0.00	0.00	65.82
1167.3	0.00	15.456	0.7119	3239.95	1147.30	64.86	0.00	0.00	64.86
1169.2	0.00	14.167	0.7101	3270.12	1135.58	63.92	0.00	0.00	63.92
1171.0	0.00	12.875	0.7083	3300.77	1123.85	62.98	0.00	0.00	62.98
1172.9	0.00	11.580	0.7065	3331.82	1112.10	62.05	0.00	0.00	62.05
1174.8	0.00	10.283	0.7047	3363.23	1100.34	61.13	0.00	0.00	61.13
1176.7	0.00	8.984	0.7029	3395.02	1088.51	60.23	0.00	0.00	60.23
1178.6	0.00	7.682	0.7011	3427.12	1076.66	59.35	0.00	0.00	59.35
1180.5	0.00	6.378	0.6993	3459.57	1064.80	58.48	0.00	0.00	58.48
1182.4	0.00	5.072	0.6975	3492.44	1052.91	57.62	0.00	0.00	57.62
1184.3	0.00	3.764	0.6958	3525.78	1041.02	56.77	0.00	0.00	56.77
1186.2	0.00	2.455	0.6940	3559.67	1029.12	55.93	0.00	0.00	55.93
1188.1	0.00	1.146	0.6922	3593.01	1017.24	55.10	0.00	0.00	55.10
1190.0	0.00	0.00	0.6904	3611.43	1005.34	54.28	0.00	0.00	54.28
1191.9	0.00	0.00	0.6886	3629.81	993.42	53.47	0.00	0.00	53.47
1193.8	0.00	0.00	0.6868	3648.11	981.48	52	0.00	0.00	52
1195.7	0.00	0.00	0.6850	3666.41	969.54	51.16	0.00	0.00	51.16
1197.6	0.00	0.00	0.6833	3684.68	957.59	50.34	0.00	0.00	50.34
1199.5	0.00	0.00	0.6815	3702.94	945.64	49.50	0.00	0.00	49.50
1201.4	0.00	0.00	0.6797	3721.19	933.69	48.67	0.00	0.00	48.67
1203.3	0.00	0.00	0.6779	3739.45	921.74	47.83	0.00	0.00	47.83
1205.2	0.00	0.00	0.6762	3757.70	909.79	46.99	0.00	0.00	46.99
1207.1	0.00	0.00	0.6744	3775.96	897.84	46.15	0.00	0.00	46.15
1209.0	0.00	0.00	0.6726	3794.22	885.89	45.31	0.00	0.00	45.31
1210.9	0.00	0.00	0.6708	3812.48	873.94	44.47	0.00	0.00	44.47
1212.8	0.00	0.00	0.6690	3830.74	861.99	43.63	0.00	0.00	43.63
1214.7	0.00	0.00	0.6673	3849.00	849.99	42.79	0.00	0.00	42.79
1216.6	0.00	0.00	0.6655	3867.26	837.99	41.95	0.00	0.00	41.95
1218.5	0.00	0.00	0.6638	3885.52	825.99	41.11	0.00	0.00	41.11
1220.4	0.00	0.00	0.6621	3903.78	813.99	40.27	0.00	0.00	40.27
1222.3	0.00	0.00	0.6603	3922.04	801.99	39.43	0.00	0.00	39.43
1224.2	0.00	0.00	0.6586	3940.30	789.99	38.59	0.00	0.00	38.59
1226.1	0.00	0.00	0.6568	3958.56	777.99	37.75	0.00	0.00	37.75
1228.0	0.00	0.00	0.6551	3976.82	765.99	36.91	0.00	0.00	36.91
1229.9	0.00	0.00	0.6533	3995.08	753.99	36.07	0.00	0.00	36.07
1231.8	0.00	0.00	0.6516	4013.34	741.99	35.23	0.00	0.00	35.23
1233.7	0.00	0.00	0.6498	4031.60	729.99	34.39	0.00	0.00	34.39
1235.6	0.00	0.00	0.6481	4049.86	717.99	33.55	0.00	0.00	33.55
1237.5	0.00	0.00	0.6463	4068.12	705.99	32.71	0.00	0.00	32.71
1239.4	0.00	0.00	0.6446	4086.38	693.99	31.87	0.00	0.00	31.87
1241.3	0.00	0.00	0.6428	4104.64	681.99	31.03	0.00	0.00	31.03
1243.2	0.00	0.00	0.6411	4122.90	669.99	30.19	0.00	0.00	30.19
1245.1	0.00	0.00	0.6393	4141.16	657.99	29.35	0.00	0.00	29.35
1247.0	0.00	0.00	0.6376	4159.42	645.99	28.51	0.00	0.00	28.51
1248.9	0.00	0.00	0.6358	4177.68	633.99	27.67	0.00	0.00	27.67
1250.8	0.00	0.00	0.6341	4195.94	621.99	26.83	0.00	0.00	26.83
1252.7	0.00	0.00	0.6323	4214.20	609.99	25.99	0.00	0.00	25.99
1254.6	0.00	0.00	0.6306	4232.46	597.99	25.15	0.00	0.00	25.15
1256.5	0.00	0.00	0.6288	4250.72	585.99	24.31	0.00	0.00	24.31
1258.4	0.00	0.00	0.6271	4268.98	573.99	23.47	0.00	0.00	23.47
1260.3	0.00	0.00	0.6253	4287.24	561.99	22.63	0.00	0.00	22.63
1262.2	0.00	0.00	0.6236	4305.50	549.99	21.79	0.00	0.00	21.79
1264.1	0.00	0.00	0.6218	4323.76	537.99	20.95	0.00	0.00	20.95
1266.0	0.00	0.00	0.6201	4342.02	525.99	20.11	0.00	0.00	20.11
1267.9	0.00	0.00	0.6183	4360.28	513.99	19.27	0.00	0.00	19.27
1269.8	0.00	0.00	0.6166	4378.54	501.99	18.43	0.00	0.00	18.43
1271.7	0.00	0.00	0.6148	4396.80	489.99	17.59	0.00	0.00	17.59
1273.6	0.00	0.00	0.6131	4415.06	477.99	16.75	0.00	0.00	16.75
1275.5	0.00	0.00	0.6113	4433.32	465.99	15.91	0.00	0.00	15.91
1277.4	0.00	0.00	0.6096	4451.58	453.99	15.07	0.00	0.00	15.07
1279.3	0.00	0.00	0.6078	4469.84	441.99	14.23	0.00	0.00	14.23
1281.2	0.00	0.00	0.6061	4488.10	429.99	13.39	0.00	0.00	13.39
1283.1	0.00	0.00	0.6043	4506.36	417.99	12.55	0.00	0.00	12.55
1285.0	0.00	0.00	0.6026	4524.62	405.99	11.71	0.00	0.00	11.71
1286.9	0.00	0.00	0.6008	4542.88	393.99	10.87	0.00	0.00	10.87
1288.8	0.00	0.00	0.5991	4561.14	381.99	10.03	0.00	0.00	10.03
1290.7	0.00	0.00	0.5973	4579.40	369.99	9.19	0.00	0.00	9.19
1292.6	0.00	0.00	0.5956	4597.66	357.99	8.35	0.00	0.00	8.35
1294.5	0.00	0.00	0.5938	4615.92	345.99	7.51	0.00	0.00	7.51
1296.4	0.00	0.00	0.5921	4634.18	333.99	6.67	0.00	0.00	6.67
1298.3	0.00	0.00	0.5903	4652.44	321.99	5.83	0.00	0.00	5.83
1300.2	0.00	0.00	0.5886	4670.70	309.99	4.99	0.00	0.00	4.99
1302.1	0.00	0.00	0.5868	4688.96	297.99	4.15	0.00	0.00	4.15
1304.0	0.00	0.00	0.5851	4707.22	285.99	3.31	0.00	0.00	3.31
1305.9	0.00	0.00	0.5833	4725.48	273.99	2.47	0.00	0.00	2.47
1307.8	0.00	0.00	0.5816	4743.74	261.99	1.63	0.00	0.00	1.63
1309.7	0.00	0.00	0.5798	4762.00	249.99	0.79	0.00	0.00	0.79
1311.6	0.00	0.00	0.5781	4780.26	237.99	0.00	0.00	0.00	0.00
1313.5	0.00	0.00	0.5763	4798.52	225.99	0.00	0.00	0.00	0.00
1315.4	0.00	0.00	0.5746	4816.78	213.99	0.00	0.00	0.00	0.00
1317.3	0.00	0.00	0.5728	4835.04	201.99	0.00	0.00	0.00	0.00
1319.2	0.00	0.00	0.5711	4853.30	189.99	0.00	0.00	0.00	0.00
1321.1	0.00	0.00	0.5693	4871.56	177.99	0.00	0.00	0.00	0.00
1323.0	0.00	0.00	0.5676	4889.82	165.99	0.00	0.00	0.00	0.00
1324.9	0.00	0.00	0.5658	4908.08	153.99	0.00	0.00	0.00	0.00
1326.8	0.00	0.00	0.5641	4926.34	141.99	0.00	0.00	0.00	0.00
1328.7	0.00	0.00	0.5623	4944.60	129.99	0.00	0.00	0.00	0.00
1330.6	0.00	0.00	0.5606	4962.86	117.99	0.00	0.00	0.00	0.00
1332.5	0.00	0.00	0.5588	4981.12	105.99	0.00	0.00	0.00	0.00
1334.4	0.00	0.00	0.5571	4999.38	93.99	0.00	0.00	0.00	0.00
1336.3	0.00	0.00	0.5553	5017.64	81.99	0.00	0.00	0.00	0.00
1338.2	0.00	0.00	0.5536	5035.90	69.99	0.00	0.00	0.00	0.00
1340.1	0.00	0.00	0.5518	5054.16	57.99	0.00	0.00	0.00	0.00
1342.0	0.00	0.00	0.5501	5072.42	45.99	0.00	0.00	0.00	0.00
1343.9	0.00	0.00	0.5483	5090.68	33.99	0.00	0.00	0.00	0.00
1345.8	0.00	0.00	0.5466	5108.94	21.99	0.			

TABLE 4. CONTINUED

TABLE 4. CONTINUED

0.030734	1121.9	42.278	0.7575	23281.95	1428.13	92.52	0.00	2.22	92.52	428.23
0.030774	1122.0	42.966	0.7534	23056.21	1435.01	93.92	0.00	0.00	93.92	428.04
0.030814	1122.9	43.650	0.7512	22973.36	1445.28	95.44	0.00	0.00	95.44	423.32
0.030854	1123.0	44.337	0.7538	24523.48	1461.54	98.06	0.00	0.00	98.06	428.21
0.030894	1123.9	45.061	0.7609	24276.68	1471.97	98.53	0.00	0.00	98.53	428.53
0.030934	1125.0	45.788	0.7607	24032.99	1483.39	100.15	0.00	0.00	100.15	428.15
0.030974	1125.8	46.485	0.7666	23792.54	1494.79	101.81	0.00	0.00	101.81	428.48
0.031014	1125.6	47.285	0.7774	23555.76	1506.17	103.53	0.00	0.00	103.53	428.41
0.031054	1125.7	47.931	0.7723	23323.18	1517.52	105.20	0.00	0.00	105.20	428.41
0.031094	1125.5	48.652	0.7771	23084.12	1528.86	106.88	0.00	0.00	106.88	428.41
0.031134	1131.5	49.398	0.7762	22868.72	1540.17	108.22	0.00	0.00	108.22	428.41
0.031174	1132.4	52.142	0.7778	22617.22	1551.48	110.94	0.00	0.00	110.94	428.41
0.031214	1133.3	51.806	0.7707	22459.18	1562.73	111.94	0.00	0.00	111.94	428.41
0.031254	1134.2	51.641	0.7815	22215.32	1573.97	115.71	0.00	0.00	115.71	428.41
0.031294	1135.1	52.359	0.7934	22005.31	1585.13	115.14	0.00	0.00	115.14	428.41
0.031334	1135.3	53.162	0.7853	21799.91	1596.37	119.35	0.00	0.00	119.35	428.41
0.031374	1135.9	53.931	0.7871	21588.64	1607.53	121.63	0.00	0.00	121.63	428.41
0.031414	1137.7	54.786	0.7899	21401.64	1618.67	123.96	0.00	0.00	123.96	428.41
0.031454	1138.5	55.485	0.7968	21269.64	1629.77	126.42	0.00	0.00	126.42	428.41
0.031494	1139.4	56.278	0.7927	21032.19	1640.84	128.94	0.00	0.00	128.94	428.41
0.031534	1140.3	57.069	0.7946	20839.64	1651.85	131.55	0.00	0.00	131.55	428.41
0.031574	1141.1	57.856	0.7983	20632.15	1662.85	134.26	0.00	0.00	134.26	428.41
0.031614	1141.9	58.657	0.7993	20490.99	1673.86	137.05	0.00	0.00	137.05	428.41
0.031654	1142.7	59.463	0.8032	20333.13	1684.79	139.95	0.00	0.00	139.95	428.41
0.031694	1143.5	62.274	0.8023	20111.76	1695.65	142.86	0.00	0.00	142.86	428.41
0.031734	1144.3	61.891	0.8039	20006.77	1706.53	145.78	0.00	0.00	145.78	428.41
0.031774	1145.1	61.512	0.8086	19856.78	1717.42	148.71	0.00	0.00	148.71	428.41
0.031814	1145.9	62.718	0.8088	19713.54	1728.31	151.63	0.00	0.00	151.63	428.41
0.031854	1146.7	63.571	0.8095	19540.66	1738.69	154.56	0.00	0.00	154.56	428.41
0.031894	1147.5	64.439	0.8114	19406.48	1749.59	157.48	0.00	0.00	157.48	428.41
0.031934	1148.3	65.251	0.8132	19323.95	1760.23	160.35	0.00	0.00	160.35	428.41
0.031974	1149.2	66.099	0.8151	19287.24	1770.83	163.25	0.00	0.00	163.25	428.41
0.032014	1149.8	66.991	0.8172	19098.73	1781.38	166.16	0.00	0.00	166.16	428.41
0.032054	1150.5	67.893	0.8198	18998.03	1791.88	169.08	0.00	0.00	169.08	428.41
0.032094	1151.3	68.671	0.8226	18935.48	1802.33	171.94	0.00	0.00	171.94	428.41
0.032134	1152.1	69.539	0.8261	18821.48	1812.71	174.81	0.00	0.00	174.81	428.41
0.032174	1152.8	72.411	0.8255	18746.38	1823.24	177.68	0.00	0.00	177.68	428.41
0.032214	1153.6	71.289	0.8254	18608.77	1833.71	180.52	0.00	0.00	180.52	428.41
0.032254	1154.3	72.171	0.8253	18547.93	1844.22	183.41	0.00	0.00	183.41	428.41
0.032294	1155.1	73.050	0.8261	18577.95	1854.66	186.32	0.00	0.00	186.32	428.41
0.032334	1155.8	73.931	0.8332	18542.53	1865.13	189.25	0.00	0.00	189.25	428.41
0.032374	1156.5	74.848	0.8339	18518.77	1875.73	192.20	0.00	0.00	192.20	428.41
0.032414	1157.3	75.752	0.8358	18585.76	1886.05	195.14	0.00	0.00	195.14	428.41
0.032454	1158.0	76.656	0.8377	18585.42	1897.59	198.08	0.00	0.00	198.08	428.41
0.032494	1158.8	77.507	0.8396	18518.49	1908.27	201.01	0.00	0.00	201.01	428.41
0.032534	1159.5	78.403	0.8415	18535.10	1918.94	203.91	0.00	0.00	203.91	428.41
0.032574	1160.3	79.484	0.8433	18516.21	1929.53	206.81	0.00	0.00	206.81	428.41
0.032614	1161.0	81.329	0.8452	18632.07	1940.13	209.71	0.00	0.00	209.71	428.41
0.032654	1161.7	82.259	0.8471	18715.37	1950.73	212.63	0.00	0.00	212.63	428.41
0.032694	1162.5	83.131	0.8490	18855.31	1961.32	215.56	0.00	0.00	215.56	428.41
0.032734	1163.3	84.067	0.8509	18917.11	1971.92	218.49	0.00	0.00	218.49	428.41
0.032774	1164.0	84.974	0.8538	19014.25	1982.52	221.42	0.00	0.00	221.42	428.41
0.032814	1164.8	85.821	0.8547	19109.99	1993.12	224.35	0.00	0.00	224.35	428.41
0.032854	1165.5	86.733	0.8566	19308.23	1997.72	227.28	0.00	0.00	227.28	428.41
0.032894	1166.3	86.889	0.8585	19554.46	1996.72	230.21	0.00	0.00	230.21	428.41
0.032934	1167.1	87.889	0.8604	19774.41	2002.53	233.14	0.00	0.00	233.14	428.41
0.032974	1167.9	88.952	0.8623	20023.61	2012.33	236.08	0.00	0.00	236.08	428.41
0.033014	1168.7	89.952	0.8652	20338.51	2022.58	239.01	0.00	0.00	239.01	428.41
0.033054	1169.5	92.792	0.8661	20659.56	2032.82	241.94	0.00	0.00	241.94	428.41

TABLE 4. CONTINUED

P.3330949	1170.4	91.768	0.8680	28952.13	2836.58	399.85	P.00	0.00	399.85	755.46
P.3331349	1171.2	92.747	0.8699	21331.11	2844.18	415.86	0.00	0.00	415.86	768.49
P.3331749	1172.1	93.730	0.8718	21749.47	2851.66	433.81	0.00	0.00	433.81	781.24
P.3332149	1173.0	94.717	0.8737	22210.55	2858.92	453.82	P.00	0.00	453.82	794.96
P.3332549	1173.9	95.707	0.8756	22718.87	2865.95	473.82	0.00	0.00	473.82	809.26
P.3332949	1174.8	96.700	0.8775	23276.18	2872.73	495.66	0.00	0.00	495.66	824.24
P.3333349	1175.7	97.696	0.8794	23889.45	2879.23	519.43	0.00	0.00	519.43	839.89
P.3333749	1176.7	98.696	0.8813	24563.16	2885.45	545.82	0.00	0.00	545.82	856.27
P.3334149	1177.7	99.698	0.8832	25303.13	2891.38	572.62	0.00	0.00	572.62	873.44
P.3334549	1178.7	100.704	0.8851	26115.96	2896.93	602.44	0.00	0.00	602.44	891.46
P.3334949	1179.8	101.711	0.8870	27009.11	2102.14	634.78	0.00	0.00	634.78	910.42
P.3335349	1180.9	102.722	0.8889	27991.86	2108.95	669.92	0.00	0.00	669.92	930.32
P.3335749	1182.0	103.734	0.8908	29071.43	2111.34	708.13	0.00	0.00	708.13	951.31
P.3336149	1183.2	104.748	0.8928	30251.23	2115.26	749.65	0.00	0.00	749.65	973.46
P.3336549	1184.5	105.765	0.8947	31573.06	2118.67	795.52	0.00	0.00	795.52	996.67
P.3336949	1185.8	106.782	0.8966	33021.39	2121.52	845.59	0.00	0.00	845.59	1021.16
P.3337349	1187.1	107.801	0.8985	34622.98	2123.75	899.72	0.00	0.00	899.72	1047.93
P.3337749	1188.5	108.821	0.9005	36399.93	2125.32	961.57	0.00	0.00	961.57	1075.85
P.3338149	1189.9	109.841	0.9024	38365.94	2126.13	1028.97	0.00	0.00	1028.97	1105.57
P.3338549	1191.6	110.862	0.9043	39786.61	2126.11	1103.88	0.00	0.00	1103.88	1137.27
P.3338949	1193.2	111.882	0.9062	39782.91	2125.17	1187.47	0.00	0.00	1187.47	1171.16
P.3339349	1194.8	112.902	0.9082	39823.42	2123.28	1281.18	0.00	0.00	1281.18	1207.47
P.3339749	1196.4	113.922	0.9101	39548.64	2122.05	1386.43	0.00	0.00	1386.43	1246.46
P.3340149	1197.9	114.937	0.9120	39479.14	2115.67	1505.48	0.00	0.00	1505.48	1288.52
P.3340549	1199.5	115.951	0.9140	39415.59	2109.65	1640.79	0.00	0.00	1640.79	1333.88
P.3340949	1201.1	116.962	0.9159	39358.79	2102.21	1795.28	0.00	0.00	1795.28	1383.36
P.3341349	1202.7	117.969	0.9178	39389.66	2092.41	1972.35	0.00	0.00	1972.35	1436.16
P.3341749	1204.2	118.979	0.9198	39269.32	2087.58	2177.14	0.00	0.00	2177.14	1494.82
P.3342149	1205.8	119.986	0.9217	39239.12	2086.19	2415.26	0.00	0.00	2415.26	1559.51
P.3342549	1207.4	120.993	0.9237	39228.66	2048.69	2694.88	0.00	0.00	2694.88	1628.74
P.3342949	1209.0	121.997	0.9256	39215.93	2027.59	3023.81	0.00	0.00	3023.81	1706.12
P.3343349	1210.5	122.999	0.9276	39227.35	2022.14	3414.14	0.00	0.00	3414.14	1791.87
P.3343749	1212.1	123.993	0.9295	39257.56	1971.79	3883.16	0.00	0.00	3883.16	1887.11
P.3344149	1213.7	124.991	0.9315	39311.55	1935.11	4457.63	0.00	0.00	4457.63	1994.12
P.3344549	1215.2	125.996	0.9332	39381.82	1897.02	5248.82	0.00	0.00	5248.82	2096.48
P.3344949	1216.8	126.993	0.9357	39485.38	1884.93	6239.86	0.00	0.00	6239.86	2199.75
P.3345349	1218.4	127.998	0.9382	39431.75	1872.27	7442.81	0.00	0.00	7442.81	2162.22
P.3345749	1219.9	128.997	0.9407	39468.46	1858.99	8649.59	0.00	0.00	8649.59	2195.43
P.3346149	1221.5	129.994	0.9431	39491.53	1845.08	9869.82	0.00	0.00	9869.82	2229.45
P.3346549	1223.0	130.993	0.9456	39525.08	1832.58	10998.72	0.00	0.00	10998.72	2264.26
P.3346949	1224.6	131.994	0.9481	39561.22	1815.21	12339.11	0.00	0.00	12339.11	2299.48
P.3347349	1226.2	132.995	0.9506	39600.88	1799.22	13898.62	0.00	0.00	13898.62	2336.25
P.3347749	1227.8	133.996	0.9531	39641.77	1782.42	15593.65	0.00	0.00	15593.65	2373.44
P.3348149	1229.4	134.997	0.9556	39688.43	1764.84	17428.59	0.00	0.00	17428.59	2411.41
P.3348549	1231.0	135.998	0.9581	39734.19	1746.42	19404.75	0.00	0.00	19404.75	2450.16
P.3348949	1232.6	136.997	0.9606	39785.19	1727.13	21515.82	0.00	0.00	21515.82	2489.47
P.3349349	1234.2	137.998	0.9631	39839.57	1706.92	23862.31	0.00	0.00	23862.31	2529.91
P.3349749	1235.8	138.997	0.9656	39897.49	1685.77	26444.04	0.00	0.00	26444.04	2572.85
P.3350149	1237.4	139.996	0.9681	39959.88	1663.62	29293.11	0.00	0.00	29293.11	2612.46
P.3350549	1239.0	140.995	0.9706	40024.51	1642.45	32445.49	0.00	0.00	32445.49	2654.68
P.3350949	1240.6	141.994	0.9731	40093.92	1618.21	35918.88	0.00	0.00	35918.88	2697.46
P.3351349	1242.2	142.993	0.9756	40167.47	1598.87	39789.37	0.00	0.00	39789.37	2740.73
P.3351749	1243.8	143.992	0.9781	40245.32	1564.38	44088.51	0.00	0.00	44088.51	2784.44
P.3352149	1245.4	144.991	0.9806	40327.61	1535.71	48883.80	0.00	0.00	48883.80	2828.42
P.3352549	1247.0	145.990	0.9831	40414.48	1507.83	54098.44	0.00	0.00	54098.44	2872.62
P.3352949	1248.6	146.989	0.9856	40508.08	1477.79	59843.43	0.00	0.00	59843.43	2918.88
P.3353349	1250.2	147.988	0.9881	40608.55	1446.38	66097.48	0.00	0.00	66097.48	2966.19
P.3353749	1251.8	148.987	0.9906	40703.99	1413.61	72899.81	0.00	0.00	72899.81	3014.49
P.3354149	1253.4	149.986	0.9931	40810.58	1379.68	80246.87	0.00	0.00	80246.87	3063.98

TABLE 4. CONCLUDED

P-0347000	1225.0	0.9455	48922.19	1344.26	13106.36	3928.72	5.36	11835.36	3891.86
P-0347100	1225.5	0.9459	41839.16	1367.68	13647.21	4148.16	5.86	12184.77	3133.83
P-0347200	1225.9	0.9464	41161.27	1289.61	14085.33	4380.67	6.38	12356.86	3174.93
P-0347300	1226.3	0.9469	41286.70	1230.31	14537.67	4617.98	6.94	12583.61	3214.72
P-0347400	1226.7	0.9474	41421.37	1189.73	14978.32	4859.37	7.52	12798.31	3252.91
P-0347500	1227.1	0.9479	41559.21	1147.91	15388.65	5104.64	8.13	12966.62	3289.23
P-0347600	1227.5	0.9484	41782.89	1104.98	15788.32	5353.12	8.78	13118.65	3323.37
P-0347700	1227.9	0.9489	41949.87	1060.76	16184.43	5604.19	9.45	13219.26	3355.02
P-0347800	1228.4	0.9494	42082.32	1015.56	16512.83	5857.15	10.15	13289.36	3383.88
P-0347900	1228.8	0.9499	42159.19	969.45	16856.82	6111.26	10.88	13318.21	3409.82
P-0348000	1229.2	0.9504	42328.16	922.48	17181.66	6365.22	11.65	13383.57	3431.96
P-0348100	1229.6	0.9509	42484.84	874.78	17533.65	6619.56	12.44	13443.96	3452.92
P-0348200	1230.0	0.9514	42622.82	826.54	17818.99	6872.28	13.27	13498.43	3469.35
P-0348300	1230.5	0.9519	42823.63	777.85	18131.93	7122.85	14.12	13546.63	3475.91
P-0348400	1230.9	0.9524	42996.75	728.98	18396.82	7369.90	15.01	13588.97	3482.18
P-0348500	1231.3	0.9529	43171.63	679.85	18738.67	7613.15	15.92	13626.63	3483.74
P-0348600	1231.8	0.9533	43324.27	632.88	19051.47	7851.37	16.86	13661.50	3488.72
P-0348700	1232.2	0.9536	43474.67	582.16	19344.68	8084.34	17.83	13696.46	3492.95
P-0348800	1232.6	0.9543	43628.79	533.68	19614.02	8318.23	18.83	13724.78	3496.48
P-0348900	1233.1	0.9548	43786.61	486.28	19858.58	8538.24	19.83	13744.22	3498.13
P-0349000	1233.5	0.9553	43951.11	439.29	20084.81	8741.67	20.82	13757.39	3498.12
P-0349100	1234.0	0.9558	44233.66	393.33	20287.58	8925.16	21.98	13764.96	3494.58
P-0349200	1234.4	0.9563	44593.71	348.55	20462.33	9095.91	23.19	13766.89	3489.42
P-0349300	1234.9	0.9568	44988.66	304.78	20624.48	9252.41	24.33	13768.95	3482.25
P-0349400	1235.3	0.9573	45424.18	262.48	20775.78	9395.76	25.49	13769.73	3473.33
P-0349500	1235.7	0.9578	45893.49	221.62	20918.19	9527.68	26.67	13769.49	3462.78
P-0349600	1236.2	0.9583	46388.45	182.32	21051.42	9649.71	27.87	13768.15	3450.16
P-0349700	1236.6	0.9588	46888.64	144.63	21178.71	9766.11	29.08	13765.55	3435.55
P-0349800	1237.1	0.9593	47393.76	108.62	21299.36	9876.31	30.28	13762.55	3419.92
P-0349900	1237.6	0.9598	47903.56	74.34	21414.78	9980.49	31.51	13759.11	3402.56
P-0350000	1238.0	0.9603	48427.87	41.81	21524.69	10078.36	32.76	13755.33	3383.52
P-0350100	1238.5	0.9608	48967.55	11.66	21629.69	10169.94	34.01	13751.11	3362.92
P-0350200	1239.0	0.9613	49526.55	-17.92	21729.68	10255.36	35.26	13746.44	3340.92
P-0350300	1239.4	0.9618	50096.67	-45.13	21824.68	10334.68	36.51	13741.33	3317.55
P-0350400	1239.8	0.9623	50688.64	-72.57	21914.68	10407.96	37.76	13735.86	3292.92
P-0350500	1240.3	0.9628	51293.63	-94.28	22000.68	10475.24	39.01	13729.96	3267.38
P-0350600	1240.8	0.9633	51903.63	-116.28	22082.68	10537.52	40.26	13723.68	3240.92
P-0350700	1241.2	0.9638	52528.63	-136.56	22160.68	10594.80	41.51	13716.96	3213.55
P-0350800	1241.7	0.9643	53168.63	-155.19	22234.68	10647.08	42.76	13709.73	3185.11
P-0350900	1242.2	0.9648	53823.63	-172.18	22304.68	10694.36	44.01	13702.00	3155.67
P-0351000	1242.6	0.9653	54493.63	-187.56	22370.68	10736.64	45.26	13693.76	3125.22
P-0351100	1243.1	0.9657	55178.63	-201.34	22432.68	10773.92	46.51	13685.00	3093.78
P-0351200	1243.6	0.9662	55878.63	-213.52	22490.68	10806.20	47.76	13675.76	3061.33
P-0351300	1244.0	0.9667	56593.63	-224.11	22544.68	10833.48	49.01	13665.96	3027.88
P-0351400	1244.5	0.9672	57323.63	-233.84	22594.68	10855.76	50.26	13655.76	2993.44
P-0351500	1245.0	0.9677	58078.63	-242.24	22640.68	10872.00	51.51	13645.00	2958.00
P-0351600	1245.4	0.9682	58848.63	-249.53	22682.68	10883.28	52.76	13633.76	2921.55
P-0351700	1245.9	0.9687	59633.63	-255.83	22720.68	10889.52	54.01	13622.00	2884.11
P-0351800	1246.4	0.9692	60433.63	-260.13	22754.68	10891.76	55.26	13610.76	2845.67
P-0351900	1246.9	0.9697	61248.63	-263.43	22784.68	10890.00	56.51	13600.00	2806.22
P-0352000	1247.4	0.9702	62078.63	-265.73	22810.68	10885.28	57.76	13589.76	2765.78
P-0352100	1247.9	0.9707	62923.63	-267.03	22834.68	10877.52	59.01	13579.52	2724.33
P-0352200	1248.4	0.9712	63783.63	-267.33	22856.68	10865.76	60.26	13569.28	2681.88
P-0352300	1248.9	0.9717	64658.63	-266.63	22876.68	10850.00	61.51	13559.00	2638.44
P-0352400	1249.4	0.9722	65548.63	-264.93	22894.68	10830.28	62.76	13548.76	2593.99
P-0352500	1249.9	0.9727	66453.63	-262.23	22910.68	10806.52	64.01	13538.52	2548.55
P-0352600	1250.4	0.9732	67373.63	-258.53	22924.68	10778.76	65.26	13528.28	2501.11
P-0352700	1250.9	0.9737	68308.63	-253.83	22936.68	10746.00	66.51	13518.00	2452.67
P-0352800	1251.4	0.9742	69258.63	-248.13	22946.68	10709.28	67.76	13507.76	2403.22
P-0352900	1251.9	0.9747	70223.63	-240.43	22954.68	10668.52	69.01	13497.52	2352.78
P-0353000	1252.4	0.9752	71203.63	-231.73	22960.68	10623.76	70.26	13487.28	2301.33
P-0353100	1252.9	0.9757	72198.63	-221.03	22964.68	10575.00	71.51	13477.00	2248.88
P-0353200	1253.4	0.9762	73208.63	-209.33	22966.68	10522.28	72.76	13466.76	2195.44
P-0353300	1253.9	0.9767	74233.63	-206.63	22966.68	10465.52	74.01	13456.52	2140.99
P-0353400	1254.4	0.9772	75273.63	-202.93	22964.68	10404.76	75.26	13446.28	2085.55
P-0353500	1254.9	0.9777	76328.63	-198.23	22960.68	10339.00	76.51	13436.00	2029.11
P-0353600	1255.4	0.9782	77398.63	-191.53	22954.68	10268.28	77.76	13425.76	1971.67
P-0353700	1255.9	0.9787	78483.63	-182.83	22946.68	10192.52	79.01	13415.52	1913.22
P-0353800	1256.4	0.9792	79583.63	-172.13	22936.68	10111.76	80.26	13405.28	1853.78
P-0353900	1256.9	0.9797	80698.63	-159.43	22924.68	10026.00	81.51	13395.00	1793.33
P-0354000	1257.4	0.9802	81828.63	-144.73	22910.68	9935.28	82.76	13384.76	1731.88
P-0354100	1257.9	0.9807	82973.63	-128.03	22894.68	9839.52	84.01	13374.52	1669.44
P-0354200	1258.4	0.9812	84133.63	-109.33	22876.68	9738.76	85.26	13364.28	1606.00
P-0354300	1258.9	0.9817	85308.63	-89.63	22856.68	9633.00	86.51	13354.00	1541.55
P-0354400	1259.4	0.9822	86498.63	-68.93	22834.68	9513.28	87.76	13343.76	1476.11
P-0354500	1259.9	0.9827	87703.63	-47.23	22810.68	9388.52	89.01	13333.52	1408.67
P-0354600	1260.4	0.9832	88923.63	-24.53	22784.68	9258.76	90.26	13323.28	1340.22
P-0354700	1260.9	0.9837	90158.63	-1.83	22756.68	9124.00	91.51	13313.00	1270.78
P-0354800	1261.4	0.9842	91408.63	20.87	22726.68	8984.28	92.76	13302.76	1200.33
P-0354900	1261.9	0.9847	92673.63	43.57	22694.68	8839.52	94.01	13292.52	1128.88
P-0355000	1262.4	0.9852	93953.63	66.27	22660.68	8690.00	95.26	13282.28	1056.44
P-0355100	1262.9	0.9857	95248.63	88.97	22624.68	8535.76	96.51	13272.00	983.00
P-0355200	1263.4	0.9862	96558.63	111.67	22587.68	8376.00	97.76	13261.76	908.55
P-0355300	1263.9	0.9867	97883.63	134.37	22549.68	8211.28	99.01	13251.52	833.11
P-0355400	1264.4	0.9872	99223.63	157.07	22510.68	8041.52	100.26	13241.28	756.67
P-0355500	1264.9	0.9877	100578.63	179.77	22470.68	7866.76	101.51	13231.00	679.22
P-0355600	1265.4	0.9882	101948.63	202.47	22429.68	7687.00	102.76	13220.76	601.78
P-0355700	1265.9	0.9887	103333.63	225.17	22387.68	7502.28	104.01	13210.52	524.33
P-0355800	1266.4	0.9892	104733.63	247.87	22344.68	7312.52	105.26	13200.28	446.88
P-0355900	1266.9	0.9897	106148.63	270.57	22300.68	7117.76	106.51	13190.00	369.44
P-0356000	1267.4	0.9902	107578.63	293.27	22256.68	6918.00	107.76	13179.76	291.99
P-0356100	1267.9	0.9907	109023.63	315.97	22212.68	6713.28	109.01	13169.52	214.55
P-0356200	1268.4	0.9912	110483.63	338.67	22168.68	6503.52	110.26	13159.28	137.11
P-0356300	1268.9	0.9917	111958.63	361.37	22124.68	6288.76	111.51	13149.00	59.67
P-0356400	1269.4	0.9922	113448.63	384.07	22080.68	6069.00	112.76	13138.76	-17.78
P-0356500	1269.9	0.9927	114953.63	406.77	22036.68	5844.28	114.01	13128.52	-84.33
P-0356600	1270.4	0.9932	116473.63	429.47	21992.68	5614.52	115.26	13118.28	-150.88
P-0356700	1270.9	0.9937	118008.63	452.17	21948.68	5379.76	116.51	13108.00	-217.44
P-0356800	1271.4	0.9942	119558.63	474.87	21904.68	5140.00	117.76	13097.76	-283.99
P-03569									

Card 2 consists of pump tube physical parameters, which are, in order: sabot start pressure, launch barrel length, initial pump tube pressure, payload weight, pump tube volume, pump tube initial temperature, launch tube area, and pump tube heat loss.

Card 3 has a propellant form flag; the number 1 indicates a constant burning surface.

2. PROGRAM OUTPUT

The program listing is given in Table 5. The output (Table 4) is for the listed input data (Table 3) and corresponds to an experimental test firing conducted with a light gas gun. The correlation of experiment to analysis for both the pump tube and the combustion tube are given in Figures 7 and 8. The time sequencing for the analytic data has been worked backward from the experimental peak pressure because, in practice, the ignition transient is exceptionally long. The phenomenally long ignition delay is due to the extremely low propellant loading density and attendant required flame spread time at low pressure. Because of the erratic combustion properties of gun propellant at very low pressure, this several hundred millisecond ignition delay is effectively non-analytic.

The computer output shows that the program will print data every 800 microseconds until the driving piston starts to move, in this case at 900 psi. The program then prints data at a rate of every 40 microseconds until the payload sabot is sheared and starts to move. This occurs at 5,000 psi light gas pressure, and the final print frequency rate becomes once every 10 microseconds.

Figures 7 and 8 present a correlation of experiment and analysis for the combustion side and for the pump side, respectively. As previously mentioned, time justification has been by coincident pressure peaking on the pump tube side.

As is seen, the correlation for both the helium and propellant chambers is very good; however, it is not exact. The pump tube side has a somewhat sharper pressure decay experimentally than is predicted by the analysis, this is doubtless due to heat loss effects or sabot friction which is not totally accounted for in the mathematical model. The combustion tube pressure rise has an analytical variance from experimental, which is to be anticipated from the non-analytic nature of the slow smouldering ignition transient described previously. Additionally, at the end of the compression stroke, the analysis predicts a slight pressure recovery, which has not been seen experimentally. The analytical muzzle velocity prediction of 11,360 ft/sec compares with the experimental velocity of 11,210 ft/sec.

In summation, it can be stated that apparently the mathematical model of the two-stage light gas system is valid for performance prediction. It serves as a useful tool in determining required propellant and gas charge loads and in optimizing sabot and piston design shot start pressures. Although useful refinements should be readily apparent, the core of the program can be easily manipulated to accept more sophisticated modeling, if required. As a heuristic design tool, the core program is largely satisfactory.

TABLE 5. PROGRAM LISTING

```

DIMENSION PSY(20),VEE(20)
DIMENSION PRS(20),RATE(20),TYPE(8)
DIMENSION PROPF (4,3)
DIMENSION FHT(18),FHT1(4),FHT2(13),DATA(4)
DIMENSION PSL(20),VLE(20)
COMMON/ /PCPRS(1000),PBDIS(1000),RUN,P,OP,NPTS
COMMON/PLTHDR/ SHOT,CHG,WEB,CVOL,AREA,VH
READ(4,3)FIMP,GAMA,RHO,CVL,(TYPE(N),N=1,4)
3 FORMAT(F8.1,F8.3,F8.4,F8.2,4A2)
READ(4,4)PRS
4 FORMAT(10F8.1)
READ(4,5)RATE
5 FORMAT(10F8.3)
READ(4,24)VEE
24 FORMAT(10F8.1)
READ(4,28)PSY
28 FORMAT(10F8.3)
READ(4,24)VLE
READ(4,28)PSL
PIT=1.5
TAD=GAMA/(GAMA-1.)
6 READ(4,7)AREA,CVOL,SHOT,RUN,WEB,BETA,CHG,SCPRS,SABPR
7 FORMAT(F7.3,F7.3,F7.3,F7.1,F7.4,F7.2,F7.3,2F8.1)
READ(4,14) RFST,HGBL,HGIP,HGSM,HGIV,HGIT,ALEA,BLTA
14 FORMAT(8F10.0)
READ(4,110) IPT,OAN,DOT,DIN,XLIN,WMOL
110 FORMAT(11,6F10.7)
IF(IPT.LY.1.OR.IPY.GY.5) IPT=1
10 NPTS=0
EFM=0
ACEL=0
VEL=0
AVOL=CVOL
R=0.
RAT=0.
NPTS=0
KUV=0
BLIS=0.
HLGP=0
HCPP=0
ILF=1
JFG=0
RTF=2780.
KUE=-1
VLG=0.
ALGY=0.
TLGS=HGIT
OTDT=0.
GMLG=1.57
GLG=GMLG-1.
MMAL=4.
DPLG=0.
GAG=1.-(1./GMLG)
CPLG=HGIP
CPEG=CPLG
TIME=0.
DELTA=0.0001
VLGS=HGIV
HGID=HGIP*MMAL/(RTF*HGIT*12.)
HGM=HGID*HGIV
BP=0.
VEL=0.

```

TABLE 5. CONTINUED

```

IF(WMOL.LE,0.0) WMOL=24,
TF=WMOL*FIMP/RTF
XTF=TF
GIN=SCPRS*WMOL/(RTF*TF*12.)
FVOL=CVOL*(CHG/RHO)
GO TO (125,123,120,123,123),IPT
120 FPU=R.
RT=0.
BARI=5.*CHG/(RHO*WEB)
GO TO 130
123 AOT=DOT*DOT*3.1417/4.
AIN=OIN*OIN*3.1417/4.
IF(IPT.EQ,4) AIN=7.0*AIN
IF(IPT.EQ,5) AIN=19.0*AIN
AEF=AOT-AIN
GRNS=CHG/(AEF*XLIN*RHO)
GO TO 130
125 BARE=2.*CHG/(RHO*WEB)
130 WRITE(6,8)
8 FORMAT(1H1,61H SHOT WT. CHARGE WEB B,LENGTH CMB VOL
1BORE AREA//)
WRITE(6,9)SHOT,CHG,WEB,RUN,CVOL,AREA
9 FORMAT(F10.2,F10.3,F10.4,F10.1,F10.2,F10.2//)
WRITE(6,20)
20 FORMAT(24H LIGHT GAS GUN DATA ,60H SHOT WEIGHT B,LENGTH
1CMB VOL, BORE AREA HEAT LOSS)
WRITE(6,25) HGSN,HGBL,HGIV,ALFA,BLTA
25 FORMAT(27X,F11.5,F11.2,F11.2,F12.3,F12.2)
DATA(1)=WMOL
DATA(2)=XLIN
DATA(3)=DOT
DATA(4)=OIN
WRITE(6,30)WMOL,BETA,(TYPE(N),N=1,4)
30 FORMAT(/21H MOLECULAR WEIGHT = ,F5.1,23H HEAT LOSS FACTOR IS ,
1F5.2,32H PROPELLANT USED IN SYSTEM IS ,4A2//)
GO TO (31,33,35,37,61),IPT
31 WRITE(6,32)
32 FORMAT(50H PROPELLANT FORM IS SINGLE PERFORATE OR CONSTANT SURFA
1CE//)
GO TO 60
33 WRITE(6,34)
34 FORMAT(47H PROPELLANT FORM IS DETERRED SINGLE PERFORATE//)
GO TO 60
35 WRITE(6,36)
36 FORMAT(35H PROPELLANT FORM IS DETERRED BALL//)
GO TO 60
37 WRITE(6,38)
38 FORMAT(47H PROPELLANT FORM IS DETERRED SEVEN PERFORATE //)
GO TO 60
61 WRITE(6,62)
62 FORMAT(49H PROPELLANT FORM IS DETERRED NINETEEN PERFORATE//)
60 WRITE(6,95)
95 FORMAT(2X,11H*****10X,18H PROPELLANT SIDE,10X,13H*****
1*****5X,13H*****10X,14HLIGHT GAS SIDE,10X,10H*****
WRITE(6,96)
96 FORMAT(8X,4HTIME,4X,10HCHAMB PRES,4X,6HTRAVEL,4X,11HPROP BURNED,10
1HPRES SLOPE,3X,17HVELOCITY*CB PRES,3X,8HVELOCITY,4X,6HTRAVEL,5X,7
2HBS PRES,6X,4HTEMP)
BP=0.0
VEL2=0.
BDIS=0.0
PTOP=3000.
CPRS=SCPRS

```

TABLE 5. CONTINUED

```

GAMB=(1.+BETA)*(GAMA-1.)
DO 39 J=1,32,8,1
IF(BLIS,GE,MCBL) GO TO 39
GO TO (74,135,74,134,134),IPT
134 IF(RAT-WEB) 135,74,74
135 RAT=R+.00005
DIN=DIN+RAT
XLIN=XLIN-RAT
AIN=DIN+DIN*3.1417/4.
AIX=DIN*3.1417
IF(IPT,NE,4) GO TO 132
AIN=7.8*AIN
AIX=7.8*AIX
GO TO 136
132 IF(IPT,NE,5) GO TO 136
AIN=19.8*AIN
AIX=19.8*AIX
136 AEF=AOT-AIN
BARE=GRNS*(2.+AEF*XLIN*AIX)
74 JA=1
IF(CPRS,LT,300,0) GO TO 76
78 IF(CPRS-PRS(JA))77,76,75
75 JA=JA+1
GO TO 78
76 R=RATE(JA)
GO TO 10
77 DIT=PRS(JA)-PRS(JA-1)
DAT=RATE(JA)-RATE(JA-1)
PIG=CPRS-PRS(JA-1)
DIM=((PIG/DIT)*DAT)
R=RATE(JA-1)+DIM
10 KG=1
IF(VLG,LT,VLE(1)) GO TO 93
91 IF(VLE(KG)-VLG)92,93,94
92 KG=KG+1
GO TO 91
93 DFLG=PSL(KG)
GO TO 90
94 HIG=(VLG-VLE(KG-1))/(VLE(KG)-VLE(KG-1))
DFLG=(PSL(KG)-PSL(KG-1))*HIG+PSL(KG-1)
90 CONTINUE
IF(BP=CHG) 11,80,80
80 ONOT=0
GO TO 12
11 IF (IPT,NE,3) GO TO 140
IF(RT-DAN) 145,145,150
145 RT=RT/1.5*(1.+(.8*RT/DAN))
RT=RT+R*DELTA
150 IF(FPU-.9) 155,155,140
155 BARE=BARI*(1.-(FPU*.17))
140 ONOT=R+RHO*BARE
BP=BP+(ONOT*DELTA)
IF(HCPP,LT,CPRS) HCPP=CPRS
IF(JFG,GT,1) GO TO 12
IF(CPRS-.T,SABPR) GO TO 54
DELTA=.000005
JFG=0
12 VEL1=VEL2
VELY=ABS(VEL2)
RTM=(VEL2*VEL2)/(GAMA*32.17*FIMP*PIT*TF/XTF)
ROOT=1./(1.+((GAMA-1.)/2.)*RTM)
TUT=ROOT*TAD
PREX=CPRS*TUT

```

TABLE 5. CONTINUED

```

      KO=1
50 IF (VEE(KO)-VEL2) 51,52,53
51 KO=KO+1
   GO TO 50
52 PFAC=PSY(KO)
   GO TO 59
53 MAG=(VEL2-VEE(KO-1))/(VEE(KO)-VEE(KO-1))
   PFAC=((PSY(KO)-PSY(KO-1))*MAG)+PSY(KO-1)
59 EFM=(SHOT+(CHG/PFAC))/32.17
   PROX=PREX
   IF (VEL2.LT.0.) PROX=CPRS
   ACEL=(PROX-CPLG)*AREA*32.17/SHOT
   VEL2=VEL1+(ACEL*DELTA)
   ACOL=(ACEL*DELTA)/2.
   BINC=(VEL1*DELTA)+(ACOL*DELTA)
   BDIS=BDIS+(BINC*12.)
13 AVOL=CVOL+(BDIS*AREA)
   IF (ILF=3) 22,22,20
22 IF (RFST=CPLG) 19,19,23
19 ILF=5
20 ALGT=CPEG*32.17*ALEA/HGSM
   VLG=VLG
   VLG=VLG+(ALGT*DELTA)
   BLIC=(VLG*DELTA)+(ALGT*DELTA*DELTA/2.)
   BLIS=BLIS+BLIC*12.
23 TLGS=TLGS+DTOT*DELTA
18 DLOT=VEL2
   GLEX=-GMLG/GLG
   PLGB=1.+(GLG*VLG*VLG*HML/7784.3*TLGS*RTF*GMLG)
   PLGR=PLGB+GLEX
   CPEG=CPLG+PLGR
   XLGS=HGIV+(BLIS*ALEA)-(BDIS*AREA)
   VLGS=XLGS-CVL*HGM/3.
   IF (DFLG.EQ.0.) PHGM=0.
   IF (DFLG.EQ.0.) GO TO 28
   PHGM=HGM/(DFLG*32.17)
28 CONTINUE
   PLGA=12.*CPLG*AREA*VEL2/VLGS
   EFGL=(PHGM+(HGSM/32.17))*(BLTA+1.)
   PLGB=12.*CPLG*ALEA*VLG/VLGS
   PLGC=12.*EFGL*VLG*ALGT*GLG/VLGS
   PLGD=12.*HGM*RTF*DTOT/(GLG*VLGS*HML)
   DPLG=PLGA-PLGB-PLGC+PLGD
   DTOT=TLGS+DPLG*GAG/CPLG
   IF (ILF=3) 54,54,56
54 XUE=XUE+1
   IF (XUE.EQ.4) GO TO 85
   GO TO 57
55 XUE=0
56 CONTINUE
   KUV=XUV+1
   IF (KUV.LT.2) GO TO 57
   KUV=0
   WRITE(8,99) TIME,CPRS,BDIS,FPU,DPOT,DLOT,CPLG,VLG,BLIS,CPEG,TLGS
99 FORMAT(F12.7,F12.1,F12.3,F12.4,7F11.2)
57 CONTINUE
   IF (HLGP.LT.CPLG) HLGP=CPLG
   CPLG=CPLG+(DPLG*DELTA)
   DLOT=VEL2
   UBW=(CHG-8P)/RMO
   COVL=CVL*8P
   GAMV=GAMB
   IF (ACEL.LT.0.) GAMV=0.

```

TABLE 5. CONCLUDED

```

DPDT=((ONDT*FIMP+12.)-(GAMV*EFM*ACEL*VEL2+12.)+(AREA*CPRS*VEL1+12
1.)))/(AVOL-(UBW+COVL))
DOPE=J
TIME=TIME+DELTA
FPU=BP/CHG
IF(CPRS.GT.PTOP) PTOP=CPRS
GN=(GIN*FVOL*BP) / (AVOL-(UBW+COVL))
TF=CPRS*WMOL/(GN*RTF+12.)
CPRS=CPRS+(DPDT*DELTA)
IF(CPLG.GE.0.) GO TO 39
HGBL=BLIS
WRITE(6,41) BLIS
41 FORMAT(//47H CASE TERMINATED AS MAXIMUM VELOCITY REACHED AT,F6.1,
117H INCHES OF TRAVEL//)
39 CONTINUE
79 CONTINUE
CNIT=(BLIS-HGBL)/HGBL
CPIC=(VLG-VLGI)*CNIT+VLG
WRITE(6,111) CPIC
111 FORMAT(///10X,33H LIGHT GAS GUN MUZZLE VELOCITY IS,F8.1,6HFT/SEC)
WRITE(6,112) HLGP
112 FORMAT(10X,26H LIGHT GAS PEAK PRESSURE IS,F8.1,4H PSI)
WRITE(6,113) HCPP
113 FORMAT(10X,32H COMBUSTION SIDE PEAK PRESSURE IS,F8.1,4H PSI)
GO TO 6
END

```

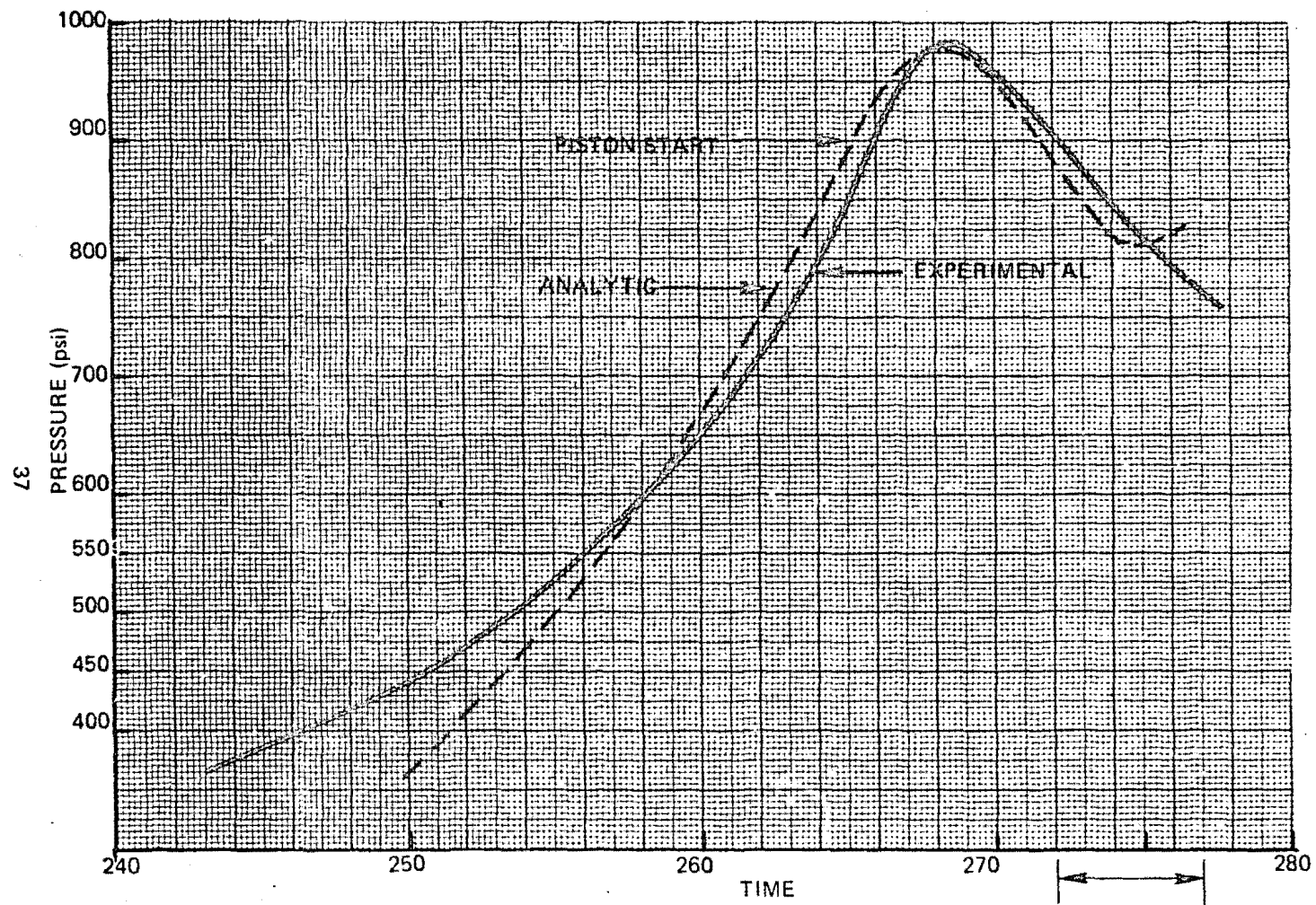


Figure 7. Combustion Tube Pressure - Firing No. 4

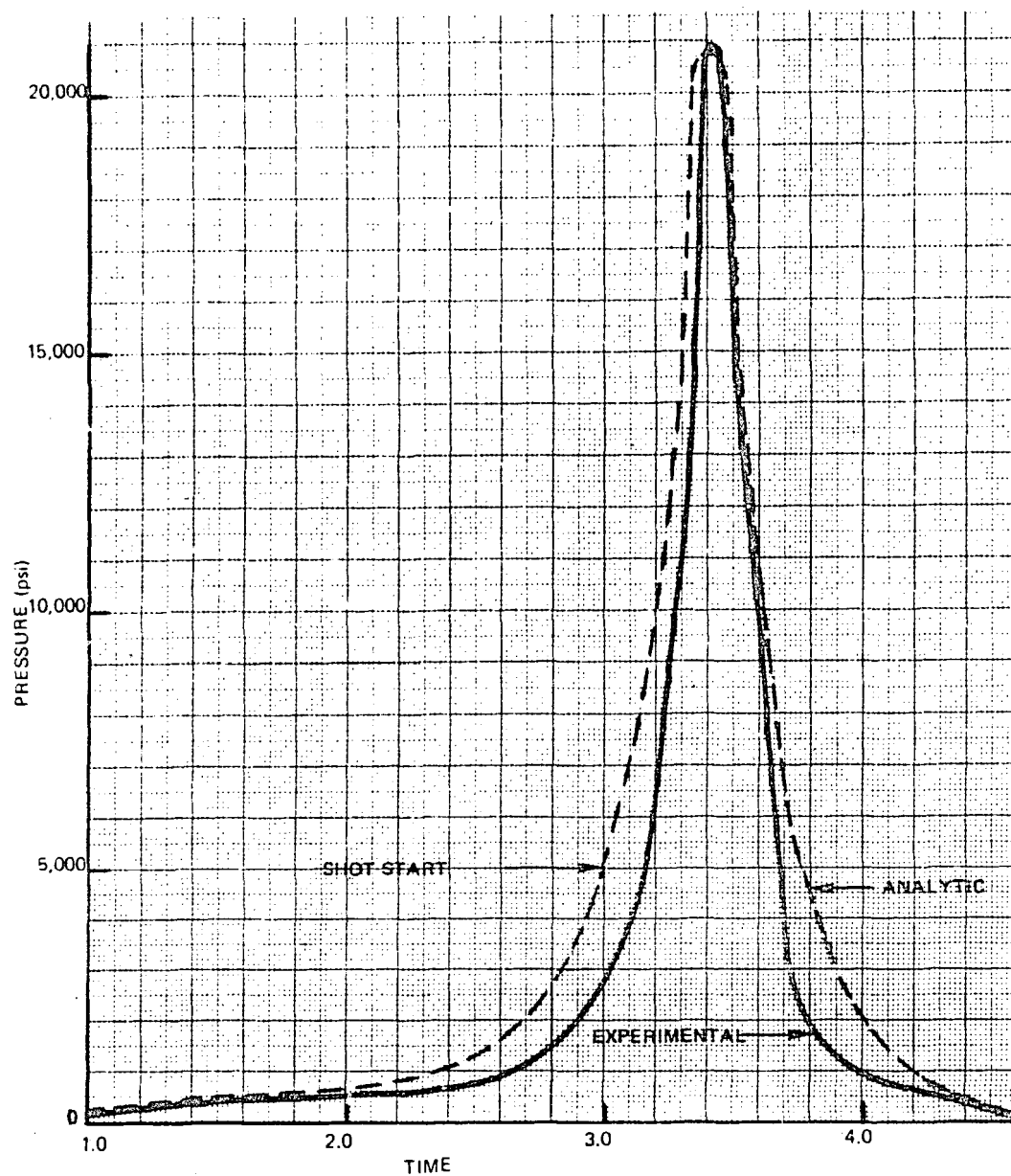


Figure 8. Pump Tube Pressure - Firing No. 4

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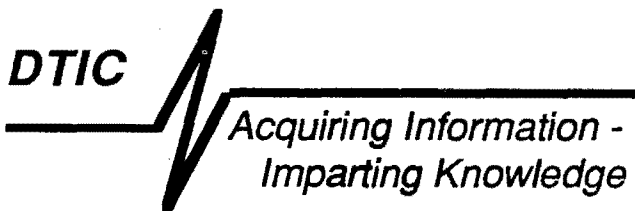


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