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STUDY OF THE GAS FLOW THROUGH THE PRESSURE PORT IN A GAS OPERATED SMALL ARMS AUTOMATIC WEAPON

Oct 1976

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MUNITIONS DEVELOPMENT AND ENGINEERING DIRECTORATE

U.S. ARMY ARMAMENT COMMAND

FRANKFORD ARSENAL

PHILADELPHIA, PENNSYLVANIA 19137

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STUDY OF THE GAS FLOW THROUGH THE PRESSURE PORT IN A GAS OPERATED SMALL ARMS AUTOMATIC WEAPON

By

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FRANKFORD ARSENAL
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STUDY OF THE GAS FLOW THROUGH THE PRESSURE PORT IN A GAS-OPERATED SMALL ARMS AUTOMATIC WEAPON

BY

SIDNEY GOLDSTEIN

The author acknowledges and appreciates the assistance of Mr. Leslie Greenbaum of the Techniques Division for helping program the computer model. Also he acknowledges the assistance of Mr. John Mikulich of the Test and Evaluation Office in obtaining the experimental data.

ABSTRACT

Data from experimental tests on the flow of the gases through the pressure port in 5.56mm test barrel was obtained and studied. A theoretical model was developed to describe both the nonsteady flow which occurs when the projectile first passes the port and the quasisteady flow following port opening. A one dimensional model which uses the method of characteristics is used to describe the nonsteady flow and a two dimensional compressible potential flow solution using the Karmen-Tsien pressure correction formula is used to describe the quasisteady flow.

INTRODUCTION

Although the importance of proper gas port design in determining the cycling kinematics of gas operated small arms weapons has long been recognized, only a limited effort has been spent in recent years to describe the gas flow through the port in a rifle barrel. Most of the work done to date[1,2] uses emperical data from incompressible flow measurements to obtain various loss factors which are then used to describe the flow from the rifle bore through the pressure port. This approach has certain inherent limitations which have become apparent from recent testing. ~~of gas flow through pressure ports.~~ These tests, which are described later in this report, ~~and~~ indicate the following:

1. When the projectile passes the port, the flow of the gases through the port becomes nonsteady and a rarefaction wave is transmitted back into the barrel.

2. The duration of this nonsteady flow is dependent to the magnitude of the port area and the velocity of the projectile when it passes the port.

3. The flow of the gases through the port subsequent to the projectile passage appears to be characteristic of quasi-steady compressible flow.

The models which use incompressible loss factors have neglected to account for this nonsteady flow.* In addition, many designs of modern gas operated weapons employ gas ports which remove gases from the barrel at angles other

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* This nonsteady gas port flow has sometimes been incorrectly identified as instrumentation problems.

1. "The Gas Flow in Gas-Operated Weapons", by J.H. Spurk, BRL Report No. 1475, Feb 1970.

2. "Weapon Dynamics-Gas Dynamcis Study", by E.W. Beans, The Ohio State Research Foundation, Columbus Ohio, Contract DAAF03-70-C-003. Also, Technical Report SWERR-TR-72-79 Research Directorate Weapons Laboratory, WECOM, Research Development & Engineering Directorate, US Army Weapons Command

than normal to the axis. For example, the 6mm Rodman SAW weapon has two prots which are inclined approximately 139° and 133° from the direction of flow in the barrel. Impingement systems and Tapper systems* are also examples of this type. There appear to be several advantages for having gas ports at angles to the barrel axis greater than 90°. Two of these are:

1. Less gas fouling material would be transmitted through the port to the gas transmission system which cycles the weapon. Brooks** has shown that the "cut-off" size (r_s) for a particle passing through the gas port is dependent on the radius of curvature of the particle path (i.e., the greater radius of curvature (R) the greater the size particle which can be transmitted.) Thus, by making the port at a sharp angle to the axis of the bore, the radius of curvature can be decreased, thereby decreasing the size and correspondingly the number of particles passing through the port.

$$\bar{r}_s = \frac{1}{V}\sqrt{\frac{9}{2}\,\frac{\bar{v}\mu R}{\rho_s}}$$

ρ_s = density of the solid particle
$\bar{r}_s$ = "cut-off" size of solid particle
μ = gas viscosity
R = radius of curvature of the particle path
$\bar{v}$ = the transverse component of the gas velocity
V = the magnitude of the gas velocity in the barrel at the port location

In view of the above equation, one would try to design a port which would give the smallest transverse velocity ($\bar{v}$) and smallest radius of curvature (R).

2. Less gilding metal would be removed from the bullet jacket and transmitted through the port. It is believed that when the port is drilled in the barrel, the lands provide a cutting edge which removes metal when the projectile passes. Drilling the port at a large angle to the barrel axis is believed to help prevent the top of the barrel lands from removing an excessive amount of gilding metal from the projectile.

** Semiemperical Model for Predicting the Upper Size of Solid Particles Migrating From the Barrel to the Gas Tube of the M16A1 Rifle", by W. B. Brooks, FA, Report R-2018, Aug 1971.

* "Engineering Design Handbook, Gun Series - Automatic Weapons," AMCP 706-260 Headquarters, U.S. Army Materiel Command, February [illegible]

EXPERIMENTAL TEST PROGRAM

The experimental test program using the M16 Test barrel consisted of two phases. In the first phase (I), the gases at the pressure port was allowed to escape to the atmosphere - the pressure at the port opposite the port hole was measured.

In the second phase (II) a plenum or collecting chamber was located downstream of the port and the pressure in both the chamber and at the port opposite the chamber were measured. Two different port holes were tried (a .089 inch diameter hole and a .060 inch diameter hole). The volume of the collecting chamber was approximately 0.14 in.^{3} and it was lcoated at 11.6 inches of projectile travel.

AMMUNITION/CYCLING MECHANISM INTERACTION

5.56MM PRESSURE PORT HOLE STUDY

Because 5.56mm ammunition is used in gas operated weapon systems (i.e. M16A1 rifle) any study of the ammunition/cycling mechanism interaction for this caliber ammunition must of necessity include a detailed analysis of the transmission of the gas energy from the rifle barrel to the bolt carrier group. Accordingly, a test was designed to better understand the effect of the pressure port hole in the cycling operation of the M16 weapon system. This test sought to measure the pressure at the port location in a 5.56mm test barrel under conditions similar to that in the rifle.

TEST PROCEDURE FOR PHASE I

Three holes were drilled in the barrel to accept Kistler 217c pressure gages*. One, (#1), was located at the port and had an opening to the barrel of diameter 0.060 inches and a length of 0.050 inches. Another , (#2), was also located at the port 180° from the first and had an opening of dimaeter 0.093 inches and a length of 0.050 inches. A third was positioned at the case mouth location. This had a diameter of 0.60" and a length of 0.10".

Because of limitation of time and funds only a small sample size was fired in each test. It was believed that this was adequate for indicating qualitative differences in the shape of the pressure time curves at the port location. These differences were indeed evidenced.

*See ~~Appendix~~ Table IA for a list of the instrumentation.

The results of the testing are shown in Appendix B, Frankford Arsenal Proof Testing Record, 5.56mm Port Hole Study. In the first part of the program, test (#1), ten rounds were fired in the barrel and pressure was taken at the case mouth position only. The two port holes were plugged. This was done to check out the instrumentation and also to determine the effect, if any, of port pressure and case mouth pressure. See Fig. 1 for a sample of the results of Test #1. Muzzle exit occurs at 1.163 milliseconds from the beginning of sweep and is observed by the decrease in intensity of the sweep.

Test #2 measured the pressure at the case mouth location and at port #1 (.060" diameter and .050" length). Port #2 was plugged during this test. See Fig. 2 for sample of the results of Test #2.

Test #3 had exactly the same arrangement. See Fig. 3 for sample of the results of Test #3.

Test #4 measured the pressures at the case mouth location and also at Port #2. Port #1 was plugged during this test. Fig. 4 shows the results of this test.

Test #5 measured the pressures at the case mouth and also at Port #2. Port #1 was kept opened. Fig. #5 shows the results of this test.

INSTRUMENTATION

Kistler Model 217C pressure transducers were used to obtain pressure time information at both the case mouth and port locations. These have been used extensively for ballistic testing of small arms ammunition*. The gage used at the case mouth location made use of a thermal protector. This is a small perforated disk which fits over the sensing element and protects it from the thermal shock. This was believed necessary because of the high flame temperature of the propellant gas at this location and because of the length of time pressure was being measured at this point. The thermal protector was not used for the gage at the port because it has been found that at this location in the barrel residue collects on it and it may therefore yield faulty information. It was believed that the error of the gage due to thermal sensitivity would be less than the error due to residue collecting on the thermal disk. The gage hole for the pressure transducer at the case mouth had a diameter of 0.060" and length of 0.100". The diameter of the port hole was varied between 0.060 and 0.093 (see "Test Procedure"). Electronic filters were used with these gages. Although the filters reduced peak pressure at the port from about 1,000 to 2,000 psi, it was nevertheless considered necessary to use it in order to eliminate cavity resonance and overshoot. Reproducibility of the pressure-time trace was

*Data for this study was obtained by Mr. John Mikulich, K4000, Frankford Arsenal.

considered more important in order to compare results at the port for different testing conditions (i.e. different port hole sizes). Thus the filter was used. Table I contains a list of the instrumentation used.

TABLE I A

INSTRUMENTATION LIST

1. Kistler Instrumentation Corporation (KIC) Ballistic Pressure Transducers (2 ea)
2. Kistler 503D148 Charge/Piezotron Amplifiers (2 ea)
3. Electronic Fileers - 20KHZ (-3db @ 20 KHZ, 12db/octave attenuation)
4. Oscilloscope - 565 Tektronex with 3A3 Vertical Amplifiers

EXPERIMENTAL RESULTS FOR PHASE I

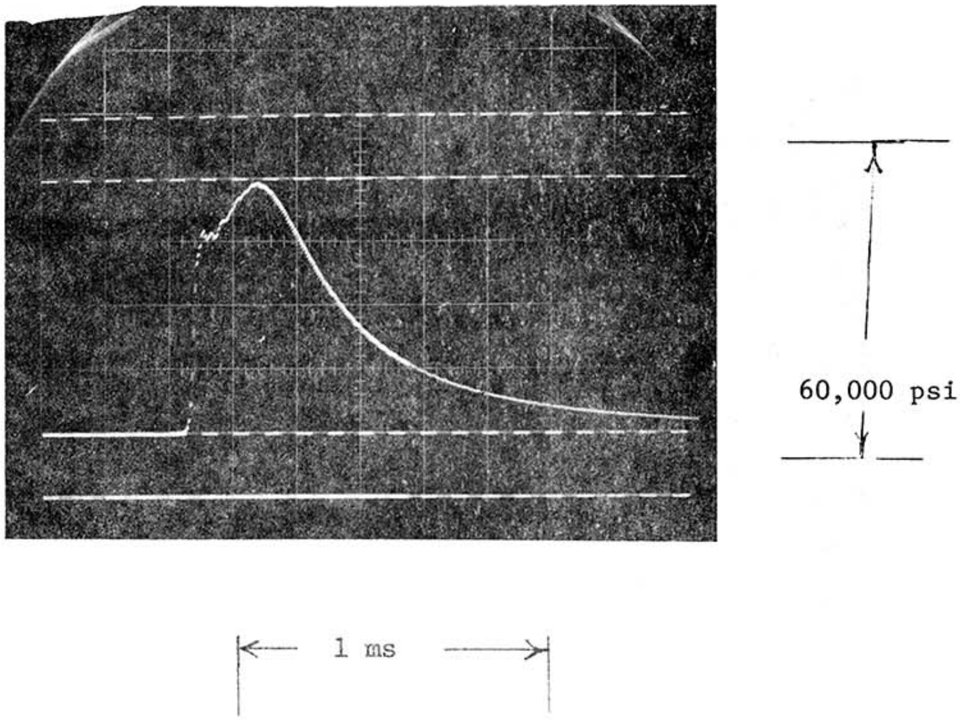
1. Test #1 revealed that the system tested was operating within the requirements for acceptance of 5.56mm ammunition.

2. A comparison of test #2 (which used a gage hole D = .060" and L = .050 at the port) with test #4 (which uses a gage hole D = .093" and L = .050 at the port) indicates that the pressure measured at the port is greater by about 500 psi for the smaller diameter gage hole.

3. A comparison of test #2 and test #3 (same as test #2, but with plug removed from port #2) reveals that the average peak port pressure has decreased by about 1400 psi as a result of the flow of gas out of port #2. For this small sample size no significant change in muzzle velocity is observed.

4. A comparison of test #3 and test #5 reveals that although there is no significant change in the magnitute of the port pressure, there is a marked difference between the shape of the curves. It may be seen that the inflection point in the port pressure-time curve occurs much earlier for test #5 where the vent hole size is smaller (i.e. 0.60"D). Correspondingly, the inflection point for test #3 occurs almost at muzzle exit.

Figure 6 shows pressure-time curves taken in an M16 rifle at the case mouth, port and bolt cavity. This record was taken several years ago during a different test program, and used a Kistler 607 Gage at the port location. The same basic characteristics of the curves in Tests #3 and 5 are evident. The inflection point in the port pressure-time curve comes soon after peak pressure. The diameter of the port in the service weapon is .092 inches. However, the location of the pressure transducer in the service weapon is 90° from the axis of the port. The pressure transducer in test #3 and #5 was located 180 from the axis of the port. This difference in orientation of the gage together with the differences in the types of gases themselves may also contribute to the difference in the magnitude of the pressure. (i.e., 13,300 psi vs. 10,700 psi).

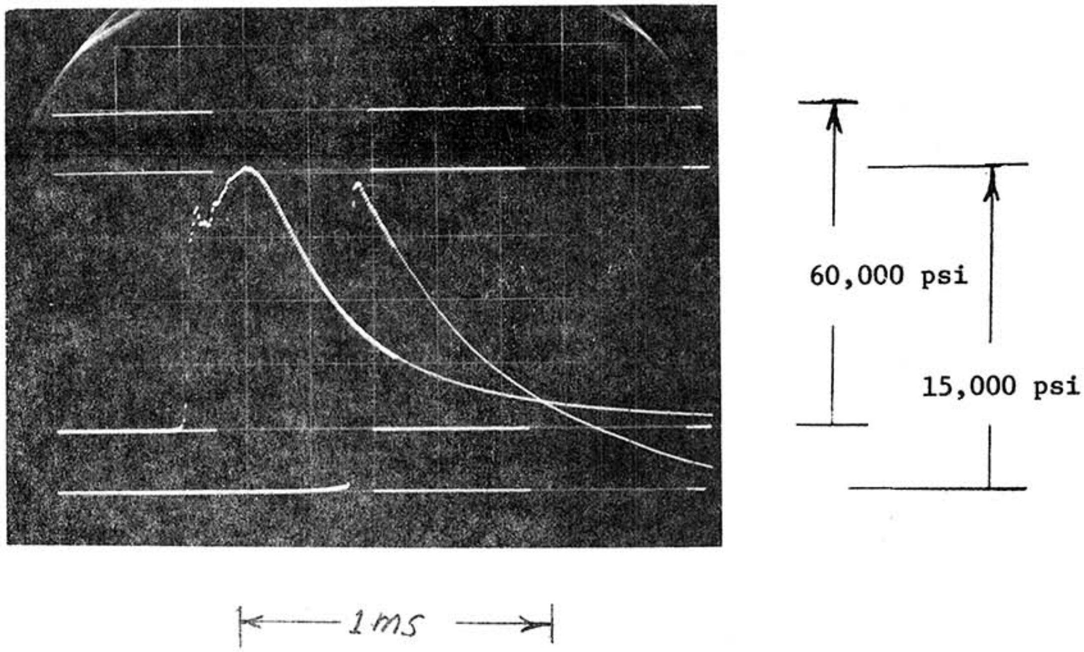


Test #1, Rd #2

Case Mouth Pressure, (Port #1 & Port #2 Plugged)

Peak Pressure 47,800 psi
Sweep Time 0.1 ms/time dot
Muzzle Velocity 3230 f/s

FIGURE #1

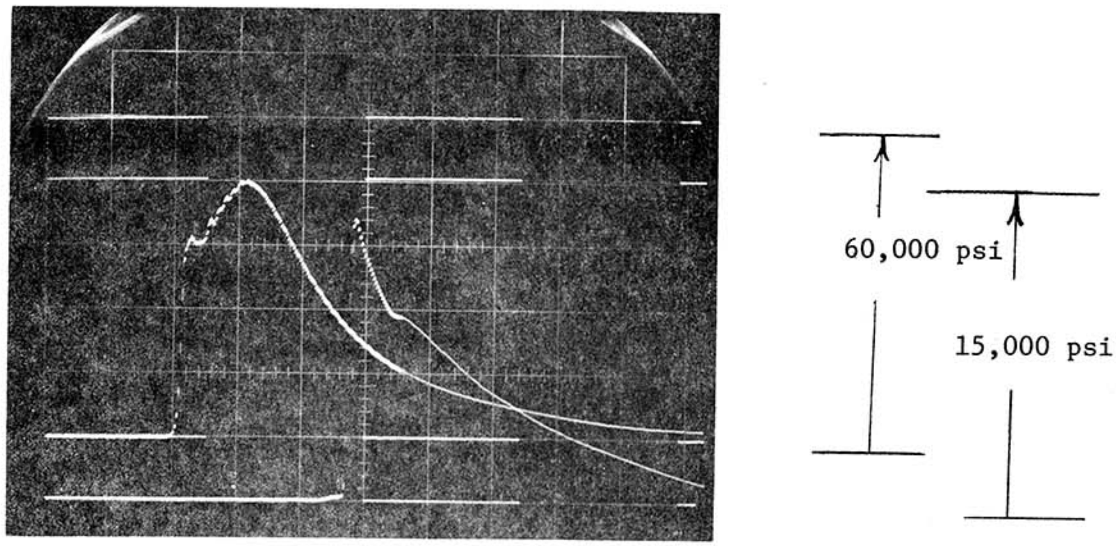


Test #2, Rd #13

Case Mouth Pressure, Port #1
(Port #2 Plugged)

Sweep Time 1.0 ms/time dot
Muzzle Velocity 3230 f/s
Peak Pressure:
1. Case mouth 49,000 psi
2. Port #1, 14,500 psi

FIGURE #2



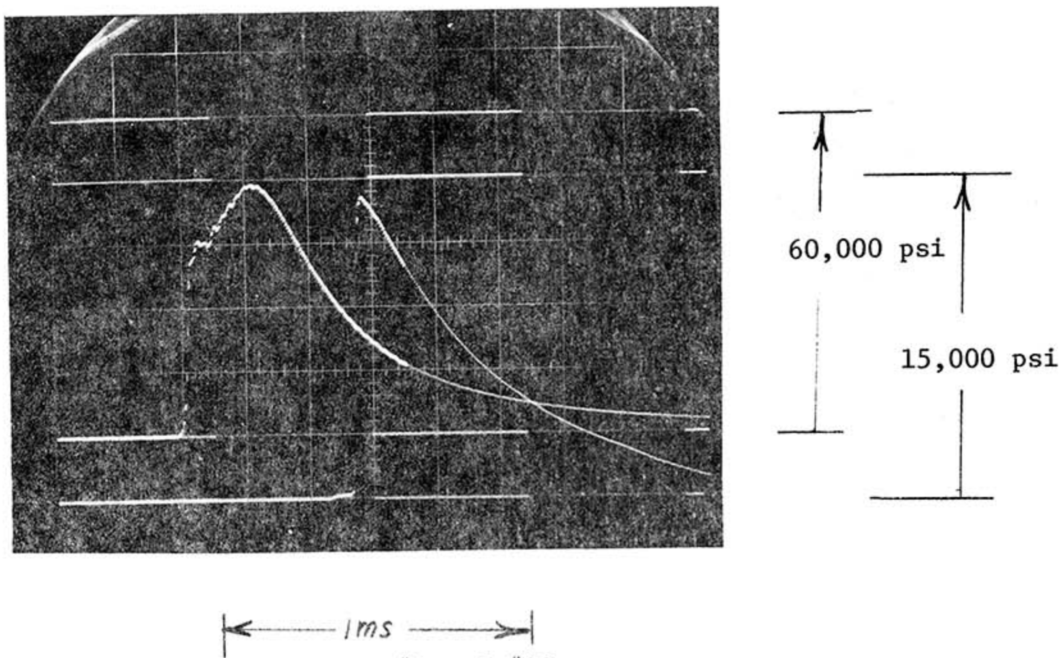
1 ms

Test #3, Rd #20

Case Mouth Pressure, Port #1
(Port #2 Opened)

Sweep Time 1.0 ms/time dot
Muzzle Velocity 3205 f/s
Peak Pressure:
1. Case Mouth 48,000 psi
2. Port #1 13,300 psi

FIGURE #3

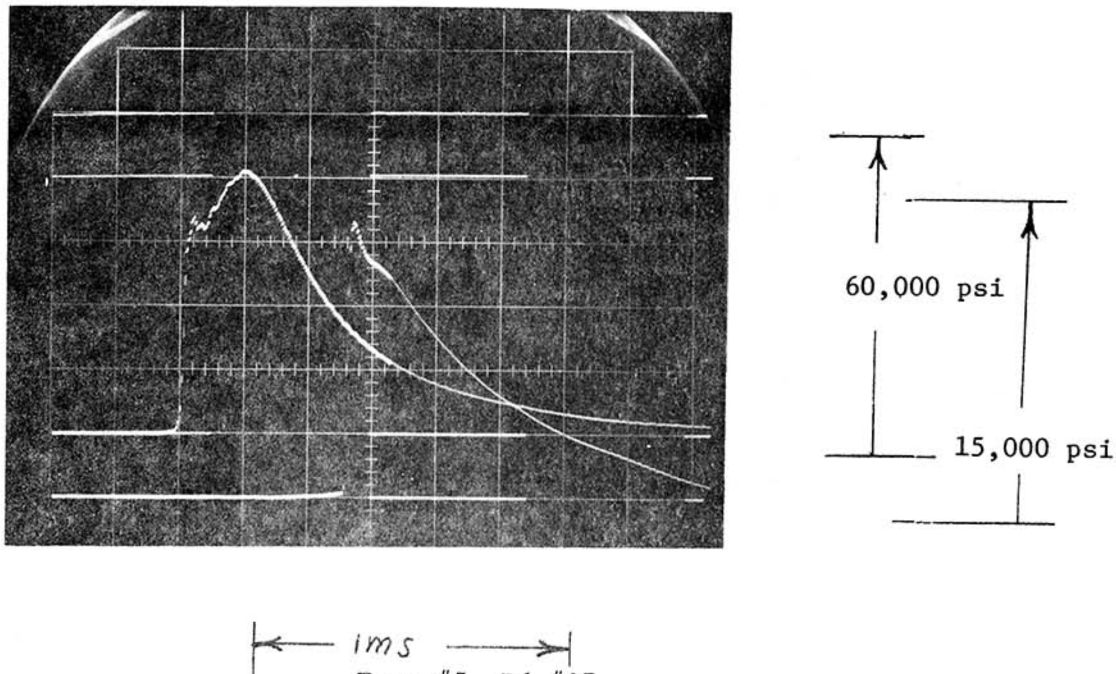


Test #4, Rd #22

Case Mouth Pressure, Port #2
(Port #1 Plugged)

Sweep Time 1.0 ms/time dot
Muzzle Velocity 3288 f/s
Peak Pressure:
1. Case Mouth 47,000 psi
2. Port #2 14,100 psi

<u>FIGURE #4</u>

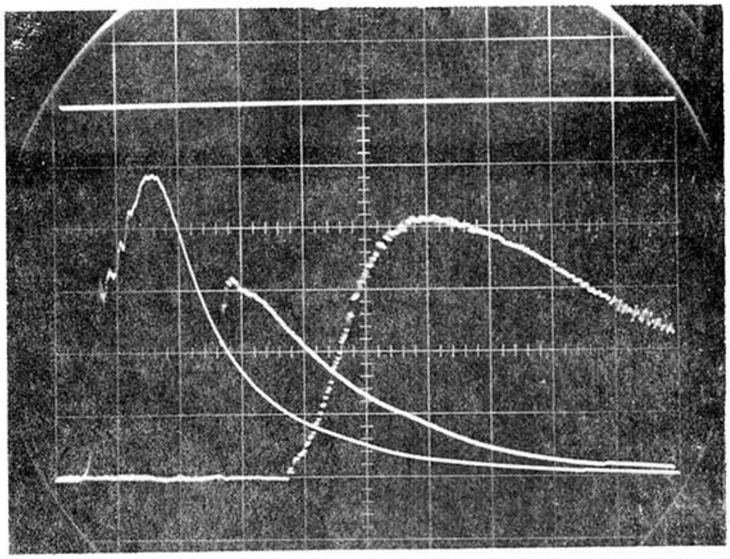


Test #5, Rd #27

Case Mouth Pressure, Port #2
(Port #1 Opened)

Sweep Time 1.0 ms/time dot
Muzzle Velocity 3228 f/s
Peak Pressure:
1. Case Mouth 49,000 psi
2. Port #2 13,000 psi

FIGURE #5



Case Mouth, Port & Bolt Cavity Pressures *In M16 Weapon

Sweep Time .3ms/cm

Peak Pressure:

1. Case Mouth 48,000 psi
2. Port 10,700 psi
3. Bolt Cavity 2,100 psi

FIGURE #6

* Calibration:

Case Mouth, 12,000 psi/cm

Port, 3333 psi/cm

Bolt cavity, 500 psi/cm

Table I B

FRANKFORD ARSENAL
Engineering Proof Testing Record

PROPELLANT
TYPE WC 844
ARMY LOT 46614
CHARGE 27.7 Grs

TEST Velocity, Chamber & Port Pressure, Action Time
SPEC/AUTH
OBJECT 5.56mm Port Hole Study

AMMUNITION
LOT LC-5.56-001
TYPE M193
CALIBER Ball
BULLET Brass
CASE

REC/UNIV NO FA 36 | BRL NO R 80 | TRFD 2405
REC/UNIV NO | BRL NO | TRFD
REC/UNIV NO | BRL NO | TRFD
REC/UNIV NO | BRL NO | TRFD

STORED +70 °F
PERIOD 2 hours
FIRED AT +70 °F

SHOT NO	#1 Vel	#1 C.P.			#2 Vel.	#2 C.P.	P.P.	A.T.
1	+3259	+49600			-3183	-46200	14800	+1.148
2	3230	47800			3191	47800	14700	1.131
3	3220	48800			3230	49000	14500	1.078
4	3207	48000			3233	49000	+14900	1.100
5	3233	-45000			+3258	+50000	-14400	-0.975
6	3214	48000						
7	3233	-45000						
8	3229	48400						
9	-3203	46000						
10	3228	48400						
11								
12								
13								
14								
15								
16								
17								
18								
19								
20								
TOTAL	10	10			5	5	5	5
MEAN	3226	47900			3219	48400	14700	1.086
CF								
COM'D								
EX VAR	56	4600			75	3800	500	.173
STD DEV	15	1300			28	1300	200	

CASUALTIES 0

REMARKS

	C.P.	P.#1	P.#2
#1	C.M.#2	Plug	Plug
#2	C.M.#2	Gage	Plug

Port #1 .060" d & .050"L
Port #2 .093" d & .050"L

PROOF TECHNICIANS Lachman & Brown

FOREMAN

X.O. 47070-31-001

DATE 21 Feb 1975

CHIEF BALLISTICIAN

REF RD DATA
AUTH
CASE LOT
BULLET LOT
PROPELLANT
JAR CHG
VEL VAL
CP VAL
PP VAL

Sheet 1 of 3

Table I B (continued)

FRANKFORD ARSENAL
Engineering Proof Testing Record

PROPELLANT		TEST	Velocity, Chamber & Port Pressure, Action Time	AMMUNITION	
TYPE	WC 844			LOT	5.56-001
ARMY LOT	46614			TYPE	M193
CHARGE	27.7 Grs	SPEC/AUTH		CALIBER	5.56mm
				BULLET	Ball
		OBJECT	5.56mm Port Hole Study	CASE	Brass

REC/UNIV NO	BRL NO	TRFD		
FA 36	R 80	2415	STORED	+70°F
			PERIOD	2 hours
			FIRED AT	+70 °F

SHOT NO	#3 Vel	#3 C.P.	#3 P.P.	#3 A.T.	#4 Vel	#4 C.P.	#4 P.P.	#4 A.T.
1	+3233	+49000	13300	-1.093	3235	48000	+14500	-1.058
2	3212	48200	+13400	1.108	3208	47000	14100	1.116
3	3213	49000	-13200	1.120	3198	47400	14100	+1.147
4	-3197	48600	13300	+1.217	-3189	-46100	-14000	1.112
5	3205	-48000	13300	1.122	+3238	+49000	14200	1.119
6								
7								
8								
9								
10								
11								
12								
13								
14								
15								
16								
17								
18								
19								
20								
TOTAL	5	5	5	5	5	5	5	5
MEAN	3210	48600	13300	1.132	3214	47500	14200	1.110
CF								
COR'D								
EX VAR	26	1000	200	.124	49	2900	500	.089
STD DEV	9	400	100		20	1000	200	

CASUALTIES 0

		C.P.	Port #1	Port #2
REMARKS	#3	C.M.#2	gage	open
	#4	C.M.#2	plug	gage

Port#1 .060 d" & .050 L Port #2 .093" d & .050" L

PROOF TECHNICIANS Lachman & Brown

FOREMAN

X.O. 47070-31-001

Sheet 2 of 3

DATE 21 Feb 1975

CHIEF BALLISTICIAN

REF RD DATA
AUTH
CASE LOT
BULLET LOT
PROPELLANT
JAR CHG
VEL VAL
CP VAL
PP VAL

SMUFA-U Form 10, 29 May 66

Table IB (continued)

FRANKFORD ARSENAL

PROPELLANT	Engineering Proof Testing Record	AMMUNITION
TYPE WC 844	TEST Velocity, Chamber & Port Pressure, Action Time	LOT LC-5.56m -001
ARMY LOT 46614		TYPE M193
CHARGE 27.7 Grs	SPEC/AUTH	CALIBER 5.56mm
		BULLET Ball
	OBJECT 5.56mm PortHole Study	CASE Brass

REC/UNIV NO FA 36	BRL NO R 80	TRFD 2420	STORED +70 °F
REC/UNIV NO	BRL NO	TRFD	PERIOD 2 hours
REC/UNIV NO	BRL NO	TRFD	FIRED AT +70 °F
REC/UNIV NO	BRL NO	TRFD	

SHOT NO	Vel	#5 C.P.	P.P.	A.T.				
1	-3200	48000	13300	+1.160				
2	3228	49000	13000	-1.070				
3	3204	+50400	-13000	1.109				
4	3206	-47800	+13300	1.134				
5	+3229	50000	13200	1.116				
6								
7								
8								
9								
10								
11								
12								
13								
14								
15								
16								
17								
18								
19								
20								
TOTAL	5	5	5	5				
MEAN	3213	49000	13200	1.118				
CF								
COR'D								
EX VAR	29	2600	300	.090				
STD DEV	13	1000	100					

CASUALTIES 0

REMARKS #5 C.P. C.M.#2 — Port #1 Open — Port#2 gage

Port#1 .060" d & .050" L

Port#2 .093" d & .050" L

PROOF TECHNICIANS Lachman & Brown

FOREMAN

X.O. 47070-31-001

Sheet 3 of 3

DATE 21 Feb 1975

CHIEF BALLISTICIAN

REF RD DATA

AUTH

CASE LOT

BULLET LOT

PROPELLANT

JAR CHG

VEL VAL

CP VAL

PP VAL

SMUFA-U Form 10, 28 May 66

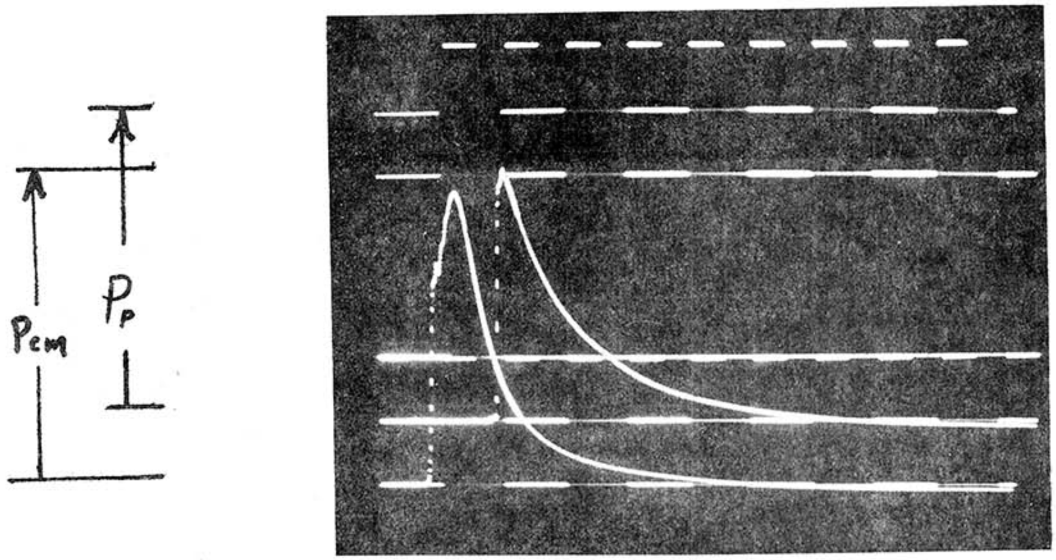
TEST PROCEDURE FOR PHASE II

The important difference between Phase I and Phase II is that a plenum or gas port collecting chamber was used in Phase II whereas in Phase I the gas through the port was vented to the atmosphere. The Frankford Arsenal Automatic Range Management System* (ARMS) was used during Phase II to record, digitize, integrate and plot the experimental data. Figure 7 shows the pressure at the case mouth and port when the .089" diameter hole is plugged. ~~Notice that~~ No ~~rarefaction is evident~~.

Continue

* This system was developed under Contract DAAA-25-74-C 0202. The contract was supervised by Mr. F. Stowell formerly of the Test and Evaluation Office, Technical Support Directorate, Frankford Arsenal.

It may be noticed that the rarefaction which occurred when the gases vented to the atmosphere (Phase I) is now missing. Table II shows a printout from the ARMS system containing the results of a 10 round program with the .089" hole plugged as in Figure 7. Both case mouth pressure and port pressues (peak and integral values) are shown. The Modified A.T. is the time from sweep initiation until the projectile reaches the port. Figure 8 is the ARMS plot of the case mouth pressure from Table II. Figure 9 is the ARMS plot of the port pressure from Table II. Figure 8A shows the pressure-time traces at the case mouth position, the port position and in the plenum chamber when the 0.060 inch diameter port was used in the test. Table III shows a printout from the ARMS system containing the results of a 10 round program with a .060" diameter hole which vents to the plenum chamber. Figure 10 is ARMS plot of the case mouth pressure taken from Tablè III. Figure 11 is an ARMS plot of the port pressure taken from Table III. Figure 12 is an ARMS plot of the plenum pressure taken from Table III. Figure 13 shows the pressure-time traces when the 0.089 inch diameter hole was used in the test. Table IV shows the computer printout from the ARMS system containing the results of a 10 round program with a 0.089" diameter hole which vents to the plenum chamber. Figure 14 is an ARMS plot of the case mouth pressure taken from Table IV. Figure 15 is an ARMS plot of the port pressure taken from Table IV. Figure 16 is an ARMS plot of the plenum chamber pressure taken from Table IV.



Rd #4 .089" Hole Plugged

P_{CM} = Case Mouth Calibration 54.12 KPSI
P_P = Port Calibration 16.236 KPSI

FIGURE 7

TABLE II

PORT PRESSURE STUDY LOT # 1

TYPE 7 RANGF 10 DOY 069 SHIFT A TECHNICIAN WBROW WORK ORDEP INFO 4707031004

AMMUNITION DATA: LOT1 OR REFERENCE LOT LC-Y-507 LOT 2 BAJ44959 LOT 3 LOT 4 COMPUTER REF LOT ID 0
CALIBER 5.56MM TYPE M193 CASE BRASS BULLET BALL JACKET GMCS TEMPERATURE 70 HUMIDITY 55

WEAPON DATA: TYPE PRES BRL SERIAL RECEIVER 87-25 BARREL WLK-374 BASE LINE (FT) 0 CP USE

PARAMETER	A/D 1	A/D 2	A/D 3
USE CODE	2	2	2
MUL RATE	6	6	5
SERIAL NUMBER	KIC343	KIC363	KIC363
CAL SIGNAL	54.120	16.236	16.236
GND SIGNAL	.000	.000	.000
LIMIT CHECK USE	0	0	0
LOW LIMIT	0	0	0
HIGH LIMIT	0	0	0
UNITS	KPSI	KPSI	KPSI
INT. UNITS	KPSEC	KPSEC	KPSEC
COR. FACT. USE	0	0	0

PARAMETER	C1	C2	C3	C4
USE CODE	1	1	2	1
UNITS	SEC	SEC	F/S	SEC
CLOCK RATE	0	0	0	0
BASELINE	.00	.00	20.00	.00
UNITS			FEET	
LIMIT CHECK USE	0		1	0
LOW LIMIT	0	0	6154	0
HIGH LIMIT	0	0	6299	0
COR. FACT. USE	0	0	0	0

RND NO	A/D #1 PEAK (10y Sample, Case mouth)	A/D #1 INTEGRAL	A/D #2 PEAK (10y Sample, Normal Port Position)	A/D #2 INTEGRAL	A/D #3 PEAK (Sample, Normal Port Position)	A/D #3 INTEGRAL	C1 (Modified A.T. (To Port))	C2	C3 (@ 15' Velocity)	C4 (Normal A.T.)	CR
1	50.8	.283F-01	13.1	.733E-02	13.0	.840F-02	.95100E-03	-1.0000	3214.9	.11280E-02	
2	50.4	.281E-01	13.3	.733E-02	13.1	.865E-02	.99400E-03	-1.0000	3206.7	-1.0000	
3	50.0	.282F-01	13.3	.733E-02	13.3	.864E-02	.10050E-02	-1.0000	3195.9	.11820E-02	
4	51.2	.281F-01	13.2	.740F-02	13.2	.852E-02	.94100E-03	-1.0000	3209.2	.11180E-02	
5*	54.4	.276F-01	12.9	.726E-02	12.8	.832E-02	.92800E-03	-1.0000	3268.0	.11010E-02	
6	52.7	.291E-01	13.3	.731E-02	13.4	.848E-02	.97200E-03	-1.0000	3222.2	.11480E-02	
7	50.5	.276F-01	13.3	.737E-02	13.1	.865E-02	.98300E-03	-1.0000	3222.2	.11600E-02	
8	54.8	.285F-01	12.9	.714E-02	12.9	.826E-02	.96300E-03	-1.0000	3234.2	-1.0000	
9	52.9	.283E-01	13.1	.729E-02	13.1	.849E-02	.96600E-03	-1.0000	3246.2	.11410E-02	
10	51.7	.284F-01	13.3	.734E-02	13.4	.853E-02	.97500E-03	-1.0000	3209.2	-1.0000	
CF											
-3SD	47.2	.270E-01	12.7	.711E-02	12.5	.811E-02	.90082E-03	-1.0000	3161.8	-1.6755	
LOW	50.0	.276E-01	12.9	.714E-02	12.8	.826E-02	.92800E-03	-1.0000	3195.9	-1.0000	
MEAN	51.9	.282E-01	13.2	.731E-02	13.1	.849E-02	.96780E-03	-1.0000	3222.9	-.29920	
HIGH	54.8	.291E-01	13.3	.740E-02	13.4	.865E-02	.10050E-02	-1.0000	3268.0	.11820E-02	
+3SD	56.7	.295E-01	13.6	.751E-02	13.7	.888E-02	.10348E-02	-1.0000	3283.9	1.0771	
S.D.	1.60	.419E-03	.145	.668E-04	.195	.129E-03	.22327E-04	.00000E+00	20.347	.45878	

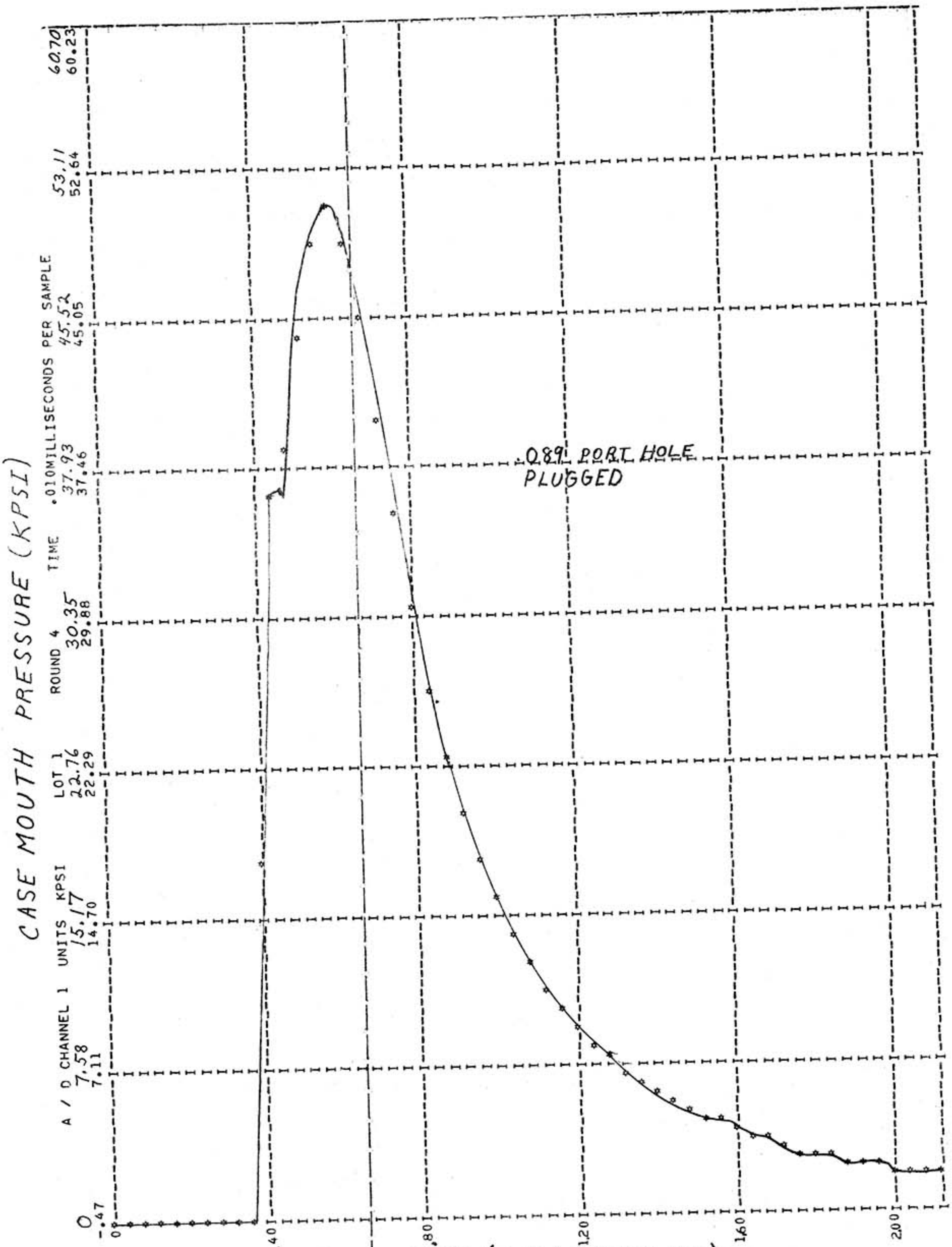
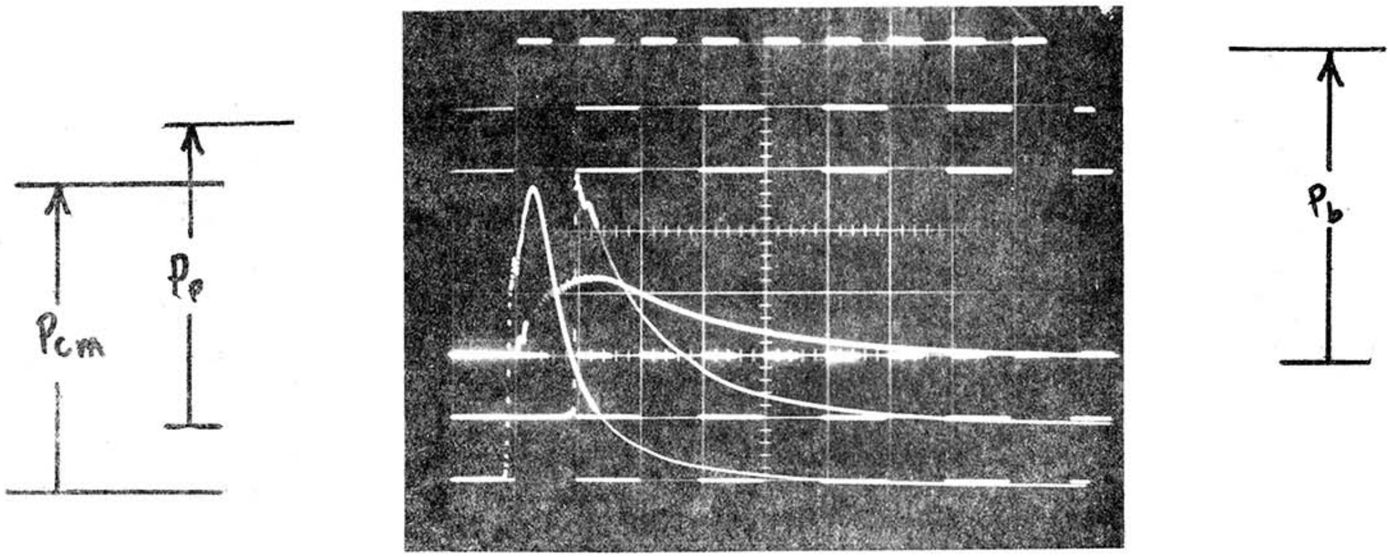


FIG. 8 TIME (MILLISECONDS)



Rd#3 .060" Diameter Port Hole

P_{cm} = Case Mouth Calibration 54.12 KPSI
P_p = Port Calibration 16.236 KPSI
P_b = Plenum Chamber Calibration 7.216 KPSI

Sweep:
Casemouth and Port 1ms/2cm
Plenum Chamber 1ms/cm.

Figure 8A

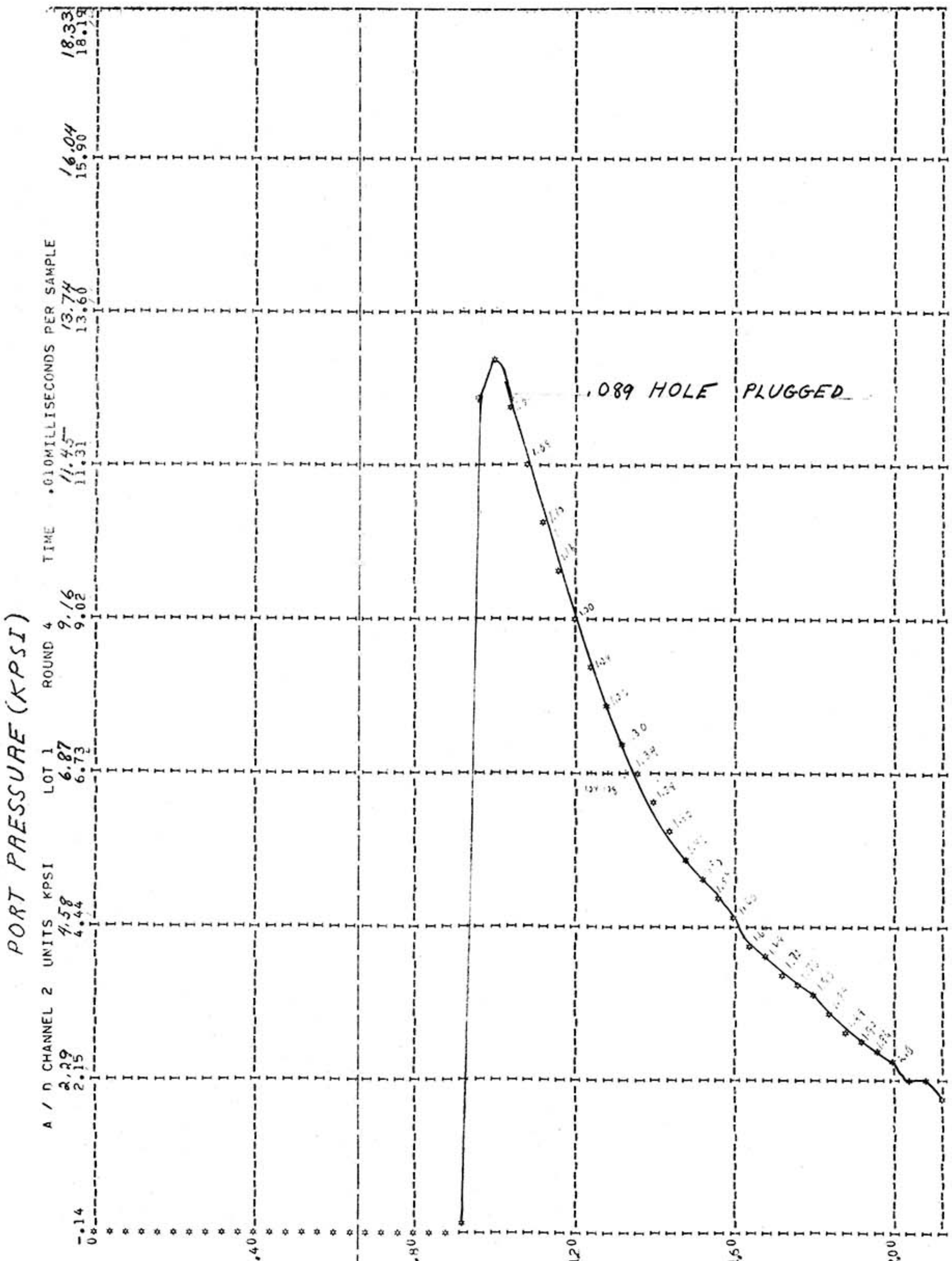


FIG 9 TIME (MILLISECONDS)

TABLE III

PORT PRESSURE STUDY LOT # 1

.060 DIA. PORT

TYPE 7 RANGE 10 DOY 069 SHIFT A TECHNICIAN WBROW WORK ORDER INFO 4707031004

AMMUNITION DATA: LOT1 OR REFERENCE LOT LC-Y-507 LOT 2 BAJ44959 LOT 3 LOT 4 COMPUTER REF LOT ID 0
CALIBER 5.56MM TYPE M193 CASE BRASS BULLET BALL JACKET GMCS TEMPERATURE 70 HUMIDITY 55

WEAPON DATA: TYPE PRES BRL SERIAL RECEIVER 87-25 BARREL WLK-374 BASE LINE (FT) 0 CR USE

PARAMETER	A/D 1	A/D 2	A/D 3	A/D 4
USE CODE	2	2	2	2
MUL RATE	6	6	5	5
SERIAL NUMBER	KIC343	KIC363	KIC363	KIC480
CAL SIGNAL	54.120	16.236	16.236	7.216
GND SIGNAL	.000	.000	.000	.000
LIMIT CHECK USE	0	0	0	0
LOW LIMIT	0	0	0	0
HIGH LIMIT	0	0	0	0
UNITS	KPSI	KPSI	KPSI	KPSI
INT. UNITS	KPSEC	KPSEC	KPSEC	KPSEC
COR. FACT. USE	0	0	0	0

PARAMETER	C1	C2	C3	C4
USE CODE	1	1	2	1
UNITS	SEC	SEC	F/S	SEC
CLOCK RATE	0	0	0	0
BASELINE	.00	.00	20.00	.00
UNITS			FEET	
LIMIT CHECK USE	0	0	1	0
LOW LIMIT	0	0	6154	0
HIGH LIMIT	0	0	6299	0
COR. FACT. USE	0	0	0	0

RND NO	A/D #1 PEAK (Case Mouth, 10 μsec)	A/D #1 INTEGRAL	A/D #2 PEAK (Port Pressure, 10 μsec)	A/D #2 INTEGRAL	A/D #3 PEAK (normal Port Pressure, 20 μsec)	A/D #3 INTEGRAL	A/D #4 PEAK (Modified (.060" port) Port Pressure, 20 μsec)	A/D #4 INTEGRAL	C1	C2	C3	C4	CR
1	52.5	.279E-01	12.8	.672E-02	13.1	.778E-02	1.82	.418E-02	.10040E-02	-1.0000	3212.9	.11810E-02	
2	52.3	.292E-01	12.9	.686E-02	12.2	.788E-02	1.82	.429E-02	.97300E-03	-1.0000	3215.4	.11510E-02	
3	51.0	.277E-01	12.7	.679E-02	12.4	.786E-02	1.82	.422E-02	.98200E-03	-1.0000	3213.4	.11600E-02	
4	52.6	.281E-01	12.9	.684E-02	13.2	.799E-02	1.83	.425E-02	.98900E-03	-1.0000	3235.2	.11650E-02	
5	50.9	.277E-01	12.8	.699E-02	13.0	.810E-02	1.86	.434E-02	.93600E-03	-1.0000	3217.0	.11130E-02	
6	52.1	.279E-01	12.8	.683E-02	12.9	.793E-02	1.83	.423E-02	.98000E-03	-1.0000	3229.5	.11570E-02	
7	51.0	.268E-01	13.0	.682E-02	12.9	.787E-02	1.83	.423E-02	.96500E-03	-1.0000	3217.0	.11420E-02	
8	52.3	.290E-01	12.8	.685E-02	12.2	.792E-02	1.86	.432E-02	.96300E-03	-1.0000	3224.2	.11400E-02	
9	51.2	.278E-01	13.1	.688E-02	12.7	.791E-02	1.86	.431E-02	.95400E-03	-1.0000	3224.2	.11310E-02	
10	52.8	.278E-01	13.2	.696E-02	13.3	.814E-02	1.83	.429E-02	.96800E-03	-1.0000	3234.7	.11440E-02	
CF													
-3SD	49.7	.260E-01	12.5	.664E-02	11.7	.762E-02	1.79	.412E-02	.91739E-03	-1.0000	3198.3	.10944E-02	
LOW	50.9	.268E-01	12.7	.672E-02	12.2	.778E-02	1.82	.418E-02	.93600E-03	-1.0000	3212.9	.11130E-02	
MEAN	51.9	.280E-01	12.9	.686E-02	12.8	.794E-02	1.83	.427E-02	.97140E-03	-1.0000	3222.3	.11484E-02	
HIGH	52.8	.292E-01	13.2	.699E-02	13.3	.814E-02	1.86	.434E-02	.10040E-02	-1.0000	3235.2	.11810E-02	
+3SD	54.0	.299E-01	13.3	.707E-02	13.9	.825E-02	1.88	.441E-02	.10254E-02	-1.0000	3246.3	.12024E-02	
S.D.	.722	.650E-03	.135	.729E-04	.374	.105E-03	.154E-01	.490E-04	.18003E-04	.00000E+00	8.0000	.17988E-04	

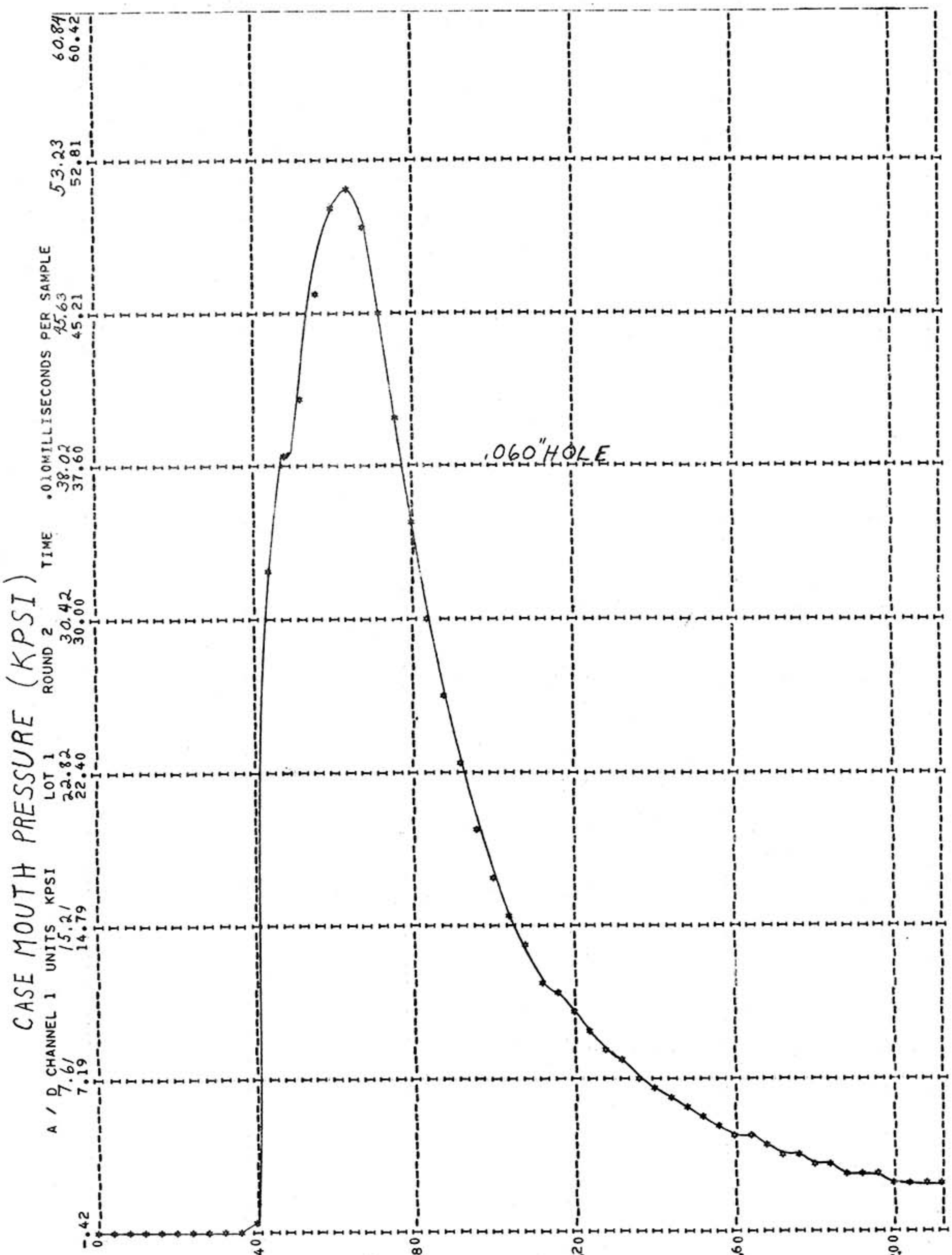


FIG-10 TIME (MILLISECONDS)

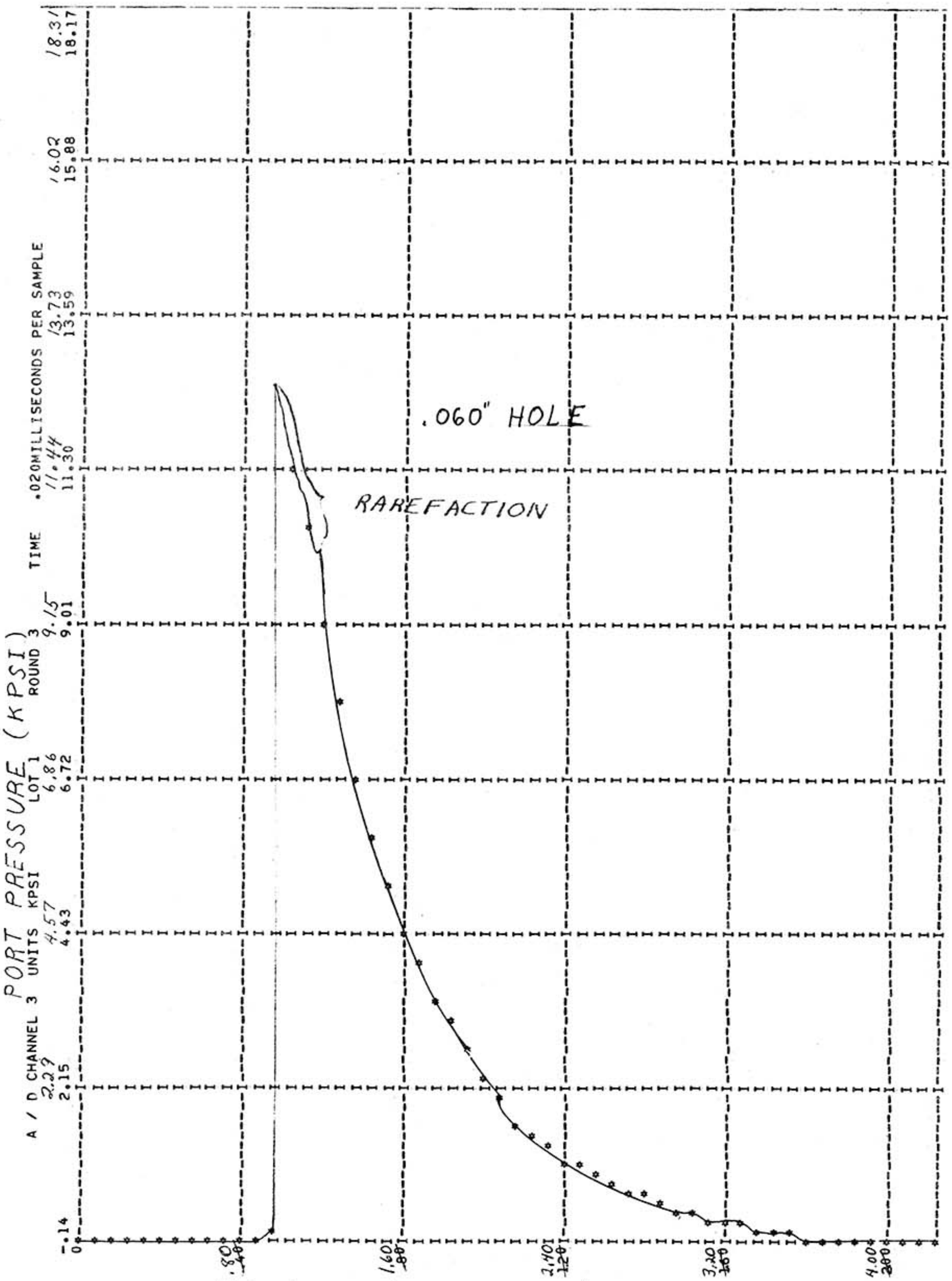


FIG 11 TIME (MILLISECONDS)

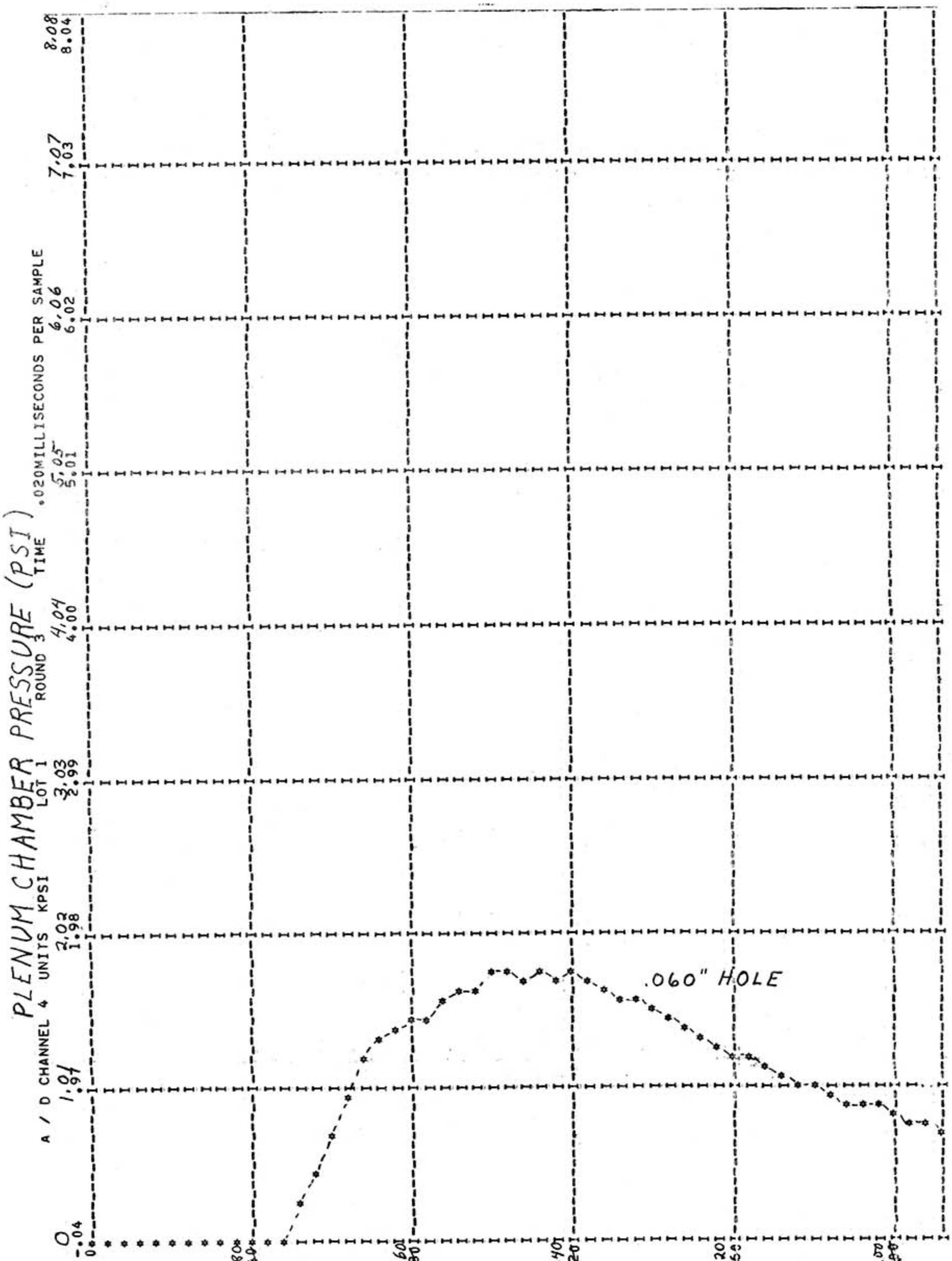
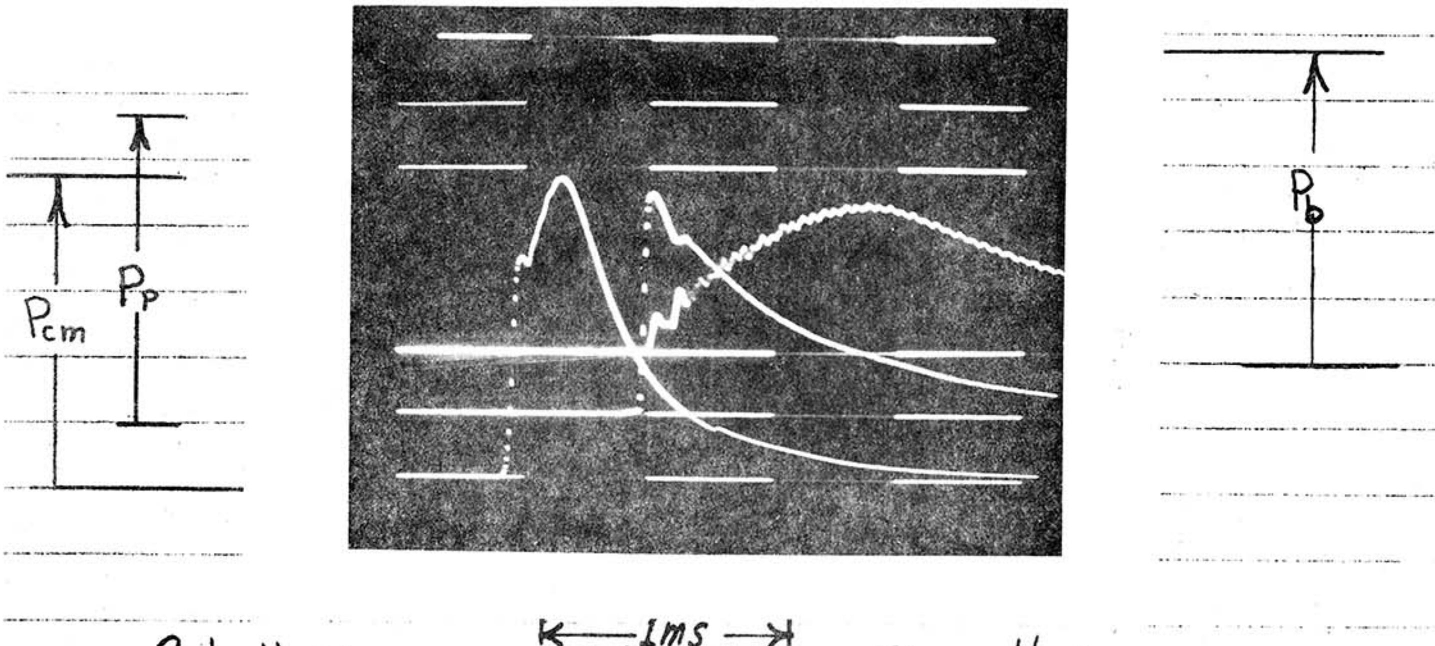


FIG 12 TIME (MILLISECONDS)



Rd # 2 .089" Diameter Port Hole

P_{cm} = Case Mouth Calibration 54.12 KPSI
P_p = Port Calibration 16.236 KPSI
P_b = Plenum Chamber Calibration 7.216 KPSI

Figure 13

TABLE IV

PORT PRESSURE STUDY LOT # 1

.089" DIA. PORT

TYPE 7 RANGE 10 DOY 069 SHIFT A TECHNICIAN WBROW WORK ORDER INFO 4707031004

AMMUNITION DATA: LOT1 OR REFERENCE LOT LC-Y-507 LOT 2 BAJ44959 LOT 3 LOT 4 COMPUTER REF LOT ID 0
CALIBER 5.56MM TYPE M193 CASE BRASS BULLET BALL JACKET GMCS TEMPERATURE 70 HUMIDITY 55

WEAPON DATA: TYPE PRES BRL SERIAL RECEIVER 87-25 BARREL WLK-374 BASE LINE (FT) 0 CR USE

PARAMETER	A/D 1	A/D 2	A/D 3	A/D 4
USE CODE	2	2	2	2
MUL RATE	6	6	5	5
SERIAL NUMBER	KIC343	KIC363	KIC363	KIC480
CAL SIGNAL	54.120	16.236	16.236	7.216
GND SIGNAL	.000	.000	.000	.000
LIMIT CHECK USE	0	0	0	0
LOW LIMIT	0	0	0	0
HIGH LIMIT	0	0	0	0
UNITS	KPSI	KPSI	KPSI	KPSI
INT. UNITS	KPSEC	KPSEC	KPSEC	KPSEC
COR. FACT. USE	0	0	0	0

PARAMETER	C1	C2	C3	C4
USE CODE	1	1	2	1
UNITS	SEC	SEC	F/S	SEC
CLOCK RATE	0	0	0	0
BASELINE	.00	.00	20.00	.00
UNITS			FEET	
LIMIT CHECK USE	0	0	1	0
LOW LIMIT	0	0	6154	0
HIGH LIMIT	0	0	6299	0
COR. FACT. USE	0	0	0	0

RND NO	A/D #1 (11 μsec Case Mouth) PEAK	INTEGRAL	A/D #2 (11 μsec Normal Port Pressure) PEAK	INTEGRAL	A/D #3 (20 μsec Normal Port Pressure) PEAK	INTEGRAL	A/D #4 (20 μsec Modified Port Pressure ← (.089" hole)) PEAK	INTEGRAL	C1	C2	C3	C4	CR
1	50.2	.270E-01	11.4	.649E-02	11.3	.815E-02	3.51	.563E-02	.99700E-03	-1.0000	3217.0	.11720E-02	
2	52.4	.277E-01	11.6	.653E-02	11.6	.804E-02	3.47	.571E-02	.97700E-03	-1.0000	3231.5	.11520E-02	
3	49.6	.273E-01	11.3	.654E-02	11.4	.798E-02	3.47	.567E-02	.95300E-03	-1.0000	3198.0	.11310E-02	
4	50.8	.269E-01	11.8	.660E-02	11.7	.806E-02	3.53	.579E-02	.96100E-03	-1.0000	3200.0	.11380E-02	
5	53.9	.287E-01	11.7	.649E-02	11.6	.795E-02	3.44	.571E-02	.97500E-03	-1.0000	3229.5	.11500E-02	
6	49.5	.277E-01	11.5	.648E-02	11.4	.791E-02	3.54	.579E-02	.98800E-03	-1.0000	3190.8	.11660E-02	
7	51.2	.277E-01	11.7	.656E-02	11.6	.799E-02	3.54	.585E-02	.97100E-03	-1.0000	3208.7	.11490E-02	
8	51.7	.290E-01	11.6	.645E-02	11.6	.788E-02	3.54	.579E-02	.98100E-03	-1.0000	3208.2	.11580E-02	
9	52.4	.272E-01	11.6	.656E-02	11.6	.790E-02	3.44	.570E-02	.93300E-03	-1.0000	3226.3	.11090E-02	
10	53.0	.287E-01	12.0	.638E-02	11.8	.787E-02	3.54	.585E-02	.99400E-03	-1.0000	3222.2	.11710E-02	
CF													
-3SD	47.3	.257E-01	11.1	.633E-02	11.2	.772E-02	3.39	.553E-02	.91710E-03	-1.0000	3173.0	.10940E-02	
LOW	49.5	.269E-01	11.3	.638E-02	11.3	.787E-02	3.44	.563E-02	.93300E-03	-1.0000	3190.8	.11090E-02	
MEAN	51.5	.278E-01	11.6	.651E-02	11.5	.797E-02	3.50	.575E-02	.97300E-03	-1.0000	3213.2	.11496E-02	
HIGH	53.9	.290E-01	12.0	.660E-02	11.8	.815E-02	3.54	.585E-02	.99700E-03	-1.0000	3231.5	.11720E-02	
+3SD	55.7	.299E-01	12.1	.669E-02	11.9	.823E-02	3.62	.596E-02	.10289E-02	-1.0000	3253.5	.12052E-02	
S.D.	1.40	.700E-03	.171	.596E-04	.123	.850E-04	.385E-01	.719E-04	.18633E-04	.00000E+00	13.416	.18529E-04	

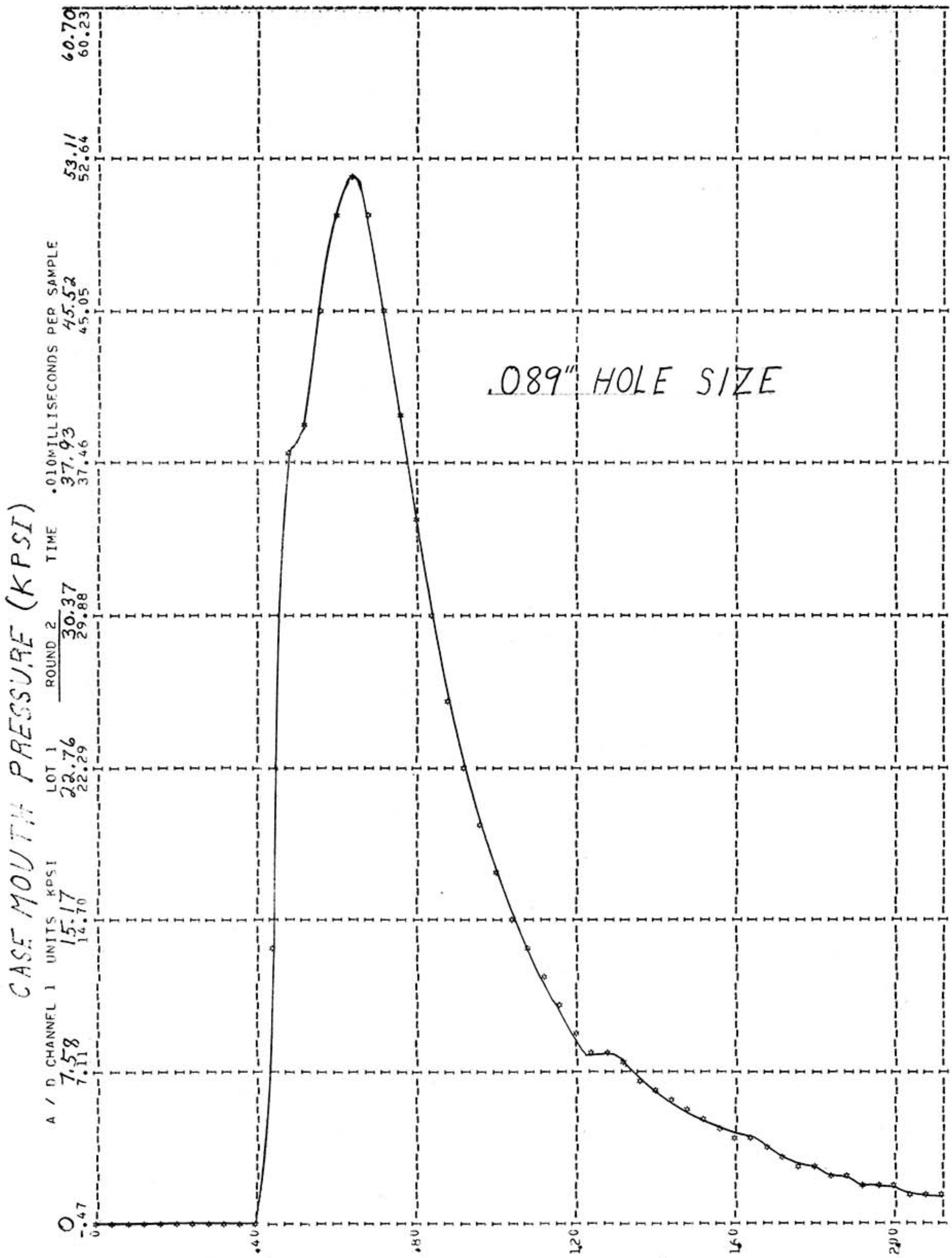


FIG 14 TIME (MILLISECONDS)

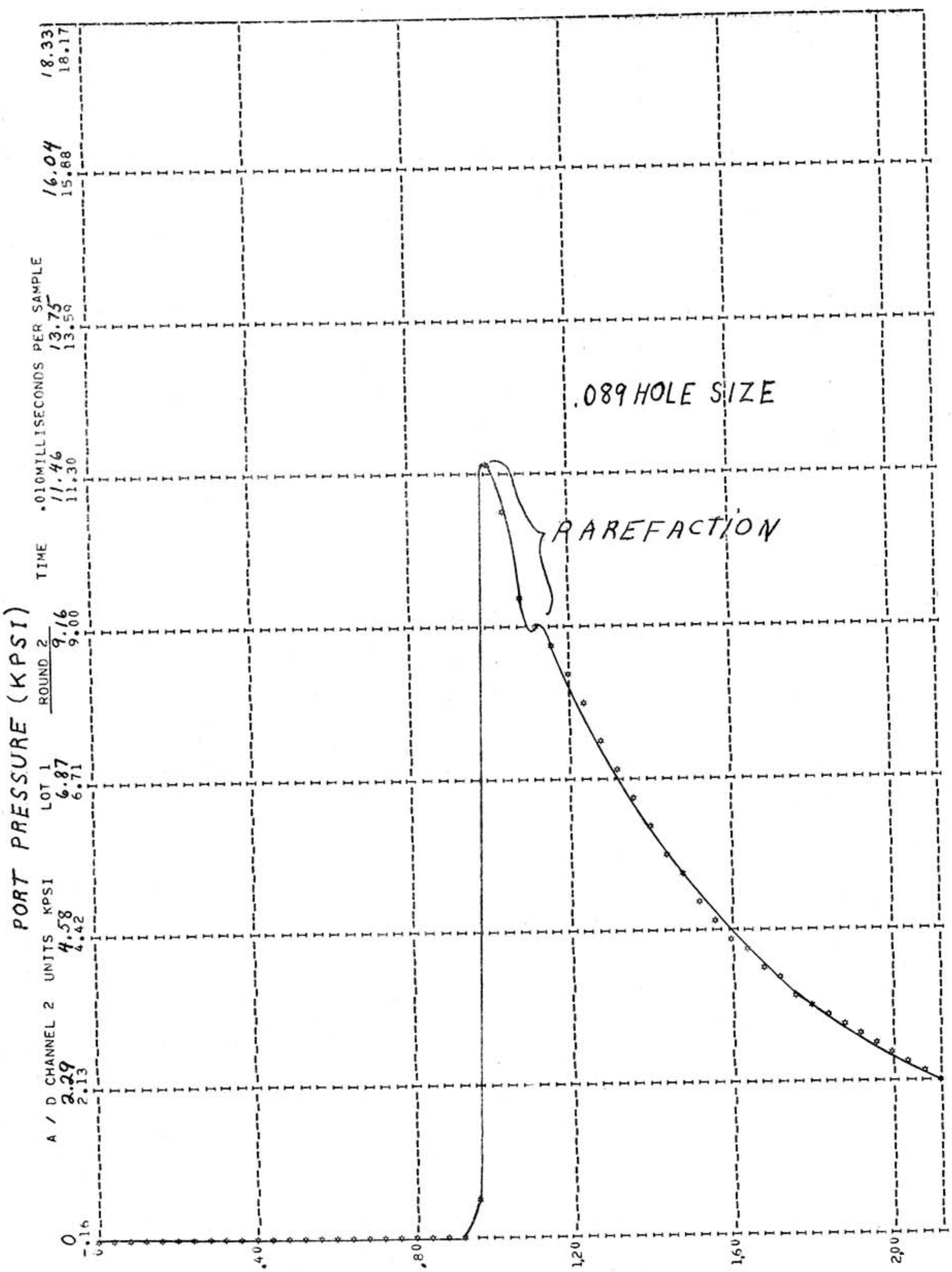


FIG 15 TIME (MILLISECONDS)

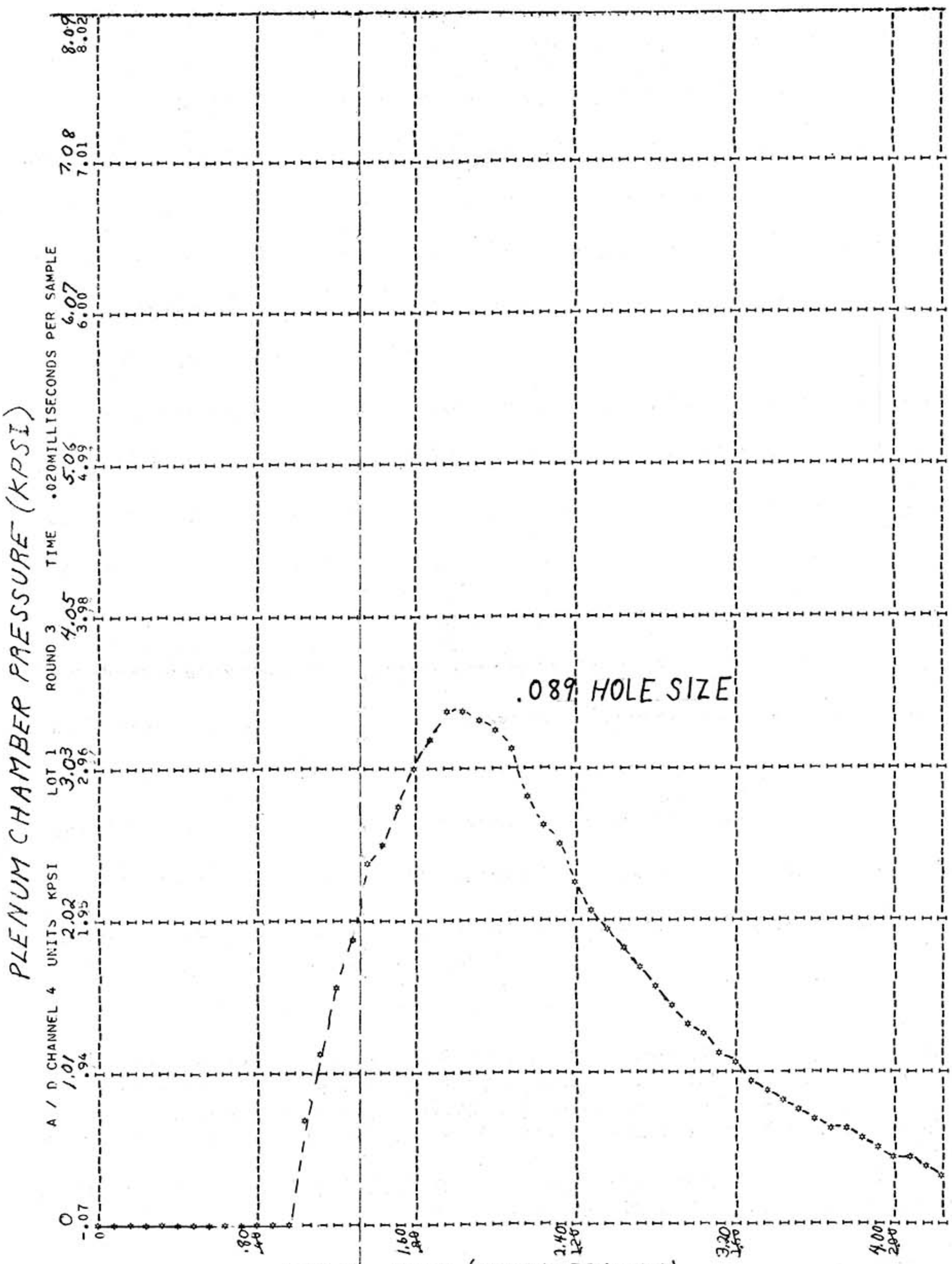


FIG 16 TIME (MILLISECONDS)

THEORY

The formulation of any complete theory on the gas flow through the pressure port in a gas operated small arms weapon is a very difficult problem. The initial flow field may be characterized as three-dimensional, compressable non-steady flow. Beans* has done work describing the flow of gas through a rifle port. He has developed a technique for describing th~~is type of~~ port flow by using quasisteady incompressable turbulent flow model which employs emperical data on nozzle efficiencies, and coefficients of discharge. A more complete theory should include a nonsteady compressable flow model during the passage of the projectile over the port combined with a quasisteady model to describe the flow after the projectile has left the muzzle. This is the approach used in this report. The nonsteady flow process which occurs when the port is being uncovered by the projectile ~~may be analogous to that identified with the starting process of a hypersonic nozzle**~~ has been mentioned previously.** This flow will be described in this report by using the method of characteristics. The quasisteady flow will be described by using a two-dimensional incompressible potential flow solution and applying the Karmen-Tsien pressure correction formula. The method of characteristics has been used successfully** to describe the nonsteady flow through the gas tube in the M16A1 rifle.

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*"Weapons Dynamics - Gas Dynamics Study", by E.W. Beans, The Ohio State University Research Foundation, Columbus, Ohio. Contract DAAF03-70-C-0033. Technical Report SWERR-TR-72-79 Research Directorate Weapons Laboratory, WECOM, Research Development & Engineering Directorate, US Army Weapons Command.

** "Model for the Gas Transmission System of the M16A1 Rifle", by S. Goldstein, Frankford Arsenal Report, R-3009, May 1974.

A. NONSTEADY FLOW THRU GAS PORT

The flow through the port which occurs when the projectile first passes the port may, in some respects, be analogous to that identified with the starting process in a hypersonic nozzle[1]. A shock wave, contact surface and centered expansion wave are created at the nozzle entrance. The change in nozzle area also causes a secondary shock to appear at the tail of the expansion. The flow of the gas from the weapon barrel to the port is even more complicated than that of a starting hypersonic nozzle because of the finite time required to expose the port by the projectile and also because of the change of the direction of flow of the gas in going from the barrel to the port.

To model the nonsteady flow of the gas from the barrel to the port during the time it is first exposed to the gases while the projectile is passing, it is necessary to make several simplifying assumptions:

1. The nonsteady flow of the gases through the port will be one dimensional (normal to the axis of the barrel).

2. The magnitude of the expansion wave (i.e. distance between the head and tail at the barrel wall opposite the port) created when the port is being exposed to the gases in the barrel will be dependent upon the time required for the projectile to pass the port. Thus, a larger size port will require a longer time for the projectile to pass and correspondingly,

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(1) C. E. Smith, Jr., "An Analytic Study of the Starting Process in a Hypersonic Nozzle," Proceedings of Heat Transfer and Fluid Mechanics, University of CA, Berkeley, LA, June 10-12, 1964.

a longer time between the head and tail of the expansion wave. This approach in the case of a port in a rifle barrel is somewhat analogous to the gradual removal of a diaphragm in a shock tube[2]. It results in a steepening compression wave through the port downstream of the accelerating ~~of the~~ contact surface followed by an expansion wave which increases during the time of the contact surface is accelerating (See Figure 1).

3. The quasisteady flow of the gases in the barrel at the port location (which is determined by the solution of the interior ballistic equations[3,4] and which is assumed independent of the gas flow out the port) can be used to establish the initial and boundary condition for the nonsteady flow of the gases out the port.

4. The gas is assumed to be ideal and the values of specific heats are constant.

5. The entropy of the gas is constant and uniform - isentropic flow:

(Such flows* have also been called homentropic)

METHOD OF SOLUTION

The technique[5] used for solving the conservation equations which form a set of quasi-linear partial differential equations of the first

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(2) I.I. Glass, W. Martin, and G. N. Patterson, 1953 Institute of Aerophysics, University of Toronto, UTIA Rep. No. 2.

(3) "Study of the Temperature Effects on the Ballistic Performance of 5.56mm Ammunition" by S. Goldstein & J. Duffy, FA Report (FA-TR-76008)

(4) "An Improved Interior Ballistic Model for Small Arms Using Deterred Propellant" by T. Trafton, BRL Report NO. 1624, November 1972.

(5) "Nonsteady Duct Flow: Wave Diagram Analysis" by George Rudinges, Dover, Publications, Inc., New York, NY, 1969.

order and hyperbolic type is known as the method of characteristics. In this approach, the dependent variable becomes the P and Q Riemann variables where:

$$P = \frac{2}{\gamma - 1} a + u$$

$$Q = \frac{2}{\gamma - 1} a - u$$

The solutions are determined along these P and Q characteristics. These characteristics represent lines along which infinitesimal disturbance are propagated at the local speed of sound. The P characteristics are propagated with a speed $\frac{dx}{dt} = u + a$, the Q characteristics with a speed $\frac{dx}{dt} = u - a$ and the gas particle is propagated with speed $\frac{dx}{dt} = u$. Since the gas is assumed to be ideal, the equation of state is $p = \rho RT$ and the speed of sound is given by $a^2 = \gamma RT$

The relationship between the entropy, pressure, and temperature is

$$s - s_1 = C_p \ln \frac{T}{T_1} - \frac{R}{gJ} \ln \frac{p}{p_1}$$

where subscript 1 indicates reference state (i.e. at atmospheric conditioning $s_1 = 0$). A dimensionless entropy S is used in the computer program where

$$S = \frac{gJs}{\gamma R}$$

The pressure at any point can be related to the speed sound and dimensionless entropy by

$$p = p_1 \left(\frac{a}{a_1}\right)^{\frac{2\gamma}{\gamma - 1}} e^{-\gamma(S - S_1)}$$

NUMERICAL PROCEDURE

The solution to the governing equations is obtained by using a numerical procedure. Through each point of the wave diagram passes one curve from each of the characteristics.

There are three types of grid points considered in the solution. These consists of boundary points (a, b, c, d, e), interior points (f, g, h, i, j), and points along the contact surface (k, l, m, n,). Figure I illustrates the location of these points.

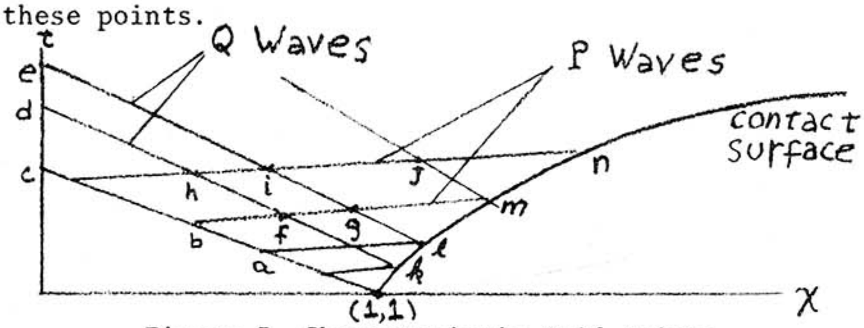

Figure I, Characteristic Grid Points

Boundary Points

Boundary points are generated in the computer program by Subroutine Start. The initial point (1,1) is obtained from a separate computer program* which describes the interior ballistics of the weapon.(3) Quantities which are necessary are:

1. The speed of the projectile as it passes the port (V01)

2. The temperature (T01) of the gas when the projectile first passes the port

* See Appendix 1A for a sample computer output from this program

3. The projectile base pressure (PO1) when the projectile passes the port

4. The rate of change of base pressure $\dot{p}$ when the projectile first passes the port (DPDT)

5. The rate of change of gas temperature $\dot{T}$ when the projectile first passes the port (DTDT)

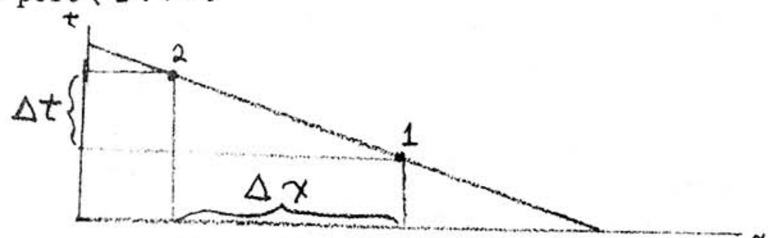

Figure II, Subroutine Start

Subroutine Start calculates a point 2 along the boundary (ie., the head of the rarefaction wave of the initial Q wave) from the known quantities at a previous point 1 on the boundary. The space interval Δx is held constant

1. The average velocity A of the Q characteristic is given by

$$\bar{A} = (A_1 + A_2)/2$$

2. The time for the Q characteristic to go from point 1 to point 2 is given by

$$\Delta t = \frac{\Delta x}{\bar{A}}$$

3. The pressure and temperature for point 2 is given by

$$p_2 = p_1 + \dot{p}\,\Delta t$$

$$T_2 = T_1 + \dot{T}\,\Delta t$$

4. The location of point 2 is given by

$$X_2 = X_1 - \Delta X$$

Note that along the left boundary (i.e., at the surface of the bore opposite to the port location) $X_2 = 0$.

5. The time of point 2 is $\tau_2 = \tau_1 + \Delta\tau$

6. The dimensionless entropy at point 2 is given by

$$S_2 = \frac{gJ}{\gamma R}\left\{ C_p \ln\frac{T_2}{T_1} - \frac{R}{gJ}\ln\frac{p_2}{p_1}\right\}$$

where $T_1 = T_{ref}$, $p_1 = p_{ref}$

7. Since the velocity of the gas is zero along the boundary, the Riemann variables P and Q are equal to

$$P_2 = Q_2 = \frac{2A_2}{\gamma - 1}$$

Thus all the flow variables and the time and location for point 2 are now determined.

CONTACT SURFACT POINTS:

The points along the contact surface are generated in the computer program by Subroutine Contact. From initial points 1 (on the intersection of the contact surface with the previous P characteristic) and point 2 (on the P characteristic whose intersection with the contact surface we are now calculating) we can determine point 4 (See Figure III).

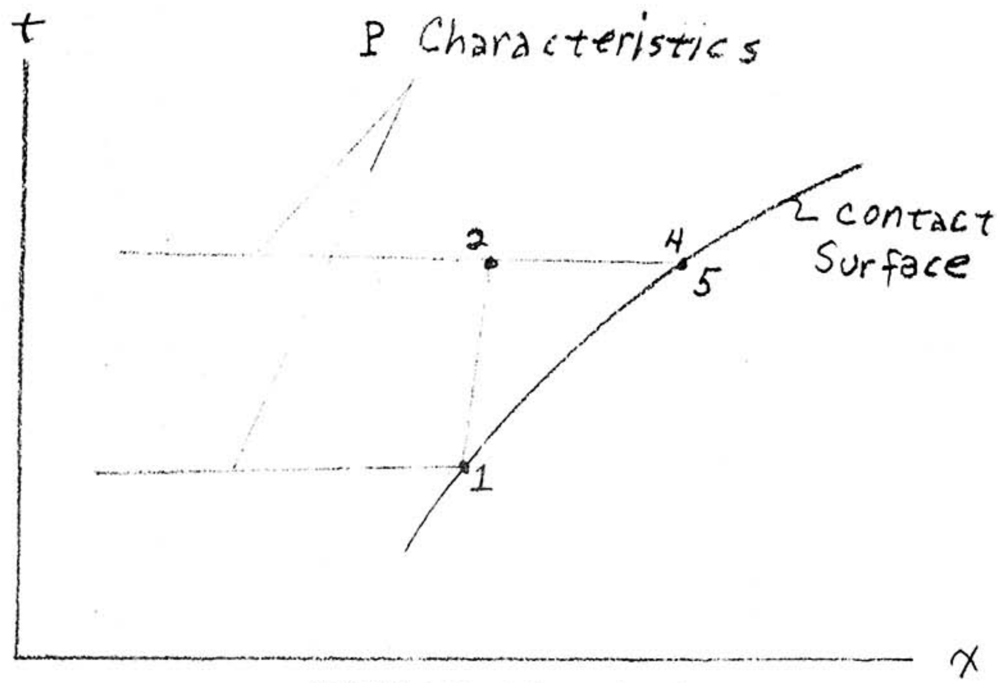

FIGURE III. Subroutine Contact

Point 5 is located on the downstream side of the contact surface.

1. Since we are assuming isentropic conditions, the following identities ~~are noted~~ hold

$$P_4 = P_2$$

$$S_4 = S_2$$

2. The speed of sound downstream of the contact surface (A_5) and the Q Riemann variable (Q_5) are determined by the reference speed of sound

$$A_5 = A_{ref}$$

$$Q_5 = \frac{2}{\gamma - 1} A_5$$

Likewise, the entropy at point 5 is given by $S_5 = S_{ref} = 0$

3. From Rudinger equations (See Reference 4), we can calculated A_4

$$A_4 = \frac{P_4 + Q_5}{\frac{2}{\gamma-1}\left[1 + e^{\frac{\gamma-1}{2}(S_5 - S_4)}\right]}$$

4. The gas temperature at point 4 is given by

$$T_4 = A_4^2/\gamma R$$

5. The gas velocity at point 4 is given by

$$U_4 = P_4 - \frac{2}{\gamma - 1} A_4$$

6. The Q Riemann at point 4 is

$$Q_4 = \frac{2}{\gamma - 1} A_4 - U_4$$

7. The pressure at point 4 is given by

$$P_4 = P_{ref} \left(\frac{A_4}{A_{ref}} \right)^{\frac{2\gamma}{\gamma - 1}} e^{-\gamma S_4}$$

8. The time coordinate of point 4 is given as

$$\tau_4 = \frac{(\chi_1 - \chi_2) - U_{1,4}\,\tau_1 + \lambda_{2,4}\,\tau_2}{\lambda_{2,4} - U_{1,4}}$$

where $U_{1,4} = \dfrac{U_1 + U_4}{2}$

and $\lambda_{2,4} = \dfrac{A_4 + U_4 + A_2 + U_2}{2}$

9. The position of point 4 is given as

$$\chi_4 = \lambda_{2,4}\,(\tau_4 - \tau_2) + \chi_2$$

INTERIOR POINTS

Points located at the intersection of a P characteristic with a Q characteristic are generated in the computer program by Subroutine Inter.

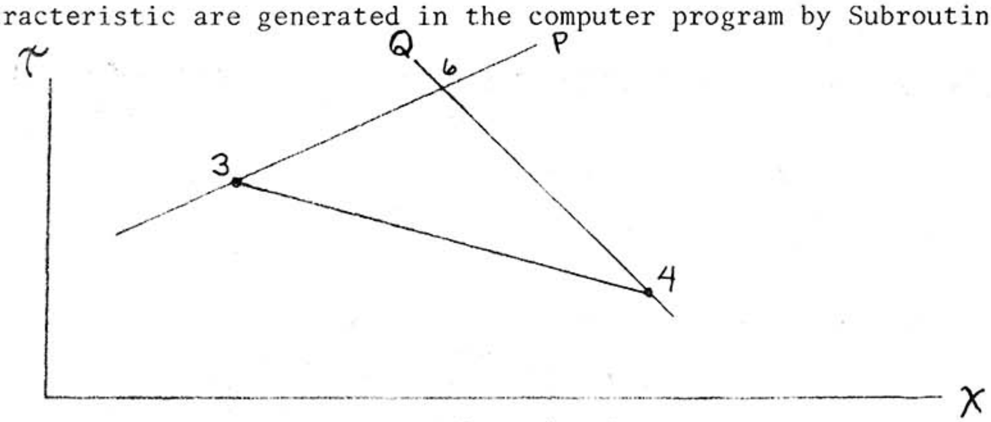

FIGURE IV, Subroutine Inter

Subroutine Inter calculates a point 6 at the intersection of a P characteristic from point 3 and a Q characteristic from point 4. All the gas properties and X - τ coordinates of points 3 and 4 are known from previous calculations. Also, this subroutine* calculates the pressure buildup in the plenum chamber during nonsteady flow.

1. Because of the assumption of uniform-isentropic flow, the entropy at point 6 will be equal to that at point 3.

$$S6 = S3$$

2. For the same reason the value of the P characteristic at point 6 is equal to that at point 3.

$$P6 = P3$$

Likewise

$$Q6 = Q4$$

3. The speed of sound of the gas at point 6 is given by the values of P and Q at point 6

$$A_6 = \frac{(\gamma - 1)}{4} \left(P_6 + Q_6 \right)$$

* By interpolating gas properties along the P characteristic between points 3 and 6 it is possible to find the pressure in the plenum chamber (see Appendix 2A).

4. The gas velocity at point 6 is given by

$$U_6 = (P_6 - Q_6)/2$$

5. The temperature at point 6 is determined by

$$T_6 = A_6^2/\gamma R$$

6. The pressure at point 6 is determined by

$$p_6 = p_{ref}\left(\frac{A_6}{A_{ref}}\right)^{\frac{2\gamma}{\gamma-1}} e^{-\gamma S_6}$$

where it is assumed that $S_{ref} = 0$

7. The time coordinate of point 6 is given by

$$\tau_6 = \frac{X_4 + X_3 + \tau_3 \lambda_{3,6} - \tau_4 \phi_{4,6}}{\lambda_{3,6} - \phi_{4,6}}$$

where
$$\lambda_{3,6} = \frac{U_3 + A_3 + U_6 + A_6}{2}$$

and
$$\phi_{4,6} = \frac{U_4 - A_4 + U_6 - A_6}{2}$$

8. The location of point 6 is given by

$$X_6 = X_3 + \lambda_{3,6}(\tau_6 - \tau_3)$$

CHARACTERISTIC MESH
(See Figure I)

The characteristic mesh[1] is constructed by building up points along the P characteristics starting from the boundary location (i.e. points a, b, c,...). This requires that Subroutine Start be called until the interal Q wave reaches the side of the barrel opposite to the port. At this point, Subroutine BREECH is called to calculate boundary conditions at the barrel wall opposite the port. When the value of the first subscript identifying a point equals that of the second subscript (ie, when $i = j$), then subroutine contact is called and the contact surface point is calculated. The control is then returned to the main program to calculate a new boundary point. An Auto flow chart set for the program is shown in ~~Figure V~~ Appendix 3A. The program checks to see when the projectile has completely uncovered the port. This time is used to locate the lost characteristic which is reflected from the wall of the barrel and the program is stopped. The flow of gas energy through the port and the buildup of pressure in the plenum chamber during the period of nonsteady flow are calculated in subroutine INTER. The properties of the gas through the port are determined by interpolating along the P characteristics.

B. TWO-DIMENSIONAL QUASI-STEADY COMPRESSIBLE FLOW THROUGH THE PORT

The flow of the gases through the port after the period of nonsteady flow will be described by applying the Karmen-Tsien pressure correction formula* to incompressible branch flow in a canal.** The Schwarz-Christoffel transformation is First used to find the complex potential for the flow of an incompressible fluid in a channel or canal which has a side branch.

Through suitable transformations the w-plane is related to the ζ plane through the relationship

$$\frac{dw}{d\zeta} = \frac{Uh}{\pi} \cdot \frac{1}{\zeta + a} - \frac{U_1 h_1}{\pi} \frac{1}{\zeta + b} + \frac{U_1 h_1 - Uh}{\pi} \frac{1}{\zeta - c}$$

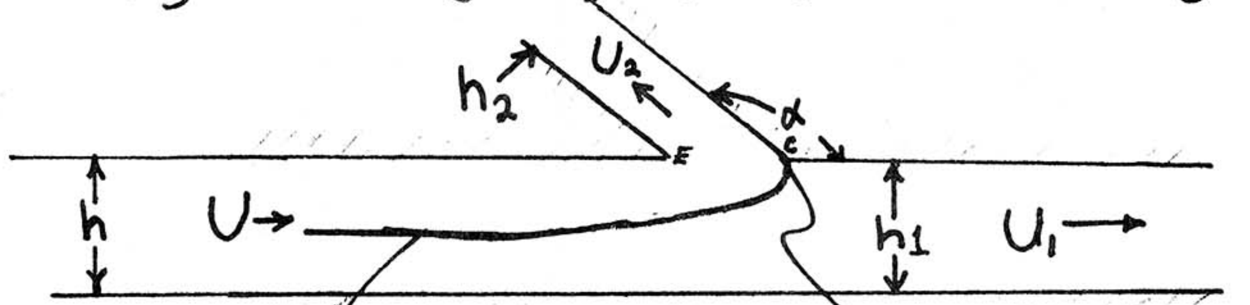

Figure A

Figure A shows the ~~mapping of~~ the physical z plane which is mapped into the ζ, Q, and w planes. We have extended the example in Reference (**) and applied it to

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*"The Dynamics and Thermodynamics of Compressible Fluid Flow", by A.H. Shapiro, The Ronald Press Co., N.Y., NY, Volume I, Chapter 11, 1953.

** "Theoretical Hydrodynamics", by L.M. Milne-Thomson, The MacMillan Co., New York, 1950.

the gas flow through a port in ~~case of a portion~~ a rifle barrel. The port attaches at an arbitrary angel α with the barrel axis. We make the assumption that there is no flow separation at the attaching streamline at point C.* The velocity of the fluid upstream of the port in the barrel is U. The dimensions of the barrel bore is h and the dimension of the port is h_2. We are assuming that the stream downstream of the port has the same dimension as the bore, (ie. $h_1 = h$). The fluid velocity downstream of the port is U_1, and the velocity in the branch is U_2. There is a streamline which divides at point C, C being a stagnation point. On the wall of the barrel where the port is connected, there is an abrupt change of direction at E and the velocity is consequently infinite. The complex velocity ν is related to ζ through the equation

$$\zeta = -\left(\frac{\nu}{U}\right)^{\pi/\alpha}$$

Since $\nu = 0$ when $\zeta = 0$, it follows that $\frac{dw}{d\zeta} = 0$ when $\zeta = 0$

and therefore, equation (1) becomes

$$\frac{Uh}{a} - \frac{U_1 h_1}{b} + \frac{Uh - U_1 h_1}{c} = 0 \qquad (2)$$

where $a = 1$, $b = \left(\frac{U_1}{U}\right)^{\pi/\alpha}$, $c = \left(\frac{U_2}{U}\right)^{\pi/\alpha}$

We have $Uh = U_1 h + U_2 h_2$ (conservation of mass)

* Through the computer programme (Appendix B) we can determine from the values of h, h_2 and α when cavitation occur, (See Figure B) so that we know under what conditions this assumption is valid.

Therefore, equation (12) becomes

$$\left(\frac{v_1}{V}\right)^{1-\pi/\alpha} - \left(\frac{V_2}{V}\right)^{1-\pi/\alpha} \frac{h_2}{h} = 1$$

Letting

$$\frac{h_1}{h} = 1, \quad \frac{h_2}{h} = \mu, \quad \frac{V_1}{V} = \chi$$

Equation (2) becomes

$$(3) \quad \chi^{1-\pi/\alpha} - \mu\left(\frac{1-\chi}{\mu}\right)^{1-\pi/\alpha} = 1$$

Equation (3) may be solved numerically to determine

$$\chi = \frac{V_1}{V} = f(\alpha, h_2, h)$$

Using this equation together with equation of conservation of mass, we obtain

$$\frac{V_2}{V} = (h - \chi h_1)/h_2 \text{ and } V_2/V = (h/h_2)(1-\chi)$$

Figure B shows χ as a function of h/h_2 for difference values of α. This is accomplished by use of a simple Newton-Raphson technique. For sufficiently large values of x, it was impossible to obtain a solution with equation (3). It was therefore concluded that this limiting condition probably represents the occurance of cavitation in the flow. Having thus obtained a simplified incompressible flwo model for the flow from the barrel into the port, we now apply the Karmen-Tsein pressure-correction to obtain compressible flow model.

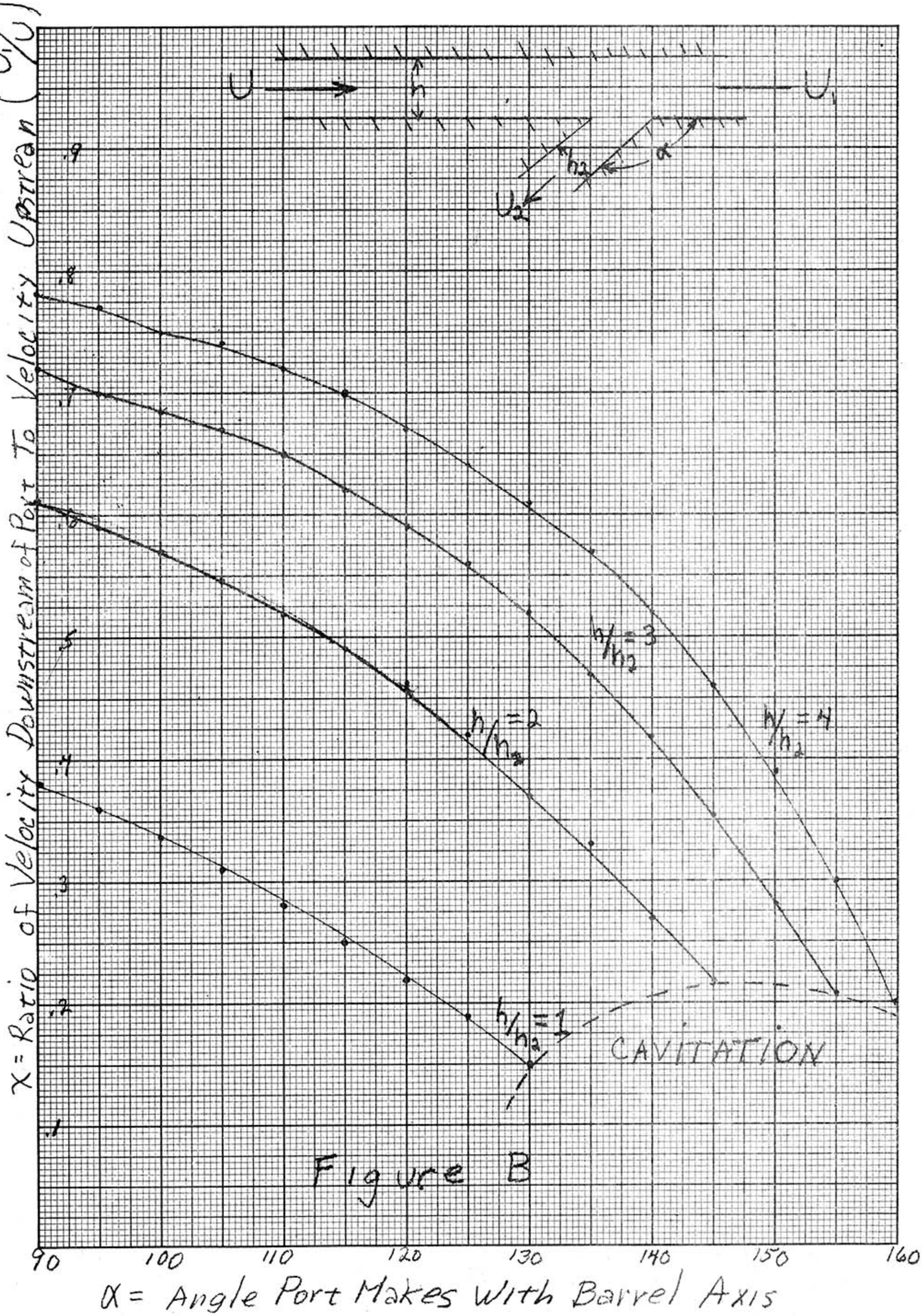
X = Ratio of Velocity Downstream of Port To Velocity Upstream (U1/U)
α = Angle Port Makes With Barrel Axis
U
h
U1
h2
α
U2
h/h2 = 1
h/h2 = 2
h/h2 = 3
h/h2 = 4
CAVITATION
.1
.2
.3
.4
.5
.6
.7
.8
.9
90
100
110
120
130
140
150
160

Figure B

In order to apply the Karmen-Tsien pressure-correction* factor to the flow entering the barrel port, ~~we shall~~ it will first be assumed that following the passage of the projectile over the port and the subsequent to period ~~the~~ of nonsteady flow, the motion of the gas may be described as being two-dimensional, subsonic, steady, frictionless and irrotational. As a final result, we can relate the velocity of the gas through the port (V_2) to the velocity of the gas just upstream of the port (V_p) and to the ratio of the velocity of the incompressible fluid through the port ($\mathcal{V}_2$) and upstream of the port (U). The relationship is given by

$$V_2 = \frac{V_p\left[\frac{\mathcal{V}_2}{U}(1-\lambda)\right]}{1-\lambda\left(\frac{\mathcal{V}_2}{U}\right)^2}$$

where

$$\lambda = \frac{M_p^2}{\left(1+\sqrt{1+M_p^2}\right)^2}$$

Similarly, we can relate the density of the gas entering the port (ρ_2) to the density just upstream of the port by the tangent-gas approximation

$$\rho_2 = \frac{\gamma\,\rho_p}{\gamma+1}$$

It is now necessary to determine V_p, M_p, and ρ_p in terms of the space mean gas properties in the barrel following projectile port passage.

From the time of completion of nonsteady flow (time Period 2, see next section) until muzzle exit, V_p, M_p, ρ_p, ~~will~~ can be determined from the solution of the interior ballistic model.** This model gives the projectile travel (y), ~~trajectory (ie, — t) and~~ velocity ($\frac{dy}{dt}$), the space mean gas temperature ($\bar{T}$), and port pressure (P_p) as functions of time. We shall assume that the p~~ressure and~~ temperature

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*"The Dynamics and Thermodynamics of Compressible Fluid Flow" by Ascher H. Shapiro, Vol. I, Chapter 11, The Ronald Press Co., NY 1953.

An ~~Improved~~ Interior Ballistics Model ~~For Small Arms~~ Using Deterred ~~Propellants~~", ~~by T. Trafton~~, BRL Report 1624, November 1972

** Appendix A

at the port can be represented by the space-mean quantities (ie, $P_p = \bar{P}$, $T_p = \bar{T}$). The velocity of the gas at the port will be given by linear interpolation of the gas velocity

$$V_p = \frac{X_e}{y}\,\frac{dy}{dt}$$

where y is the location of the projectile and X_e is the location of the port.

After muzzle exit (Time Period 3, See next Section), the space mean quantities are determined by using Hugoniot's Equations* for sonic discharge from the muzzle of the barrel.

$$\bar{P} = P_{ei}\left\{1 + \frac{(t - t_{ei})}{\theta}\right\}^{-\frac{2\gamma}{\gamma-1}}$$

where

$$\theta = \frac{2\omega}{(\gamma-1)A}\sqrt{\frac{1}{\gamma R T_{ei}}\left(\frac{\gamma+1}{2}\right)^{\frac{\gamma+1}{\gamma-1}}}$$

ω = total Free volume (chamber and bore)

Tei = space mean temperature of the gas at muzzle exit

Likewise

$$\bar{T} = T_{ei}\left(\frac{\bar{P}}{P_{ei}}\right)^{\frac{\gamma-1}{\gamma}}$$

Pei = space mean Pressure of the gas in the barrel at muzzle exit.

By using the space mean properties of the gas in the barrel and by assuming that the velocity of the gases vary linearly down the barrel after projectile muzzle exit, it may be shown that by assuming sonic flow at the muzzle the Mach number at the port during time Period 3 is simply the ratio of the location of the port to the location of the muzzle.

$$M_p = \frac{X}{X_e}$$

*"Theory of the Interior Ballistics of Guns", by J. Corner, John Wiley and Sons, Inc. New York, 1950.

Several simple tests were run to test the model developed in this report to describe gas flow through a pressure port at an arbitrary angle α with the barrel axis.

A small plenum chamber was attached to a test rifle barrel and pressure stations ~~ploud~~ put both in this chamber and in the test barrel 180° from the entrance to the chamber. The purpose of this chamber was to collect the gas it passed through the port and allow the transducer to measure its pressure-time history. The pressure-time history computed using the model developed in this report was then compared with that obtained experimentally in order to verify the model. Also, the pressure-time history measured opposite the port was compared with the computed pressure-time history.

MODEL TO PREDICT PRESSURE-TIME IN PLENUM CHAMBER

In order to predict the pressure-time history in the plenum chamber, it is necessary to use the model of the flow through the gas port together with the equation of state and energy for the chamber.

Three periods of time will be considered during which the gas passes through the port.

1. Period of Nonsteady Flow

During this time, the flow of mass and energy through the port will be obtained by use of the method of characteristics. Interpolation of the characteristics at the opening to the port premits one to determine the gas density (ρ_i), the velocity (V_i), pressure (p_i), and temperature (Ti) of the gases at this location for different times. By use of the equation conservation of energy, the pressure in the chamber during ~~Phase I~~ this period can be determined. This was done in Subroutine INTER as mentioned in Part A "Nonsteady Flow Through Port."

Rate of Energy Entering Chamber = Rate of Change of Internal Energy of the Chamber

The rate of energy entering the chamber is given by

$$\dot{E}i = \dot{M}i \; Hi \; g$$

where $\dot{M}i$ is the mass rate of gas flow entering

$$\dot{M}i = \rho_i \, v_i \, A_P$$

and Hi is the total enthropy of the gas

$$Hi = \frac{v_i^2}{2gJ} + \frac{R\,T_i}{gJ(\gamma-1)} + \frac{P_i}{\rho_i g J} = \frac{V_i^2}{2gJ} + C_P T_i$$

Thus $$\dot{E}_i = \rho_i \, v_i \, A_P g \left[\frac{v_i^2}{2gJ} + \frac{R\,T_i}{gJ(\gamma-1)} + \frac{P_i}{\rho_i g J} \right]$$

The rate of change of internal energy of the chamber is given by

$$\dot{E}_b = \frac{d}{dt}(M_b g \, C_v \, T_b) \text{, where } C_v = \frac{R}{gJ(\gamma-1)} \left(\frac{BTU}{lbm-{}^\circ R}\right)$$

where Mb is the mass of gas inside the chamber and Tb is the temperature of the gas inside the chamber

$$Mb = \rho_b \, U_b \text{, } U_b \text{ is the chamber volume}$$

therefore $$\dot{E}_b = \frac{d}{dt}\left[\frac{\rho_b U_b R T_b}{J(\gamma-1)}\right]$$

or $$\dot{E}_b = \frac{d}{dt}\left[\frac{U_b P_b}{J(\gamma-1)}\right]$$

The pressure in the chamber* may now be obtained by integration

$$P_{b1} = \frac{J(\gamma - 1)}{U_b}\, g \int_0^{t_1} A_p \rho_i V_i \left[\frac{V_i^2}{2gJ} + \frac{R_i T_i}{gJ(\gamma - 1)} + \frac{p_i}{\rho g J} \right] dt$$

2. Period of Quasisteady Flow Between Nonsteady Flow and Muzzle Exit of the Projectile

During this period of time, the effective stagnation temperature of the gas entering the port will be assumed equal to the space mean temperature behind the projectile. This is obtained from the solution of the interior ballistic equations. The density of the gas entering the port is obtained by use of the Karmen-Tsien pressure correction factor

$$\rho_2 = \frac{\gamma \rho_p}{\gamma + 1}$$

where $\rho_p = \frac{\bar{P}}{R\bar{T}}$ and $\bar{P}$ and $\bar{T}$ are the space mean pressure and temperature respectively.

The velocity of the gas through the port is likewise given by

$$V_2 = V_p \frac{\left(\frac{U_2}{U}\right)(1 - \lambda)}{1 - \lambda \left(\frac{U_2}{U}\right)^2}$$

where

$$\lambda = \frac{M_p^2}{\left(1 + \sqrt{1 + M_p^2}\right)^2}, \quad V_p = \frac{X_p}{Y}\frac{dy}{dt}$$

and

$$M_p = \frac{V_p}{\bar{A}} = \frac{X_p}{Y}\frac{dy}{dt} \Big/ \sqrt{\gamma R \bar{T}}$$

* During the period of nonsteady flow the area of the port will be changing as more area is being exposed by the projectile. Thus:

$$A_p = \frac{\pi r^2}{2} - \left[x\sqrt{r^2 - x^2} + r^2 \sin^{-1}\left(\frac{x}{r}\right)\right]$$

for the time when the projectile has exposed an amount determined by $l \leq r$ and

$$A_p = \frac{\pi r^2}{2} + \left[x\sqrt{r^2 - x^2} + r^2 \sin^{-1}\left(\frac{x}{r}\right)\right]$$

for the time when the projectile has exposed an amount determined by $r < l \leq 2r$ where r is the radius of the port and x is the distance from the center to the cord.

Therefore, during Period #2, the pressure in the chamber is given by

$$P_{b2} = P_{b1} + \frac{J(\gamma - 1) A_p g}{V_b} \int_{t_1}^{t_2} \rho_2 V_2 C_p \bar{T} \, dt$$

3. Period of Quasisteady Flow Follow Muzzle Exit of the Projectile

The third period of interest begins when the projectile passes the muzzle and ends when the pressure in the chamber equals that in the barrel*. During this period of time, the effective stagnation temperature $\bar{\bar{T}}$ will be determined through Hugoniot's equation

$$\bar{T} = T_{ei} \left(\frac{\bar{P}}{P_{ei}} \right)^{\frac{\gamma - 1}{\gamma}}$$

where $\bar{P} = P_{ei} \left\{ 1 + \frac{(t - t_{ei})}{\theta} \right\}^{-\frac{2\gamma}{\gamma - 1}}$; t = time

Likewise, the density during period #3 is given by

$$\rho_p = \rho_{ei} \left(\frac{\bar{P}}{P_{ei}} \right)^{1/\gamma}$$

or

$$\rho_p = \rho_{ei} \left[1 + \frac{t - t_{ei}}{\theta} \right]^{-\frac{2}{\gamma - 1}}$$

where

$$\rho_{ei} = \frac{P_{ei}}{R T_{ei}}$$

* The possibility of reverse flow will not be considered in this model.

and Pei and Tei are the space mean pressure and temperature at muzzle exit.

Also, during this same period

$$M_p = \frac{X_p}{X_e}, \quad \rho_2 = \frac{\gamma \rho_p}{\gamma + 1}$$

Thus
$$P_{b3} = P_{b2} + \frac{J(\gamma-1) A_p g}{\upsilon_b} \int_{t_2}^{t_3} \rho_2 V_2 C_p \bar{T} \, dt$$

where
$$V_p = \frac{X_p}{X_e} \sqrt{\gamma R \bar{T}},$$

and
$$V_2 = \frac{V_p \left(\frac{U_2}{U} \right) (1 - \lambda)}{1 - \lambda \left(\frac{U_2}{U} \right)^2}$$

and
$$\rho_2 = \frac{\gamma \rho_p}{\gamma + 1} = \frac{\gamma \rho_{e_1}}{\gamma + 1} \left[1 + \frac{t - t_{e_1}}{t_{e_1}} \right]^{-\frac{2}{\gamma + 1}}$$

An examination of experimental results indicates that for the 5.56mm system the end of the period of nonsteady flow occurs very close to muzzle exit of the projectile. Also, there seems to be no change in the slope of the pressure-time curve in the barrel at the port location at the time of muzzle exit. To simplify the computer program, it was therefore assumed ~~that~~ for calculating the pressure in the plenum chamber muzzle exit occurred at the end of the period of nonsteady flow. Therefore, time period 2 is included in time period 3 (ie., tei = t_1).

The equations just presented are assumed to apply for the period of time that the flow through the port remains independent of the pressure in the plenum chamber. However, at some time in the flow, the mass discharge will be influenced by the pressure in the plenum chamber. It therefore becomes convenient to assume that the flow through the port behaves as steady, isentropic flow as in a convergent nozzle during the third period of quasi-steady flow. The flow will then remain independent of the pressure in the plenum as long as the ratio of the pressure in the plenum chamber (P_b) to the stagnation pressure of the gas flowing through the port (P_{sg}) is less than some critical value.

$$\frac{P_b}{P_{sg}} < \left(\frac{2}{\gamma+1}\right)^{\frac{\gamma}{\gamma-1}}$$

Should this ratio be greater than this value, then the rate of mass discharge is dependent on $\frac{P_b}{P_{sg}}$ and is given by

$$\dot{m} = \psi \frac{A_P \, P_{sg}}{\sqrt{R \, T_0}}$$

where
$$\psi = \left\{ \frac{2\gamma}{\gamma-1} \left[\left(\frac{P_b}{P_{sg}}\right)^{\frac{2}{\gamma}} - \left(\frac{P_b}{P_{sg}}\right)^{\frac{\gamma+1}{\gamma}} \right] \right\}^{1/2}$$

Using the tangent gas approximation the stagnation pressure of the gas in the port can be shown to be given by (see Shapiro, Vol I)

$$P_{sg} = P_p \left[1 + \gamma \left(1 - \sqrt{1 - M_p^2} \right) \right]$$

If the ratio of $\frac{P_b}{P_{sg}} \geq 1$ then it is assumed that the pressure in the plenum chamber is equal to the space mean pressure in the barrel. (ie., $P_b = \bar{P}$)

The problem still remains of relating the gas pressure and velocity at the port to the space mean properties of the gas in the barrel.

and

$$\rho_e \cong \rho_o \cong \frac{P_o}{RT_o} \tag{4B}$$

By climinating ρ_e and V_e in the second term for $\dot{m}_e$ we obtain:

$$\sqrt{\gamma} \left(\frac{2}{\gamma+1}\right)^{\frac{\gamma+1}{2(\gamma-1)}} \cong \sqrt{\frac{2\gamma}{\gamma-1}\left[1 - \frac{P_e}{P_o}\right]} \tag{5B}$$

Solving for P_e/P_o we obtain

$$\left(\frac{P_e}{P_o}\right) \cong 1 - \left(\frac{\gamma-1}{2}\right)\left(\frac{2}{\gamma+1}\right)^{\frac{\gamma+1}{\gamma-1}} \tag{6B}$$

We shall now derive an expression which relates the pressure and velocity of the gas to its location in the barrel and to the effective stagnation properties at that particular time. The approach used will be similar to Lagrange's approximation[6] where ρ is independent of x_i (position along the barrel) and the gas velocity is given by:

$$v = \frac{x_i}{X_e} V_e$$

As found in Reference 7, we also shall assume that the Fanning friction factor (f_f) is independent of Reynolds number. This implies that the roughness of the barrel is sufficient to make this assumption justifiable.

Reference 7 found that by using cold gas experiments $f_f \approx 0.006$.

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[6] J. Corner, Theory of the Interior Ballistics of Guns, John Wiley and Sons, Inc., New York, NY, 1950.

[7] W. B. Brooks, "Semiempirical Model for Predicting the Upper Size of Solid Particles Migrating from the Barrel to the Gas Tube of the M16A1 Rifle," Frankford Arsenal Report R-2018, August 1971.

$$\left(\frac{\partial v}{\partial t}\right)_{x_i} = \frac{x_i}{X_e} \frac{d V_e}{dt} \qquad (7B)$$

$$\left(\frac{\partial v}{\partial x_i}\right)_t = \frac{1}{X_e} V_e \qquad (8B)$$

$$v \left(\frac{\partial v}{\partial x_i}\right)_t = \left(\frac{x_i}{X_e} V_e\right) \left(\frac{1}{X_e} V_e\right) = \frac{x_i}{X_e^2} V_e^2 \qquad (9B)$$

The equation of motion for the gas in the barrel may be written

$$\left(\frac{\partial v}{\partial t}\right)_{x_i} + v \left(\frac{\partial v}{\partial x_i}\right)_t = - \frac{1}{\rho} \frac{\partial P}{\partial x_i} - \frac{2 f v^2}{D} \qquad (10B)$$

where f = fanning friction factor, D = diameter of the bore substituting for

$$\left(\frac{\partial v}{\partial t}\right)_{x_i}, \; v, \; \left(\frac{\partial v}{\partial x_i}\right)_t$$

we obtain

$$\frac{x_i}{X_e} \frac{d V_e}{dt} + \frac{x_i}{X_e^2} V_e^2 = - \frac{1}{\rho} \frac{\partial P}{\partial x_i} - \frac{2f}{D} \left(\frac{x_i}{X_e} V_e\right)^2 \qquad (11B)$$

where $\frac{d V_e}{dt}$, V_e and ρ are functions of time which will be determined later.

$$\frac{\partial P}{\partial x_i} = - \rho \left[\frac{x_i}{X_e} \frac{dV_e}{dt} + \frac{x_i}{X_e^2} V_e^2\right] - \frac{2\rho f}{D} \frac{x_i^2}{X_e^2} V_e^2 \qquad (12B)$$

$$= \frac{- \rho V_e^2}{X_e^2} \left\{x_i + \frac{2 f x_i^2}{D}\right\} - \frac{\rho}{X_e} \left(\frac{d V_e}{dt}\right) x_i$$

Integrating the above equation with respect to x_i

$$P \cong \frac{-\rho V_e^2}{X_e^2}\left\{\frac{x_i^2}{2} + \frac{2f\, x_i^3}{3D}\right\} - \frac{\rho}{X_e}\left(\frac{d\, V_e}{dt}\right)\frac{x_i^2}{2} + g\,(t) \qquad (13B)$$

where g (t) is a function of time to be determined.

To determine the arbitrary function we will use the boundary condition that when $x \simeq 0$, $P = \overline{P}$

$$\therefore\ g\,(t) = \overline{P} \qquad (14B)$$

$$P = -\frac{3\, V_e^2}{X_e^2}\left\{\frac{x_i^2}{2} + \frac{2}{3}\,\frac{f\, x_i^3}{D}\right\} - \frac{\rho}{X_e}\left(\frac{d\, V_e}{dt}\right)\frac{x_i^2}{2} + \overline{P} \qquad (15B)$$

It now remains to determine V_e, dV_e/dt, ρ and $\overline{P}$ as functions of time to obtain a complete solution of $P = P\,(x_i,\ t)$

Now, at the time the projectile leaves the muzzle we will make $\overline{P} \simeq P_{ei}$ (the space mean pressure in the barrel at the time the projectile leaves the muzzle).

Using Hugoniot's equation (see Reference 6)

$$\overline{P} = P_{ei}\left[1 + \frac{t - t_{ei}}{\theta}\right]^{-\frac{2\gamma}{\gamma-1}}$$

where

$$\theta = \frac{2U}{(\gamma-1)\,A}\left[\frac{1}{\gamma}\left(\frac{\gamma+1}{2}\right)^{\frac{\gamma+1}{\gamma-1}}\frac{C}{U\,P_{ei}}\right]^{\frac{1}{2}}$$

[6] J. Corner, Theory of the Interior Ballistics of Guns, John Wiley and Sons, Inc., New York, NY, 1950.

Likewise

$$\overline{T} = T_{ei}\left(\frac{\overline{P}}{P_{ei}}\right)^{\frac{\gamma-1}{\gamma}}$$

$$\therefore \overline{T} = T_{ei}\left[1 + \frac{t - t_{ei}}{\theta}\right]^{-2}$$

Since the flow of the gas out the muzzle is assumed sonic

$$V_e = \sqrt{\gamma R \overline{T}}$$

$$V_e = \sqrt{\left(\frac{2\gamma}{\gamma-1}\right) R \overline{T}_o \left[1 - \frac{P_e}{\overline{P}_o}\right]}$$

using the approximation $P_e/\overline{P}_o = 1 - \left(\frac{\gamma-1}{2}\right)\left(\frac{2}{\gamma+1}\right)^{\frac{\gamma+1}{\gamma-1}}$ and substituting for $\overline{T}_o$

$$V_e = \sqrt{\gamma R T_{ei}}\left[1 + \frac{t-t_{ei}}{\theta}\right]^{-1} \qquad (16B)$$

or

$$V_e = V_{ei}\left[1 + \frac{t - t_{ei}}{\theta}\right]^{-1}, \quad V_{ei} = \sqrt{\gamma R T_{ei}}$$

where

$$V_{ei} = \sqrt{\gamma\left(\frac{2}{\gamma+1}\right)^{\frac{\gamma+1}{\gamma-1}} R T_{ei}}$$

$$\frac{dV_e}{dt} = -\frac{V_{ei}}{\theta}\left[1 + \frac{t - t_{ei}}{\theta}\right]^{-2} \qquad (17B)$$

now

$$\frac{\rho}{\rho_{ei}} = \left(\frac{\overline{P}}{P_{ei}}\right)^{1/\gamma}$$

Thus

$$\therefore \rho = \rho_{ei}\left[1 + \frac{t - t_{ei}}{\theta}\right]^{-\frac{2}{\gamma-1}}$$

since

$$\rho_{ei} \cong \frac{C}{A X_e}$$

$$\rho = \frac{C}{A X_e} \left[1 + \frac{t - t_{ei}}{\theta} \right]^{-\frac{2}{\gamma + 1}} \qquad (18B)$$

Thus, the pressure at the port after the projectile has left is given by

$$P_p = - \frac{\rho V_e^2}{X_e^2} \left\{ \frac{X_p^2}{2} + \frac{2}{3} \frac{f X_p^3}{D} \right\} - \frac{\rho}{X_e} \frac{dV_e}{dt} \frac{X_p^2}{2} + P_o \qquad (19B)$$

and can now be determined.

Also, the Mach number at the port is ~~given by~~ approximated by

$$M_p = \frac{X_e}{X_p} \qquad (20B)$$

where V_p is the speed of the gas at the port and a_p is the speed of sound at the port which is given by: $a_p = \sqrt{\gamma R T_p}$. Now T_p can be calculated from the equation

$$V_p^2 = \left(\frac{X_p}{X_e} V_e \right)^2 = \frac{2 \gamma R T_o}{\gamma - 1} \left(1 - \frac{T_p}{T_o} \right) \qquad (21B)$$

or

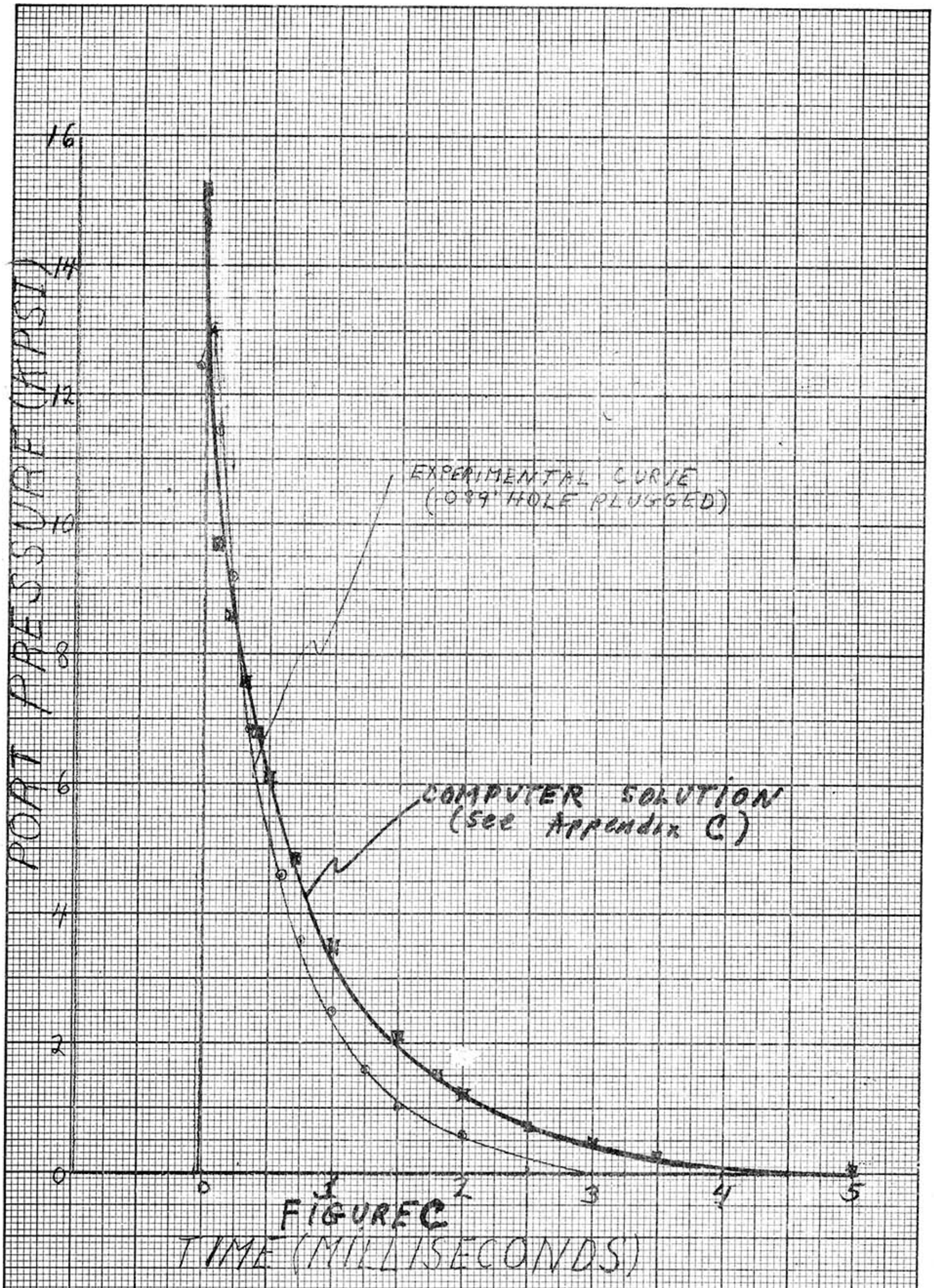
$$T_p = T_o \left\{ 1 - \frac{(\gamma - 1)}{2 \gamma R T_o} \frac{X_p^2}{X_e^2} V_e^2 \right\} \qquad (22B)$$

Substituting Equations 21B and 22B into Equation 20B gives

$$M_p = \frac{X_p V_e}{X_e \sqrt{\gamma R T_o} \left\{ 1 - \frac{(\gamma - 1)}{2 \gamma R T_o} \frac{X_p^2}{X_e^2} V_e^2 \right\}^{1/2}}$$

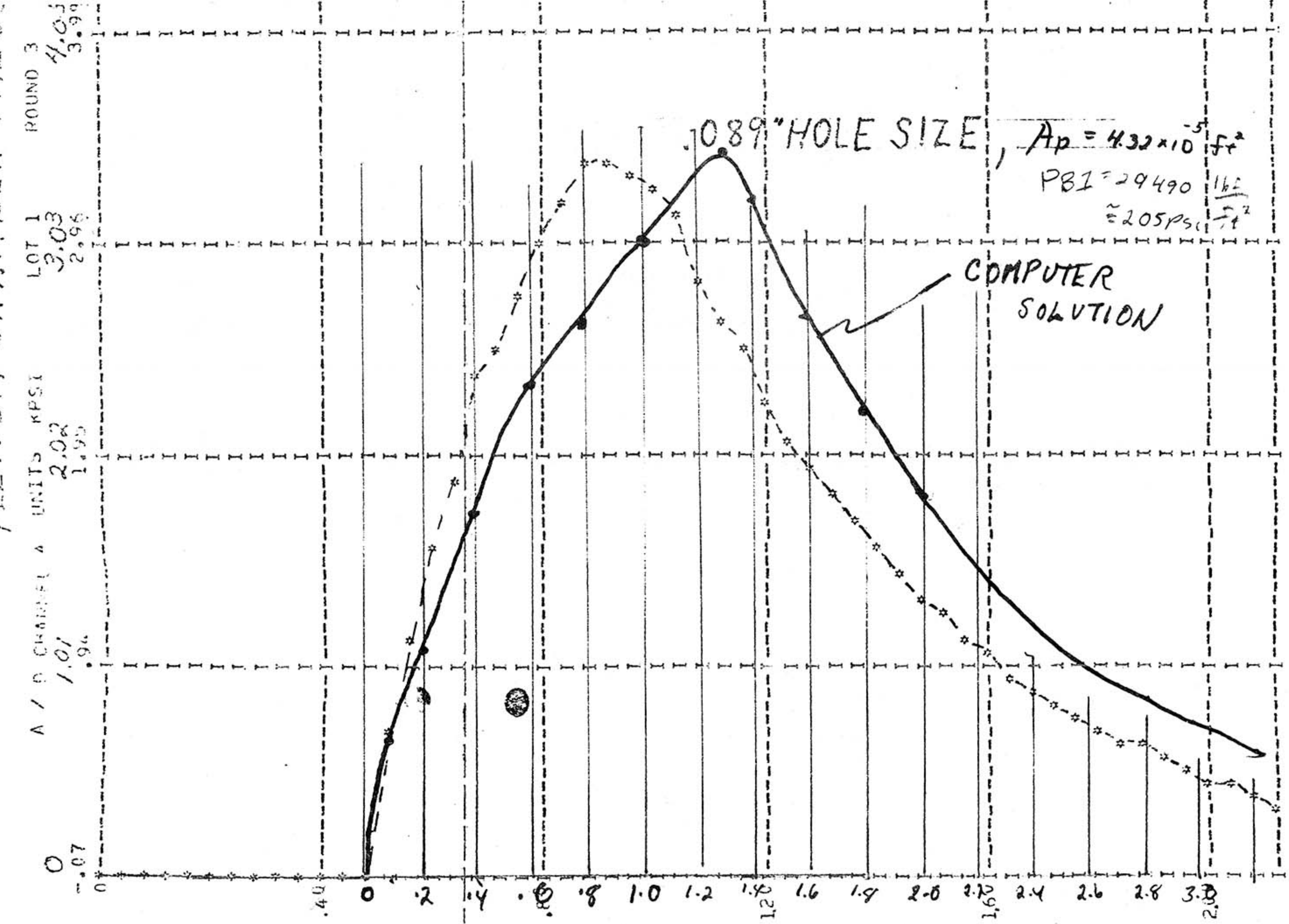
The computer program for describing the pressure buildup in the plenum chamber during the period of quasisteady flow is listed in Appendix C together with a sample output.

The results of the computer program are compared with the experimental results in Figures C and D.



PORT PRESSURE (KPSI)
16
14
12
10
8
6
4
2
0
EXPERIMENTAL CURVE
(.089" HOLE PLUGGED)
COMPUTER SOLUTION
(see Appendix C)
0
1
2
3
4
5
TIME (MILLISECONDS)

FIGURE C



.089" HOLE SIZE, $A_p = 4.32 \times 10^{-5}$ ft²
PBI = 29490 lbf/ft²
≈ 205 psi
COMPUTER SOLUTION
PLENUM CHAMBER PRES
A / D CHANNEL A UNITS KPSI LOT 1 ROUND 3
0 .07
1.01 .94
2.02 1.99
3.03 2.96
4.03 3.99
0 .2 .4 .6 .8 1.0 1.2 1.4 1.6 1.8 2.0 2.2 2.4 2.6 2.8 3.0
TIME (MILLISECONDS)

FIGURE D

<u>ENERGY LOSSES IN THE FLOW TO THE PLENUM CHAMBER</u>

The flow of the gas from the port to the plenum chamber can be influenced by frictional effects due to the boundary layer on the walls of the port. Two kinds of losses will be assumed to occur:

1. Losses* due to flow in the port. These will be described in terms of the velocity coefficient of the port (ϕ) and the energy efficiency of the port (η_n).

2. Losses due to the flow from the port to the plenum chamber. These types of losses are found to be characteristic of subsonic diffusers * and result from losses due primarily to flow turbulence and separation.

A. Nozzle Losses

It is possible to define a quantity called the velocity coefficient for the port defined by $\phi = \dfrac{V_2'}{V_2} = \left(\dfrac{H - h_2'}{H - h_2} \right)^{1/2}$

where H is the stagnation (total) specific enthalpy of the flow entering the port

$$H = C_p T_0$$

h_2' is the actual static specific enthalpy of the gas in the port

$$h_2' = C_p T_2'$$

h_2 is the static specific enthalpy that the gas in the port if the flow were isentropic $\quad h_2 = C_p T_2$

---

* "Aircraft and Missile Propulsion", Volume I, p.372, by M.J. Zucrow, John Wiley and Sons, Inc. Publishers 1958.

V_2' is the actual velocity of the gas in the port

V_2' is the velocity of the gas in the port if the flow were isentropic.

The flow of the gas through the port is then given by

$$\dot{M}_2 = \rho_2 A_p \phi V_2 = \rho_2 A_p V_2'$$

where $V_2' = \phi V_2$

If it is assumed that there is a contraction of the fluid jet, then a contraction coefficient C_c must be introduced in the discharge equation.

Therefore,

$$\dot{M}_2 = \rho_2 A_p \phi C_c V_2$$

It is also possible to define a quantity know as the energy efficiency of the port

$$\eta_n = \left(\frac{V_2'}{V_2}\right)^2 = \frac{H - h_2'}{H - h_2} = \phi^2$$

Substituting for H, h_2' and h_2 we have

$$\eta_n = \frac{T_0 - T_2'}{T_0 - T_2}, \quad T_2' > T_2$$

We shall combine diffuser losses with all other types of losses (heat, turbulence, etc.) of the gas and assume that they are proportional to the rate of energy entering the plenum chamber.

$$\frac{\text{Rate of energy loss}}{\text{Rate of energy entering plenum chamber}} = \beta$$

$\therefore$ The rate at which energy increases in the plenum chamber is

$$\dot{E}_{ib} = (1 - \beta) E_{in}$$

Velocity losses and energy losses are used in order to optimize the computer program describing the quasisteady flow through the port and the pressure buildup in the plenum (see Appendix C).

CONCLUSIONS

1. The model developed in this report appears adequate for describing the nonsteady flow which occurs when the projectile first passes the port in a gas operated weapon and the quasisteady flow following port opening.

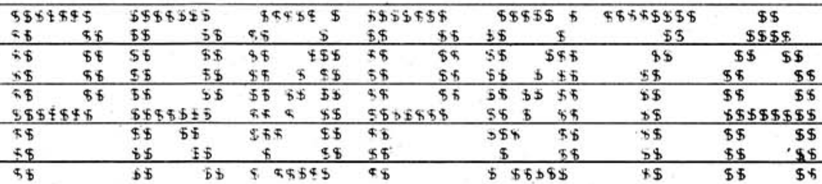
2. The two-dimensional incompressible potential flow solution using the Karmen-Tsien pressure correction formula can be used to describe the quasisteady flow.

RECOMMENDATIONS

1. The model developed in this report should be extended and made applicable for simulating different types of ammunition (ie., blank, tracer, etc.), different types of gas operating systems, and also different modes of firing (ie., burst firing, continuous firing).

2. The model developed in this report should be used as a tool for developing new ammunition for existing and proposed weapon systems.

3. The model should be used for developing new gas operated small caliber and cannon caliber weapon systems.



Conditioning Temperature
294 °K

CONDITIONING TEMPERATURE
294 °K

APPENDIX 1A

A

WEIGHT FRACTION	GRAIN DIAMETER
.890000E-01	.273900E-01
.571000	.211600E-01
.260000	.159300E-01
.650000E-01	.114100E-01
.150000E-01	.783000E-02

PROPELLANT CONSTITUENTS

MATERIAL	PERCENT	DENSITY	CVI	EI	XMOL
NC	82.0000	1.66200	.342100	283.100	.392000E-01
DBP	4.10000	1.04600	.462100	-2335.10	.970700E-01
NG	10.5000	1.57500	.343900	951.900	.308300E-01
DIPHENYL	.980000	1.15900	.347500	-3009.70	.106450
MOISTURE	.880000	1.00000	.650700	-1567.60	.555600E-01
SOLVENT	.380000	.789300	.608300	-2785.00	.108540
CACO3	.410000	2.71000	.125000	-800.000	.574000E-02
NA2SO4	.120000	2.68000	.125000	-800.000	.574000E-02
DINITRO	.630000	1.32500	.321300	-668.400	.604200E-01

RMA.DMIT = .392900E-02 .144000E-01

RHOBP. DOS. VCBAR. XMV .574919E-01 .177824E-01 .238419E-05 .137072E-06

DETERRED LAYER

DENSITY	.542979E-01
VOLUME	.631598E-06
FLAME TEMPERATURE	2192.17
RATIO OF SPECIFIC HEATS	1.26322
IMPETUS	.351408E+07
BURNING RATE COEFFICIENT	.104445E-02

CONDITIONING TEMP	294.000

DET TEMP SENSITIVITY . .123557E-02

NON DET TEMP SENSITIVITY	.595489E-03
UNDETERRED LAYER	
DENSITY	.587705E-01
FLAME TEMPERATURE	3284.94
RATIO OF SPECIFIC HEATS	1.22677
IMPETUS	.431651E+07
BURNING RATE COEFFICIENT	.421803E-02

5.56 MM M16 WC846 PROPELL 15.0 PC SCD 3 INCR SAIB
CASE NO. 1

PROJ. WT.	BARREL	CHAMBER	BORE AREA	P-K	SS PRESS	MAX GUN PRESSURE
.007357	18.50000	.10880	.03890	3.00000	3200.0	200000.0

DT	NO.INCR	RKV	RKX	EST.MUZ.VEL.	DIAMETER	EROS.BURN.COEFF.	S VEL.
.00001	3	0.0000000	.0000000	3300.	.2227	.0000025	900.

PORT LOC.	GAGE LOC.	BULLET BASE	BOAT TAIL
11.61	1.81	1.51	.100

PRIMER

CHARGE	FORCE	GAMMA	COVOL.	TEMP	PR.DEL.	TOTAL CHARGE PROPELLANT
.00007	1738000.	1.25000		2000.0	.00010	.00401

PROPELLANT. NO. 1

CHARGE	W.FRACT	OD GRAIN	MIN.DIAM.	GR.LENGTH	NO.PERF.	INCR.VOL.	DETERR.
.00401	1.0000	.0176	.0144	0.0000	0.	.00000065	.0410

SURF CONC DET	IGN TIME RANGE	IGN DELAY
.150000	.00025	.00005

CHARGE	FORCE	GAMMA	COVOL.	TEMP	DENSITY	BETA	ALPHA	UOD
.00110	3514081.	1.26322	32.2000	2192.2	.0542979	.00104445	.7000	.0000000
.00110	3915296.	1.24500	32.2000	2738.6	.0565342	.00293124	.7000	.0016640
.00182	4316511.	1.22677	32.2000	3284.9	.0587705	.00421803	.7000	.0038166

RESISTANCE

PROJ. TRAVEL	PRESSURE
0.0000	0.0
.0950	3200.0
.2150	3800.0
.4550	11000.0
.5600	14400.0

RESISTANCE = .030000 TIMES PRESSURE

5.56 MM M16 WC846 PROPELL 15.? PC SCD ~~2~~ 3 INCR SAIH

MUZZLE VEL.	MAX. PRESSURE	X AT PMAX	T AT PMAX	MUZ PRESSURE	FORCE
3214.4	51920.	1.430	.590	9822.4	4061746.

Z AT PMAX	Z AT MUZ	MAX PORT PRESS	MAX GAGE PRESS	T AT MUZ
.29004763	.85935677	15395.428	46883.718	1.1800

PIEZ. EFF.	BAL. EFF.
.40317	.25803

WEIGHT FRACTION 1	1.00000000
NUMBER POWDER GRAINS	29572.13
INITIAL GRAIN SURFACE	.0069
INITIAL FRACTION SURFACE	25.7316

5.56 MM M16 WC846 PROPELL 15.0 PC SCD ~~2~~ 3 INCR SAI8
CASE NO. 2

PROJ. WT.	BARREL	CHAMBER	BORE AREA	P-K	SS PRESS	MAX GUN PRESSURE
.007857	18.50000	.10880	.03899	3.00000	3200.0	200000.0

DT	NO.INCR	RKV	RKX	EST.MUZ.VEL.	DIAMETER	EROS.BURN.COEFF.	S VEL.
.00001	3	0.0000000	.0000000	3214.	.2227	.0000025	900.

PORT LOC.	GAGE LOC.	BULLET BASE	BOAT TAIL
11.61	1.81	1.51	.100

PRIMER

CHARGE	FORCE	GAMMA	COVOL.	TEMP	PR.DEL.	TOTAL CHARGE PROPELLANT
.00007	1738000.	1.25000		2000.0	.00010	.00401

PROPELLANT. NO. 1

CHARGE	W.FRACT	OD GRAIN	MIN.DIAM.	GR.LENGTH	NO.PERF.	INCR.VOL.	DETERR.
.00401	1.0000	.0178	.0144	0.0000	0.	.00000065	.0410

SURF CONC DET	IGN TIME RANGE	IGN DELAY
.150000	.00025	.00005

CHARGE	FORCE	GAMMA	COVOL.	TEMP	DENSITY	BETA	ALPHA	UOD
.00110	3514081.	1.26322	32.2[illegible]	2192.2	.0542979	.00164445	.7000	.0000000
.00110	3915296.	1.24500	32.2[illegible]	2738.6	.0565342	.00293124	.7000	.0016640
.00182	4316511.	1.22677	32.2[illegible]	3284.9	.0587705	.00421803	.7000	.0038166

RESISTANCE

PROJ. TRAVEL	PRESSURE
0.0000	0.0
.0950	3200.0
.2150	3800.0
.4550	11000.0
.5600	14400.0

RESISTANCE = .030000 TIMES PRESSURE

5.56 MM M16 WC846 PROPELL 15.0 PC SCD ~~2~~ 3 INCR SAIB

MUZZLE VEL.	MAX. PRESSURE	X AT PMAX	T AT PMAX	MUZ PRESSURE	FORCE
3204.2	51741.	1.428	.590	9734.5	4062234.

Z AT PMAX	Z AT MUZ	MAX PORT PRESS	MAX GAGE PRESS	T AT MUZ
.28966950	.85846100	15269.975	46709.113	1.1900

PIEZ. EFF.	BAL. EFF.
.40091	.25582

WEIGHT FRACTION 1	1.00000000
NUMBER POWDER GRAINS	29572.03
INITIAL GRAIN SURFACE	.0009
INITIAL FRACTION SURFACE	25.7316

5.56 MM M16 WC846 PROPELL 15.0 PC SCD 3 INCR SAIB
CASE NO. 3

PROJ. WT.	BARREL	CHAMBER	BORE AREA	P-K	SS PRESS	MAX GUN PRESSURE
.007857	18.50000	.15880	.03890	3.00000	3200.0	200000.0

DT	NO.INCR	RKV	RKX	EST.MUZ.VEL.	DIAMETER	EROS.BURN.COEFF.	S VEL.
.00001	3	0.0000000	.0000000	3204.	.2227	.0000025	900.

PORT LOC.	GAGE LOC.	BULLET BASE	BOAT TAIL
11.61	1.81	1.51	.100

CHARGE	FORCE	PRIMER GAMMA	COVOL.	TEMP	PR.DEL.	TOTAL CHARGE PROPELLANT
.00007	1738000.	1.25000		2000.0	.00010	.00401

PROPELLANT. NO. 1

CHARGE	W.FRACT	OD GRAIN	MIN.DIAM.	GR.LENGTH	NO.PERF.	INCR.VOL.	DETERR.
.00401	1.0000	.0178	.0144	0.0000	0.	.00000065	.0410

SURF CONC DET	IGN TIME RANGE	IGN DELAY
.150000	.00025	.00005

CHARGE	FORCE	GAMMA	COVOL.	TEMP	DENSITY	BETA	ALPHA	UOD
.00110	3514081.	1.26322	32.2000	2192.2	.0542979	.00124445	.7000	.0000000
.00110	3915296.	1.24500	32.2000	2738.6	.0565342	.00293124	.7000	.0016640
.00182	4316511.	1.22677	32.2000	3284.9	.0587705	.00421803	.7000	.0038166

RESISTANCE

PROJ. TRAVEL	PRESSURE
0.0000	0.0
.0950	3200.0
.2150	3800.0
.4550	11000.0
.5600	14400.0

RESISTANCE = .030000 TIMES PRESSURE

5.56 MM M16 WC846 PROPELL 15. PC SCD ~~[illegible]~~ 3 INCR SAIB

T	XI	PBR	PC	PB	PPORT	V	AF	
T	XI	XF	TEMP	DL	PR	ST	Z	
T	XI	Z(I)	DCZ(I)	R(I)	S(I)	FTC(I)	UB(I)	INCR
.0900	0.000	0.00	0.00	0.00	0.00	0.00	0.00	
.0900	0.000	0.0000	0.00	0.000	0.0	25.73	0.0000	
.0900	0.000	0.0000	0.000	0.000	25.73	0.	.01440	0
GAGE PRESSURE =		0.0	GAMMA =0.00000	DEL = 3.0000				
.1000	0.000	3176.95	3176.95	3176.95	0.00	0.00	0.00	
.1000	0.000	0.0000	2000.00	0.000	3177.0	25.73	0.0000	
.1000	0.000	0.0000	0.000	0.000	25.73	0.	.01440	0
GAGE PRESSURE =		0.0	GAMMA =0.00000	DEL = 3.0000				
.1500	0.000	3176.95	3176.95	3176.95	0.00	0.00	0.00	
.1500	0.000	0.0000	2000.00	0.000	3177.0	25.73	0.0000	
.1500	0.000	0.0000	0.000	0.000	25.73	0.	.01440	0
GAGE PRESSURE =		0.0	GAMMA =0.00000	DEL = 3.0000				
.1600	.000	3436.61	3202.29	2754.39	0.00	.73	439110.16	
.1600	.000	.0000	2001.31	.000	0.0	25.73	.0001	
.1600	.000	.0001	.027	.468	25.73	1.	.01440	1
GAGE PRESSURE =		0.0	GAMMA =1.25009	DEL = 3.1385				
.1700	.000	3489.90	3251.95	2797.09	0.00	5.18	444007.60	
.1700	.000	.0000	2003.63	.001	12.0	25.73	.0002	
.1700	.000	.0002	.055	.473	25.73	3.	.01440	1
GAGE PRESSURE =		0.0	GAMMA =1.25027	DEL = 3.1385				
.1800	.001	3569.37	3326.00	2860.79	0.00	9.70	449366.71	
.1800	.001	.0001	2006.79	.001	42.1	25.73	.0004	
.1800	.001	.0004	.084	.480	25.73	6.	.01440	1
GAGE PRESSURE =		0.0	GAMMA =1.25053	DEL = 3.1385				
.1900	.003	3676.29	3425.63	2946.47	0.00	14.28	455299.38	
.1900	.003	.0002	2010.72	.002	90.5	25.73	.0007	
.1900	.003	.0007	.115	.491	25.73	10.	.01440	1
GAGE PRESSURE =		0.0	GAMMA =1.25087	DEL = 3.1384				
.2000	.005	3812.27	3552.34	3055.45	0.00	18.95	461964.34	
.2000	.005	.0004	2015.32	.003	157.7	25.73	.0011	
.2000	.005	.0011	.147	.503	25.73	15.	.01440	1
GAGE PRESSURE =		0.0	GAMMA =1.25128	DEL = 3.1384				
.2100	.007	3979.34	3708.02	3189.35	0.00	23.71	469564.40	
.2100	.007	.0006	2023.48	.004	243.9	25.73	.0015	
.2100	.007	.0015	.182	.519	25.73	21.	.01440	1
GAGE PRESSURE =		0.0	GAMMA =1.25176	DEL = 3.1383				
.2200	.010	4180.99	3895.92	3350.95	0.00	28.58	478482.10	
.2200	.010	.0009	2026.28	.006	349.6	25.70	.0021	
.2200	.010	.0021	.221	.540	25.70	29.	.01439	1
GAGE PRESSURE =		0.0	GAMMA =1.25227	DEL = 3.1383				

5.56 MM M16 WC846 PROPELL 15.0 PC SCD ~~2~~ 3 INCR SAIB

T	XI	PBR	PC	PB	PPORT	V	AF	
T	XI	XF	TEMP	DL	PR	ST	Z	
T	XI	Z(I)	DCZ(I)	R(I)	S(I)	FTC(I)	UD(I)	INCR
.2300	.014	4419.23	4117.92	3541.89	0.00	33.56	488904.66	
.2300	.014	.0012	2032.41	.008	475.2	25.70	.0027	
.2300	.014	.0027	.263	.562	25.70	38.	.01439	1
GAGE PRESSURE =		0.0 GAMMA =1.25283 DEL = 3.1382						
.2400	.018	4697.38	4377.10	3764.81	0.00	38.68	501172.76	
.2400	.018	.0015	2038.74	.010	621.1	25.70	.0035	
.2400	.018	.0035	.308	.586	25.70	49.	.01439	1
GAGE PRESSURE =		0.0 GAMMA =1.25342 DEL = 3.1381						
.2500	.023	5021.15	4678.80	4024.29	0.00	43.96	515919.76	
.2500	.023	.0019	2045.44	.012	788.1	25.66	.0044	
.2500	.023	.0044	.361	.618	25.66	62.	.01438	1
GAGE PRESSURE =		0.0 GAMMA =1.25402 DEL = 3.1381						
.2600	.029	5393.24	5025.53	4322.50	0.00	49.43	533377.50	
.2600	.029	.0024	2052.09	.015	976.8	25.66	.0054	
.2600	.029	.0054	.417	.650	25.66	77.	.01438	1
GAGE PRESSURE =		0.0 GAMMA =1.25462 DEL = 3.1380						
.2700	.035	5820.94	5424.07	4665.27	0.00	55.13	554343.79	
.2700	.035	.0029	2058.90	.018	1188.1	25.62	.0066	
.2700	.035	.0066	.482	.690	25.62	94.	.01436	1
GAGE PRESSURE =		0.0 GAMMA =1.25521 DEL = 3.1379						
.2800	.042	6307.53	5877.48	5055.24	0.00	61.09	579080.30	
.2800	.042	.0035	2065.42	.022	1422.9	25.62	.0080	
.2800	.042	.0080	.553	.730	25.62	113.	.01436	1
GAGE PRESSURE =		0.0 GAMMA =1.25580 DEL = 3.1379						
.2900	.050	6863.19	6395.25	5500.57	0.00	67.36	608702.83	
.2900	.050	.0042	2072.04	.026	1682.4	25.57	.0096	
.2900	.050	.0096	.635	.780	25.57	136.	.01435	1
GAGE PRESSURE =		0.0 GAMMA =1.25635 DEL = 3.1378						
.3000	.058	7493.76	6982.83	6005.93	0.00	74.00	643740.75	
.3000	.058	.0049	2078.49	.031	1968.0	25.54	.0114	
.3000	.058	.0114	.727	.834	25.54	161.	.01434	1
GAGE PRESSURE =		0.0 GAMMA =1.25687 DEL = 3.1377						
.3100	.068	8207.81	7648.20	6578.19	0.00	81.07	685029.45	
.3100	.068	.0056	2084.70	.036	2281.2	25.50	.0135	
.3100	.068	.0135	.829	.893	25.50	191.	.01433	1
GAGE PRESSURE =		0.0 GAMMA =1.25736 DEL = 3.1377						
.3200	.078	9014.67	8400.05	7224.84	0.00	88.65	733461.73	
.3200	.078	.0065	2090.67	.041	2624.1	25.46	.0158	
.3200	.078	.0158	.945	.960	25.46	224.	.01431	1
GAGE PRESSURE =		0.0 GAMMA =1.25781 DEL = 3.1376						

5.56 MM M16 WC846 PROPELL 15.0 PC SCD ~~2~~ 3 INCR SAIB

T T T	XI XI XI	PBR XF Z(I)	PC TEMP DCZ(I)	PB DL R(I)	PPORT PR S(I)	V ST FTC(I)	AF Z UD(I)	INCR
.3300	.089	9924.81	9248.14	7954.26	0.00	96.81	790022.82	
.3300	.089	.0074	2096.39	.048	2998.7	25.42	.0185	
.3300	.089	.0185	1.076	1.034	25.42	262.	.01430	1
GAGE PRESSURE =		0.0	GAMMA =1.25821	DEL = 3.1376				
.3400	.101	10949.83	10203.28	8775.76	0.00	105.66	883984.61	
.3400	.101	.0084	2101.85	.055	3230.8	25.37	.0216	
.3400	.101	.0216	1.224	1.116	25.37	305.	.01428	1
GAGE PRESSURE =		0.0	GAMMA =1.25857	DEL = 3.1375				
.3500	.114	12100.04	11275.07	9697.58	0.00	115.79	1020369.06	
.3500	.114	.0095	2106.67	.062	3297.2	25.31	.0251	
.3500	.114	.0251	1.391	1.208	25.31	355.	.01426	1
GAGE PRESSURE =		0.0	GAMMA =1.25888	DEL = 3.1375				
.3600	.129	13390.04	12477.12	10731.44	0.00	127.45	1173565.81	
.3600	.129	.0107	2111.26	.071	3370.1	25.24	.0290	
.3600	.129	.0290	1.580	1.310	25.24	411.	.01424	1
GAGE PRESSURE =		0.0	GAMMA =1.25914	DEL = 3.1375				
.3700	.145	14832.34	13821.08	11887.35	0.00	140.82	1345025.58	
.3700	.145	.0121	2115.43	.080	3450.5	25.17	.0335	
.3700	.145	.0335	1.793	1.424	25.17	475.	.01422	1
GAGE PRESSURE =		0.0	GAMMA =1.25936	DEL = 3.1375				
.3800	.163	16440.92	15319.99	13176.54	0.00	156.12	1536361.13	
.3800	.163	.0136	2119.19	.090	3539.5	25.08	.0385	
.3800	.163	.0385	2.034	1.550	25.08	547.	.01419	1
GAGE PRESSURE =		0.0	GAMMA =1.25952	DEL = 3.1374				
.3900	.183	18230.31	16987.39	14610.64	0.00	173.56	1749235.56	
.3900	.183	.0152	2122.58	.101	3638.3	24.98	.0443	
.3900	.183	.0443	2.306	1.690	24.98	630.	.01416	1
GAGE PRESSURE =		0.0	GAMMA =1.25963	DEL = 3.1374				
.4000	.205	20215.49	18837.22	16201.65	0.00	193.39	1985343.44	
.4000	.205	.0170	2125.61	.113	3748.3	24.87	.0508	
.4000	.205	.0508	2.612	1.847	24.87	723.	.01412	1
GAGE PRESSURE =		16211.4	GAMMA =1.25968	DEL = 3.1374				
.4100	.229	22293.32	20773.38	17866.92	0.00	215.70	2174755.81	
.4100	.229	.0191	2127.66	.125	4225.4	24.75	.0579	
.4100	.229	.0579	2.833	2.013	24.75	825.	.01408	1
GAGE PRESSURE =		17933.0	GAMMA =1.25968	DEL = 3.1374				
.4200	.256	24456.37	22788.96	19600.50	0.00	239.72	2320450.80	
.4200	.256	.0214	2129.37	.137	5045.1	24.62	.0655	
.4200	.256	.0655	3.063	2.187	24.62	935.	.01404	1
GAGE PRESSURE =		19736.5	GAMMA =1.25964	DEL = 3.1374				

5.56 MM M16 WC846 PROPELL 15.0 PC SCD 2 3 INCR SAIH

T	XI	PRR	PC	PB	PPORT	V	AF	
T	XI	XF	TEMP	DL	PR	ST	Z	
T	XI	Z(I)	DCZ(I)	R(I)	S(I)	FTC(I)	UD(I)	INCR
.4300	.287	25685.51	24866.11	21387.04	0.00	265.30	2460426.58	
.4300	.287	.0239	2130.23	.150	5953.6	24.47	.0737	
.4300	.287	.0737	3.301	2.372	24.47	1055.	.01399	1
GAGE PRESSURE =		21665.3 GAMMA =1.25955 DEL = 3.1374						
.4400	.320	28968.55	26993.50	23216.80	0.00	292.39	2592179.73	
.4400	.320	.0267	2130.64	.162	6957.0	24.32	.0826	
.4400	.320	.0826	3.548	2.565	24.32	1183.	.01394	1
GAGE PRESSURE =		23530.4 GAMMA =1.25942 DEL = 3.1375						
.4500	.357	31289.91	29156.59	25077.27	0.00	320.88	2712882.67	
.4500	.357	.0297	2130.72	.174	8060.3	24.15	.0921	
.4500	.357	.0921	3.801	2.767	24.15	1321.	.01388	1
GAGE PRESSURE =		25498.5 GAMMA =1.25924 DEL = 3.1375						
.4600	.397	33633.54	31340.43	26955.59	0.00	350.65	2819714.23	
.4600	.397	.0331	2130.59	.186	9268.5	23.98	.1022	
.4600	.397	.1022	4.062	2.979	23.98	1470.	.01382	1
GAGE PRESSURE =		27495.6 GAMMA =1.25903 DEL = 3.1375						
.4700	.441	35983.60	33530.26	28839.68	0.00	381.56	2909957.68	
.4700	.441	.0368	2130.39	.198	10585.9	23.79	.1130	
.4700	.441	.1130	4.328	3.199	23.79	1629.	.01376	1
GAGE PRESSURE =		29506.3 GAMMA =1.25879 DEL = 3.1375						
.4800	.489	38325.71	35712.68	30716.21	0.00	413.39	2968317.42	
.4800	.489	.0407	2130.29	.209	12097.0	23.58	.1245	
.4800	.489	.1245	4.599	3.429	23.58	1798.	.01369	1
GAGE PRESSURE =		31514.5 GAMMA =1.25851 DEL = 3.1376						
.4900	.540	40647.78	37876.43	32577.28	0.00	445.80	2998974.00	
.4900	.540	.0450	2130.48	.220	13765.8	23.37	.1366	
.4900	.540	.1366	4.874	3.667	23.37	1979.	.01362	1
GAGE PRESSURE =		33506.2 GAMMA =1.25819 DEL = 3.1376						
.5000	.596	42504.67	39606.71	34065.54	0.00	494.45	5267878.54	
.5000	.596	.0497	2109.41	.230	1022.0	23.14	.1495	
.5000	.596	.1495	5.156	3.918	23.14	2170.	.01354	1
GAGE PRESSURE =		35920.6 GAMMA =1.25784 DEL = 3.1376						
.5100	.659	44700.83	41653.13	35825.73	0.00	551.02	5540072.51	
.5100	.659	.0549	2115.79	.240	1074.8	22.90	.1630	
.5100	.659	.1630	5.414	4.157	22.90	2373.	.01346	1
GAGE PRESSURE =		38025.2 GAMMA =1.25746 DEL = 3.1377						
.5200	.729	46445.20	43278.57	37223.84	0.00	610.03	5756275.63	
.5200	.729	.0607	2108.46	.248	1116.7	22.64	.1771	
.5200	.729	.1771	5.665	4.399	22.64	2586.	.01337	1
GAGE PRESSURE =		39789.1 GAMMA =1.25705 DEL = 3.1377						

5.56 MM M16 WC846 PROPELL 15.' PC SCD ~~2~~ 3 INCR SAI8

T	XI	PBR	PC	PH	PPORT	V	AF	
T	XI	XF	TEMP	DL	PR	ST	Z	
T	XI	Z(I)	DCZ(I)	R(I)	S(I)	FTC(I)	UD(I)	INCR
.5300	.806	47949.52	44680.37	38429.61	0.00	671.15	5942735.60	
.5300	.806	.0671	2160.44	.256	1152.9	22.37	.1918	
.5300	.806	.1918	5.901	4.637	22.37	2810.	.01328	1
GAGE PRESSURE =		41358.8 GAMMA =1.25661 DEL = 3.1378						
.5400	.890	49201.07	45846.52	39432.71	0.00	734.05	6097855.26	
.5400	.890	.0742	2091.92	.263	1183.0	22.09	.2071	
.5400	.890	.2071	6.118	4.869	22.09	3043.	.01318	1
GAGE PRESSURE =		42743.6 GAMMA =1.25614 DEL = 3.1378						
.5500	.982	50194.28	46772.00	40228.82	0.00	798.37	6220964.48	
.5500	.982	.0816	2083.11	.268	1206.9	21.80	.2228	
.5500	.982	.2228	6.316	5.093	21.80	3285.	.01308	1
GAGE PRESSURE =		43922.3 GAMMA =1.25565 DEL = 3.1379						
.5600	1.081	50931.89	47459.32	40820.09	0.00	863.79	6312398.09	
.5600	1.081	.0901	2074.23	.273	1224.6	21.50	.2390	
.5600	1.081	.2390	6.492	5.309	21.50	3535.	.01297	1
GAGE PRESSURE =		44890.9 GAMMA =1.25514 DEL = 3.1379						
.5700	1.189	51423.75	47917.03	41214.40	0.00	929.97	6373373.70	
.5700	1.189	.0991	2065.46	.277	1236.4	21.19	.2556	
.5700	1.189	.2550	6.647	5.514	21.19	3793.	.01286	1
GAGE PRESSURE =		45649.0 GAMMA =1.25460 DEL = 3.1380						
.5800	1.305	51690.15	48165.86	41428.01	0.00	996.60	6406407.61	
.5800	1.305	.1087	2057.10	.279	1242.8	20.87	.2725	
.5800	1.305	.2725	6.785	5.715	20.87	4059.	.01275	1
GAGE PRESSURE =		46277.6 GAMMA =1.25404 DEL = 3.1381						
.5900	1.428	51719.06	48192.79	41451.29	0.00	1063.37	6410097.67	
.5900	1.428	.1190	2048.36	.281	1243.5	20.55	.2896	
.5900	1.428	.2896	6.864	5.874	20.55	4329.	.01263	2
GAGE PRESSURE =		46549.4 GAMMA =1.25348 DEL = 3.1381						
.6000	1.560	51532.16	48018.04	41301.62	0.00	1129.99	6386862.49	
.6000	1.560	.1300	2039.03	.282	1239.0	20.22	.3069	
.6000	1.560	.3069	6.915	6.014	20.22	4603.	.01251	2
GAGE PRESSURE =		46687.3 GAMMA =1.25293 DEL = 3.1382						
.6100	1.699	51156.88	47668.92	41000.94	0.00	1196.18	6340364.40	
.6100	1.699	.1416	2030.59	.283	1230.0	19.88	.3242	
.6100	1.699	.3242	6.943	6.140	19.88	4879.	.01239	2
GAGE PRESSURE =		46047.9 GAMMA =1.25237 DEL = 3.1382						
.6200	1.847	50620.76	47169.33	40571.35	0.00	1261.71	6273932.84	
.6200	1.847	.1539	2022.56	.282	1217.1	19.54	.3415	
.6200	1.847	.3415	6.951	6.252	19.54	5157.	.01226	2
GAGE PRESSURE =		46431.1 GAMMA =1.25182 DEL = 3.1383						

5.56 MM M16 WC846 PROPELL 15.0 PC SCD ~~2~~3 INCR SAIB

T T T	XI XI XI	PBR XF Z(I)	PC TEMP DCZ(I)	PB DL R(I)	PPORT PR S(I)	V ST FTC(I)	AF Z UD(I)	INCR
.6300	2.002	49950.88	46545.12	40034.56	0.00	1326.38	6190924.12	
.6300	2.002	.1668	2014.46	.282	1201.0	19.20	.3588	
.6300	2.002	.3588	6.938	6.352	19.20	5437.	.01214	2
GAGE PRESSURE =		46079.5 GAMMA =1.25128	DEL = 3.1384					
.6400	2.165	49172.68	45819.96	39410.94	0.00	1390.06	6094488.94	
.6400	2.165	.1804	2006.76	.280	1182.3	18.86	.3760	
.6400	2.165	.3760	6.909	6.441	18.86	5716.	.01201	2
GAGE PRESSURE =		45607.6 GAMMA =1.25073	DEL = 3.1384					
.6500	2.335	48309.33	45015.48	38719.09	0.00	1452.61	5987500.83	
.6500	2.335	.1946	1999.53	.278	1161.6	18.52	.3932	
.6500	2.335	.3932	6.865	6.519	18.52	5996.	.01188	2
GAGE PRESSURE =		45035.4 GAMMA =1.25019	DEL = 3.1385					
.6600	2.513	47381.49	44150.88	37975.53	0.00	1513.94	5872517.56	
.6600	2.513	.2095	1992.80	.276	1139.3	18.17	.4101	
.6600	2.513	.4101	6.809	6.587	18.17	6275.	.01175	2
GAGE PRESSURE =		44381.8 GAMMA =1.24965	DEL = 3.1386					
.6700	2.699	46407.12	43242.95	37194.69	0.00	1573.98	5751768.23	
.6700	2.699	.2249	1986.60	.273	1115.8	17.83	.4270	
.6700	2.699	.4270	6.741	6.647	17.83	6553.	.01161	2
GAGE PRESSURE =		43063.6 GAMMA =1.24911	DEL = 3.1386					
.6800	2.891	45401.63	42306.00	36388.89	0.00	1632.70	5627159.40	
.6800	2.891	.2409	1980.94	.270	1091.7	17.49	.4436	
.6800	2.891	.4436	6.664	6.700	17.49	6830.	.01148	2
GAGE PRESSURE =		42895.8 GAMMA =1.24858	DEL = 3.1387					
.6900	3.090	44377.93	41352.05	35568.49	0.00	1690.06	5500293.93	
.6900	3.090	.2575	1975.83	.267	1067.1	17.15	.4600	
.6900	3.090	.4600	6.579	6.746	17.15	7105.	.01135	2
GAGE PRESSURE =		42091.4 GAMMA =1.24806	DEL = 3.1387					
.7000	3.297	43346.72	40391.19	34742.08	0.00	1746.04	5372497.59	
.7000	3.297	.2747	1971.25	.264	1042.3	16.81	.4762	
.7000	3.297	.4762	6.487	6.786	16.81	7377.	.01121	2
GAGE PRESSURE =		41261.7 GAMMA =1.24753	DEL = 3.1388					
.7100	3.509	42316.72	39431.41	33916.62	0.00	1800.66	5244849.45	
.7100	3.509	.2925	1967.20	.261	1017.5	16.47	.4921	
.7100	3.509	.4921	6.389	6.821	16.47	7647.	.01107	2
GAGE PRESSURE =		40416.0 GAMMA =1.24701	DEL = 3.1389					
.7200	3.729	41294.89	38479.24	33097.71	0.00	1853.92	5118213.31	
.7200	3.729	.3107	1963.65	.257	992.9	16.13	.5078	
.7200	3.729	.5078	6.287	6.852	16.13	7914.	.01094	2
GAGE PRESSURE =		39562.5 GAMMA =1.24650	DEL = 3.1389					

5.56 MM M16 WC846 PROPELL 15. PC SCD 3 INCR SAI

T	XI	PBR	PC	PB	PPORT	V	AF	
T	XI	XF	TEMP	DL	PR	ST	Z	
T	XI	Z(I)	DCZ(I)	R(I)	S(I)	FTC(I)	UD(I)	INCR
.7300	3.954	40286.71	37539.79	32289.73	0.00	1905.84	4993268.14	
.7300	3.954	.3295	1960.59	.254	968.7	15.80	.5232	
.7300	3.954	.5232	6.181	6.878	15.80	8178.	.01080	2
GAGE PRESSURE =		38707.4 GAMMA =1.24599 DEL = 3.1390						
.7400	4.186	39296.39	36616.99	31496.67	0.00	1956.45	4870536.52	
.7400	4.186	.3488	1957.98	.250	944.9	15.47	.5383	
.7400	4.186	.5383	6.071	6.902	15.47	8440.	.01066	2
GAGE PRESSURE =		37856.3 GAMMA =1.24549 DEL = 3.1390						
.7500	4.424	38306.05	35694.17	30702.38	0.00	2005.75	4747800.56	
.7500	4.424	.3686	1955.13	.246	921.1	15.14	.5531	
.7500	4.424	.5531	5.966	6.863	15.14	8695.	.01053	3
GAGE PRESSURE =		36993.0 GAMMA =1.24500 DEL = 3.1391						
.7600	4.667	37296.27	34753.23	29893.19	0.00	2053.75	4622654.13	
.7600	4.667	.3889	1951.22	.242	896.8	14.82	.5672	
.7600	4.667	.5672	5.681	6.742	14.82	8940.	.01039	3
GAGE PRESSURE =		36099.7 GAMMA =1.24456 DEL = 3.1391						
.7700	4.917	36278.73	33805.17	29077.60	0.00	2100.41	4496544.95	
.7700	4.917	.4097	1945.46	.238	872.3	14.51	.5808	
.7700	4.917	.5808	5.461	6.618	14.51	9176.	.01026	3
GAGE PRESSURE =		35188.7 GAMMA =1.24416 DEL = 3.1392						
.7800	5.171	35262.13	32857.75	28262.81	0.00	2145.73	4370546.66	
.7800	5.171	.4309	1940.98	.234	847.9	14.21	.5939	
.7800	5.171	.5939	5.247	6.492	14.21	9402.	.01013	3
GAGE PRESSURE =		34269.1 GAMMA =1.24378 DEL = 3.1392						
.7900	5.431	34253.50	31917.92	27454.46	0.00	2189.71	4245543.42	
.7900	5.431	.4526	1934.91	.230	823.6	13.92	.6065	
.7900	5.431	.6065	5.040	6.366	13.92	9620.	.01000	3
GAGE PRESSURE =		33348.3 GAMMA =1.24344 DEL = 3.1393						
.8000	5.697	33258.63	3 990.86	26657.10	0.00	2232.40	4122240.27	
.8000	5.697	.4747	1928.35	.226	799.7	13.64	.6186	
.8000	5.697	.6186	4.841	6.241	13.64	9829.	.00988	3
GAGE PRESSURE =		32434.1 GAMMA =1.24312 DEL = 3.1393						
.8100	5.967	32281.93	30080.78	25874.30	0.00	2273.80	4001189.03	
.8100	5.967	.4973	1921.40	.222	776.2	13.37	.6302	
.8100	5.967	.6302	4.649	6.116	13.37	10029.	.00975	3
GAGE PRESSURE =		31530.1 GAMMA =1.24283 DEL = 3.1393						
.8200	6.242	31326.82	29191.79	25130.80	0.00	2313.94	3892812.34	
.8200	6.242	.5202	1914.12	.218	753.3	13.10	.6413	
.8200	6.242	.6413	4.465	5.993	13.10	10222.	.00964	3
GAGE PRESSURE =		3 640.3 GAMMA =1.24256 DEL = 3.1394						

5.56 MM M16 #C845 PROPELL 15. PC SCD 3 INCR SATP

T	XI	PPR	PC	PS	PPORT	V	AF	
T	XI	XF	TEMP	DL	PR	ST	Z	
T	XI	Z(I)	DCZ(I)	R(I)	S(I)	FTC(I)	UD(I)	INCR
.8300	6.522	30395.63	28323.27	24302.63	0.00	2352.87	3767424.89	
.8300	6.522	.5435	1916.59	.214	730.9	12.84	.6526	
.8300	6.522	.0523	4.259	5.871	12.84	10417.	.00952	3
GAGE PRESSURE =	29769.5 GAMMA =1.24231 DEL = 3.1394							
.8400	6.807	29496.77	27479.91	23637.24	0.00	2390.61	3655251.88	
.8400	6.807	.5673	1898.50	.210	709.1	12.59	.6623	
.8400	6.807	.0623	4.127	5.752	12.59	10588.	.00940	3
GAGE PRESSURE =	28918.5 GAMMA =1.24207 DEL = 3.1394							
.8500	7.096	28012.88	26661.97	22933.63	0.00	2427.20	3546444.97	
.8500	7.096	.5913	1890.97	.206	688.0	12.35	.6721	
.8500	7.096	.6721	3.958	5.635	12.35	10756.	.00929	3
GAGE PRESSURE =	28089.5 GAMMA =1.24185 DEL = 3.1394							
.8600	7.389	27762.98	25859.86	22252.37	0.00	2462.68	3441095.85	
.8600	7.389	.6158	1882.57	.202	667.6	12.12	.6816	
.8600	7.389	.6810	3.814	5.521	12.12	10921.	.00918	3
GAGE PRESSURE =	27283.7 GAMMA =1.24158 DEL = 3.1395							
.8700	7.687	26941.15	25104.13	21593.76	0.00	2497.09	3339247.82	
.8700	7.687	.6496	1874.29	.199	647.8	11.89	.6907	
.8700	7.687	.6907	3.627	5.418	11.89	11078.	.00907	3
GAGE PRESSURE =	26502.1 GAMMA =1.24146 DEL = 3.1395							
.8800	7.989	26147.71	24364.80	20957.81	0.00	2530.46	3240965.39	
.8800	7.989	.6657	1865.75	.195	628.7	11.67	.6995	
.8800	7.989	.6995	3.516	5.299	11.67	11230.	.00897	3
GAGE PRESSURE =	25745.0 GAMMA =1.24128 DEL = 3.1395							
.8900	8.294	25382.33	23651.91	20344.36	0.00	2562.84	3146042.40	
.8900	8.294	.6912	1855.38	.191	610.3	11.45	.7079	
.8900	8.294	.7079	3.382	5.193	11.45	11376.	.00886	3
GAGE PRESSURE =	25012.5 GAMMA =1.24111 DEL = 3.1395							
.9000	8.604	24644.62	22964.2[illegible]	19753.09	0.00	2594.26	3054698.76	
.9000	8.604	.7170	1851.41	.188	592.6	11.24	.7161	
.9000	8.604	.7161	3.254	5.089	11.24	11516.	.00876	3
GAGE PRESSURE =	24304.7 GAMMA =1.24095 DEL = 3.1396							
.9100	8.917	23934.13	22302.[illegible]7	19183.56	0.00	2624.75	2966535.95	
.9100	8.917	.7431	1842.24	.184	575.5	11.04	.7239	
.9100	8.917	.7239	3.132	4.989	11.04	11651.	.00866	3
GAGE PRESSURE =	23621.3 GAMMA =1.24080 DEL = 3.1396							
.9200	9.234	23249.90	21664.58	18635.22	0.00	2654.36	2881741.62	
.9200	9.234	.7695	1834.10	.181	559.1	10.84	.7314	
.9200	9.234	.7314	3.016	4.891	10.84	11781.	.00857	3
GAGE PRESSURE =	22961.8 GAMMA =1.24066 DEL = 3.1396							

5.56 MM M16 WC846 PROPELL 15. PC SCD Z INCR SAIB

T	XT	PBR	PC	PH	PPORT	V	AF	
T	XT	XF	TEMP	DL	PR	ST	Z	
T	XT	Z(I)	DCZ(I)	R(I)	S(I)	FTC(I)	UD(I)	INCR
.9300	9.554	22591.47	21351.04	18107.49	0.00	2683.11	2800133.32	
.9300	9.554	.7962	1825.99	.177	543.2	10.65	.7386	
.9300	9.554	.7386	2.435	4.795	10.65	11907.	.00847	3
GAGE PRESSURE =		22325.7 GAMMA =1.24053 DEL = 3.1396						
.9400	9.878	21957.94	20460.71	17599.72	0.00	2711.04	2721611.48	
.9400	9.878	.8231	1817.92	.174	528.0	10.47	.7456	
.9400	9.878	.7456	2.799	4.703	10.47	12028.	.00838	3
GAGE PRESSURE =		21712.6 GAMMA =1.24040 DEL = 3.1396						
.9500	10.204	21348.47	19892.80	17111.23	0.00	2738.18	2646071.93	
.9500	10.204	.8504	1809.91	.171	513.3	10.28	.7523	
.9500	10.204	.7523	2.659	4.613	10.28	12144.	.00828	3
GAGE PRESSURE =		21121.7 GAMMA =1.24028 DEL = 3.1396						
.9600	10.535	20762.21	19346.51	16641.34	0.00	2764.56	2573407.83	
.9600	10.535	.8779	1801.96	.168	499.2	10.11	.7588	
.9600	10.535	.7588	2.602	4.526	10.11	12257.	.00819	3
GAGE PRESSURE =		20552.4 GAMMA =1.24017 DEL = 3.1396						
.9700	10.868	20198.28	18821.03	16189.34	0.00	2790.21	2503511.24	
.9700	10.868	.9057	1794.08	.165	485.7	9.94	.7651	
.9700	10.868	.7651	2.510	4.442	9.94	12365.	.00810	3
GAGE PRESSURE =		20003.9 GAMMA =1.24006 DEL = 3.1397						
.9800	11.204	19655.30	18315.54	15754.54	0.00	2815.16	2436274.37	
.9800	11.204	.9337	1786.26	.162	472.6	9.77	.7711	
.9800	11.204	.7711	2.422	4.360	9.77	12469.	.00802	3
GAGE PRESSURE =		19475.6 GAMMA =1.23996 DEL = 3.1397						
.9900	11.544	19133.92	17829.25	15336.25	15254.33	2839.44	2371590.53	
.9900	11.544	.9620	1778.52	.159	460.1	9.61	.7770	
.9900	11.544	.7770	2.339	4.280	9.61	12570.	.00793	3
GAGE PRESSURE =		18956.7 GAMMA =1.23986 DEL = 3.1397						
1.0000	11.886	18631.30	17361.36	14933.80	15071.32	2863.07	2309354.91	
1.0000	11.886	.9905	1770.86	.156	448.0	9.45	.7826	
1.0000	11.886	.7825	2.259	4.203	9.45	12668.	.00785	3
GAGE PRESSURE =		18476.4 GAMMA =1.23977 DEL = 3.1397						
1.0100	12.231	18148.60	16911.11	14546.51	14837.79	2886.08	2249465.09	
1.0100	12.231	1.0192	1763.29	.154	436.4	9.29	.7880	
1.0100	12.231	.7880	2.182	4.128	9.29	12762.	.00776	3
GAGE PRESSURE =		18004.3 GAMMA =1.23968 DEL = 3.1397						
1.0200	12.578	17683.53	16477.75	14173.75	14601.75	2908.49	2191821.53	
1.0200	12.578	1.0482	1755.79	.151	425.2	9.14	.7933	
1.0200	12.578	.7933	2.109	4.055	9.14	12853.	.00768	3
GAGE PRESSURE =		17548.9 GAMMA =1.23960 DEL = 3.1397						

$\frac{\Delta P}{\Delta t} = \frac{15755 - 15336}{.01 \times 10^{-3}}$

$= 2.9/\times 10^{5}$ PSF/Sec $= 4.19 \times 10^{7}$ PSI/SEC

$\frac{\Delta T}{\Delta t} = \frac{1786 - 1778\ ^{\circ}K}{.01 \times 10^{-3}} = 8 \times 10^{5}\ ^{\circ}K/SEC$

$= 14.4 \times 10^{5}$

5.56 MM M16 WC846 PROPELL 15. PC SCD 3 INCR SATH

T	XI	PBR	PC	PB	PPORT	V	AF	
T	XI	XF	TEMP	DL	PR	ST	Z	
T	XI	Z(I)	DCZ(I)	R(I)	S(I)	FTC(I)	UD(I)	INCR
1.0300	12.929	17235.80	16765.55	13814.89	14364.34	2930.32	2136327.79	
1.0300	12.929	1.0774	1748.38	.148	414.4	9.00	.7984	
1.0300	12.929	.7984	2.039	3.984	9.01	12941.	.00760	3
GAGE PRESSURE =		17111.3 GAMMA =1.23952 DEL = 3.1397						
1.0400	13.282	16814.07	15658.82	13469.33	14126.54	2951.59	2082890.80	
1.0400	13.282	1.1063	1741.35	.146	404.1	8.85	.8033	
1.0400	13.282	.8033	1.972	3.916	8.85	13026.	.00753	3
GAGE PRESSURE =		16687.6 GAMMA =1.23944 DEL = 3.1397						
1.0500	13.637	16389.41	15271.87	13136.49	13889.17	2972.34	2031420.93	
1.0500	13.637	1.1364	1733.60	.143	394.1	8.72	.8081	
1.0500	13.637	.8081	1.906	3.849	8.72	13109.	.00745	3
GAGE PRESSURE =		16280.0 GAMMA =1.23937 DEL = 3.1397						
1.0600	13.995	15989.32	14899.06	12815.82	13652.94	2992.57	1981832.11	
1.0600	13.995	1.1662	1726.65	.141	384.5	8.58	.8127	
1.0600	13.995	.8127	1.847	3.784	8.58	13188.	.00737	3
GAGE PRESSURE =		15887.1 GAMMA =1.23930 DEL = 3.1397						
1.0700	14.355	15603.75	14539.74	12506.78	13418.45	3012.30	1934041.78	
1.0700	14.355	1.1963	1719.57	.139	375.2	8.45	.8171	
1.0700	14.355	.8171	1.788	3.721	8.45	13265.	.00730	3
GAGE PRESSURE =		15508.1 GAMMA =1.23923 DEL = 3.1397						
1.0800	14.718	15232.04	14193.42	12208.85	13186.18	3031.56	1887970.91	
1.0800	14.718	1.2265	1712.59	.136	366.3	8.32	.8214	
1.0800	14.718	.8214	1.731	3.661	8.32	13340.	.00722	3
GAGE PRESSURE =		15142.4 GAMMA =1.23917 DEL = 3.1398						
1.0900	15.083	14873.51	13859.42	11921.56	12956.56	3050.36	1843543.97	
1.0900	15.083	1.2567	1705.08	.134	357.0	8.19	.8256	
1.0900	15.083	.8256	1.677	3.601	8.19	13413.	.00715	3
GAGE PRESSURE =		14789.0 GAMMA =1.23911 DEL = 3.1398						
1.1000	15.450	14527.85	13537.24	11644.43	12724.92	3068.72	1800688.77	
1.1000	15.450	1.2875	1698.26	.132	349.3	8.07	.8297	
1.1000	15.450	.8297	1.626	3.543	8.07	13483.	.00708	3
GAGE PRESSURE =		14449.1 GAMMA =1.23905 DEL = 3.1398						
1.1100	15.819	14194.22	13226.36	11377.02	12500.55	3086.64	1759336.45	
1.1100	15.819	1.3133	1692.13	.130	341.3	7.95	.8336	
1.1100	15.819	.8336	1.576	3.487	7.95	13551.	.00701	3
GAGE PRESSURE =		14121.2 GAMMA =1.23899 DEL = 3.1398						
1.1200	16.191	13872.12	12925.24	11113.96	12286.07	3104.16	1719421.36	
1.1200	16.191	1.3492	1685.46	.128	333.6	7.83	.8374	
1.1200	16.191	.8374	1.528	3.433	7.83	13617.	.00694	3
GAGE PRESSURE =		13802.6 GAMMA =1.23894 DEL = 3.1398						

5.56 MM M16 WC846 PROPELL 15. PC SCD 3 INCR SAIB

T	XI	PBR	PC	PB	PPORT	V	AF	
T	XI	XF	TEMP	DL	PR	ST	Z	
T	XI	Z(I)	DCZ(I)	R(I)	S(I)	FTC(I)	UD(I) INCR	
1.1300	16.564	13561.24	12636.54	10869.67	12070.46	3121.28	1680880.90	
1.1300	16.564	1.3803	1678.91	.126	326.1	7.71	.8411	
1.1300	16.564	.8411	1.483	3.380	7.71	13681.	.00687	3
GAGE PRESSURE =		13495.8	GAMMA =1.23889	DEL = 3.1398				
1.1400	16.540	13260.90	12356.68	10628.95	11858.05	3138.01	1643655.48	
1.1400	16.540	1.4116	1672.42	.124	318.9	7.60	.8447	
1.1400	16.540	.8447	1.439	3.328	7.60	13743.	.00681	3
GAGE PRESSURE =		13199.3	GAMMA =1.23884	DEL = 3.1398				
1.1500	17.317	12970.72	12086.28	10396.36	11049.56	3154.37	1607688.32	
1.1500	17.317	1.4431	1666.01	.122	311.9	7.49	.8482	
1.1500	17.317	.8482	1.396	3.278	7.49	13803.	.00674	3
GAGE PRESSURE =		12912.7	GAMMA =1.23879	DEL = 3.1398				
1.1600	17.697	12690.25	11824.94	10171.56	11445.06	3170.38	1572925.38	
1.1600	17.697	1.4747	1659.68	.120	305.1	7.38	.8516	
1.1600	17.697	.8516	1.356	3.229	7.38	13862.	.00668	3
GAGE PRESSURE =		12635.5	GAMMA =1.23874	DEL = 3.1398				
1.1700	18.078	12419.08	11572.26	9954.22	11244.59	3186.04	1539315.25	
1.1700	18.078	1.5065	1653.42	.118	298.6	7.28	.8548	
1.1700	18.078	.8548	1.317	3.181	7.28	13918.	.00661	3
GAGE PRESSURE =		12307.4	GAMMA =1.23870	DEL = 3.1398				
1.1800	18.461	12156.82	11327.85	9744.01	11048.18	3201.36	1506838.96	
1.1800	18.461	1.5385	1647.25	.117	292.3	7.17	.8580	
1.1800	18.461	.8580	1.279	3.135	7.17	13974.	.00655	3
GAGE PRESSURE =		12158.0	GAMMA =1.23865	DEL = 3.1398				
1.1900	18.846	11903.09	11091.46	9540.64	10855.84	3216.36	1475359.95	
1.1900	18.846	1.5705	1641.14	.115	286.2	7.07	.8611	
1.1900	18.846	.8611	1.243	3.090	7.07	14027.	.00649	3
GAGE PRESSURE =		11857.3	GAMMA =1.23861	DEL = 3.1398				

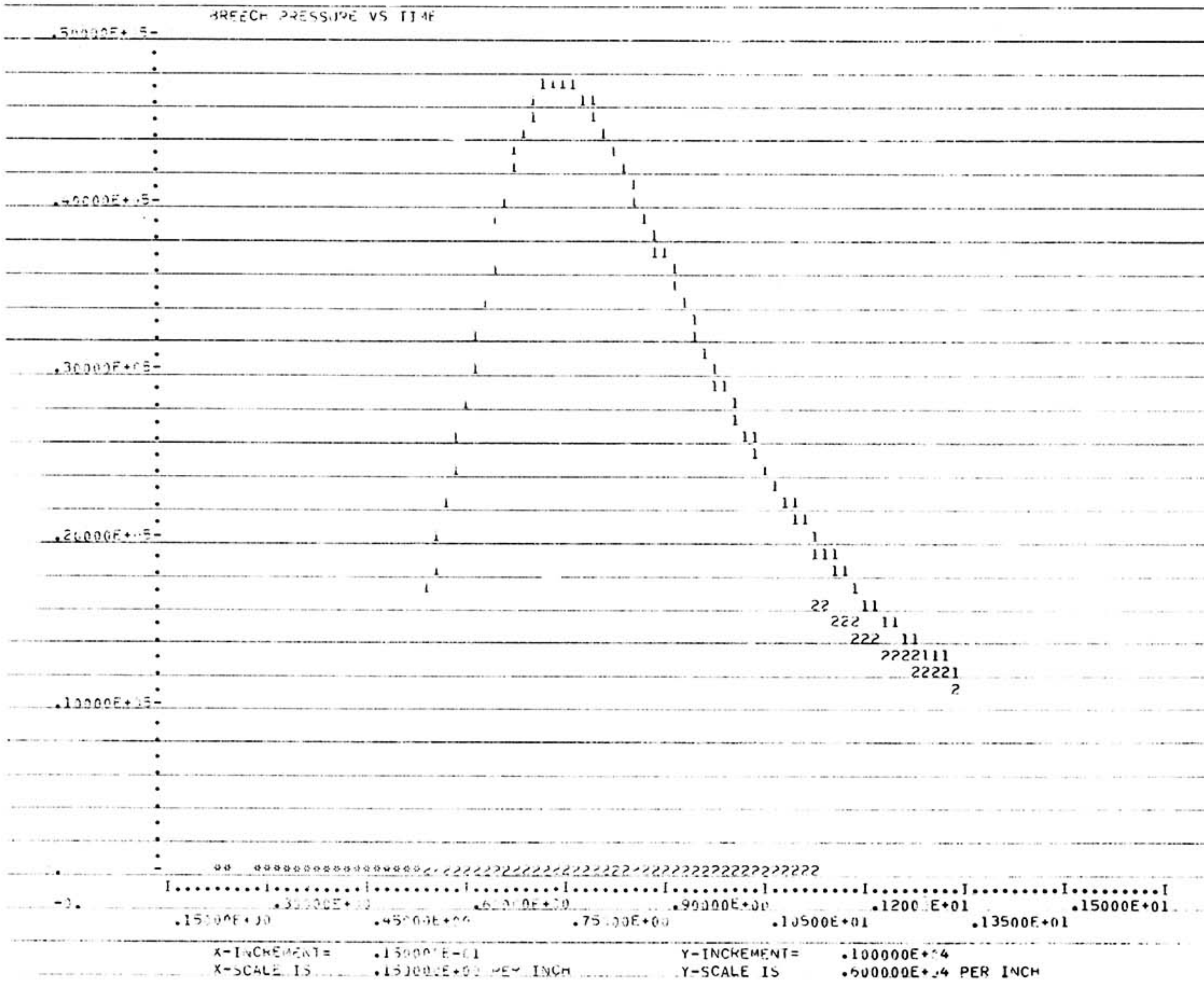
5.56 MM M16 WC846 PROPELL 15.0 PC SCD 3 INCR SAIB

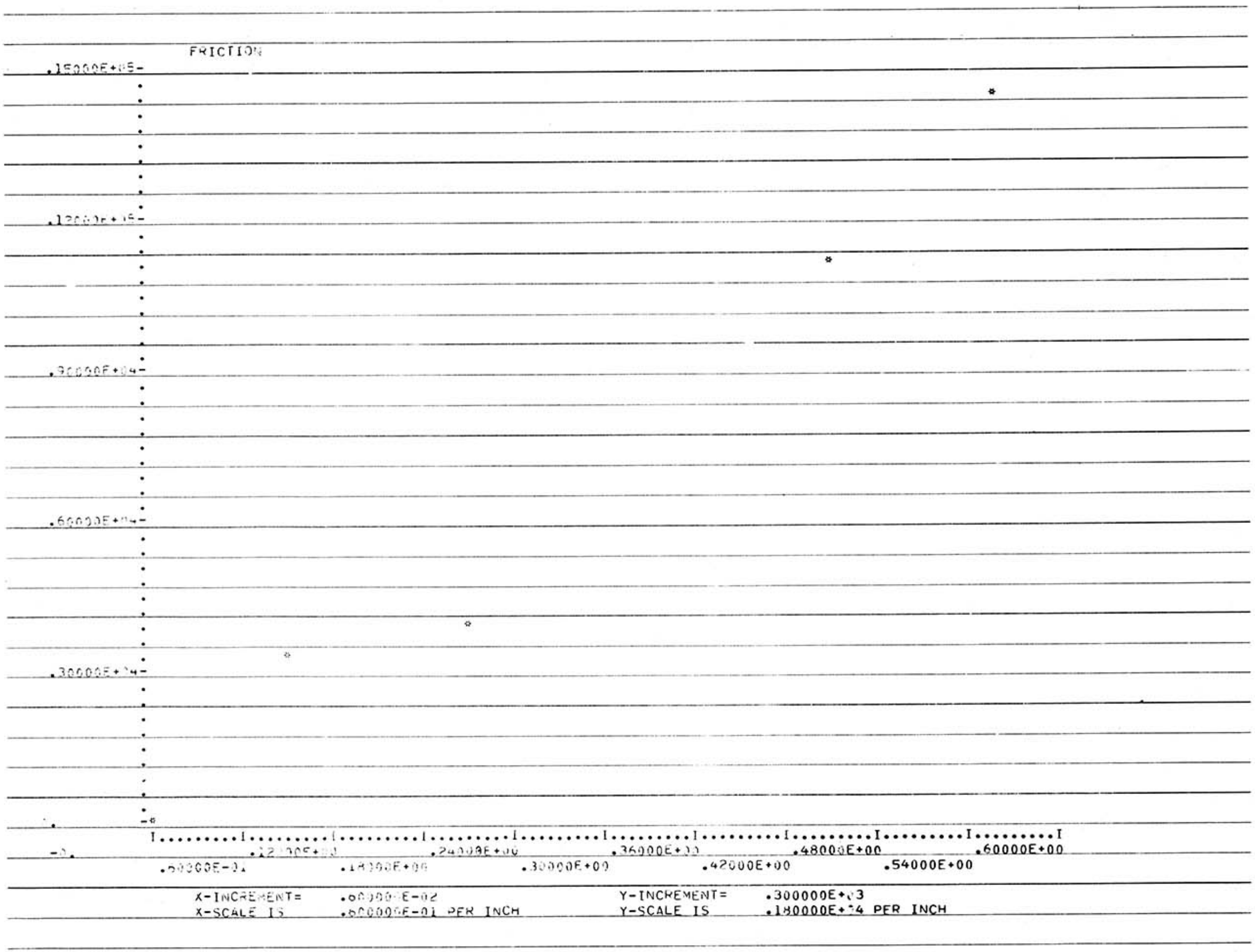
MUZZLE VEL.	MAX. PRESSURE	X AT PMAX	T AT PMAX	MUZ PRESSURE	FORCE
3202.9	51719.	1.428	.590	9723.6	4062181.

Z AT PMAX	Z AT MUZ	MAX PORT PRESS	MAX GAGE PRESS	T AT MUZ
.28962217	.85834793	15254.327	40687.287	1.1900

PIEZ. EFF.	BAL. EFF.
.40689	.25567

WEIGHT FRACTION 1	1.00000000
NUMBER POWDER GRAINS	29572.03
INITIAL GRAIN SURFACE	.0009
INITIAL FRACTION SURFACE	23.7316


BREECH PRESSURE VS TIME
.50000E+05
.40000E+05
.30000E+05
.20000E+05
.10000E+05
-0.
.15000E+00
.30000E+00
.45000E+00
.60000E+00
.75000E+00
.90000E+00
.10500E+01
.12000E+01
.13500E+01
.15000E+01
X-INCREMENT= .15000E-01
X-SCALE IS .150000E+00 PER INCH
Y-INCREMENT= .100000E+04
Y-SCALE IS .600000E+04 PER INCH


FRICTION
.15000E+05
.12000E+05
.90000E+04
.60000E+04
.30000E+04
-0.
.60000E-01
.12000E+00
.18000E+00
.24000E+00
.30000E+00
.36000E+00
.42000E+00
.48000E+00
.54000E+00
.60000E+00
X-INCREMENT= .600000E-02
X-SCALE IS .600000E-01 PER INCH
Y-INCREMENT= .300000E+03
Y-SCALE IS .180000E+04 PER INCH

APPENDIX 2A


```
      PROGRAM PORT (INPUT,OUTPUT,TAPE1=INPUT,TAPE5=OUTPUT,TAPE6=OUTPUT)
C     THIS PROGRAM CALCULATES THE NONSTEADY FLOW PROCESS IN THE
C     M16 RIFLE BARREL WHEN PROJECTILE PASSES THE PORT
C     XCL=LENGTH OF HOLE DIAMETER UNCOVERED(FT)
C     DP=PORT DIAMETER (FT)
C     UP=VOLUME OF PLENUM CHAMBER(FT*3)
C     PB(K)=PRESSURE IN PLENUM CHAMBER AT TIME TAU(K)(LBF/FT*2
C     T01=TEMP WHEN PROJECTILE FIRST PASSES PORT              R
C     P01=PRES WHEN PROJECTILE FIRST PASSES PORT         LBF/FT-FT
C     V01=VELOCITY PROJ AT PORT                          FT/SEC
C     PREF=ATMOS. PRES                                   LBF/FT-FT
C     SSI=ENTROPY AT PT I                                    DIMN.
C     AREF=REF SPEED OF SOUND                                FT/SEC
C     G   =ACCEL DUE TO GRAVITY                              FT/SEC-SEC
C     D   =BORE   DIAM.                                      FT
C     TREF=ATMOS. TEMP.                                       R
C     R = PROPELLANT GAS CONSTANT                        FT-LB/SLUG-R
C     NA =NO.OF POINTS ALONG 1ST Q WAVE                       DIMN.
C     GAMA=RATIO OF SP,HEAT                                   DIMN.
C     ND =NO.OF SEGMENTS ALONG 1ST Q WAVE                     DIMN.
C     UI =VELOCITY OF GAS AT PT I                            FT/SEC
C     DPDT=RATE OF PRES CHANGE                           LBF/FT-FT-SEC
C     DTDT=RATE OF TEMP CHANGE                                 R/SEC
C     RPI =RIEMANN VAR AT PT I                               FT/SEC
C     RQI =RIEMANN VAR AT PT I                               FT/SEC
C     AI =SPEED OF SOUND AT PT I                             FT/SEC
C     XJ =MECH. EQUIV. OF HEAT (778)                     FT-LB/BTU
C     T=GAS TEMP                                         R
C     P=GAS PRES.                                        LBF/FT-FT
C     TAU= TIME COORDINATE                               SEC
C     X=POSITION COORDINATE                              FT
C     TOL=TOLERANCE OF CONVERGENCE                       DIMN
C     ITMAX=MAX NO. ITERATIONS                           DIMN
C     UB=VOLUME OF PLENUM CHAMBER(FT**3)
C     DP=PORT DIAMETER(FT)
C     TTT =TIME FOR PROJECTIEE TO UNCOVER PORT           SEC
      DIMENSION A(50,50),SS(50,50),RP(50,50),RQ(50,50),TAU(50,50),
     1T(50,50),X(50,50),P(50,50),U(50,50),XX(50),XTAU(50)
      COMMON/CONST/ND,D,DTDT,DPDT,T01,P01,V01,PREF,TREF,TOL ,ITMAX,
     1GAMA,R,XJ,G,DX,AREF,CP,J
      COMMON/TPR/K,YX(50),PB(50),YP(50),DP,UB,RHO(50),YU(50),YTAU(50),
     CDTAU(50),AU(50),ARHO(50),AP(50),AT(50),YT(50)
     C,VYT(50),XCL(50),APRT(50),COEF(50)
      DO 8 I=1,50
      DO 8 J=1,50
      A(I,J)=0.0
      SS(I,J)=0.0
      RP(I,J)=0.0
      RQ(I,J)=0.0
      TAU(I,J)=0.0
      T(I,J)=0.0
      X(I,J)=0.0
      P(I,J)=0.0
```

```
      U(I,J)=0.0
    8 CONTINUE
      READ(1,100)TREF,PREF,GAMA ,R,TOL,XJ,G,VO1,TO1
      READ(1,101)D,NA,ITMAX,DP,UB
  100 FORMAT(4F10.2)
  101 FORMAT(F10.2,2I5,2F10.2)
      READ(1,105)PO1,DPDT,DTDT
105   FORMAT(3E15.6)
      AREF=SQRT(GAMA*R*TREF)
C  INITIALIZATION
      ND=NA-1
      DX=D/FLOAT(ND)
      T(1,1)=TO1
      P(1,1)=PO1
      A(1,1)=SQRT(GAMA*R*T(1,1))
      CP=GAMA*R/(GAMA-1.)/G/XJ
      SS(1,1)=G*XJ/R/GAMA*(CP*ALOG(T(1,1)/TREF)-R/G/XJ*ALOG(P(1,1)
     1/PREF))
      TAU(1,1)=0.0
      X(1,1)=D
      RP(1,1)=2.*A(1,1)/(GAMA-1.)
      RQ(1,1)=RP(1,1)
      TTT=DP/VO1
      U(1,1)=0.0
      U(1,1)=100.
      K=1
      RHO(1)=P(1,1)/(R*T(1,1))
      YU(1)=U(1,1)
      YP(1)=P(1,1)
      PB(1)=14.7*144.
      YT(1)=530.
      YTAU(1)=TAU(1,1)
      YX(1)=X(1,1)
C  START BUILDING MESH
      II=1000
      IMAX=50
      DO 50 I=2,IMAX
      DO 45 J=1,I
      IF(I.GT.NA)GO TO 40
      IF(J.GT.1)GO TO 25
      CALL START(A(I-1,1),SS(I-1,1),RP(I-1,1),RQ(I-1,1),TAU(I-1,1),
     1T(I-1,1),X(I-1,1),P(I-1,1),A(I,1),SS(I,1),RP(I,1),RQ(I-1),TAU(I,1)
     2,T(I,1),X(I,1), P(I,1))
      GO TO 45
   25 IF(J.EQ.I)GO TO 35
      CALL INTER(A(I,J-1),SS(I,J-1),RP(I,J-1),RQ(I,J-1),TAU(I,J-1),
     1T(I,J-1),X(I,J-1),P(I,J-1),U(I,J-1),A(I-1,J),SS(I-1,J),RP(I-1,J),
     2RQ(I-1,J),TAU(I-1,J),T(I-1,J),X(I-1,J),P(I-1,J),U(I-1,J),A(I,J),
     3SS(I,J),RP(I,J),RQ(I,J),TAU(I,J),T(I,J),X(I,J),P(I,J),U(I,J))
      GO TO 45
   35 CALL CONTACT(A(I-1,J-1),SS(I-1,J-1),RP(I-1,J-1),RQ(I-1,J-1),
     1TAU(I-1,J-1),T(I-1,J-1),X(I-1,J-1),P(I-1,J-1),U(I-1,J-1),A(I,J-1),
     2SS(I,J-1),RP(I,J-1),RQ(I,J-1),TAU(I,J-1),T(I,J-1),X(I,J-1),P(I,J-1
```

```
      3),U(I,J-1),A(I,J),SS(I,J),RP(I,J),RQ(I,J),TAU(I,J),T(I,J),X(I,J),
      4P(I,J),U(I,J))
       IF(II.NE.1000)GO TO 45
       IF(TAU(I,J).GE.TTT)II=J+ND
       GO TO 45
    40 IF(J.LT.(I-ND))GO TO 45
       IF(J.GT.(I-ND))GO TO 25
       CALL START(
      1                                    A(I-1,J),SS(I-1,J),RP(I-1,
      2J),RQ(I-1,J),TAU(I-1,J),T(I-1,J),X(I-1,J),P(I-1,J),
      3A(I,J),SS(I,J),
      3RP(I,J),RQ(I,J),TAU(I,J),T(I,J),X(I,J),P(I,J))
    45 CONTINUE
       IF(II.LT.I)GO TO 111
       IF(I.EQ.II)GO TO 111
    50 CONTINUE
   111 IM=MIN0(II,IMAX)
       WRITE(5,499)
   499 FORMAT(1H ,*                           CHARACTERISTIC MESH*)
       WRITE(5,500)
   500 FORMAT(1H ,1X,1HI,1X,1HJ,10X,1HA,10X,2HSS,10X,3HTAU,10X,1HT,
      1 10X,1HX,10X,1HP,10X,1HU)
       ICNT=0
       JJ=1
       DO 700 I=1,IM
       DO 600 J=1,I
       IF((I.GT.NA).AND.(J.LT.(I-ND)))GOTO 600
       ICNT=ICNT+1
       XTAU(ICNT)=TAU(I,J)
       XX(ICNT)=X(I,J)
       IF(MOD(ICNT,55).EQ.0) WRITE(5,500)
       WRITE(5,501) I,J,A(I,J),SS(I,J),TAU(I,J),T(I,J),X(I,J),
      1P(I,J),U(I,J)
   501 FORMAT(1H ,2I3,7E12.4)
   600 CONTINUE
   700 CONTINUE
       NN=ICNT
       WRITE(5,799)
   799 FORMAT(1H ,*INTERPOLATED VALUES AT PORT AND IN PLENUM CHAMBER*)
       WRITE(5,800)
   800 FORMAT(1H ,5X,1HK,1X,3HTAU,10X,1HP,10X,1HU,10X,1HT,10X,
      C3HRHO,10X,2HPB)
       KK=IM-1
       DO 900 K=1,KK
       WRITE(5,601) K,YTAU(K),YP(K),YU(K),YT(K),RHO(K),PB(K)
   601 FORMAT(1H ,I3,6E12.4)
   900 CONTINUE
       STOP
       END
```

```
      SUBROUTINE INTER(A3,SS3,RP3,RQ3,TAU3,T3,X3,P3,U3,A4,SS4,RP4,RQ4,
     1TAU4,T4,X4,P4,
     2           U4,A6,SS6,RP6,RQ6,TAU6,T6,X6,P6,U6)
      COMMON/CONST/ND,D,DTDT,DPDT,T01,P01,V01,PREF,TREF,TOL,ITMAX,
     1GAMA,R,XJ,G,DX,AREF,CP,J
      COMMON/TPR/K,YX(50),PB(50),YP(50),DP,UB,RHO(50),YU(50),YTAU(50),
     CDTAU(50),AU(50),ARHO(50),AP(50),AT(50),YT(50)
     C,VYT(50),XCL(50),APRT(50),COEF(50)
      SS6=SS3
      RP6=RP3
      RQ6=RQ4
      A6=(GAMA-1.)/4.*(RP6+RQ6)
      U6=(RP6-RQ6)/2.
      T6=A6**2/GAMA/R
      WORK=2.*GAMA/(GAMA-1.)
      P6=PREF*(A6/AREF)**WORK*EXP(-(GAMA*SS6))
      AVOF1=(U3+A3+U6+A6)/2.
      AVOF2=(U4-A4+U6-A6)/2.
      IF(AVOF1.EQ.AVOF2)GO TO 55
      TAU6=(X4-X3+TAU3*AVOF1-TAU4*AVOF2)/(AVOF1-AVOF2)
      IF(TAU6.LT.TAU3) GO TO 55
      X6=X3+AVOF1*(TAU6-TAU3)
      IF(X6.LT.0.0) GO TO 55
      IF((X6.GT.YX(1)).AND.(X3.LT.YX(1)))GO TO 11
      RETURN
   11 K=K+1
      X163=(YX(1)-X3)/(X6-X3)
      YTAU(K)=TAU3+X163*(TAU6-TAU3)
      YP(K)=P3+X163*(P6-P3)
      YU(K)=U3+X163*(U6-U3)
      YT(K)=T3+X163*(T6-T3)
      RHO(K)=YP(K)/(R*YT(K))
      DTAU(K)=YTAU(K)-YTAU(K-1)
      AU(K)=(YU(K)+YU(K-1))/2.
      ARHO(K)=(RHO(K)+RHO(K-1))/2.
      AT(K)=(YT(K)+YT(K-1))/2.
      AP(K)=(YP(K)+YP(K-1))/2.
      C1=AU(K)**2/(2.*G*XJ)
      C2=R*AT(K)/((GAMA-1.)*G*XJ)
      C3=AP(K)/( ARHO(K)*G*XJ)
      DP2=DP/2.
      VYT(K)=V01*YTAU(K)
      XCL(K)= DP2-VYT(K)
      IF(XCL(K)) 13,12,12
   12 APRT(K)=3.141*DP2**2/2.-(XCL(K)*SQRT(DP2**2-XCL(K)**2)+DP2**2
     C*ASIN(XCL(K)/DP2))
      GO TO 14
   13 XCL(K)=-XCL(K)
      IF(XCL(K).GE.DP2) XCL(K)=DP2
      APRT(K)=3.141*DP2**2/2.+(XCL(K)*SQRT(DP2**2-XCL(K)**2)+DP2**2
     C*ASIN(XCL(K)/DP2))
   14 COEF(K)=(GAMA-1.)*APRT(K)*G/UB*XJ
      PB(K)=PB(K-1)+COEF(K)*DTAU(K)*ARHO(K)*AU(K)*(C1+C2+C3)
```

```
                    55 RETURN
      55               END
```

```
      SUBROUTINE START(A1,SS1,RP1,RQ1,TAU1,T1,X1,P1,A2,SS2,RP2,RQ2,
     CTAU2,T2,X2,P2)
      COMMON/CONST/ND,D,DTDT,DPDT,T01,P01,V01,PREF,TREF,TOL,ITMAX,
     1GAMA,R,XJ,G,DX,AREF,CP,J
C ASSUME FOR A FIRST ESTIMATE A2=A1
      IT=1.
      A1=SQRT(GAMA*R*T1)
      A2=A1
   20 ABAR=(A1+A2)/2.
      IF(DX.GT.X1) DX=X1
      DLT=DX/ABAR
      CXDTQ=-ABAR
      X2=X1+DXDTQ*DLT
      IF(J.GT.1) X2=0.0
      TAU2=TAU1+DLT
      T2=T01+TAU2*DTDT
      P2=P01+TAU2*DPDT
      SS2=G*XJ/R/GAMA*(CP*ALOG(T2/TREF)-R/G/XJ*ALOG(P2/PREF))
      RQ2=2./(GAMA-1.)*A2
      RP2=RQ2
      AF=(GAMA-1.)/4.*(RP2+RQ2)
      A2=SQRT(GAMA*R*T2)
      IF(ABS((A2-AF)/A2)-TOL) 550,550,50
  550 RETURN
   50 IT=IT+1
      A2=AF
      IF(IT-ITMAX)20,20,53
   53 WRITE (5,56)
   56 FORMAT(1H *ITMAX  START*)
      RETURN
      END
```

```
      SUBROUTINE CONTACT(A1,SS1,RP1,RQ1,TAU1,T1,X1,P1,U1,A2,SS2,RP2,
     1RQ2,TAU2,T2,X2,P2,U2,A4,SS4,RP4,RQ4,TAU4,T4,X4,P4,U4)
      COMMON/CONST/ND,D,DTDT,DPDT,TO1,PO1,VO1,PREF,TREF,TOL,ITMAX,
     CGAMA,R,XJ,G,DX,AREF,CP,J
      A5=AREF
      RP4=RP2
      SS4=SS2
      RQ5=2./(GAMA-1.)*AREF
      SS5=0.0
      XNUM=(RP4+RQ5)/AREF
      DENOM=2./(GAMA-1.)*(1.+EXP((GAMA-1.)/2.*(SS5-SS4)))
      A4=AREF*XNUM/DENOM
      T4=A4**2/GAMA/R
      U4=RP4-2./(GAMA-1.)*A4
      RQ4=2./(GAMA-1.)*A4-U4
      P4=PREF*(A4/AREF)**(2.*GAMA/(GAMA-1.))*EXP(-(GAMA*SS4))
      SLOP24=(A4+U4+A2+U2)/2.
      U14=(U1+U4)/2.
      TAU4=((X1-X2)-U14*TAU1+SLOP24*TAU2)/(SLOP24-U14)
      X4=SLOP24*(TAU4-TAU2)+X2
      RETURN
      END
```

```
      SUBROUTINE BREECH (A2,SS2,RP2,RQ2,TAU2,T2,X2,P2,U2,A3,SS3,RP3,RQ3,
     1TAU3,T3,X3,P3,U3)
      COMMON/CONST/ND,D,DTDT,DPDT,T01,P01,V01,PREF,TREF,TOL,ITMAX,
     1GAMA,R,XJ,G,DX,AREF,CP
      X3=0.0
      U3=0.0
      SLOP23=U2-A2
      RQ3=RQ2
      RP3=RQ3
      SS3=SS2
      A3=(GAMA-1.)/4.*(RP3+RQ3)
      T3=A3**2/GAMA/R
      P3=PREF*(A3/AREF)**(2.*GAMA/(GAMA-1.))*EXP(-(GAMA*SS3))
      DLT=X2/ABS(SLOP23)
      TAU3=TAU2+X2/ABS(SLOP23)
      RETURN
      END
```

ITMAX START

CHARACTERISTIC MESH

I	J	A	SS	TAU	T	X	P	U
1	1	.2881E+04	.1921E+01	0.	.3202E+04	.1870E-01	.2197E+07	.1000E+03
2	1	.2880E+04	.1918E+01	.1298E-05	.3200E+04	.1496E-01	.2197E+07	0.
2	2	.2258E+04	.1918E+01	.4153E-05	.1967E+04	.2974E-01	.1760E+06	.5215E+04
3	1	.2879E+04	.1916E+01	.2597E-05	.3198E+04	.1122E-01	.2197E+07	0.
3	2	.2257E+04	.1916E+01	.8870E-05	.1966E+04	.4368E-01	.1762E+06	.5211E+04
3	3	.2257E+04	.1916E+01	.1360E-04	.1965E+04	.7898E-01	.1760E+06	.5214E+04
4	1	.2878E+04	.1913E+01	.3896E-05	.3196E+04	.7480E-02	.2197E+07	0.
4	2	.2257E+04	.1913E+01	.1359E-04	.1965E+04	.5761E-01	.1764E+06	.5208E+04
4	3	.2257E+04	.1913E+01	.1832E-04	.1965E+04	.9295E-01	.1761E+06	.5211E+04
4	4	.2256E+04	.1913E+01	.2306E-04	.1964E+04	.1283E+00	.1759E+06	.5213E+04
5	1	.2878E+04	.1911E+01	.5195E-05	.3195E+04	.3740E-02	.2197E+07	0.
5	2	.2256E+04	.1911E+01	.1831E-04	.1964E+04	.7154E-01	.1766E+06	.5204E+04
5	3	.2256E+04	.1911E+01	.2305E-04	.1964E+04	.1069E+00	.1763E+06	.5207E+04
5	4	.2256E+04	.1911E+01	.2779E-04	.1963E+04	.1423E+00	.1761E+06	.5210E+04
5	5	.2255E+04	.1911E+01	.3254E-04	.1963E+04	.1777E+00	.1758E+06	.5213E+04
6	1	.2877E+04	.1908E+01	.6495E-05	.3193E+04	.1388E-16	.2197E+07	0.
6	2	.2256E+04	.1908E+01	.2303E-04	.1964E+04	.8545E-01	.1768E+06	.5201E+04
6	3	.2256E+04	.1908E+01	.2778E-04	.1963E+04	.1209E+00	.1765E+06	.5204E+04
6	4	.2255E+04	.1908E+01	.3253E-04	.1962E+04	.1563E+00	.1763E+06	.5206E+04
6	5	.2255E+04	.1908E+01	.3728E-04	.1962E+04	.1918E+00	.1760E+06	.5209E+04
6	6	.2255E+04	.1908E+01	.4203E-04	.1961E+04	.2272E+00	.1757E+06	.5212E+04
7	2	.2256E+04	.1874E+01	.2469E-04	.3166E+04	0.	.2197E+07	0.
7	3	.1945E+04	.1874E+01	.9679E-04	.1459E+04	.2453E+00	.3962E+05	.2603E+04
7	4	.1945E+04	.1874E+01	.1067E-03	.1459E+04	.2902E+00	.3955E+05	.2606E+04
7	5	.1944E+04	.1874E+01	.1165E-03	.1458E+04	.3352E+00	.3948E+05	.2609E+04
7	6	.1944E+04	.1874E+01	.1264E-03	.1458E+04	.3802E+00	.3941E+05	.2612E+04
7	7	.1905E+04	.1874E+01	.4321E-03	.1400E+04	.1817E+01	.3198E+05	.2936E+04

INTERPOLATED VALUES AT PORT AND IN PLENUM CHAMBER

K	TAU	P	U	T	RHO	PB
1	0.	.2197E+07	.1000E+03	.5300E+03	.3280E+00	.2117E+04
2	.4043E-05	.1731E+07	.1201E+04	.2914E+04	.2840E+00	.4339E+04
3	.6065E-05	.1745E+07	.1166E+04	.2921E+04	.2855E+00	.7143E+04
4	.8089E-05	.1751E+07	.1148E+04	.2923E+04	.2864E+00	.9900E+04
5	.1011E-04	.1755E+07	.1138E+04	.2924E+04	.2869E+00	.1263E+05
6	.3019E-04	.2033E+07	.1985E+03	.3036E+04	.3200E+00	.2949E+05

```
NE65   ***NE65      START JOB  68    2:42:47 PM 10 SEP 76     NFAT   FALWG    D500064000     E   NE65   ***NE65
NE65   ***NE65      START JOB  68    2:42:47 PM 10 SEP 76     NFAT   FALWG    D500064000     E   NE65   ***NE65
NE65   ***NE65      START JOB  68    2:42:47 PM 10 SEP 76     NFAT   FALWG    D500064000     E   NE65   ***NE65
NE65   ***NE65      START JOB  68    2:42:47 PM 10 SEP 76     NFAT   FALWG    D500064000     E   NE65   ***NE65
NE65   ***NE65      START JOB  68    2:42:47 PM 10 SEP 76     NFAT   FALWG    D500064000     E   NE65   ***NE65
NE65   ***NE65      START JOB  68    2:42:47 PM 10 SEP 76     NFAT   FALWG    D500064000     E   NE65   ***NE65
```

Appendix 3A

AUTOFLOW CHART SET

PORT

09/10/76

FORTRAN MODULE (LIST1)

CARD NO **** CONTENTS ****

```
C     THIS PROGRAM CALCULATES THE NONSTEADY FLOW PROCESS IN THE
C     M16 RIFLE BARREL WHEN PROJECTILE PASSES THE PORT
C     XCL=LENGTH OF HOLE DIAMETER UNCOVERED(FT)
C     DP=PORT DIAMETER (FT)
C     UP=VOLUME OF PLENUM CHAMBER(FT*3)
C     PB(K)=PRESSURE IN PLENUM CHAMBER AT TIME TAU(K)(LBF/FT*2
C     TO1=TEMP WHEN PROJECTILE FIRST PASSES PORT                R
C     PO1=PRES WHEN PROJECTILE FIRST PASSES PORT           LBF/FT-FT
C     VO1=VELOCITY PROJ AT PORT                            FT/SEC
C     PREF=ATMOS. PRES                                     LBF/FT-FT
C     SSI=ENTROPY AT PT I                                      DIMN.
C     AREF=REF SPEED OF SOUND                                  FT/SEC
C     G   =ACCEL DUE TO GRAVITY                                FT/SEC-SEC
C     D   =BORE   DIAM.                                        FT
C     TREF=ATMOS. TEMP.                                          R
C     R = PROPELLANT GAS CONSTANT                          FT-LB/SLUG-R
C     NA  =NO.OF POINTS ALONG 1ST Q WAVE                         DIMN.
C     GAMA=RATIO OF SP.HEAT                                      DIMN.
C     ND  =NO.OF SEGMENTS ALONG 1ST Q WAVE                       DIMN.
C     UI  =VELOCITY OF GAS AT PT I                             FT/SEC
C     DPDT=RATE OF PRES CHANGE                             LBF/FT-FT-SEC
C     DTDT=RATE OF TEMP CHANGE                                   R/SEC
C     RPI =RIEMANN VAR AT PT I                                 FT/SEC
C     RQI =RIEMANN VAR AT PT I                                 FT/SEC
C     AI  =SPEED OF SOUND AT PT I                              FT/SEC
C     XJ  =MECH. EQUIV. OF HEAT (778)                      FT-LB/BTU
C     T=GAS TEMP                                           R
C     P=GAS PRES.                                          LBF/FT-FT
C     TAU= TIME COORDINATE                                 SEC
C     X=POSITION COORDINATE                                FT
C     TOL=TOLERANCE OF CONVERGENCE                         DIMN
C     ITMAX=MAX NO. ITERATIONS                             DIMN
C     UB=VOLUME OF PLENUM CHAMBER(FT**3)
C     DP=PORT DIAMETER(FT)
C     TTT =TIME FOR PROJECTIEE TO UNCOVER PORT             SEC
      DIMENSION A(50,50),SS(50,50),RP(50,50),RQ(50,50),TAU(50,50),
     1T(50,50),X(50,50),P(50,50),U(50,50),XX(50),XTAU(50)
      COMMON/CONST/ND,D,DTDT,DPDT,TO1,PO1,VO1,PREF,TREF,TOL ,ITMAX,
     1GAMA,R,XJ,G,DX,AREF,CP,J
      COMMON/TPR/K,YX(50),PB(50),YP(50),DP,UB,RHO(50),YU(50),YTAU(50),
     CDTAU(50),AU(50),ARHO(50),AP(50),AT(50),YT(50)
     C,VYT(50),XCL(50),APRT(50),COEF(50)
      DO 8 I=1,50
      DO 8 J=1,50
      A(I,J)=0.0
      SS(I,J)=0.0
      RP(I,J)=0.0
      RQ(I,J)=0.0
      TAU(I,J)=0.0
      T(I,J)=0.0
      X(I,J)=0.0
      P(I,J)=0.0
      U(I,J)=0.0
    8 CONTINUE
      READ(1,100)TREF,PREF,GAMA ,R,TOL,XJ,G,VO1,TO1
      READ(1,101)D,NA,ITMAX,DP,UB
  100 FORMAT(6F10.2)
  101 FORMAT(F10.2,2I5,2F10.2)
      READ(1,105)PO1,DPDT,DTDT
105   FORMAT(3E15.6)
      AREF=SQRT(GAMA*R*TREF)
C   INITIALIZATION
      ND=NA-1
      DX=D/FLOAT(ND)
      T(1,1)=TO1
      P(1,1)=PO1
      A(1,1)=SQRT(GAMA*R*T(1,1))
      CP=GAMA*R/(GAMA-1.)/G/XJ
      SS(1,1)=G*XJ/R/GAMA*(CP*ALOG(T(1,1)/TREF)-R/G/XJ*ALOG(P(1,1)
     1/PREF))
      TAU(1,1)=0.0
      X(1,1)=D
      RP(1,1)=2.*A(1,1)/(GAMA-1.)
```

```
      RQ(1,1)=RP(1,1)
      TTT=DP/VD1
      U(1,1)=0.0
      U(1,1)=100.
      K=1
      RHO(1)=P(1,1)/(R*T(1,1))
      YU(1)=U(1,1)
      YP(1)=P(1,1)
      PB(1)=14.7*144.
      YT(1)=530.
      YTAU(1)=TAU(1,1)
      YX(1)=X(1,1)
C   START BUILDING MESH
      II=1000
      IMAX=50
      DO 50 I=2,IMAX
      DO 45 J=1,I
      IF(I.GT.NA)GO TO 40
      IF(J.GT.1)GO TO 25
      CALL START(A(I-1,1),SS(I-1,1),RP(I-1,1),RQ(I-1,1),TAU(I-1,1),
     1T(I-1,1),X(I-1,1),P(I-1,1),A(I,1),SS(I,1),RP(I,1),RQ(I-1),TAU(I,1)
     2,T(I,1),X(I,1), P(I,1))
      GO TO 45
   25 IF(J.EQ.I)GO TO 35
      CALL INTER(A(I,J-1),SS(I,J-1),RP(I,J-1),RQ(I,J-1),TAU(I,J-1),
     1T(I,J-1),X(I,J-1),P(I,J-1),U(I,J-1),A(I-1,J),SS(I-1,J),RP(I-1,J),
     2RQ(I-1,J),TAU(I-1,J),T(I-1,J),X(I-1,J),P(I-1,J),U(I-1,J),A(I,J),
     3SS(I,J),RP(I,J),RQ(I,J),TAU(I,J),T(I,J),X(I,J),P(I,J),U(I,J))
      GO TO 45
   35 CALL CONTACT(A(I-1,J-1),SS(I-1,J-1),RP(I-1,J-1),RQ(I-1,J-1),
     1TAU(I-1,J-1),T(I-1,J-1),X(I-1,J-1),P(I-1,J-1),U(I-1,J-1),A(I,J-1),
     2SS(I,J-1),RP(I,J-1),RQ(I,J-1),TAU(I,J-1),T(I,J-1),X(I,J-1),P(I,J-1
     3),U(I,J-1),A(I,J),SS(I,J),RP(I,J),RQ(I,J),TAU(I,J),T(I,J),X(I,J),
     4P(I,J),U(I,J))
      IF(II.NE.1000)GO TO 45
      IF(TAU(I,J).GE.TTT)II=J+ND
      GO TO 45
   40 IF(J.LT.(I-ND))GO TO 45
      IF(J.GT.(I-ND))GO TO 25
C     CALL BREECH(
      CALL START(
     1                                            A(I-1,J),SS(I-1,J),RP(I-1,
     2J),RQ(I-1,J),TAU(I-1,J),T(I-1,J),X(I-1,J),P(I-1,J),
     3A(I,J),SS(I,J),
     3RP(I,J),RQ(I,J),TAU(I,J),T(I,J),X(I,J),P(I,J))
   45 CONTINUE
      IF(II.LT.I)GO TO 111
      IF(I.EQ.II)GO TO 111
   50 CONTINUE
  111 IM=MIN0(II,IMAX)
      WRITE(5,499)
  499 FORMAT(1H ,*                          CHARACTERISTIC MESH*)
      WRITE(5,500)
  500 FORMAT(1H ,1X,1HI,1X,1HJ,10X,1HA,10X,2HSS,10X,3HTAU,10X,1HT,
     1 10X,1HX,10X,1HP,10X,1HU)
      ICNT=0
      JJ=1
      DO 700 I=1,IM
      DO 600 J=1,I
      IF((I.GT.NA).AND.(J.LT.(I-ND)))GOTO 600
      ICNT=ICNT+1
      XTAU(ICNT)=TAU(I,J)
      XX(ICNT)=X(I,J)
      IF(MOD(ICNT,55).EQ.0) WRITE(5,500)
      WRITE(5,501) I,J,A(I,J),SS(I,J),TAU(I,J),T(I,J),X(I,J),
     1P(I,J),U(I,J)
  501 FORMAT(1H ,2I3,7E12.4)
  600 CONTINUE
  700 CONTINUE
      NN=ICNT
      WRITE(5,799)
  799 FORMAT(1H ,*INTERPOLATED VALUES AT PORT AND IN PLENUM CHAMBER*)
      WRITE(5,800)
  800 FORMAT(1H ,5X,1HK,1X,3HTAU,10X,1HP,10X,1HU,10X,1HT,10X,
     C3HRHO,10X,2HPB)
      KK=IM-1
      DO 900 K=1,IM
      WRITE(5,601) K,YTAU(K),YP(K),YU(K),YT(K),RHO(K),PB(K)
  601 FORMAT(1H ,I3,6E12.4)
  900 CONTINUE
```

CARD NO **** CONTENTS ****

```
      STOP
      END
      SUBROUTINE INTER(A3,SS3,RP3,RQ3,TAU3,T3,X3,P3,U3,A4,SS4,RP4,RQ4,
     1TAU4,T4,X4,P4,
     2            U6,A6,SS6,RP6,RQ6,TAU6,T6,X6,P6,U6)
      COMMON/CONST/ND,D,DTDT,DPDT,TO1,PO1,VO1,PREF,TREF,TOL,ITMAX,
     1GAMA,R,XJ,G,DX,AREF,CP,J
      COMMON/TPR/K,YX(50),PB(50),YP(50),DP,UB,RHO(50),YU(50),YTAU(50),
     CDTAU(50),AU(50),ARHO(50),AP(50),AT(50),YT(50)
     C,VYT(50),XCL(50),APRT(50),COEF(50)
      SS6=SS3
      RP6=RP3
      RQ6=RQ4
      A6=(GAMA-1.)/4.*(RP6+RQ6)
      U6=(RP6-RQ6)/2.
      T6=A6**2/GAMA/R
      WORK=2.*GAMA/(GAMA-1.)
      P6=PREF*(A6/AREF)**WORK*EXP(-(GAMA*SS6))
      AVOF1=(U3+A3+U6+A6)/2.
      AVOF2=(U4-A4+U6-A6)/2.
      IF(AVOF1.EQ.AVOF2)GO TO 55
      TAU6=(X4-X3+TAU3*AVOF1-TAU4*AVOF2)/(AVOF1-AVOF2)
      IF(TAU6.LT.TAU3) GO TO 55
      X6=X3+AVOF1*(TAU6-TAU3)
      IF(X6.LT.0.0) GO TO 55
      IF((X6.GT.YX(1)).AND.(X3.LT.YX(1)))GO TO 11
      RETURN
   11 K=K+1
      X163=(YX(1)-X3)/(X6-X3)
      YTAU(K)=TAU3+X163*(TAU6-TAU3)
      YP(K)=P3+X163*(P6-P3)
      YU(K)=U3+X163*(U6-U3)
      YT(K)=T3+X163*(T6-T3)
      RHO(K)=YP(K)/(R*YT(K))
      DTAU(K)=YTAU(K)-YTAU(K-1)
      AU(K)=(YU(K)+YU(K-1))/2.
      ARHO(K)=(RHO(K)+RHO(K-1))/2.
      AT(K)=(YT(K)+YT(K-1))/2.
      AP(K)=(YP(K)+YP(K-1))/2.
      C1=AU(K)**2/(2.*G*XJ)
      C2=R*AT(K)/((GAMA-1.)*G*XJ)
      C3=AP(K)/( ARHO(K)*G*XJ)
      DP2=DP/2.
      VYT(K)=VO1*YTAU(K)
      XCL(K)= DP2-VYT(K)
      IF(XCL(K)) 13,12,12
   12 APRT(K)=3.14*DP2**2/2.-(XCL(K)*SQRT(DP2**2-XCL(K)**2)+DP2**2
     C*ASIN(XCL(K)/DP2))
      GO TO 14
   13 XCL(K)=-XCL(K)
      IF(XCL(K).GE.DP2) XCL(K)=DP2
      APRT(K)=3.14*DP2**2/2.+(XCL(K)*SQRT(DP2**2-XCL(K)**2)+DP2**2
     C*ASIN(XCL(K)/DP2))
   14 COEF(K)=(GAMA-1.)*APRT(K)*G/UB*XJ
      PB(K)=PB(K-1)+COEF(K)*DTAU(K)*ARHO(K)*AU(K)*(C1+C2+C3)
   55 RETURN
      END
      SUBROUTINE START(A1,SS1,RP1,RQ1,TAU1,T1,X1,P1,A2,SS2,RP2,RQ2,
     CTAU2,T2,X2,P2)
      COMMON/CONST/ND,D,DTDT,DPDT,TO1,PO1,VO1,PREF,TREF,TOL,ITMAX,
     1GAMA,R,XJ,G,DX,AREF,CP,J
C ASSUME FOR A FIRST ESTIMATE A2=A1
      IT=1
      A1=SQRT(GAMA*R*T1)
      A2=A1
   20 ABAR=(A1+A2)/2.
      IF(DX.GT.X1) DX=X1
      DLT=DX/ABAR
      T2= T1+DTDT*DLT
      DXDTQ=-ABAR
      X2=X1+DXDTQ*DLT
      IF(J.GT.1) X2=0.0
      TAU2=TAU1+DLT
      P2=P1+DPDT*DLT
      SS2=G*XJ/R/GAMA*(CP*ALOG(T2/TREF)-R/G/XJ*ALOG(P2/PREF))
      RQ2=2./(GAMA-1.)*A2
```

```
      RP2=RQ2
      AF=(GAMA-1.)/4.*(RP2+RQ2)
      IF(ABS((A2-AF)/A2)-TOL) 550,550,50
  550 RETURN
   50 IT=IT+1
      A2=AF
      IF(IT-ITMAX)20,20,53
 53   WRITE (5,56)
 56   FORMAT(1H *ITMAX  START*)
      RETURN
      END
      SUBROUTINE CONTACT(A1,SS1,RP1,RQ1,TAU1,T1,X1,P1,U1,A2,SS2,RP2,
     1RQ2,TAU2,T2,X2,P2,U2,A4,SS4,RP4,RQ4,TAU4,T4,X4,P4,U4)
      COMMON/CONST/ND,D,DTDT,DPDT,TO1,PO1,VO1,PREF,TREF,TOL,ITMAX,
     CGAMA,R,XJ,G,DX,AREF,CP,J
      A5=AREF
      RP4=RP2
      SS4=SS2
      RQ5=2./(GAMA-1.)*AREF
      SS5=0.0
      XNUM=(RP4+RQ5)/AREF
      DENOM=2./(GAMA-1.)*(1.+EXP((GAMA-1.)/2.*(SS5-SS4)))
      A4=AREF*XNUM/DENOM
      T4=A4**2/GAMA/R
      U4=RP4-2./(GAMA-1.)*A4
      RQ4=2./(GAMA-1.)*A4-U4
      P4=PREF*(A4/AREF)**(2.*GAMA/(GAMA-1.))*EXP(-(GAMA*SS4))
      SLOP24=(A4+U4+A2+U2)/2.
      U14=(U1+U4)/2.
      TAU4=((X1-X2)-U14*TAU1+SLOP24*TAU2)/(SLOP24-U14)
      X4=SLOP24*(TAU4-TAU2)+X2
      RETURN
      END
      SUBROUTINE BREECH (A2,SS2,RP2,RQ2,TAU2,T2,X2,P2,U2,A3,SS3,RP3,RQ3,
     1TAU3,T3,X3,P3,U3)
      COMMON/CONST/ND,D,DTDT,DPDT,TO1,PO1,VO1,PREF,TREF,TOL,ITMAX,
     1GAMA,R,XJ,G,DX,AREF,CP
      X3=0.0
      U3=0.0
      SLOP23=U2-A2
      RQ3=RQ2
      RP3=RQ3
      SS3=SS2
      A3=(GAMA-1.)/4.*(RP3+RQ3)
      T3=A3**2/GAMA/R
      P3=PREF*(A3/AREF)**(2.*GAMA/(GAMA-1.))*EXP(-(GAMA*SS3))
      DLT=X2/ABS(SLOP23)
      TAU3=TAU2+X2/ABS(SLOP23)
      RETURN
      END
```

```
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CARD ID   PAGE/BOX    NAME                               REFERENCES  (SOURCE SEQUENCE NO. AND PAGE/BOX)


FORTRAN MODULE


CHART TITLE - INTRODUCTORY COMMENTS


CHART TITLE - PROCEDURES

(000044)    2.02                (000054)   2.06
(000045)    2.03                (000054)   2.05
(000054)    2.05  8
(000090)    2.23                (000122)   3.07
(000091)    2.24                (000119)   3.04
(000097)    2.26  25            (000092)   2.25     (000112)   3.02
(000103)    2.32  35            (000097)   2.26
(000110)    2.37                (000109)   2.35
(000111)    3.01  40            (000091)   2.24
(000119)    3.04  45            (000102)   2.29     (000096)   2.31     (000108)   2.34     (000110)   2.37     (000111)   3.01
(000122)    3.07  50
(000123)    3.08  111           (000120)   3.05     (000121)   3.06
(000132)    3.13                (000142)   3.21
(000133)    3.14                (000141)   3.20
(000138)    3.18                (000137)   3.16
(000141)    3.20  600           (000133)   3.14
(000142)    3.21  700
(000151)    3.27                (000153)   3.29
(000153)    3.29  900

CHART TITLE - NON-PROCEDURAL STATEMENTS


CHART TITLE - SUBROUTINE   INTER(A3,SS3,RP3,RQ3,TAU3,T3,X3,P3,U3,A4,SS4,RP4,RQ4,T

(000164)    5.01  INTER         (000098)   2.27-X
(000181)    5.11  11            (000179)   5.09
(000200)    5.18  12
(000203)    5.19  13            (000199)   5.17
(000205)    5.22                (000204)   5.20
(000207)    5.23  14            (000202)   5.18
(000209)    5.24  55            (000174)   5.04     (00017[illegible])  5.06     (000178)   5.0[illegible]
```

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CHART TITLE - NON-PROCEDURAL STATEMENTS

CHART TITLE - SUBROUTINE  START(A1,SS1,RP1,RQ1,TAU1,T1,X1,P1,A2,SS2,RP2,RQ2,TAU2

(000215)    7.01  START        (000093)   2.30-X   (000114)   3.03-X
(000219)    7.02  20           (000236)   7.13
(000221)    7.05               (000220)   7.03
(000226)    7.08               (000225)   7.06
(000233)    7.11  550
(000234)    7.12  50           (000232)   7.10
(000237)    7.14  53

CHART TITLE - NON-PROCEDURAL STATEMENTS

CHART TITLE - SUBROUTINE  CONTACT(A1,SS1,RP1,RQ1,TAU1,T1,X1,P1,U1,A2,SS2,RP2,RQ2

(000245)    9.01  CONTACT      (000103)   2.32-X

CHART TITLE - NON-PROCEDURAL STATEMENTS

CHART TITLE - SUBROUTINE  BREECH(A2,SS2,RP2,RQ2,TAU2,T2,X2,P2,U2,A3,SS3,RP3,RQ3,

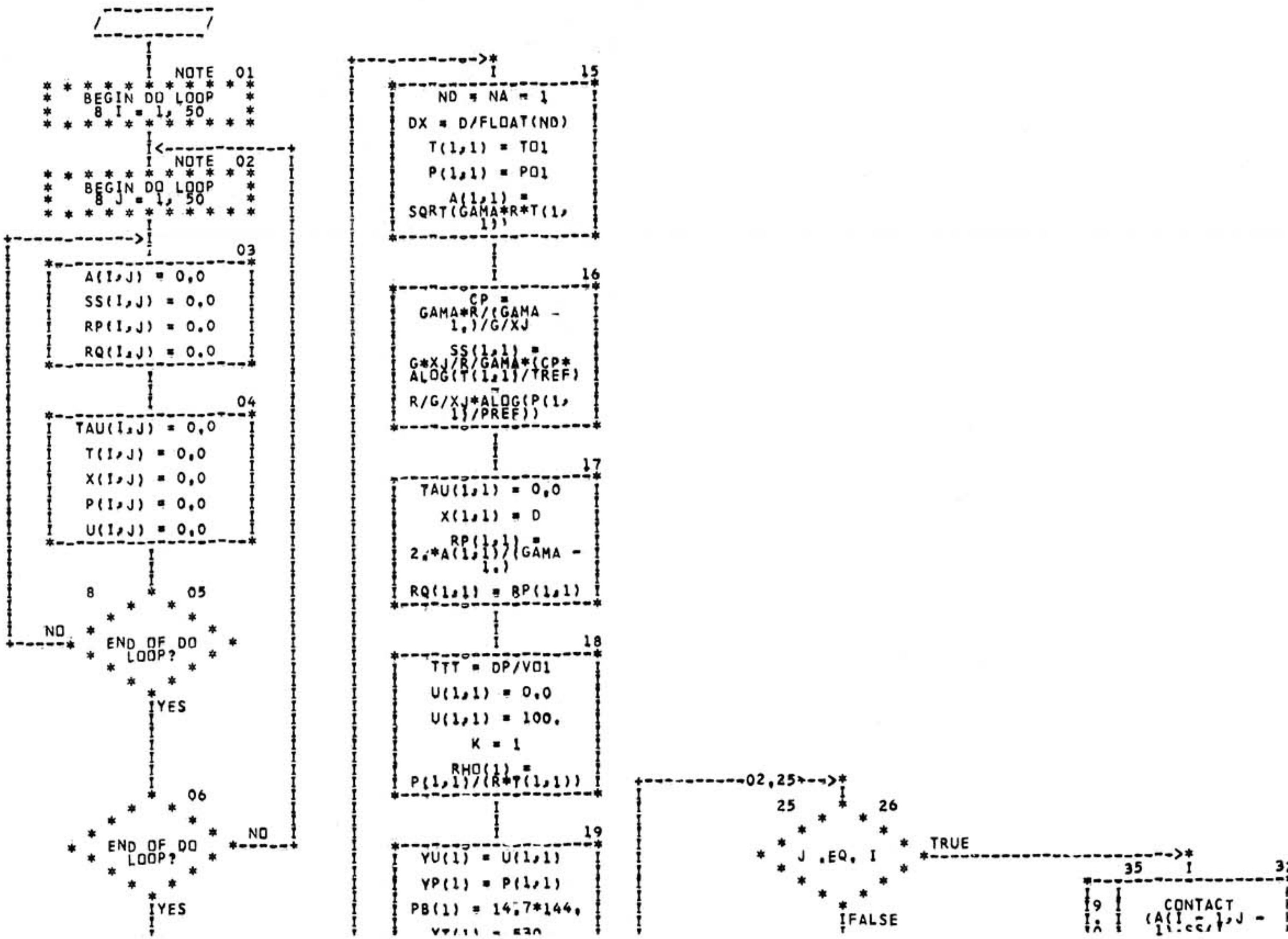
(000267)   11.01  BREECH

CHART TITLE - NON-PROCEDURAL STATEMENTS
```

CHART TITLE - INTRODUCTORY COMMENTS

```
THIS PROGRAM CALCULATES THE NONSTEADY FLOW PROCESS IN THE
M16 RIFLE BARREL WHEN PROJECTILE PASSES THE PORT
XCL=LENGTH OF HOLE DIAMETER UNCOVERED(FT)
DP=PORT DIAMETER (FT)
UP=VOLUME OF PLENUM CHAMBER(FT*3)
PB(K)=PRESSURE IN PLENUM CHAMBER AT TIME TAU(K)(LBF/FT*2
TO1=TEMP WHEN PROJECTILE FIRST PASSES PORT           R
PO1=PRES WHEN PROJECTILE FIRST PASSES PORT       LBF/FT-FT
VO1=VELOCITY PROJ AT PORT                        FT/SEC
PREF=ATMOS, PRES                                 LBF/FT-FT
SSI=ENTROPY AT PT I                                DIMN.
AREF=REF SPEED OF SOUND                            FT/SEC
G  =ACCEL DUE TO GRAVITY                           FT/SEC-SEC
D  =BORE   DIAM.                                   FT
TREF=ATMOS, TEMP.                                    R
R = PROPELLANT GAS CONSTANT                      FT-LB/SLUG-R
NA =NO.OF POINTS ALONG 1ST Q WAVE                   DIMN.
GAMA=RATIO OF SP,HEAT                               DIMN.
ND =NO.OF SEGMENTS ALONG 1ST Q WAVE                 DIMN.
UI =VELOCITY OF GAS AT PT I                        FT/SEC
DPDT=RATE OF PRES CHANGE                         LBF/FT-FT-SEC
DTDT=RATE OF TEMP CHANGE                             R/SEC
RPI =RIEMANN VAR AT PT I                           FT/SEC
RQI =RIEMANN VAR AT PT I                           FT/SEC
AI =SPEED OF SOUND AT PT I                         FT/SEC
XJ =MECH, EQUIV, OF HEAT (778)                   FT-LB/BTU
T=GAS TEMP                                       R
P=GAS PRES,                                      LBF/FT-FT
TAU= TIME COORDINATE                             SEC
X=POSITION COORDINATE                            FT
TOL=TOLERANCE OF CONVERGENCE                     DIMN
ITMAX=MAX NO, ITERATIONS                         DIMN
UB=VOLUME OF PLENUM CHAMBER(FT**3)
DP=PORT DIAMETER(FT)
TTT =TIME FOR PROJECTIEE TO UNCOVER PORT         SEC
```

CHART TITLE - PROCEDURES



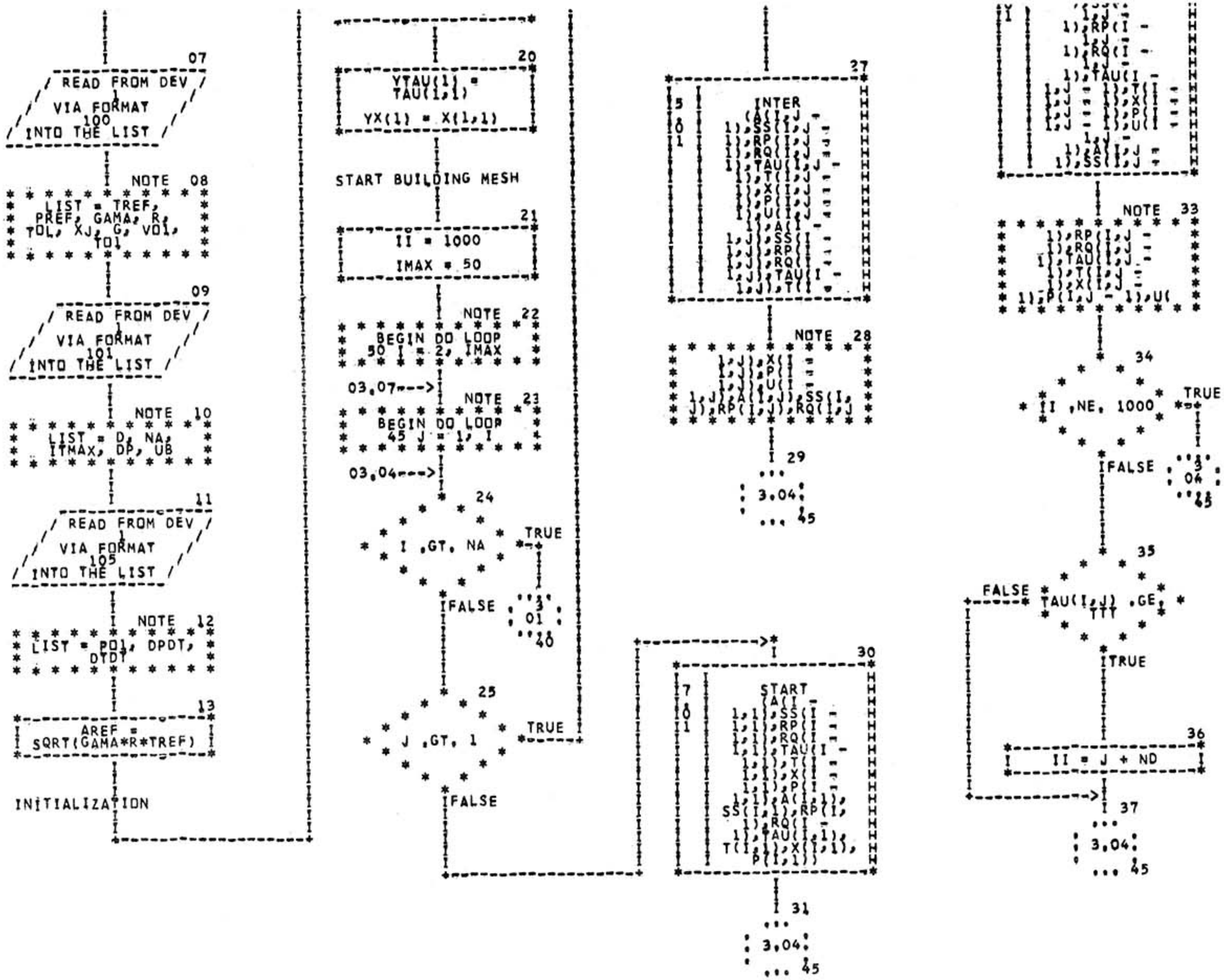
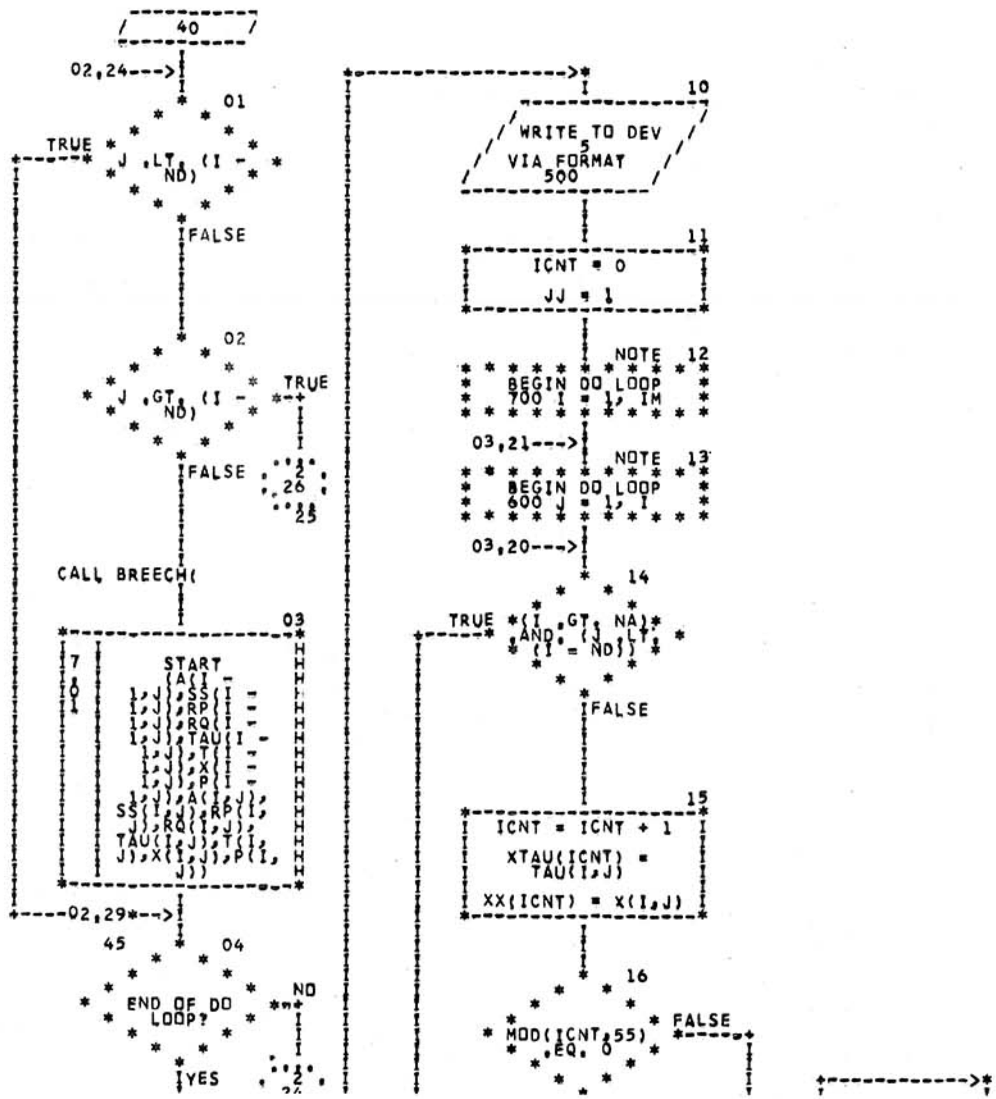

READ FROM DEV 1 VIA FORMAT 100 INTO THE LIST
NOTE 08
LIST = TREF, PREF, GAMA, R, TOL, XJ, G, V01, T01
READ FROM DEV 1 VIA FORMAT 101 INTO THE LIST
NOTE 10
LIST = D, NA, ITMAX, DP, UB
READ FROM DEV 1 VIA FORMAT 105 INTO THE LIST
NOTE 12
LIST = P01, DPDT, DTDT
AREF = SQRT(GAMA*R*TREF)
INITIALIZATION
YTAU(1) = TAU(1,1)
YX(1) = X(1,1)
START BUILDING MESH
II = 1000
IMAX = 50
NOTE 22
BEGIN DO LOOP 50 I = 2, IMAX
NOTE 23
BEGIN DO LOOP 45 J = 1, I
I .GT. NA
TRUE
FALSE
J .GT. 1
TRUE
FALSE
INTER
NOTE 28
3,04
START
3,04
NOTE 33
II .NE. 1000
TRUE
FALSE
TAU(I,J) .GE. TTT
FALSE
TRUE
II = J + ND
3,04

CHART TITLE - PROCEDURES



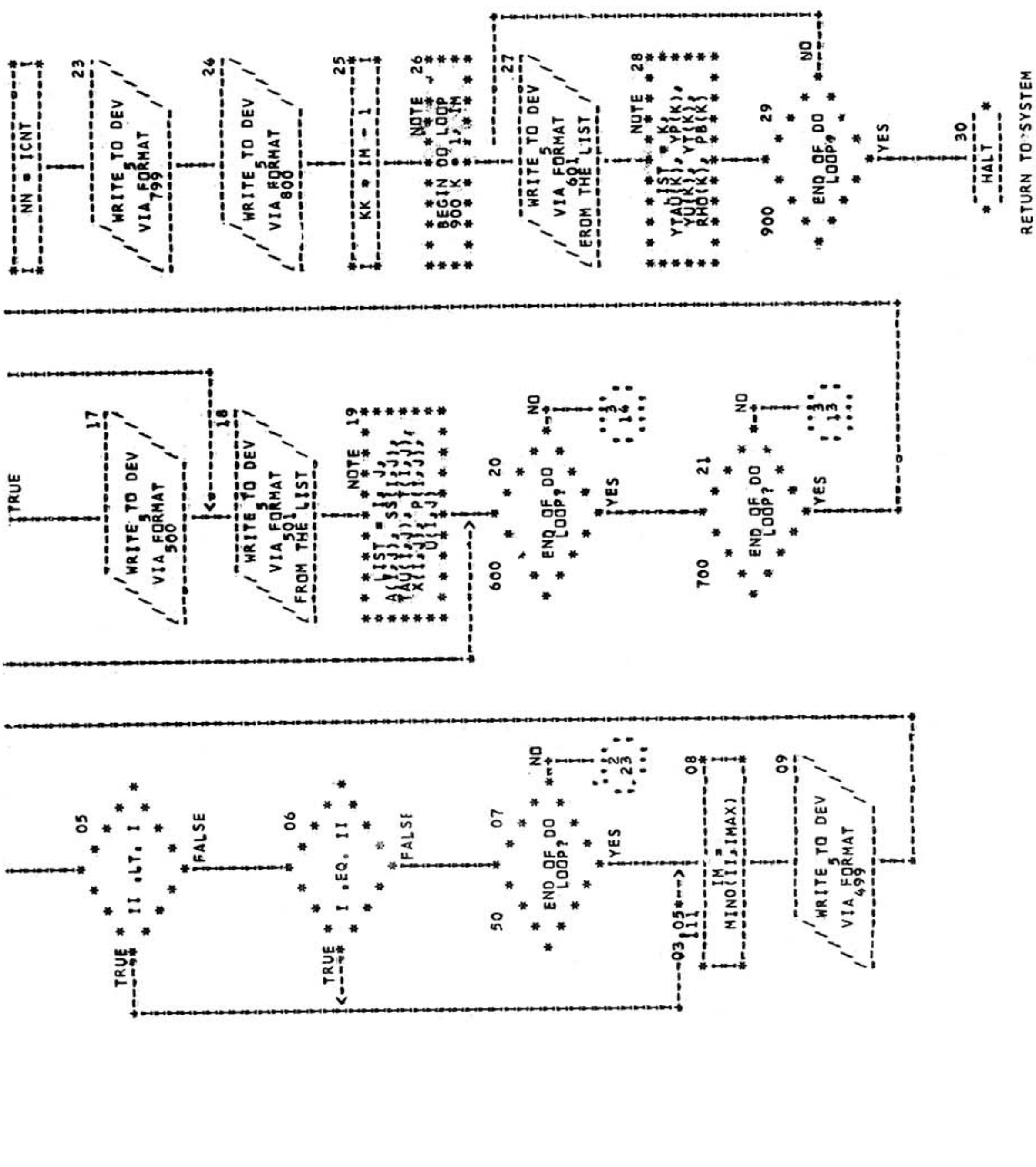

05
II .LT. I
TRUE
FALSE
06
I .EQ. II
TRUE
FALSE
07
50
END OF DO LOOP?
YES
NO
2
23
03 05
111
08
IM = MINO(II,IMAX)
09
WRITE TO DEV 5 VIA FORMAT 499
TRUE
17
WRITE TO DEV 5 VIA FORMAT 500
18
WRITE TO DEV 5 VIA FORMAT 501 FROM THE LIST
19
NOTE
LIST = I, J, A(I,J), SS(I,J), TAU(I,J), T(I,J), X(I,J), P(I,J), U(I,J)
20
600
END OF DO LOOP?
YES
NO
3
14
21
700
END OF DO LOOP?
YES
NO
3
13
NN = ICNT
23
WRITE TO DEV 5 VIA FORMAT 799
24
WRITE TO DEV 5 VIA FORMAT 800
25
KK = IM - 1
26
NOTE
BEGIN DO LOOP 900 K = 1, IM
27
WRITE TO DEV 5 VIA FORMAT 601 FROM THE LIST
28
NOTE
LIST = K, YTAU(K), YP(K), YU(K), YT(K), RHO(K), PB(K)
29
900
END OF DO LOOP?
YES
NO
30
HALT
RETURN TO SYSTEM

CHART TITLE - NON-PROCEDURAL STATEMENTS

```
           DIMENSION A(50,50),SS(50,50),RP(50,50),RQ(50,50),TAU(50,50),
           T(50,50),X(50,50),P(50,50),U(50,50),XX(50),XTAU(50)
           COMMON/CONST/ND,D,DTDT,DPDT,T01,P01,V01,PREF,TREF,TOL ,ITMAX,
           GAMA,R,XJ,G,DX,AREF,CP,J
           COMMON/TPR/K,YX(50),PB(50),YP(50),DP,UB,RHO(50),YU(50),YTAU(50),
           DTAU(50),AU(50),ARHO(50),AP(50),AT(50),YT(50)
           ,VYT(50),XCL(50),APRT(50),COEF(50)
100        FORMAT(4F10,2)
101        FORMAT(F10.2,2I5,2F10.2)
105        FORMAT(3E15,6)
499        FORMAT(1H ,*                     CHARACTERISTIC MESH*)
500        FORMAT(1H ,1X,1HI,1X,1HJ,10X,1HA,10X,2HSS,10X,3HTAU,10X,1HT,
            10X,1HX,10X,1HP,10X,1HU)
501        FORMAT(1H ,2I3,7E12,4)
799        FORMAT(1H ,*INTERPOLATED VALUES AT PORT AND IN PLENUM CHAMBER*)
800        FORMAT(1H ,5X,1HK,1X,3HTAU,10X,1HP,10X,1HU,10X,1HT,10X,
           3HRHO,10X,2HPB)
601        FORMAT(1H ,I3,6E12,4)
```

CHART TITLE - SUBROUTINE INTER(A3,SS3,RP3,RQ3,TAU3,T3,X3,P3,U3,A4,SS4,RP4,RQ4,T

```
      / INTER /
         |
02,27--->|
         |                 01
*------------------------*
| SS6 = SS3              |
| RP6 = RP3              |
| RQ6 = RQ4              |
| A6 = (GAMA -           |
| 1.)/4.*(RP6 +          |
| RQ6)                   |
| U6 = (RP6 -            |
| RQ6)/2.                |
*------------------------*
         |
         |                 02
*------------------------*
| T6 = A6**2/GAMA/R      |
| WORK =                 |
| 2.*GAMA/(GAMA -        |
| 1.)                    |
| P6 =                   |
| PREF*(A6/AREF)         |
| **WORK*EXP(-           |
| (GAMA*SS6))            |
*------------------------*
         |                      *------------------>*
         |                 03   |              11   I          11
*------------------------*      |    *--------------------------*
| AVOF1 = (U3 +          |      |    | K = K + 1                |
| A3 + U6 + A6)/2.       |      |    | X163 = (YX(1) -          |
| AVOF2 = (U4 -          |      |    | X3)/(X6 - X3)            |
| A4 + U6 - A6)/2.       |      |    | YTAU(K) = TAU3 +         |
*------------------------*      |    | X163*(TAU6 -             |
         |                      |    | TAU3)                    |
         |   04                 |    *--------------------------*
       *   *                    |                 |
    *         *     TRUE        |                 |            12
 * AVOF1 .EQ.   *  *-+          |    *--------------------------*
    * AVOF2   *      |          |    | YP(K) = P3 +             |
       *   *         |          |    | X163*(P6 - P3)           |
         |FALSE    . 24 .       |    | YU(K) = U3 +             |
         |           35         |    | X163*(U6 - U3)           |
         |                      |    | YT(K) = T3 +             |
         |                 05   |    | X163*(T6 - T3)           |
*------------------------*      |    *--------------------------*
| TAU6 = (X4 - X3 +      |      |                 |            13
| TAU3*AVOF1 -           |      |    *--------------------------*
| TAU4*AVOF2)            |      |    | RHO(K) =                 |
| /(AVOF1 - AVOF2)       |      |    | YP(K)/(R*YT(K))          |
*------------------------*      |    | DTAU(K) =                |
         |                      |    | YTAU(K) -                |
         |  06                  |    | YTAU(K - 1)              |
                                |    | AU(K) = (YU(K) +         |
```

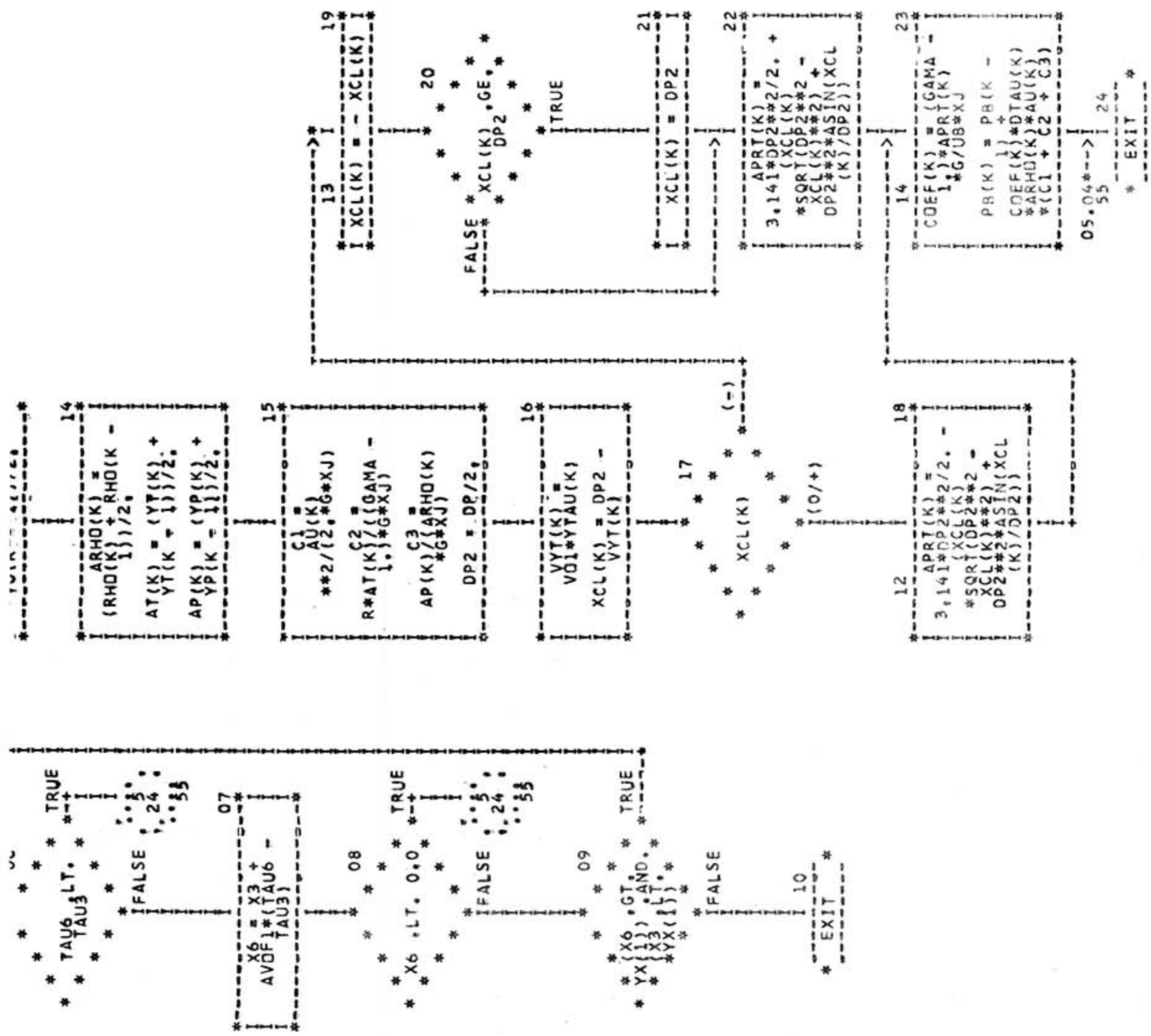


CHART TITLE - NON-PROCEDURAL STATEMENTS

```
COMMON/CONST/ND,D,DTDT,DPDT,TO1,PO1,VO1,PREF,TREF,TOL,ITMAX,
GAMA,R,XJ,G,DX,AREF,CP,J
COMMON/TPR/K,YX(50),PB(50),YP(50),DP,UB,RHO(50),YU(50),YTAU(50),
DTAU(50),AU(50),ARHO(50),AP(50),AT(50),YT(50)
,VYT(50),XCL(50),APRT(50),COEF(50)
```

CHART TITLE - SUBROUTINE START(A1,SS1,RP1,RQ1,TAU1,T1,X1,P1,A2,SS2,RP2,RQ2,TAU2

```
                 / START /

             02.30*-->*

             ASSUME FOR A FIRST
             ESTIMATE A2=A1
                      *
                      I               01
             *--------------------*
             I      IT = 1,        I
             I                     I
             I        A1 =         I
             I  SQRT(GAMA*R*T1)    I
             I                     I
             I      A2 = A1        I
             *--------------------*
                      I
                      I<----------------+
               20     I            02   I
             *--------------------*     I
             I   ABAR = (A1 +      I    I
             I        A2)/2,       I    I
             *--------------------*     I
                      I                 I
                      *  03             I
        FALSE *   DX .GT. X1  *         I
     +------*                           I
     I                *                 I
     I                ITRUE             I
     I                I                 I
     I                I            04   I
     I       *--------------------*     I
     I       I      DX = X1        I    I
     I       *--------------------*     I
     I                I                 I
     +-------------->I                  I
                                   05   I
             *--------------------*     I
             I   DLT = DX/ABAR     I    I
             I                     I    I
             I     T2 = T1 +       I    I
             I     DTDT*DLT        I    I
             I                     I    I
             I  DXDTQ = - ABAR     I    I
             I                     I    I
             I     X2 = X1 +       I    I
             I     DXDTQ*DLT       I    I
             *--------------------*     I
                      I                 I
                      *  06             I
        FALSE *    J .GT. 1   *         I
     +------*                           I
     I                *                 I
```

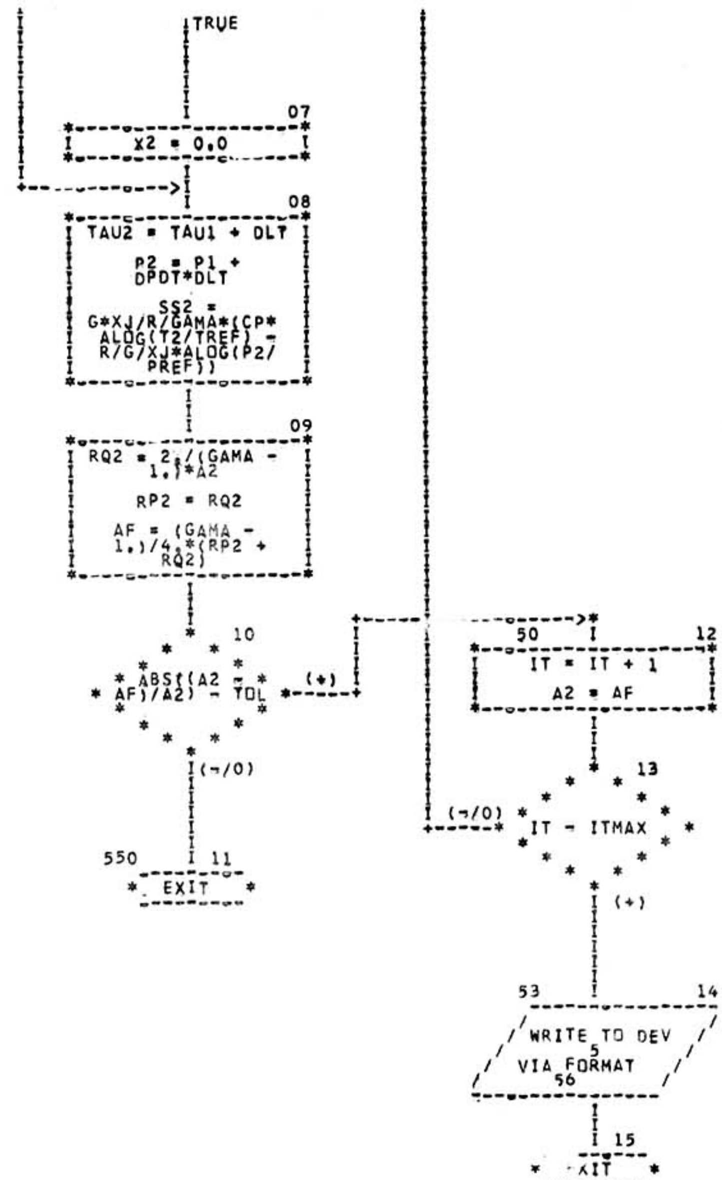

TRUE
07
X2 = 0.0
08
TAU2 = TAU1 + DLT
P2 = P1 + DPDT*DLT
SS2 = G*XJ/R/GAMA*(CP*ALOG(T2/TREF) - R/G/XJ*ALOG(P2/PREF))
09
RQ2 = 2./(GAMA - 1.)*A2
RP2 = RQ2
AF = (GAMA - 1.)/4.*(RP2 + RQ2)
10
ABS((A2 - AF)/A2) - TOL
(+)
(¬/0)
550
11
EXIT
50
12
IT = IT + 1
A2 = AF
13
IT - ITMAX
(¬/0)
(+)
53
14
WRITE TO DEV 5 VIA FORMAT 56
15
XIT

CHART TITLE - NON-PROCEDURAL STATEMENTS

```
          COMMON/CONST/ND,D,DTDT,DPDT,TO1,PO1,VO1,PREF,TREF,TOL,ITMAX,
          GAMA,R,XJ,G,DX,AREF,CP,J
   56     FORMAT(1H *ITMAX  START*)
```

CHART TITLE - SUBROUTINE CONTACT(A1,SS1,RP1,RQ1,TAU1,T1,X1,P1,U1,A2,SS2,RP2,RQ2

```
                  / CONTACT   /
                  ------------
                       I
          02,32--->I
                       I                 01
      *----------------------------------*
      I         A5 = AREF                I
      I         RP4 = RP2                I
      I         SS4 = SS2                I
      I  RQ5 = 2./(GAMA -                I
      I        1.)*AREF                  I
      I         SS5 = 0.0                I
      *----------------------------------*
                       I
                       I                 02
      *----------------------------------*
      I    XNUM = (RP4 +                 I
      I         RQ5)/AREF                I
      I          DENOM =                 I
      I       2./(GAMA -                 I
      I        1.)*(1. +                 I
      I        EXP((GAMA -               I
      I     1.)/2.*(SS5 -                I
      I          SS4)))                  I
      I           A4 =                   I
      I   AREF*XNUM/DENOM                I
      *----------------------------------*
                       I
                       I                 03
      *----------------------------------*
      I T4 = A4**2/GAMA/R                I
      I     U4 = RP4 -                   I
      I 2./(GAMA - 1.)*A4                I
      I RQ4 = 2./(GAMA -                 I
      I     1.)*A4 - U4                  I
      *----------------------------------*
                       I
                       I                 04
      *----------------------------------*
      I           P4 =                   I
      I  PREF*(A4/AREF)                  I
      I  **(2.*GAMA/(GAMA                I
      I           -                      I
      I           1.))                   I
      I *EXP(-(GAMA*SS4))                I
      I  SLOP24 = (A4 +                  I
      I U4 + A2 + U2)/2.                 I
      I    U14 = (U1 +                   I
      I       U4)/2.                     I
      *----------------------------------*
                       I
                       I                 05
      *----------------------------------*
      I     TAU4 = ((X1 -                I
      I X2) - U14*TAU1 +                 I
      I   SLOP24*TAU2)                   I
      I  /(SLOP24 - U14)                 I
      I        X4 =                      I
```

```
I  SLOP24*(TAU4 -   I
I   TAU2) + X2      I
*-------------------*
         I
         I 06
     ---------
   *   EXIT    *
     ---------
```

CHART TITLE - NON-PROCEDURAL STATEMENTS

```
COMMON/CONST/ND,B,DTOT,DPDT,TO1,PO1,VO1,PREF,TREF,TOL,ITMAX,
GAMA,R,XJ,G,DX,AREF,CP,J
```

CHART TITLE - SUBROUTINE BREECH(A2,SS2,RP2,RQ2,TAU2,T2,X2,P2,U2,A3,SS3,RP3,RQ3,

```
             -----------
            /  BREECH  /
            ------------
                 I
                 I
                 I                 01
   *-----------------------------*
   I         X3  =  0.0          I
   I         U3  =  0.0          I
   I  SLOP23  =  U2  -  A2       I
   I        RQ3  =  RQ2          I
   I        RP3  =  RQ3          I
   I        SS3  =  SS2          I
   *-----------------------------*
                 I
                 I                 02
   *-----------------------------*
   I     A3  =  (GAMA  -         I
   I     1.)/4.*(RP3  +          I
   I          RQ3)               I
   I  T3  =  A3**2/GAMA/R        I
   I          P3  =              I
   I   PREF*(A3/AREF)            I
   I   **(2.*GAMA/(GAMA          I
   I           -                 I
   I          1.))               I
   I  *EXP(-(GAMA*SS3))          I
   *-----------------------------*
                 I
                 I                 03
   *-----------------------------*
   I          DLT  =             I
   I   X2/ABS(SLOP23)            I
   I    TAU3  =  TAU2  +         I
   I   X2/ABS(SLOP23)            I
   *-----------------------------*
                 I
                 I
                 I  04
             ---------
            *  EXIT  *
             ---------
```

CHART TITLE - NON-PROCEDURAL STATEMENTS

```
COMMON/CONST/ND,D,DTDT,DPDT,TO1,PO1,VO1,PREF,TREF,TOL,ITMAX,
GAMA;R,XJ,G,DX,AREF,CP
```

END OF AUTOFLOW CHART SET   279 INPUT STATEMENTS PROCESSED   EXECUTION TIME -   54 SEC

```
NE65   ***NE65   ..END JOB 68   2.44.08 PM 10 SEP 76   NFAT   FALWG   D500064000   E   NE65   ***NE65
NE65   ***NE65   ..END JOB 68   2.44.08 PM 10 SEP 76   NFAT   FALWG   D500064000   E   NE65   ***NE65
NE65   ***NE65   ..END JOB 68   2.44.08 PM 10 SEP 76   NFAT   FALWG   D500064000   E   NE65   ***NE65
NE65   ***NE65   ..END JOB 68   2.44.08 PM 10 SEP 76   NFAT   FALWG   D500064000   E   NE65   ***NE65
NE65   ***NE65   ..END JOB 68   2.44.08 PM 10 SEP 76   NFAT   FALWG   D500064000   E   NE65   ***NE65
NE65   ***NE65   ..END JOB 68   2.44.08 PM 10 SEP 76   NFAT   FALWG   D500064000   E   NE65   ***NE65
```

```
$$$$$$$   $$$$$$$    $$$$$ $  $$$$$$$    $$$$$ $  $$$$$$$$  $$$$$$$$
$$    $$  $$    $$  $$    $  $$    $$  $$    $  $$        $$
$$    $$  $$    $$  $$   $$$  $$    $$  $$   $$$  $$        $$
$$    $$  $$    $$  $$  $ $$  $$    $$  $$  $ $$  $$$$$$$   $$$$$
$$    $$  $$    $$  $$ $$ $$  $$    $$  $$ $$ $$        $$  $$
$$$$$$$   $$$$$$$   $$ $  $$  $$$$$$$   $$ $  $$        $$  $$
$$        $$  $$    $$$   $$  $$        $$$   $$        $$  $$
$$        $$   $$    $    $$  $$         $    $$  $$    $$  $$
$$        $$    $$ $ $$$$$    $$        $ $$$$$    $$$$$$   $$$$$$$$
```

Appendix B

```
            PROGRAM PORT (INPUT,OUTPUT,TAPE1=INPUT,TAPE5=OUTPUT,TAPE6=CUTPUT
           1,DEBUG=OUTPUT)
      C PROGRAM CALCULATES THE FLOW THROUGH THE PORT IN A RIFLE BARREL
      C USING THE NEWTCN-RHAPSON METHOD
      C X=RATIO OF VELCCITY DOWNSTREAM OF PORT(U1) TO THE VELOCITY UPSTREAM(U)
      C LFA=ANGLE PORT MAKES WITH THE BARREL AXIS(DEGREES)
      C XMU=RATIO OF PCRT DIAM. TO BORE DIAM.(H2/H)
      C MV=RECIPROCL OF XMU(H/H2)
      C IN=ITERATION NUMBER
      C EPS=ACCURACY VALUE
      C MAX NO. ITERATIONS
      C F=FUNCTION TO BE SOLVED
      C D=DERIVATIVWE FUNCTION
      C XN=NEW VALUE OF ROOT
      C H=BORE DIAM
      C H2=PORT DIAM
      C$    STORES(E,F,D,XN,X)
DEBUG- C$ DEBUG CARD MISSING OR IN ERROR AT START OF PACKET. ↑C$ DEBUG↑ ASSUMED.
            READ(1,5) X,EPS,MAX
          5 FORMAT(2F10.5,I5)
            DO 500 MV=1,4
            DO 500LFA=90,160,5
            XMU=1./FLOAT(MV)
            IN=0
            E=1.-180./FLOAT(LFA)
         15 F=X**E-XMU**(1.-E)*(1.-X)**E-1.
            D=E*X**(E-1.)+XMU**(1.-E)*E*(1.-X)**(E-1.)
            XN=X-F/D
            IN=IN+1
            WRITE(5,20) IN,XN,MV,LFA
         20 FORMAT(10H ITERATION,I4,10X,5HROOT=,F15.8,10X,5HH/H2=,I4,10X,
           15HALFA=,I4)
            IF(ABS((X-XN)/XN)-EPS)500,500,25
         25 X=XN
            IF(X.GT.1.0) GO TO 500
            IF(IN-MAX)15,30,30
         30 WRITE(5,31)
         31 FORMAT(*ITMAX EXCEEDED*)
        500 CONTINUE
            END
```

```
/DEBUG/  PORT    AT LINE   24- THE NEW VALUE OF THE VARIABLE E     IS  -1.000000000
/DEBUG/          AT LINE   25- THE NEW VALUE OF THE VARIABLE F     IS  -1.000000000
/DEBUG/          AT LINE   26- THE NEW VALUE OF THE VARIABLE D     IS  -8.000000000
/DEBUG/          AT LINE   27- THE NEW VALUE OF THE VARIABLE XN    IS   .3750000000
ITERATION   1        ROOT=      .37500000         H/H2=   1       ALFA=  90
/DEBUG/  PORT    AT LINE   33- THE NEW VALUE OF THE VARIABLE X     IS   .3750000000
/DEBUG/          AT LINE   25- THE NEW VALUE OF THE VARIABLE F     IS   .6666666667E-01
/DEBUG/          AT LINE   26- THE NEW VALUE OF THE VARIABLE D     IS  -9.671111111
/DEBUG/          AT LINE   27- THE NEW VALUE OF THE VARIABLE XN    IS   .3818933824
ITERATION   2        ROOT=      .38189338         H/H2=   1       ALFA=  90
/DEBUG/  PORT    AT LINE   33- THE NEW VALUE OF THE VARIABLE X     IS   .3818933824
/DEBUG/          AT LINE   25- THE NEW VALUE OF THE VARIABLE F     IS   .6880231190E-03
/DEBUG/          AT LINE   26- THE NEW VALUE OF THE VARIABLE D     IS  -9.474128031
/DEBUG/          AT LINE   27- THE NEW VALUE OF THE VARIABLE XN    IS   .3819660036
ITERATION   3        ROOT=      .38196600         H/H2=   1       ALFA=  90
/DEBUG/  PORT    AT LINE   24- THE NEW VALUE OF THE VARIABLE E     IS  -.8947368421
/DEBUG/          AT LINE   25- THE NEW VALUE OF THE VARIABLE F     IS  -.1717519894
/DEBUG/          AT LINE   26- THE NEW VALUE OF THE VARIABLE D     IS  -7.770023464
/DEBUG/          AT LINE   27- THE NEW VALUE OF THE VARIABLE XN    IS   .3597889460
ITERATION   1        ROOT=      .35978895         H/H2=   1       ALFA=  95
/DEBUG/  PORT    AT LINE   33- THE NEW VALUE OF THE VARIABLE X     IS   .3597889460
/DEBUG/          AT LINE   25- THE NEW VALUE OF THE VARIABLE F     IS   .5505654046E-02
/DEBUG/          AT LINE   26- THE NEW VALUE OF THE VARIABLE D     IS  -8.289670791
/DEBUG/          AT LINE   27- THE NEW VALUE OF THE VARIABLE XN    IS   .3604531043
ITERATION   2        ROOT=      .36045310         H/H2=   1       ALFA=  95
/DEBUG/  PORT    AT LINE   24- THE NEW VALUE OF THE VARIABLE E     IS  -.8000000000
/DEBUG/          AT LINE   25- THE NEW VALUE OF THE VARIABLE F     IS  -.1632134823
/DEBUG/          AT LINE   26- THE NEW VALUE OF THE VARIABLE D     IS  -6.822658764
/DEBUG/          AT LINE   27- THE NEW VALUE OF THE VARIABLE XN    IS   .3358666764
ITERATION   1        ROOT=      .33586668         H/H2=   1       ALFA= 100
/DEBUG/  PORT    AT LINE   33- THE NEW VALUE OF THE VARIABLE X     IS   .3358666764
/DEBUG/          AT LINE   25- THE NEW VALUE OF THE VARIABLE F     IS   .6300942718E-02
/DEBUG/          AT LINE   26- THE NEW VALUE OF THE VARIABLE D     IS  -7.372713328
/DEBUG/          AT LINE   27- THE NEW VALUE OF THE VARIABLE XN    IS   .3367213065
ITERATION   2        ROOT=      .33672131         H/H2=   1       ALFA= 100
/DEBUG/  PORT    AT LINE   24- THE NEW VALUE OF THE VARIABLE E     IS  -.7142857143
/DEBUG/          AT LINE   25- THE NEW VALUE OF THE VARIABLE F     IS  -.1595764485
/DEBUG/          AT LINE   26- THE NEW VALUE OF THE VARIABLE D     IS  -6.076859686
/DEBUG/          AT LINE   27- THE NEW VALUE OF THE VARIABLE XN    IS   .3096069869
ITERATION   1        ROOT=      .30960699         H/H2=   1       ALFA= 105
/DEBUG/  PORT    AT LINE   33- THE NEW VALUE OF THE VARIABLE X     IS   .3096069869
/DEBUG/          AT LINE   25- THE NEW VALUE OF THE VARIABLE F     IS   .7543158788E-02
/DEBUG/          AT LINE   26- THE NEW VALUE OF THE VARIABLE D     IS  -6.678550650
/DEBUG/          AT LINE   27- THE NEW VALUE OF THE VARIABLE XN    IS   .3107364473
ITERATION   2        ROOT=      .31073645         H/H2=   1       ALFA= 105
/DEBUG/  PORT    AT LINE   24- THE NEW VALUE OF THE VARIABLE E     IS  -.6363636364
/DEBUG/          AT LINE   25- THE NEW VALUE OF THE VARIABLE F     IS  -.1571104638
/DEBUG/          AT LINE   26- THE NEW VALUE OF THE VARIABLE D     IS  -5.501166910
/DEBUG/          AT LINE   27- THE NEW VALUE OF THE VARIABLE XN    IS   .2810475073
ITERATION   1        ROOT=      .28104751         H/H2=   1       ALFA= 110
/DEBUG/  PORT    AT LINE   33- THE NEW VALUE OF THE VARIABLE X     IS   .2810475073
/DEBUG/          AT LINE   25- THE NEW VALUE OF THE VARIABLE F     IS   .9080958563E-02
/DEBUG/          AT LINE   26- THE NEW VALUE OF THE VARIABLE D     IS  -6.170043395
/DEBUG/          AT LINE   27- THE NEW VALUE OF THE VARIABLE XN    IS   .2825192893
ITERATION   2        ROOT=      .28251929         H/H2=   1       ALFA= 110
/DEBUG/  PORT    AT LINE   24- THE NEW VALUE OF THE VARIABLE E     IS  -.5652173913
/DEBUG/          AT LINE   25- THE NEW VALUE OF THE VARIABLE F     IS  -.1559418542
/DEBUG/          AT LINE   26- THE NEW VALUE OF THE VARIABLE D     IS  -5.068279174
/DEBUG/          AT LINE   27- THE NEW VALUE OF THE VARIABLE XN    IS   .2502793020
ITERATION   1        ROOT=      .25027930         H/H2=   1       ALFA= 115
/DEBUG/  PORT    AT LINE   33- THE NEW VALUE OF THE VARIABLE X     IS   .2502793020
/DEBUG/          AT LINE   25- THE NEW VALUE OF THE VARIABLE F     IS   .1104872647E-01
/DEBUG/          AT LINE   26- THE NEW VALUE OF THE VARIABLE D     IS  -5.828166294
/DEBUG/          AT LINE   27- THE NEW VALUE OF THE VARIABLE XN    IS   .2521750486
```

```
ITERATION   2        ROOT=      .25217505        H/H2=   1        ALFA= 115
/DEBUG/  PORT   AT LINE   24- THE NEW VALUE OF THE VARIABLE E     IS  -.5000000000
/DEBUG/         AT LINE   25- THE NEW VALUE OF THE VARIABLE F     IS  -.1560318781
/DEBUG/         AT LINE   26- THE NEW VALUE OF THE VARIABLE D     IS  -4.763536673
/DEBUG/         AT LINE   27- THE NEW VALUE OF THE VARIABLE XN    IS   .2175238330
ITERATION   1        ROOT=      .21752383        H/H2=   1        ALFA= 120
/DEBUG/  PORT   AT LINE   33- THE NEW VALUE OF THE VARIABLE X     IS   .2175238330
/DEBUG/         AT LINE   25- THE NEW VALUE OF THE VARIABLE F     IS   .1362354674E-01
/DEBUG/         AT LINE   26- THE NEW VALUE OF THE VARIABLE D     IS  -5.650818976
/DEBUG/         AT LINE   27- THE NEW VALUE OF THE VARIABLE XN    IS   .2199347307
ITERATION   2        ROOT=      .21993473        H/H2=   1        ALFA= 120
/DEBUG/  PORT   AT LINE   33- THE NEW VALUE OF THE VARIABLE X     IS   .2199347307
/DEBUG/         AT LINE   25- THE NEW VALUE OF THE VARIABLE F     IS   .9383090408E-04
/DEBUG/         AT LINE   26- THE NEW VALUE OF THE VARIABLE D     IS  -5.573355465
/DEBUG/         AT LINE   27- THE NEW VALUE OF THE VARIABLE XN    IS   .2199515663
ITERATION   3        ROOT=      .21995157        H/H2=   1        ALFA= 120
/DEBUG/  PORT   AT LINE   24- THE NEW VALUE OF THE VARIABLE E     IS  -.4400000000
/DEBUG/         AT LINE   25- THE NEW VALUE OF THE VARIABLE F     IS  -.1683704862
/DEBUG/         AT LINE   26- THE NEW VALUE OF THE VARIABLE D     IS  -4.524571115
/DEBUG/         AT LINE   27- THE NEW VALUE OF THE VARIABLE XN    IS   .1827222565
ITERATION   1        ROOT=      .18272226        H/H2=   1        ALFA= 125
/DEBUG/  PORT   AT LINE   33- THE NEW VALUE OF THE VARIABLE X     IS   .1827222565
/DEBUG/         AT LINE   25- THE NEW VALUE OF THE VARIABLE F     IS   .1973126437E-01
/DEBUG/         AT LINE   26- THE NEW VALUE OF THE VARIABLE D     IS  -5.675488009
/DEBUG/         AT LINE   27- THE NEW VALUE OF THE VARIABLE XN    IS   .1861988323
ITERATION   2        ROOT=      .18619883        H/H2=   1        ALFA= 125
/DEBUG/  PORT   AT LINE   33- THE NEW VALUE OF THE VARIABLE X     IS   .1861988323
/DEBUG/         AT LINE   25- THE NEW VALUE OF THE VARIABLE F     IS   .2323044515E-03
/DEBUG/         AT LINE   26- THE NEW VALUE OF THE VARIABLE D     IS  -5.542898506
/DEBUG/         AT LINE   27- THE NEW VALUE OF THE VARIABLE XN    IS   .1862407426
ITERATION   3        ROOT=      .18624074        H/H2=   1        ALFA= 125
/DEBUG/  PORT   AT LINE   24- THE NEW VALUE OF THE VARIABLE E     IS  -.3846153846
/DEBUG/         AT LINE   25- THE NEW VALUE OF THE VARIABLE F     IS  -.1735927556
/DEBUG/         AT LINE   26- THE NEW VALUE OF THE VARIABLE D     IS  -4.454601980
/DEBUG/         AT LINE   27- THE NEW VALUE OF THE VARIABLE XN    IS   .1472295245
ITERATION   1        ROOT=      .14722952        H/H2=   1        ALFA= 130
/DEBUG/  PORT   AT LINE   33- THE NEW VALUE OF THE VARIABLE X     IS   .1472295245
/DEBUG/         AT LINE   25- THE NEW VALUE OF THE VARIABLE F     IS   .2613480685E-01
/DEBUG/         AT LINE   26- THE NEW VALUE OF THE VARIABLE D     IS  -5.937511955
/DEBUG/         AT LINE   27- THE NEW VALUE OF THE VARIABLE XN    IS   .1516311673
ITERATION   2        ROOT=      .15163117        H/H2=   1        ALFA= 130
/DEBUG/  PORT   AT LINE   33- THE NEW VALUE OF THE VARIABLE X     IS   .1516311673
/DEBUG/         AT LINE   25- THE NEW VALUE OF THE VARIABLE F     IS   .4781433953E-03
/DEBUG/         AT LINE   26- THE NEW VALUE OF THE VARIABLE D     IS  -5.722816130
/DEBUG/         AT LINE   27- THE NEW VALUE OF THE VARIABLE XN    IS   .1517147177
ITERATION   3        ROOT=      .15171472        H/H2=   1        ALFA= 130
/DEBUG/  PORT   AT LINE   24- THE NEW VALUE OF THE VARIABLE E     IS  -.3333333333
/DEBUG/         AT LINE   25- THE NEW VALUE OF THE VARIABLE F     IS  -.1810444034
/DEBUG/         AT LINE   26- THE NEW VALUE OF THE VARIABLE D     IS  -4.537549820
/DEBUG/         AT LINE   27- THE NEW VALUE OF THE VARIABLE XN    IS   .1117320123
ITERATION   1        ROOT=      .11173201        H/H2=   1        ALFA= 135
/DEBUG/  PORT   AT LINE   33- THE NEW VALUE OF THE VARIABLE X     IS   .1117320123
/DEBUG/         AT LINE   25- THE NEW VALUE OF THE VARIABLE F     IS   .3593942957E-01
/DEBUG/         AT LINE   26- THE NEW VALUE OF THE VARIABLE D     IS  -6.584437017
/DEBUG/         AT LINE   27- THE NEW VALUE OF THE VARIABLE XN    IS   .1171902511
ITERATION   2        ROOT=      .11719025        H/H2=   1        ALFA= 135
/DEBUG/  PORT   AT LINE   33- THE NEW VALUE OF THE VARIABLE X     IS   .1171902511
/DEBUG/         AT LINE   25- THE NEW VALUE OF THE VARIABLE F     IS   .1052089140E-02
/DEBUG/         AT LINE   25- THE NEW VALUE OF THE VARIABLE D     IS  -6.206017764
/DEBUG/         AT LINE   27- THE NEW VALUE OF THE VARIABLE XN    IS   .1173597784
ITERATION   3        ROOT=      .11735978        H/H2=   1        ALFA= 135
/DEBUG/  PORT   AT LINE   24- THE NEW VALUE OF THE VARIABLE E     IS  -.2857142857
/DEBUG/         AT LINE   25- THE NEW VALUE OF THE VARIABLE F     IS  -.1911076169
/DEBUG/         AT LINE   26- THE NEW VALUE OF THE VARIABLE D     IS  -4.833914375
/DEBUG/         AT LINE   27- THE NEW VALUE OF THE VARIABLE XN    IS   .7765549688E-01
ITERATION   1        ROOT=      .07765550        H/H2=   1        ALFA= 140
```

```
/DEBUG/  PORT   AT LINE   33- THE NEW VALUE OF THE VARIABLE X     IS   .7765549688E-01
/DEBUG/         AT LINE   25- THE NEW VALUE OF THE VARIABLE F     IS   .5199610669E-01
/DEBUG/         AT LINE   26- THE NEW VALUE OF THE VARIABLE D     IS  -7.952787373
/DEBUG/         AT LINE   27- THE NEW VALUE OF THE VARIABLE XN    IS   .8419359532E-01
ITERATION   2       ROOT=       .08419360          H/H2=    1     ALFA= 140
/DEBUG/  PORT   AT LINE   33- THE NEW VALUE OF THE VARIABLE X     IS   .8419359532E-01
/DEBUG/         AT LINE   25- THE NEW VALUE OF THE VARIABLE F     IS   .2530436411E-02
/DEBUG/         AT LINE   26- THE NEW VALUE OF THE VARIABLE D     IS  -7.201941622
/DEBUG/         AT LINE   27- THE NEW VALUE OF THE VARIABLE XN    IS   .8454495007E-01
ITERATION   3       ROOT=       .08454495          H/H2=    1     ALFA= 140
/DEBUG/  PORT   AT LINE   24- THE NEW VALUE OF THE VARIABLE E     IS  -.2413793103
/DEBUG/         AT LINE   25- THE NEW VALUE OF THE VARIABLE F     IS  -.2042033010
/DEBUG/         AT LINE   26- THE NEW VALUE OF THE VARIABLE D     IS  -5.479209453
/DEBUG/         AT LINE   27- THE NEW VALUE OF THE VARIABLE XN    IS   .4692484283E-01
ITERATION   1       ROOT=       .04692484          H/H2=    1     ALFA= 145
/DEBUG/  PORT   AT LINE   33- THE NEW VALUE OF THE VARIABLE X     IS   .4692484283E-01
/DEBUG/         AT LINE   25- THE NEW VALUE OF THE VARIABLE F     IS   .8097788201E-01
/DEBUG/         AT LINE   26- THE NEW VALUE OF THE VARIABLE D     IS  -11.02069964
/DEBUG/         AT LINE   27- THE NEW VALUE OF THE VARIABLE XN    IS   .5427264148E-01
ITERATION   2       ROOT=       .05427264          H/H2=    1     ALFA= 145
/DEBUG/  PORT   AT LINE   33- THE NEW VALUE OF THE VARIABLE X     IS   .5427264148E-01
/DEBUG/         AT LINE   25- THE NEW VALUE OF THE VARIABLE F     IS   .6879766194E-02
/DEBUG/         AT LINE   26- THE NEW VALUE OF THE VARIABLE D     IS  -9.244664346
/DEBUG/         AT LINE   27- THE NEW VALUE OF THE VARIABLE XN    IS   .5501682926E-01
ITERATION   3       ROOT=       .05501683          H/H2=    1     ALFA= 145
/DEBUG/  PORT   AT LINE   33- THE NEW VALUE OF THE VARIABLE X     IS   .5501682926E-01
/DEBUG/         AT LINE   25- THE NEW VALUE OF THE VARIABLE F     IS   .5624385025E-04
/DEBUG/         AT LINE   26- THE NEW VALUE OF THE VARIABLE D     IS  -9.094275808
/DEBUG/         AT LINE   27- THE NEW VALUE OF THE VARIABLE XN    IS   .5502301379E-01
ITERATION   4       ROOT=       .05502301          H/H2=    1     ALFA= 145
/DEBUG/  PORT   AT LINE   24- THE NEW VALUE OF THE VARIABLE E     IS  -.2000000000
/DEBUG/         AT LINE   25- THE NEW VALUE OF THE VARIABLE F     IS  -.2253019964
/DEBUG/         AT LINE   26- THE NEW VALUE OF THE VARIABLE D     IS  -6.706902252
/DEBUG/         AT LINE   27- THE NEW VALUE OF THE VARIABLE XN    IS   .2142427222E-01
ITERATION   1       ROOT=       .02142427          H/H2=    1     ALFA= 150
/DEBUG/  PORT   AT LINE   33- THE NEW VALUE OF THE VARIABLE X     IS   .2142427222E-01
/DEBUG/         AT LINE   25- THE NEW VALUE OF THE VARIABLE F     IS   .1525034323
/DEBUG/         AT LINE   26- THE NEW VALUE OF THE VARIABLE D     IS  -20.33985173
/DEBUG/         AT LINE   27- THE NEW VALUE OF THE VARIABLE XN    IS   .2892203742E-01
ITERATION   2       ROOT=       .02892204          H/H2=    1     ALFA= 150
/DEBUG/  PORT   AT LINE   33- THE NEW VALUE OF THE VARIABLE X     IS   .2892203742E-01
/DEBUG/         AT LINE   25- THE NEW VALUE OF THE VARIABLE F     IS   .2532021610E-01
/DEBUG/         AT LINE   26- THE NEW VALUE OF THE VARIABLE D     IS  -14.25325554
/DEBUG/         AT LINE   27- THE NEW VALUE OF THE VARIABLE XN    IS   .3069848884E-01
ITERATION   3       ROOT=       .03069849          H/H2=    1     ALFA= 150
/DEBUG/  PORT   AT LINE   33- THE NEW VALUE OF THE VARIABLE X     IS   .3069848884E-01
/DEBUG/         AT LINE   25- THE NEW VALUE OF THE VARIABLE F     IS   .8796801774E-03
/DEBUG/         AT LINE   26- THE NEW VALUE OF THE VARIABLE D     IS  -13.28406705
/DEBUG/         AT LINE   27- THE NEW VALUE OF THE VARIABLE XN    IS   .3076470954E-01
ITERATION   4       ROOT=       .03076471          H/H2=    1     ALFA= 150
/DEBUG/  PORT   AT LINE   24- THE NEW VALUE OF THE VARIABLE E     IS  -.1612903226
/DEBUG/         AT LINE   25- THE NEW VALUE OF THE VARIABLE F     IS  -.2511070559
/DEBUG/         AT LINE   26- THE NEW VALUE OF THE VARIABLE D     IS  -9.382436051
/DEBUG/         AT LINE   27- THE NEW VALUE OF THE VARIABLE XN    IS   .3934964041E-02
ITERATION   1       ROOT=       .00393496          H/H2=    1     ALFA= 155
/DEBUG/  PORT   AT LINE   33- THE NEW VALUE OF THE VARIABLE X     IS   .3934964041E-02
/DEBUG/         AT LINE   25- THE NEW VALUE OF THE VARIABLE F     IS   .4423037548
/DEBUG/         AT LINE   26- THE NEW VALUE OF THE VARIABLE D     IS  -100.2957439
/DEBUG/         AT LINE   27- THE NEW VALUE OF THE VARIABLE XN    IS   .8344959297E-02
ITERATION   2       ROOT=       .00834496          H/H2=    1     ALFA= 155
/DEBUG/  PORT   AT LINE   33- THE NEW VALUE OF THE VARIABLE X     IS   .8344959297E-02
/DEBUG/         AT LINE   25- THE NEW VALUE OF THE VARIABLE F     IS   .1626320369
/DEBUG/         AT LINE   26- THE NEW VALUE OF THE VARIABLE D     IS  -41.98808869
/DEBUG/         AT LINE   27- THE NEW VALUE OF THE VARIABLE XN    IS   .1221824913E-01
ITERATION   3       ROOT=       .01221825          H/H2=    1     ALFA= 155
/DEBUG/  PORT   AT LINE   33- THE NEW VALUE OF THE VARIABLE X     IS   .1221824913E-01
```

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/DEBUG/          AT LINE   25- THE NEW VALUE OF THE VARIABLE F       IS   .3293333111E-01
/DEBUG/          AT LINE   26- THE NEW VALUE OF THE VARIABLE D       IS  -27.02609990
/DEBUG/          AT LINE   27- THE NEW VALUE OF THE VARIABLE XN      IS   .1343682418E-01
ITERATION    4          ROOT=      .01343682         H/H2=   1          ALFA= 155
/DEBUG/  PORT    AT LINE   33- THE NEW VALUE OF THE VARIABLE X       IS   .1343682418E-01
/DEBUG/          AT LINE   25- THE NEW VALUE OF THE VARIABLE F       IS   .1769194771E-02
/DEBUG/          AT LINE   26- THE NEW VALUE OF THE VARIABLE D       IS  -24.21850932
/DEBUG/          AT LINE   27- THE NEW VALUE OF THE VARIABLE XN      IS   .1350987553E-01
ITERATION    5          ROOT=      .01350988         H/H2=   1          ALFA= 155
/DEBUG/  PORT    AT LINE   24- THE NEW VALUE OF THE VARIABLE E       IS  -.1250000000
/DEBUG/          AT LINE   25- THE NEW VALUE OF THE VARIABLE F       IS  -.2878814409
/DEBUG/          AT LINE   26- THE NEW VALUE OF THE VARIABLE D       IS  -16.07014647
/DEBUG/          AT LINE   27- THE NEW VALUE OF THE VARIABLE XN      IS  -.4477227907E-02
ITERATION    1          ROOT=     -.00447723         H/H2=   1          ALFA= 160
/DEBUG/  PORT    AT LINE   33- THE NEW VALUE OF THE VARIABLE X       IS  -.4477227907E-02

NEGATIVE TO THE REAL POWER
ERROR NUMBER    0035 DETECTED BY XTOY*    AT ADDRESS 000031
CALLED FROM PORT     AT  LINE 0025
```

APPENDIX C


```
      PROGRAM NELS (INPUT,OUTPUT,TAPE1=INPUT,TAPE5=OUTPUT,TAPE6=OUTPUT)
C THIS PROGRAM CALCULATES THE PRESSURE BUILD IN THE PLENUM CHAMBER
C U1U = VELOCITY DOWNSTREAM OF PORT TO VELOCITY UPSTREAM(DIMEN)
C XLAM= LAMBDA CONSTANT(DIMEN)
C PEI=PRESS IN THE PLENUM CHBR AT END PERIOD OF NONSTEADY FLOW(LB-FT2)
C HB=DIAMETER OF BORE(FT)
C BETA=FRACTION OF THE ENERGY LOST AS HEAT(DIMEN)
C PBI=INITIAL PRESSURENIN PLENUM CHAMBER (PSF)
C AP=PORT AREA(FT**2)
C ETAD= DIFFUSION ISENTROPIC EFFICIENCY(DIMEN)
C HB2=DIAMETER OF PORT (FT)
C GAMA =RATIO OF SPECIFIC HEATS (DIMEN)
C PB2=PRESS IN PLENUM CHBR DURING PRESS BUILDUP(LBF/FT2)
C TAUEI=TIME AT THE START OF PBUP(PRESSURE BUILDUP (SEC)
C AB=BORE AREA (FT**3)
C XJ=MECHANICAL EQUIVALENT OF HEAT(FT-LBS/BTU)
C XP=DISTANCE FROM BREECH TO PORT(FT)
C UB=VOLUME OF PLENUM CHAMBER(FT**3)
C  R=PROPELANT GAS CONST.FT-LBS/SLUG-R
C TAU=TIME FROM START OF PASSAGE OF PORT (SEC)
C TTAU=TAU-TAUEI (SEC)
C FF=FRICTION FACTOR (DIMEN)
C VP=VELOCITY OF GAS IN THE BARREL AT PORT (FT/SEC)
C OMEGA=TOTAL FREE VOLUME OF BARREL ( FT**3)
C PEI=SPACE MEAN PRES IN THE BARREL FOLLOWING NONSTEADY FLOW(LBF/FT2.)
C CC=CONTRACTION COEF.(DIMEN.)
C PHI=VELOCITY COEF.FOR PORT (DIMEN)
C ETAN = ENERGY EFFICIENCY FOR PORT(DIMEN)
C XMP=MACH NUMBER AT PORT(DIMEN)
C TEI=SPACE MEAN TEMPERATURE OF GAS IN THE BARREL AT THE START OF
C XE=DISTANCE FROM BREECH TO NOZZLE(FT)
C FOLLOWING THE PERIOD OF NONSTEADY FLOW   YHROUGH PORT
C CP=SP HEAT AT CONSTANT PRES (BTU/LBM-R)
C U2U =RATIO OF VELOCITY THROUGH PORT TO VELOCITY UPSTREAM OF PORT
      DIMENSION P0(500),TAU(500),TTAU(500),TJ(500),VE(500),VP(500),
     CV2(500),T2(500),RHOP(500),RHO2(500),PSTAG(500),EIN(500),WSH(500),
     CEINSB(500),VEGT(500),PP(500),RATIO(500),CSUB(500),PH(500)
      DIMENSION PPP(500),PAP(500),PPST(500),POP(500)
      READ (1,99)XP,XE,U1U,TEI,R,PEI,XJ,HB,HB2,AB
      READ (1,99)PBI,GAMA,TAUEI,AP,UB,DTAU,OMEGA
      READ(1,99)CC,PHI,ETAD,BETA,FF
   99 FORMAT(7F10.2)
      READ (1,15) N
   15 FORMAT(I3)
      WRITE(5,11) XP,XE,U1U,TEI,R,PEI
   11 FORMAT(1H ,3HXP=,F10.3,3HXE=,F10.3,4HU1U=,F10.8,4HTEI=,F10.2,2HR=
     1,F10.2,4HPEI=,F10.2)
      WRITE(5,12) HB,HB2,AB,PBI,GAMA,TAUEI
   12 FORMAT(1H ,3HHB=,F13.6,4HHB2=,F13.6,3HAB=,F13.6,4HPBI=,F13.6,
     C5HGAMA=,F13.6,6HTAUEI=,F13.6)
      WRITE(5,13) AP,UB,DTAU,OMEGA
   13 FORMAT(1H ,3HAP=,F13.6,3HUB=,F13.6,5HDTAU=,F13.6,6HOMEGA=,F13.6)
      WRITE(5,14)CC,PHI,ETAD,BETA,FF
```

```
14 FORMAT(1H ,3HCC=,F13.6,4HPHI=,F13.6,5HETAD=,F13.6,5HBETA=,F13.6
  C,3HFF=,F13.6)
   GCRT=(2./(GAMA+1.))**(GAMA/(GAMA-1.))
   G=32.174
   D=SQRT(4.*AB/3.141)
   GG1=2.*GAMA/(GAMA-1.)
   G11=(GAMA+1.)/(GAMA-1.)
   G12=2./(GAMA+1.)
   GG=G12**G11
   G2G=SQRT(GAMA*GG)
   U20=(1.-U1C)*AH/AB2
   CP=GAMA*R/(GAMA-1.)/G/XJ
   VEI=G2G*SQRT(R*TEI)
   THETA=2.*OMEGA/(GAMA-1.)/AB/SQRT(GAMA*R*TEI)*((GAMA+1.)/2.)**
  C(G11/2.)
   ETAD=PHI**2
   TAU(1)=TAUEI
   PO(1)=PEI
   PB(1)=PBI
   TE(1)=TEI
   PSO(1)=PEI/144.
   PSP(1)=PB1/144.
   PPST(1)=PEI/144.
   PSP(1)=PEI/144.
   DO 1 I K=2,N
   TAU(K)=TAU(K-1)+DTAU
   IF (TAU(K).GT..C1 ) GO TO 49
   TTAU(K)=TAU(K)-TAUEI
   PO(K)=PEI*(1.+TTAU(K)/THETA)**(-   GG1)
   TE(K)=TEI*(PO(K)/PEI)**((GAMA-1.)/GAMA)
   XMIN=14.7*144.
   IF (PO(K).LT.XMIN)PO(K)=XMIN
   RHOP(K)=PO(K)/R/TE(K)
   VE(K)=SQRT(GAMA*R*TE(K))
   VP(K)=XP/XE*VE(K)
   XMP=XP/XE
   XLAM=XMP**2/(1.+SQRT(1.-XMP**2))**2
   C11=U20*(1.-XLAM)
   C12=1.-XLAM*U20**2
   C1=C11/C12
   V2(K)=C1*VE(K)
   V2(K)=V2(K)*CC*PHI
   T2(K)=TE(K)
   DVEDT(K)=-VEI/THETA*1./(1.+TTAU(K) /THETA)**2
   PP(K)=-RHOP(K)*VE(K)**2/XE**2*(XP**2/2.+2./3.*FF*XP**3/D)
  C-RHOP(K)/XE*XP**2/2.*DVEDT(K)+PO(K)
   RHO2(K)=GAMA*RHOP(K)/(GAMA+1.)
   COEF=XJ*(GAMA-1.)*G/UH
   PSTAG(K)=PP(K)*(1.+GAMA*(1.-SQRT(1.-XMP**2)))
   RATIO(K)=PB(K-1)/PSTAG(K)
   IF(RATIO(K).GT.GCRT) GO TO 60
   EIN(K)=RHO2(K)*V2(K)*T2(K)*CP*AP
   PB(K)=PB(K-1)+COEF*EIN(K)*DTAU*(1.-BETA)
```

```
      GO TO 777
  600 IF(RATIO(K).GT.1.) GO TO 700
      CSUB(K)=SQRT(   GGI*(RATIO(K)**(2./GAMA)-RATIO(K)**((GAMA+1.)/GAMA
     C)))
      WSB(K)=AP*CSUB(K)*PSTAG(K)/SQRT(R*T0(K))*CC*PHI
      EINSB(K)=WSB(K)*CP*T0(K)
      PB(K)=PB(K-1)+COEF*EINSB(K)*DTAU*(1.-BETA)
      GO TO 777
  700 PB(K)=P0(K)
  777 PPP(K)=PP(K)/144.
      PBP(K)=PB(K)/144.
      PPST(K)=PSTAG(K)/144.
      POP(K)=P0(K)/144.
 1001 CONTINUE
   99 KK=K
      WRITE(6,201)
  201 FORMAT(1H0,5X,8HTIME(MS),5X,18HPORT PRESSURE(PSI),5X,22HCYLINDER P
     CRESSURE(PSI),5X,19HSTAGN PRESSURE(PSI),5X,19HPRES IN BARREL(PSI))
      DO 1002 K=1,KK
      WRITE(6,202) TTAU(K),PPP(K),PBP(K),PPST(K),POP(K)
  202 FORMAT(1H ,5E20.10)
 1002 CONTINUE
      WRITE(6,203)
  203 FORMAT(1H0,4HTIME,15X,2HT0,15X,2HV2,15X,2HT2,15X,5HRATIO)
      DO 2000 K=1,KK
      WRITE(6,204)TTAU(K),T0(K),V2(K),T2(K),RATIO(K)
  204 FORMAT(5F13.6)
 2000 CONTINUE
      STOP
      END
```

```
.467000000XE=1.667000000JU= .563300000TEI=   3202.00R=   2092.00PEI=2197000.00
   .416330482=      .007420A3=      .000256PHI= 29490.000000GAMA=     1.239000TAUFI=      .000030
   .900043UB=       .000810TAU=     .000100OMEGA=      .000470
   .900000PHI=      .950000ET+D=    0.000000BETA=      .200000FF=       .006000
```

TIME(MS)	PORT PRESSURE(PSI)	CYLINDER PRESSURE(PSI)	STAGN PRESSURE(PSI)	PRES IN BARREL(PSI)
0.	.1525694444E+05	.2247916697E+03	.1525694444E+05	.1525694444E+05
.1000000000E-03	.9053723437E+04	.6542324962E+03	.1186811499E+05	.1355139856E+05
.2000000000E-03	.8583381442E+04	.1049473222E+04	.1055553592E+05	.1205265322E+05
.3000000000E-03	.7044192494E+04	.1397549721E+04	.9400431925E+04	.1073371801E+05
.4000000000E-03	.6810318141E+04	.1704521026E+04	.8382464591E+04	.9571369901E+04
.5000000000E-03	.6085304576E+04	.1975013574E+04	.7484105101E+04	.8545593903E+04
.6000000000E-03	.5442246915E+04	.2215342917E+04	.6690221352E+04	.7639111694E+04
.7000000000E-03	.4859005731E+04	.2427616587E+04	.5987729341E+04	.6836983535E+04
.8000000000E-03	.4302857132E+04	.2615821210E+04	.5365298232E+04	.6126271510E+04
.9000000000E-03	.3913839747E+04	.2782496396E+04	.4813100392E+04	.5495754110E+04
.1000000000E-02	.3514981335E+04	.3074613706E+04	.4322599177E+04	.4935683916E+04
.1100000000E-02	.3160254772E+04	.3300443759E+04	.3886368444E+04	.4437581519E+04
.1200000000E-02	.2844397773E+04	.3416946178E+04	.3497938788E+04	.3994059941E+04
.1300000000E-02	.2552821497E+04	.3598674832E+04	.3151666341E+04	.3598674832E+04
.1400000000E-02	.2311515554E+04	.3245796407E+04	.2842620621E+04	.3245796407E+04
.1500000000E-02	.2085975990E+04	.2930499834E+04	.2566448853E+04	.2930499834E+04
.1600000000E-02	.1883127351E+04	.2644471240E+04	.2319492053E+04	.2644471240E+04
.1700000000E-02	.1705276232E+04	.2395927007E+04	.2098317535E+04	.2395927007E+04
.1800000000E-02	.1545055214E+04	.2169544355E+04	.1900054948E+04	.2169544355E+04
.1900000000E-02	.1400386655E+04	.1966401568E+04	.1722145491E+04	.1966401568E+04
.2000000000E-02	.1270435700E+04	.1783926429E+04	.1562336455E+04	.1783926429E+04
.2100000000E-02	.1153538725E+04	.1619851686E+04	.1418642216E+04	.1619851686E+04
.2200000000E-02	.1044420839E+04	.1472176540E+04	.1289310501E+04	.1472176540E+04
.2300000000E-02	.9535731402E+03	.1339133277E+04	.1172793173E+04	.1339133277E+04
.2400000000E-02	.8584321531E+03	.1219158338E+04	.1067720891E+04	.1219158338E+04

.2500000000E-02	.7911118606E+03	.1110867201E+04	.9728811100E+03	.1110867201E+04
.2600000000E-02	.7214382127E+03	.1013032527E+04	.8871989463E+03	.1013032527E+04
.2700000000E-02	.6584355515E+03	.9245651522E+03	.8097205238E+03	.9245651522E+03
.2800000000E-02	.6014148118E+03	.8444974998E+03	.7395984548E+03	.8444974998E+03
.2900000000E-02	.5497632173E+03	.7719691191E+03	.6760791687E+03	.7719691191E+03
.3000000000E-02	.5029352778E+03	.7062140412E+03	.6184918413E+03	.7062140412E+03
.3100000000E-02	.4604449130E+03	.6465497194E+03	.5662387083E+03	.6465497194E+03
.3200000000E-02	.4218585549E+03	.5923673443E+03	.5187865833E+03	.5923673443E+03
.3300000000E-02	.3867899993E+03	.5431233500E+03	.4756594194E+03	.5431233500E+03
.3400000000E-02	.3548905973E+03	.4983319603E+03	.4364317809E+03	.4983319603E+03
.3500000000E-02	.3258535892E+03	.4575586367E+03	.4007231055E+03	.4575586367E+03
.3600000000E-02	.2994010010E+03	.4204143161E+03	.3681926574E+03	.4204143161E+03
.3700000000E-02	.2752845295E+03	.3865503355E+03	.3385350826E+03	.3865503355E+03
.3800000000E-02	.2532814581E+03	.3556539578E+03	.3114764907E+03	.3556539578E+03
.3900000000E-02	.2331918410E+03	.3274444241E+03	.2867709971E+03	.3274444241E+03
.4000000000E-02	.2148362235E+03	.3016694660E+03	.2641976689E+03	.3016694660E+03
.4100000000E-02	.1980524456E+03	.2781022214E+03	.2435578238E+03	.2781022214E+03
.4200000000E-02	.1826956943E+03	.2565385056E+03	.2246726395E+03	.2565385056E+03
.4300000000E-02	.1686347860E+03	.2367943928E+03	.2073810367E+03	.2367943928E+03
.4400000000E-02	.1557516309E+03	.2187040714E+03	.1915378001E+03	.2187040714E+03
.4500000000E-02	.1439397081E+03	.2021179413E+03	.1770119119E+03	.2021179413E+03
.4600000000E-02	.1331028013E+03	.1869009222E+03	.1636850710E+03	.1869009222E+03
.4700000000E-02	.1231539878E+03	.1729309501E+03	.1514503756E+03	.1729309501E+03
.4800000000E-02	.1140146555E+03	.1600976391E+03	.1402111511E+03	.1600976391E+03
.4900000000E-02	.1056136596E+03	.1483010889E+03	.1298799063E+03	.1483010889E+03
.5000000000E-02	.9788656582E+02	.1374508218E+03	.1203774024E+03	.1374508218E+03
.5100000000E-02	.9077497499E+02	.1274648345E+03	.1116318220E+03	.1274648345E+03
.5200000000E-02	.8422591952E+02	.1182687507E+03	.1035780275E+03	.1182687507E+03
.5300000000E-02	.7819132430E+02	.1097950642E+03	.9615689787E+02	.1097950642E+03
.5400000000E-02	.7262752438E+02	.1019824613E+03	.8931473545E+02	.1019824613E+03
.5500000000E-02	.6749483336E+02	.9477521447E+02	.8300273499E+02	.9477521447E+02
.5600000000E-02	.6275715591E+02	.8812263925E+02	.7717650774E+02	.8812263925E+02
.5700000000E-02	.5838163931E+02	.8197860688E+02	.7179565480E+02	.8197860688E+02
.5800000000E-02	.5433836811E+02	.7630110718E+02	.6682338430E+02	.7630110718E+02
.5900000000E-02	.5060097702E+02	.7105185597E+02	.6222616751E+02	.7105185597E+02
.6000000000E-02	.4714193[illegible]5E+02	.6619594223E+02	.5797342988E+02	.6619594223E+02
.6100000000E-02	.4394116322E+02	.6170151076E+02	.5403727308E+02	.6170151076E+02
.6200000000E-02	.4097714141E+02	.5753947656E+02	.5039222492E+02	.5753947656E+02
.6300000000E-02	.3823091520E+02	.5368326763E+02	.4701501402E+02	.5368326763E+02
.6400000000E-02	.3568518505E+02	.5010859305E+02	.4388436674E+02	.5010859305E+02
.6500000000E-02	.3332412939E+02	.4679323389E+02	.4098082409E+02	.4679323389E+02
.6600000000E-02	.3113326423E+02	.4371685447E+02	.3828657636E+02	.4371685447E+02
.6700000000E-02	.2909932772E+02	.4086083186E+02	.3578531389E+02	.4086083186E+02
.6800000000E-02	.2721016744E+02	.3820810183E+02	.3346209205E+02	.3820810183E+02
.6900000000E-02	.2545464176E+02	.3574301950E+02	.3130320930E+02	.3574301950E+02
.7000000000E-02	.2382253014E+02	.3345123323E+02	.2929609669E+02	.3345123323E+02
.7100000000E-02	.2230445156E+02	.3131957046E+02	.2742921788E+02	.3131957046E+02
.7200000000E-02	.2088179105E+02	.2933593420E+02	.2569197849E+02	.2933593420E+02
.7300000000E-02	.1957563292E+02	.2748920922E+02	.2407464400E+02	.2748920922E+02
.7400000000E-02	.1835169994E+02	.2576917696E+02	.2256826511E+02	.2576917696E+02
.7500000000E-02	.1721429832E+02	.2416643823E+02	.2116461017E+02	.2416643823E+02
.7600000000E-02	.1614626793E+02	.2267234300E+02	.1985610361E+02	.2267234300E+02
.7700000000E-02	.1515393671E+02	.2127892665E+02	.1863577012E+02	.2127892665E+02
.7800000000E-02	.1422817937E+02	.1997885190E+02	.1749718382E+02	.1997885190E+02
.7900000000E-02	.1336387978E+02	.1876535603E+02	.1643442204E+02	.1876535603E+02
.8000000000E-02	.1255689678E+02	.1763220281E+02	.1544202316E+02	.1763220281E+02
.8100000000E-02	.1180303293E+02	.1657363870E+02	.1451494833E+02	.1657363870E+02
.8200000000E-02	.1109830612E+02	.1558435291E+02	.1364854643E+02	.1558435291E+02
.8300000000E-02	.1046870800E+02	.1470000000E+02	.1287404319E+02	.1470000000E+02
.8400000000E-02	.1046870800E+02	.1470000000E+02	.1287404319E+02	.1470000000E+02
.8500000000E-02	.1046870800E+02	.1470000000E+02	.1287404319E+02	.1470000000E+02
.8600000000E-02	.1046870800E+02	.1470000000E+02	.1287404319E+02	.1470000000E+02
.8700000000E-02	.1046870800E+02	.1470000000E+02	.1287404319E+02	.1470000000E+02
.8800000000E-02	.1046870800E+02	.1470000000E+02	.1287404319E+02	.1470000000E+02
.8900000000E-02	.1046870800E+02	.1470000000E+02	.1287404319E+02	.1470000000E+02
.9000000000E-02	.1046870800E+02	.1470000000E+02	.1287404319E+02	.1470000000E+02

.9100000000E-02	.1046870800E+02	.1470000000E+02	.1287404319E+02	.1470000000E+02
.9200000000E-02	.1046870800E+02	.1470000000E+02	.1287404319E+02	.1470000000E+02
.9300000000E-02	.1046870800E+02	.1470000000E+02	.1287404319E+02	.1470000000E+02
.9400000000E-02	.1046870800E+02	.1470000000E+02	.1287404319E+02	.1470000000E+02
.9500000000E-02	.1046870800E+02	.1470000000E+02	.1287404319E+02	.1470000000E+02
.9600000000E-02	.1046870800E+02	.1470000000E+02	.1287404319E+02	.1470000000E+02
.9700000000E-02	.1046870800E+02	.1470000000E+02	.1287404319E+02	.1470000000E+02
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.9900000000E-02	.1046870800E+02	.1470000000E+02	.1287404319E+02	.1470000000E+02
0.	0.	1.	1.	0.

TIME	IO	V2	IS	RATIO
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.000300	2992.006457	1109.898135	2992.006457	.111641
.000400	2926.582996	1097.696303	2926.582996	.166723
.000500	2863.282140	1085.760231	2863.282140	.227752
.000600	2802.013050	1074.080755	2802.013050	.295299
.000700	2742.689697	1062.649876	2742.689697	.369980
.000800	2685.230550	1051.459741	2685.230550	.452466
.000900	2629.558328	1040.502823	2629.558328	.543479
.001000	2575.599680	1029.771906	2575.599680	.643802
.001100	2523.285000	1019.259071	2523.285000	.791128
.001200	2472.548179	1008.960675	2472.548179	.943540
.001300	2423.326395	998.867343	2423.326395	1.284171
.001400	2375.559924	988.973552	2375.559924	1.265971
.001500	2329.191954	979.274620	2329.191954	1.264684
.001600	2284.168421	969.763691	2284.168421	1.263423
.001700	2240.437845	960.435730	2240.437845	1.262188
.001800	2197.951190	951.285507	2197.951190	1.260978
.001900	2156.661722	942.307590	2156.661722	1.259792
.002000	2116.524881	933.498334	2116.524880	1.258629
.002100	2077.498158	924.851576	2077.498158	1.257489
.002200	2039.540992	916.364123	2039.540992	1.256371
.002300	2002.614653	908.030744	2002.614653	1.255274
.002400	1966.682149	899.847560	1966.682149	1.254198
.002500	1931.708135	891.810564	1931.708135	1.253142
.002600	1897.658820	883.915657	1897.658820	1.252106
.002700	1864.501892	876.159698	1864.501892	1.251089
.002800	1832.206436	868.538472	1832.206436	1.250091
.002900	1800.742865	861.048689	1800.742865	1.249110
.003000	1770.082852	853.686976	1770.082852	1.248148
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.003200	1711.066109	839.334844	1711.066109	1.246273
.003300	1682.658464	832.338236	1682.658464	1.245360
.003400	1654.952439	825.457308	1654.952439	1.244463
.003500	1627.925119	818.689217	1627.925119	1.243582
.003600	1601.554515	812.031210	1601.554515	1.242715
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.003800	1550.699874	799.034873	1550.699874	1.241026
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.004100	1478.842169	780.302092	1478.842169	1.238595
.004200	1455.996740	774.251508	1455.996740	1.237811
.004300	1433.676632	768.294035	1433.676632	1.237039
.004400	1411.865860	762.427543	1411.865860	1.236280
.004500	1390.549046	756.649561	1390.549046	1.235533
.004600	1369.711384	750.959284	1369.711384	1.234798
.004700	1349.338622	745.353567	1349.338622	1.234074
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.004900	1309.933390	734.389509	1309.933390	1.232659
.005000	1290.874952	729.027558	1290.874952	1.231968
.005100	1272.229434	723.743336	1272.229434	1.231287
.005200	1253.984995	718.535167	1253.984995	1.230617
.005300	1236.130213	713.401419	1236.130213	1.229956

.005400	1218.654069	708.340510	1218.654069	1.229305
.005500	1201.545934	703.350900	1201.545934	1.228664
.005600	1184.795546	698.431092	1184.795546	1.228032
.005700	1168.393000	693.579633	1168.393000	1.227409
.005800	1152.328731	688.795107	1152.328731	1.226795
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.006000	1121.178385	679.421392	1121.178385	1.225593
.006100	1106.074758	674.829562	1106.074758	1.225005
.006200	1091.274285	670.299382	1091.274285	1.224425
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.006400	1062.550826	661.419074	1062.550826	1.223289
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.006900	995.514535	640.214728	995.514535	1.220581
.007000	982.870246	636.135969	982.870246	1.220061
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.007200	958.293793	628.132400	958.293793	1.219041
.007300	946.349807	624.205667	946.349807	1.218541
.007400	934.627739	620.327724	934.627739	1.218047
.007500	923.122125	616.497668	923.122125	1.217560
.007600	911.827668	612.714617	911.827668	1.217079
.007700	900.739233	608.977712	900.739233	1.216603
.007800	889.851839	605.286112	889.851839	1.216134
.007900	879.160655	601.638599	879.160655	1.215671
.008000	868.660995	598.035574	868.660995	1.215214
.008100	858.348311	594.475056	858.348311	1.214762
.008200	848.218190	590.956684	848.218190	1.214315
.008300	838.266349	587.479714	838.266349	1.210525
.008400	828.488627	584.043418	828.488627	1.141832
.008500	818.880988	580.647088	818.880988	1.141832
.008600	809.439508	577.290030	809.439508	1.141832
.008700	800.160378	573.971568	800.160378	1.141832
.008800	791.039898	570.691038	791.039898	1.141832
.008900	782.074471	567.447795	782.074471	1.141832
.009000	773.260602	564.241207	773.260602	1.141832
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.009500	731.348986	548.736931	731.348986	1.141832
.009600	723.376335	545.737764	723.376335	1.141832
.009700	715.533347	542.771203	715.533347	1.141832
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.009900	700.225242	536.933795	700.225242	1.141832
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