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ANALYTIC AND EXPERIMENTAL INTERIOR BALLISTICS

OF CLOSED BREECH GUNS

by

Otto K. Heiney, 1st Lt, USAFR

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FOREWORD

This report has been generated under the interior ballistic analysis portion of Project 62405094 2560. It is an extension of a propellant actuated device interior ballistic formulism developed at the Jet Propulsion Laboratory (reference 1) at Pasadena, California, under NAS 7-100. The report was written by 1st Lt O. K. Heiney, USAFR, attached to the Air Force Armament Laboratory [AFATL (ATWG)] for an annual active duty tour. Assistance of the personnel of both AFATL (ATBA) and the Armament Development and Test Center [ADTC (ADTVF-2)] with the formulation and execution of the computer program is gratefully acknowledged.

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This technical report is approved.

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

ABSTRACT

A closed breech incremental interior ballistic formulism is presented along with a Fortran ¹/₄ computer program which utilizes the system. Typical input and output data, both plotted and tabular, are included. A unique characteristic of the system is that it avoids the inaccuracies associated with approximate analytic propellant regression expressions in that regression rates are determined by a tabular routine. Various pressure gradient expressions are investigated. Correlation of the mathematical model and computer predictions to experimental device firings are presented. A shock-driven deflagration effect which may be initiated during the ignition transient is described and a postulated correlation parameter defined.

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iii

CONTENTS

Section		Page
	NOMENCLATURE	vii
I.	INTRODUCTION	1
II.	ANALYSIS	2
	Energy Balance	2
	Pressure Gradient and Gas Kinetic Energy	24
	Gas Production	13
III.	COMPUTER PROGRAM	15
	Input Data and Usage	15
	Results	16
	Computer Program	16
TV.	EXPERIMENTAL RESULTS	27
	Normal Deflagration	27
	Shock_Driven Deflagration	31
	REFERENCES	36
		10

ILLUSTRATIONS AND TABLES

Figure

1.	Density Gradient as Function of Shot Velocity	7
2.	δ Value as Function of Projectile Velocity	9
3.	Shot Pressure to Static Pressure Ratio, $T = T_0$	11
4.	Shot Pressure to Static Pressure Ratio, $T = .7T_{o}$	12
5.	Graph of 20mm Performance 0.015 Web	19
6.	Graph of 20mm Performance 0.020 Web	23
7.	Device to Measure Pressure-Time History and Muzzle	
	Velocity	27
8.	Ignition and Propellant Loading Techniques	28
9.	Pressure Time Plot With $\Delta = 57.0 \text{ in.}^2/\text{in.}^3 \dots$	29
10.	Pressure Time Plot With $\Delta = 61.0 \text{ in.}^2/\text{in.}^3$	30
11.	Pressure Time Plot With $\Delta = 65.5 \text{ in.}^2/\text{in.}^3$	30
12.	Pressure Time Plot With $\Delta = 76.7 \text{ in.}^2/\text{in.}^3$	32
13.	Pressure Time Plot With $\Delta = 80.0 \text{ in.}^2/\text{in.}^3$	33
14.	Pressure Time Plot With $\Delta = 82.0 \text{ in.}^2/\text{in.}^3$	33
15.	End Cap After Detonative Reaction	34

v

ILLUSTRATIONS AND TABLES (CONTINUED)

Table

Page

I.	PROGRAM INPUT: TYPICAL PROPELLANT AND CASE	
	DATA CARDS	17
II.	COMPUTER PRINTOUT OF 20MM PERFORMANCE 0.015 WEB	18
III.	COMPUTER PRINTOUT OF 20MM PERFORMANCE 0.020 WEB	21
IV.	INTERIOR BALLISTIC PROGRAM FORTRAN 4 LISTING	24
ν.	CHARGE CHARACTERISTICS	31

NOMENCLATURE

- A = Bore Area
- = Acceleration a
- С = Arbitrary Constant
- Cv = Constant Volume Gas Specific Heat

 C_{W} = Charge Weight

EG = Kinetic Energy of Propellant Gas

F = Force

- Fp = Impetus of Propellant
- = Acceleration Due to Gravity
- mA = Pseudo Mass of Propelled Device
- = Mass of Propelled Device mp
- = Mach Number M
- N_B = Propellant Burned
- PAV = Average Plenum Pressure
- $P_0 = Total Pressure$
- P_s = Shot Base Pressure
- = Regression Rate of Propellant r
- = Gas Constant R
- S_B = Burning Surface of Propellant
- = Gas Temperature T
- To = Isochoric Flame Temperature of Propellant
 - = Shot Velocity
- v_c = Initial Chamber Volume
- = Gas Velocity V

V

- = Distance from Shot Base to Xo X
- X_o = Initial Shot Reference
- = Arbitrary Reference Behind Shot X
- = Heat Loss Factor 8
- Y = Specific Heat Ratio of Propellant Gas
- = Density Distribution Factor 8
- = Covolume of Propellant Gases η
- = Average Density of Gas ۵
- ρ_p = Density of Propellant
- = Breech Gas Density PO
- = Density of Gas at Projectile PS
- = Pressure Gradient Factor ð
- wo = Initial Propellant Web
- = Burning Surface Factor Δ

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vii

SECTION I

INTRODUCTION

The basic interior ballistic problem of any closed breech gun system is to determine the energy release and corresponding pressure generated by the burning of propellant in a variable volume. From the energy balance and the equation of state, the pressure-time or pressure-travel as well as muzzle velocity and piezometric efficiency of the system is established, thus providing the complete ballistic solution.

The results of the analysis, Section II, are essentially contained in equations (9) and (26) which are in an incremental form specifically tailored for machine computation. Program listing and typical results are presented in Section III.

The analysis in Section II considers first the energy balance of the system in paragraph A, Section II. In paragraph B, Section II, the kinetic energy in the propellant gas is determined. Also investigated are various expressions for the pressure gradient from the breech to the moving shot. In paragraph C, Section II, the constant burning surface of single perforate propellant is demonstrated and a tabular regression routine defined.

Section IV illustrates the comparison of the presented model to experimentally measured pressure histories of device firings. The experimental set_up is described, and a shock_driven deflagration phenomenon that was encountered is defined.

SECTION II

ANALYSIS

ENERGY BALANCE

The Noble-Abel equation of state is:

P(V - T) = nRT

Where η is the "covolume" of the propellant and has the units of volume/ mass which arises due to the fact that the combustion products are not perfect gases.

The central property of the propellant is its "impetus," F_p , which is qualitatively similar to the c* of rocket propellants.

$$F_{p} = RT_{0}$$
 (2)

(1)

Where T_0 is the isochoric flame temperature of the propellant gases and F_p has units of specific energy (ft-lb/lb).

The energy equation, following the techniques in reference 2, for the system will be

$$E_1 = E_2 + E_3 + E_4$$
, where

The instantaneous free chamber volume is a function of the initial chamber volume plus the barrel volume exposed by shot motion minus volume occupied by unburnt propellant and combustion gases. Combining equations (1) and (2) then gives

$$P\left[\left(\mathbf{v}_{c} + A\mathbf{X}\right) - \frac{\left(\mathbf{C}_{w} - N_{b}\right)}{\rho_{p}} - \eta N_{b}\right] = \frac{N_{b}F_{p}\mathbf{T}}{\mathbf{T}_{o}}$$
(3)

Thermal and chemical energy released by propellant will be

$$E_1 = N_D C_v (T_0 - T)$$

(4)

(5)

Translational energy of the piston will be

$$E_2 = 1/2 m_p V^2$$

The heat loss of the gases is proportional to the distance traveled, which (following reference 3) is roughly proportional to the square of the velocity. We can, to a good approximation, say that

$$E_3 = 1/2 \beta m_A V^2$$

Using the expression developed in paragraph B, below, for the kinetic energy contained in the accelerating gas and unburned propellant, we may write

$$E_{l_{\downarrow}} = 1/2 \frac{C_{W}V^{2}}{g\delta}$$

We may define

$$m_{A} = m_{p} + \frac{C_{w}}{\delta g}$$

Then

$$E_2 + E_3 + E_4 = (1 + \beta) (1/2) m_A V^2$$

Defining Y by equation (6)

$$(Y - 1) = \frac{R}{C_{\Psi}} = F_{p}/C_{\Psi}T_{o}$$
(6)

Then from equations (4), (5), and (6)

$$N_{\rm b}F_{\rm p}(1 - T/T_{\rm o}) = 1/2 (Y - 1) (1 + \beta) m_{\rm A} V^2$$
 (7)

The temperature ratio is eliminated by the introduction of the equation of state to give the fundamental ballistic equation

$$N_{b}F_{p} - (Y - 1) (1 + \beta) \frac{m_{A}}{2} V^{2} = P_{AV} \left[(v_{c} + AX) - \frac{(C_{w} - N_{b})}{\rho_{p}} - TN_{b} \right] (8)$$

or as a differential form of equation (8) is more convenient for incremental computation, differentiating, and taking differential chamber volume changes due to charge regression as second order; this is

$$\frac{dP_{AV}}{dt}\left[\left(v_{c}+AX\right) - \frac{\left(c_{w}-N_{b}\right)}{P_{p}} - TN_{b}\right] = \frac{dN_{b}}{dt}F_{p} - (\gamma-1)(1+\beta) m_{A} \frac{dV}{dt} \frac{dx}{dt} - P_{AV}A \frac{dx}{dt} (9)$$

Equation (9) provides the basis for the complete incremental interior ballistic solution; however, two additional functions are necessary to provide required relationship in the above formulation.

The first is projectile velocity as a function of average chamber pressure, or $V = f(P_s, t, m_p)$

This relation is determined in paragraph B below. The second expression required is a value for the surface exposed to burning as a function of web fraction burned.

$$N_{t} = f(P_{AV}, t)$$

which is covered in paragraph C below.

PRESSURE GRADIENT AND GAS KINETIC ENERGY

The determination of the pressure gradient in the barrel is central to the ballistic solution, as the velocity of the shot is a function of the pressure at the shot while equation (9) gives a value for P_{AV}. The density distribution in the gas is also required to give a value for the gas kinetic energy. The density and pressure variations are determined for an average temperature in the combustion chamber of T_0 and also for an average temperature of 7/10 T_0 . This problem was first studied by La'Grange and his approach introduces the analysis.

$$\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x} (\rho v) = 0$$

(10)

and assuming constant density

$$\frac{9x}{9b} = 0$$

results in equation (10) being separable with the result.

$$\frac{1}{\rho}\frac{\partial\rho}{\partial t} = -\frac{\partial\nu}{\partial x} = C$$
(11)

Equation (11) is integrated with the boundary conditions

BD 1.
$$X = X_0 = 0$$
, $v = 0$
BD 2. $X = X$, $v = V = \frac{dx}{dt}$
 $\int_0^V dv = C \int_0^X dx$

v = Cx

at boundary 2

$$C = \frac{1}{X} \frac{dX}{dt}$$

then

$$=\frac{x}{X}\frac{dX}{dt}$$
(13)

(12)

It is thus seen the constant density assumption of La'Grange will directly result in a linear velocity profile for the gases, equation (13). Constant density is then a sufficient condition for velocity linearity, though not necessarily a necessary condition.

The kinetic energy in the gas using the above approach is then

$$E_{\rm G} = 1/2 \int_0^{\mathbf{x}} A_{\rm p} v^2 \, dx = \frac{A_{\rm p}}{2} v^2 \int_0^{\mathbf{x}} \frac{x^2}{x^2} \, dx = (1/2) (1/3) A_{\rm p} X v^2$$

but

$$ApX = \frac{C_W}{g}$$

then

$$C_{\rm G} = (1/2) (1/3) \frac{C_{\rm w} V^2}{g} = 1/2 \frac{C_{\rm w} V^2}{\delta g}$$

where

 $\delta = 3$ for the La'Grange solution.

The factor δ was introduced by Hirschfelder (reference 3) in his extension of the work of Kent (reference 4) who allowed the gas density to vary and solved for δ as a function of the charge to projectile mass ratio.

Solutions of the form $\delta = f(C_w/m_rg)$

are useful for the approximate closed form ballistics of Hirschfelder but are of less utility for incremental computer solvable interior ballistic system discussed here. The results of La'Grange ($\delta = 3$) essentially state that the energy in the accelerating gas is equivalent to 1/3 of the gas mass traveling at shot velocity. This is a good approximation at velocities where the gas density is almost constant. It falls apart, as would be expected, at velocities where the density is no longer uniform.

For incremental computations, δ is most effectively formulated as a function of shot velocity. To do this, it is first necessary to describe the density variation behind the projectile as a function of shot velocity. It is then assumed that a linear velocity gradient exists behind the shot and also that isontropic flow relations may be used during an interval to describe the flow behind the shot.

This requires that the flow during the short interval considered be looked upon as "quasi-isentropic." From reference 5, the density ratio is then

$$\rho/\rho_{0} = \left(1 + \frac{\gamma - 1}{2} \frac{v^{2}}{gRT}\right)^{-1/\gamma - 1}$$
(15)

The question then arises as to what temperature should be used to define the speed of sound in the environment of the burning gases. An upper bound for this temperature would be the isochoric flame temperature of the gases T_0 ; a reasonable lower bound would be 7/10 T_0 . The analysis is then conducted with the above values as bounds.

The results of equation (15) are plotted on Figure 1 for a $\gamma = 1.222$ and an RT_o = 375,000 ft-1b/lb.

(14)





The energy increment in a small control volume of gas will then be

$$E_{I} = 1/2 \rho_{N} V_{N}^{2} A\Delta X_{N}$$

$$E_{G} = \frac{A\rho_{0}}{2} \sum \frac{\rho_{N}}{\rho_{0}} V_{N}^{2} \Delta X_{N} = 1/2 \frac{C_{w}}{g\delta} V^{2} \qquad (16)$$

The value of δ , for a given velocity, is determined by performing the numerical summation of equation (16) on a digital computer. The results of this procedure are plotted on Figure 2. As would be expected at low velocities, the value of δ approaches 3.0. The results of δ as a function of velocity is then fed into the main ballistic program as data and allows for the computation of the value of the kinetic energy of the gas.

PRESSURE GRADIENT

The necessity of relating $P_s = f(P_{AV})$ has been explained above. The approach used here is to relate P_s to P_o by two independent methods and then empirically determine a P_{AV} to P_s relationship. A value for the ratio of P_s/P_o may be obtained by means of the "quasi-isentropic" assumption used for densities above.

$$P/P_{o} = \left(1 + \frac{\gamma - 1}{2} \frac{v^{2}}{gRT}\right)^{-\gamma/\gamma - 1}$$
(17)

The results of this relation are plotted on Figures 3 and 4 for the temperatures $T = T_0 \& T = .7T_0$ respectively.

Another approach to the pressure gradient solution would be to assume a constant temperature process. In which case Euler's equation and the equation of state will give:

 $P = \rho RT$ (18)

(19)

$$vdv = -\frac{dp}{o}$$

combining equations (18) and (19) and integrating

$$\int_{0}^{V} v dv = -\int_{P_{0}}^{P_{s}} \frac{RT}{P} dP$$



Figure 2. § Value as Function of Projectile Velocity.

$$\frac{v^2}{2} = -RT \ln (P_s - P_o)$$

PΛ

then

The results of equation (20) are also plotted on Figures 3 and 4. The constant temperature equation predicts a lower shot pressure than the quasiisentropic relation. To relate P_s to P_{AV} then, a heuristically reasonable approach would be to assume that a relation of the form

$$P_{S}/P_{AV} = \left(1 + \frac{\gamma - 1}{2\phi} \frac{v^{2}}{gRT}\right)^{-\gamma/\gamma - 1}$$
(21)

with $\phi > 1$ would be satisfactory. To investigate this possibility, it is necessary to develop a value for P_{AV} which has only the gas acceleration energy accounted for. This is done as follows:

$$P_{o} v_{c} - \frac{mv^{2}}{2\delta} = P_{AV} v_{c}$$

$$P_{AV}/P_{o} = 1 - \frac{V^{2}}{2\delta gF_{p}(T/T_{o})}$$
(22)

Using the expression developed for $\delta = f(v)$ with $\Phi = 1.5$ the combined results of equations (21) and (22) will give a value for P_S/P_0 which is again plotted on Figures 3 and 4. It is seen that this value of Φ gives consistent results for both temperature extremes. It is used in the interior ballistic formulism to relate the average pressures generated by equation (9) to the pressure at the base of the shot required for the equation of motion, as shown below.

$$V = V_0 + at$$
 (23)

$$=\frac{m_{\rm p}}{m_{\rm p}}$$

$$+ \frac{Y-1}{2\phi} M^2 \qquad P_{AV} \qquad (2)$$

$$\mathbf{V} = \mathbf{V}_{0} + \frac{\mathbf{A} \mathbf{P}_{AV}}{\mathbf{m}_{p}} \left[1 + \frac{(\gamma - 1)}{3} \frac{\mathbf{v}^{2}}{\mathbf{g} \mathbf{Y} \mathbf{F}_{p}} \right]^{-\gamma/\gamma - 1}$$
(26)

10

7 -V/V-1







Figure 4. Shot Pressure to Static Pressure Ratio, T = $.7T_{O}$

Equation (26) thus provides the necessary relationship to solve for the projectile motion once the average chamber pressure is shown. The final information required is an expression for the total rates of combustion.

GAS PRODUCTION

The time rate of gas production is simply written as

$$\frac{dN_B}{dt} = r S_B \rho_p$$

In most prior interior ballistic formulisms the approximation $r = BP^n$ with constant N has been made. Frequently, for closed form solutions, the often questionable assumption that N = 1 is made. For a numeric solution, however, no approximations are required. Burning rates as a function of pressure, for currently used propellants, are tabulated in reference 7. These values are read into the program as data, and a tabular interpolation routine in the program determines the correct burning rate. Thus all recourse to Vielle's law has been avoided.

The surface of burning of single perforate propellants is very nearly constant as shown below. For other forms, such as cord, disk, and multiperforate, various empirical "form" functions exist to evaluate burning surface as a function of unburned web. These functions are covered in detail in references 3, 6, and 8.



 $w_0 = ra_{,0} - r_{1,0}$ for a propellant with $\frac{w_0}{l_0} \ll 1$.

Burning surface for each grain will be

 $S_{I,0} = 2l_0 \pi (r_2 + r_1)$

after a burning increment of Ar

$$S_{I,t} = 2 l_0 \pi \left(\begin{bmatrix} r & -\Delta r \end{bmatrix} + \begin{bmatrix} r & +\Delta r \end{bmatrix} \right) = 2 l_0 \pi \left(\begin{array}{c} r & +r \\ p & 1 \end{array} \right)$$

thus at all times the burning surface is constant.

Volume of grain = $l_0 \pi (r_2^2 - r_1^2)$

N¹ = Number of grains/unit mass

Then the burning surface/unit mass of the propellant will be

$$\frac{S_{B}}{C_{W}} = \frac{S_{I} N^{*}}{\rho_{p} V_{0} N^{*}} = \frac{2 l_{0} \pi (r_{2} + r_{1})}{\rho_{p} l_{0} \pi (r_{2} - r_{1}) (r_{2} + r_{1})} = \frac{2}{\rho_{p} w_{0}}$$

or

$$S_{\rm B} = \frac{2}{\rho_{\rm p} \omega_{\rm o}} C_{\rm w}$$
(27)

Thus equations (9), (26), and (27) plus burning rate data provide the relationships necessary to solve for peak pressure, muzzle velocity and complete pressure_time, pressure_travel, and velocity_travel of any type of closed breech weapon.

SECTION III

COMPUTER PROGRAM

INPUT DATA AND USAGE

The input data for the program is in two parts. The first is the burning rate and impetus data for the propellant and may remain unchanged as long as one type of propellant is used. The second type card d lineates the exact parameters for one given case and will change for each case. Propellant data are determined from the tables in references 7 and 9.

PROPELLANT CARDS.

lst CARD

Columns	Data	Decimal Point	Units
1_8	Impetus of Propellant	7	Ft_Lb/Lb
12-16	Specific Heat Ratio of Gases	13	Dimensionless
20_24	Density of Propellant	20	Lb/In. ²
28_31	Covolume of Gases	30	In. ³ /Lb
33-36	Propellant Type	Alpha Meric	,

2nd AND 3rd CARDS

20 reference pressures - 10 per card from 500 to 200,000 psia.

4th AND 5th CARDS

20 burning rates taken from reference 7 at pressures listed above.

6th AND 7th CARDS

20 reference velocities taken from 0 to 12,000 ft/sec.

8th AND 9th CARDS

Density distribution factor appropriate to propellant used and corresponding to velocity listed above. Values can be extracted from Figure 2.

PROBLEM CARDS.

Columns	Data	Decimal Point	Units
1_7	Bore Area	4	In. ²
8-14	Chamber Volume	11	In. ³
15-21	Projectile Weight	19	Lb
22_28	Barrel Length	27	In.
29-35	Propellant Web	31	In.
36_42	Heat Loss	40	Dimensionles
43-49	Charge Weight	44	Lb
50-56	Shot Start Press	56	Lb/In. ²

As many problem cards as desired may be loaded after the data for a given propellant and will be handled sequentially by the program. Data in the above format is illustrated in Table I.

RESULTS

Typical output is illustrated in Figures 5 and 6 and Tables II and III. Output includes time from propellant ignition, chamber pressure, shot base pressure, projectile velocity, chamber pressure slope, and distance traveled for a typical 25mm. The two sample cases are identical except for a decrease in charge weight in the latter. Subsequent to the case run, additional computations of extrapolated muzzle velocity to the specified barrel length, ballistic efficiency, and piezometric efficiency are also made. Following each printed output is the pressure-travel plot generated by the computer, which is also a standard output. It should be noted that the program is currently set up to run single perforate uninhibited propellant. For other forms, a proper form function, as mentioned above, must be inserted in the program. The heat loss factor, β , has a value of between .3 to .4 for a 25mm and will be somewhat larger for smaller bores and less for larger bore weapons.

COMPUTER PROGRAM

The FORTRAN Program listing used is given as Table IV. Run time on the 709⁴ computer is quite short (about .05 second per case). The program number is 958, and it is being maintained by ADTC (ADTVF-2).

TABLE I. PROGRAM INPUT: TYPI

	1 2 3 4 3 6 7 7 5 5 1 -	1 - 1 - 1 - 1 - 1 - 16 - 17 - 16	e 15/20 21 22 23 24 24 26 27 28 26 34 24 54 54 54 5
ls	346180.	1.252	.0603 29.69 M-1
ar(3 00 .	500	700.1000.15
t (6000.	8000.	10000.20000. 300
lan	. 1 3	. 2	. 28
pel	1.72	2.20	2.70 4.6 6
Pro	0.	500.	11 d d d . 11 5 00 . 20
al	5000.	5500.	6000.6500.70
pic	3.	3.	3.05.3.1 3
Ty	4.05	4.3	4.55 4.85 5
a			
Datids	761 5	7.4	397 69 022
Se Jari	761 5	. 74	. 3 9 7 6 9
Ca			

DT: TYPICAL PROPELLANT AND CASE DATA CARDS.

ł

		1		5 66 57 68 62 70 71	1 72 73 74 75 76 77 78 78 80
M-10					김 도무 김 김 김 영 생
1 500 .	20.00.	2500.	3000	4000	5000.
30000.	40000.	50000.	70000.	100000	. 200000.
. 5 2	6 8	. 81	. 96	1.2	1.45
6.7	8.3	9.6	12.2	15.8	25.
2000.	2500.	3.0.0.0	13 5 00.1	4000	. 4500.
7000.	7500.	8000.	8500.	9000	. 12000.
3.18	3.25	3.38	3.50	3.7	0 3.85
5.2	5.55	5 9 5	6.40	7.0	
22	3 20	4000			
22	3 . 18	4000			

TABLE II. COMPUTER PRINTOUT OF 20NM PERFORMANCE 0.015 WEB.

SHOT WI. CHANGE WEH H.LENGTH CHB VOL HOME AMEA

.4n .200 .0220 64.0 5.74

.70

PHOPFLLANT USED IN DEVICE IS M-10

CITY HS PH	.17 .00.6	.75	.11.	.52 7402.	.39 8445.	.17 10881.	.32 13070.	.28 15544.	.53 18322.	.55 21417.	.87 24855.	1.06 28664.4	1.66 32827.	.2917E 10.	•14 41031 •	- FRACE R0.	· 10/00 03.	- 78 56874.	.37 59+05.	.80 61253.	.00 62405.1	-95 62467-	• 46/20 01 •	-26020 24-		-96646 13.	.89 56038.	.30 54105.	.66 52135	-01105 20·1	- 4 C 9 4 - 6 - 7	.62 44574.	1.70 42865.	.2H 41236.	• +8 34648.	.44 38245.	-14 36540	WILLE AL	-VESEE 04-1	.94 32164.	.03 31159.	.60 30205.	.77 24305.	-A4 24453.
VELO	e	13			9	65	69	109	137	170	208	253	303	361	524				SEA	424	1026	1122	1219	2151	16.1	1590	1676	1760	1440	1918	2063	2132	2198	2362	2323	2962		2547	2548	2647	2696	2742	2787	IEHS.
PHES SLOP	37466827.5	A. ALEESTAA	53923001.5	63735640.1	75458912.4	87596429.3	99010671.9	111229256.8	124020755.7	0.7628697e1	152968938.1	167549065.0	1762965+0.3	179851794.3	8.1/FCCC//1	2.70045101	8-H22420451	11180355.0	85908750.3	59766233.0	34247727.2	10637852.3	A-20002101-	-21508789.0		-59150429.2	-63874372.3	-66465412.9	-67365417.6	-66986763.1	P-54140169-	-61315026.5	-58659080.5	-55868375.1	-53036011.8	A-61282205-		0.8974554-	-30442954.8	+37935121.4	-35874977.8	-34016715.2	-32261274.3	-30606644.1
PHOP HUMPED	.0021	.0000	200°.	.0146	.0202	• n267	• U341	·0427	•0524	•0635	E470.	40AU .	•1072	•1251	• 1 • • 0	• 103C	2010	E+E2.	2452°	.2841	.3107	.3369	2505.	• 359•	1144	5040	+14+.	•515H	1963.	-5632		• 6305	1569.	· 4732	HEA9.	141/0	19570	9477.	B147.	. P104	•828e	.H465	• 264 l	+ - I .
	1000	400 ·	600.	A10.	160.	H+0.	010.	***	AE1.	. IH3	.239	.309	67E .	~ ~ ~	0100		640.1	1.403	1.540	1.005	2°048	0440	11101	145.5	1441	4.461	144.4	5.447	6.007	1/5.4	7.746	R. 345	9*0*6	9.714	10.402	HU1 • 1 1	12.51	14.477	14.044	14.8HS	15.644	14.503	17.337	IH . I VA
	4000 ° 0	4936 al	4014 . H	7402.4	5.920H	1 1 RH2 . 7	A. 570F 1	15547.4	A.HSEAL	21424.1	24A77.6	24701 .H	2.0PACE	5.15010		50431 - 7	54244	57616.1	4.345ch	42443.3	A40.37.4	A4843.4	4 4 1 1 4 4	54214 - 1	6 21 HS.O	61440	Anall.n	ERR]4.6	67153.n	5-24-5 5-75-5	52142.3	50549.A	49076.7	475n0.7	5 - 1 - 1 - 4	1015 m 00	1.475.64	41273.1	41214°4	14214.1	+"0/ CHE	4°E121E	1.65446	2.214.5E
dan 1	0000.	0000	1000.	1000.	1000.	.000	2000-	2000.	2000.	2000.	Euvu*	£000°	EU-0.	5000°	+000	-000	000	.000°	\$0011°	\$0u0*	\$000		4040	8000 ·	1000-	1000.	10001	1000.	HUUC:	HOUD-	H000.	PU00 "	+000 ·	+ c c o •	6000°	0100	0100.	.0010	1100.	1100.	1100-	1100.	5100.	elub.

RALLISTIC EFFICIENCY IS 34.7 PERCENT

CORRECTED PIEZOMETHIC EFFICIENCY IS 37.9 PENCENT

PLEZOMETHIC EFFICIENCY IS 33.4 PENCENT

-1-

MUZZLE VELUCITY IS 1924.3 FEET PEH SECONU PLEZOMETHIC PHESSIME IS 21734.75

16.7.2		L. CENECIE.	10101	68-633	5.21511	.002.
7645.1	3012.05	F-1079457-	1.0109	67.457	11849.5	-0024
7434.00	3001-10	-7617144.3	1.0109	66°245	U-04051	• 0023
1 1 1 1 1 1		-1874957.4	1.0109	65.114	12245.4	.0023
1.1.1.1	3004 × 40		101001	41.451	12440.7	-0023
949:049	3851.44	1.551951-	1.0109	61 c 0 3 3	12461	5005 ·
8040.5	3838+38		A010-1	00.419	- 0+1E1	- COD
8420 * 0	3825.06	-9392672.2	1.0169	54.330	F. INEEL	2200.
9000	3611.47	-9746462.7	1.0109	58.184	0*52961	2200.
9201.3	3797.58	-10120009.8	1.0109	57+0+3	138/M.II	1200.
9.603.	3783.40	-10514767.4	1.0109	55.906	14140.4	1200.
0.0140	2748.00	-10023321.6	1.0109	511.42	14414.2	.0021
4.1540	14.00.10	C. 31734011-	10101	51.645	14448.5	-0021
0.00201	AF+F2/5	0.13442631-	AU10+1	104-10		10201
10556.3	3707-50	-12867707.7	1.0109	50.247	N. 42421	0200.0
10621.9	3691.23	-13428774:7	1.0109	49.177	5°04651	.020
11098.2	3674.54	-140258:4.4	1.0109	48.072	1.116.11	6100°
11367.9	3657.43	-14662039.4	1.0109	46.972	14617.7	0100°
12011.9	3621.85	-16065304.5	1.0109	44° / 81	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	7100
[5348.3	3603-34	-16640196.1	1-0109	502 - 54	17843.4	HIU0.
12702.7	3564.30	-17669837.6	1.0109	42.676	14325.6	Flun.
1 1076.3	3544.72	-1655256.0	1.0109	41.554	12740.5	. U 11 M
13487.7	3523-79	-20240575.0	1-0104		10277.4	. 100.
14324.7	3502.36	-21644997.4	1.0109	38.373	1.512.0	1100.
14740.4	3480.29	-228356+3.9	1.0109	37.324	2090.3.U	1100.
15292.5	3457.48	-24121315.8	1.0104	34.245	21504.0	1100.
15814.7	3433.90	-25511803.9	1.0109	35.252	4.64145	.0010
109/10-0	02.005.	C-4402C002-	1010-1	30.200	C. 01466	.0016
17617.0	3358.09	-30429391.5	1-0109	261-26	1 4745 4	-1.00 ·
18299.5	3330.93	-32364149.2	1.0104	31.141	251 n5. •	· 015
19030.6	3302.72	-34474815.8	1.0109	30.146	24457.3	\$100.
6-51W01	85 . L L L L	-16781676-	1.0109	29.210	PARMA	\$100.
21567.3	3210-98	-42079247.1	1-0109	24-2-15 24-254	5 . 125HC	-100 ·
22546.0	3177.73	-45125915.0	1.0109	26.306	Baney.A	+100.
23077.3	3142.97	-205074+0.1	1.0104	25.35	10542.1	+100·
24610.2	3070.96	-22574981.6	4616°		100.00 0.00115	+100 ·
7.65945	2033.62	-23711010.3	.9640	22.578	5.7256	1 1 VU .
25482.1	*E-5667	-24921854.7	0846.	21.674	S. OHAGE	Eluu.
C. 19902	21.0142	1.51203612.	2120	147.08	5 - 5 - 5 - E	1001
276411.8	2870.26	-29049746.5	596H .	14.042	4.1494E	2100.
28453.4	2831.64	-30606644.1	4[H4.	14.I7A	35714.A	5100°
29305.0	2707.77	-32261274.3	. 2641	17.311	3+523.1	\$100.
8. 2070E	2742.40	-34016718.2		14.503	1173.6	1100-
11150.4	2000.00	-1507407.8	4020	15.544	A. 01046	1100-
STATES -	20.00	A. 10105075-		TA. 494	1 20214	1100-

.



Figure 5. Graph of 20mm Performance 0.015 Web.

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TABLE III. COMPUTER PRINTOUT OF 20MM PERFORMANCE 0.020 WEB.

SHOT WE'. CHANGE WEH H.LENGTH CHB VOL HUNE AMEA

.4" .1M0 .0220 69.0 5.74

•76

PROPELLANT USED IN DEVICE IS M-10

A

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C THE O	+000.0	4741.0	5.44.5		1014.3	10440.6	12152.1	134/2.3	15454.4	14100.0	20402.4	22856.4	29464.6	24218.1	2.01010	5.94/4	344444	1,1937.1	4+1+0.6	40012+5	6.65414	*****	1	C**104*	2-1-04-	P.64194	4.16444	8.44674	+++249+	45+06-U	[]]]]]]]]]]]]]]]]]]]	5.25/14	4.61C04	34266.3	34043.1	36411.4	0.87765	7 - 16 VE E	12618.3	31045.1	10/100	24823.1	294/1.4	2.46145	4.64615	200000	1.46425	35188.8
	6.17	13.48	22 10	36.42	C1 • • • •	74.22	92.95	114.44	139.04	167.00	198.45	69.665	272.95	316.45	16.414	47 1. 40	534.21	548 · H6	666.41	59.161	811.11	HEGel J	10-206	11+4501	1100.0111	1268.29	1342.95	1+16.25	1+87.98	1557-98	C1.0201	1750.81	1414.27	1879.83	+4.8661	1495.45	0000	5155 C	2206.21	4255.00	2302.35	<348.32	2342.44	6+30+40	2478.62	¢514.64	2554.64	2504.43
	29640546.3	3+13930++6	39557022.5	- 344447 15	1.1214705	5.12589699	72872565.5	7441150A.7	#5470003.4	92360045.4	94556620.7	050940U1 .4	110832996.5	1.2404845./	1 4 7 1 7 5 4 2 . 1	1012889	L 03277387.3	42745849.4	H0477086.9	001110100	52837240.0	38621883.1		C.U3441411	1.1040740-	-185248+7.0	-25643059.4	-31284109.7	-35579106.H	- 34084249.		-+2509456.2	-+2478/00.H	+-14-13447.4	-4121HHU3.H	-40180924.H	- 1001000	- 16602359.1	-35328732.4	-34019064.H	-326973/0.3	-313H2032.2	-30086H/n.J	-29822040.1	-2754+185.H	-24+10050.4	-25269544.5	- 24176247.2
	• 0027	+20U+	2600.	9110	5+2U.	40EU.	• 0376	+0455	5+CU+	9E9U .	-0745	.0463	4560.	9611.	1461	.1634	1541.	·2022	+222+	6645.	- 2940	TOKA.		1050.	0526.	5792.	.4142	. 4411 .	. 4427	- 4H4		6445.	. 5660	- 5465 -		• • • • • •	NC44	01444	0664.	. 7166	. 7334 ·	. 7509	. 7476 .	. (hell .	- 200r -	- 4141	• P318	2 A 4 7
	luo.	•00•	- 0114	07.01		+ U h h	0H0 .	.120	a 1 % H	* 5 E + 4	6-2.	+26.	000*		107	141.	655°	1.142	1.352	1.543	1.745	2.02 C	1.63.6	0.250	3.247	3	0.047	4+47]	104 · +	407 · 0	0 C F = 4	A.HS7	FUL.	7+44	H.521	111°5		017.01	11.014	12.303	12.447	1 3.646	14. 444	15.150	15.257	14.017	P45 . 1	
	000	4741 . n	5.4755 6.623.4	1.0277	1.4107	10401	12154.1	4.214F1	14941 .	19110.4	20419.4	PPRH3.4	4.01245	2.145.45	34047.4	44941	34714°5	42246.5	44010.4	******	1°20544	1.67474	4.01012	51510.1	SISIR.	51211.7	SPHIN. 4	S.)] h7 . 4	2°52774			44440 ° 0	1.746.04	1 . 75554	2.420C4	2.42C14	1.276.1	34330.4	47415.4	14532.1	74AH1 .7	1+404+1	1 * 71 1 42	44427.44	10 - 1 L - CE	1.1.1.1	2-225-5	
	.0000		1000	1000	1000	enno.	-000°	.0002	- 0005 ·	• 0003	.0003	6 UUU *	5000°	-000	0004	\$000°	\$000°	4000°	-000 ·	5000.	4000	4000 ·	0000	1000	1000	.0007	1000.	+000·	HU20.		+U-U-U-	P000.	*UUU*	+000 ·	0100.	0100*	0100	1100	.0011	.0011	.0011	<100.	<100°	~1v0.	diu.	1100.	E LUO*	

(The

33.4 PERCENT BALLISTIC EFFICIENCY IS

17.0 PEHCHNT

PLEZNMETHIC FEFICIENCY 15

TATO.3 FEET PER SECONU

MUZZLE VFLORITY 15

PLEZOMETHIC PRESSIME IS 19071.34

+1.7 PERCENT

COMRECTFU PIEZOWETHIC FFFICIENCY IS

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21

20434.2 8034.8 H+62.1 7526.4 7391.5 7256.7 7130.7 7005.8 7005.8 0.00565 2.2211 5+01.0 0.0+6.01 9. HL 06 9214.0 8128.2 7970.0 7817.5 2420-Y 0.40855 21009.8 9524.9 4120.4 9.84EB 5430.2 0+606+1 C. COCE 1 4.9400 L. 9+22.2 9015.3 8.6288 8242.3 1070.4 2+625-1 24013.3 20343.2 4-5+25 2441.144 PUBBE + · F090 2.686 5439.1 7087. 1++32.1 2030.00 2073.62 2709.73 2744.98 2774.98 2813.99 2813.99 2878.349 2940.18 2940.18 2970.28 29999.76 3028.13 3028.13 3028.14 3107.22 3131.77 3131.77 3131.77 3131.77 3131.77 3131.52 3131.52 326.55 11.52 52.65 52.5 3407.11 3424.06 3424.06 3424.06 3424.06 144.69 140.69140.69 140.69 140.69 140.69 140.69140.69 140.69 140.69 140.69140.69 140.69 140.69140.69 140.69 140.69140.69 140.69 140.69140.69 140.69 140.69140.69 140.69 140.69140.69 140.69 140.69140.69 140.69140.69 140.69140.69 140.69140.69 140.691400 2559.AH 62 2548.03 -15018383.5 -149278/4.1 -149278.6 -12554116.2 -12049660.5 -11570002.6 -32581343.4 -30691354.3 -675+486-1 -6352504.3 -6160050.2 -5975946.2 -13070505.H -1309/603.5 -27594745.H -2520954H.5 -1982+036.6 -1907H1+1.0 -18363653.4 -17026125.4 -24459286.1 -23176143.6 -2198+104.9 -20875373.2 -1984212H.6 -11117094.5 -106890/5.2 -1028+21+.1 -300864 / 0 . 3 -24410050.6 -24175207.3 -23124531.4 -21+11+11.H -2060175H.3 -16401314.0 -24946863.2 -188748+7.6 -17980956.0 -171+0829.4 -1035+7.35.5 -15804460.4 -27334430. £100.1 F100. 100.11 100.11 E100. 1441. 9405 . 1476. 5146. - 9449 1.0013 LI00.1 .0013 LI00. fluu. 1594. .001J 24.157 50.751 50.407 67.405 59.004 13.545 14.405 14.1/1 15.1/1 E 4 1 + 1 1.349 24.071 34.144 +1-5/7 57.070 54.137 14.124 72.174 A. 647 465-04 54-54 000 .000 91.419 32.454 36.554 AL-16 414+H1 14.546 415-04 1.541 022.44 2090C 525.44 17.044 511.64 1+4-24 59.492 142.42 24.694 50.2H3 542.14 A3+5 30 214.40 21.350 H01 . EE HL ATE 56.007 52.44A 111.44 24.124 *131.e 1.256.4 1.256.1 1.51.11 1.51.14 1.61.44 1.6 5 . 4 1 4 / 1 5 . 4 1 4 / 1 11145.4 10740.4 10471.4 1+114.1 1 " NT EE I 1.999.1 2-140 v 1.2435.1 2446.6 1931.2 1332.4 4-2022 CH15.5 LALIE 1. 30 m2 . h 2366 .H 1724.1 1525.2 1-11-11 4-2++62 PHRHA .? 17444.1 145E.5 4415. 1.4114 1.5145.1 1.5+10 ALM. 2100 .0022 5200. 2200. 1100 HIU0. 0000 E200. 5100 Hluu. ALUD. vin. PIND. 0200 0200 0200. 1200. EZUU. 1200. +200 · +200. 2500. 4200. Club. FLAD elon. VI00. 1200. ESAU. 00.45 0125 1200 42U0 +2v() . 4100. 1200



Figure 6. Graph of 20mm Performance 0.020 Web.

TABLE IV. INTERIOR BALLISTIC PROGRAM FORTRAN 4 LISTING.

<pre>runuare protectiveUriouri.riteEsinPUT.riteEsenUrT.riteEsenUrT.riteEsenUrT.ritePsenter runuare protections = 0000 0000 0000 0000 0000 0000000000</pre>	NUCHA	PDOLX	FUNTHAN EATENDED V 1.	0	28/03/69	-	5+19+47+	
<pre>AIMS FILE FILE FILE J 11025a3V1 H95a-2 045661 00109 9 9095 FILETIE THE FILE FILE FILE FILE FILE FILE FILE FIL</pre>		H-10,814	A PUSPICIANUT. OUTPUT.	APESEINPUT, TAPE6	=UUTPUT .FILMPL	•	P095800	0
<pre>A TAUE us bLO FEACTUR us bLO FEACTUR LAUNA FEACTUR STORD FMULS (1000) + WUN, PTOP + WPTS (1000000 + PAST20) + WELS (1000) + WUN, PTOP + WPTS (1000000 + PAST20) + WELS (1000) + WUN, PTOP + WPTS (1000000 + PAST20) + WELS (1000) + WUN, PTOP + WPTS (1000000 + PAST20) + WELS (10000 + WUN, PTOP + WPTS (1000000 + PAST20) + WELS (10000 + WUN, PTOP + WPTS (1000000 + PAST20) + WELS (10000 + WUN, WTOP + WPTS) (100000 + WTS) + WTS (10000 + PAST20) + WTS (10000 + WTS) + WTS (10000 + WTS) + WTS (10000 + WTS) + WTS (100000 + WTS) + WTS (10000 + WTS) + WTS (10000 + WTS)</pre>		* 10H	F44 SAULFR. J 111	02543V1 H958-2 0	95AG1 00109	•	Poyse	0
<pre>A tracture Function Funct</pre>		NH 1/U +5	PL01				Payse	0
<pre>05 \$1500 ***********************************</pre>		4FAERUIF	HOUH]				P0958	9
<pre>1 HIFT C Game Toward Converts Toward Propriet Converts Toward Towar</pre>	15	HUCE1 .	AAN				POYSH	0
<pre>In clowent/ / PCPWS110001.PPUIS(10001.WUW.PTOP.NPTS clowent(PAS1.0001.PPUIS(10001.WUW.PTOP.NPTS clowent(PAS1.00.404E(20) TYPE(R)</pre>		ALHETC 94H					P0956	0
<pre>10</pre>		U~~~())	SINHA. (0001) SHADA/ /**	. 4014. NUN. PTOP.	NPTS		POVSH	0
<pre>10</pre>		1 4 M 2 1 1	STUR PSY (20) . VEE (20)				POYSU	-
<pre>10</pre>		4 4 m 1 ()	SION PHS (20) . HATE (20) . 1	YPE (H)			POYSU	-
3 1 0	c I	HF ALLE	5.3) FIMP . GAMA . HHU. CVL . (TVPE (N) +N=1 ++)			POUSU	-
<pre>vraitions.static v</pre>		2 P ()MM	T (FM.] .FR. 3. FR. 4. FH. 2.4	A2)			POUSH	-
<pre>1% * FORMATION * FORMATION * * * * * * * * * * * * * * * * * * *</pre>		TIV 4M	5.4) FTS				P0450	-
<pre>15 % UPAUTSSTANTE * UPAUTSSTANTE * COMMATTIONEW31 * FOUNDATTIONEW31 * FOUNDATTIONEW32 * FOUNDATTIO</pre>		A FOUND	T(10FH.1)				PO456	-
1 5 0.04441(10000.31) 2 0.04441(10000.31) 2 0.0441(10000.31) 2 0.0441(10000.31) 2 0.0441(10000.31) 2 0.0441(10000.31) 2 0.0441(10000.31) 2 0.0441(10000.31) 2 0.0441(10000.31) 3 0.0441(10000.31) 4 0.0441(10000.31) 4 0.0441(100000.31) 4 0.0441(100000.31) 4 0.0441(1000000.31) 4 0.0441(100000000000000000000000000000000		NIN 4W	3.51 HATE				POUSA	-
<pre>2. * found(10F4.1) 2. * found(10F4.1) 2. * found(10F4.1) 2. * found(10F4.1) 2. * found(10F4.1) 2. * found(10F4.1) 3. * found(10F1.3+F).3+F7.3+F7.3+F7.3+F7.3+F7.3+F7.3+F7.3+F7</pre>	5	S FUUMA	[[]0+H.3]				POUSH	-
24 FOUMATIINF41 20 FEANIS-201441 21 FEANIS-201441 21 FEANIS-201441 21 FEANIS-20145 22 FEANIS-20145 23 FEANIS-2014 24 FEANIS-2014 25 FEANIS 26 FEANIS 27 FEANIS 27 FEANIS 26 FEANIS 27 FEANIS 26 FEANIS 27 FEANIS 26 FEANIS 27 FEANIS 27 FEANIS 28 FEANIS 29 FEANIS 29 FEANIS 29 FEANIS 20 FEANIS		MF 411 (5+24) VEF				POUSA	-
 Prime Franciscon Period Prime Franciscon Prime Franciscon Prime Franciscon		24 FOUMA	I(10FH.1)				POYSH	-
 Z. Z. FULMATIIOFM.3) PTTELS: TATETAMA (GAMA-1.) PTTELS: TATETAMA (GAMA-1.) FULMATIFT.3.FT.3.FT.3.FT.3.FT.3.FT.3.FFM.1) PTTELS: TATETAMA (GAMA-1.) FULMATIFT.3.FT.3.FT.3.FT.3.FT.3.FFM.1) PTTELS: TATETAMA (GAMA-1.) PTTELS: TATES PTTELS: TATES PTTELS: TATES P		HEAD	5-28-751				P0458	-
 PTTETLAN PTT		ANUIT PAG	1(10FM.3)				P0956	-
A WEALLENDARGAMALLO P0055 A WEALLENDARGENER P0055 7 FOLWART(F7.3.0.7).0.677.3.677.3.677.3.670.5 P0055 7 FOLWART(F7.3.0.7).0.677.3.677.3.677.3.670.5 P0055 7 FOLWART(F7.3.0.7).0.677.3.677.3.677.3.670.5 P0055 7 FOLWART(F7.3.0.7).0.677.3.677.3.677.3.670.5 P0055 7 FOLWART(F1.0.0 P0055 7 FOLWART(F1.0.0 P0055 8 FOLWART(F1.0.0 P0055 9 P0055 P0055 9 P0055 P0055 9 P0055 P0055 9 P0045 P0055 9 P0055 P0055 9 P0045 P0055 9 P0045 P0055 9 P0055							POYSE	-
<pre>75 W Fault5.7) AMEA.CVOL.SMOTAUN.WEH.WETA.CM6.SCPHS 7 FOUWAT(F7.3.P7.3.F7.3.F7.3.F7.3.FA.1) 7 FOUWAT(F7.3.P7.3.F7.3.F7.3.F7.3.FA.1) 7 FOUWAT(F7.3.P7.3.F7.3.F7.3.F7.3.FA.1) 7 POYSU 4015 AMEA/1 7 POWSU 7</pre>		TADEG	AMA/ ((3AMA-] .)				PSAOA	-
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<pre>25 WPTSEU HPE0. HPE0. VfLe0. WANFE(A.M) A FOWMAT(IMI.AIM SHOT WT. CMARGE WEB M.LENGTM CMB VOL P0958 HHOWF AMEA//) WPTTF(A.915HU1.CMG.WEB.HUN.CVOL.AMEA HHOWF AMEA//) WPTTF(A.915HU1.CMG.WEB.HUN.CVOL.AMEA 9 FOWMAT(F10.2.6F10.3.6F10.3.6F10.2.6F10.2.7//) 18 FOWMAT(F10.2.6F10.3.6F10.4.6F10.1.6F10.2.6F10.2///) 18 FOWMAT(F10.2.6F10.3.6F10.4.6F10.1.6F10.2.6F10.2///) 18 FOWMAT(F10.2.6F10.3.6F10.4.6F10.1.6F10.2.6F10.2///) 18 FOWMAT(F10.2.6F10.3.6F10.4.6F10.1.6F10.2.6F10.2///) 18 FOWMAT(F10.2.6F10.3.6F10.4.6F10.1.6F10.2.6F10.2.7//) 18 FOWMAT(F10.2.6F10.3.6F10.4.6F10.1.6F10.2.6F10.2.7//) 19 POWSE 10 PUES SLOPE VELOCITY BS PHES//) 10 PUES SLOPE VELOCITY BS PHES//) 10 PUES SLOPE VELOCITY BS PHES//) 10 POWSE 10 PUES SLOPE VELOCITY BS PHES//) 10 POWSE 10 PUES SLOPE VELOCITY BS PHES//) 10 POWSE 10 POWSE 10 PUES SLOPE VELOCITY BS PHES//) 10 PUES SLOPE VELOCITY BS PHES//) 10 POWSE 10 PUES SLOPE VELOCITY BS PHES//) 10 POWSE 10 PUES SLOPE VELOCITY BS PHES//) 11 PUENDER 11 PUENDER 12 PUENDER 13 PUENDER 14 PUENDER 15 PUENDER 15 PUENDER 16 PUENDER 17 PUENDER 17 PUENDER 17 PUENDER 17 PUENDER 18 PUENDER 19 PUENDER 19 PUENDER 10 PUENDER 1</pre>		A FUNAA	1 (F / . 3 . + / . 3 . F / . 3 . F / . 4 . F	7.4.F7.2.F7.3.FR	• []		PO958	-
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9 FORWATTE (6.35) (TYPE (N), NE] + FIO.2. FIO.2. FIO.2. //) WHITE (6.35) (TYPE (N), NE] +) 35 FORMAT (32M PHOPELLANT USED IN ULVICE IS + A.2. //) POSSE (POSSE		31 JAH	(++4) SHU1+CHG+#E8+HUN+C	VOL . AHEA			POVSH	-
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THE CHAME PRES TRAVEL PRO POSSE OF POSS		AMAO 4 SF	1 (32H PHOPELLANT USED	IN ULVICE IS .4	A2.///)		P9958	-
77 FORMAT (101H TIME CHANNE PRES TRAVEL PRO POSSE (1 P RUNNEU PHES SLOPE VELOCITY BS PHES//) TRAVEL PRO POSSE (HP=0.0	36	AT THE	(4.27)				P9954	-
IP RUNNEU PHES SLOPE VELOCITY BS PHES//) POSS (27 F 044A	T(101H TIME	CHANG PRES	TRAVEL	PRO	P0958	-
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30		P0958	00070
	52 PFAGEPSY (KO)	P0958	12000
	60 10 59	P0958	22600
	53 HAG=(VEL2-VEE(KU-1))/(VEE(KO)-VEE(KO-1))	P0458	£2000
	FFAC#((PSY (KO) - PSY (KO-1)) #AAG) + PSY (KO-1)	P0458	42000
	59 FFW=(SHOT+(CHG/PFAC))/32.17	PO458	00075
75	ACFLEPHEX*AKEA*32*17/SHUT	P0958	00076
	VEL.2=VFL1+(ACEL.++000025)	P0958	12000
	ACAL=(ACEL*000025)/2.	P0958	00078
	HINC=(VEL1*.000025)+(ACUL*.000025)	POASA	00079
		P0958	09000
64	13 AVIL=CVUL+(BUIS*AMEA)	P0958	18000
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	UHWE (CHG-HP) / HHO	P0958	28000
	CONLECKLehp	P0958	+8000
	DPDT=((UNDT#FIMP*12.)=((GAMB#EFM#ACEL#VEL2#12.)+(AREA#PREX#VEL1#1	2 P0958	00085
1	1.)) / (AVOL = (UBW+COVL))	P0458	00086
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And Anterverbanding and	AGE AND AGE AN		VM=VELI+AI)V	BCY04	20100
<pre>arritronserversessame second sec</pre>	<pre></pre>		ADE (VM&VM/HUN) &SHDI #12./ (AREA*64.4)	P0458	EOTOO
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<pre>4. FUTF(formally)Mentaly Mentaly Mentaly</pre>	<pre>1 #ITF(GALIVEL WELGELIV 15.FK.1.10M FEET PEN SECOND/)</pre>	40	FORMAT(//25H PIFLOMEIRIC PRESSURE IS "F9"2"//)	P0958	00105
<pre>a from AICLIP WENCLIP VELUCITY IS.FA.110H FEET PER SECOND/) Admano/PIOS Admano/PIOS FEALENDO. FEALEND</pre>	<pre> 1</pre>		WHITF (6041)VM	P0958	00100
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<pre>#FIFE FORMER FOR FORMER FORMER FOR FORMER FORMER FOR FORMER FOR FORMER FOR FORMER FOR FORMER FOR FORMER FOR FORMER F</pre>	************************************		AH=AD/PIUP	POY5H	00108
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<pre>AP COMMUNICASEN FIELCHENCY IS.FT.A.BM PERCENT) APPLICATION DECOMPOSITION DECOMPOSITION DECOMPOSITION FFETUREWENDS.TIT/SETTINE PERCENT PERCENT FFETUREWENDS.TIT/SETTINE FFETUREWENDS FFET</pre>	<pre>*** Commit/CSenser/Ficker Is.Fri.BM PERCENT) 00000 000000000000000000000000000000</pre>		wk 7 7 F (5. * * 2) A F	P0458	00110
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<pre>FFFEr(Fig): FFFE(Fig): FFFE(</pre>	<pre>FKETCHONEYNESHUIT/IE-32.17) FKETCHONEYNESHUIT/IE-32.17) FKETCHONEYNESHUIT/IE-32.17) FKETCHONEYNESHUIT/IE-10 FFETCHONEYNESHUIT/IE-10 FFETCHONEYNES</pre>		AH= (AF + FF M+32 - 1 7) / SHOT	POSSA	00112
<pre>FECTORSFIP/(GAMA-L) FECTORSFIP/(GAMA-L) F</pre>	<pre>FECTORFIND(INALIS) FECTORFIND(0</pre>		FKF=(VM*VM*SHUT)/(2.*32.17)		
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G0 TO A F00 TO A F00 TO A A14FTC PAU.01 UNANOTINE #PLOT F00 TO A SUBRIDITINE #PLOT F00 TO A F00 TO A TEPPUDISCID F10 TO A F00 TO A F00 TO A TEPTOP TELL UNIVU(2.*******0*****************************	<pre>cn Tn + tn tn</pre>		CALL HPLOT	P0958	00120
<pre>*INF F MI *INF F MPLOT SUBRICTINE MPLOT SUBRICTINE MPLOT SUBRICTINE MPLOT SUBRICTINE MPLOT SUBRICTINE MPLOT SUBRICTINE MPLOT COMMON/ PPCPUS(1000).PBUIS(1000).MUN.PTOP.MPTS P095B 00125 ME=PPUS(1) M=PCPWS(1</pre>	\$14F T Hui P0055 00123 \$14F T SUBRIOTINE MELOT COMMON' / PCPMS(1000).PBUJS(1000).MUN.PTOP.NPTS 00055 00125 \$14F PUDJS(1) COMMON' / PCPMS(1000).PBUJS(1000).MUN.PTOP.NPTS 00055 00125 \$15 COMMON' / PCPMS(10) P0055 00125 \$15 COMMON' / PCPMS(1) P0055 00125 \$15 COLL D011V(1.XL.XR.VB.VP.NO.D) P0055 00125 \$15 COLL D011V(1.XL.XR.VB.VP.NO.D) P0055 00125 \$15 COLL D011V(1.XL.XR.VB.VD.NO.D) P0055 00135 \$15 COLL P0011V(1.XL.XR.VB.VD.NO.D) P0055 00135 \$15 COLL P0011V(1.XL.XR.VD.NO.D) P0055 P0055 P0055		60 T0 +	N S S S S S S S S S S S S S S S S S S S	10101
<pre>*latic wilding * * * * * * * * * * * * * * * * * * *</pre>	\$14FTC HELOI \$000000000000000000000000000000000000		F MI		00100
SUBRIUTINE WELDT COMMONY /PECRS(1000),PBUIS(1000),MUN,PTOP,MPTS COMMONY /PECRS(1000),PBUIS(1000),MUN,PTOP,MPTS CLEPHUJS(1) XE=PHUJS(1) XE=PHUJS(1) XE=PHUJS(1) XE=PHUJS(1) XE=PHUJS(1) XE=PHUJS(1) XE=PHUJS(1) XE=PHUJS(1) XE=PHUJS(1) XE=PHUJS(1) XE=PHUJS(1) XE=PHUJS(1) XE=PHUJS(1) XE=PHUJS(1) XE=PHUJS(1) CALL VXIVY(2,MH,J)NY,20,0.1ERR) I=-1 J=-J J=-J CALL PHINTV(-+++HDIS,500+10) J=-J J=-J CALL PHINTV(-+++HDIS,500+10) CALL PHINTV(-+++HDIS,500+10) CALL PHINTV(-+++HDIS,500+10) CALL PHINTV(-+++HDIS,500+10) CALL APLUTV(HDTS,011),11:11:138,1ERR) TY=NY(PCPRS(1)) 11:11:11:11:11:11:11:11,11;11,11;11;11,11;11;	SUMMOUTINE WELOT SUMMOUTINE WELOT COMMONY / PCCMS(1000).PBUIS(1000).MUN.PTOP.NPTS COMMONY / PCCMS(1000).PBUIS(1000).MUN.PTOP.NPTS COMMONY / PCCMS(1) XL=PHUJS(1) YEPCDAS(1) YEPC	CINET (22100
COMMON, PECHS(1000), PBUIS(1000), WUN, PTOP, NPTS Ten X=PHUIS(1) X=PHUIS(1) X=PFUP X=PFUP X=PTUP X=PTUP CALL UXUYV(1; X4, 0,0, 1, 1, 1, 2, 1, 1, 1, 2, 1, 1, 1, 1, 2, 1, 1, 1, 1, 2, 1, 1, 1, 1, 2, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1,	Commond Procession Pro	•			53100
Control Treation P0958 00125 Treation Treation P0958 00126 Treation Treation P0958 00136 Treation Treation P0958<	C C			PCA04	42100
T = 0 T	TIERHUIS(I) XHERHUIS(I) XHERHUIS(I) XHERHUIS(I) XHERHUIS(I) XHERHUIS(I) XHERHUIS(I) XHERHUIS(I) XHERHUIS(I) XHERHUIS(I) XHERHUIS(I) XHERHUIS(I) XHERHUIS(I) XHERHUIS(I) ZALL UNIVY(I:XL:XR:YB,YT:0X.00.1ERR) J=-J J=-J J=-J J=-J J=-J J=-J J=-J J=-J J=-J J=-J ZALL UNIVY(I:XL:XR:YB,YT:0X.00.1ERR) J=-J J=-J ZALL UNIVY(I:XL:XR:YB,YT:0X.00.1ERR) J=-J J=-J ZALL UNIVY(I:XL:XR:YB,YT:0X.00.1ERR) J=-J ZALL UNIVY(I:XL:XR:YB,YT:0X.00.1ERR) J=-J ZALL UNIVY(I:XL:XR:YB,YT:0X.00.1ERR) J=-J ZALL UNIVY(I:XL:XR:YB,YT:0X.00.1013) J=-J ZALL UNIVY(I:XL:XR:YB,YT:0X.00.1ERR) J=-J ZALL UNIVY(I:XL:XR:YB,YT:0X.00.10013) P0958 00133 P0958 00133 P0058 00133 P00		COMMON / PCPHS(1000), PBUIS(1000), WUN, PTOP, NPTS	P0958	00125
XH=PHUIS(I) P0958 00127 XH=PHUIS(INPTS) P0958 00120 YH=PFUD P10P P0958 00131 YH=PFUD P10P P0958 00131 YH=PFUD P11V(1,xL,xt+,vt+,DY+m,J=nY+20.0.1ERR) P0958 00133 Zall UXDYV(2:YH+YT,0Y+m,J=nY+20.0.1ERR) P0958 00133 J=-J P11V(1,xL,xt+yt+0Y+m,J=nY+20.0.1ERR) P0958 00133 J=-J P11V(1,xL,xt+yt+0Y+m,J=nY+20.0.116R) P0958 00133 J=-J Call GHUJV(1,xL,xt+yt+0Y+0010) P0958 00133 J=-J Call APMNY(01+++HDIS:50.16RR) P0958 00133 J=-J Call APMNY(0-1++++HDIS:50.10.500) P0958 00133 Call APMNY(FORTS:PT(1).PR2(1).11.1.1.38.1ERR) P0958 00133 ITI=NXV(PHDIS:(1)) ITI=NXV(PHDIS:(1) P0958 00133 ITI=NXV(PHDIS:(1)) ITI=1.2 P0958 00133 ITI=NXV(PHDIS:(1)) ITI=1.2 P0958 00133 ITI=NXV(PHDIS:(1)) ITI=1.2 P0958 00140 ITI=1.2 ITI=1.2 P0958 00140 ITI=1.2 <td>XL=FHUIS(I) XL=FHUIS(I) P0958 00123 YT=PTUP YT=PTUP P0958 00131 YT=PTUP YT=PTUP P0958 00131 YT=PTUP CALL VXDYY(1:xL,xX+,0X+,01+,0,0115RR) P0958 00131 ZALL VXDYY(2:YR+,YT,0Y+,00115RR) P0958 00133 ZALL VXDYY(2:YR+,YT,0Y+,00115RR) P0958 00133 ZALL VXDYY(2:YR+,YT,0Y+,00115RR) P0958 00133 ZALL VXDYY(2:YR+,YT,0Y+,0) P0958 00133 ZALL VXDYY(2:YR+,YT,0Y+,0) P0958 00133 ZALL APLOTY(NPTS-PT(1)+PR12(1)+11+1.536,156RR) P0958 00133 ZALL APLOTY(NPTS-PT(1)+PR12(1)+11+1.536,156RR) P0958 00133 ZALL APLOTY(NPTS-PT(1)+PR12(1)+11+1.1-386,156RR) P0958 00133 TY1=XXV(PPTS(1)) P1111-1.536,156RR) P0958 00133 TY1=XXV(PPTS(1)) P1111-1.536,156RR) P0958 00143 TY1=XXV(PPTS(1)) P1111-1.536,156RR) P0958 00143 TY1=XXV(PPTS(1)) P1111-1.536,156RR) P0958 00143 TY1=XXV(PPTS(1)) P111-1.536,156RR) P0958 00143 TY1=XXV(PPT</td> <td></td> <td>011</td> <td>P0958</td> <td>00126</td>	XL=FHUIS(I) XL=FHUIS(I) P0958 00123 YT=PTUP YT=PTUP P0958 00131 YT=PTUP YT=PTUP P0958 00131 YT=PTUP CALL VXDYY(1:xL,xX+,0X+,01+,0,0115RR) P0958 00131 ZALL VXDYY(2:YR+,YT,0Y+,00115RR) P0958 00133 ZALL VXDYY(2:YR+,YT,0Y+,00115RR) P0958 00133 ZALL VXDYY(2:YR+,YT,0Y+,00115RR) P0958 00133 ZALL VXDYY(2:YR+,YT,0Y+,0) P0958 00133 ZALL VXDYY(2:YR+,YT,0Y+,0) P0958 00133 ZALL APLOTY(NPTS-PT(1)+PR12(1)+11+1.536,156RR) P0958 00133 ZALL APLOTY(NPTS-PT(1)+PR12(1)+11+1.536,156RR) P0958 00133 ZALL APLOTY(NPTS-PT(1)+PR12(1)+11+1.1-386,156RR) P0958 00133 TY1=XXV(PPTS(1)) P1111-1.536,156RR) P0958 00133 TY1=XXV(PPTS(1)) P1111-1.536,156RR) P0958 00143 TY1=XXV(PPTS(1)) P1111-1.536,156RR) P0958 00143 TY1=XXV(PPTS(1)) P1111-1.536,156RR) P0958 00143 TY1=XXV(PPTS(1)) P111-1.536,156RR) P0958 00143 TY1=XXV(PPT		011	P0958	00126
XH2-HULDS(NPTS) P0958 00128 YH=PCCPKS(1) YH=PCCPKS(1) P0958 00131 YH=PCCPKS(1) YH=PCCPKS(1) P0958 00132 YH=PCCPKS(1) YH=PCCPKS(1) P0958 00132 YH=PCCPKS(1) YH=PCCPKS(1) P0958 00133 YH=PCCPKS(1) YH=PCCPKS(1) P0958 00143 YH=PCCPKS(1) YH=PCCPKS(1) P0958 00143 YH=PCPKCPKS(1) YH=PCPKS(1) P0958 00143 YH=PCPKCPKS(1) YH=PCPKS(1) P0958 00143 YH=PCPKCPKS(1) YH=PCPKS(1) P0958 00143 YH=PCPKCPKS(1) YH=PCPKS(1)	XP2=HUIS(NPTS) P0958 00123 YH=PCCPKS(1) YT=PUDS(NPTS) P0958 00133 YT=PUDS(NPTS) YT=PUDS(NPTS) P0958 00133 YT=PUDS(NPTS) TALL UXDYV(2-YH+YT+0Y+W-1+NX+Z0.0015ERR) P0958 00133 ZaLL UXDYV(2-YH+YT+0Y+W-1+NX+Z0.0015ERR) P0958 00133 J=-J J=-J P0958 00134 Call APLOTV(MPTS-PT(1)+PR1(1)+1+1+30+158 P0958 00134 TXI=XX(PHDDIS(1)) P011+1+1+304 P0958 00144 P11=P P0111 P011+1+1+1+1+1+1+1+1+1+1+1+1+1+1+1+1+1+1		хL=PHU]S(])	P0958	00127
Y1=PCPMS(1) Y1=PCPMS(1) P0958 00129 Y1=PTUP P0958 00131 Call UXUVY(2.*YH.*YT.0Y*M.J.NY.20.0.1ERR) P0958 00131 T=-1 P0958 P0958 00131 Call UXUVY(2.*YH.*YT.0Y*M.J.NY.20.0.1ERR) P0958 00131 T=-1 P0958 P0958 00133 Call UXUV(2.*YH.*YT.0Y*M.J.NY.20.0.1ERR) P0958 00133 T=-1 P0958 P0958 P0958 Call PRINTV(-4.+HRDIS5500.10) P0958 P0135 Call APMNTV(014.*A*YB.J.NY.NY) P0958 P0135 Call APMNTV(014.*A*YB.J.0.500) P0958 P0135 Call APMNTV(014.*A*YB.J.1.1.1.1.1.1.551ERR) P0958 P0135 Call APMNTV(0.PTS.PT(1).PH1(1).1.1.1.1.551ERR) P0958 P0135 Tal=NXV(PHDIS(1)) P111.1.1.1.1.551FR P0958 P0135 Tal=NVV(PCPRS(1)) P111.1.1.1.1.551FR P0958 P0145 Ty=NVV(PCPRS(1)) P111.1.1.1.1.551FR P0958 P0145 Ty=NVV(PCPRS(1)) P111.1.1.1.1.551FR P0958 P0145 Ty=NVV(PCPRS(1)) P111.1.1.1.1.2.2.1YZ <t< td=""><td>YH=PCFWS(1) YT=PTUP P0958 00129 YT=PTUP P0958 00131 YT=PTUP P0958 00131 YT=PTUP P0958 00131 Call UXUYY(2:YR+YT+0Y+M-J+NY+20.0.1ERR) P0958 00131 J=-J P0958 00131 Call SHIUV(L-XL+XR+YB+YT+0Y+M-J+NX+NY) P0958 00133 J=-J P0958 00131 Call SHIUV(L-XL+XR+YB+YT+0Y+M-J+NX+NY) P0958 00134 J=-J Call APLNTY((1+A++HBDIS-500+10) P0958 00136 Call APLNTY((1+A++HBDIS-550+10) P0958 00137 Call APLNY(POTYS-PT(1)+PH2(1)+1101-55.IERR) P0958 00137 TYI=NXV(PHDIS(1)) P01101-1101-55.IERR) P0958 00143 TYI=NXV(PHDIS(1)) P01101-1101-55.IERR) P0958 00143 TYI=NVV(PCPRS(1)) P01101-1101-55.IERR) P0958 00143 TYI=NVV(PCPRS(1)) P01101-1101-55.IERR) P0958 00143 TYI=NVV(PCPRS(1)) P01101-1101-55.IERR) P0958 00143 TYI=NVV(PCPRS(1)) P0111-1101-55.IERR) P0958 P01458 TYI=</td><td></td><td>XH=PHUIS(NPTS)</td><td>P0958</td><td>00128</td></t<>	YH=PCFWS(1) YT=PTUP P0958 00129 YT=PTUP P0958 00131 YT=PTUP P0958 00131 YT=PTUP P0958 00131 Call UXUYY(2:YR+YT+0Y+M-J+NY+20.0.1ERR) P0958 00131 J=-J P0958 00131 Call SHIUV(L-XL+XR+YB+YT+0Y+M-J+NX+NY) P0958 00133 J=-J P0958 00131 Call SHIUV(L-XL+XR+YB+YT+0Y+M-J+NX+NY) P0958 00134 J=-J Call APLNTY((1+A++HBDIS-500+10) P0958 00136 Call APLNTY((1+A++HBDIS-550+10) P0958 00137 Call APLNY(POTYS-PT(1)+PH2(1)+1101-55.IERR) P0958 00137 TYI=NXV(PHDIS(1)) P01101-1101-55.IERR) P0958 00143 TYI=NXV(PHDIS(1)) P01101-1101-55.IERR) P0958 00143 TYI=NVV(PCPRS(1)) P01101-1101-55.IERR) P0958 00143 TYI=NVV(PCPRS(1)) P01101-1101-55.IERR) P0958 00143 TYI=NVV(PCPRS(1)) P01101-1101-55.IERR) P0958 00143 TYI=NVV(PCPRS(1)) P0111-1101-55.IERR) P0958 P01458 TYI=		XH=PHUIS(NPTS)	P0958	00128
YT=PTUP YT=PTUP P0958 00131 Call UXUYY([:X[+X4+UX+N]•NX,20.0•1ERR)] P0958 00133 I=-1 Call UXUYY([:X[+X4+UX+N]•NX,20.0•1ERR)] P0958 00133 I=-1 Call UXUYY([:X[+X4+UX+N]•NY,20.0•1ERR)] P0958 00133 J=-1 J=-1 P0958 00133 J=-1 J=-1 P0958 00133 J=-1 Call GHUUY(L-XL+XR+YB+YT-0Y+N+) P0958 00134 J=-1 Call APUNTY(0+-++HRDIS-500+10) P0958 00136 Call APUNTY(0+-14+-+++HDIS-500+10) Call APUNTY(0+-14+-+++HDIS-500+10) P0958 00136 Call APUNTY(0+-14+-+++HDIS-500+10) Call APUNTY(POPERS-11)+1+1+1+1+1+1+1+1+1+1+1+1+1+1+1+1+1+1	YT=PTUP VT=PTUP Call UXUYY(1*XL*XH*DX*N)I*NY*20.001ERR) Call UXUYY(2*YH*YTDY*N)I*NY*20.001ERR) T==1 J==-J J==-J Call APHNTY(0*=14*NPD15/500010 Call APHNTY(0*=14*NPD15/50010) Call APHNTY(0*=14*NPD15/5010) Call APHNTY(0*=14*NPD15/5010) Call APHNTY(0*=14*NPD15/5010) Call APHNTY(0*=14*NPD15/5010) Call APHNTY(0*=14*NPD15/5010) TY1=NYY(PHD15/1)) TY1=NYY(PHD15/1)) TY1=NYY(PPD15/1)) TY1=NYY(PPD15/1)) TY1=NYY(PPD15/1)) TY1=NYY(PPD15/1)) TY1=NYY(PPD15/1)) TY1=TZ TY2=NYY(PPD15/1)) TY1=TZ TY2=NYY(PPD15/1) TY1=TZ TY2=NYY(PPD15/1) TY1=TZ TY2=NYY(PPD15/1) TY1=TZ TY2=NYY(PPD15/1) TY1=TZ TY2=NYY(PPD15/1) TY1=TZ TY2=TX1/11/11/11/11/11/11/11/11/11/11/11/11/1		YH=PCPHS(1)	DAGEN	00100
Call UXUYY(1,xL,xW,UX,NI,NX,20,0)ERR) Call UXUYY(1,xL,xW,UX,NI,0X,00,1ERR) I=-1 J=-J J=-J Call GHUUY(L,xL,xR,YB,YT,0X,0Y,NNM,I*J,0NX,NY) Call APUNIY(0,-14,-4,4HR)IS,500,10) Call APUNIY(0,-14,-4,4HR)IS,000,10) Call APUNIY(0,-14,-14,-11,0,000,10) Call APUNIY(0,-14,-14,-11,0,000,10) Call APUNIY(0,-14,-14,-11,0,000,10) Call APUNIY(0,-14,-14,-11,0,000,10) Call APUNIY(0,-14,-14,-14,000,10) Call APUNIY(0,-14,-14,000,10) Call APUNIY(0,-14,-14,000,100,10) Call APUNIY(0,-14,-14,000,10) Call APUNIY(0,-14,-14,000,10) Call APUNIY(0,-14,-14,000,100,10) Call APUNIY(0,-14,000,100,100,100,100,10) Call APUNIY(0,-14,000,100,100,100,100,100,100,100,100,1	Call UXUYV(1,×L,·KP.UX.NI)•NX.20.01ERR) T=-1 Call UXUYV(2.*YH.*YT.UY;M.J.NY.20.001ERR) T=-1 J=-3 Call UXUYV(2.*YH.*YT.UY;M.J.NY.20.001ERR) J=-4 Call CHUUV(L-XL.*R+YB,VT.0X,UY,N.M.1J.NX.NY) Call CHUUV(NPTS:PT(1).PH1(1).11.1.55.IERR) Call APLOTV(NPTS:PT(1).PH1(1).11.1.1.38.IERR) Call APLOTV(NPTS:PT(1).PH1(1).1.1.1.38.IERR) TY1=XXV(PHDIS(1)) TY1=XXV(PHDIS(1)) TY1=XXV(PHDIS(1)) TY1=XXV(PHDIS(1)) TY1=XXV(PHDIS(1)) TY1=XXV(PHDIS(1)) TY1=XX CALL LINEV(IX1.1Y1.1X2.IY2) TY1=XY CALL LUNEV(IX1.1Y1.1X2.IY2) TY1=XY TY			00401	42100
Call UXUVY(1.XL.XX.000.1ERR) T=-1 J=-J J=-J J=-J Call GR[U]V(L.XL.XR.YB.YT.0X.UY.N.M.I.J.NX.NY) Call APMNTV(2.744.YT.0Y.UY.N.M.I.J.)NX.NY) Call APMNTV(-4.4HPDI5.550010) Call APMNTV(-1.4.4HPDI5.550010) Call APLOTV(NPT5.PT(1).9H1(1).1.1.1.55.1ERR) Call APLOTV(NPT5.PT(1).9H2(1).1.1.1.1.55.1ERR) Call APLOTV(NPT5.PT(1).9H2(1).1.1.1.1.55.1ERR) Call APLOTV(NPT5.PT(1).9H2(1).1.1.1.1.55.1ERR) Call APLOTV(NPT5.PT(1).9H2(1).1.1.1.1.55.1ERR) Call APLOTV(NPT5.PT(1).9H2(1).1.1.1.1.55.1ERR) Call APLOTV(NPT5.PT(1).9H2(1).1.1.1.1.55.1ERR) Call APLOTV(NPT5.PT(1).9H2(1).1.1.1.1.1.55.1ERR) Call APLOTV(NPT5.PT(1).9H2(1).1.1.1.1.1.55.1ERR) Call APLOTV(NPT5.PT(1).9H2(1).1.1.1.1.2.1.2.1.2.1.2.1.2.1.2.1.2.1.2	Call UXUVY(1:AL:AV:UDANNIINX:20:001ERR) Call UXUVY(2:YR:YT:UY:MUJONY:20:001ERR) J=-J J=-J Call GRIUJY(L:XL:XR:YB:YT:DX:MU]:J.NX:MY) Call APHNTY(0:=14.=4.4HRD[5:500] Call APHNTY(0:=14.=4.4HRD[5:500] Call APLUTY(MPT5:PT(1):PR2(1):11:11:55.IERR) Call APLUTY(MPT5:PT(1):PR2(1):11:11:55.IERR) TXI=KXY(PHD[5(1)) TYI=KXY(PHD[5(1)) TYI=KXY(PHD[5(1)) TYI=KXY(PHD[5(1)) TYI=KXY(PHD[5(1)) TYI=KXY(PHD[5(1)) TYI=KXY(PHD[5(1)) TYI=KXY(PHD[5(1)) TYI=KXY(PHD[5(1)) TYI=KXY(PHD[5(1)) TYI=KXY(PHD[5(1)) TYI=TZ			8560d	00130
Call UXUYY(Z*YH*YT.0Y*M.J*NY.Z0.0.1E4R) P0958 00133 I=-1 P0958 00133 J=-J P0958 00133 Call GHIUY(L.XL*XR*YB*YT.0Y*N*M.I.J.NX*NY) P0958 00137 Call APMNTY(0-=144.4HRDIS.50010) P0958 00137 Call APLOTY(NPTS.PT(1).PH2(1).11.11.1555.IEAR) P0958 00130 IXI=AVX(PHDIS(1)) TVINTS.PT(1).PH2(1).11.11.1538.IEAR) P0958 00140 IXI=AVX(PHDIS(1)) P02(1)) P12(1).11.11.1538.IEAR) P0958 00140 IXI=AVX(PHDIS(1)) P12(1).PH2(1).11.11.1538.IEAR) P0958 00140 IXI=AVX(PHDIS(1)) P12(1).PH2(1).11.11.1538.IEAR) P0958 00140 IXI=AVX(PHDIS(1)) P12(1).PH2(1).11.11.1538.IEAR) P0958 00140 IXI=AVX(PDIS(1)) P12(1).11.11.12.172 P0958 00140 IXI=IX2 P00958 P0140 IXI=IX2 P00958 P0140 IXI=IX2 P00958 P0140 IXI=IX2 P00958 P0140 P0958 P0140 P0058 P00140 P0058 P00140 P0058 P00140 P0058 P00140 P0058 P00140 P0058 P00140 P0058 P00140 P0058 P00140 P0058	Call UXUYY(Z.YR.YT.0Y.M.J.NY.Z0.0.1ERR) P0956 00133 I=-1 P0956 00133 J=-J J=-J P0956 00134 J=-J Call GHIUY(L.XL.XR.YB.YT.0X.0Y.N.M.I.J.NX.NY) P0956 00135 J=-J Call APUNTY(014.4HRDIS.50010) P0956 00136 Call APUNTY(014.4HRDIS.50010) P0956 00137 Call APUNTY(014.4HRDIS.50010) P0956 00137 Call APUNTY(014.4HRDIS.5010) P0956 00137 Call APUNTY(014.4HRDIS.11).11.1.1.38.1ERR) P0956 00140 TX1=NXV(PPDIS(1)) TX1=NXV(PPDIS(1)) P0956 00140 TX2=NAV(PPDIS(1)) TX2=NAV(PPDIS(1)) P0956 00140 <t< td=""><td></td><td>CALL UXUYV(]+XL+XH+UX+N+I+NX+20+0FERR)</td><td>P0958</td><td>16100</td></t<>		CALL UXUYV(]+XL+XH+UX+N+I+NX+20+0FERR)	P0958	16100
I=-I J=-J P0958 00135 J=-J J=-J P0958 00135 J=-J Gall WINT(-+,XL,XR,YB,YT,DX,UY,NM,I) P0958 00135 Call APMNTV(014,-44HDJIS,500+10) P0958 00136 Call APMNTV(014,-44HDJIS,500+10) P0958 00137 Call APUOTV(NPTS,PT(1),PPH1(1),-1101,55,IERR) P0958 00137 Call APUOTV(NPTS,PT(1),PPH1(1),010,10,10,55,IERR) P0958 00137 Call APUOTV(NPTS,PT(1),PPH1(1),010,10,10,55,IERR) P0958 00137 Call APUOTV(NPTS,PT(1),PPH2(1),010,500) P0958 00137 IX1=hXX(PHDIS(1)) IX1=10,055,IERR) P0958 00140 IX1=hXX(PHDIS(1)) IX1=10,0500 P0958 00140 IX1=hXX(PHDIS(1)) IX1=10,0500 P0958 00140 IX1=10,0 IX1=10,0500 P0958 P01458 IX1=10,0 IX1=10,0500	Is-I J=-J P0958 00135 J=-J J=-J P0958 00135 CALL WHNTV(-+,XR,YB,YT,DX,UY,N,M,I,J,NX,NY) P0958 00135 CALL WHNTV(014,+HRDIS,55010) P0958 00135 CALL APUNTV(014,+HRDIS,50010) P0958 00136 CALL APUNTV(014,+HRDIS,50010) P0958 00137 CALL APUNTV(014,+HRDIS,50010) P0958 00137 CALL APUNTV(PTS,PT(11),PH2(1)).11,11,055,1ERR) P0958 00137 CALL APLUTV(NPTS,PT(11),PH2(1)).11,11,055,1ERR) P0958 00137 TX1=NXV(PHDIS(1)) TX1=NXV(PHDIS(1)) P0958 00142 TY3=NXV(PHDIS(1)) TY1+1,138,155,172 P0958 00142 TY2=NVV(PCPRS(1)) TY2=NYV(PCPRS(1)) P0958 00142 <td< td=""><td></td><td>CALL UXUYV(2.YH.YT.UY.M.J.NY.ZO.O)IERR)</td><td>P0958</td><td>00132</td></td<>		CALL UXUYV(2.YH.YT.UY.M.J.NY.ZO.O)IERR)	P0958	00132
J=-J Call GWIUIV(L.xL.xR.YB.YT.DX.UV.N.M.I.J.NX.NY) Call WHINTV(-4.4MMDIS.500110) Call APMNTV(0-14.4MMDIS.50010) Call APMNTV(0-14.4MMCPKS.10.500) Call APLOTV(NPTS.PT(1).9H1(1).1.1.1.55.IERR) P0958 00138 Call APLOTV(NPTS.PT(1).9H2(1).1.1.1.55.IERR) P0958 00139 IX1=hXV(PHDIS(1)) IY1=hXV(PHDIS(1)) IY1=hXV(PHDIS(1)) IY1=hXV(PHDIS(1)) IY1=hXV(PHDIS(1)) IY1=hXV(PHDIS(1)) IY1=hXV(PHDIS(1)) IY1=hX Ann CONTINUE A	J=-J Call GRIUIV(L-xL+xR+YB+YT+DX+DY+N+M+I+J+NX+MY) Call APHNTY(0-+14+-AHADIS+500+10) Call APHNTY(014+-A+HADIS+500+10) Call APHNTY(014+-A+HADIS+500+10) Call APHNTY(014+-A+HADIS+500) Call APHNTY(014+-A+HADIS+500) Call APHNTY(014+-A+HADIS+500) Call APHNTY(014+-A+HADIS+500) IX1=NXY(PHDIS(1)) IY1=NYY(PCPRS(1)) IY1=NYY(PCPRS(1)) IY1=NYY(PCPRS(1)) IY1=NY IY1=172 300 CONTINUE HETUHN FOUTHOUE		[se]	P0958	00133
Call GHIUTV(L+XL+XR+YB+YT+DX+UY+N+M+I+J+NX+NY) Call PRINTV(-+++HPDIS+500+10) Call APHNTV(00-14+++HPDIS+500+10) Call APHNTV(00-14+++HPDIS+500+10) Call APLOTV(NPTS+PT(1)+10+10+10+10+10+10+10+10+10+10+10+10+10+	Call GRIUTV(L-XL-XR.YB.YT.0X.0V) Call PRINTV(-4.4HBDIS.500.10) Call PRINTV(014.4HBDIS.500.10) Call APMNTV(014.4HBDIS.500.10) Call APMNTV(014.4HBDIS.90010) Call APLOTV(NPTS.PT(1).01.11.11.55.1ERR) Call APLOTV(NPTS.PT(1).01.11.11.158.1ERR) TXT=XXV(PPDIS(1)) TYT=XXV(PPDIS(1)) TYT=XXV(PPDIS(1)) TYT=XXV(PPDIS(1)) TYT=XXV(PPDIS(1)) TYT=XXV(PPDIS(1)) TYT=XXV(PPDIS(1)) TYT=XXV(PPDIS(1)) TYT=XXV(PPDIS(1)) TYT=XXV(PPDIS(1)) TYT=XXV(PPDIS(1)) TYT=XXV(PPDIS(1)) TYT=TX2 TXT=XXV(PPDIS(1)) TYT=TX2 TXT=XXV(PPDIS(1)) TYT=TX2 TXT=XXV(PPDIS(1)) TYT=TX2 TXT=TXV(PPDIS(1)) TYT=TX2 TXT=TX2 TXT=TXV(PPDIS(1)) TYT=TX2 TXT=TX2		Dest	P0958	00134
Call PRINTV(-4.4HPDIS,500*10) Call APHNTV(0-14.4HPDIS,500*10) Call APLOTV(NPTS,PT(1),PH1(1)+1.1.55,1EAR) Call APLOTV(NPTS,PT(1),PH2(1)+1.1.1.55,1EAR) TX1=hXv(PHDIS(1)) TX1=hXv(PHDIS(1)) TY1=hXv(PHDIS(1)) TY1=hXv(PHDIS(1)) D0 300 Inte22.NPTS TX2=NAv(PHDIS(1X)) D0 300 Inte22.NPTS TX2=NAv(PHDIS(1KK)) TY2=NVv(PCPRS(1KK)) TY2=NAv(PHDIS(1KK)) TY2=NAv(PHDIS(1KK)) TY2=NAv(PHDIS(1KK)) TY2=NAv(PHDIS(1KK)) TY2=NAv(PHDIS(1KK)) TY2=NAv(PHDIS(1KK)) TY2=NAv(PHDIS(1KK)) TY2=NAv(PHDIS(1KK)) TY2=NAv(PHDIS(1KK)) TY2=NAv(PHDIS(1KK)) TY2=NAv(PHDIS(1KK)) TY2=NAv(PHDIS(1KK)) TY2=NAv(PHDIS(1KK)) TY2=NAv(PHDIS(1KK)) TY2=NAv(PHDIS(1KK)) TY2=NAV	C CALL PHINTV(-4.4HPD)[5,500,10) C CALL APWNTV(0,-14,-4,4HPD)[5,500,10) C CALL APWNTV(0,-14,-4,4HPD)[5,5,1EAR) C CALL APLOTV(NPTS,PT(1),PH1(1).1.1,155,1EAR) C CALL APLOTV(NPTS,PT(1),PH2(1)).1.1,11,55,1EAR) D 0958 00139 I X1=h.Xv(PHD[S(1)) I Y1=h.Xv(PHD[S(1)) I Y1=h.Xv(PHD[S(1)) I Y1=h.Xv(PHD[S(1)) I Y1=h.Xv(PHD[S(1)) I Y1=h.Xv(PHD[S(1)) I Y1=h.Xv(PHD[S(1)) I Y1=h.X2,HY2) I Y2=hVV(PCPHS(1KL)) I Y1=172 300 C0N11NUE FULN		CALL GRIUIV(L.xL.xR.YB.YT.DX.UV.N.M.T.J.NX.NY)	POGGH	25100
C CALL APHNTV(0144.4HCPHS.10.500) C CALL APLOTV(NPTS.PT(1).PH1(1).1.1.1.55.IERR) IX1=hXv(PHDIS(1)) IY1=hXv(PHDIS(1)) IY1=hXv(PHDIS(1)) IY1=hXv(PHDIS(1)) IY1=hXv(PHDIS(1)) IY1=hXv(PHDIS(1)) IY1=hXv(PHDIS(1)) IY1=hXv(PCPRS(1)) IY1=hXv(PCPRS(1)) IY1=172 IX1=172	C CALL APKNTV(0144.4HCPKS.10.500) C CALL APLOTV(NPTS.PT(1).011.1.1.55.1ERR) TX1=NXV(PHDIS(1)) TX1=NXV(PHDIS(1)) TY1=NVV(PCPKS(1)) TY1=NVV(PCPKS(1)) TY1=NVV(PCPKS(1)) TY1=NVV(PCPKS(1)) TY1=NVV(PCPKS(1)) TY2=		CALL PRINTV(-4-4HRDIS-500.10)		
C Call APLOTV(NPTS,PT(1),PH1(1),1,1,55,1ERR) C Call APLOTV(NPTS,PT(1),PH1(1),1,1,55,1ERR) TX1=hXV(PHDIS(1)) TY1=hXV(PHDIS(1)) TY1=hXV(PHDIS(1)) TY1=hXV(PHDIS(1)) D0 300 TKK=2,NPTS TX2=hXV(PHDIS(1KK)) D0 300 TKK=2,NPTS TX2=hXV(PHDIS(TKK)) D0 300 TKK=2,NPTS TX2=hXV(PHDIS(TKK)) D0 300 TKK=2,NPTS TX2=hXV(PHDIS(TKK)) D0 300 TKK=2,NPTS TX2=hXV(PHDIS(TKK)) D0 300 TKK=2,NPTS TX2=hXV(PPHS(TKK)) D0 300 TKK=2,NPTS TX2=hXV(PPHS(TKK)) D0 300 TKK=2,NPTS TX2=hXV(PPHS(TKK)) D0 300 TKK=2,NPTS TX2=hXV(PPHS(TKK)) D0 300 TKK=2,NPTS TX2=hXV(PPHS(TKK)) D0 300 TKK=2,NPTS TX2=hXV(PPHS(TKK)) D0 958 00145 D0 958 00145 P0 958 000145 P0 958 000145 P	C Call APLOTY(NPTS,PT(1),PH1(1),1,1,1,55,1ERR) IX1=KXV(PHDIS(1)) IY1=KXV(PHDIS(1)) IY1=KXV(PHDIS(1)) P0958 00140 P0958 00140 P0958 00143 P0958 00143 P00558 00158 P00558 00143 P00558 000				
C CALL APLOIV(NPTS,PT(1),PH2(1),1,1,55,1ERR) I X1=hxv(PH0IS(1)) I X1=hxv(PH0IS(1)) I X1=hxv(PH0IS(1)) I Y1=hxv(PH0IS(1)) I Y1=hxv(PH0IS(1)) P0958 00142 P0958 00143 P0958 00145 P0958 00145 P0958 00145 P0958 00145 P0958 00147 P0958 00144 P0958 00145 P0958 000145 P0958 000145	C CalL APLOTY (NPTS, PT(1), PH2(1), 1, 1, 1, 1, 1, 55, 1ERR) C CalL APLUTY (NPTS, PT(1), PH2(1), 1, 1, 1, 1, 55, 1ERR) 1 X1 = KX (PHDIS(1)) 1 X1 = KX (PHDIS(1)) 1 Y1 = KX (PHDIS(1)) 1 Y1 = KX (PHDIS(1)) 1 Y2 = KX (RCA01	16100
C CALL APLOIVINPTS.PT(1).PHZ(1).11.38.IEAR) IX1=NXV(PHDIS(1)) IX1=NXV(PHDIS(1)) IX1=NXV(PHDIS(1)) P0958 00142 P0958 00143 P0958 00143 P0958 00145 P0958 0015 P0958 00145 P0958 00145 P0958 00145 P0958 00	C CALL APLOIV(NPTS,PT(1),PN2(1),1)38,1EAR) 1X1=KX(PHDIS(1)) 1X1=KX(PHDIS(1)) 1Y1=KX(PHDIS(1)) 10 300 [KK=2,NPTS 10 300 [KK=2,NPTS 10 300 [KK=2,NPTS 10 300 [KK=1)) 1X2=KX(PHU]S([KK]) 1X2=KX(PHU]S([KK]) 1X2=KX(PHU]S([KK]) 1X2=KX(PHU]S([KK]) 1X1=1/2 1X1=		Call APCOIV (NPIS+PT(1), PH1(1), +1.01, 550, IERR)	P0958	00138
IXI=hXV(PH0IS(1)) IYI=hXV(PH0IS(1)) IYI=hYV(PCPRS(1)) IYI=hYV(PCPRS(1)) D0 300 IKK=2.NPTS IX2=NAV(PHUIS(IKK)) IY2=NVV(PCPRS(IKK)) P0958 00145 P0958 00145 P0958 00145 P0958 00145 P0958 00147 P0958 00145 P0958 000145 P0958 00145 P0958 000145 P0058	IXI=KXV(PHDIS(1)) IYI=KXV(PHDIS(1)) IYI=KVV(PCPKS(1)) IYI=KVV(PCPKS(1)) IYI=KVV(PCPKS(1)) IYI=KVV(PCPKS(1)) IYI=KVV(PHDIS(1KK)) IYI=KVV(PHDIS(1KK)) IYI=KVV(PHDIS(1KK)) IYI=KVV(PHDIS(1KK)) IYI=KVV(PHDIS(1KK)) IYI=KVV(PHDIS(1KK)) IYI=KVV(PHDIS(1KK)) IYI=KVVV(PCPKS(1KK)) IYI=KVVVV(PCPKS(1KK)) IYI=KVVVV(PCPKS(1KK)) IYI=KVVVVVVVV(PCPKS(1KK)) IYI=KVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVV		CALL APLUIV(NPIS.PI(1),PRZ(1),1,1,1,38,1ERR)	P0458	6E100
IY]=NYV(PCPRS(1)) IY]=NYV(PCPRS(1)) IJ 300 IKK=2.NPTS IX2=NAV(PHUJS(IKK)) IY2=NYV(PCPRS(IKK)) P0958 00145 P0958 00145 P0958 00145 P0958 00145 P0958 00147 P0958 000147 P0958 000147 P0958 00	IY]=NYV(PCPHS(I)) IY]=NYV(PCPHS(I)) IY]=NXV(PHU]IS(IKK)) IY2=NXV(PHU]IS(IKK)) IY2=NYV(PCPHS(IKK)) P0958 00145 P0958 00145 P0058 00145 P0058 00145 P0058 00145 P0058 00145 P0058 00145 P0058 00145 P0058 000145 P0058 000145 P0058 000145 P0058 000145 P0058 000145 P0058 000145		IX1=NXV(PHDIS(1))	P0958	00140
10 300 IKK=2.NPTS 122=NAV(PHUJS(IKK)) 122=NAV(PHUJS(IKK)) 122=NAV(PCPRS(IKK)) 122=NAV(PCPRS(IKK)) 121=142	10 300 KKK=2.NPTS 122=NAV (PHU)15(1KK)) 172=NAV (PHU)15(1KK)) 172=NAV (PCPRS(1KK)) Cal.L LINEV(1X1.1Y1.1X2.1Y2) Cal.L LINEV(1X1.1Y1.1X2.00146 P0958 00146 P0958 00147 P0958 000147 P0958 000147 P0958 000147 P0958 000147 P0958 000147 P0958 000147 P0958 000147 P0958 000147 P0958 000147 P0058 00010		IY1=NYV(PCPRS(1))	00000	
IX2=NXV(PHDIS(IKK)) IY2=NYV(PCPRS(IKK)) IY2=NYV(PCPRS(IKK)) CALL LINEV(IX1.IY1.IX2.IY2) P0958 00145 IX1=1X2 IX1=1X2 IY1=1Y2 300 CONTINUE HETUHN	IX7=NAV(PHDIS(IKK)) IY7=NYV(PCPRS(IKK)) IY7=NYV(PCPRS(IKK)) Cal.L LINEV(IX1.IY1.IX2.IY2) P0958 00145 P0958 00145 P0958 00147 P0958 00147 P0958 00147 P0958 00147 P0958 00147 P0958 00147 P0958 00147 P0958 00147 P0958 00147 P0958 00149		STON STON STON		
IYZENYV (PCPAS(IKK)) IYZENYV (PCPAS(IKK)) IYZENYV (PCPAS(IKK)) CALL LINEV(IX1.IY1.IX2.IY2) IXIEIXZ IXIEIXZ IYIEIYZ 300 CONTINUE METUHN P0958 00147 P0958 00147 P0958 00147 P0958 00147 P0958 00147	IY2=NYV(PCPRS(IKK)) IY2=NYV(PCPRS(IKK)) Cal.L LINEV(IX1.IY1.IX2.IY2) IX1=1X? IX1=1X? IX1=1X? IX1=1Z? P095B 00145 P095B 00149 P095B 00149 P095B 00149 P095B 00149 P095B 00149 P095B 00149			0000	24100
IY7=NTV(PCPHS(IKK)) CALL LINEV(IX1.IY1.IX2.IY2) CALL LINEV(IX1.IY1.IX2.IY2) IX1=14? P0958 00147 P0958 00147 P0958 00147 P0958 00149 P0958 00149 P0958 00149	IT7=NTVPCPHS(IKK)) CALL LINEV(IX1.IY1.IX2.IY2) CALL LINEV(IX1.IY1.IX2.IY2) IX1=1X2 IX1=1X2 IX1=1Y2 IX1=1Y2 P0958 00147 P0958 00147 P0958 00149 P0958 00149 F00 F00			P0958	E+100
CALL LINEV(IX1.IY1.IX2.IY2) IX1=142 IX1=142 P0958 00146 P0958 00147 P0958 00147 P0958 00147 P0958 00149 METUHN	CALL LINEV(IX1.IY1.IX2.IY2) IX1=1X2 IX1=1X2 IY1=1Y2 300 CONTINUE HETUHN FND		IYPENTV (PCPRS(IKK))	P0958	00144
IX1=1A2 IY1=1Y2 P0958 00146 P0958 00147 P0958 00146 P0958 00146 P0958 00146 P0958 00149	IX1=142 IY1=172 300 CONTINUE HETURN FUD		CALL LINEV(IX]. IV]. IX2. IV2.	DAUCH	SALOO
300 CONTINUE HETURN HETURN	171=172 300 CONTINUE METURN FND		[X]=142		
300 CONTINUE METUHN METUHN	300 CONTINUE METURN FND			90404	0+100
ADD CONTINUE P0458 00148 METUHN P0458 00149	POYSE 00148 METURN FND POYSE 00149			P0458	14100
METUHN P0958 00149	HETURN P0958 00149 FND	105	CONTINUE	B2604	00148
	END		HETUHN	P0958	00149

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SECTION IV

EXPERIMENTAL RESULTS

NORMAL DEFLAGRATION

The validity of the preceding analysis is easily assessed by measuring the pressure-time history and muzzle velocity of a given device and correlating the results with those predicted by the theory. This experimental effort was conducted at the Jet Propulsion Laboratory of the California Institute of Technology under NASA sponsorship. The device which was used for this purpose is shown in Figure 7.





Pressures were measured in the chamber and at two additional points down the barrel by means of high-pressure Kistler piezometric pressure transducers feeding Kistler charge amplifiers and recorded on persistent phosphor Techtronix oscilloscopes. Muzzle velocities were measured by means of break screens connected to Hewlett-Packard digital clocks.

The launch tube was of smooth bore configuration and for maximum flexibility was constructed with a uniform bore diameter rather than with an expanded chamber; this design allows an infinitely variable chamber volume. Ignition and propellant loading techniques are shown in Figure 8.





The initial chamber volume is determined by the location of the piston base while the loading volume is a function of the diameter and length of the phenolic sleeve into which the propellant is initially packed. The ignitor used consists of a firing nut containing an Atlas electric match surrounded by 300 mg of black powder. This type igniter gives a short-duration flame of high intensity with little brisance. When the tubular propellant grains are not too tightly packed, the effect of the phenolic loading sleeve may be neglected except insofar as the volume it displaces is concerned.

Firings demonstrating proper deflagration and typical correlation with the above referenced theory are illustrated in Figures 9, 10, and



Figure 9. Pressure Time Plot With $\Delta = 57.0$ in.²/in.³.

11. A qualitative delineation of the phenomena occurring in Figure 9, for example, would be as follows:

1. t = 0 to t = 1.0 m/sec: Very slow increase in chamber volume as the result of an almost negligible projectile velocity, hence very rapid pressure increase due to energy release by propellant in almost constant chamber volume.

2. t = 1.0 m/sec to t = 1.9 m/sec: Projectile velocity increasing and, thus, exposed chamber volume increasing more rapidly. Excess energy input decreasing as function of incremental volume to be pressurized.

3. Peak pressure (t = 1.9) to propellant burnout (t = 2.9 experimentally, 3.2 analytically): Plenum volume increasing more rapidly than energy input. Sharp break in curve slope due to propellant burnout.

4. Subsequent to burnout, a very rapid pressure decrease occurs as a result of the expansion of the gases, heat loss to tube, and further energy imparted to projectile.



Figure 10. Pressure Time Plot With $\Delta = 61.0 \text{ in.}^2/\text{in.}^3$.





In these three firings, the primary difference exhibited between the experimental data and the analysis is a result of the following factor: the single-perforate propellant is assumed to burn externally and internally in a radial manner until the total charge is consumed.

In reality, this does not occur. A certain fraction of the grains fragment during combustion, and this increases the exposed burning surface and, in general, leads to slightly higher peak pressures and somewhat earlier web burnout than is analytically predicted. The difference, typically, is of only a few percent in peak pressure and is of such a nature that there is no way to express it analytically.

Figures 9, 10, and 11 show the quite good correlation between theory and experiment which is attainable when the density of loading Δ is kept at less than 75 in.²/in.³. At loadings above this level, a different mechanism of combustion becomes manifest and could probably be best described as a transition through shock-driven deflagration to virtual charge detonation. The charge characteristics are presented in Table V.

Plot	Charge	Propellant	Slug		Muzzle Ve (fps	locity
References	Weight (gm)	Web (in.)	Weight (gm)	$(in.^{2}/in.^{3})$	Predicted	Actual
Figure 9	86.2	0.0164	560	57.0	2,080	2,040
Figure 10	90.0	0.0164	560	61.0	2,220	2,210
Figure 11	110.0	0.0190	508	65.5	2,360	2,300
Figure 12	97.5	0.0164	560	76.7	2,250	2,150
Figure 13	93.0	0.0164	550	80.0	2,190	2,220
Figure 14	105.0	0.0164	560	82.0	2,350	2,700

TABLE V. CHARGE CHARACTERISTICS.

SHOCK-DRIVEN DEFLAGRATION

It was mentioned previously that the phenolic tube had no effect on the interior ballistic solution. This is not true, however, if the propellant is packed too tightly into the tube. The propellant used was M-10, which is virtually 100 percent nitrocellulose with no nitroglycerine

loading and, hence, would be expected to be relatively insensitive to detonation characteristics.

Figures 12, 13, and 14 show this phenomenon of transition from weak shock-driven deflagration to strongly shock-driven deflagration. Figure 15 shows the remains of an end cap when loading was increased to the point where a response similar to complete detonation occurred. No pressure record is available for this firing because the breech pressure transducer was also destroyed. An indirect method of pressure determination may be made by the calculation of the force necessary to shear the normalized 4130 end cap and indicates a peak pressure of at least 450,000 psig.



Figure 12. Pressure Time Plot With $\Delta = 76.7 \text{ in.}^2/\text{in.}^3$.

From the illustrated firings, it is possible to characterize the combustion of the propellant into various regimes as a function of the burning surface per unit of free initial volume. Symbolically, this would be

 $\Delta = S_B / V_{IF}$

as

 $S_B = 2 C_w / \rho_p w_o$

then

$$V_{IF} = L A_p - C_w / \rho_p$$

32

.



Figure 13. Pressure Time Plot With $\Lambda = 80.0$ in.²/in.³.



Figure 14. Pressure Time Plot With $\Delta = 82.0$ in.²/in.³.

It was mentioned earlier that, for proper deflagration in this system, Δ must be less than 75 in.²/in.³. In Figure 12, $\Delta = 76.7$ in.²/in.³ and it was seen that a slight pressure pulse occurs, then damps out, but drives the peak pressure to a value approximately 30 percent higher than what would have been encountered during proper deflagration.



Figure 15. End Cap After Detonative Reaction.

In Figure 13, for which $\Delta = 80$ in.²/in.³, the initial pressure spike is rapid and narrow and quickly decays to be followed by another broader pressure pulse to approximately the same value. Figure 14 shows the pressure-time profile of a loading with a $\Delta = 82$ in.²/in.³.

The initial pressure wave is virtually identical to that exhibited by the previous loading. The second spike, however, is much higher and gives a peak pressure almost 100 percent higher than would be expected if linear regression were the only mechanism at work.

The loading represented by the wreckage shown in Figure 15 was $\Delta = 86.5 \text{ in.}^2/\text{in.}^3$. A detonation-like reaction phenomenon had occurred, resulting in a pressure probably well above the 450,000 psig mentioned previously. The response could have been a true detonation of the individual propeliant grains, which then formed a gaseous blast over-pressure wave to act on the restraining steel. The energy release rate was such that this is the most likely mode of reaction.

The Δ values given for the onset of this highly undesirable mode of reaction would include most fully loaded cartridge cases with thin web propellant. This demonstrates the requirements for either deterring or inhibiting a large fraction of the initial surface area. Good ballistic design, however, requires a tradeoff between reproducible ignition and the formation of these dangerous shock waves in the deflagrating propellant bed.

From the previous results for the system under consideration, the following regimes can be defined:

△ < 75	Proper deflagration
75 < 0 < 86	Shock-driven deflagration
A > 86	Detonation like response

These particular Δ values are doubtless a function of propellant composition and ignition technique. They do graphically demonstrate, however, that the ballistic designer must be cautious when approaching very high loading densities to be certain that the regimes, other than normal propellant regression, are avoided.

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