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ROCK ISLAND ARSENAL
RESEARCH & DEVELOPMENT DIVISION
DESIGN ENGINEERING BRANCH



TECHNICAL REPORT

CONTRIBUTION TO THE ANALYSIS OF
MUZZLE BRAKE DESIGN

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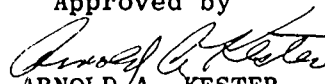
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CONTRIBUTION TO THE ANALYSIS OF
MUZZLE BRAKE DESIGN

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May 1962

OMS Code No. 5520.11.440A0.01

Department of the Army Project
No 5W01-01-034

Rock Island Arsenal
Rock Island, Illinois

ABSTRACT

A theory of gaseous discharge from the end of a tube was constructed using an isentropic model with account taken of axial gradients in the state variables. On the assumption that the flow rates from such a tube were not appreciably altered by the presence of conventionally designed muzzle brakes, formulas for the forces on the brake and tube were obtained for brakes of various design.

In order to implement the computation of parameters associated with a complete brake analysis, a digital computer program was written for the Royal McBee, LGP-30 which permits one to perform an analysis with relative ease. This program is included in the report.

A comprehensive bibliography on muzzle brake studies, gun induced shock, and allied fields is also included in this report.

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LIST OF SYMBOLS

Due to the large number of parameters considered, the symbols used are divided into three classes: those applicable in general and in particular to the period prior to gas ejection, those concerned primarily with the period during which gas is discharged from the muzzle (discharge period), and lastly those concerned with the design of the brake. Any symbol not listed here or one having two meanings is defined in one of the appendices, where it first appears.

PART I

GENERAL

<u>Symbol</u>	<u>Meaning</u>	<u>Dimension</u>
ξ	travel of projectile from beginning of rifling	inches
g_0	length of bore from beginning of rifling	inches
D	diameter of bore	inches
r_N	radius of a tube of cross sectional area A; also the radius of a sonic nozzle	inches
A	area of bore plus cross sectional area of grooves	in^2
A_{cnct}	area of ammunition band in contact with tube after shear deformation	in^2
$\mathcal{V}$	total internal volume	in^3
$\mathcal{V}_c$	volume of chamber	in^3
M_p	mass of projectile	lb_m
M_c	mass of charge	lb_m
M_{ig}	mass of igniter	lb_m
$M_T = M_c + M_{\text{ig}}$	total propellant mass	lb_m
M_r	mass of recoiling parts	lb_m

<u>Symbol</u>	<u>Meaning</u>	<u>Dimension</u>
T	temperature of the propellant gases	$^{\circ}\text{R}$
v	velocity (with subscripts)	ft/sec
v_c	muzzle velocity of the projectile	ft/sec
V	specific volume of the propellant gases	$\frac{\text{ft}^3}{\text{lb}_m}$
$\rho = \frac{1}{V}$	density	$\frac{\text{lb}_m}{\text{ft}^3}$
$p = p(\gamma, t)$	pressure in the gas	psia
P_{max}	maximum pressure	psia
t	time	secs
t_c	time at which base of projectile leaves gun tube	secs
B(t)	force on breech	lb_f
a	speed of sound in gas	ft/sec
$M = \frac{v}{a}$	mach number in gas	
$\gamma = C_p/C_v$	ratio of specific heats of propellant gas	
$\mathcal{R}$	universal gas constant ≈ 1545	$\frac{\text{lb}_f \text{ ft}}{\text{mole } ^{\circ}\text{R}}$
m	molecular weight of gas	$\frac{\text{lb}_m}{\text{mole}}$
$R = \frac{\mathcal{R}}{m}$	gas constant	$\frac{\text{lb}_f \text{ ft}}{\text{lb}_m ^{\circ}\text{R}}$
C_p	specific heat of gas at constant pressure	$\frac{\text{Btu}}{\text{lb}_m ^{\circ}\text{R}}$
C_v	specific heat of gas at constant volume	$\frac{\text{Btu}}{\text{lb}_m ^{\circ}\text{R}}$
J	Joule's constant ≈ 777.5	$\frac{\text{lb}_f \text{ ft}}{\text{Btu}}$

<u>Symbol</u>	<u>Meaning</u>	<u>Dimension</u>
g	acceleration due to gravity = 32.17	ft/sec ²
e_c	heat of explosion of the propellant charge	$\frac{\text{Btu}}{\text{lb}_m}$
e_{ig}	heat of explosion of the igniter	$\frac{\text{Btu}}{\text{lb}_m}$
E	energy involved in a process	Btu
KEP	kinetic energy of the projectile at $t = t_0$	Btu
KEG	kinetic energy of the gas at t_0	Btu
KER	kinetic energy of the recoiling parts at t_0	Btu
KEB	kinetic energy spent in engraving the bore and in forcing the projectile thru at t_0	Btu
E_g	energy remaining in the gas at t_0	Btu
$\mathcal{H}$	total heat released by charge and igniter during combustion	Btu
$\mathcal{H}_c$	heat released by charge	Btu
$\mathcal{H}_{ig}$	heat released by igniter	Btu
$x = \frac{1}{2} + \frac{v_c}{A}$	length of tube of uniform cross section	inches
$L = \frac{1}{2} + \frac{v_c}{A}$	length of tube of uniform cross section having an internal volume equal to v_r	inches
$\eta = \frac{x}{L}$	dimensionless length	
$a = \frac{v_e}{a_b}$	dimensionless velocity	
$\beta = \frac{v_0}{a_{av \text{ init}}}$	dimensionless velocity	
$\phi = \frac{p}{p_b} = \phi(\eta)$	dimensionless pressure at t_0	
$\zeta = \frac{v}{v_b} = \zeta(\eta)$	dimensionless specific volume at t_0	
$\mathcal{T} = \frac{T}{T_b} = \mathcal{T}(\eta)$	dimensionless temperature at t_0 ; also used as an angle in the brake design	degrees

PART II

LIST OF SYMBOLS
PERTAINING TO THE DISCHARGE PERIOD

<u>Symbol</u>	<u>Meaning</u>	<u>Dimension</u>
z	axial distance measured positively in streamwise direction	inches
r	radial distance from axis	inches
$P_b = p$	pressure at the breech (written in digital computer program without the subscript)	psia
P_c	pressure at the muzzle	psia
B	breech force	lb_f
P	cumulative momentum discharged	$lb_f \text{ secs}$
M	cumulative mass discharged	lb_m
$B_T = B_{cml}$	breech impulse	$lb_f \text{ secs}$
H	cumulative stagnation enthalpy discharged from the muzzle	Btu
F_z	force on brake in axial direction of gun tube	lb_f
F_y	force on brake normal to axis of gun tube	lb_f
I_z	resultant impulse received by brake and gun tube during gas discharge in axial direction	$lb_f \text{ secs}$
I_y	impulse received by brake and gun tube in the normal direction	$lb_f \text{ secs}$
$\alpha_T =$	$\frac{A \ g \ P_b \ \text{init}}{a_b \ \text{init} \ M_T}$; dimensional constant used in formulas in Appendix III	secs^{-1}
$\tau = \alpha_T t$	dimensionless time	
$\Phi =$	$\frac{P_b}{P_b \ \text{init}}$; dimensionless breech pressure, defined in Appendix III	

<u>Symbol</u>	<u>Meaning</u>	<u>Dimension</u>
$\Phi_T =$	$\frac{B_T \alpha_T}{A p_{b \text{ init}}}$; dimensionless cumulative breach impulse, defined in Appendix III	
$\mu =$	$\frac{\dot{P}}{A p_{b \text{ init}}}$; dimensionless momentum rate of discharge, defined in Appendix III	
$\mu_T =$	$\frac{P g}{M_T a_{b \text{ init}}}$; dimensionless cumulative momentum discharged from muzzle, defined in Appendix III	
$\nu =$	$\frac{\dot{M}}{M_T \alpha_T} = \left[\frac{g A p_{b \text{ init}}}{a_{b \text{ init}}} \right]^{-1} \dot{M}$; dimensionless mass rate of discharge, defined in Appendix III	
$\nu_T =$	$\frac{M}{M_T}$; dimensionless cumulative mass discharged, defined in Appendix III	
$\eta =$	$\frac{\dot{H}}{E_g \alpha_T}$; dimensionless stagnation enthalpy rate of discharge, defined in Appendix III	
$\eta_T =$	$\frac{H}{E_g}$; dimensionless cumulative stagnation enthalpy discharged, defined in Appendix III	
ϵ	expansion ratio, i.e., ratio of cross sectional area of gas flow at any axial station to area of muzzle	
n	speed-up factor, i.e., ratio of one- dimensional velocity of gas at any station to velocity of gas at the muzzle	dimensionless
Δ	empirical divergence angle of the flow with respect to the axis at entrance to a control volume surround- ing the baffle (Appendix V)	radians

<u>Symbol</u>	<u>Meaning</u>	<u>Dimension</u>
$\sigma = \frac{z}{r_N}$	dimensionless axial or stream-wise distance	
$\lambda = \frac{r}{r_N} = \frac{y}{r_N}$	dimensionless radial or lateral distance	
$\left. \begin{array}{l} a \\ b_1 \\ b_2 \\ b_3 \end{array} \right\}$	coefficients used in a cubic fit of the shock boundary of the jet for $\sigma_m < 2$; $y_m = \lambda_m \frac{r_N}{r_N} = \lambda_m(\sigma_m)$ $\lambda_m = a + b_1 \sigma_m + b_2 \sigma_m^2 + b_3 \sigma_m^3$	
$\left. \begin{array}{l} a \\ b_1' \\ b_2' \end{array} \right\}$	coefficients used in a quadratic fit of the shock boundary of the jet for $\sigma_m \geq 2$; $\lambda_m = a' + b_1' \sigma_m + b_2' \sigma_m^2$	
α_j, β_{ij}	coefficients used in a cubic fit of shock boundary coefficients: $a = a(p_o/p_\infty)$, $b_1 = b_1(p_o/p_\infty)$, etc.	
α_j', β_{ij}'	coefficients used in a cubic fit of shock boundary coefficients: $a = a'(p_o/p_\infty)$, $b_1' = b_1'(p_o/p_\infty)$, and $b_2' = b_2'(p_o/p_\infty)$	

PART III

LIST OF SYMBOLS
PERTAINING TO BRAKE DESIGN

<u>Symbol</u>	<u>Meaning</u>	<u>Dimension</u>
z	axial direction of brake measured positively away from breech	inches
y	direction normal to axis of brake measured positively upwards when gun tube is horizontal	inches
α_j	angle thru which gas is deflected with respect to the z - direction	radians
β_j	angle thru which gas is deflected with respect to the y - direction in a plane normal to the z - axis. See figure 4.2 in appendix IV.	radians
S_{ij} , $i=0,1,2$	closed-baffle port areas, used with subscripts to indicate the baffle referred to in a multi-baffle brake. See figure 4.1 in appendix IV.	
r_j	ratio of the mass flow rate captured by the j th baffle to the mass flow rate of gas from the muzzle	
K_j	ratio of the mass flow rate of gas passing the j th baffle undeflected to the mass flow rate from the muzzle	
$\lambda = \frac{F_z}{\dot{p}}$	ratio of axial brake force to momentum rate of discharge, $\dot{p}$	
λ_r	ratio of resultant momentum rate of discharge in the z -direction thru a control volume enclosing only the brake orifices to the momentum rate of discharge from the muzzle	
$\omega = \frac{F_y}{\dot{p}}$	ratio of normal brake force to momentum rate of discharge	

<u>Symbol</u>	<u>Meaning</u>	<u>Dimension</u>
$b = \frac{F_z}{B}$	momentum index, i.e., the ratio of the axial brake force to the breech force	
$\left. \begin{matrix} f_0 \\ f_1 \\ f_2 \\ f_3 \end{matrix} \right\}$	empirical correction factors	
$\psi_{ij}, i = 1, 2, 3$	angles associated with free-periphery brake design. See appendix VI.	radians
z_m	distance from muzzle to projection of rim of open baffle on z- axis. See figure 5.1b in appendix V.	inches
y_m	radial distance at z_m from axis to shock envelope	inches
I	inner radius in open brake design. See figure 5.1b in appendix V.	inches
Q	outer radius in open brake design. See figure 5.1b in appendix V.	inches

SUBSCRIPTS

°	refers to conditions at projectile ejection
∞	refers to ambient conditions
g	pertains to the gas
p	pertains to the projectile
r	pertains to the recoiling parts
ig	pertains to the igniter
c	pertains to the charge
b	refers to value of variable at the breech
eff	refers to an effective value
av	refers to an average value
max	refers to a maximum value
init	refers to initial conditions for gas ejection
T	refers to a cumulative or integrated value
i	dummy index; takes integral values from 0 to m
j	dummy index representing the baffle number; take integral values from 1 to N
0,1,2,...	indicates coefficient in power series, baffle number, and, in general, distinguishes members of a set

SUPERSCRIPTS

- ° refers to a stagnation value
- . indicates first deviative of variable
 with respect to time
- ' indicates value of variable at time gases
 become sonic at the muzzle
- indicates a mean value

INTRODUCTION

The primary purpose of this study was to establish a reliable and convenient means for analysing the internal ballistics of an artillery piece during the gas discharge period and for evaluating the performance of an associated muzzle brake of one of a number of different configurations. Several standard brake designs and some novel designs were considered and are examined separately later in this report.

A secondary motive for this study was to establish relations for computing parameters useful in other studies such as shock establishment and decay.

The method of approach to the determination of internal ballistic parameters during the gas discharge period involves several assumptions:

- 1) that, at the advent of discharge, all of the propellant is burnt;
- 2) that the heat released by the reaction may be computed by taking the sum of the product of the heat of explosion of the igniter and its mass and that of the propellant and its mass;
- 3) that the amount of gas discharged after projectile ejection necessary to make the gas velocity at the muzzle sonic is negligible;
- 4) that the gas discharge proceeds nearly isentropically;
- 5) and that the presence of the muzzle brake does not appreciably affect the discharge rate from the muzzle.

To obtain accurate initial conditions for the gas discharge period the following method was used. An analysis of energy disposition prior to gas discharge was made (Appendix I). As a result of this analysis one can compute the total thermal energy remaining in the gas at the advent of gas discharge. From the latter value, one can compute the average temperature and pressure at the start of discharge. By making certain assumptions regarding momentum transport within the tube prior to gas discharge, one can predict the relationship that exists between the average values of the temperature, pressure, and specific volume and the values of these parameters at the breech. This derivation is made in appendix II. These values, then, are used as initial conditions for the nearly isentropic flow from the muzzle

With the initial breech pressure and specific volume given, one assumes that the gas rapidly becomes sonic at the muzzle. By applying isentropic flow theory, one can obtain expressions for the breech pressure and breech force, the momentum rate of discharge, the mass rate of discharge, the stagnation enthalpy rate of discharge, and integrals of all of these. See Appendix III. It was found that convenient non-dimensional expressions for these parameters could be obtained in terms of a dimensionless time τ . Evaluation of these expressions provided a set of tables suitable for use with dimensional constants in obtaining the dimensional parameters relative to the discharge period. A computer program which takes certain thermodynamic data and computes the dimensional parameters was given the acronym "DIPARDIP."

DIPARDIP also requires muzzle brake data and furnishes loads and impulses on the brake as well as the effective momentum index. Use of this program and some typical results are described in later sections of the report. A special feature of this program is the large number of different brake designs which can be analysed.

In order to clarify what is meant by the terms "closed brake" and "open brake" designs, the reader is referred to figures 0.1 thru 0.4. Appendix IV treats the analysis of the closed brake design. Appendix V treats open brake design, and the special equations for the free periphery design are derived in Appendix VI.

In the next section all of the equations used by DIPARDIP are presented together with tables, graphs of tables, and graphs of some of the equations. These graphs and tables could be used for a hand calculation of the equations in lieu of DIPARDIP. For the derivation of any of the equations, the reader is referred to the appendices.



Figure 0.1
A SINGLE-BAFFLE,
CLOSED ASYMMETRIC
BRAKE

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3 January 1962

HOWITZER, LIGHT, TOWED, 105mm, XM102. UBU MUZZLE BRAKE.

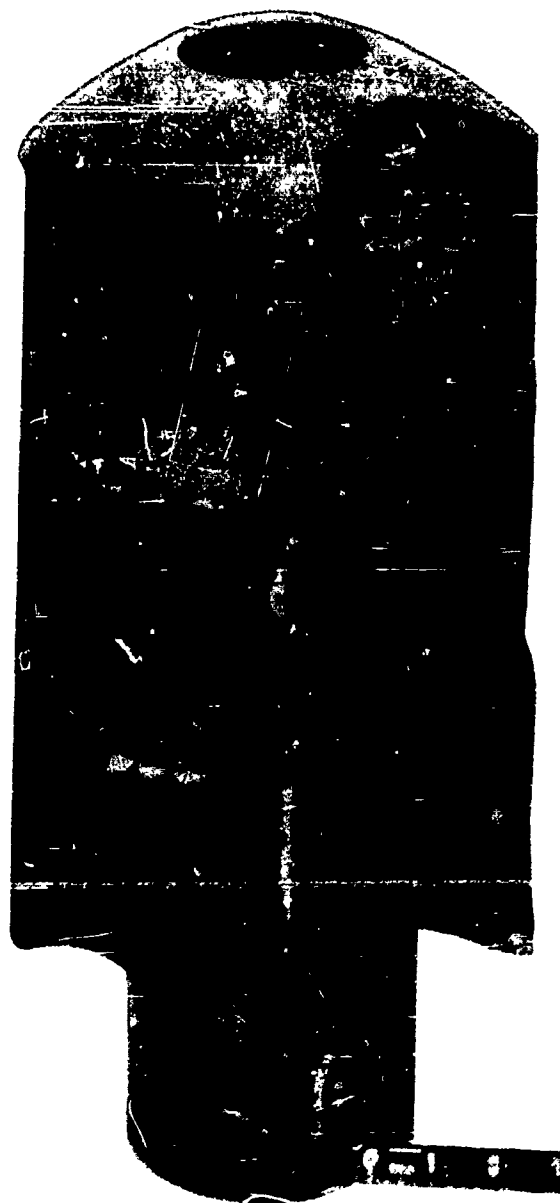


Figure 0.2

A TRIPLE-BAFFLE,
CLOSED SYMMETRIC
BRAKE



Figure 0.3
A SINGLE-BAFFLE,
OPEN BRAKE

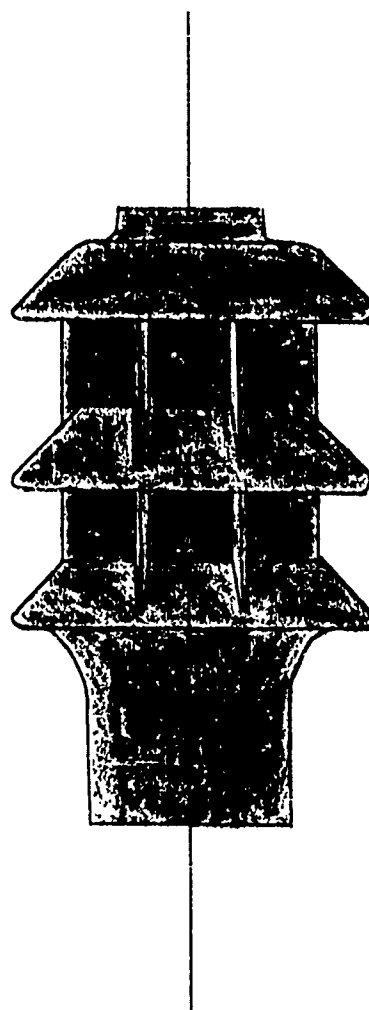
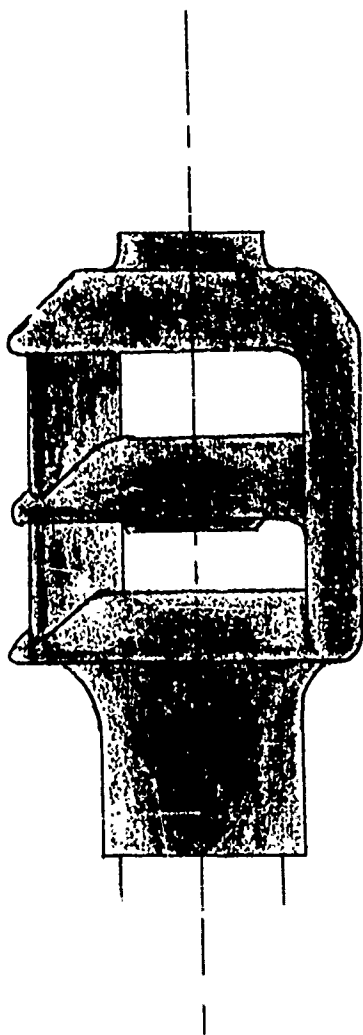


Figure 0.4
A DOUBLE-BAFFLE,
CLOSED BRAKE WITH
FREE PERIPHERY

EQUATIONS

$$0.1 \quad \mathcal{H}_{ig} = e_{ig} M_{ig}$$

$$0.2 \quad \mathcal{H}_c = e_c M_c$$

$$0.3 \quad \mathcal{H} = \mathcal{H}_{ig} + \mathcal{H}_c$$

$$0.4 \quad \text{KEP} = \frac{M_p v_o^2}{2 g J}$$

$$0.5 \quad \text{KEG} = \frac{M_T v_o^2}{2 g J} (\text{const})$$

$$0.6 \quad \text{const.} =$$

$$1/3 \left(\frac{1+v_r}{v_o} \right)^2 + \left(\frac{v_r}{v_o} \right)^2 - \frac{v_r}{v_o} \left(\frac{1+v_r}{v_o} \right), \text{ where}$$

$$\frac{v_r}{v_o} = \frac{M_T + M_p}{\frac{M_T + M_r}{2}}$$

$$0.7 \quad \text{KER} = \frac{M_r v_r^2}{2 g J}$$

$$0.8 \quad \text{KEB} = \frac{.18 A_{\text{cnct}}}{A} (\text{KEP})$$

$$0.9 \quad E_g = \mathcal{H} - \Sigma(\text{kinetic energies})$$

$$0.10 \quad T_{av \text{ init}} = T_g = \frac{E_g (\gamma - 1) J}{R M_T}$$

$$0.11 \quad p_{av \text{ init}} = p_g = \frac{12 E (\gamma - 1) J}{v_r}$$

$$0.12 \quad a_{av \text{ init}} = (\gamma g R T_{av \text{ init}})^{1/2}$$

$$0.13 \quad \beta = \frac{v_o}{a_{av \text{ init}}}$$

$$0.14 \quad \phi_{av} = 1.0495200 - .25021815\beta - .061082024\beta^2$$

$$0.15 \quad \chi_{av} = .97960297 + .10274869\beta + .19109947\beta^2$$

$$0.16 \quad \gamma_{av} = \phi_{av} \kappa_{av}$$

$$0.17 \quad p_{b \text{ init}} = \left(\frac{p_{2v}}{\phi_{av}} \right)_{\text{init}}$$

$$0.18 \quad v_{b \text{ init}} = \left(\frac{v_{av}}{\kappa_{av}} \right)_{\text{init}}$$

$$0.19 \quad a_{b \text{ init}} = \frac{a_{av \text{ init}}}{(\gamma_{av})^{1/2}}$$

$$0.20 \quad \alpha_{\tau} = \frac{A g p_{b \text{ init}}}{a_{b \text{ init}} M_{\tau}}$$

$$0.21 \quad t = \frac{\tau}{\alpha_{\tau}}$$

$$0.22 \quad p_b = p = p_{b \text{ init}} \Phi$$

$$0.23 \quad B = A p_{b \text{ init}} \Phi$$

$$0.24 \text{ a) } B_{\tau} = \frac{A p_{b \text{ init}}}{\alpha_{\tau}} \Phi_{\tau}$$

$$\text{b) } B_{\tau} = \frac{a_{b \text{ init}} M_{\tau}}{g} \Phi_{\tau}$$

$$0.25 \quad \dot{p} = A p_{b \text{ init}} \mu$$

$$0.26 \quad \dot{p} = \frac{a_{b \text{ init}} M_{\tau}}{g} \mu_{\tau}$$

$$0.27 \quad \dot{M} = \left(\frac{g A p_{b \text{ init}}}{a_{b \text{ init}}} \right) \nu$$

$$0.28 \quad M = M_{\tau} \nu_{\tau}$$

$$0.29 \quad \dot{H} = E_g \alpha_{\tau} \eta$$

$$0.30 \quad H = E_g \eta_{\tau}$$

EQUATIONS FOR SYMMETRICAL
AND ASYMMETRICAL CLOSED BRAKES

$$0.31 \text{ a)} \quad \epsilon_{1j} = \left(\frac{S_{0j} + S_{1j}}{S_{0j-1}} \right) \epsilon_{1j-1} ,$$

where b) $\epsilon_{10} = 1$

c) $S_{00} = A$ and j is the number of the baffle

$$0.32 \quad \epsilon_{2j} = \frac{S_{2j}}{S_{1j}} \epsilon_{1j}$$

$$0.33 \quad n_{1j} = n(\epsilon_{1j}) \quad \left. \vphantom{\begin{matrix} n_{1j} \\ n_{2j} \end{matrix}} \right\} \text{Function is tabulated,}$$

$$0.34 \quad n_{2j} = n(\epsilon_{2j})$$

$$0.35 \quad v_{1j} = a_0 n_{1j}$$

$$0.36 \quad v_{2j} = a_0 n_{2j}$$

$$0.37 \quad \dot{M}_{2j} = r_j \dot{M}_0$$

$$0.38 \text{ a)} \quad r_j = \left(\frac{S_{1j}}{S_{0j} + S_{1j}} \right) K_{j-1} , \text{ where}$$

b) $K_0 = 1$

$$0.39 \quad K_j = \left(\frac{S_{0j}}{S_{0j} + S_{1j}} \right) K_{j-1}$$

$$0.40 \quad \lambda_r = \frac{\sum_{j=1}^N [n_{2j} r_j \cos \alpha_j] + n_{1N} (1 - \sum_{j=1}^N r_j)}{f_2} \text{ or}$$

$$\lambda_r = (aps - n_{1N}(1-bps))/f_2$$

$$0.41 \text{ a)} \quad aps = \sum_{j=1}^N r_j n_{2j} \cos \alpha_j$$

b) $bps = \sum_{j=1}^N r_j$

c) $cps = \sum_{j=1}^N r_j n_{2j} \cos \beta_j$

d) $dps = \sum_{j=1}^N r_j n_{1j}$

$$0.42 \quad \omega = \frac{\sum_{j=1}^N r_j n_{2j} \cos \beta_j}{f_1} \quad \text{or}$$

$$\omega = \frac{\text{cps}}{f_1}$$

$$0.43 \quad \lambda = \frac{\sum_{j=1}^N r_j (n_{1j} - n_{2j} \cos \alpha_j)}{f_0}$$

$$\text{or } \lambda = \frac{\text{aps} - \text{aps}}{f_0}$$

$$0.44 \quad b = \frac{\dot{p}}{B} \lambda$$

$$0.45 \quad F_z = \lambda \dot{p}$$

$$0.46 \quad F_z = b B$$

$$0.47 \quad F_y = \omega \dot{p}$$

$$0.48 \quad I_z = B_T - \lambda P \quad \text{or}$$

$$I_z = (1 - b) B_T$$

$$0.49 \quad I_y = \omega P$$

EQUATIONS FOR SINGLE-BAFFLE SYMMETRICAL OPEN BRAKES

$$0.50 \quad b = \frac{\dot{p}}{B} n_{21} r_1 \cos \Delta (1 - \cos \alpha_1),$$

$$\text{where } \cos \Delta \cong 1$$

$$0.51 \quad r_1 = 1 - \frac{I^2}{y_m^2}, \quad \text{for } y_m \leq Q$$

$$\text{or } r_1 = \left(1 - \frac{\nu^2}{\pi}\right) + \frac{\left(\frac{\nu^2}{\pi} Q^2 - I^2\right)}{y_m^2}, \quad \text{for } y_m > Q$$

$$0.52 \quad n_{21} = n(\epsilon_{21})$$

$$0.53 \quad \epsilon_{21} = 1 + \frac{\nu^2}{\pi} \lambda_m^2$$

$$0.54a \quad \lambda_m = y_m/r_N$$

$$0.54b \quad r_N = (A/\pi)^{1/2}$$

$$0.55 \quad \sigma_m = \frac{z_m}{r_N}$$

$$0.55 \ a) \quad \lambda_m = a + b_1 \sigma_m + b_2 \sigma_m^2 + b_3 \sigma_m^3, \text{ for } \sigma_m < 2$$

$$b) \quad \lambda_m = a' + b'_1 \sigma_m + b'_2 \sigma_m^2, \text{ for } \sigma_m > 2$$

$$0.57 \quad \frac{p_o}{p_\infty} = \frac{p_b}{(1+\gamma) p_\infty}$$

$$0.58 \quad a = \alpha_0 + \beta_{10} \left(\frac{p_o}{p_\infty}\right) + \beta_{20} \left(\frac{p_o}{p_\infty}\right)^2 + \beta_{30} \left(\frac{p_o}{p_\infty}\right)^3$$

$$b_1 = \alpha_1 + \beta_{11} \left(\frac{p_o}{p_\infty}\right) + \beta_{21} \left(\frac{p_o}{p_\infty}\right)^2 + \beta_{31} \left(\frac{p_o}{p_\infty}\right)^3$$

$$b_2 = \alpha_2 + \beta_{12} \left(\frac{p_o}{p_\infty}\right) + \beta_{22} \left(\frac{p_o}{p_\infty}\right)^2 + \beta_{32} \left(\frac{p_o}{p_\infty}\right)^3$$

$$b_3 = \alpha_3 + \beta_{13} \left(\frac{p_o}{p_\infty}\right) + \beta_{23} \left(\frac{p_o}{p_\infty}\right)^2 + \beta_{33} \left(\frac{p_o}{p_\infty}\right)^3$$

$$0.59 \quad a' = \alpha'_0 + \beta'_{10} \left(\frac{p_o}{p_\infty}\right) + \beta'_{20} \left(\frac{p_o}{p_\infty}\right)^2 + \beta'_{30} \left(\frac{p_o}{p_\infty}\right)^3$$

$$b'_1 = \alpha'_1 + \beta'_{11} \left(\frac{p_o}{p_\infty}\right) + \beta'_{21} \left(\frac{p_o}{p_\infty}\right)^2 + \beta'_{31} \left(\frac{p_o}{p_\infty}\right)^3$$

$$b'_2 = \alpha'_2 + \beta'_{12} \left(\frac{p_o}{p_\infty}\right) + \beta'_{22} \left(\frac{p_o}{p_\infty}\right)^2 + \beta'_{32} \left(\frac{p_o}{p_\infty}\right)^3$$

$$0.60 \quad I_z = \sum_{i=1}^N (1-b_i) (B_{Ti} - B_{T(i-1)}) \quad \text{or}$$

$$I_z = B_{TN} - \sum_{i=1}^N b_i (B_{Ti} - B_{T(i-1)}),$$

$$\text{where } B_{T0} = 0$$

$$0.61 \quad b_{\text{eff}} = \frac{\sum_{i=1}^N b_i (B_{Ti} - B_{T(i-1)})}{B_{TN}}$$

$$0.62 \quad I_z = B_{TN} (1 - b_{\text{eff}})$$

$$0.63 \quad \omega = 0, \text{ for a symmetrical brake}$$

$$0.64 \quad \lambda_r = n_{21} r_1 \cos \alpha_1 + n_{21} (1-r_1)$$

EQUATION FOR FREE-PERIPHERY BRAKE

$$0.65 \quad \omega = \frac{1}{\pi} \sum_j n_{2j} r_j [\cos \nu_{1j} - \cos \nu_{2j} + \sin \nu_{3j} (\pi/2 - \nu_{1j})]$$

τ	Ξ	μ	ν
.10	.91138	.62049	.68128
.20	.83134	.56600	.62736
.30	.75899	.51674	.57815
.40	.69352	.47216	.53321
.50	.63422	.43179	.49213
.70	.53169	.36199	.42013
1.00	.41052	.27949	.33314
1.30	.31910	.21725	.26575
1.60	.24962	.16995	.21321
2.00	.18162	.12365	.16029
2.50	.12377	.084268	.11364
3.10	.079635	.054217	.076510
3.70	.052227	.035557	.052405
4.50	.030576	.020817	.032418
6.10	.011365	.0077378	.013343
7.50	.0051568	.0035109	.0065672

Table 0.1

τ	$\bar{\Phi}_\tau$	μ_τ	ν_τ
.10	.095494	.065014	.071039
.20	.18256	.12429	.13643
.30	.26202	.17839	.19667
.40	.33459	.22780	.25220
.50	.40093	.27297	.30344
.70	.51719	.35211	.39445
1.00	.65755	.44775	.50688
1.30	.76646	.52183	.59629
1.60	.85130	.57958	.66781
2.00	.93675	.63776	.74195
2.50	1.01209	.68905	.80969
3.10	1.07204	.72987	.86592
3.75	1.11096	.75637	.90408
4.50	1.14323	.77834	.93730
6.10	1.17404	.79931	.97143
7.50	1.18498	.80676	.98474

Table 0.2

τ	η	η_{τ}
.10	.84170	.088621
.20	.76055	.16866
.30	.68788	.24101
.40	.62273	.30648
.50	.56427	.36578
.70	.46454	.46831
1.00	.34925	.58948
1.30	.26452	.68090
1.60	.20176	.75038
2.00	.14207	.81838
2.50	.093072	.87622
3.10	.057223	.92037
3.75	.035934	.94777
4.50	.019909	.96942
6.10	.0066835	.98863
7.50	.0027956	.99484

Table 0.3

β	Φ_{av}	κ_{av}	$\mathcal{J}_{av}$
.4535	.92324	1.06639	.98453
.5047	.90800	1.08088	.98144
.5561	.89197	1.09665	.97818
.6077	.87532	1.11364	.97479
.6595	.85821	1.13177	.97129
.7116	.84079	1.15097	.96772
.7638	.82321	1.17117	.96411
.8163	.80557	1.19230	.96048

Table 0.4

TABLE 0.5

η	ϵ
1.0000	1.00058
1.1000	1.00631
1.1750	1.02471
1.2500	1.05571
1.3000	1.08392
1.3500	1.11876
1.4000	1.16089
1.4500	1.21118
1.5000	1.27072
1.5500	1.34089
1.6000	1.42340
1.6500	1.52040
1.7000	1.63460
1.7500	1.76943
1.8000	1.92926
1.8500	2.11970
1.9000	2.34809
1.9750	2.78365
2.0500	3.37414
2.1250	4.19466
2.2000	5.36933
2.2750	7.11299
2.3500	9.81834
2.4250	14.25250
2.5000	22.04302
2.5750	37.02652
2.6250	69.60049
2.7250	153.98911
2.8000	441.19018

Coefficients for Cubic Fit of a_1 , b_1 , b_2 , and b_3

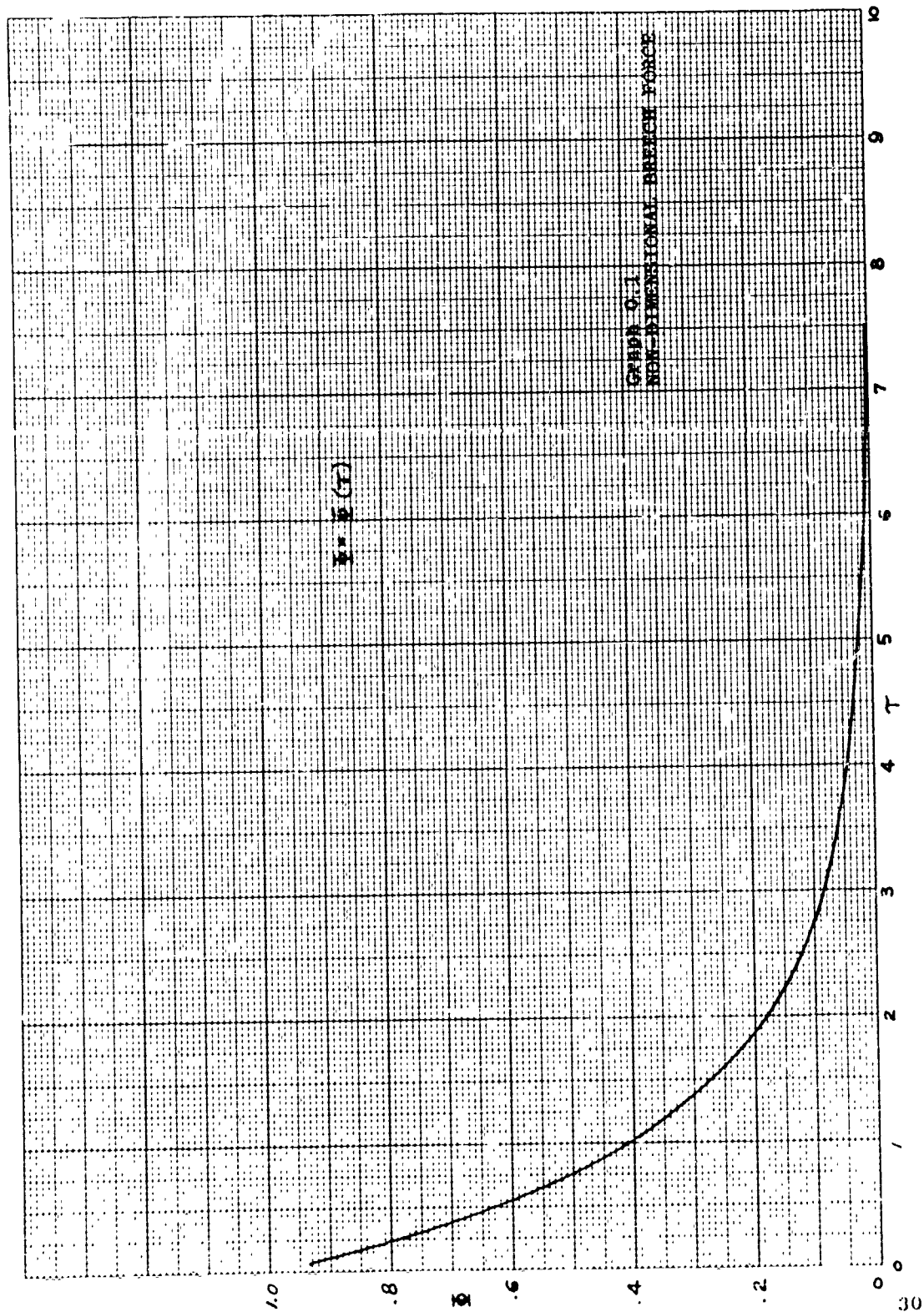
SET I				$j =$
α_j	$\beta_{1,j}$	$\beta_{2,j}$	$\beta_{3,j}$	
1.0029575x10 ⁰	9.7146227x10 ⁻⁴	-1.2464600x10 ⁻⁵	1.6405071x10 ⁻⁷	0
1.3227139x10 ⁻¹	8.7822392x10 ⁻²	-2.1672912x10 ⁻³	2.2107067x10 ⁻⁵	1
-8.2074898x10 ⁻²	-2.0354335x10 ⁻²	3.5434135x10 ⁻⁴	-3.1316625x10 ⁻⁶	2
1.3076924x10 ⁻²	3.2693895x10 ⁻³	-2.2656165x10 ⁻⁵	1.6469917x10 ⁻⁸	3
SET II				$j =$
α_j	$\beta_{1,j}$	$\beta_{2,j}$	$\beta_{3,j}$	
1.0112126x10 ⁰	5.1616179x10 ⁻⁴	1.9529640x10 ⁻⁶	-2.9900434x10 ⁻⁹	0
9.3730118x10 ⁻¹	1.8788970x10 ⁻²	-5.3483022x10 ⁻⁵	7.4938991x10 ⁻⁸	1
-2.5026538x10 ⁻¹	-7.5733961x10 ⁻³	1.8646556x10 ⁻⁵	-2.6977477x10 ⁻⁸	2
4.3505442x10 ⁻²	1.6938484x10 ⁻³	-3.4027765x10 ⁻⁶	4.3278227x10 ⁻⁹	3

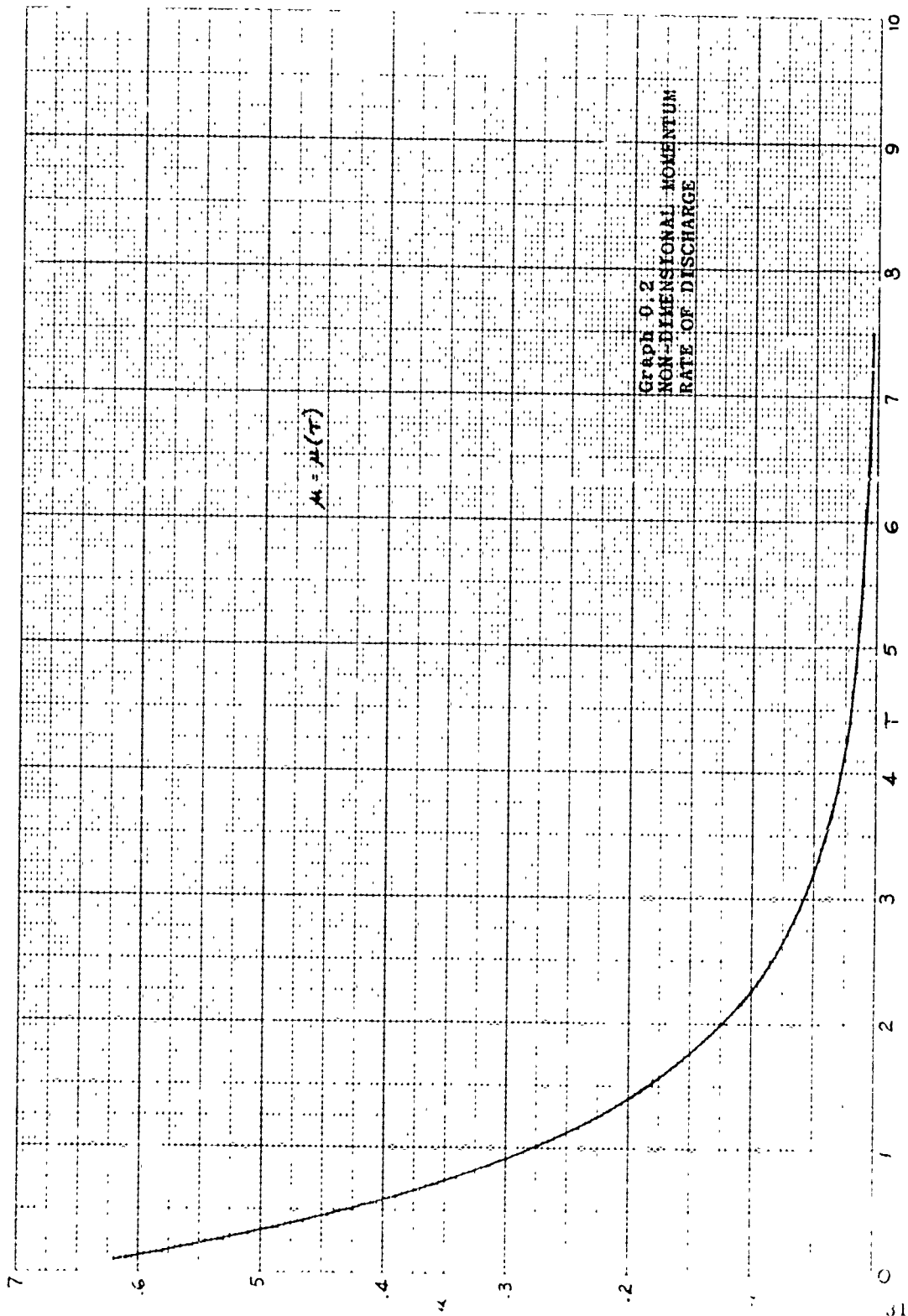
Table 0.6

Coefficients for Cubic Fit of a'_i , b'_i , and b'_2

α'_j	SET I			β'_{a_j}	$j = 0$
	$\beta'_{i,j}$	$\beta'_{i,j}$	$\beta'_{i,j}$		
1.1788745x10 ⁰	9.8121657x10 ⁻³	-5.5985875x10 ⁻⁵	1.5484761x10 ⁻⁷	1	0
2.0359081x10 ⁻¹	2.0669444x10 ⁻²	-1.4975523x10 ⁻⁴	4.0250616x10 ⁻⁷	1	1
-2.3007762x10 ⁻²	-5.5381965x10 ⁻⁴	4.2869848x10 ⁻⁶	-1.2578841x10 ⁻⁸	2	2
	SET II				
	$\beta'_{i,j}$	$\beta'_{i,j}$	$\beta'_{i,j}$		
	$\beta'_{i,j}$	$\beta'_{i,j}$	$\beta'_{i,j}$		
1.200684x10 ⁰	4.825827x10 ⁻³	3.690608x10 ⁻⁶	-2.377028x10 ⁻⁸	0	0
8.452055x10 ⁻¹	5.898632x10 ⁻³	-2.323C79x10 ⁻⁵	4.253296x10 ⁻⁸	1	1
-2.753219x10 ⁻²	-6.423429x10 ⁻⁴	4.200171x10 ⁻⁶	-8.089821x10 ⁻⁹	2	2

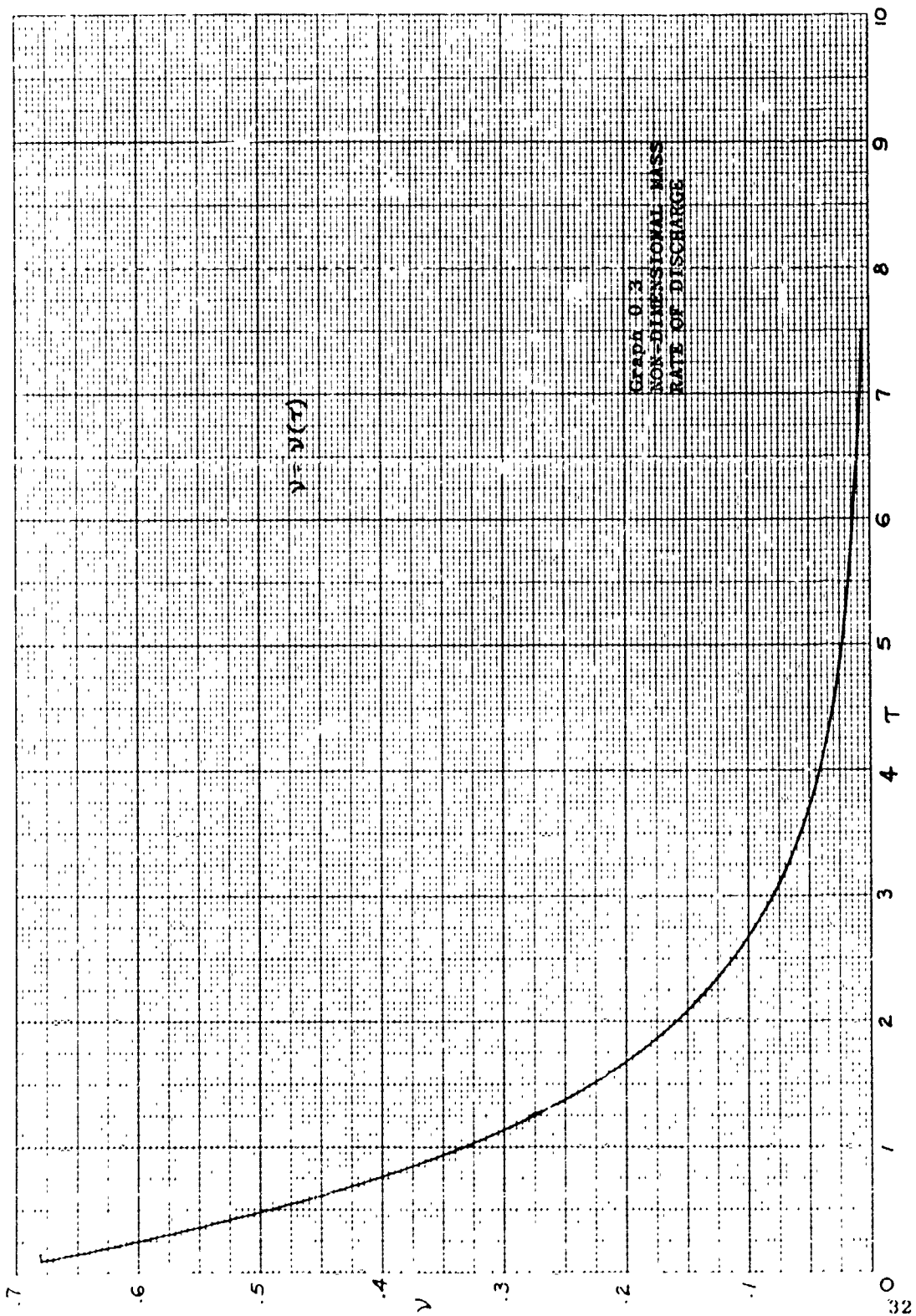
Table 0.7

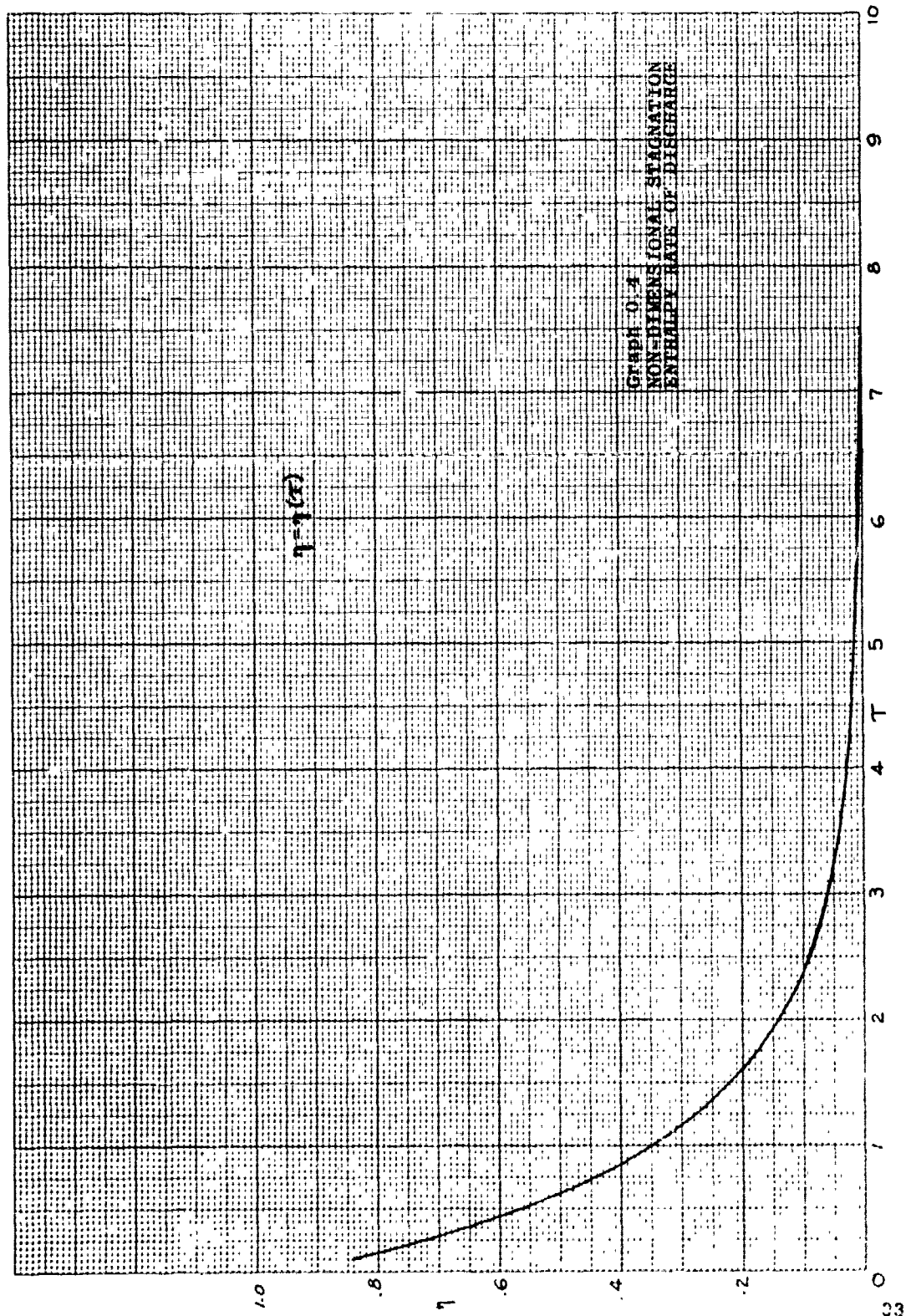


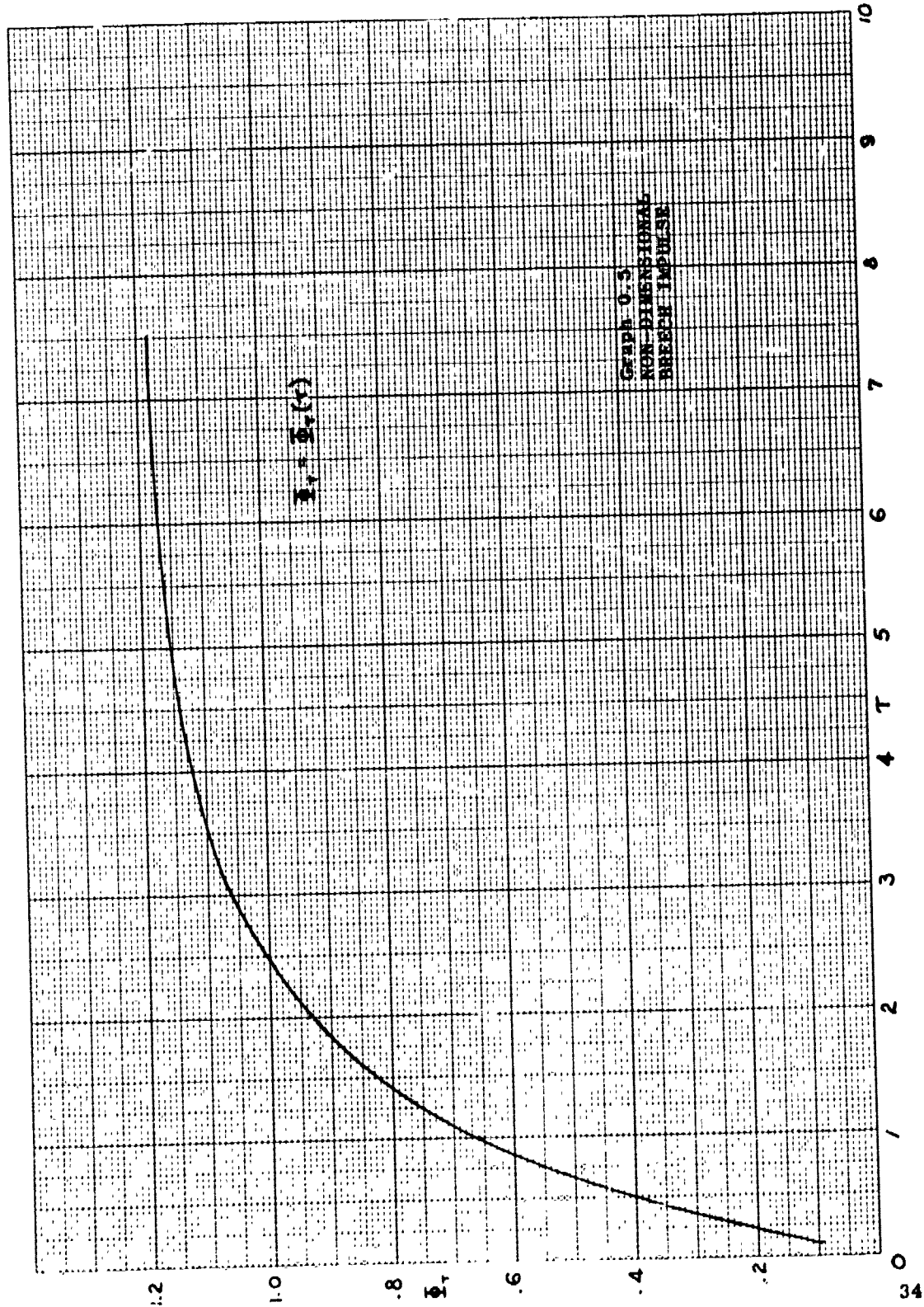


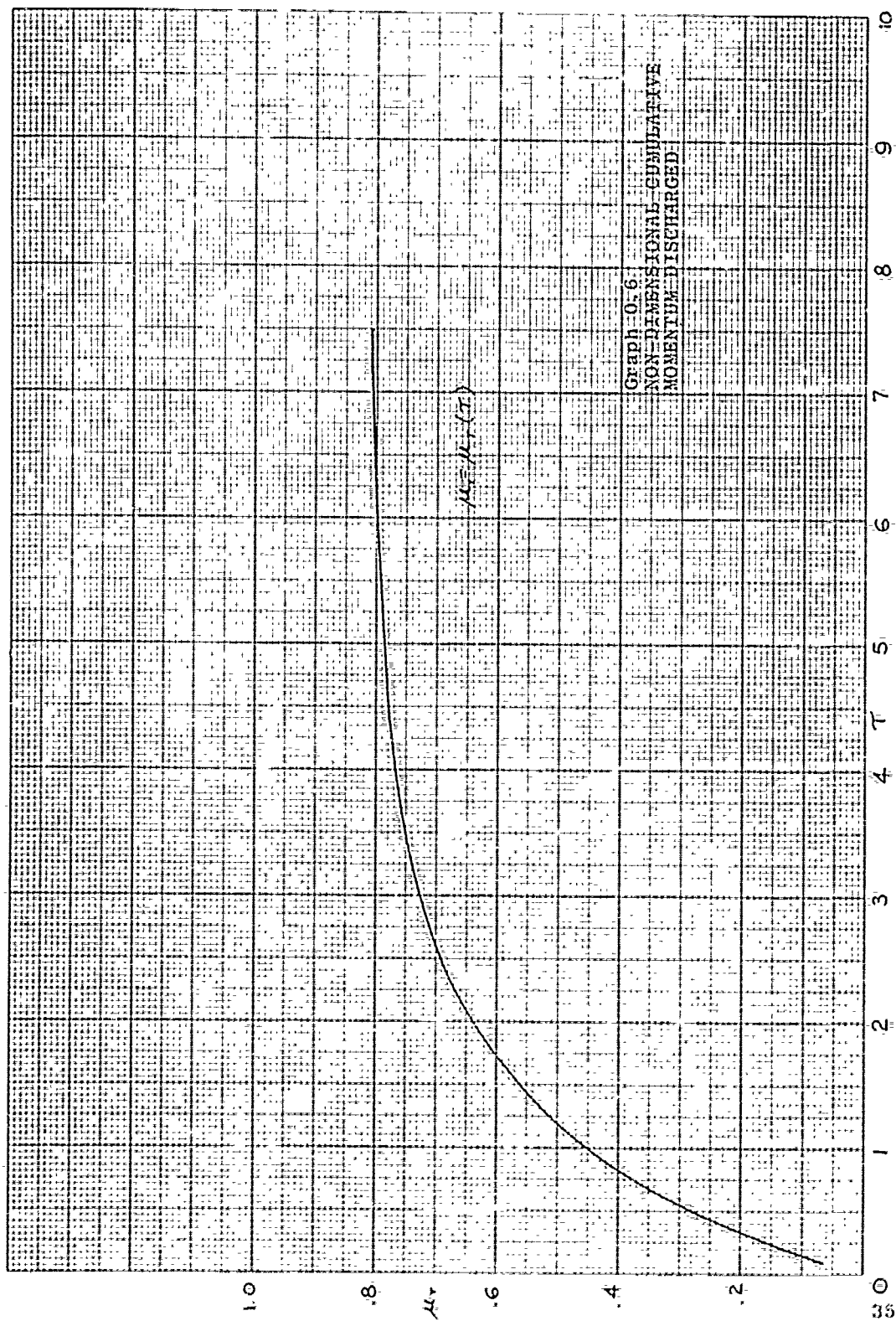
Graph 0.2
NON-DIMENSIONAL MOMENTUM
RATE OF DISCHARGE

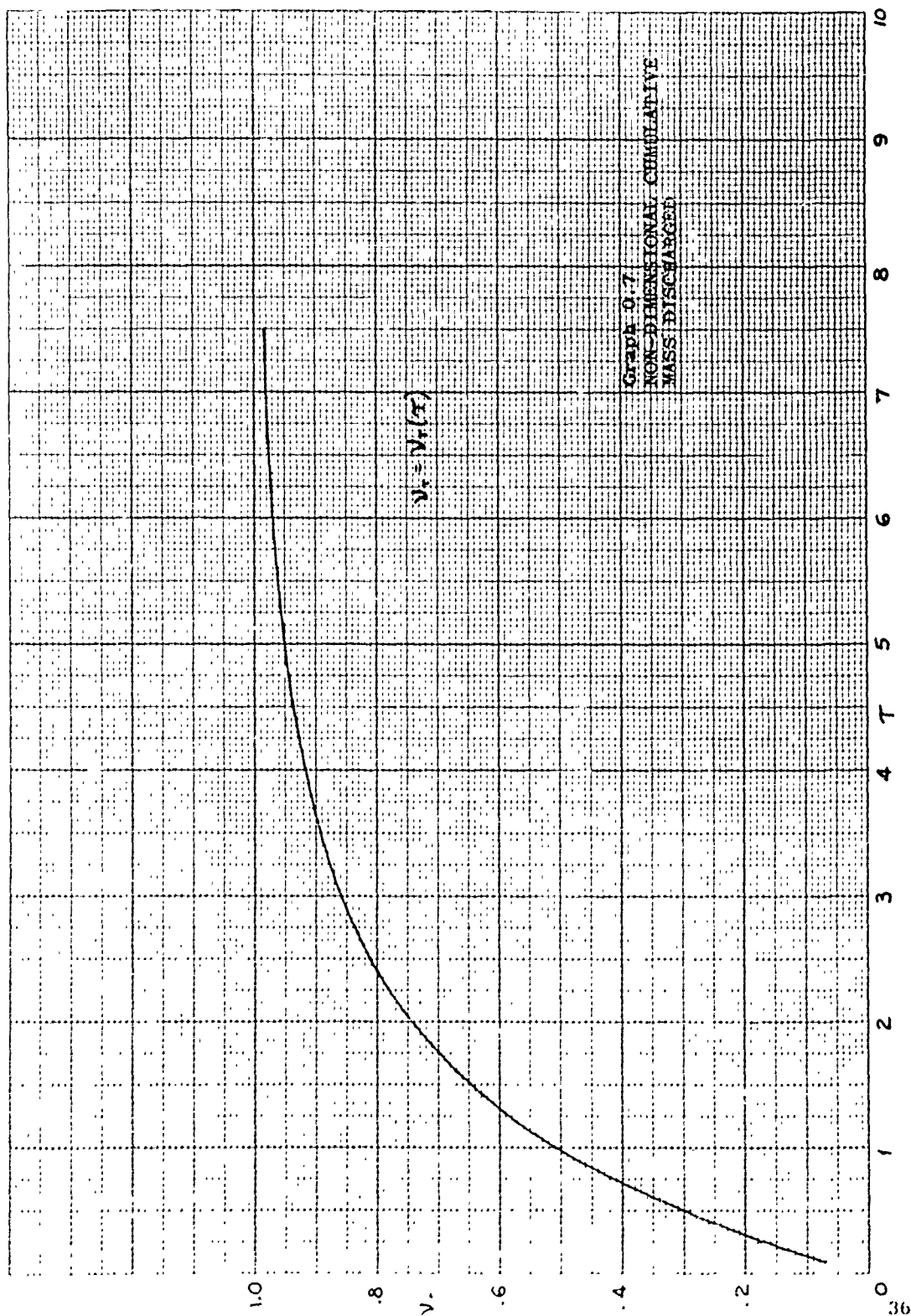
$M = \mu(\tau)$

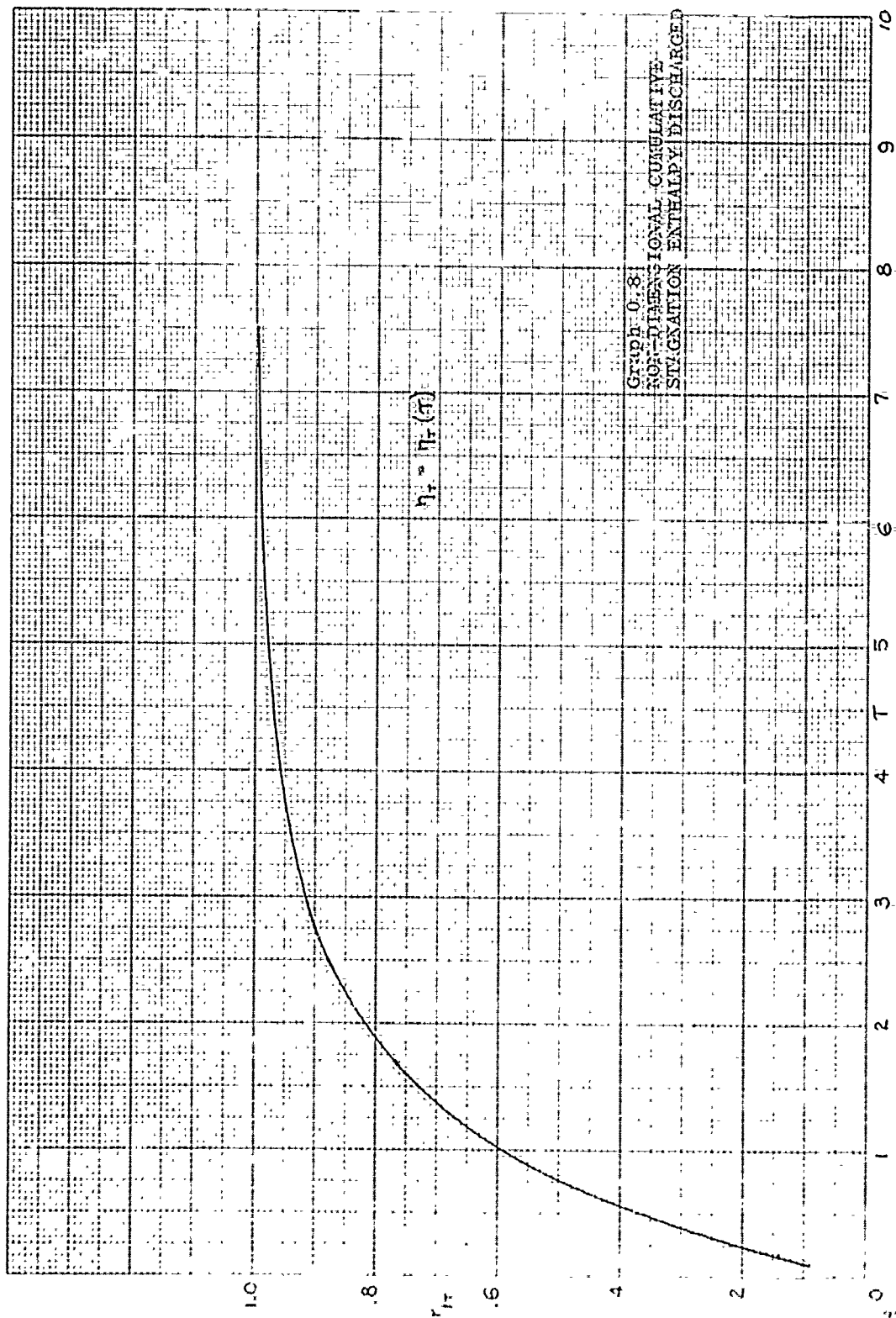


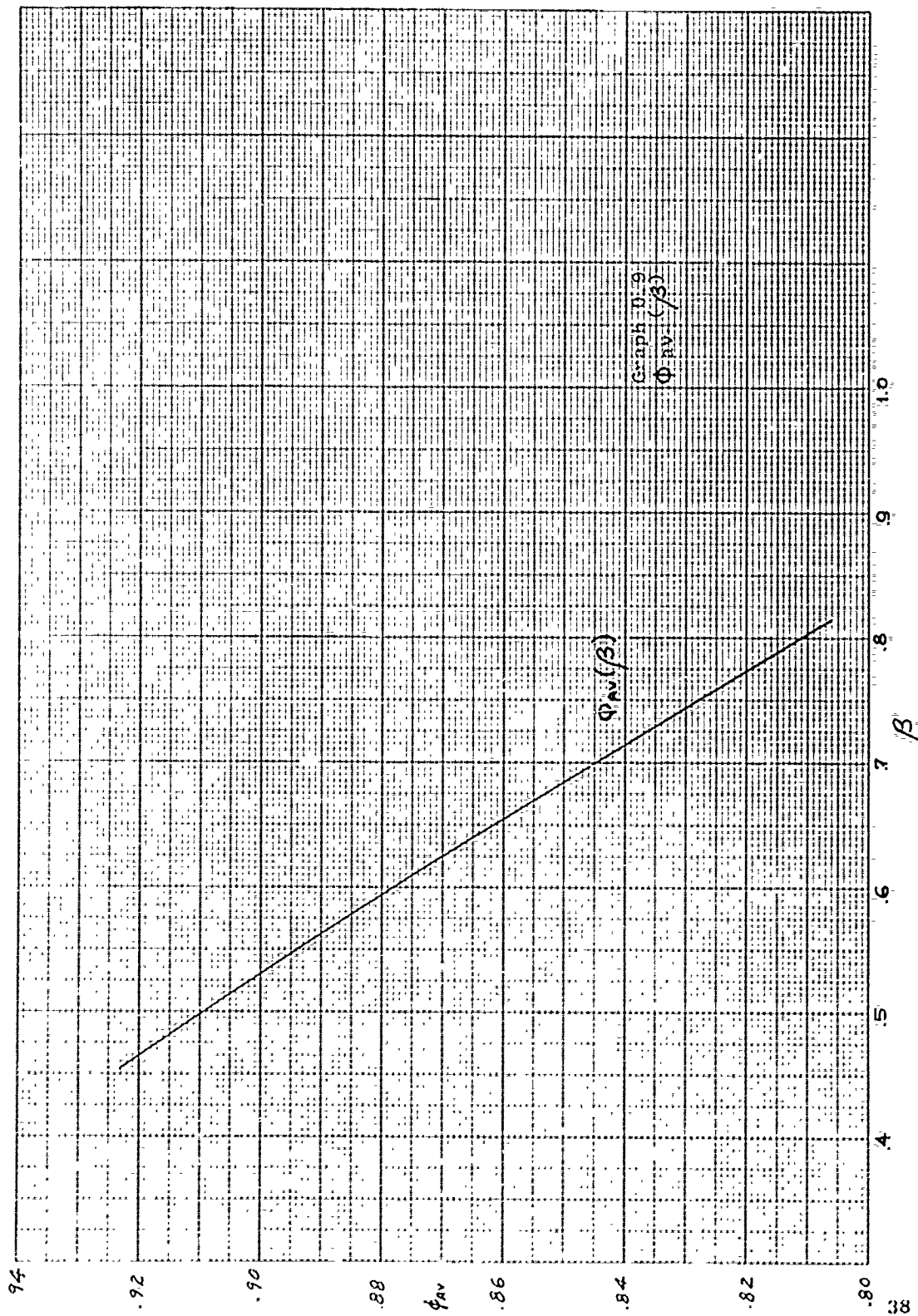


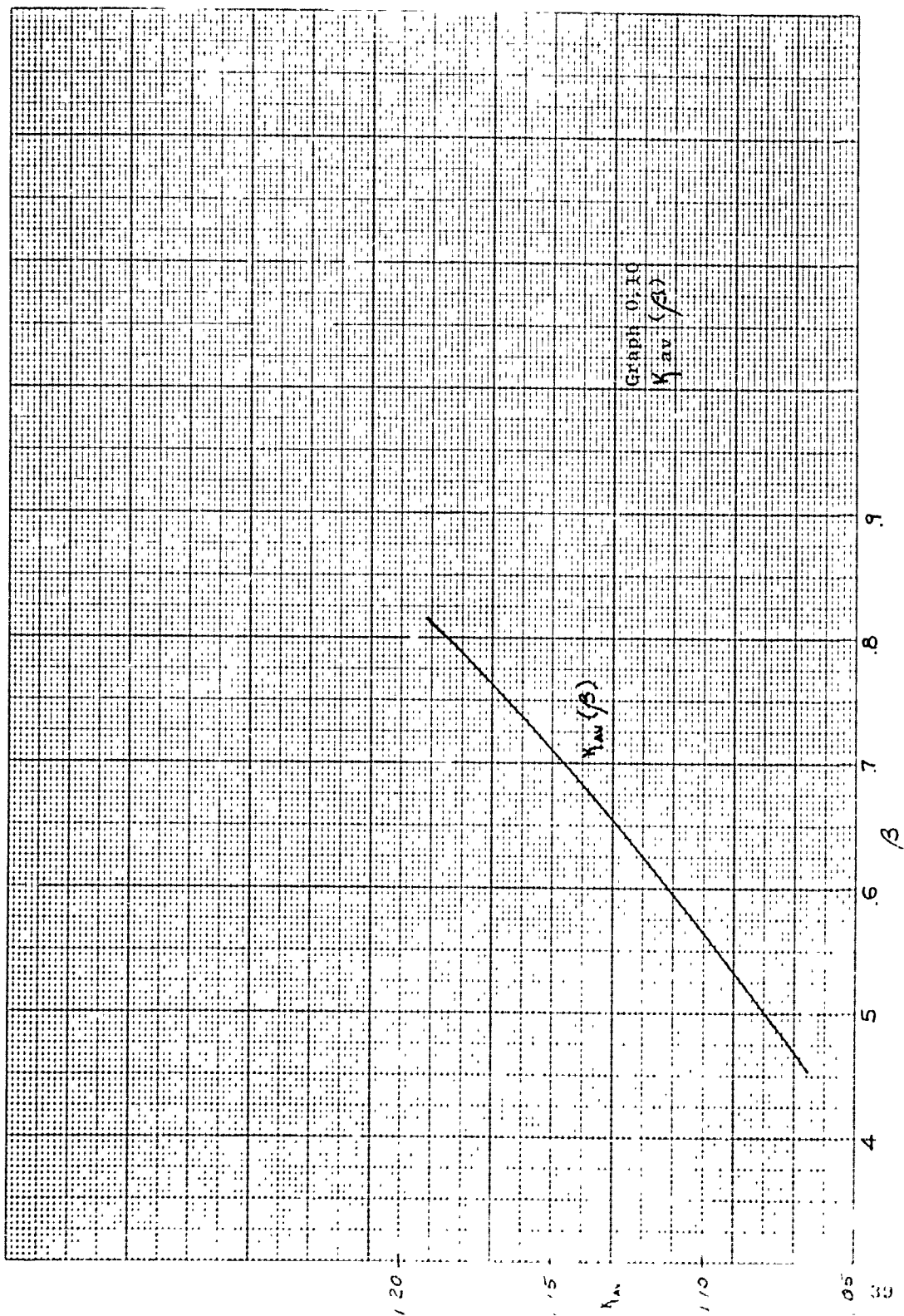


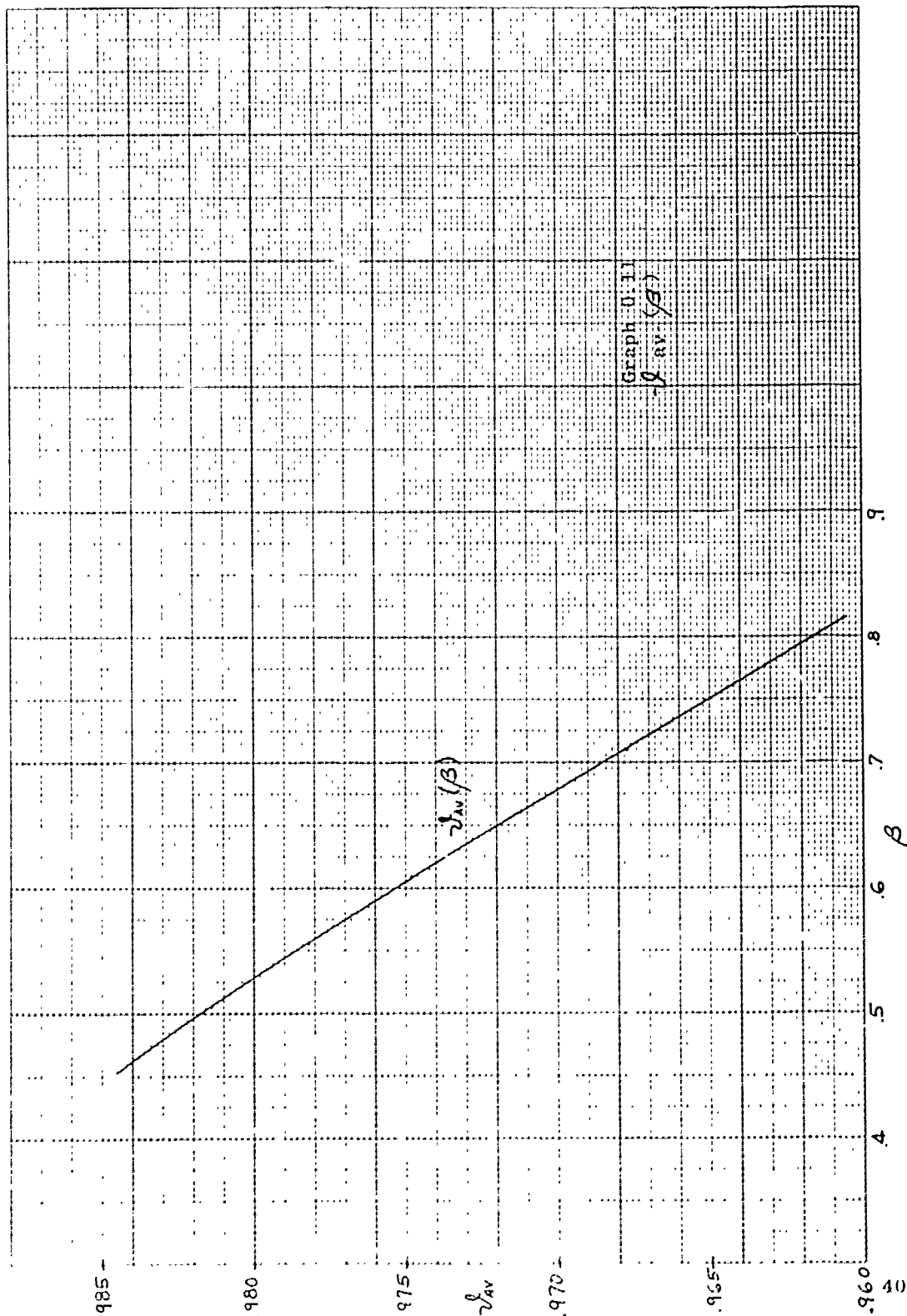


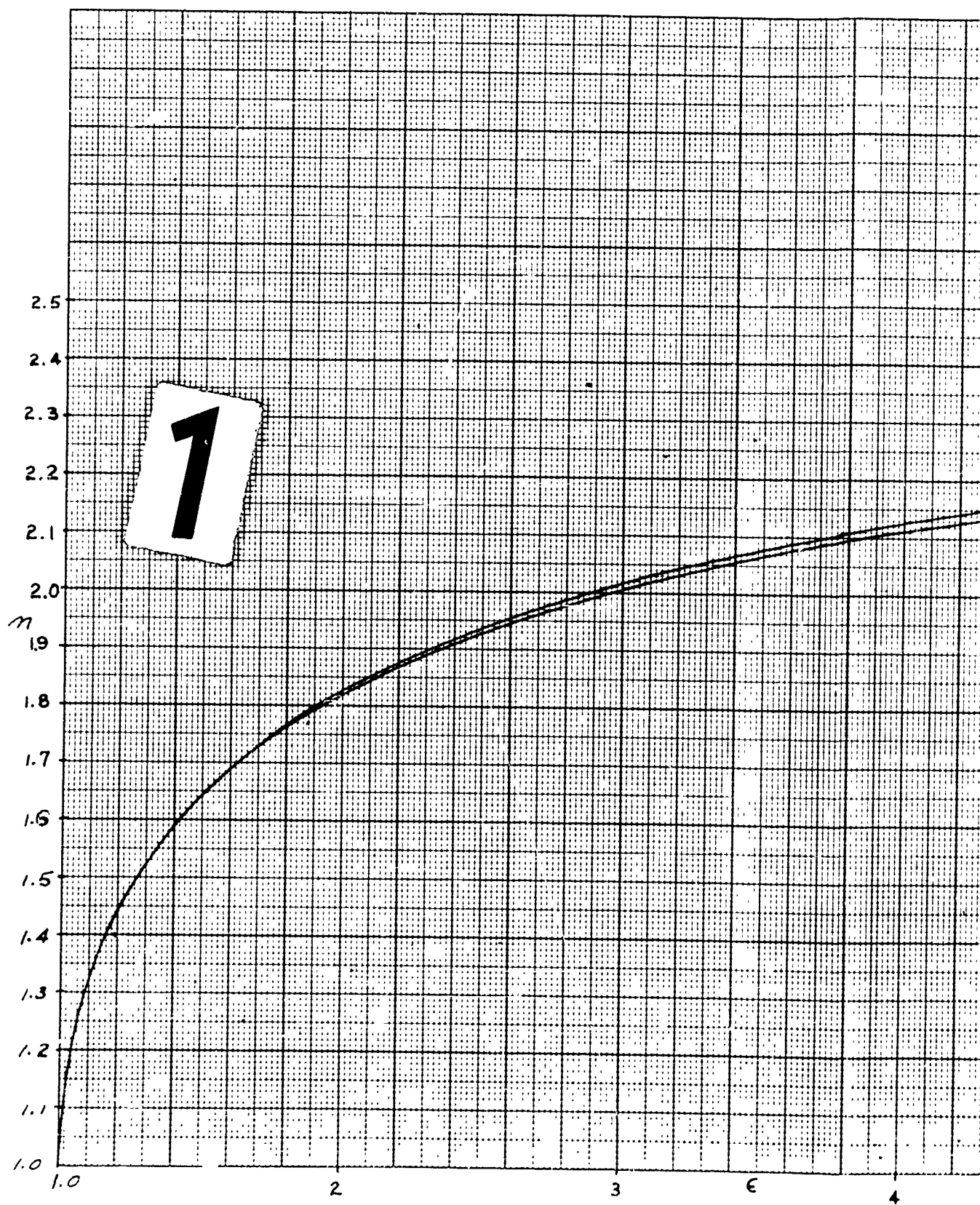


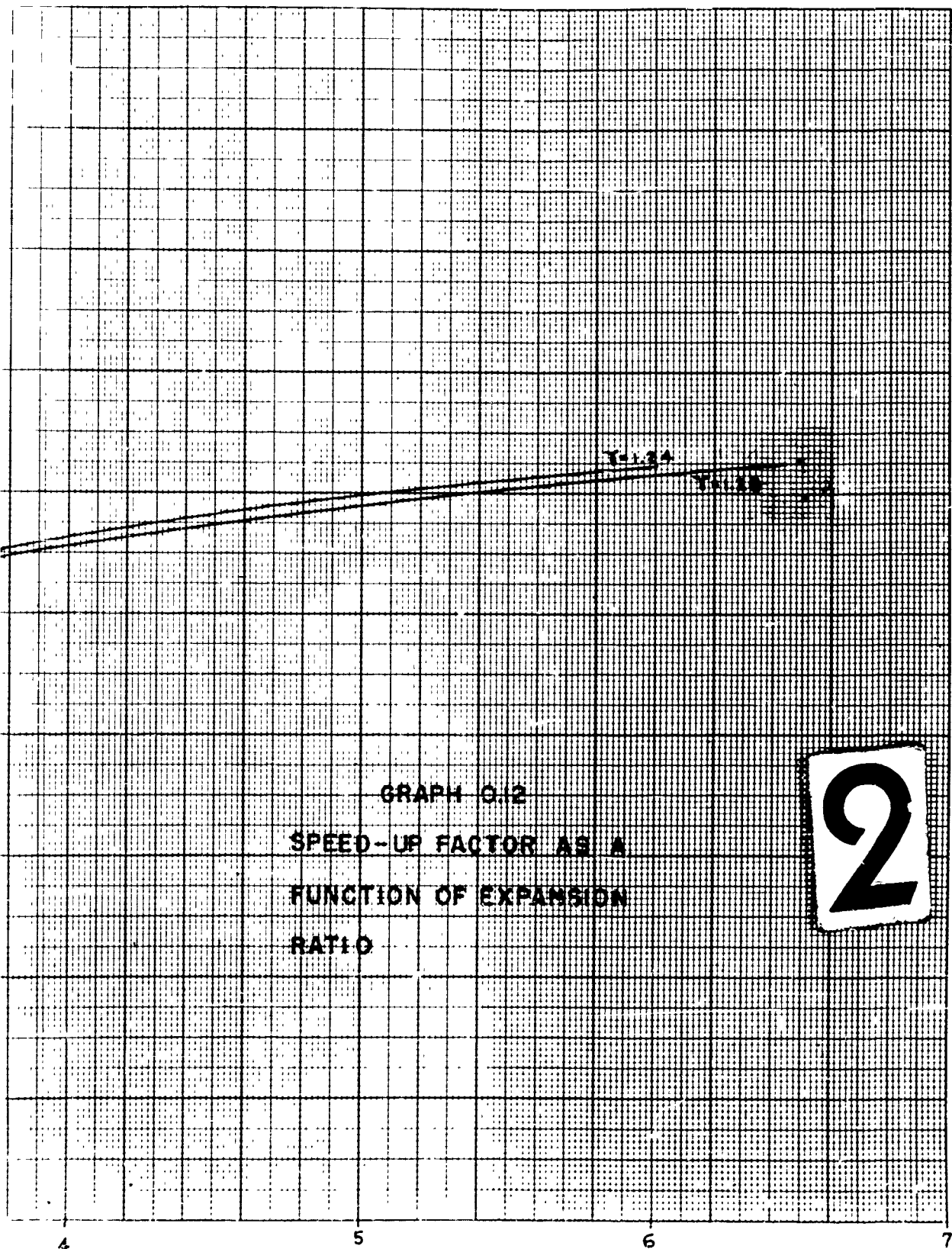












USE OF DIPARDIP

This program was designed to be used with an interpretive routine for the LGP-30 computer called DICTATOR. Consequently the conventions established for that routine will be followed here.

As explained in the INTRODUCTION, DIPARDIP will compute the various parameters of interest in connection with a particular weapon-brake system during the gas discharge period. These parameters are labeled when printed. A sample format with explanations is shown on the next page.

DIPARDIP FORMAT

Energies

Etu

tot	(total energy available)			
proj	(energy taken by projectile)			
gas, kin	(kinetic energy in gas at t.)			
rec mass	(energy of recoiling parts)			
engrv	(engraving energy)			
gas, therm	(thermal energy remaining in gas at t.)			
av T	(average temperature in gas in tube at t.)			
av p	(average pressure in gas in tube at t.)			
1.	t, sec (time from t.)	P, psi (pressure at the breech)	B, lb f (breech force)	dP/dt, lb f (momentum rate of discharge)
2.	B cml (breech impulse)	P, lb f sec (cumulative momentum discharged)	M, lb m (cumulative mass discharged)	H, Btu (cumulative stagnation enthalpy discharged)
3.	I z, lb f sec (resultant axial impulse)	F z, lb f (axial brake force)	I y, lb f sec (normal impulse)	F y, lb, f (normal brake force)
	<u>λ</u> r(closed brakes only)		v eff	ω
				dM/dt, lb m/sec (mass rate of discharge)
				dH/dt, Btu/sec (stagnation enthalpy rate of discharge)
				P-index (momentum index)

To obtain these results, it is necessary to prepare a different type of data tape for each type of brake considered. They are classed as follows:

- Type 1. Closed, asymmetric brakes
- 2. Closed, symmetric brakes
- 3. Open, symmetric brakes
- 4. Closed, free-periphery brakes .

For each of the types, the data pertaining to the weapon and propellant charge must be entered on the data tape as follows:

20000100

γ^*

R

e_c

e_{ig}

A

A_{cnot}

γ_r

M_c

M_{ig}

M_F

M_r

V

exit' .

The data tapes for each type may be completed as shown below. (Refer to the appropriate appendix for a drawing of the brake)

Type 1

20000070'

S01 S11 S21 α_1 β_1 (by rows)

S02 S12 S22 α_2 β_2

S03 S13 S23 α_3 β_3

exit' **

* All numbers must be written in the "x50" system which is used with the DICTATOR interpreter.

** The "exit' " must be typed after β_j for $j=1$ or 2 for a

Type 2

The same data tape format is followed for this type as for type 1, with the exception that β_j is assigned the value 1.5707, $\pi/2$.

Type 3

```
20000090'  
   $\beta_j$  *  
    I  
    Q  
     $z_m$   
     $\alpha_1$   
  exit'
```

Type 4

In addition to the data prepared for a type 1 brake, the following data should be entered:

```
20000052'      *  
 $\beta_{11}$    $\beta_{21}$    $\beta_{31}$   (by rows)  
 $\beta_{12}$    $\beta_{22}$    $\beta_{32}$   
 $\beta_{13}$    $\beta_{23}$    $\beta_{33}$   
  
  exit' ** .
```

The value of β_j used for a type 1 brake is not used for a type 4. Substitution of 0 for this value is, therefore, recommended in preparing a data tape for a type 4 brake.

one or two baffle brake, respectively, i.e., after the last value.

For a two- or three-baffle brake the following must also be typed:

```
10001512'  
8000000(j-1)' .
```

* op cit

** The "exit' " should be placed after the last β_{3j} .

For each of the four types of brake designs considered, there is an initial program location. Corresponding to each initial location, there is a start compute instruction. These are:

- for type 1. 30001509'
- 2. 30001500'
- 3. 30001000'
- 4. 30001505' .

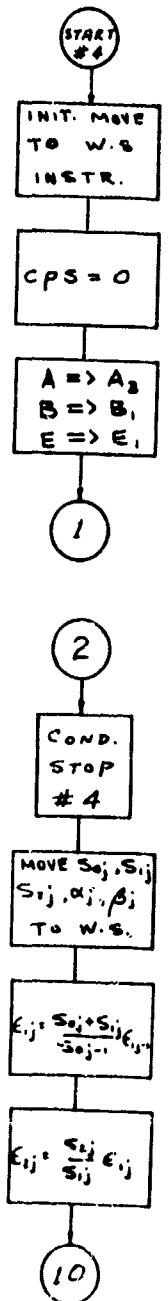
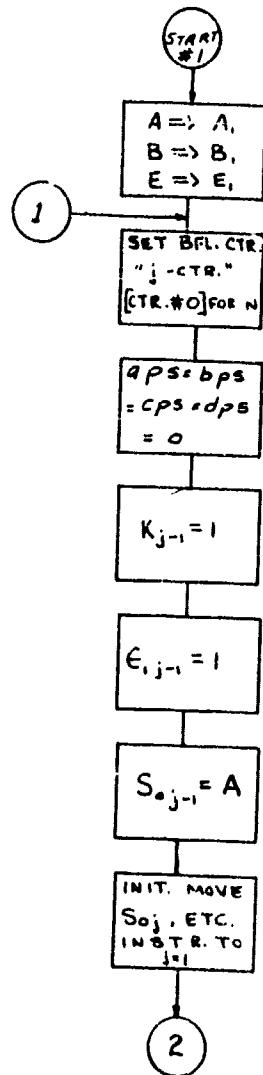
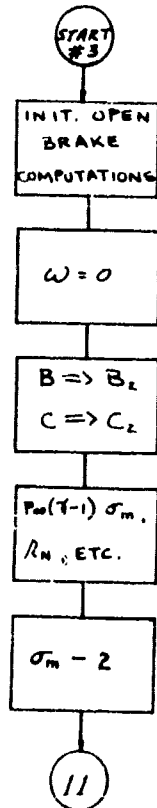
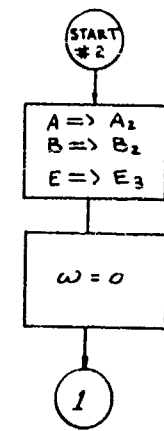
The program uses all breakpoints except 8. Therefore, these must be depressed for uninterrupted operation. If, and only if, the high speed punch is to be used, DICTATOR requires that break point 8 be depressed also.

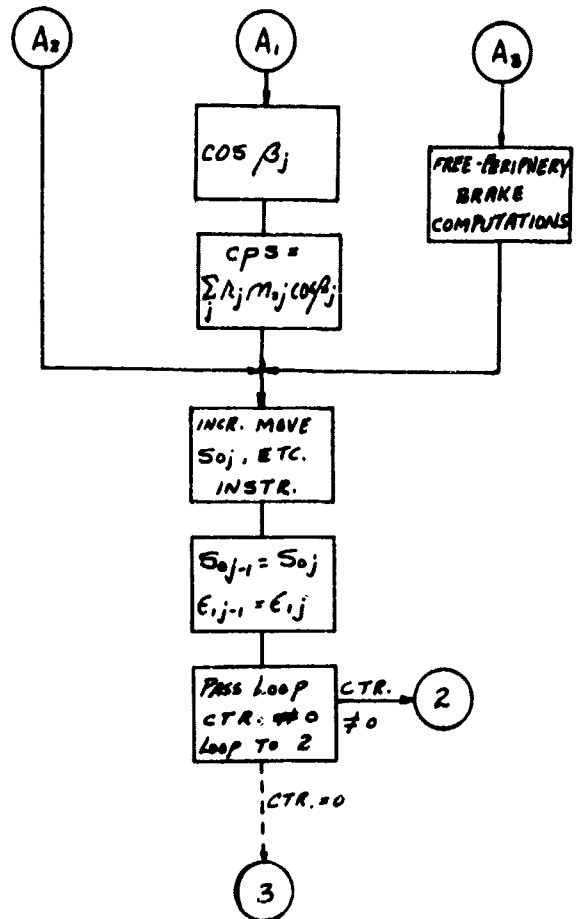
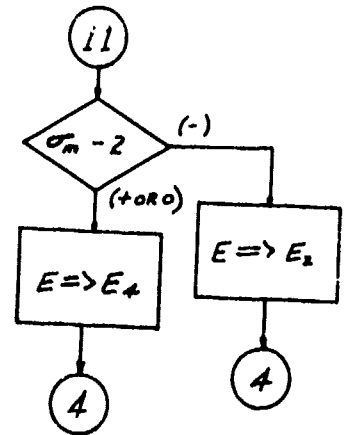
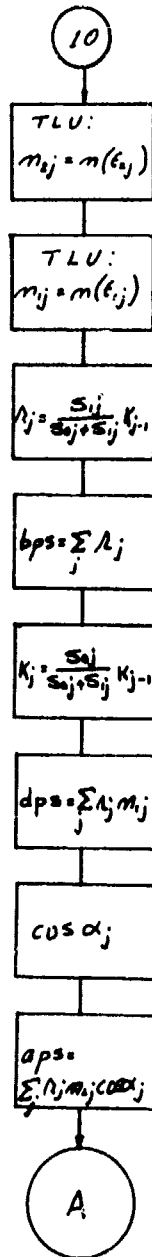
When the break points are not depressed, the computer will stop -- at conditional stop 4 during the computation of the momentum index for closed brakes and prior to printing the parameters for the present value of time, t -- at conditional stop 16 prior to computing the parameters for the next instant in time -- and at stop 32 prior to initializing non-dimensional parameter locations for type 1 brakes.

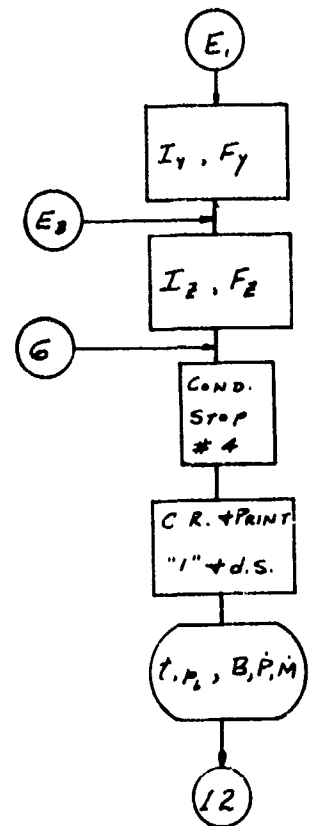
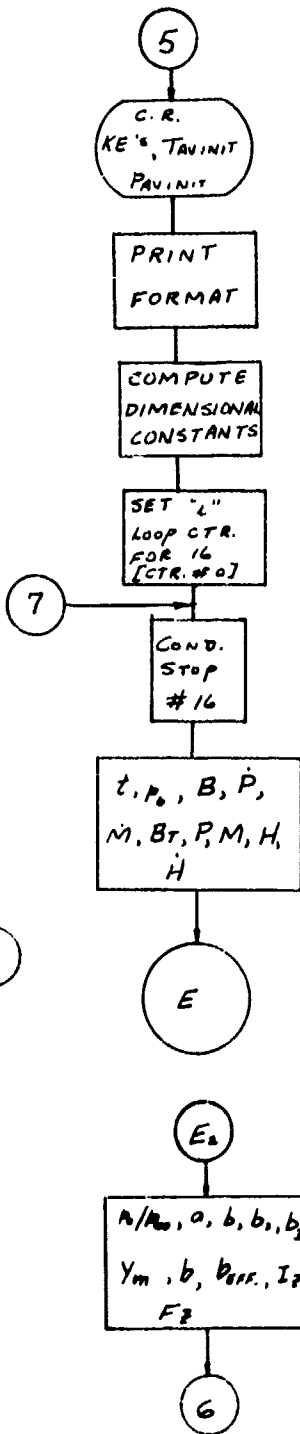
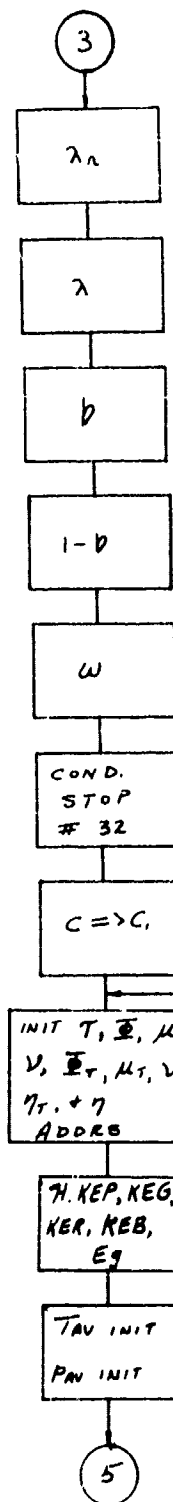
When used with the high speed punch, the computer takes about twenty minutes to complete the computations for one weapon-brake system.

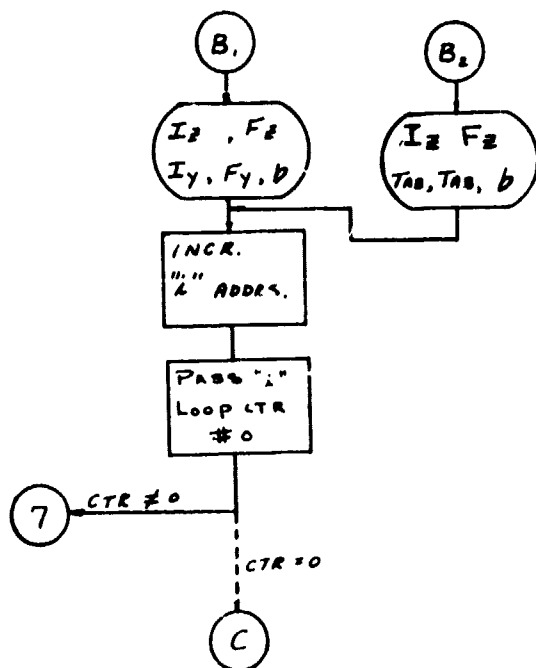
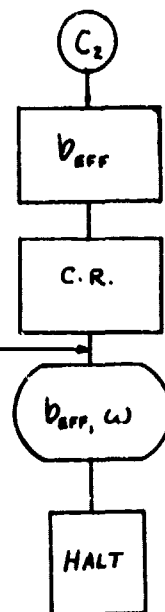
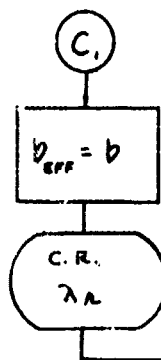
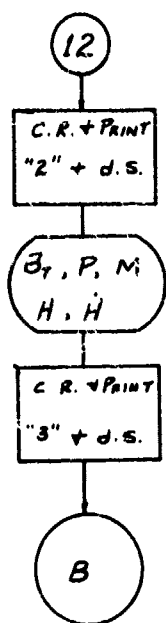
LOGIC DIAGRAM

DIPARDIP

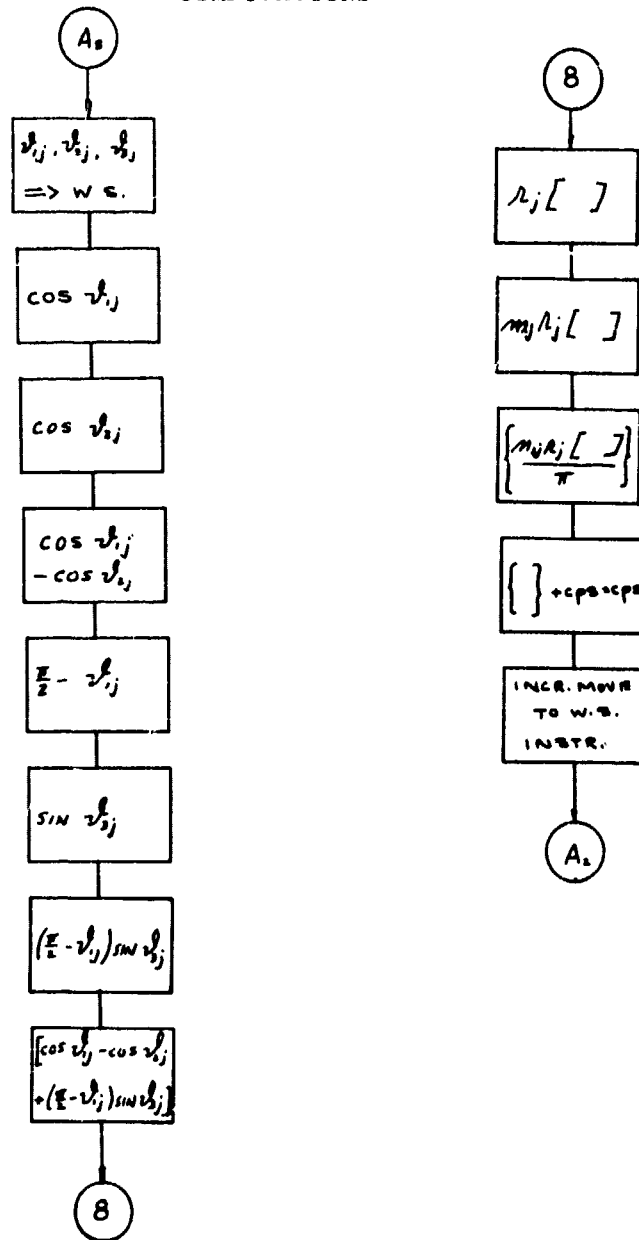




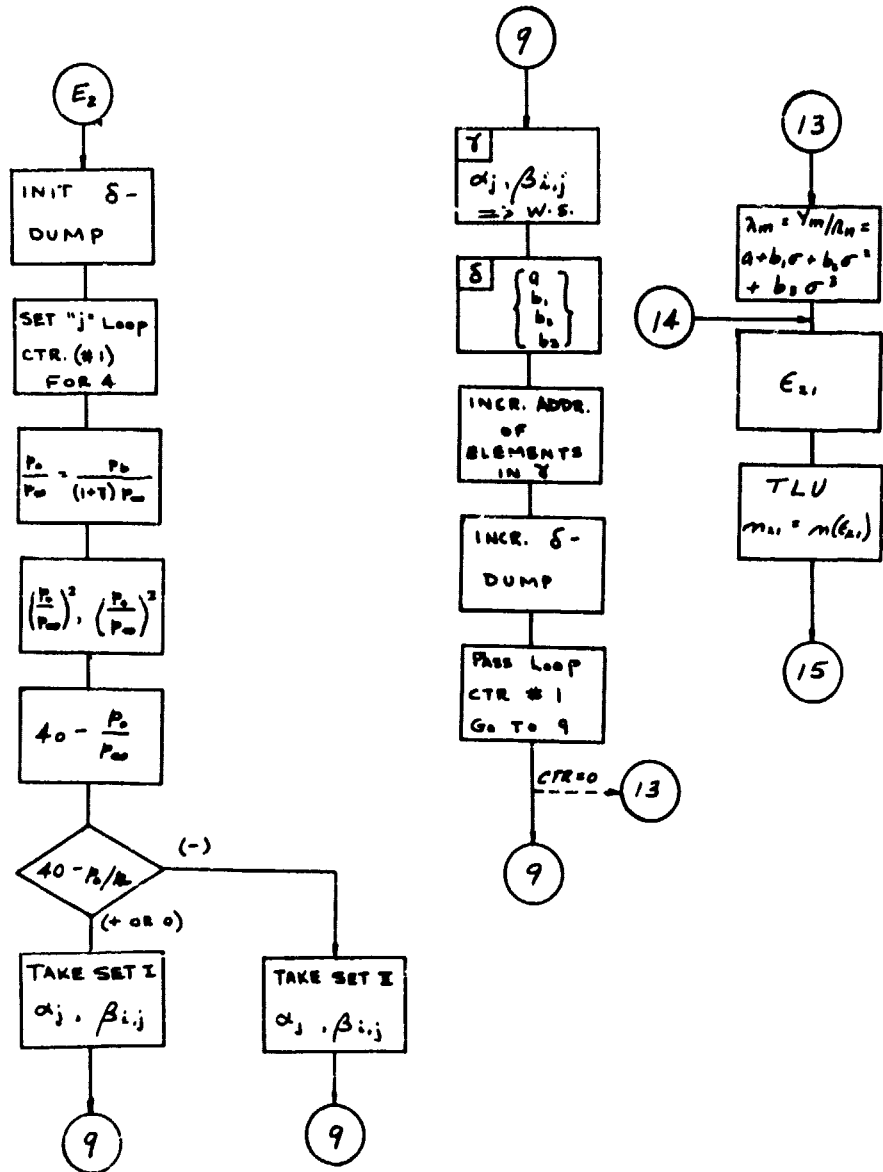


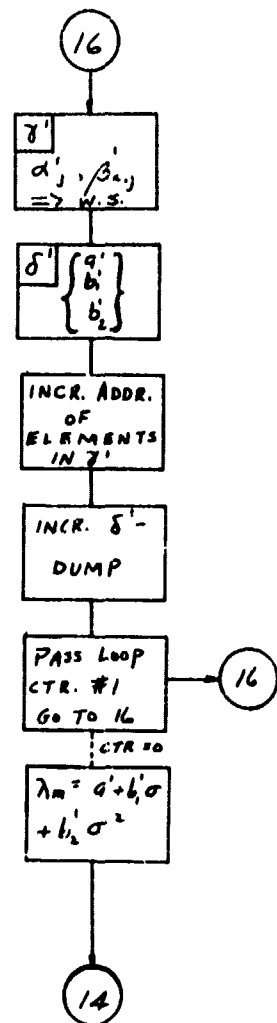
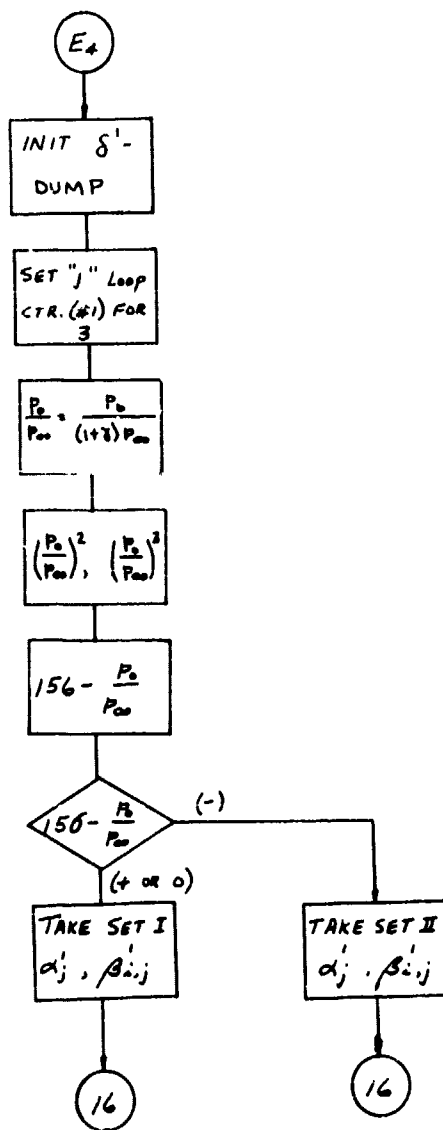


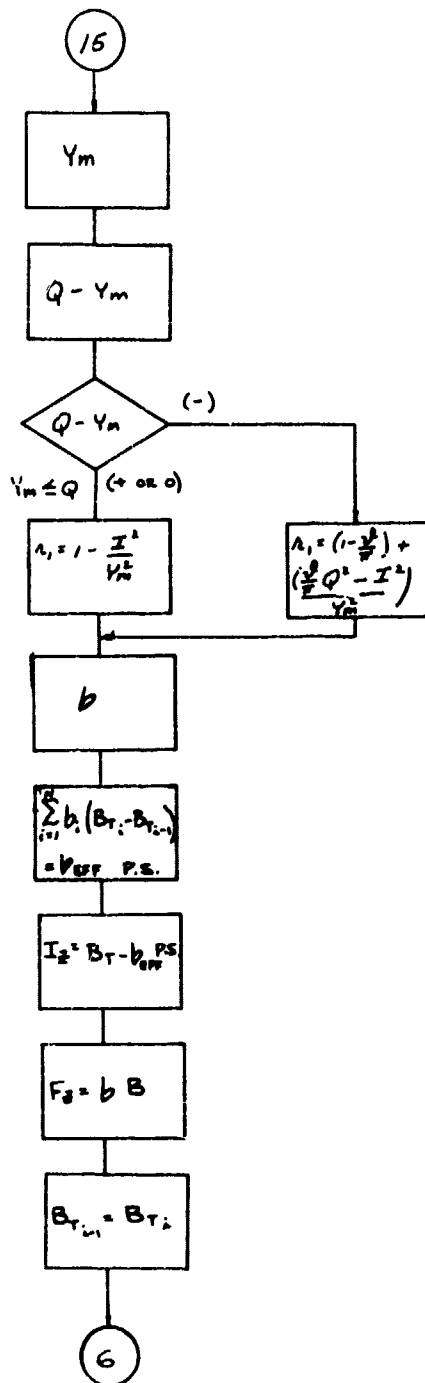
DETAIL LOGIC DIAGRAM FOR
FREE-PERIPHERY BRAKE
COMPUTATIONS



DETAIL LOGIC DIAGRAM
FOR OPEN BRAKE
COMPUTATIONS







STORAGE ALLOCATIONS

General

<u>Locations</u>	<u>Contents</u>
0012-0036	constants
0038-0050	open
0052-0068	$\mathcal{V}_{11} \dots \mathcal{V}_{33}$, for free-periphery brakes
0070-0098	$S_{01} \dots \beta_3$, for closed brakes
0090-0098	$\mathcal{V}$, I, Q, z_m , α , for open brakes
0100-0128	interior ballistic data
0130-0142	constants
0144-0174	$\mathcal{T}$ table
0176-0206	Φ table
0208-0238	μ table
0240-0270	γ table
0272-0302	Φ_r table
0304-0334	μ_r table
0336-0366	γ_r table
0368-0398	η_r table
0400-0498	working storage
0500-0558	print out
0560	$\dot{P}/B = \mu / \Phi$ = .6808226 for $\gamma = 1.26$
0562-0648	open
0650-0680	η table
0682-0738	n table
0740-0796	ϵ table

<u>Locations</u>	<u>Contents</u>	
0798-0820	$\alpha_0 \dots \beta_{32}$	Set I
0822-0844	$\alpha_0' \dots \beta_{32}'$	Set II
0846-0896	open	
0898-0928	$\alpha_0 \dots \beta_{33}$	Set I
0930-0960	$\alpha_0 \dots \beta_{33}$	Set II
0962-0998	open	
1000-1632	program	

Print Out

<u>Location</u>	<u>Content</u>
0500	t, secs
0502	p_b , psia
0504	B, lb _f
0506	$\dot{P}$, lb _f
0508	$\dot{M}$, lb _m /sec
0510	B_T , lb _f secs
0512	P, lb _f secs
0514	M, lb _m
0516	H, Btu
0518	$\dot{H}$, Btu and $\dot{H}$, Btu/sec
0520	KEP, Btu
0522	KEG, Btu
0524	KER, Btu
0526	KEB, Btu

<u>Location</u>	<u>Content</u>
0528	E_g , Btu
0530	$T_{av \text{ init}}$, °R
0532	$P_{av \text{ init}}$, psia
0534	$1 - \phi$
0536	ϕ
0538	λ_r
0540	ω
0542	λ
0544	$\sum_i \phi_i (B_{Ti} - B_{Ti-1})$, ϕ_{eff}
0546	I_z
0548	F_z
0550	I_y
0552	F_y
0554	open
0556	
0558	

Constants and Internal
Ballistic Data

<u>Location</u>	<u>Content</u>
0012	0
0014	14.7, p_{∞}
0016	3.141593, π
0018	40
0020	1.570796, $\pi/2$
0022	1.0495200
0024	-.25021815
0026	-.061082024
0028	.97960297
0030	.10274869
0032	.19109947
0034	156
0036	1.33, f_3
.....	
0100	γ
0102	R
0104	e_c
0106	e_{ig}
0108	A
0110	A_{cnct}
0112	$\mathcal{V}_T$
0114	M_c
0116	M_{ig}
0118	M_p

<u>Location</u>	<u>Content</u>
0120	M_r
0122	v_o
0124	f_o
0126	f_1
0128	f_2
0130	1
0132	2
0134	0.18, tube coefficient of friction
0136	32.17, g
0138	777.5, J
0140	3
0142	12

Closed Brake Data
Storage

<u>Location</u>	<u>Content</u>
0070	S_{01} , in ²
0072	S_{11} , in ²
0074	S_{21} , in ²
0076	α_1 , radians
0078	β_1 , radians
0080	S_{02} , in ²
0082	S_{12} , in ²
0084	S_{22} , in ²
0086	α_2 , radians
0088	β_2 , radians
0090	S_{03} , in ²
0092	S_{13} , in ³
0094	S_{23} , in ²
0096	α_3 , radians
0098	β_3 , radians

Additional Closed Brake Data
Storage for Free-Periphery Designs

<u>Location</u>	<u>Content</u>
0052	ψ_{11} , radians
0054	ψ_{21}
0056	ψ_{31}
0058	ψ_{12}
0060	ψ_{22}
0062	ψ_{32}
0064	ψ_{13}
0066	ψ_{23}
0068	ψ_{33}

Open Brake Data
Storage

<u>Location</u>	<u>Content</u>
0090	ψ , radians
0092	I , inches
0094	Q , inches
0096	z_m , inches
0098	α_1 , radians

General Working Storage

<u>Location</u>	<u>Content</u>
0400	$\beta = \frac{v_o}{a_{av} \text{ init}}$
0402	$p_b \text{ init}$
0404	$A p_b \text{ init}$
0406	$A g p_b \text{ init}$
0408	$a_{av} \text{ init}$
0410	$a_b \text{ init}$
0412	$a_b \text{ init } M_T$
0414	$\frac{M_T a_b \text{ init}}{g} = \frac{A p_b \text{ init}}{\alpha_T}$
0416	$\frac{A g p_b \text{ init}}{a_b \text{ init}}$
0418	$\alpha_T = \frac{A g p_b \text{ init}}{M_T a_b \text{ init}}$
0420	β^2
0422	open
0424	open
0426	ϕ_{av}
0428	ν_{av}
0430	η_{av}
0432	$\left(\frac{v_r}{v_o}\right)^2$
0434	$\frac{v_o^2}{2gJ}$

<u>Location</u>	<u>Content</u>
0436	M_{τ}
0438	$\frac{M_{\tau}}{2} , \left(1 + \frac{v_r}{v_o} \right)$
0440	$\frac{M_{\tau}}{2} + M_p , \frac{v_r}{v_o}$
0442	$\frac{1 + \frac{v_r}{v_o}}{3} , \frac{\left(\frac{v_r}{v_o} \right)^2 + \left(1 + \frac{v_r}{v_o} \right)^2}{3} ,$ $\frac{\left(\frac{v_r}{v_o} \right)^2 + \left(1 + \frac{v_r}{v_o} \right)^2 - \left(\frac{v_r}{v_o} \right) \left(1 + \frac{v_r}{v_o} \right)}{3}$
0444	$(\gamma - 1) E_g J$
0446	$\gamma g R$
0448	$E_g \alpha_{\tau}$
0450	I^2
0452	$\frac{\sqrt{2}}{\pi} Q^2 - I^2$
0454	$1 - \cos \alpha_1$
- - - - -	
0520	$(p_o/p_{\infty})^2$
0522	$(p_o/p_{\infty})^3$

Closed Brake Working Storage

<u>Location</u>	<u>Content</u>
0400	$aps = \sum_j r_j n_{2j} \cos \alpha_j$
0402	$bps = \sum_j r_j$
0404	$cps = \sum_j r_j n_{2j} \cos \beta_j$
0406	$dps = \sum_j r_j n_{1j}$
0408	space
0410	K_{j-1}
0412	ϵ_{1j-1}
0414	s_{0j-1}
0416	$s_{0j} + s_{1j}$
0418	ϵ_{1j}
0420	s_{0j}
0422	s_{1j}
0424	s_{2j}
0426	α_j
0428	β_j
0430	ϵ_{2j}
0432	n_{1j}
0434	n_{2j}
0436	r_j
0438	$n_{1N} (1 - \sum_{j=1}^N r_j)$

LocationContent

0440

$$\nu_{1j}^l$$

0442

$$\nu_{2j}^l$$

0444

$$\nu_{3j}^l$$

0446

$$\cos \nu_{1j}^l, \cos \nu_{1j}^l - \cos \nu_{2j}^l$$

0448

$$\pi/2 - \nu_{1j}^l,$$

$$n_{2j} r_j [\cos \nu_{1j}^l - \cos \nu_{2j}^l + (\pi/2 - \nu_{1j}^l) \cdot \sin \nu_{3j}^l]$$

Open Brake Working Storage

<u>Location</u>	<u>Content</u>
0450	I^2
0452	$\frac{v^l}{\pi} Q^2 - I^2$
0454	$1 - \cos \alpha_1$
0456	open
0458	$r_N = \sqrt{\frac{A}{\pi}}$
0460	α_j
0462	β_{1j}
0464	β_{2j}
0466	β_{3j}
0468	a
0470	b_1
0472	b_2
0474	b_3
0476	$\sigma_m = \frac{z_m}{r_N}$
0478	σ_m^2
0480	σ_m^3
0482	$(1 + \gamma) p_{\infty}$
0484	$\frac{v^l}{\pi}$
0486	$1 - \frac{v^l}{\pi}$
0488	$(B_T)_{1-1}$

<u>Location</u>	<u>Content</u>
0490	$\frac{y_m}{r_N}, y_m$
0492	$1 + \frac{\sqrt{q}}{\pi} \left(\frac{y_m}{r_N} \right)^2 = \epsilon_{21}$
0494	$n_{21} = n(\epsilon_{21})$
0496	p_o / p_∞
0498	r_1

LGP-30 CODING SHEET (Dictator Format)											
PREPARED FOR: MUZZLE BRAKES						JOB NO.		PROGRAM NO.		PAGE NO. NO. OF PAGES	
PROGRAM PREPARED BY: G. SCHLENKER				PROGRAM CHECKED BY:		DATE PREPARED:		DATE RUN:		SUPERSEDED BY PROGRAM NO.	
PROBLEM:											
LOCATION (MARK APPROP. COLUMNS)				OPER- ATION	A	OPER- ATION	B	C	REMARKS		
1000	25	50	75			15	0098	0000	START E. OPEN BRAKE		
01	26	51	76	2	0130		0000	0454	COS α_1		
02	27	52	77			4	1417	1421	$B \Rightarrow B_1$		
03	28	53	78			4	1437	1444	☒ $C \Rightarrow C_1$		
04	29	54	79	6	0002		0012	0540	$\omega = 0$		
05	30	55	80	6	0002		0012	0488	$(B_1)_{1-1} = 0$		
06	31	56	81	6	0002		0012	0544	FOR P.S. = 0		
07	32	57	82	3	0094		0094	0452	☒ Q^1		
08	33	58	83	3	0092		0092	0450	I^1		
09	34	59	84			1	0000	1628			
1010	35	60	85	1	0130		0100	0000	$1 + T$		
11	36	61	86	3	0000		0014	0482	☒ $(1 + T) P_0$		
12	37	62	87	4	0108		0016	0000	Q / T		
13	38	63	88			13	0000	0458	R_N		
14	39	64	89	4	0096		0000	0476	σ_m		
15	40	65	90	3	0000		0000	0478	☒ σ_m^1		
16	41	66	91	3	0000		0476	0480	σ_m^3		
17	42	67	92	2	0476		0132	0000	$\sigma_m - 2$		
18	43	68	93			2	1585	1019	FOR $\sigma_m^E 2$, $\Rightarrow 1585$		
1019	44	69	94			4	1397	1451	☒ $E \Rightarrow E_1$		
1020	45	70	95			6	1386	0144	INITIALIZE T FOR t		
21	46	71	96			5	1387	0176	FOR P		
22	47	72	97			5	1388	0176	FOR B		
23	48	73	98			5	1389	0208	☒ FOR P		
1021	49	74	99			5	1390	0240	☒ FOR M		

LGP-30 CODING SHEET (Dictator Format)															
PREPARED FOR:							JOB NO.			PROGRAM NO.		PAGE NO. 2		NO. OF PAGES 26	
PROGRAM PREPARED BY:				PROGRAM CHECKED BY:				DATE PREPARED:			DATE RUN:		SUPERSEDED BY PROGRAM NO.		
PROBLEM:															
LOCATION (MAKE APPROP. COLUMNS)				OPER- ATION	A	OPER- ATION	B	C	REMARKS						
00	1025	50	75			5	1391	0272	INITIALIZE E_r FOR B_r						
01	26	51	76			5	1392	0304	μ_r FOR P						
02	27	52	77			5	1393	0336	V_r FOR M						
03	28	53	78			5	1394	0368	X η_r FOR H						
04	29	54	79			5	1395	0650	η FOR H						
05	30	55	80	3	0104		0114	0518	H_a						
06	31	56	81	3	0106		0116	0000	H_g						
07	32	57	82	1	0000		0518	0518	X H						
08	33	58	83	3	0122		0122	0000	V_a^2						
09	34	59	84	4	0000		0132	0000	$V_a^2/2$						
10	35	60	85	4	0000		0136	0000	$V_a^2/2g$						
11	36	61	86	4	0000		0138	0434	X $V_a^2/2gJ$						
12	37	62	87	3	0000		0118	0520	K.E.P.						
13	38	63	88	1	0114		0116	0436	M_r						
14	39	64	89	4	0000		0132	0438	$M_r/2$						
15	40	65	90	1	0000		0118	0440	X $M_r/2 + M_p$						
16	41	66	91	1	0438		0120	0000	$M_r/2 + M_a$						
17	42	67	92	4	0440		0000	0440	V_a/V_a						
18	43	68	93	1	0000		0130	0438	$(1 + V_a/V_a)$						
19	44	69	94	3	0000		0000	0000	X $(1 + V_a/V_a)^2$						
20	45	70	95	4	0000		0140	0442	$1/2 (1 + V_a/V_a)^2$						
21	46	71	96	3	0440		0440	0432	$(V_a/V_a)^2$						
22	47	72	97	1	0000		0442	0442	$(V_a/V_a)^2 + 1/2 (1 + V_a/V_a)^2$						
23	48	73	98	5	0438		0440	0000	X $-(V_a/V_a)(1 + V_a/V_a)$						
24	1049	74	99	1	0000		0442	0442							

LGP-30 CODING SHEET (Dictator Format)													
PREPARED FOR:						JOB NO.		PROGRAM NO.		PAGE NO. 3		NO. OF PAGES 26	
PROGRAM PREPARED BY:				PROGRAM CHECKED BY:				DATE PREPARED:		DATE RUN:		SUPERSEDED BY PROGRAM NO.	
PROBLEM:													
LOCATION (MARK APPROP. COLUMNS)				OPERATION	A	OPERATION	B	C	REMARKS				
00	25	1050	75	3	0000		0436	0000					
01	26	51	76	3	0000		0434	0522	K.E.G.				
02	27	52	77	3	0432		0434	0000	$V_n^2 / 2gJ$				
03	28	53	78	3	0000		0120	0524	X K.E.R.				
04	29	54	79	3	0134		0110	0000	.180 CMT				
05	30	55	80	4	0000		0108	0000	.180 CMT / 0				
06	31	56	81	3	0000		0520	0526	K.E.B.				
07	32	57	82	1	0000		0524	0000	X				
08	33	58	83	1	0000		0522	0000					
09	34	59	84	1	0000		0520	0000	$\Sigma K.E. 5$				
10	35	60	85	2	0518		0000	0528	Eg				
11	36	61	86	2	0100		0130	0000	X				
12	37	62	87	3	0000		0528	0000					
13	38	63	88	3	0000		0138	0444	(3-1) Eg J/R				
14	39	64	89	4	0000		0102	0000					
15	40	65	90	4	0000		0436	0530	X TAV INIT				
16	41	66	91	3	0142		0444	0000					
17	42	67	92	4	0000		0112	0532	TAV INIT				
18	43	68	93				8009	0016	C.R.				
19	44	69	94					0008	X U.C.				
20	45	70	95					0037	E				
21	46	71	96					0025	N				
22	47	72	97					0037	E				
23	48	73	98					0013	X R				
24	49	1074	99				8009	0046	G				

LGP-30 CODING SHEET (Dictator Format)

PREPARED FOR:	JOB NO.	PROGRAM NO.	PAGE NO. 4	NO. OF PAGES 26
PROGRAM PREPARED BY:	PROGRAM CHECKED BY:	DATE PREPARED:	DATE RUN:	SUPERSEDED BY PROGRAM NO.

PROBLEM:

LOCATION (MARK APPROP. COLUMNS)				OPER ATION	A	OPER ATION	B	C	REMARKS
00	25	50	1075				8009	0017	I
01	26	51	76					0037	E
02	27	52	77					0061	S
03	28	53	78					0024	X TAB
04	29	54	79					0005	B
05	30	55	80					0004	L.C.
06	31	56	81					0045	t
07	32	57	82					0041	X u
08	33	58	83					0016	C.R.
09	34	59	84					0045	t
10	35	60	85					0035	o
11	36	61	86					0045	X t
12	37	62	87				8009	0024	TAB
13	38	63	88			18	0518	0518	H
14	39	64	89				8009	0016	C.R.
15	40	65	90					0033	X P
16	41	66	91					0013	A
17	42	67	92					0035	o
18	43	68	93					0050	j
19	44	69	94				8009	0024	X TAB
20	45	70	95			18	0520	0520	K.F.B.
21	46	71	96				8009	0016	C.R.
22	47	72	97				8009	0046	j
23	48	73	98				8009	0057	X A
24	49	74	1099				8009	0061	S

LGP-30 CODING SHEET (Dictator Format)											
PREPARED FOR:						JOB NO.		PROGRAM NO.		PAGE NO. NO. OF PAGES	
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PROBLEM:										SUPERSEDED BY PROGRAM NO.	
LOCATION (MARK APPROP. COLUMNS)				OPERATION	A	OPERATION	B	C	REMARKS		
1100	25	50	75				8009	0027			
01	26	51	76					0003	SP.		
02	27	52	77					0054	K		
03	28	53	78					0017	X I		
04	29	54	79					0025	N		
05	30	55	80				8009	0024	TAB		
06	31	56	81			18	0522	0522	K.E.G.		
07	32	57	82				8009	0016	X C.R.		
08	33	58	83					0013	R		
09	34	59	84					0037	E		
10	35	60	85					0053	C		
11	36	61	86					0003	X SP.		
12	37	62	87					0029	M		
13	38	63	88					0057	A		
14	39	64	89					0061	S		
15	40	65	90					0061	X S		
16	41	66	91				8009	0024	TAB		
17	42	67	92			18	0524	0524	K.E.R.		
18	43	68	93				8009	0016	C.R.		
19	44	69	94					0037	X E		
20	45	70	95					0025	N		
21	46	71	96					0046	G		
22	47	72	97					0013	R		
23	48	73	98					0031	X V		
1124	49	74	99				8009	0024	TAB		

LGP-30 CODING SHEET (Dictator Format)											
PREPARED FOR:						JOB NO.		PROGRAM NO.		PAGE NO. NO. OF PAGES	
PROGRAM PREPARED BY:						PROGRAM CHECKED BY:		DATE PREPARED:		DATE RUN:	
PROBLEM:										SUPERSEDED BY PROGRAM NO.	
LOCATION (MARK APPROP. COLUMNS)				OPERATION	A	OPERATION	B	C	REMARKS		
00	1125	50	75			18	0526	0526	K.E. B.		
01	26	51	76				8009	0016	C.R.		
02	27	52	77					0046	G		
03	28	53	78					0057	X A		
04	29	54	79					0061	S		
05	30	55	80					0027	.		
06	31	56	81					0003	SP		
07	32	57	82					0045	X T		
08	33	58	83					0049	H		
09	34	59	84					0037	E		
10	35	60	85					0013	R		
11	36	61	86					0029	X M		
12	37	62	87				8009	0024	TAB		
13	38	63	88			18	0528	0528	Eg		
14	39	64	89				8009	0016	C.R.		
15	40	65	90					0016	X C.R.		
16	41	66	91					0057	A		
17	42	67	92					0031	V		
18	43	68	93					0003	SP		
19	44	69	94					0008	X U.C.		
20	45	70	95					0045	T		
21	46	71	96					0004	L.C.		
22	47	72	97				8009	0024	TAB		
23	48	73	98			18	0530	0530	X TAN INIT		
24	1149	74	99				8009	0016	C.R.		

LGP-30 CODING SHEET (Dictator Format)											
PREPARED FOR:						JOB NO.		PROGRAM NO.		PAGE NO. NO. OF PAGES	
PROGRAM PREPARED BY:						PROGRAM CHECKED BY:		DATE PREPARED:		DATE RUN:	
PROBLEM:										SUPERSEDED BY PROGRAM NO.	
LOCATION (MARK APPROP. COLUMNS)				OPER ATION	A	OPER ATION	B	C	REMARKS		
00	25	1150	75				8009	0057	A		
01	26	51	76					0031	V		
02	27	52	77					0003	SP		
03	28	53	78					0033	P		
04	29	54	79				8009	0024	TAB		
05	30	55	80			18	0532	0532	Fav INIT		
06	31	56	81				8009	0016	C.B.		
07	32	57	82					0016	C.B.		
08	33	58	83					0006	I FORMAT		
09	34	59	84					0003	SP		
10	35	60	85					0003	SP		
11	36	61	86					0045	t		
12	37	62	87					0027	.		
13	38	63	88					0003	SP		
14	39	64	89					0061	S		
15	40	65	90					0037	E		
16	41	66	91					0053	C		
17	42	67	92					0024	TAB		
18	43	68	93					0033	P		
19	44	69	94					0027	.		
20	45	70	95					0003	SP		
21	46	71	96					0033	P		
22	47	72	97					0061	S		
23	48	73	98					0017	I		
24	49	1174	99				8009	0057	A		

LGP-30 CODING SHEET (Dictator Format)											
PREPARED FOR:						JOB NO.		PROGRAM NO.		PAGE NO. NO. OF PAGES	
PROGRAM PREPARED BY:				PROGRAM CHECKED BY:		DATE PREPARED:		DATE RUN:		SUPERSEDED BY PROGRAM NO.	
PROBLEM:											
LOCATION (MARK APPROP. COLUMNS)				OPER ATION	A	OPER ATION	B	C	REMARKS		
00	25	50	1175				8009	0024			TAB
01	26	51	76					0008			V.C.
02	27	52	77					0005			B
03	28	53	78					0004	X		L.C.
04	29	54	79					0027			,
05	30	55	80					0003			SP
06	31	56	81					0006			L
07	32	57	82					0005	X		B
08	33	58	83					0003			SP
09	34	59	84					0042			F
10	35	60	85					0024			TAB
11	36	61	86					0021	X		D
12	37	62	87					0008			V.C.
13	38	63	88					0033			P
14	39	64	89					0004			L.C.
15	40	65	90					0019	X		/
16	41	66	91					0021			D
17	42	67	92					0045			T
18	43	68	93					0027			,
19	44	69	94					0003	X		SP
20	45	70	95					0006			L
21	46	71	96					0005			B
22	47	72	97					0003			SP
23	48	73	98					0042	X		F
24	49	74	1199				8009	0024			TAB

LGP-30 CODING SHEET (Dictator Format)											
PREPARED FOR:						JOB NO.		PROGRAM NO.		PAGE NO. 9	
PROGRAM PREPARED BY:				PROGRAM CHECKED BY:		DATE PREPARED:		DATE RUN:		SUPERSEDED BY PROGRAM NO. 26	
PROBLEM:											
LOCATION (MARK APPROP. COLUMNS)				OPER- ATION	A	OPER- ATION	B	C	REMARKS		
1200	25	50	75				8009	0021			D
01	26	51	76					0008			V.C.
02	27	52	77					0029			M
03	28	53	78					0004	X		L.C.
04	29	54	79					0019			/
05	30	55	80					0021			D
06	31	56	81					0045			T
07	32	57	82					0027	X		,
08	33	58	83					0003			SP
09	34	59	84					0006			L
10	35	60	85					0005			B
11	36	61	86					0003	X		SP.
12	37	62	87					0029			M
13	38	63	88					0019			/
14	39	64	89					0061			S
15	40	65	90					0037	X		E
16	41	66	91					0053			C
17	42	67	92					0016			C.B.
18	43	68	93					0010			2
19	44	69	94					0003	X		SP
20	45	70	95					0003			SP
21	46	71	96					0008			V.C.
22	47	72	97					0005			B
23	48	73	98					0004	X		L.C.
1200	49	74	99				8009	0003			SP

LGP-30 CODING SHEET (Dictator Format)											
PREPARED FOR:						JOB NO.		PROGRAM NO.		PAGE NO. NO. OF PAGES	
										10 26	
PROGRAM PREPARED BY:				PROGRAM CHECKED BY:				DATE PREPARED:		DATE RUN:	
										SUPERSEDED BY PROGRAM NO.	
PROBLEM:											
LOCATION (MARK APPROP. COLUMNS)				OPER ATION	A	OPER ATION	B	C	REMARKS		
00	1225	50	75				8009	0053	C		
01	26	51	76					0029	M		
02	27	52	77					0006	L		
03	28	53	78					0024	TAB		
04	29	54	79					0008	U.C.		
05	30	55	80					0033	P		
06	31	56	81					0004	L.C.		
07	32	57	82					0027	,		
08	33	58	83					0003	SP		
09	34	59	84					0006	L		
10	35	60	85					0005	B		
11	36	61	86					0003	SP		
12	37	62	87					0042	F		
13	38	63	88					0003	SP		
14	39	64	89					0003	SP		
15	40	65	90					0061	S		
16	41	66	91					0037	E		
17	42	67	92					0053	C		
18	43	68	93					0024	TAB		
19	44	69	94					0008	U.C.		
20	45	70	95					0029	M		
21	46	71	96					0004	L.C.		
22	47	72	97					0027	,		
23	48	73	98					0003	SP		
24	1249	74	99				8009	0006	L		

LGP-30 CODING SHEET (Dictator Format)									
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PROGRAM PREPARED BY:			PROGRAM CHECKED BY:			DATE PREPARED:		DATE RUN:	
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PROBLEM:									
LOCATION (MARK APPROP. COLUMNS)				OPER- ATION	A	OPER- ATION	B	C	REMARKS
00	25	1250	75				8009	0005	B
01	26	51	76					0003	SP
02	27	52	77					0029	M
03	28	53	78					0024	X TAB
04	29	54	79					0008	U.C.
05	30	55	80					0049	H
06	31	56	81					0004	L.C.
07	32	57	82					0027	X ,
08	33	58	83					0008	U.C.
09	34	59	84					0003	SP
10	35	60	85					0005	B
11	36	61	86					0004	X L.C.
12	37	62	87					0045	T
13	38	63	88					0041	U
14	39	64	89					0024	TAB
15	40	65	90					0021	X D
16	41	66	91					0008	U.C.
17	42	67	92					0049	H
18	43	68	93					0004	L.C.
19	44	69	94					0019	X /
20	45	70	95					0021	D
21	46	71	96					0045	I
22	47	72	97					0027	,
23	48	73	98					0003	X SP
24	49	1274	99				8009	0008	U.C.

LGP-3G CODING SHEET (Dictator Format)											
PREPARED FOR:						JOB NO.		PROGRAM NO.		PAGE NO. NO. OF PAGES	
PROGRAM PREPARED BY:				PROGRAM CHECKED BY:		DATE PREPARED:		DATE RUN:		SUPERSEDED BY PROGRAM NO.	
PROBLEM:											
LOCATION (MAKE APPROP. COLUMNS)				OPERATION	A	OPERATION	B	C	REMARKS		
00	25	50	1275				8009	0005			B
01	26	51	76					0004			L.C.
02	27	52	77					0045			T
03	28	53	78					0041	X		V
04	29	54	79					0019			/
05	30	55	80					0061			S
06	31	56	81					0037			E
07	32	57	82					0053	X		C
08	33	58	83					0016			C.R.
09	34	59	84					0014			3
10	35	60	85					0003			SP.
11	36	61	86					0003	X		SP.
12	37	62	87					0008			V.C.
13	38	63	88					0017			I
14	39	64	89					0004			L.C.
15	40	65	90					0003	X		SP.
16	41	66	91					0001			Z
17	42	67	92					0027			,
18	43	68	93					0003			SP.
19	44	69	94					0006	X		L
20	45	70	95					0005			B
21	46	71	96					0003			SP.
22	47	72	97					0042			F
23	48	73	98					0003	X		SP.
24	49	74	1299				8009	0061			S

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PREPARED FOR:						JOB NO.		PROGRAM NO.		PAGE NO. NO. OF PAGES	
PROGRAM PREPARED BY:						PROGRAM CHECKED BY:		DATE PREPARED:		DATE RUN:	
PROBLEM:										SUPERSEDED BY PROGRAM NO.	
LOCATION (MARK APPROP. COLUMNS)				OPER- ATION	A	OPER- ATION	B	C	REMARKS		
1300	25	50	75				8009	0037			E
01	26	51	76					0053			C
02	27	52	77					0024			TAB
03	28	53	78					0008	X		U.C.
04	29	54	79					0042			E
05	30	55	80					0004			L.C.
06	31	56	81					0003			SP
07	32	57	82					0001	X		Z
08	33	58	83					0027			,
09	34	59	84					0003			SP
10	35	60	85					0006			L
11	36	61	86					0005	X		B
12	37	62	87					0003			SP
13	38	63	88					0042			E
14	39	64	89					0024			TAB
15	40	65	90					0008	X		U.C.
16	41	66	91					0017			I
17	42	67	92					0004			L.C.
18	43	68	93					0003			SP
19	44	69	94					0009	X		Y
20	45	70	95					0027			,
21	46	71	96					0003			SP
22	47	72	97					0006			L
23	48	73	98					0005	X		B
1324	49	74	99				8009	0003			SP

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PROGRAM PREPARED BY:			PROGRAM CHECKED BY:			DATE PREPARED:		DATE RUN:		SUPERSEDED BY PROGRAM NO.	
PROBLEM:											
LOCATION (MARK APPROP. COLUMNS)				OPER- ATION	A	OPER- ATION	B	C	REMARKS		
00	13	25	50	75			8009	0042			F
01	26	51	76					0003			SP.
02	27	52	77					0061			S
03	28	53	78					0037	X		E
04	29	54	79					0053			C
05	30	55	80					0024			TAB
06	31	56	81					0008			U.C.
07	32	57	82					0042	X		F
08	33	58	83					0004			L.C.
09	34	59	84					0003			SP.
10	35	60	85					0009			Y
11	36	61	86					0027	X		I
12	37	62	87					0003			SP.
13	38	63	88					0006			L
14	39	64	89					0005			B
15	40	65	90					0003	X		SP.
16	41	66	91					0042			F
17	42	67	92					0024			TAB
18	43	68	93					0008			U.C.
19	44	69	94					0033	X		P
20	45	70	95					0004			L.C.
21	46	71	96					0007			-
22	47	72	97					0017			I
23	48	73	98					0025	X		N
24	13	49	74	99			8009	0021			D

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PROBLEM:													
LOCATION (MARK APPROP. COLUMNS)				OPER ATION	A	OPER ATION	B	C	REMARKS				
00	25	1350	75				8009	0037	E				
01	26	51	76				8009	0039	X				
02	27	52	77				8009	0016	C.R.				
03	28	53	78			1	0000	1354	X				
04	29	1354	79	3	0100		0136	0000	8g				
05	30	55	80	3	0000		0102	0000	8gR				
06	31	56	81	3	0000		0530	0000	8gR TAN INIT				
07	32	57	82			13	0000	0408	X TAN INIT				
08	33	58	83	4	0122		0000	0400	A				
09	34	59	84	3	0000		0000	0420	B				
10	35	60	85	3	0000		0026	0426					
11	36	61	86	3	0400		0024	0000	X				
12	37	62	87	1	0000		0426	0000					
13	38	63	88	1	0000		0022	0426	TAN INIT				
14	39	64	89			1	0000	1366					
15	40	65	90			1	0000	1366	X				
16	41	1366	91	4	0532		0000	0402	E INIT				
17	42	17	92	3	0000		0108	0404	AP INIT				
18	43	18	93	3	0000		0136	0406	ag P INIT				
19	44	69	94	3	0420		0032	0430	X				
20	45	70	95	3	0400		0030	0000					
21	46	71	96	1	0000		0430	0000					
22	47	72	97	1	0000		0028	0430	K INIT				
23	48	73	98			1	0000	1374	X				
24	49	1374	99	3	0000		0426	0428	TAN INIT				

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PROBLEM:											
LOCATION (MARK APPROP. COLUMNS)				OPERATION	A	OPERATION	B	C	REMARKS		
00	25	50	1375			13	0000	0000	(2)AV INIT) %		
01	26	51	76	4	0408		0000	0410	Ab INIT		
02	27	52	77	3	0000		0436	0412	MT Ab INIT		
03	28	53	78	4	0000		0136	0414	X MT Ab INIT / g		
04	29	54	79	4	0406		0412	0418	AT		
05	30	55	80	4	0406		0410	0416	ag Pb INIT / Ab INIT		
06	31	56	81	3	0528		0418	0448	Eg AT		
07	32	57	82	6	0002		0012	0552	X Ey = 0 , INIT		
08	33	58	83			1	0000	1384			
09	34	59	84				8000	0015	SET LOOP STR. #0 FOR 16		
10	35	60	35				8008	0016	COND. STOP #16		
11	36	61	86	4	[0144]		0418	0500	X t		
12	37	62	87	3	0402		[0176]	0502	P		
13	38	63	88	3	0404		[0176]	0504	B		
14	39	64	89	3	0404		[0208]	0506	P		
15	40	65	90	3	0416		[0240]	0508	X M		
16	41	66	91	3	0414		[0272]	0510	Br		
17	42	67	92	3	0414		[0304]	0512	P		
18	43	68	93	3	0436		[0336]	0514	M		
19	44	69	94	3	0528		[0368]	0516	X H		
20	45	70	95	3	0448		[0650]	0518	H		
21	46	71	96			1	0000	1397			
22	47	72	97			1	0000	1398			
23	48	73	98	3	0540		0512	0550	X Iy = w P		
24	49	74	1399	3	0540		0506	0552	Fy = w P		

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PROBLEM:													
LOCATION (MARK APPROP. COLUMNS)				OPERATION	A	OPERATION	B	C	REMARKS				
1400	25	50	75	3	0534		0510	0546	I ₂				
01	26	51	76	3	0536		0504	0548	F ₂				
1432	27	52	77				8008	0004	COND. STOP # 4				
03	28	53	78				8009	0016	X C.R.				
04	29	54	79				8009	0006	1				
05	30	55	80				8009	0003	SP				
06	31	56	81				8009	0003	SP				
07	32	57	82			18	0500	0508	X I.P., B., P., M.				
08	33	58	83				8009	0016	C.R.				
09	34	59	84				8009	0010	2				
10	35	60	85				8009	0003	SP				
11	36	61	86				8009	0003	X SP				
12	37	62	87			18	0510	0518	B., P., M., H., A				
13	38	63	88				8009	0016	C.R.				
14	39	64	89				8009	0014	3				
15	40	65	90				8009	0003	X SP				
16	41	66	91				8009	0003	SP				
1417	42	67	92			1	0000	1418	SWITCH B				
18	43	68	93			18	0546	0552	I ₂ , F ₂ , I ₄ , F ₄				
19	44	69	94			18	0536	0536	X b				
20	45	70	95			1	0000	1425					
1421	46	71	96			18	0546	0548	I ₂ , F ₂				
22	47	72	97				8009	0024	TAB				
23	48	73	98				8009	0024	X TAB				
1424	49	74	99			18	0536	0536	b				

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PROBLEM:

LOCATION (MARK APPROP. COLUMNS)				OPER- ATION	A	OPER- ATION	B	C	REMARKS
00	1425	50	75			9	1386	0002	INCREMENT: $t \quad t+1 = 6$
01	26	51	76			8	1387	0002	P_n
02	27	52	77			8	1388	0002	B
03	28	53	78			8	1389	0002	P
04	29	54	79			8	1390	0002	M
05	30	55	80			8	1391	0002	B_r
06	31	56	81			8	1392	0002	P
07	32	57	82			8	1393	0002	M
08	33	58	83			8	1394	0002	H
09	34	59	84			8	1395	0002	H
10	35	60	85			1	0000	1436	
11	1436	61	86			3	0000	1385	i Loop
12	1437	62	87			1	0000	1438	SWITCH C
13	38	63	88	6	0002		0536	0544	D EFF.
14	39	64	89				8009	0016	C.R.
15	40	65	90			18	0538	0538	λ_n
16	1441	66	91			18	0544	0544	D EFF
17	42	67	92			18	0540	0540	ω
18	43	68	93				8008	0000	HALT 1
19	1444	69	94	4	0544		0510	0544	$\sum_{i=1}^n b_i (B_{r_i} - B_{r_{i-1}}) / B_{r_n}$
20	45	70	95				8009	0016	C.R.
21	46	71	96			1	0000	1441	
22	1447	72	97	2	0510		0000	0546	I_2
23	48	73	98	3	0536		0504	0548	F_2
24	1449	74	99	6	0002		0510	0488	$B_{r_1} \Rightarrow B_{r_{i-1}}$

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PROBLEM:													
LOCATION (MAKE APPROP. COLUMNS)				OPERATION	A	OPERATION	B	C	REMARKS				
00	25	1450	75			1	0000	1402					
01	26	1451	76			4	1467	1403	INITIALIZE S ADDR.				
02	27	52	77				8001	0003	SET LOOP CTR. #1 FOR 4				
03	28	53	78	4	0502		0482	0496	X P_0/P_m				
04	29	54	79	3	0000		0000	0520	$(P_0/P_m)^2$				
05	30	55	80	3	0000		0496	0522	$(P_0/P_m)^3$				
06	31	56	81	2	0018		0496	0000	$40 - (P_0/P_m)$				
07	32	57	82			2	1458	1460	X				
08	33	58	83			5	1461	0898	TAKE SET I				
09	34	59	84			1	0000	1461					
10	35	60	85			5	1461	0930	TAKE SET II				
11	36	61	86	6	0008		[0898]	0460	X $\alpha_j, \beta_{ij} \Rightarrow W.S.$				
12	37	62	87	3	0522		0466	0490					
13	38	63	88	3	0520		0464	0000					
14	39	64	89	1	0000		0490	0490					
15	40	65	90	3	0496		0462	0000	X				
16	41	66	91	1	0000		0490	0000					
17	42	67	92	1	0000		0460	[0468]	$\begin{Bmatrix} a \\ b_1 \\ b_2 \end{Bmatrix} \Rightarrow []$				
18	43	68	93			8	1461	0008					
19	44	69	94			7	1467	0002	X				
20	45	70	95			3	0001	1461	Loop to 1461 (D)				
21	46	71	96	3	0480		0474	0490					
22	47	72	97	3	0478		0472	0000					
23	48	73	98	1	0000		0490	0490	X				
24	49	1474	99	3	0476		0470	0000					

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								20		26	
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PROBLEM:											
LOCATION (MARK APPROP. COLUMNS)				OPER- ATION	A	OPER- ATION	B	C	REMARKS		
00	25	50	1475	1	0000		0490	0000			
01	26	51	76	1	0000		0468	0490	$\lambda_m = y_m / \mu_m$		
02	27	52	77			1	0000	1574			
03	28	53	1478	3	0490		0458	0490	X y_m		
04	29	54	79	2	0094		0000	0000	$\rho - y_m$		
05	30	55	80			2	1481	1485	FOR $\rho \geq y_m \Rightarrow 1481$		
06	31	56	1481	4	0092		0490	0000	I / y_m		
07	32	57	82	3	0000		0000	0000	X I^2 / y_m^2		
08	33	58	83	2	0130		0000	0498	μ_m FOR $\rho \geq y_m$		
09	34	59	84			1	0000	1488			
10	35	60	1485	4	0452		0490	0000			
11	36	61	PC	4	0000		0490	0000	X $(\frac{1}{\mu} \rho^2 - I^2) / y_m^2$		
12	37	62	87	1	0000		0486	0498	μ_m FOR $\rho < y_m$		
13	38	63	1488	3	0000		0454	0000	$(\mu_m)(1 - \cos \alpha_m)$		
14	39	64	89	3	0000		0494	0000	$[M_{21}(\mu_m)(1 - \cos \alpha_m)]$		
15	40	65	90	3	0000		0560	0000	X $\{ \mu / \pi [] \}$		
16	41	66	91	4	0000		0036	0536	$\{ \} / F_2 = b$		
17	42	67	92	2	0510		0488	0000	$[(B_T)_i - (B_T)_{i-1}]$		
18	43	68	93	3	0000		0536	0000	$b []$		
19	44	69	94	1	0000		0544	0544	X b SEE P.S.		
20	45	70	95			1	0000	1447			
21	46	71	1496				1000	1500			
22	47	72	97								
23	48	73	98						X		
24	49	74	99								

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PREPARED FOR:						JOB NO.		PROGRAM NO.		PAGE NO. 21		NO. OF PAGES 26	
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PROBLEM:													
LOCATION (MARK APPROX. IN LINES)				OPER ACTION	A	OPER ACTION	B	C	REMARKS				
1500	25	50	75			4	1552	1557	CLOSED, SYMM. BRAKE START 2. $A \Rightarrow A_1$				
01	26	51	76			4	1417	1421	$B \Rightarrow B_1$				
02	27	52	77			4	1397	1400	$E \Rightarrow E_3$				
03	28	53	78	6	0002		0012	0540	☒ $W = 0$				
04	29	54	79			1	0000	1512					
1505	30	55	80			5	1585	0052	FREE PERIPHERY BRAKE START 4. INIT. MOVE TO WS. INSTR.				
06	31	56	81			1	0000	1507					
07	32	57	82			4	1552	1613	☒ $A \Rightarrow A_2$				
08	33	58	83			1	0000	1510					
1509	34	59	84			4	1552	1553	CLOSED, ASYMM. BRAKE START 1. $A \Rightarrow A_1$				
09	35	60	85			4	1417	1418	$B \Rightarrow B_1$				
10	36	61	86			4	1397	1398	☒ $E \Rightarrow E_1$				
1512	37	62	87				8000	[0000]	SET BAFFLE LOOP CTS. TO (N-1)				
11	38	63	88	6	0002		0012	0400	$d = 0$ P.S.				
12	39	64	89	6	0006		0400	0402	$b = 0, c = 0, d = 0$ P.S.				
13	40	65	90	6	0002		0130	0410	☒ $K_2 = 1$				
14	41	66	91	6	0002		0130	0412	$E_{10} = 1$				
15	42	67	92	6	0002		0108	0414	$S_{10} = A$				
16	43	68	93			5	1521	0070	INIT. MOVE S_1				
17	44	69	94				8008	0004	☒ COND STOP #4				
1520	45	70	95				8008	0004	COND STOP #4				
1521	46	71	96	6	0010		0070	0420	MOVE $S_0, S_1, S_2, S_3, S_4, S_5, S_6, S_7$ TO WS.				
22	47	72	97	1	0420		0422	0416	$S_{0j} + S_{1j}$				
23	48	73	98	4	0000		0414	0000	☒				
1524	49	74	99	3	0000		0412	0418	E_{1j}				

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PROBLEM:											
LOCATION (MARK APPROP. COLUMNS)				OPERATION	A	OPERATION	B	C	REMARKS		
00	1525	50	75	3	0000		0424	0000			
01	26	51	76	4	0000		0422	0430	E_j		
02	27	52	77	7	0000		0740	0682			
03	28	53	78	2	0004		0002	0010	X $E_n - E_i$		
04	29	54	79	2	0008		0006	0000			
05	30	55	80	4	0000		0010	0010	$(m_n - m_i) / (E_n - E_i)$		
06	31	56	81	2	0430		0002	0000			
07	32	57	82	3	0000		0010	0000	X		
08	33	58	83	1	0000		0006	0434	m_j		
09	34	59	84	7	0418		0740	0682			
10	35	60	85	2	0004		0002	0010			
11	36	61	86	2	0008		0006	0000	X		
12	37	62	87	4	0000		0010	0010			
13	38	63	88	2	0418		0002	0000			
14	39	64	89	3	0000		0010	0000			
15	40	65	90	1	0000		0006	0432	X m_j		
16	41	66	91	4	0422		0416	0000			
17	42	67	92	3	0000		0410	0436	A_j		
18	43	68	93	1	0000		0402	0402	$b.p.s. = \frac{1}{2} A_j$		
19	44	69	94	4	0420		0416	0000	X		
20	45	70	95	3	0000		0410	0410	K_{j-1}		
21	46	71	96	3	0436		0432	0000	$A_j m_j$		
22	47	72	97	1	0000		0406	0406	$d.p.s.$		
23	48	73	98			15	0426	0000	X $\cos \alpha_j$		
24	1549	74	99	3	0000		0436	0000			

LGP-30 CODING SHEET (Dictator Format)											
PREPARED FOR:						JOB NO.		PROGRAM NO.		PAGE NO. NO. OF PAGES 23 26	
PROGRAM PREPARED BY:			PROGRAM CHECKED BY:			DATE PREPARED:		DATE RUN:		SUPERSEDED BY PROGRAM NO.	
PROBLEM:											
LOCATION (MARK APPROX. COLUMNS)				OPER- ATION	A	OPER- ATION	B	C	REMARKS		
00	25	1550	75	3	0000		0434	0000	$\Delta_j m_j \cos \alpha_j$		
01	26	51	76	1	0000		0400	0400	A p.s.		
02	27	1562	77			1	0000	1553			
03	28	53	78			15	0428	0000	X		
04	29	54	79	3	0000		0436	0000			
05	30	55	80	3	0000		0434	0000	$\Delta_j m_j \cos \beta_j$		
06	31	56	81	1	0000		0404	0404	C p.s.		
07	32	1567	82			8	1521	0010	X INCR. MAKE S'S INSTR.		
08	33	58	83	6	0004		0418	0412	$E_j \Rightarrow E_{j-1}; S_{aj} \Rightarrow S_{aj-1}$		
09	34	59	84			1	0000	1560			
10	35	1560	85			3	0000	1520	#0 Loop TO 1520		
11	36	61	86	2	0130		0402	0000	X $1 - \frac{1}{2} \Delta_j$		
12	37	62	87	3	0000		0432	0000	$m_{jj} (1 - \frac{1}{2} \Delta_j)$		
13	38	63	88	1	0000		0400	0000			
14	39	64	89	4	0000		0128	0538	$\lambda_a \Rightarrow 0.538$		
15	40	65	90	2	0406		0400	0000	X		
16	41	66	91	1	0000		0124	0542	λ		
17	42	67	92	3	0000		0208	0000	$\lambda \mu$		
18	43	68	93	4	0000		0176	0536	$\lambda \mu / \bar{E} = b$		
19	44	69	94	2	0130		0000	0534	X $1 - b$		
20	45	70	95	4	0404		0126	0540	ω		
21	46	71	96				8008	0032	COND. STOP. #32		
22	47	72	97			4	1437	1438	$C \Rightarrow C_i$		
23	48	73	98			1	0000	1020	X		
24	49	1574	99	3	0000		0000	0000	$\lambda \bar{E}$		

LGP-36 CODING SHEET (Dictator Format)											
PREPARED FOR:						JOB NO.		PROGRAM NO.		PAGE NO. 24	NO. OF PAGES 26
PROGRAM PREPARED BY:			PROGRAM CHECKED BY:			DATE PREPARED:		DATE RUN:		SUPERSEDED BY PROGRAM NO.	
PROBLEM:											
LOCATION (MAPS APPROP. COLUMNS)				OPERATION	A	OPERATION	B	C	REMARKS		
00	25	50	1575	3	0000		0484	0000	$\frac{2}{\pi} \lambda_m$		
01	26	51	76	1	0000		0130	0492	$1 + \frac{2}{\pi} \lambda_m \equiv \epsilon_{21}$		
02	27	52	77	7	0000		0740	0682	T.L.U. : $m(\epsilon_{21})$		
03	28	53	78	2	0008		0006	0010	$m_n - m$		
04	29	54	79	2	0004		0002	0000	$\epsilon_n - \epsilon_1$		
05	30	55	80	4	0010		0000	0010			
06	31	56	81	2	0492		0002	0000	$\epsilon_n - \epsilon_1$		
07	32	57	82	3	0000		0010	0000			
08	33	58	83	1	0000		0006	0494	m_{21}		
09	34	59	84			1	0000	1478			
10	35	60	1585			4	1397	1587	$E \Rightarrow E_1$		
11	36	61	86			1	0000	1020			
12	37	62	1587			4	1603	0468	INIT. B' ADDR.		
13	38	63	88				8001	0002	SET LOOP CTR. #1 FOR 3		
14	39	64	89	4	0502		0482	0496	(P_1/P_2)		
15	40	65	90	3	0000		0000	0520	$(P_1/P_2)^2$		
16	41	66	91	3	0000		0496	0522	$(P_1/P_2)^3$		
17	42	67	92	2	0034		0496	0000	$156 - (P_1/P_2)$		
18	43	68	93			2	1594	1596			
19	44	69	1594			5	1597	0798	TAKE SET 1		
20	45	70	95			1	0000	1597			
21	46	71	96			5	1597	0822	TAKE SET II		
22	47	72	1597	6	0008		[0798]	0460	$\alpha_j, \beta_{ij} \Rightarrow W.S.$		
23	48	73	98	3	0522		0466	0490			
24	49	74	1599	3	0520		0464	0000			

LSP-3C CODING SHEET (Dictator Format)											
PREPARED FOR:						JOB NO.:		PROGRAM NO.:		PAGE NO.	NO. OF PAGES
										25	26
PROGRAM PREPARED BY:				PROGRAM CHECKED BY:				DATE PREPARED:		DATE RUN:	
PROBLEM:											
LOCATION (MARK APPROX. COLUMNS)				OPERATION	A	OPERATION	B	C	REMARKS		
1600	25	50	75	1	0000		0490	0490			
01	26	51	76	3	0496		0462	0000			
02	27	52	77	1	0000		0490	0000			
1603	28	53	78	1	0000		0460	[0468]	☒ a', b', b'		
04	29	54	79			8	1597	0000	INCR. T' ADDR.		
05	30	55	80			7	1603	0002	INCR. E' ADDR.		
06	31	56	81			3	0001	1597	#1 Loop TO 1597		
07	32	57	82	3	0478		0472	0490	☒ b, σ_m		
08	33	58	83	3	0476		0470	0000	b, σ_m		
09	34	59	84	1	0000		0490	0000			
10	35	60	85	1	0000		0468	0490	λ_m		
11	36	61	86			1	0000	1575	☒		
12	37	62	87				8008	0032	COND. STOP # 22		
1613	38	63	88	6	0006		[0052]	0440	$z_{ij} \Rightarrow W.S.$		
14	39	64	89			15	0440	0446	$\cos z_{ij}$		
15	40	65	90			15	0442	0000	☒ $\cos z_{ij}$		
16	41	66	91	2	0446		0000	0446	$C = z_{ij} - \cos z_{ij}$		
17	42	67	92	2	0020		0440	0448	$\pi/2 - z_{ij}$		
18	43	68	93			14	0444	0000	$\sin z_{ij}$		
19	44	69	94	3	0000		0448	0000	☒ $(\pi/2 - z_{ij}) \sin z_{ij}$		
20	45	70	95	1	0000		0446	0000	$[\cos z_{ij} - \cos z_{ij} + (\) \sin z_{ij}]$		
21	46	71	96	3	0000		0436	0000	$A_j, I, 1$		
22	47	72	97	3	0000		0434	0448	$m_j A_j, I, 2$		
23	48	73	98			1	0000	1624	☒		
1324	49	74	99	4	0000		0016	0000	ω P.S.		

LGP-30 CODING SHEET (Dictator Format)											
PREPARED FOR:						JOB NO.		PROGRAM NO.		PAGE NO. NO. OF PAGES 26 26	
PROGRAM PREPARED BY:			PROGRAM CHECKED BY:			DATE PREPARED:		DATE RUN:		SUPERSEDED BY PROGRAM NO.	
PROBLEM:											
LOCATION (MARK APPROP. COLUMNS)				OPERATION	A	OPERATION	B	C	REMARKS		
00	1625	50	75	1	0000		0404	0404			
01	26	51	76			8	1613	0006	INCR. ADDR. OF MOVE INSTR.		
02	27	52	77			1	0000	1557			
03	1628	53	78	4	0090		0016	0484	X $2^1/\pi$		
04	29	54	79	2	0130		0000	0486	1- $2^1/\pi$		
05	30	55	80	3	0452		0484	0000	$2^1/\pi Q^2$		
06	31	56	81	2	0000		0450	0452	$2^1/\pi Q^2 - I^2$		
07	1632	57	82			1	0000	1010	X		
08	33	58	83								
09	34	59	84								
10	35	60	85								
11	36	61	86						X		
12	37	62	87								
13	38	63	88								
14	39	64	89								
15	40	65	90						X		
16	41	66	91								
17	42	67	92								
18	43	68	93								
19	44	69	94						X		
20	45	70	95								
21	46	71	96								
22	47	72	97								
23	48	73	98						X		
24	49	74	99								

SAMPLE BRAKE ANALYSES

I. An example of a type 1 brake which has been analysed by use of DIPARDIP is the single-baffle, closed, asymmetric brake pictured in figure 0.1 of the INTRODUCTION. When used with the standard 105mm howitzer at zone 7, the weapon-break system produces the following data.

<u>Location</u>	<u>Number</u>	<u>Parameter</u>
0100	1.2593	γ
0102	70.036	R
0104	1350	e_c
0106	1231	e_{ig}
0108	13.717	A
0110	10.896	A_{cnct}
0112	1431.17	$\sqrt{T}$
0114	2.83	M_c
0116	.042857	M_{ig}
0118	33	M_p
0120	1492	M_r
0122	1550	v_o

0070	15.6228	S_{01}
0072	40	S_{11}
0074	53.19	S_{21}
0076	1.5707 (90°)	α_1
0078	0.6109 (35°)	β_1

The printed results take the following form:

The computer print out for the following sample brake analyses is in the "+50" system of notation. The "+50" system is analogous to the powers-of-ten notation used in scientific work, i.e.,

$$.0004172 = 4.172 \times 10^{-4}$$

$$8190000.0 = 8.19 \times 10^6$$

$$-27.05 = -2.705 \times 10^1$$

In the "+50" system these numbers would be written:

$$4.172 \times 10^{-4} = 41720000'+46'$$

$$8.19 \times 10^6 = 81900000'+56'$$

$$-27.05 = 27050000'-51'$$

Notice that to obtain the correct "characteristic" or exponent of the "+50" system, the usual exponent of 10 is algebraically added to the "base" 50. The sign of the number always preceeds the "characteristic." The "mantissa" is always eight digits long. If there aren't enough significant digits to fill eight spaces, fill out with zeros as was done in the above examples.

ENERGIES

tot
prc.j
gas, kin
rec mass
engrv
gas, therm

Btu

38732570+53
15848781+53
44955162+51
38098992+51
22665848+52
19786662+53

av T

19826223+53

av p

33447631+53

SINGLE BAFFLE, ASYMMETRICAL BRAKE

U-FU

1 t, sec
2 H cm
3 I z, lb f sec

P, psia
P, lb f sec
F z, lb f

B, lb f
M, lb m
I y, lb f sec

dP/dt, lb f
H, Btu
F y, lb f

dM/dt, lb m/sec
dH/dt, Btu/sec
P-index

1 39982950+46 35474565+53
2 20385754+51 13879082+51
3 72108659+50 31448244+54
1 79965901+46 32359190+53
2 38972881+51 26533619+51
3 13785520+51 28686461+54
1 11994885+47 29542847+53
2 55934943+51 38081775+51
3 19785354+51 26189769+54
1 15993180+47 26994444+53
2 7142718+51 48629245+51
3 25265284+51 23930607+54
1 19991474+47 24686356+53
2 85588844+51 58270820+51
3 30274556+51 21884484+54
1 27988065+47 20695579+53
2 11040747+52 75167907+51
3 39053423+51 18346655+54
1 39982952+47 15979149+53
2 14039437+52 95583666+51
3 49660414+51 14165535+54
1 51977835+47 12420617+53
2 16362256+52 11139794+52
3 57876707+51 11010892+54
1 63972720+47 97162547+52
2 18173357+52 12372832+52
3 64282947+51 86134713+53
1 79965901+47 70692786+52
2 19997603+52 13614820+52
3 70735687+51 62669238+53
1 99957376+47 48177814+52
2 21605748+52 14709683+52
3 76424030+51 42709688+53
1 12394714+48 30997101+52
2 22885603+52 15581036+52
3 80951143+51 27478967+53
1 14793691+48 20328933+52
2 23716519+52 16146742+52
3 83890268+51 18021623+53
1 17992327+48 11901330+52
2 24405473+52 16615798+52
3 86327241+51 10550543+53
1 24389600+48 44238485+51
2 25063028+52 17063477+52
3 88653150+51 39217469+52
1 29987213+48 20072478+51
2 25296588+52 17222490+52
3 87473300+51 17794276+52
38284936+49 64627921+49

48660460+54 20408599+49
11609319+51 44387102+54
39194354+9 22194354+51
40523923+54 56499941+49
31853945+51 26189769+54
37028279+54 72541264+49
40676498+51 33862274+54
87173520+49 48741304+51
28388126+54 11332048+50
62875071+51 21918599+54
14561929+50 79952070+51
17037361+54 17130521+50
93180103+51 13327786+54
19185249+50 10349399+52
96969294+53 66018889+53
21315186+50 11388274+52
66085506+53 23261206+50
12304085+52 42518724+53
24876549+50 13032939+52
27885197+53 25973036+50
13506131+52 16325055+53
26927360+50 13898477+52
60681930+52 27907714+50
14272944+52 27533417+52
28290306+50 19684626+53
14405952+52 83646164+49

33129140+54 17535141+52
27711255+54 30219742+54
33371841+52 25277654+54
27589603+54 47688445+52
23077644+54 25209690+54
60642997+52 21086938+54
23054202+54 72375939+52
19283955+54 19327278+54
92662668+52 16166526+54
14922677+54 11663817+53
12482247+54 11599421+54
13472762+53 97024708+53
90738584+53 14847499+53
75899343+53 66018889+53
16193063+53 55222268+53
44992509+53 17337590+53
37634508+53 28947709+53
18210955+53 24213647+53
18984872+53 18753261+53
15801117+53 11114466+53
19181670+53 92968247+52
41313631+52 19561780+53
34557268+52 18745374+52
19684626+53 15679786+52

48951311+52 41653713+55
64627921+49 45076975+52
37637816+53 64627921+49
41541370+52 34041430+53
64627921+49 38312137+52
30817422+53 64627921+49
75360235+52 27924312+53
64627921+49 30187012+52
22988340+53 64627921+49
23936487+52 17283463+53
64627921+49 19094759+52
13090436+53 64627921+49
15319668+52 99846388+54
64627921+49 11517174+52
70305320+54 64627921+49
81651219+51 46059104+54
64627921+49 54973706+51
28318557+54 64627921+49
37653934+51 17782907+54
64627921+49 23293249+51
98524659+53 64627921+49
7870265+50 33075056+53
64627921+49 47186572+50
13834632+53 64627921+49

II. A hypothetical triple-baffle, closed, symmetric brake, which is used with the 105mm howitzer is analysed in this example. Figure 0.2 of the INTRODUCTION illustrates this type. Since the thermodynamic data for this example is identical to that of example I, the contents of locations 0100-0122 are not written here, only the brake data being given.

<u>Location</u>	<u>Number</u>	<u>Parameter</u>
0070	16	S_{01}
0072	50	S_{11}
0074	100	S_{21}
0076	2.3562 (135°)	α_1
0078	1.5707 (90°)	β_1
0080	20	S_{02}
0082	50	S_{12}
0084	100	S_{22}
0086	2.3562	α_2
0088	1.5707	β_2
0090	25	S_{03}
0092	50	S_{13}
0094	100	S_{23}
0096	2.3562	α_3
0098	1.5707	β_3

The computer print out for example II follows.

ENERGIES
tot 38732570+53
proj 15848781+53
gas, kin 44955162+51
rec mass 35098992+51
engrv 22665848+52
gas, therm 19786662+53

av T 19826223+53
av F 33447631+53

105 MM HOWITZER AT ZONE 7
WITH A TRIPLE-BAFFLE, CLOSED,
SYMMETRIC BRAKE

1	t, sec	P, psia	B, lb f	dP/dt, lb f	dM/dt, lb m/sec
2	B cml	P, lb f sec	M, lb m	H, Btu	dH/dt, Btu/sec
3	I z, lb f sec	F z, lb f	I y, lb f sec	F y, lb f	P-index
1	39962595+46	35213178+53	48713426+54	33165201+54	48976245+52
2	20397554+51	13887115+51	20408599+49	17535141+52	41674931+55
3	12553620-51	78693976+54			16154474+50
1	79925189+46	32394413+53	44435416+54	30252636+54	45099936+52
2	38995440+51	26548977+51	39194355+49	33371841+52	37656988+55
3	23999640-51	71783076+54			16154474+50
1	11988778+47	29575004+53	40568032+54	27619633+54	41562530+52
2	55967319+51	38103817+51	56499941+49	47688445+52	34058769+55
3	34444937-51	65535522+54			16154474+50
1	15985037+47	27023828+53	37068584+54	25237131+54	38331653+52
2	71468532+51	48657391+51	72454126+49	60642997+52	30833120+55
3	43985117-51	59882348+54			16154474+50
1	19981296+47	24713227+53	33899134+54	23079296+54	35378268+52
2	85638383+51	58304548+51	87173520+49	72375939+52	27938537+55
3	52705915-51	54762266+54			16154474+50
1	27973815+47	20718106+53	28419026+54	19348315+54	30202388+52
2	11047138+52	75211414+51	11332048+50	92662668+52	23000650+55
3	67989318-51	45909440+54			16154474+50
1	39962595+47	15996542+53	21942457+54	14938920+54	23948680+52
2	14047563+52	95638990+51	14561929+50	11663817+53	17292269+55
3	86455360-51	35446885+54			16154474+50
1	51951372+47	12434137+53	17055906+54	11612046+54	19104486+52
2	16371726+52	11146241+52	17130521+50	13472762+53	13097165+55
3	10075936-52	27552919+54			16154474+50
1	63940151+47	97268307+52	13342293+54	90837350+53	15327471+52
2	18183075+52	12379993+52	19185249+50	14847499+53	99897247+54
3	11191218-52	21553773+54			16154474+50
1	79925188+47	70769733+52	97074843+53	66090750+53	11523041+52
2	20009178+52	13622700+52	21315186+50	16193063+53	70341132+54
3	12314595-52	15681930+54			16154474+50
1	99906486+47	48230254+52	66157440+53	45041482+53	81692811+51
2	21618253+52	14718197+52	23261206+50	17337590+53	46032565+54
3	13304896-52	10687386+54			16154474+50
1	12388404+48	31030841+52	42565004+53	28979218+53	55001708+51
2	22898849+52	15590054+52	24876549+50	18210955+53	28332982+54
3	14093036-52	68761526+53			16154474+50
1	14786160+48	20351060+52	27915549+53	19005537+53	37673115+51
2	23730246+52	16156089+52	25973036+50	18753261+53	17791965+54
3	14604717-52	45096100+53			16154474+50
1	17983167+48	11914284+52	16342824+53	11126564+53	23305114+51
2	24419599+52	16625415+52	26527360+50	19181670+53	98574846+53
3	15020977-52	26400972+53			16154474+50
1	24377182+48	44286638+51	60747981+52	41358600+52	95919099+50
2	25077534+52	17073354+52	27907714+50	19561780+53	33091903+53
3	15433902-52	98135167+52			16154474+50
1	29971945+48	20094327+51	27563388+52	18765778+52	47210609+50
2	25311229+52	17232458+52	28290306+50	19684626+53	13841679+53
3	15577729-52	44527202+52			16154474+50
99445308-49		16154474+50	00000000+49		

III. The single-baffle open brake, pictured in figure 0.3 of the INTRODUCTION, has been analysed using DIPARDIP. When this brake is used with the XM103 cannon at zone 11, the following system data are used in the analysis.

<u>Location</u>	<u>Number</u>	<u>Parameter</u>
0090	1.4388 (82.5°)	ψ
0092	2.21	I
0094	7.86	Q
0096	5.85	z_m
0098	1.9635 (112.5°)	α_1
0100	1.2402	γ
0102	67	R
0104	1727.5	e_c
0106	1231	e_{ig}
0108	13.717	A
0110	10.8984	A_{cnct}
0112	1710	ψ_T
0114	4.46	M_C
0116	0.042837	M_{ig}
0118	28.5	M_p
0120	1430	M_r
0122	2200	v_o

The results of the analysis of this example follow.

ENERGIES
tot 77574071+53
proj 27574571+53
gas, kin 14217041+52
rec mass 63781100+51
engrv 39435274+52
gas, therm 43996456+53

XM103 CANNON AT ZONE 11
WITH SINGLE-BAFFLE,
GERMAN, OPEN BRAKE

av T 27235043+53
av p 57660201+53

1 t, sec	p, psia	B, lb f	dP/dt, lb f	dM/dt, lb m/sec
2 B cml	P, lb f sec	M, lb m	H, Btu	dH/dt, Btu/sec
3 I z, lb f sec	F z, lb f	I y, lb f sec	F y, lb f	P-index
1 38612499+46	65408216+53	89720448+54	61083708+54	79448446+52
2 36299034+51	24713203+51	31988020+49	38990108+52	95906011+55
3 12910970-50	92911659+54			10355683+50
1 77224936+46	59664069+53	81841205+54	55719341+54	73160362+52
2 69395419+51	47245970+51	61432428+49	74203662+52	86659571+55
3 28123245-50	85602916+54			10459635+50
1 11583749+47	54471279+53	74718253+54	50869874+54	67422042+52
2 99598199+51	67808710+51	88556846+49	10603722+53	78379033+55
3 115265971-50	78959169+54			10567587+50
1 15444999+47	49772518+53	68272964+54	46481779+54	62180967+52
2 12718381+52	86589616+51	11356310+50	13484220+53	70955885+55
3 67268782-50	73718547+54			10797619+50
1 19306249+47	45516853+53	62435467+54	42507477+54	57390035+52
2 15240016+52	10375748+52	13663398+50	16093087+53	64294616+55
3 90214535-50	68116815+54			10909955+50
1 27028748+47	38158633+53	52342195+54	35635751+54	48993811+52
2 19659241+52	13384456+52	17761619+50	20603925+53	52931116+55
3 13876987-51	58093190+54			11098729+50
1 38612499+47	29462451+53	40413644+54	27514522+54	38849148+52
2 24998733+52	17019702+52	22824068+50	25934978+53	39794489+55
3 21440872-51	46138612+54			11416592+50
1 50196246+47	22901209+53	31413589+54	21387082+54	30990977+52
2 29134762+52	19835604+52	26850028+50	29957240+53	30140346+55
3 29187960-51	37297587+54			11873073+50
1 61779996+47	17914888+53	24573853+54	16730434+54	24863968+52
2 32359622+52	22031162+52	30070565+50	33014025+53	22989232+55
3 37287181-51	30745566+54			12511495+50
1 77224936+47	13034578+53	17879256+54	12172602+54	18692485+52
2 35607389+52	24242656+52	33408984+50	36005942+53	16187519+55
3 45242431-51	22258020+54			12449074+50
1 96531245+47	88830542+52	12184885+54	82957458+53	13252071+52
2 38471364+52	26192176+52	36459137+50	38550845+53	10604924+55
3 50311224-51	14341798+54			11770154+50
1 11969874+48	57152642+52	78396280+53	53373959+53	89222852+51
2 40750284+52	27743715+52	38990992+50	40492808+53	65202346+54
3 52321012-51	85310077+53			10881904+50
1 14286624+48	37482607+52	51414893+53	35004422+53	61112697+51
2 42229820+52	28751017+52	40709602+50	41698648+53	40944433+54
3 52350629-51	51517815+53			10020018+50
1 17375624+48	21943744+52	30100234+53	20492919+53	37805166+51
2 43456576+52	29586221+52	42203391+50	112651233+53	22684909+54
3 51162351-51	27184625+53			90313670+49
1 23553624+48	81567184+51	11188570+53	76174323+52	15359836+51
2 44627423+52	30383361+52	43741977+50	43496423+53	76153995+53
3 48521706-51	86651805+52			77446717+49
1 28959373+48	37009756+51	50766283+52	34562833+52	76584261+50
2 45043303+52	30666501+52	44341646+50	43769575+53	31853689+53
3 47357602-51	36556079+52			72008581+49
11051379+50	00000300+49			

IV. As a final example of the use of DIPARDIP, a double-baffle, closed, free-periphery brake was chosen. This is pictured in figure 0.4 of the INTRODUCTION. The brake was designed to be used with an improved 155mm howitzer for which the system data are given below.

<u>Location</u>	<u>Number</u>	<u>Parameter</u>
0052	0.78530	v_{11}^h
0054	1.44835	v_{21}^h
0056	0.314136	v_{31}^h
0058	0.78530	v_{12}^h
0060	1.44835	v_{22}^h
0062	0.314136	v_{32}^h
- - - - -		
0070	31.371	S_{01}
0072	139.0	S_{11}
0074	16.36	S_{21}
0076	2.3562 (135°)	α_1
0078	1.5707 (not used)	β_1
0080	32.170	S_{02}
0082	139.0	S_{12}
0084	222.5	S_{22}
0086	2.3562	α_2
- - - - -		
0100	1.2402	γ
0102	67	R
0104	1727.5	e_c
0106	1500	e_{ig}
0108	29.823	A

<u>Location</u>	<u>Number</u>	<u>Parameter</u>
0110	19.30	A_{cnct}
0112	6707.1	$\sqrt{\tau}$
0114	24.08	M_c
0116	2.714 10^{-3}	M_{ig}
0118	95	M_p
0120	4900	M_r
0122	2700	v_o

The print out of this analysis follows.

ENERGIES

tot 41602270+54
 proj 13844258+54
 gas, kin 11449128+53
 rec mass 33909495+52
 engrv 16126798+53
 gas, therm 24661325+54

av T 28543649+53
 av p 82401704+53

155 MM HOWITZER WITH TWO BAFFLE,
 FREE PERIPHERY BRAKE

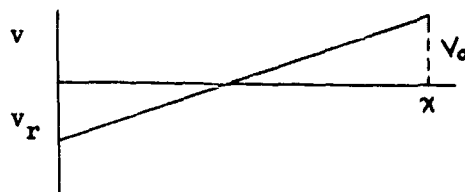
1	t, sec	p, psia	B, lb f	dP/dt, lb f	dm/dt, lb m/sec
2	B cml	P, lb f sec	M, lb m	H, Btu	dH/dt, Btu/sec
3	I z, lb f sec	F z, lb f	I y, lb f sec	F y, lb f	P-index
1	62822650+46	10118946+54	30177733+55	20545682+55	26116461+53
2	19864543+52	13524230+52	17108212+50	21855118+53	33041229+56
3	11966464-52	48356926+55	51310358+51	77949453+54	16024042+50
1	12564529+47	92303010+53	27527526+55	18741362+55	24049429+53
2	37976446+52	25835222+52	32856020+50	41593363+53	29855675+56
3	22877171-52	44110225+55	98093627+51	71103937+54	16024042+50
1	18846794+47	84269529+53	25131701+55	17110230+55	22163116+53
2	54504832+52	37108124+52	47363021+50	59437023+53	27002891+56
3	32833939-52	40271143+55	14078665+52	64915491+54	16024042+50
1	25129060+47	77000334+53	22963809+55	15634281+55	20440259+53
2	69600981+52	47385922+52	60737100+50	75583073+53	24445492+56
3	41927923-52	36797305+55	17978019+52	59315003+54	16024042+50
1	31411324+47	70416626+53	21000350+55	14297513+55	18865374+53
2	83400559+52	56780986+52	73076206+50	90206554+53	22150573+56
3	50240845-52	33651049+55	21542467+52	54244162+54	16024042+50
1	43975853+47	59033128+53	17605449+55	11986188+55	16105349+53
2	10758464+53	73246060+52	94994801+50	11549114+54	18235657+56
3	64809440-52	28211046+55	27789245+52	45475092+54	16024042+50
1	62822651+47	45579743+53	13593246+55	92545895+54	12770574+53
2	13680485+53	93139840+52	12207038+51	14537328+54	13709869+56
3	82411819-52	21761876+55	35336862+52	35111522+54	16024042+50
1	81669443+47	35429205+53	10566051+55	71936072+54	10187419+53
2	15943916+53	10854978+53	14360250+51	16791926+54	10383854+56
3	96046818-52	16931086+55	41183330+52	27292242+54	16024042+50
1	10051623+48	27715141+53	82654868+54	56273300+54	81733362+52
2	17708711+53	12056491+53	16082696+51	18505344+54	79201760+55
3	10667802-53	13244650+55	45741818+52	21349853+54	16024042+50
1	12564529+48	20164771+53	60137398+54	40942901+54	61446332+52
2	19486316+53	13266724+53	17868189+51	20182404+54	55768717+55
3	11730639-53	96364420+54	50333394+52	15533564+54	16024042+50
1	15705662+48	13742485+53	40984214+54	27902981+54	43562488+52
2	21053345+53	14333595+53	19497508+51	21608898+54	36535744+55
3	12682623-53	65673279+54	54381054+52	10586273+54	16024042+50
1	19475021+48	63417717+52	26368816+54	17952435+54	29329524+52
2	22300477+53	15182670+53	20853624+51	22697426+54	22463302+55
3	13433901-53	42253501+55	57602410+52	68110775+53	16024042+50
1	23244380+48	57987287+52	17293548+54	11773838+54	20089095+52
2	23110149+53	15733912+53	21727792+51	23373335+54	14106044+55
3	13921650-53	27711255+54	59693801+52	44669447+53	16024042+50
1	28279192+48	33747962+52	10124501+54	68928529+53	12427394+52
2	23701408+53	16110775+53	22572788+51	23307237+54	78153316+54
3	14326068-53	16223222+54	61427379+52	26151193+53	16024042+50
1	30321815+48	12613011+52	37633382+53	25622145+53	51143621+51
2	24422231+53	10627200+53	25374673+51	24331042+54	26236328+54
3	14712054-53	60303974+53	63602923+52	97206717+52	16024042+50
1	41164077+48	57255744+51	17075308+53	11625300+53	25174940+51
2	24641017+53	10712156+53	23715321+51	24534152+54	10741300+54
3	14712054-53	23715321+53	63707173+52	44105735+52	16024042+50
1	12570747-48	10240342+50	37135163+53		

APPENDIX I

Momentum and Energy Distribution at Start of Gas Discharge Period

In a frame of reference which is stationary with respect to the ground, the assumed velocity distribution in the gas behind the projectile within a gun tube of uniform cross section and length x is shown below in figure 1.1

Figure 1.1



$$v = \left(\frac{v_o + v_r}{L} \right) x - v_r$$

$$x = \xi + \frac{V_c}{A}$$

$$L = \xi_o + \frac{V_c}{A}$$

Let $\frac{x}{L} = \eta$, then

$$1.1 \quad \frac{v}{v_o} = \left(1 + \frac{v_r}{v_o} \right) \eta - \frac{v_r}{v_o} .$$

Now, momentum conservation requires that

$$1.2a \quad \frac{M_r v_r}{g} = P_T + \frac{M_p}{g} v_o \quad \text{or}$$

$$b \quad v_r = \frac{P_T + M_p v_o / g}{M_r / g} .$$

However, P_T , the momentum taken by the charge and igniter gases, is found by averaging the momentum distribution, i.e.,

$$1.3a \quad P_T = \frac{\dot{M}_T}{gL} \int_0^L v \, dx \quad \text{or}$$

$$P_T = \frac{M_T v_o}{g} \int_0^1 \frac{v}{v_o} (\eta) \, d\left(\frac{x}{L}\right)$$

$$b \quad P_T = \frac{M_T v_o}{g} \int_0^1 \left[\left(1 + \frac{v_r}{v_o}\right) \eta - \frac{v_r}{v_o} \right] d\eta$$

$$P_T = \frac{M_T v_o}{2g} \left(1 - \frac{v_r}{v_o}\right)$$

Substitution of 1.3b into 1.2b gives

$$1.4 \quad \frac{v_r}{v_o} = \frac{\frac{M_T}{2} + M_p}{\frac{M_T}{2} + M_r}$$

Since the projectile leaves the muzzle with velocity v_o , it carries off an energy given by

$$KEP = \frac{1}{2} M_p v_o^2$$

In engineering units the kinetic energy of the projectile in Btu is

$$1.5 \quad KEP = \frac{M_p v_o^2}{2gJ}$$

Similarly, the kinetic energy of the recoiling parts is

$$1.6 \quad KER = \frac{M_r v_r^2}{2gJ} \quad \text{with } v_r \text{ being given by equation 1.4}$$

The kinetic energy of the gas itself may be found by integration of an elemental mass of gas over the entire internal volume of the gun tube. Thus

$$1.7 \quad KEG = \frac{1}{2} \frac{M_T v_o^2}{g} \int_0^1 \left(\frac{v}{v_o}\right)^2 d\eta$$

Substitution of 1.1 for $\frac{v}{v_0}$ and integration yields, in Btu

$$1.8 \quad KEG = \frac{1}{2} \frac{M_T v_0^2}{gJ} \left[\left(\frac{1+v_r}{v_0} \right)^3 + \left(\frac{v_r}{v_0} \right)^2 - \frac{v_r}{v_0} \left(\frac{1+v_r}{v_0} \right) \right].$$

After an assumed initial shear deformation in the ammunition band as the projectile leaves the chamber, during which relatively little energy is expended, work is performed in forcing the projectile thru the tube against frictional forces. The energy thereby expended, called the engraving energy, is computed as follows.

The minimum pressure which may exist between the band and the walls of the tube to effect a seal is the pressure at the base of the projectile, p . Using .18 as the effective coefficient of friction between the band and walls, the frictional force is given by

$$.18 A_{\text{cnct}} p.$$

The work performed by this force in Btu is, then,

$$1.9 \quad KEB = .18 A_{\text{cnct}} \int_{\xi_1}^{\xi_0} p d\xi, \text{ where } \xi_1 \text{ is the travel of the projectile during band deformation.}$$

$$\text{However, } KEP = A \int_{\xi_1}^{\xi_0} p d\xi.$$

Hence,

$$1.10 \quad KEB = \frac{.18 A_{\text{cnct}}}{A} KEP.$$

The sources of energy for the sinks mentioned above are the energies obtained by the combustion of the igniter and charge. Thus

$$1.11a \quad \mathcal{H}_{ig} = e_{ig} M_{ig}$$

b $\mathcal{H}_c = e_c M_c$, where e_{ig} and e_c are the heats of explosion for the igniter and charge, respectively. The total energy is, therefore,

$$1.12 \quad \mathcal{H} = \mathcal{H}_{ig} + \mathcal{H}_c.$$

At the start of the gas discharge, the thermal energy remaining in the gas (assumed to be completely combusted) can be found by subtracting all of the above kinetic energies from the total energy. Thus,

$$1.13 \quad E_g = \mathcal{H} - \sum KE's$$

This energy can be expressed in terms of the average initial temperature of the gas, $T_g = T_{av \text{ init}}$.

$$1.14 \quad E_g = T_g M_T C_v$$

However, $C_v = \frac{R}{(\gamma - 1) J}$. Substituting the latter expression into equation 1.14 and solving for T_g gives

$$1.15 \quad T_g = \frac{E_g (\gamma - 1) J}{R M_T} .$$

At t_0 the gas behaves in a nearly ideal fashion so that

$$1.16 \quad \frac{pV}{12} = RT \quad \text{where}$$

$$1.17 \quad V = \frac{\mathcal{V}_T}{M_T} .$$

From the last three relationships, one can solve for the average initial pressure in the gas as

$$1.18 \quad p_g = \frac{12 E_g (\gamma - 1) J}{\mathcal{V}_T} .$$

Figure 1.2 shows graphically the energy distribution at the start of gas discharge for the standard 105mm howitzer (zone 7). Values for the energy of all sources and sinks (including some for which no equations are given here) have been computed. Some are seen to be negligible and were not considered in subsequent analyses.

PERCENT DISTRIBUTION OF ENERGY
AT EJECTION OF PROJECTILE
FROM STANDARD 105MM HOWITZER
(ZONE 7)

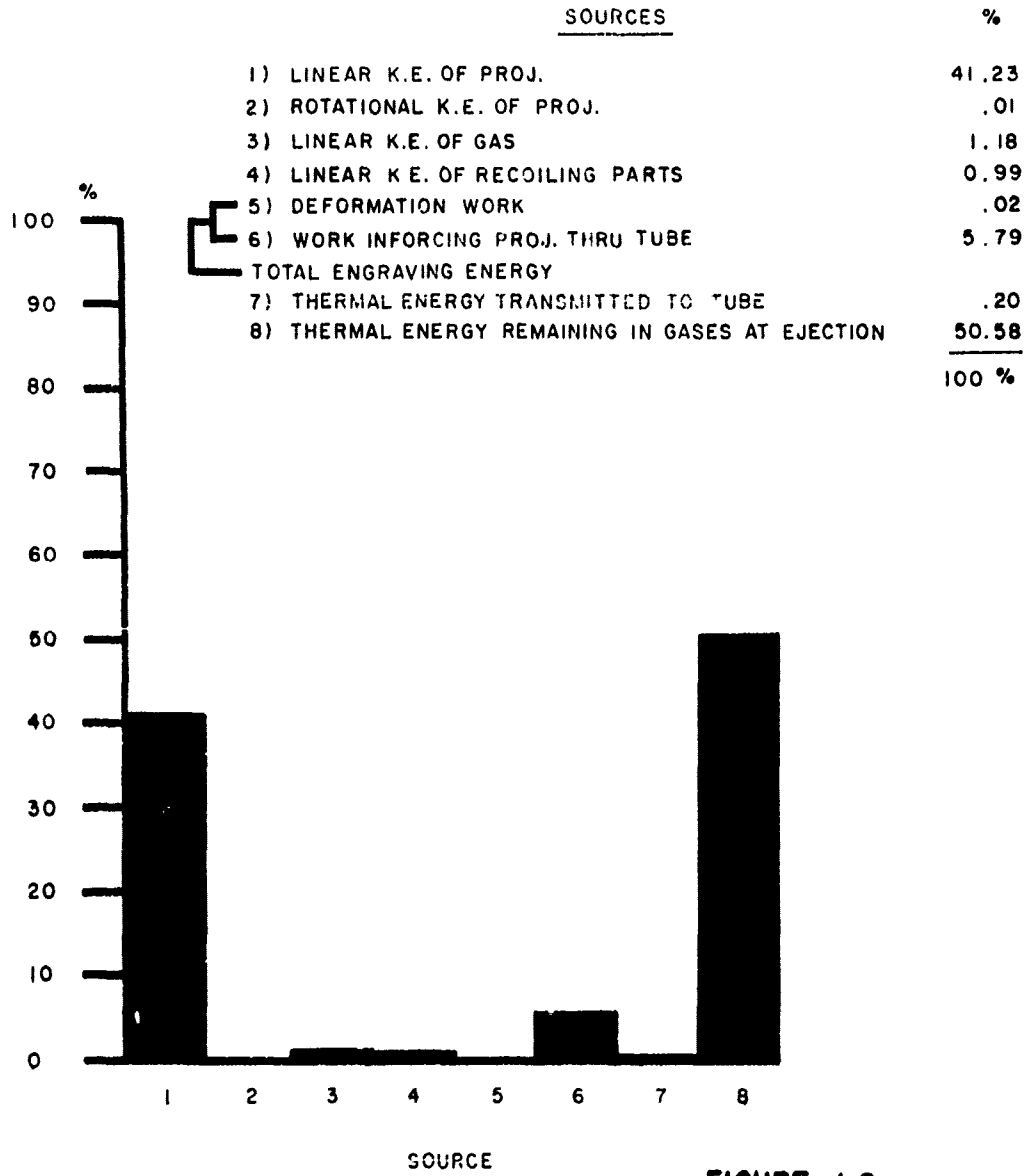


FIGURE 1.2

APPENDIX II

Derivation of the Relationships:

$$\underline{\phi_{av}(\beta), \eta_{av}(\beta), v_{av}(\beta)}$$

Having determined the average pressure, temperature, and specific volume in the gas within the gun tube at t_0 , it is desirable to compute their local values anywhere along the tube length--and, in particular, at the breech--as a function of the average values and the muzzle velocity.

As before, we examine a tube of uniform cross section of length L and total internal volume V , and we define a dimension x such that

$$2.1 \quad x = \xi + \frac{V_c}{A}, \text{ where}$$

$$2.2 \quad L = \xi_0 + \frac{V_c}{A}.$$

For convenience, let us also define some dimensionless variables:

$$2.3a \quad \phi = \frac{p}{p_b},$$

$$b \quad v^i = \frac{T}{T_b},$$

$$c \quad \eta = \frac{v}{v_b}, \text{ and}$$

$$2.4 \quad \eta = \frac{x}{L}.$$

Since the average temperature within the tube was obtained from the thermal energy remaining in the gas, it is necessary to require that the enthalpy integrated over the volume of the tube equal the thermal energy. Thus,

$$2.5 \quad \Sigma_g = M_T C_v T_{av} = C_v A \int_0^L \frac{T}{V} dx$$

or

$$2.6 \quad T_{av} = \frac{A L}{M_T} \int_0^L \frac{T}{V} d\left(\frac{x}{L}\right).$$

as If we regard $T(\eta)$, $V(\eta)$, then 2.6 can be expressed

$$2.7 \quad T_{av} = V_{av} \int_0^1 \frac{T}{V} (\eta) d\eta .$$

However, in an ideal gas $\frac{p}{T} = \frac{RT}{V}$;

therefore,

$$2.8a \quad p_{av} = \int_0^1 p(\eta) d\eta , \text{ or}$$

in non-dimensional terms

$$b \quad \phi_{av} = \int_0^1 \phi(\eta) d\eta .$$

Sutton (reference book 5, p. 81) has shown that isentropic decay and momentum conservation within the tube demands that

$$2.9 \quad \frac{1}{\phi} = 1 + \gamma M^2 , \text{ where } M \text{ is the local mach number.}$$

Also for isentropic expansion:

$$2.10a \quad v^{\frac{2}{\gamma}} = \phi^{(\gamma-1)/\gamma}$$

$$b \quad v = 1 / \phi^{1/\gamma}$$

$$c \quad a/a_b = v^{1/2} = \phi^{(\gamma-1)/2\gamma} .$$

2.11 M can be written as

$$M = \frac{v}{a} = \frac{v}{a_b(a/a_b)} = \frac{v}{a_b \phi^{(\gamma-1)/2\gamma}} .$$

As an approximation to equation 1.1, we may state

$$2.12 \quad v = v_0 \eta .$$

By further defining

$$2.13 \quad \frac{v_0}{a_b} = \alpha , \text{ 2.11 can be written as}$$

$$2.14 \quad M = \frac{\alpha \eta}{\phi^{(\gamma-1)/2\gamma}} .$$

Substitution of the latter expression for M into 2.9 gives

$$2.15 \quad \eta = \left(\frac{1 - \phi}{\gamma \alpha^2 \phi^{1/\gamma}} \right)^{1/2}$$

This equation expresses ϕ implicitly as a function of η ; and, unfortunately, does not permit a convenient explicit formulation. However, numerical evaluation permits one to establish $\phi(\eta)$. Then, numerical evaluation of equation 2.8b determines the relationship $\phi_{av}(\alpha)$.

For mass conservation,

$$2.16a \quad M = A \int_0^L \rho \, dx \quad \text{or}$$

$$b \quad 1 = V_{av} \int_0^1 \frac{1}{V(\eta)} \, d\eta.$$

Division of 2.16b by V_b gives

$$2.17 \quad \frac{1}{K_{av}} = \int_0^1 \frac{d\eta}{K(\eta)}, \quad \text{which with 2.10b give}$$

$$2.18 \quad K_{av} = \left(\int_0^1 \phi^{1/\gamma} d\eta \right)^{-1}.$$

This expression also must be evaluated numerically.

Since the gas behaves nearly ideally,

$$2.19a \quad \frac{pV}{12} = RT \quad \text{and}$$

$$b \quad \frac{p_b V_b}{12} = RT_b.$$

Thus,

$$2.20a \quad \phi K = \gamma \quad \text{and}$$

$$b \quad \phi_{av} K_{av} = \gamma_{av}.$$

If we define a parameter β such that

$$2.21 \quad \beta = \frac{\gamma_o}{\gamma_{av}}, \quad \text{it follows that}$$

$$2.22 \quad \alpha = \beta \gamma_{av}^{1/2}.$$

Having determined ϕ_{av} , κ_{av} , and γ_{av} as functions of α , one can with equation 2.22 determine these as functions of β .

An optimum quadratic fit to the numerical values $\phi_{av}(\beta)$ and $\kappa_{av}(\beta)$ was performed using a least squares criterion. These quadratics were used in DIPARDIP to calculate ϕ_{av} and κ_{av} to a degree of accuracy warranted by the data.

After projectile ejection, the gas rapidly becomes sonic at the muzzle and equation 2.9 becomes

$$2.23 \quad \phi'_0 = \frac{p_0}{p_b} = \frac{1}{1+\gamma} \quad .$$

APPENDIX III

State Variables During the Discharge Period

In appendix III are derived the equations governing the dimensional and non-dimensional state variables as functions of time. The relationship $n(\xi)$ is also derived for one-dimensional isentropic flow.

For one-dimensional gas discharge from a tube or choked nozzle, the isentropic mass rate of discharge is given by (p. 61, reference book 5).

$$3.1a \quad \dot{M} = \frac{A p_b g \gamma}{a_b} \left(\frac{2}{\gamma+1} \right)^{\frac{\gamma+1}{2(\gamma-1)}} = \frac{C_1^* p_b}{a_b}$$

$$b \quad C_1^* = A g \gamma \left(\frac{2}{\gamma+1} \right)^{\frac{(\gamma+1)}{2(\gamma-1)}}.$$

The average specific volume of the gas within the tube is the total internal volume divided by the mass present within the tube. The mass present at time t equals the initial total mass minus the mass discharged. Thus,

$$3.2 \quad v_{av} = \frac{V}{M_T - \int_0^t \dot{M} dt}.$$

Also,

$$3.3 \quad v_{av} = \kappa_{av} v_b \text{ and}$$

$$3.4 \quad \frac{v_{b \text{ init}}}{v_b} = \left(\frac{p_b}{p_{b \text{ init}}} \right)^{1/\gamma}.$$

From 3.3 and 3.4 one obtains

$$3.5 \quad v_{av} = \frac{v_{av \text{ init}} \kappa_{av}}{\kappa_{av \text{ init}}} \left(\frac{p_{b \text{ init}}}{p_b} \right)^{1/\gamma}.$$

Elimination of v_{av} by substitution of the latter expression into 3.2 yields

$$3.6 \quad \frac{V_{av \text{ init}} \kappa_{av \text{ init}} \left(\frac{p_b \text{ init}}{p_b} \right)^{1/\gamma}}{\kappa_{av \text{ init}}} = \frac{\mathcal{V}_T}{M_T - C_1^* \int_0^t p_b / a_b \, dt}.$$

As long as the gas velocity at the muzzle remains sonic, $\kappa_{av} / \kappa_{av \text{ init}} = 1$. (Equation 2.23 implies that ϕ_{av} is constant for a choked nozzle.)

Therefore, 3.6 becomes

$$3.7 \quad \left(\frac{p_b \text{ init}}{p_b} \right)^{1/\gamma} = \frac{\mathcal{V}_T / p_b \text{ init} \, V_{av \text{ init}}}{\frac{M_T}{p_b \text{ init}} - C_1^* \int_0^t \frac{p_b}{p_b \text{ init} \, a_b} \, dt}.$$

Let us define

$$3.8 \quad \Phi = \frac{p_b}{p_b \text{ init}}, \text{ so that equation 3.7 may be}$$

written as

$$3.9 \quad \frac{1}{\Phi^{1/\gamma}} = \frac{\mathcal{V}_T / p_b \text{ init} \, V_{av \text{ init}}}{\frac{M_T}{p_b \text{ init}} - C_1^* \int_0^t \frac{\Phi}{a_b} \, dt}.$$

$$\text{But, } \frac{T_b \text{ init}}{T_b} = \left(\frac{p_b \text{ init}}{p_b} \right)^{\frac{\gamma-1}{\gamma}} \text{ or}$$

$$3.10 \quad T_b = T_b \text{ init} \, \Phi^{(\gamma-1)/\gamma}$$

and

$$3.11 \quad a_b = (\gamma g R T_b)^{1/2}; \text{ so that}$$

$$3.12 \quad a_b = a_b \text{ init} \, \Phi^{(\gamma-1)/2\gamma}.$$

Substitution of a_b in equation 3.12 for that value in 3.9 yields

$$3.13 \quad \Phi^{1/\gamma} = \left[\frac{M_T}{p_b \text{ init}} - \frac{C_1^*}{a_b \text{ init}} \int_0^t \Phi^{\frac{\gamma+1}{2\gamma}} \, dt \right] \frac{p_b \text{ init} \, V_{av \text{ init}}}{\mathcal{V}_T}.$$

Differentiating both sides of this equation with respect to t gives

$$3.14 \quad \frac{1}{\gamma} \Phi \frac{1-\gamma}{\gamma} \frac{d\Phi}{dt} = - \frac{C_1^* P_{b \text{ init}} V_{av \text{ init}}}{a_{b \text{ init}} \sqrt{\tau}} \Phi \frac{1+\gamma}{2\gamma} .$$

Letting,

$$3.15 \quad C_2^* = \frac{\gamma C_1^* P_{b \text{ init}} V_{av \text{ init}}}{a_{b \text{ init}} \sqrt{\tau}} ,$$

we have

$$3.16 \quad \Phi^{(1-3\gamma)/2\gamma} d\Phi = -C_2^* dt .$$

Integrating the last expression gives

$$3.17a \quad \frac{2\gamma}{1-\gamma} \Phi^{(1-\gamma)/2\gamma} \Big|_1^{\Phi} = -C_2^* t \quad \text{or}$$

$$b \quad \frac{2\gamma}{\gamma-1} \left(\Phi \frac{1-\gamma}{2\gamma} - 1 \right) = C_2^* t .$$

By use of equations 3.1b, 3.15, and 3.17b, one has

$$3.18 \quad \Phi = \left[\frac{\gamma(\gamma-1) \left(\frac{2}{\gamma+1} \right)^{\frac{\gamma+1}{2(\gamma-1)}}}{2} \cdot \left(\frac{A g P_{b \text{ init}}}{a_{b \text{ init}} M \tau} \right) t + 1 \right]^{-\frac{2\gamma}{\gamma-1}} .$$

Let us define a dimensionless time τ such that

$$3.19a \quad \tau = \alpha_{\tau} t \quad \text{where}$$

$$b \quad \alpha_{\tau} = \frac{A g P_{b \text{ init}}}{a_{b \text{ init}} M \tau} .$$

Finally,

$$3.20 \quad \Phi = \left[\frac{\gamma(\gamma-1)}{2} \left(\frac{2}{\gamma+1} \right)^{\frac{\gamma+1}{2(\gamma-1)}} \gamma+1 \right]^{-\left(\frac{2\gamma}{\gamma-1} \right)}.$$

To compute the momentum rate of discharge from the muzzle, one observes that

$$3.21 \quad \dot{p} = \frac{\dot{M} a'_o}{g}.$$

And from equations 3.1a and 3.21 is derived

$$3.22 \quad \dot{p} = \frac{A \gamma a'_o}{a'_b} \left(\frac{2}{\gamma+1} \right)^{\frac{\gamma+1}{2(\gamma-1)}} p_b.$$

From equations 2.10c and 2.23, one has

$$3.22 \quad \frac{a'_o}{a'_b} = (1+\gamma) \frac{1-\gamma}{2\gamma}.$$

Substitution of the latter expression for $\frac{a'_o}{a'_b}$ in 3.22 gives

$$3.23 \quad \dot{p} = \frac{\gamma \left(\frac{2}{\gamma+1} \right)^{\frac{\gamma+1}{2(\gamma-1)}}}{(1+\gamma)^{(\gamma-1)/2\gamma}} A p_b.$$

We may also define a dimensionless momentum rate of discharge μ as

$$3.24 \quad \mu = \frac{\dot{p}}{A p_{b \text{ init}}}.$$

Then using this and 3.8, we have

$$3.25 \quad \mu = \gamma(1+\gamma)^{-\left(\frac{\gamma-1}{2\gamma} \right)} \left(\frac{2}{\gamma+1} \right)^{\frac{\gamma+1}{2(\gamma-1)}} \Phi.$$

It is also desirable to know the total momentum discharged to time t (assuming that the gas at the muzzle remains sonic). That is

$$3.26 \quad P = \int_0^t \dot{p} dt, \text{ which with 3.24 produce}$$

$$3.27a \quad P = A p_{b \text{ init}} \int_0^t \mu \, dt \quad \text{or}$$

$$b \quad P = \frac{A p_{b \text{ init}}}{\alpha_T} \int_0^T \mu \, dT \quad \text{and}$$

$$c \quad P = \frac{a_{b \text{ init}} M_T}{g} \int_0^T \mu \, dT, \quad \text{from 3.19b.}$$

Defining,

$$3.28 \quad \mu_T = \int_0^T \mu \, dT, \quad \text{we can write 3.27c as}$$

$$3.29 \quad P = \frac{a_{b \text{ init}} M_T}{g} \mu_T.$$

In a similar manner to that in which μ was defined, let us define a dimensionless mass rate of discharge γ .

$$3.30a \quad \gamma = \frac{\dot{M} a_{b \text{ init}}}{A g p_{b \text{ init}}}, \quad \text{so that}$$

$$b \quad \dot{M} = \frac{A g p_{b \text{ init}}}{a_{b \text{ init}}} \gamma.$$

From equations 3.1a, 3.8, and 3.30a, one obtains

$$3.31 \quad \gamma = \frac{\Phi \gamma \left(\frac{2}{\gamma+1} \right)^{\frac{\gamma+1}{2(\gamma-1)}}}{a_b / a_{b \text{ init}}}.$$

However,

$$3.32 \quad \frac{a_b}{a_{b \text{ init}}} = \left(\frac{p_b}{p_{b \text{ init}}} \right)^{\frac{\gamma-1}{2\gamma}} = \Phi^{\frac{\gamma-1}{2\gamma}}$$

Therefore,

$$3.33 \quad \gamma = \gamma \left(\frac{2}{\gamma+1} \right)^{\frac{\gamma+1}{2(\gamma-1)}} \Phi^{\frac{\gamma+1}{2\gamma}}.$$

Let us define the following constants

$$3.34a \quad C_1 = \frac{\gamma(\gamma-1)}{2} \left(\frac{2}{\gamma+1} \right)^{\frac{\gamma+1}{2(\gamma-1)}} = \frac{\gamma-1}{2} C_4 ,$$

$$b \quad C_2 = \frac{2\gamma}{\gamma-1} ,$$

$$c \quad C_3 = \frac{\gamma \left(\frac{2}{\gamma+1} \right)^{\frac{\gamma+1}{2(\gamma-1)}}}{(1+\gamma)} = \frac{C_4}{(\gamma-1)/2\gamma} (1+\gamma) ,$$

$$d \quad C_4 = \gamma \left(\frac{2}{\gamma+1} \right)^{\frac{\gamma+1}{2(\gamma-1)}} , \text{ and}$$

$$e \quad C_5 = \frac{\gamma+1}{\gamma-1} .$$

Then, equation 3.20 becomes

$$3.35 \quad \bar{\Phi} = (C_1 \tau + 1)^{-C_2} .$$

The cumulative breech force to time t --or breech impulse--is given by

$$3.36 \quad B_\tau = \int_0^t B \, dt , \text{ where}$$

$$3.37a \quad B = A p_b \quad \text{or}$$

$$b \quad B = A p_{b \text{ init}} \bar{\Phi} .$$

Thus,

$$3.38 \quad B_\tau = \frac{A p_{b \text{ init}}}{\alpha_\tau} \int_0^\tau \bar{\Phi} \, d\tau .$$

Defining a dimensionless breech impulse,

$$3.39 \quad \bar{\Phi}_\tau = \int_0^\tau \bar{\Phi} \, d\tau , \text{ we have}$$

$$3.40 \quad B_{\tau} = \frac{A p_{b \text{ init}}}{\alpha_{\tau}} \Phi_{\tau} .$$

3.39. Φ_{τ} may be found by substitution of Φ in 3.35 into One obtains

$$3.41a \quad \Phi_{\tau} = \int_0^{\tau} [C_1 \tau + 1]^{-C_2} d\tau \quad \text{or}$$

$$b \quad \Phi_{\tau} = \frac{1}{C_1(C_2-1)} \left[1 - (C_1 \tau + 1)^{-(C_2-1)} \right] .$$

Thus, from 3.25, 3.28, 3.34c, and 3.41b, one can write μ_{τ} as

$$3.42 \quad \mu_{\tau} = \frac{C_3}{C_1(C_2-1)} \left[1 - (C_1 \tau + 1)^{-(C_2-1)} \right] .$$

Further, it is desired to have the cumulative mass discharged to time t . This is given by

$$3.43 \quad M = \int_0^t \dot{M} dt .$$

Substitution of $\dot{M}$ in equation 3.30b into 3.43 gives

$$3.44 \quad M = M_{\tau} \int_0^{\tau} \nu d\tau .$$

The latter may be expressed as

$$3.45 \quad M = M_{\tau} \nu_{\tau} \quad \text{where}$$

$$3.46 \quad \nu_{\tau} = \int_0^{\tau} \nu d\tau , \quad \text{a dimensionless cumulative mass discharged.}$$

ν_{τ} can be found by substitution of ν in equation 3.33 into 3.46 . Using the constants defined in 3.34, ν_{τ} may be expressed as

$$3.47 \quad \nu_{\tau} = \frac{C_4}{C_1(C_5-1)} \left[1 - (C_1 \tau + 1)^{-(C_5-1)} \right] .$$

The total energy rate of discharge or stagnation enthalpy rate of discharge is given by

$$3.48 \quad \dot{H} = C_p T_{av} \dot{M} .$$

However,

$$3.49a \quad C_p = \frac{\gamma R}{(\gamma - 1)J} \quad \text{and}$$

$$b \quad T_{av} = T_{av \text{ init}} \Phi^{\frac{\gamma-1}{\gamma}} .$$

From equations 3.30b, 3.48, and 3.49,

$$3.50 \quad \dot{H} = \frac{\gamma R}{(\gamma - 1)J} \frac{T_{av \text{ init}} A g p_b \text{ init}}{a_b \text{ init}} \gamma \Phi^{\frac{\gamma-1}{\gamma}}$$

that is, with 3.33 and 3.35

$$3.51 \quad \dot{H} = \frac{\gamma R}{(\gamma - 1)J} \frac{T_{av \text{ init}} A g p_b \text{ init}}{a_b \text{ init}} .$$

$$. \quad C_4 \left[C_1 \tau + 1 \right]^{-(C_5+2)} .$$

or, from 1.15, 3.19b, and 3.51, we have

$$3.52 \quad \dot{H} = E_g \alpha_T \gamma C_4 \left[C_1 \tau + 1 \right]^{-(C_5+2)} .$$

Defining a dimensionless stagnation enthalpy rate of discharge η as

$$3.53 \quad \eta = \gamma C_4 \left[C_1 \tau + 1 \right]^{-(C_5+2)} , \quad \text{one obtains for } \dot{H}$$

$$3.54 \quad \dot{H} = E_g \alpha_T \eta .$$

The cumulative stagnation enthalpy discharged is, then,

$$3.55 \quad H = \int_0^t \dot{H} dt \quad \text{or from the preceding two relations}$$

$$3.56 \quad H = E_g \int_0^\tau \eta d\tau .$$

With the definition

$$3.57 \quad \eta_{\tau} = \int_0^{\tau} \eta \, d\tau, \text{ equation 3.56 becomes}$$

$$3.58 \quad H = E_g \eta_{\tau}.$$

One can obtain a computational expression for η_{τ} from 3.53 and 3.57 as follows

$$3.59 \quad \eta_{\tau} = \frac{\gamma C_4}{C_1(C_5+1)} \left[1 - (C_1\tau+1)^{-(C_5+1)} \right].$$

All of the non-dimensional parameters were evaluated as functions of τ for $\gamma = 1.26$ in the equations:

3.20 or 3.35 for $\bar{\Phi}$

3.25 for μ

3.33 for ν

3.53 for η

3.41b for $\bar{\Phi}_{\tau}$

3.42 for μ_{τ}

3.47 for ν_{τ}

3.59 for η_{τ}

Auxiliary constants are defined in 3.34a thru e.

Derivation of the Relationship: $n(\epsilon)$

In appendices IV and V a relationship is required which exists between the velocity to throat velocity ratio and the area to throat area ratio in one-dimensional, isentropic flows. The following is a derivation of this relationship.

In any of the books listed in the BIBLIOGRAPHY, are found one-dimensional, isentropic flow formulas involving the variables: M , mach number;

ϵ , expansion ratio;

$\frac{T}{T_b}$, temperature ratio; and

$\frac{a}{a_b}$ ratio of speed of sound to stagnation

speed of sound.

The subscript "b" is used here to denote a stagnation value or the value of the variable at the breech of a tube. The subscript "o" denotes the value of the variable at the muzzle or throat. Variables without subscripts are evaluated at a station downstream of the throat.

The formulas used in the derivation are:

$$3.60 \quad \epsilon = \frac{S}{A_o}, \text{ by definition.}$$

$$3.61 \quad n = \frac{v}{a_o}, \text{ by definition.}$$

$$3.62 \quad \frac{1}{\epsilon^2} = M^2 \left[\frac{1 + \frac{\gamma - 1}{2}}{1 + \frac{(\gamma - 1)}{2} M^2} \right]^{\frac{\gamma + 1}{\gamma - 1}},$$

from isentropic flow theory.

$$3.63 \quad M^2 = \frac{v^2}{\gamma g R T}, \text{ by definition.}$$

$$3.64 \quad \frac{T_b}{T} = 1 + \frac{\gamma - 1}{2} M^2, \text{ from isentropic flow theory.}$$

$$3.65 \quad \frac{a_o}{a_b} = (1 + \gamma)^{\frac{1 - \gamma}{2\gamma}}, \text{ from isentropic flow theory.}$$

3.66 $a_b = (\gamma g R T_b)^{1/2}$, by regarding sound propagation as a strictly adiabatic process. Substitution of T from 3.63 into 3.64 gives

3.67 $T_b(M^2 \gamma g R) = v^2(1 + \frac{\gamma - 1}{2} M^2)$, which by 3.66 becomes

$$3.68 \quad M^2 a_b^2 = v^2(1 + \frac{\gamma - 1}{2} M^2)$$

Elimination of a_b between 3.65 and 3.68 yields

$$3.69 \quad n^2 = \left(\frac{v}{a_0}\right)^2 = \frac{M^2 (1 + \gamma) \frac{\gamma - 1}{2}}{1 + \frac{\gamma - 1}{2} M^2}.$$

By solving this expression for M^2 , we get

$$3.70 \quad M^2 = \frac{n^2}{(1 + \gamma) \frac{\gamma - 1}{2} - \left(\frac{\gamma - 1}{2\gamma}\right) n^2}.$$

Substitution of this value of M^2 into 3.62 produces

$$3.71 \quad \frac{1}{\epsilon^2} = \frac{n^2}{a - b n^2} \left[\frac{\gamma + 1}{2 + \frac{(\gamma - 1)n^2}{a - b n^2}} \right]^c, \quad \text{where}$$

$$a = (1 + \gamma) \frac{\gamma - 1}{2}$$

$$b = \frac{\gamma - 1}{2}$$

$$c = \frac{\gamma + 1}{\gamma - 1}$$

This formula defines n implicitly as a function of ϵ and has been evaluated numerically for $\gamma = 1.26$ to obtain the tabular relationship used in DIPARDIP.

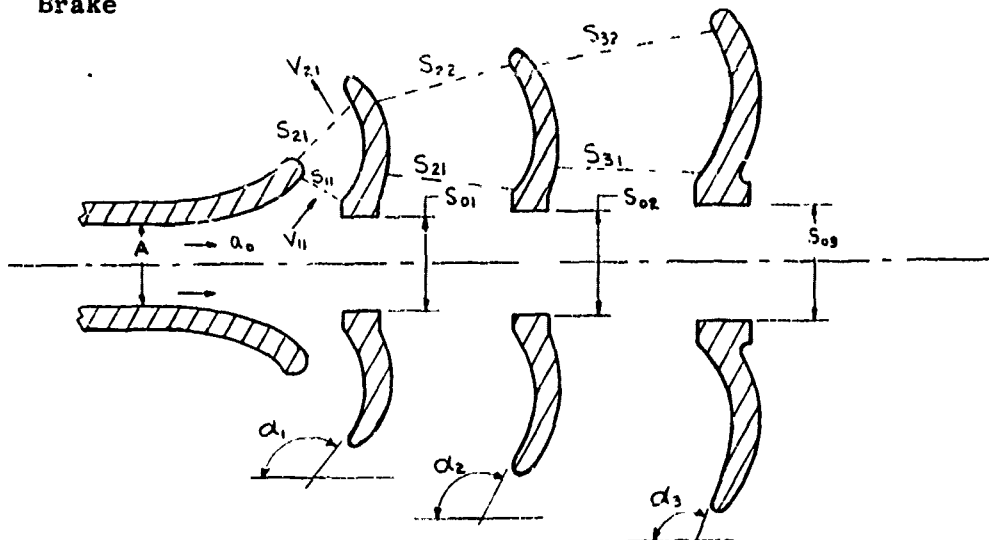
APPENDIX IV

Formulas for Closed Brakes

As was shown in the report "Muzzle Brakes" by Hammer (Document No. 7 in the BIBLIOGRAPHY), the derivation of the equations for closed brake designs is based upon finding the change in the momentum flux thru a control volume enclosing the brake.

Regard figure 4.1 .

Figure 4.1 . Schematic Plan View of Triple-Baffle, Closed Brake



Regarding the passage of gas toward the first baffle, it can be seen that, with the brake flowing full (i.e., with no separation), the gas captured by the baffle will have experienced an approximate area expansion of

$$4.1 \quad \epsilon_{11} = \frac{S_{01} + S_{11}}{A}$$

when it starts to be deflected by the first baffle. This gas will have a speed

$$4.2 \quad |v_{11}| = a_0 \cdot n(\epsilon_{11}) = a_0 \cdot n_{11} .$$

n is the speed up factor developed in appendix III.

It is also apparent that this gas experiences further expansion by a factor $\frac{S_{21}}{S_{11}}$. Thus, the resultant total

expansion of the gas caught and turned by the first baffle is

$$4.3 \quad \epsilon_{21} = \epsilon_{11} \frac{S_{21}}{S_{11}}$$

The speed of the gas as it leaves the first baffle is

$$4.4a \quad |v_{21}| = a_0 n_{21}, \quad \text{where}$$

$$b \quad n_{21} = n(\epsilon_{21}).$$

If the mass flux thru S_{01} is the same as that thru S_{11} , a fraction of the mass flow $\dot{M}_0$ equal to

$$4.5 \quad r_1 = \frac{S_{11}}{S_{01} + S_{11}} \quad \text{will be caught by the first}$$

baffle. For mass conservation, a fraction

$$4.6 \quad K_1 = \frac{S_{01}}{S_{01} + S_{11}} \quad \text{will be passed without deflection by this baffle.}$$

We assume that v_{11} is nearly paraxial and that v_{21} makes an angle of α_1 with respect to the axis.

For momentum conservation, the force felt by the first baffle equals the difference in the momentum fluxes entering and leaving it in the axial direction. Thus,

$$4.7a \quad F_{z1} = \dot{M}_0 r_1 |\vec{v}_{11}| - \dot{M}_0 r_1 |\vec{v}_{21}| \cos \alpha_1$$

$$b \quad F_{z1} = \dot{M}_0 r_1 a_0 n_{11} - \dot{M}_0 r_1 a_0 n_{21} \cos \alpha_1$$

or

$$c \quad F_{z1} = \dot{M}_0 a_0 r_1 (n_{11} - n_{21} \cos \alpha_1).$$

The gas which passes the first baffle undeflected has expanded in cross-sectional area by a factor ϵ_{11} . For full flow into the second baffle, the total area expansion from the muzzle is, therefore,

$$4.8 \quad \epsilon_{12} = \epsilon_{11} \left(\frac{S_{02} + S_{12}}{S_{01}} \right).$$

Further expansion of the deflected gas results in an expansion ratio of

$$4.9 \quad \epsilon_{22} = \frac{S_{22}}{S_{12}} \epsilon_{12} \quad \text{as the gas leaves the baffle.}$$

The velocities of entrance to and exit from the second baffle corresponding to these expansion ratios are, respectively,

$$4.10a \quad v_{12} = a_c n(\epsilon_{12}) = a_o n_{12}$$

and

$$b \quad v_{22} = a_o n(\epsilon_{22}) = a_o n_{22} .$$

Since only a fraction K_1 of the total mass flux enters the second baffle, the fraction turned by this baffle is

$$4.11 \quad r_2 = \frac{S_{12}}{S_{02} + S_{12}} K_1 \quad \text{and}$$

the fraction of the total passing undeflected is

$$4.12 \quad K_2 = \frac{S_{02}}{S_{02} + S_{12}} K_1 .$$

Again, using the momentum rate of change principle, we find that the force on the second baffle in the axial direction is

$$4.13 \quad F_{z2} = \dot{M}_o a_o r_2 (n_{12} - n_{22} \cos \alpha_2) .$$

By the same reasoning, the force on the third baffle is

$$4.14 \quad F_{z3} = \dot{M}_o a_o r_3 (n_{13} - n_{23} \cos \alpha_3) .$$

The total brake force in the axial direction is simply the sum of the forces on each baffle, i.e.,

$$4.15 \quad F_z = F_{z1} + F_{z2} + F_{z3} \quad \text{or}$$

$$4.16 \quad F_z = \dot{M}_o a_o \sum_j r_j (n_{1j} - n_{2j} \cos \alpha_j) , \quad \text{where}$$

$$4.17a \quad n_{1j} = n(\epsilon_{1j})$$

$$b \quad n_{2j} = n(\epsilon_{2j}) \quad \text{and}$$

$$4.18a \quad \epsilon_{1j} = \left(\frac{S_{0j} + S_{1j}}{S_{0j-1}} \right) \epsilon_{1j-1}$$

$$b \quad \epsilon_{10} = 1$$

$$c \quad S_{00} = A$$

$$4.19 \quad \epsilon_{2j} = \frac{S_{2j}}{S_{1j}} \epsilon_{1j}$$

$$4.20a \quad r_j = \left(\frac{S_{1j}}{S_{0j} + S_{1j}} \right)^{K_j - 1}$$

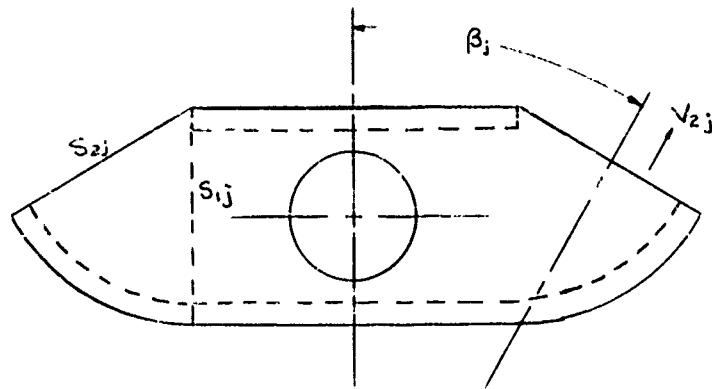
$$b \quad K_0 = 1$$

$$4.21 \quad K_j = \left(\frac{S_{0j}}{S_{0j} + S_{1j}} \right)^{K_j - 1} .$$

For brakes which exhaust gas asymmetrically with respect to the vertical, at zero quadrant elevation, there is an additional vertical force on the brake.

Regard figure 4.2 .

Figure 4.2 . Schematic Front View of Asymmetric, Closed Brake



For the j^{th} baffle, the gas which escapes thru the area S_{2j} is moving with speed $|v_{2j}|$ at an angle β_j with respect to the vertical. Since this is a closed brake, the previous analysis which produced formulas 4.16 thru 4.21 is valid here.

The downward vertical force on the brake is simply equal to the vertical component of the rate of change of

momentum. Since gas impinges upon each baffle without having a vertical velocity component, the vertical force equals the vertical momentum flux. That is,

$$4.22a \quad F_y = \sum_j r_j \dot{M}_0 |v_{2j}| \cos \beta_j \quad \text{or}$$

$$b \quad F_y = \dot{M}_0 a_0 \sum_j r_j n_{2j} \cos \beta_j .$$

It is convenient to define several non-dimensional parameters which are useful in computing forces on closed muzzle brakes. These are:

$$4.23a \quad \lambda = \frac{F_z}{\dot{p}} ,$$

$$b \quad b = \frac{F_z}{B} , \text{ the momentum index}$$

$$c \quad \lambda_r = \frac{\text{total momentum flux in axial direction thru a control surface completely enclosing the brake}}{\dot{p}}$$

λ and b are alternative ways of defining a non-dimensional axial brake force. λ_r is a non-dimensional parameter of interest in evaluating the strength of the induced atmospheric shock.

For closed brakes, $\frac{F_z}{B}$ is taken to be a constant throughout the discharge period; hence

$$4.24a \quad b = \frac{\int_0^\infty F_z dt}{B_\tau} \quad \text{or}$$

$$b \quad b B_\tau = \int_0^\infty F_z dt .$$

The resultant axial impulse felt by the weapon is

$$4.25 \quad I_z = B_\tau - \int_0^\infty F_z dt .$$

By 4.24b, the last expression may be written as

$$4.26 \quad I_z = B_T (1 - b).$$

One also can define a non-dimensional vertical brake force ω .

$$4.27 \quad \omega = \frac{F_y}{\dot{P}}$$

By integration of this expression, one obtains the resultant vertical impulse I_y .

$$4.28 \quad I_y = \omega P.$$

To find computational expressions for λ , b , λ_r , and ω , one need merely make appropriate substitutions in 4.23 and 4.27 for the dimensional parameters involved. For example, from 3.21, 4.16, and 4.23a, one finds

$$4.29 \quad \lambda = \sum_j^N r_j (n_{1j} - n_{2j} \cos \alpha_j).$$

Due to the simplifying assumptions made in the derivation of 4.29, this expression is adjusted to agree with experiments performed on closed baffles, by means of a correction factor $\frac{1}{F_0}$.

Thus

$$4.30 \quad \lambda = \frac{1}{F_0} \sum_j^N r_j (n_{1j} - n_{2j} \cos \alpha_j).$$

From 4.23b and the last expression, the momentum index can be written as

$$4.31 \quad b = \frac{\dot{P}}{B} \frac{1}{F_0} \sum_j^N r_j (n_{1j} - n_{2j} \cos \alpha_j).$$

The axial component of the corrected momentum transport thru a control surface enclosing the brake can be written as

$$\frac{\dot{M} a_z}{F_1} \left[\sum_j^N r_j n_{2j} \cos \alpha_j - n_{2N} \left(1 - \sum_j^N r_j \right) \right].$$

With 3.21 and 4.23c this expression produces

$$4.32 \quad \lambda_r = \frac{1}{F_1} \left[\sum_j^N r_j n_{2j} \cos \alpha_j - n_{2N} \left(1 - \frac{N}{2} r_j \right) \right] .$$

Finally, using an empirical correction factor $\frac{1}{F_2}$,
equations 3.21, 4.22b, and 4.27 yield

$$4.33 \quad \omega = \frac{1}{F_2} \sum_j^N r_j n_{2j} \cos \beta_j .$$

APPENDIX V

Formulas for Open Brakes

For single-baffle, symmetric, open brakes, the region between the muzzle and the baffle remains relatively open for free expansion of the gas prior to deflection. The baffle is mechanically connected to a tube attached to the muzzle by supports which partially confine the flow. However, even without ducting of the flow, confinement is achieved by the shock envelope which develops in flow from sonic and supersonic nozzles.

Regard figure 5.1 .

Figure 5.1a Schematic Plan View of a Single-Baffle, Open Brake

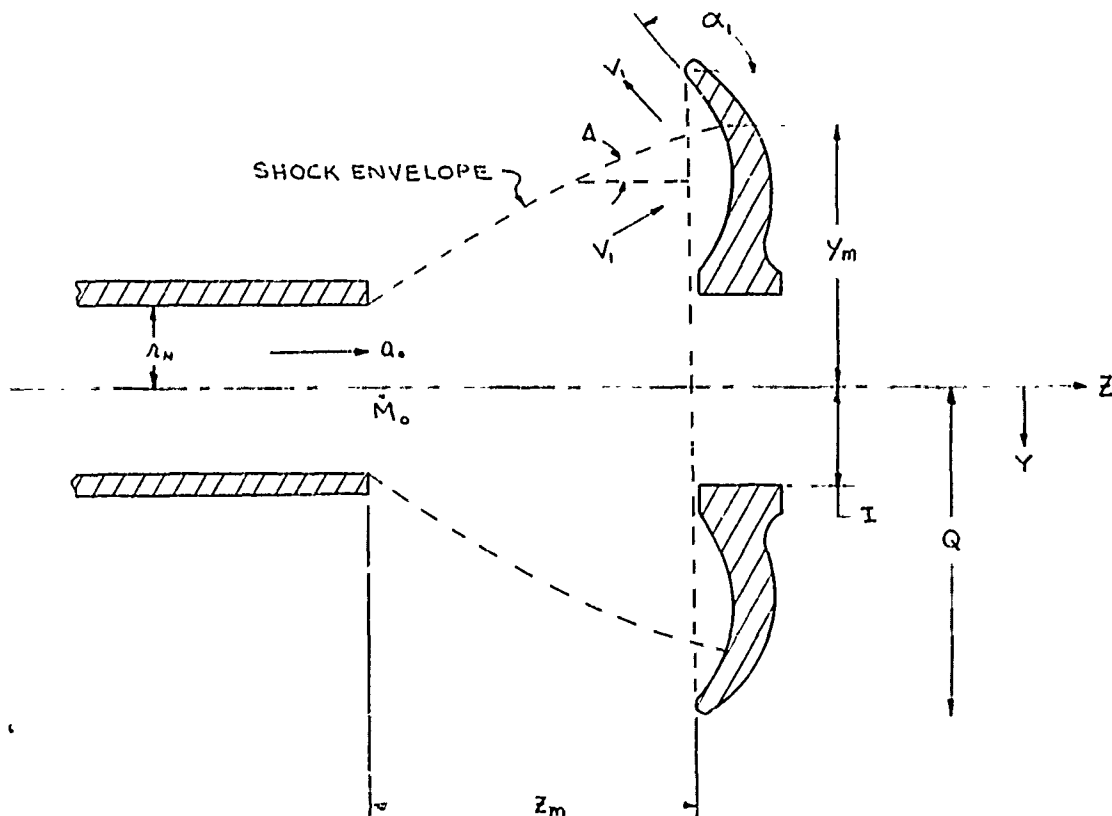
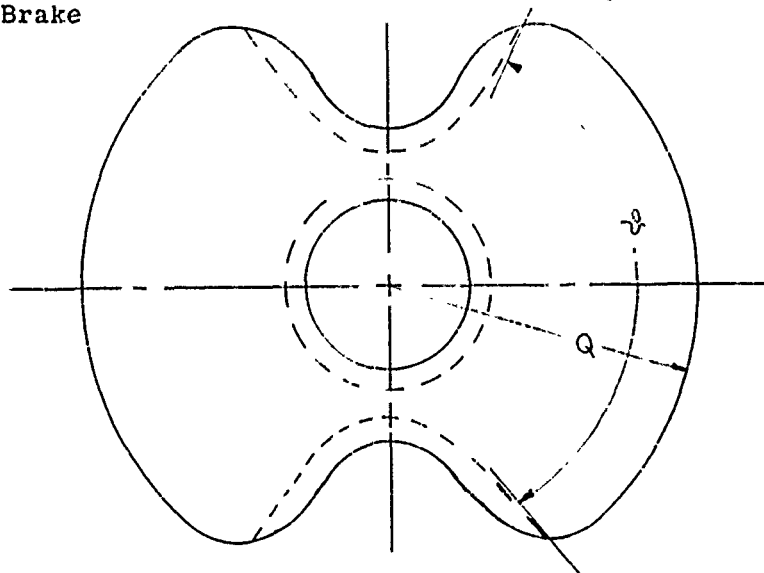


Figure 5.1b Schematic Front View of a Single-Baffle, Open Brake



In the absence of a muzzle brake, the free discharge from the tube would cause a shock envelope to develop in the flow. This has been sketched in in figure 5.1a . The presence of the brake would alter the flow pattern considerably and consequently alter any shock structure within the flow. However, it is not unreasonable to expect that the fraction of the total mass flux captured and turned by the baffle could be computed by assuming that that portion is captured which would be masked by a virtual baffle in a corresponding position of the free stream. With this as a working hypothesis, it is necessary to be able to predict the free stream shock envelope. A method for doing this is described in document number 1 of the BIBLIOGRAPHY. This method was used for a sonic nozzle with $\gamma = 1.26$ for several values of p_0 , and the resulting envelopes $\lambda(\sigma)$ were

optimally fit with quadratic and cubic equations in σ .

For the case pictured in figure 5.1a, that is, when $y_m \leq Q$, the mass fraction captured and deflected by the baffle is given by

$$5.1a \quad r_1 = \frac{\dot{M}_1}{\dot{M}_0} = \frac{\pi y_m^2 - \pi I^2}{\pi y_m^2} \quad \text{or}$$

$$b \quad r_1 = 1 - \frac{I^2}{y_m^2}, \quad (y_m \leq Q).$$

However, for $y_m > Q$, the gas deflected by the baffle equals the total amount minus that lost thru the center and that which would be lost by spilling over the outer edge. This mass is

$$5.2 \quad \dot{M}_1 = \frac{\dot{M}_0}{\pi y_m^2} \left[\pi y_m^2 - \pi I^2 - \pi \frac{\gamma \ell}{\pi} (y_m^2 - Q^2) \right].$$

The fraction captured is

$$5.3 \quad r_1 = 1 - \frac{\gamma \ell}{\pi} \div \left(\frac{\gamma \ell}{\pi} Q^2 - I^2 \right) / y_m^2, \quad (y_m > Q).$$

The momentum flux in the z- direction into a control surface surrounding the baffle is

$$5.4 \quad \dot{P}_1 = v_1 \dot{M}_1 \cos \Delta = v_1 \dot{M}_0 r_1 \cos \Delta$$

and the momentum flux in the z- direction out of the control surface is

$$5.5 \quad \dot{P}_2 = v_1 \dot{M}_1 \cos \alpha_1 = v_1 \dot{M}_0 r_1 \cos \alpha_1.$$

For momentum conservation,

$$5.6 \quad \dot{P}_1 - \dot{P}_2 = F_z, \text{ which from equations 5.4 and 5.5} \\ \text{may be written as}$$

$$5.7 \quad F_z = \dot{M}_0 r_1 v_1 (\cos \Delta - \cos \alpha_1).$$

Using the speed-up factor, n , developed in appendix III, we can write

$$5.8a \quad v_1 = n_{21} a_0, \quad \text{where}$$

$$b \quad n_{21} = n(\epsilon_{21})$$

$$c \quad \epsilon_{21} \approx 1 + \frac{\gamma \ell}{\pi} \left(\frac{y_m}{r_N} \right)^2 \quad \text{and}$$

d $\Delta \approx 0$, for the weapons under consideration. Equations 5.7 and 5.8a and d give

$$5.9 \quad F_z = \dot{M}_0 a_0 n_{21} r_1 (1 - \cos \alpha_1).$$

It is recognized that non-uniformity in the density distribution and non-paraxial flow into the baffle will give rise to a value of F_z slightly different from that predicted by equation 5.9 . Therefore, F_z has been corrected with an empirical correction factor $1/f_3$. f_3 has been found to be approximately 1.33 . Thus,

$$5.10 \quad F_z = \dot{M}_0 a_0 \frac{n_{21} r_1 (1 - \cos \alpha_1)}{f_3} \quad \text{or}$$

$$5.11 \quad \lambda = \frac{F_z}{\dot{p}} = \frac{n_{21} r_1 (1 - \cos \alpha_1)}{f_3} .$$

By 4.23b and 5.11 ,

$$5.12 \quad b = \frac{\dot{p}}{B} \frac{n_{21} r_1 (1 - \cos \alpha_1)}{f_3} .$$

Since the open brake was assumed to be symmetric with respect to a horizontal axis, $\omega = 0$.

It should be noted that in the expression for b , n_{21} and r_1 both depend upon the dimensions of the shock envelope. Since the latter changes markedly throughout the discharge period, one should expect to find some change in b as a function of time (See graph 5.1.) .

Artillery designers are fundamentally concerned with an effective momentum index in order to compute the total impulse which must be taken up by the recoil mechanism. The engineer, therefore, is not primarily concerned with the instantaneous value of b . To find the effective value of b which the engineer uses, we note that the resultant axial impulse is given by

$$5.13 \quad I_z = B_T - \int_0^{\infty} F_z dt .$$

However, from 4.23b, the definition of b ,

$$5.14 \quad F_z = b B; \text{ hence}$$

$$5.15a \quad I_z = B_T - \int_0^{\infty} b B dt \quad \text{or}$$

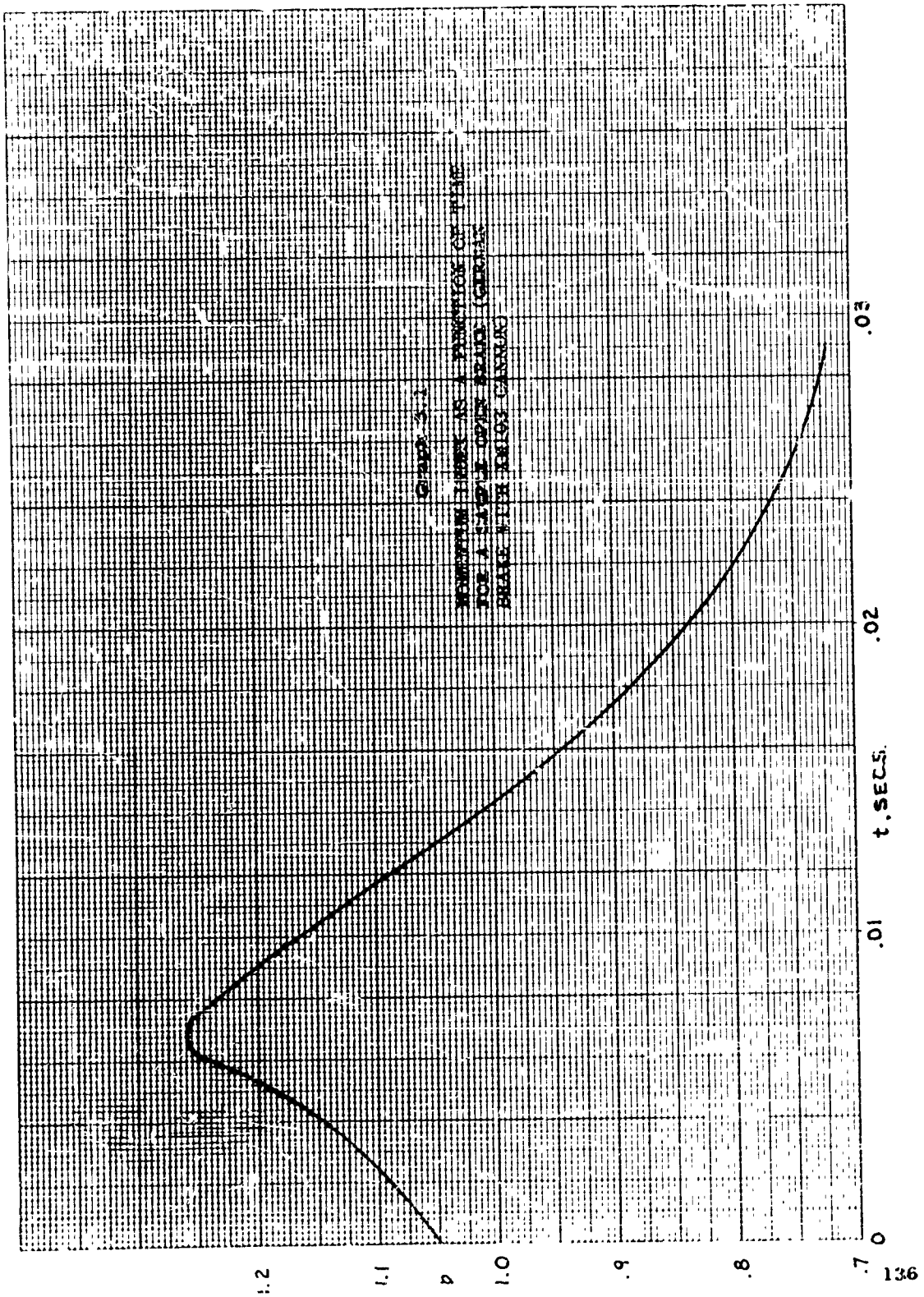
$$b \quad I_z = B_T - \int_0^{B_T} b dB_T .$$

The effective value of b , b_{eff} , which the engineer uses is obtained from

$$5.16 \quad I_z = B_T (1 - b_{\text{eff}}) .$$

Comparing equations 5.15b and 5.16, it is apparent that b_{eff} should be

$$5.17 \quad b_{\text{eff}} = \frac{\int_0^{B_T} b \, dB_T}{B_T} .$$



Therefore, the downward force due to efflux thru this portion of the periphery and its mirror image with respect to the vertical can be written as

$$6.3a \quad F_{y1} = 2v_{21} K \int_{-\vartheta_1}^{\vartheta_2} \sin \vartheta d\vartheta \quad \text{or}$$

$$b \quad F_{y1} = 2v_{21} K (\cos \vartheta_1 - \cos \vartheta_2), \quad \text{where}$$

$$c \quad K = \frac{\dot{M}_0 r_1}{2\pi}$$

For peripheral discharge thru $-\frac{\pi}{2} \leq \vartheta < -\vartheta_1$ and

its mirror image, all of the mass is assumed to be deflected thru ϑ_3 . Thus, the contribution to the downward force from this momentum discharge is

$$6.4 \quad F_{y2} = 2Kv_{21} (\sin \vartheta_3) (\pi/2 - \vartheta_1)$$

No flux passes thru the periphery $\vartheta_2 < \vartheta \leq \frac{\pi}{2}$

and its mirror image and, hence, there is no vertical force component for this portion of the periphery. The total downward force is, therefore,

$$6.5a \quad F_y = 2v_{21} K \left[(\cos \vartheta_1 - \cos \vartheta_2) + \left(\frac{\pi}{2} - \vartheta_1\right) \sin \vartheta_3 \right] \quad \text{or}$$

$$b \quad F_y = \frac{\dot{M}_0 r_1 v_{21}}{\pi} \left[(\cos \vartheta_1 - \cos \vartheta_2) + \left(\frac{\pi}{2} - \vartheta_1\right) \sin \vartheta_3 \right].$$

From equations 4.4 and 4.27, and 6.5b, ω can be written as

$$6.6 \quad \omega = \frac{r_1 n_{21}}{\pi} \left[(\cos \vartheta_1 - \cos \vartheta_2) + \left(\frac{\pi}{2} - \vartheta_1\right) \sin \vartheta_3 \right].$$

For a multiple baffle brake, this expression becomes

$$6.7 \quad \omega = \frac{1}{\pi} \sum_j^N n_{2j} r_j \left[(\cos \vartheta_{1j} - \cos \vartheta_{2j}) + \left(\frac{\pi}{2} - \vartheta_{1j}\right) \sin \vartheta_{3j} \right].$$

As indicated in appendix IV,

$$6.8a \quad F_y = \omega \dot{P} \quad \text{and}$$

$$b \quad I_y = \omega P.$$

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In order to implement the computation of parameters associated with a complete brake analysis, a digital computer program was written for the Royal McBee, LGP-30 which permits one to perform an analysis with relative ease. This program is included in the report.

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