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THEORY AND APPLICATION OF MATHEMATICAL MODELING OF SHOULDER-FIRED WEAPONS

PART I: M16A1 RIFLE

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FINAL REPORT

U.S. ARMY ARMAMENT COMMAND

RESEARCH DIRECTORATE

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Now define the following linear operations:

$$L_o = -C \frac{d()}{dt} - K$$

$$L_1 = m \frac{d^2()}{d+^2} + (C+C_\infty) \frac{d()}{dt} + (K+K_\infty)$$

$$L_2 = m \frac{d^2()}{d+^2} + 2C \frac{d()}{dt} + 2K$$

Then equations (C-7), (C-8), and (C-9) can be rewritten as:

$$
\begin{aligned}
&L_1X_1 + L_oX_2 + 0X_3 + 0X_4 + \cdots + 0X_n = K_\infty (X_{FP}-X_{FP_o}) + C_\infty\dot{X}_{FP} \\
&L_oX_1 + L_2X_2 + L_oX_3 + 0X_4 + \cdots + 0X_n = 0 \\
&0X_1 + L_oX_2 + L_2X_3 + L_oX_4 + \cdots + 0X_n = 0 \\
&\cdot \\
&\cdot \\
&\cdot \\
&0X_1 + 0X_2 + 0X_3 + 0X_4 + L_oX_{n-1} + L_1X_n = K_\infty (X_{MG}-X_{MG_o}) + C_\infty\dot{X}_{MG}
\end{aligned}
\qquad \text{(C-10)}
$$

Now take Laplace transforms of $L_oX(t)$, $L_1X(t)$, $L_2X(t)$

$$\mathcal{L}\{L_o[X(t)]\} = -C\ [S\overline{X}(S) - X(0) - K\overline{X}(S)]$$

$$\mathcal{L}\{L_1[X(t)]\} = m\ [S^2\overline{X}(S) - SX(0) - \frac{dx}{dt}(0)] + (C+C_\infty)[S\overline{X}(S) - X(0)] + (K+K_\infty)\ \overline{X}(S)$$

$$\mathcal{L}\{L_2[X(t)]\} = m\ [S^2\overline{X}(S) - SX(0) - \frac{dx(0)}{dt}] + 2C\ [S\overline{X}(S) - X(0)] + 2K\overline{X}(S)$$

Assume $X(0) = \dot{X}(0) = 0$

$$\mathcal{L}\{L_o[X(t)]\} = -C\ [S + \frac{K}{C}]\ \overline{X}(S) \equiv \alpha_o(S)\overline{X}(S)$$

$$\mathcal{L}\{L_1[X(t)]\} = [mS^2 + (C+C_\infty)\ S + (K+K_\infty)]\overline{X}(S) \equiv \alpha_1(S)\overline{X}(S)$$

$$\mathcal{L}\{L_2[X(t)]\} = [mS^2 + 2CS + 2K]\ \overline{X}(S) \equiv \alpha_2(S)\overline{X}(S)$$

Also define

$$\mathcal{L}\{K_\infty[X_{FP}-X_{FP_o}] + C_\infty[\dot{X}_{FP}]\} \equiv g_1(S)$$

$$\mathcal{L}\{K_\infty[X_{MG}-X_{MG_o}] + C_\infty[\dot{X}_{MG}]\} \equiv g_n(S)$$

Now take the Laplace transforms of Equation (C-10)

$$\alpha_1(S)\,\overline{X}_1(S) + \alpha_o(S)\,\overline{X}_2(S) + 0\overline{X}_3(S) + 0\overline{X}_4(S) + \cdots + 0\overline{X}_n(S) = g_1(S)$$

$$\alpha_o(S)\,\overline{X}_1(S) + \alpha_2(S)\,\overline{X}_2(S) + \alpha_o(S)\overline{X}_3(S) + 0\overline{X}_4(S) + \cdots + 0\overline{X}_n(S) = 0$$

$$0\,\overline{X}_1(S) + \alpha_o(S)\,\overline{X}_2(S) + \alpha_2(S)\overline{X}_3(S) + \alpha_o(S)\overline{X}_4(S) + \cdots + 0\overline{X}_n(S) = 0$$

$$\vdots$$

$$0\,\overline{X}_1(S) + 0\,\overline{X}_2(S) + 0\,\overline{X}_3(S) + 0\,\overline{X}_4(S) + \alpha_o(S)\,\overline{X}_{n-1}(S) + \alpha_1(S)\overline{X}_n(S) = g_2(S)$$

Consider $g_1(S)$ and $g_2(S)$ as known. Such an assumption implies that X_{FP} and X_{MG} are given.

$$\begin{bmatrix} \alpha_1 & \alpha_o & 0 & 0 & \cdots & 0 \\ \alpha_o & \alpha_2 & \alpha_o & 0 & \cdots & 0 \\ 0 & \alpha_o & \alpha_2 & \alpha_o & \cdots & 0 \\ \vdots \\ 0 & 0 & 0 & 0 & \cdots & \alpha_o\ \alpha_1 \end{bmatrix} \begin{bmatrix} \overline{X}_1(S) \\ \overline{X}_2(S) \\ \overline{X}_3(S) \\ \vdots \\ \overline{X}_n(S) \end{bmatrix} = \begin{bmatrix} g_1(S) \\ 0 \\ 0 \\ \vdots \\ g_2(S) \end{bmatrix}$$

Solve for $\overline{X}_1(S)$ using Cramer's rule. The denominator of the resulting expression for $\overline{X}_1(S)$ is:

$$\det[\alpha] = \alpha_1 \left[\alpha_1 \frac{U^{n-1} - V^{n-1}}{U-V} - \alpha_o^2 \frac{U^{n-2} - V^{n-2}}{U-V} \right] - \alpha_o^2 \left[\alpha_1 \frac{U^{n-2} - V^{n-2}}{U-V} - L_o^2 \frac{U^{n-3} - V^{n-3}}{U-V} \right]$$

$$\det[\alpha] = \frac{U^{n-3}}{U-V}\,[U\alpha_1 - \alpha_o^2]^2 - \frac{V^{n-3}}{U-V}\,[\alpha_1 V - \alpha_o^2]$$

$$\text{where } U \equiv \frac{\alpha_2 + \sqrt{\alpha_2^2 - 4\alpha_o^2}}{2} \qquad V \equiv \frac{\alpha_2 - \sqrt{\alpha_2^2 - 4\alpha_o^2}}{2}$$

In Reference [11], it is shown that the determinate of a MXM triple-banded matrix is:

$$\begin{vmatrix} A_2 & A_o & 0 & 0 & 0 & \cdots & 0 & 0 \\ A_o & A_2 & A_o & 0 & 0 & \cdots & 0 & 0 \\ 0 & A_o & A_2 & A_o & 0 & \cdots & 0 & 0 \\ \vdots \\ 0 & 0 & 0 & 0 & \cdots & A_o & A_2 & A_o & 0 \\ 0 & 0 & 0 & 0 & \cdots & 0 & A_o & A_2 & A_o \\ 0 & 0 & 0 & 0 & \cdots & 0 & 0 & A_o & A_2 \end{vmatrix} = \frac{U^{m+1} - V^{m+1}}{U-V}$$

where U and V are the roots of $X^2 - A_2 X - A_o^2 = 0$

By this fact, the surprisingly simple result for det $[\alpha]$ was made possible.

The numerator of the Cramer's rule solution for $\overline{X}_1(S)$ is:

$$g_1 [\alpha_1 K_{n-2} - \alpha_o^2 K_{n-3}] + (-1)^{n+1} g_2 \alpha_o^{n-1}$$

where $K_i \equiv \frac{U^{i+1} - V^{i+1}}{U-V}$

thus

$$\overline{X}_1(S) = \frac{(-1)^{n+1} g_2 \alpha_o^{n-1} + g_1 \left[\alpha_1 \frac{U^{n-1} - V^{n-1}}{U-V} - \alpha_o^2 \frac{U^{n-2} - V^{n-2}}{U-V}\right]}{\frac{U^{n-3}}{U-V}\left[U\alpha_1 - \alpha_o^2\right]^2 - \frac{V^{n-3}}{U-V}\left[\alpha_1 V - \alpha_o^2\right]^2}$$

$$\overline{X}_1(S) = \frac{(-1)^{n+1} g_2 \alpha_o^{n-1} (U-V) + g_1 U^{n-2}(\alpha_1 U - \alpha_o^2) - V^{n-2} g_1 (\alpha_1 V - \alpha_o^2)}{U^{n-3}[\alpha_1 U - \alpha_o^2]^2 - V^{n-3}[\alpha_1 V - \alpha_o^2]^2}$$

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[11] Muir, Thomas, A Treatise on the Theory of Determinants, Dover Publication, pp 564.

One finds a similar expression for the last coil. If these are rewritten in the K_i-notation, the result is:

$$\overline{X}_1(S) = \frac{(-1)^{n+1} g_2 \alpha_o^{n-1} + g_1 (\alpha_1 K_{n-2} - \alpha_o^2 K_{n-3})}{\alpha_1^2 K_{n-2} - 2\alpha_1 \alpha_o^2 K_{n-3} + \alpha_o^4 K_{n-4}}$$

$$\overline{X}_n(S) = \frac{(-1)^{n+1} g_1 \alpha_o^{n-1} + g_2 (\alpha_1 K_{n-2} - \alpha_o^2 K_{n-3})}{\alpha_1^2 K_{n-2} - 2\alpha_1 \alpha_o^2 K_{n-3} + \alpha_o^4 K_{n-4}}$$

The great difficulty is in taking the inverse transforms. If one can find the inverse transform of $\overline{X}_1$ (S), one can then easily evaluate the spring force acting on the firing pin if the motion of the firing pin is given. Many methods for finding inverse transforms were used. The following expression is shown in Reference[12].

$$f(t) = \mathcal{L}^{-1} [\overline{f}(s)] = e^{-t/2} \sum_{k=o}^{\infty} \frac{C_k L_k(t)}{k!}$$

where $C_k = \sum_{j=o}^{k} \binom{k}{j} \frac{1}{j!} \overline{f}^{\,j} \left(\frac{1}{2}\right) \quad k=o,1,2,\ldots$

$$L_k(t) = e^t \frac{d^k}{dt^k}(t^k e^{-t}) = (-1)^k [X^k - k^2 X^{k-1} + \frac{k^2(k-1)^2}{2!} X^{k-2} \mp \ldots]$$

The $K_K(t)$ are Laguerre polynominals.

The above method did not appear to converge. Because of time consideration, the transfer function approach was temporarily abandoned, and a direct solution of the equation was sought. However, the finding of a transfer function for such a mechanical system is of such importance to weapon modeling that efforts should be resumed; perhaps Fourier transforms could also be tried.

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[12]Korn, G.A. and Korn, T.M., Mathematical Handbook for Scientists and Engineers; definitions, theorems, and formulas for reference and review, McGraw-Hill, New York, N.Y. (1961), pg 226.

In solving the equations directly, the approach was to assume that the right side of the equation for the ith coil,

$$M\ddot{X}_i + 2C\dot{X}_i + 2KX_i = K(X_{i-1} + X_{i+1}) + C(\dot{X}_{i-1} + \dot{X}_{i+1}),$$

is constant within any given time increment of integration. It can, of course, vary from increment-to-increment. With the right side thus held constant temporarily, homogeneous and particular solutions are easily obtained for the ith coil, and one can evaluate its position and velocity at the end of each time interval so that these become initial conditions for the next time increment. The method was found to give more accurate results than the fourth-order Runge-Kutta algorithm in less than one-half the computation time. Comparisons were made between these two methods, and the exact solutions for two and three masses.

A derivation of the method now will be presented. Assume, for simplicity, that $c_\infty = c$ and $K_\infty = K$, and rewrite the equations as follows:

$$M\ddot{X}_1 + 2KX_1 + 2C\dot{X}_1 = KX_2 + C\dot{X}_2 + K(X_{FP} - X_{FP_o}) + C\dot{X}_{FP} = h_1 \qquad \text{(C-11)}$$

$$\vdots$$

$$M\ddot{X}_i + 2KX_i + 2C\dot{X}_i = K(X_{i+1} + X_{i-1}) + C(\dot{X}_{i+1} + \dot{X}_{i-1}) = h_i \qquad \text{(C-12)}$$

$$\vdots$$

$$M\ddot{X}_n + 2KX_n + 2C\dot{X}_n = K X_{n-1} + K(X_{MG} - X_{MG_o}) + C(\dot{X}_{MG} + \dot{X}_{n-1}) = h_n \qquad \text{(C-13)}$$

Integrate these equations from $t=t_1$ to $t=t_1 + \Delta t$. During this interval, assume that the right side of each equation does not change. The homogeneous equations are of the form

$$M\ddot{X}_h + \alpha\dot{X}_h + \beta X_h = 0,$$

where

$$\alpha = 2C, \ \beta = 2K.$$

Assume homogeneous solutions of the form $X = e^{rt}$.

Substitution of the assumed solution into the homogeneous equation yields the following:

$$mr^2 + \alpha r + \beta = 0$$

$$r = \frac{-\alpha \pm \sqrt{\alpha^2 - 4\,m\beta}}{2m}$$

Three cases exist that are analogous to the underdamped, overdamped, and critically-damped cases for a single mass-spring-dashpot system.

CASE I

$\alpha^2 - 4\,m\beta < 0$ or $\frac{2K}{m} - (\frac{C}{m})^2 > 0$ **This case corresponds to underdamping.**

$$r = -\frac{\alpha}{2m} \pm i\sqrt{\frac{\beta}{m} - (\frac{\alpha}{2m})^2}$$

$$X_h = e^{-\frac{\alpha}{2m}t}\left[Ae^{i\sqrt{\frac{\beta}{m} - (\frac{\alpha}{2m})^2}\,t} + Be^{-i\sqrt{\frac{\beta}{m} - (\frac{\alpha}{2m})^2}\,t}\right]$$

$$X_h = e^{-\frac{\alpha}{2m}t}\left[(A+B)\cos\sqrt{\frac{\beta}{m} - (\frac{\alpha}{2m})^2}\;t + i\,(A - B)\sin\sqrt{\frac{\beta}{m} - (\frac{\alpha}{2m})^2}\;t\right]$$

$$X_h = e^{-\frac{\alpha}{2m}t}\left[C_1\cos\sqrt{\frac{\beta}{m} - (\frac{\alpha}{2m})^2}\;t + C_2\sin\sqrt{\frac{\beta}{m} - (\frac{\alpha}{2m})^2}\;t\right]$$

Now, find a particular solution to:

$$M\ddot{X}_j + \alpha\,\dot{X}_j + \beta\,X_j = h_j = \text{constant} = h_j\ (t=0).$$

$$X_{P_j} = \frac{h_j}{\beta}$$

Thus, the complete solution to equations (C-11), (C-12), (C-13) is:

$$X_j = e^{-\frac{\alpha}{2m}t}\left[C_{1j}\cos\sqrt{\frac{\beta}{m} - (\frac{\alpha}{2m})^2}\;t + C_{2j}\sin\sqrt{\frac{\beta}{m} - (\frac{\alpha}{2m})^2}\;t\right] + \frac{h_j(t=0)}{\beta} \quad \text{(C-14)}$$

C_{1j} and C_{2j} are determined from the initial conditions

$$X_j(t_1) = P_j \quad \text{(C-15)}$$

and

$$\dot{X}_j(t_1) = V_j. \quad \text{(C-16)}$$

For simplicity, equation (C-14) will be applied individually over each time increment. Thus, t_1 will be equated to zero; and P_j and V_j will be equated to the respective values at the end of the previous time increment. A separate accounting is made of the true value of t as the solution progresses.

Application of the initial condition (C-15) yields:

$$P_j = C_{1j} + \frac{h_j(t=0)}{\beta} \tag{C-17}$$

$$C_{1j} = P_j - \frac{h_j(t=0)}{\beta} \tag{C-18}$$

Now,

$$\dot{X}_j = \frac{-\alpha}{2m} e^{-\frac{\alpha}{2m}t} \left[C_{1j} \cos \sqrt{\frac{\beta}{m} - (\frac{\alpha}{2m})^2}\, t + C_{2j} \sin \sqrt{\frac{\beta}{m} - (\frac{\alpha}{2m})^2}\, t \right]$$

$$+ e^{-\frac{\alpha}{2m}t} \left[-C_{1j} \sqrt{\frac{\beta}{m} - (\frac{\alpha}{2m})^2} \sin \sqrt{\frac{\beta}{m} - (\frac{\alpha}{2m})^2}\, t + C_{2j} \sqrt{\frac{\beta}{m} - (\frac{\alpha}{2m})^2} \cos \sqrt{\frac{\beta}{m} - (\frac{\alpha}{2m})^2}\, t \right]$$

Application of (C-16) yields:

$$V_j = -\frac{\alpha}{2m} C_{1j} + C_{2j} \sqrt{\frac{\beta}{m} - (\frac{\alpha}{2m})^2}$$

$$V_j = -\frac{\alpha}{2m} \left[P_j - \frac{h_j(t=0)}{\beta} \right] + C_{2j} \sqrt{\frac{\beta}{m} - (\frac{\alpha}{2m})^2}$$

$$C_{2j} = \frac{1}{\sqrt{\frac{\beta}{m} - (\frac{\alpha}{2m})^2}} \left[V_j + \frac{\alpha}{2m} \left(P_j - \frac{h_j(t=0)}{\beta} \right) \right] \tag{C-19}$$

From (C-14), (C-18), and (C-19)

$$X_j = e^{-\frac{\alpha}{2m}t}\left\{\left(P_j - \frac{h_j(t=0)}{\beta}\right)\cos\sqrt{\frac{\beta}{m} - (\frac{\alpha}{2m})^2}\, t \right. \tag{C-20}$$

$$\left. + \frac{1}{\sqrt{\frac{\beta}{m} - (\frac{\alpha}{2m})^2}}\left[V_j + \frac{\alpha}{2m}\left(P_j - \frac{h_j(t=0)}{\beta}\right)\right]\sin\sqrt{\frac{\beta}{m} - (\frac{\alpha}{2m})^2 t}\right\}$$

$$+ \frac{h_j(t=0)}{\beta}$$

$$X_j\ (t = t_1 + \Delta t) = e^{-\frac{C\Delta t}{m}}\left\{\left(P_j - \frac{h_j(t=t_1)}{2K}\right)\cos\left(\sqrt{\frac{2K}{m} - (\frac{C}{m})^2}\,\Delta t\right)\right. \tag{C-21}$$

$$\left. + \frac{1}{\sqrt{\frac{2K}{m} - (\frac{C}{m})^2}}\left[V_j + \frac{C}{m}\left(P_j - \frac{h_j(t=t_1)}{2K}\right)\right]\sin\left(\sqrt{\frac{2K}{m} - (\frac{C}{m})^2}\,\Delta t\right)\right\}$$

$$+ \frac{h_j(t=t_1)}{2K}$$

P_j and V_j are position and velocity of the jth mass as calculated at the end of the previous time interval.

Since the value of $\dot{X}_j$ at the end of each time interval is needed as an initial condition for the next increment, $\dot{X}_j$ will now be calculated:

$$\dot{X}_j = e^{-\frac{\alpha}{2m}t}\left\{\left[-\frac{\alpha}{2m}C_{1j} + C_{2j}\sqrt{\frac{\beta}{m} - (\frac{\alpha}{2m})^2}\right]\cos\sqrt{\frac{\beta}{m} - (\frac{\alpha}{2m})^2}\, t\right. \tag{C-22}$$

$$\left. - \left[\frac{\alpha}{2m}C_{2j} + C_{1j}\sqrt{\frac{\beta}{m} - (\frac{\alpha}{2m})^2}\right]\sin\sqrt{\frac{\beta}{m} - (\frac{\alpha}{2m})^2}\, t\right\}$$

$$\dot{X}_j = e^{-\frac{\alpha}{2m}t}\left\{\left[-\frac{\alpha}{2m}\left(P_j - \frac{h_j}{\beta}\right) + \frac{1}{\sqrt{\frac{\beta}{m} - (\frac{\alpha}{2m})^2}}\left(V_j + \frac{\alpha}{2m}\left(P_j - \frac{h_j}{\beta}\right)\right)\sqrt{\frac{\beta}{m} - (\frac{\alpha}{2m})^2}\right]\right.$$

$$\times \cos\sqrt{\frac{\beta}{m} - (\frac{\alpha}{2m})^2}\, t + \left[-\frac{\alpha}{2m}\frac{1}{\sqrt{\frac{\beta}{m} - (\frac{\alpha}{2m})^2}}\left(V_j + \frac{\alpha}{2m}\left(P_j - \frac{h_j}{\beta}\right)\right)\right. \tag{C-23}$$

$$\left.\left. - \left(P_j - \frac{h_j}{\beta}\right)\sqrt{\frac{\beta}{m} - (\frac{\alpha}{2m})^2}\right]\sin\sqrt{\frac{\beta}{m} - (\frac{\alpha}{2m})^2}\, t\right\}$$

$$\dot{X}_j = e^{-\frac{\alpha}{2m}t}\left\{V_j \cos\sqrt{\frac{\beta}{m} - \left(\frac{\alpha}{2m}\right)^2}\, t - \left[\frac{\alpha V_j + 2\beta(P_j - \frac{h}{\beta})}{2m\sqrt{\frac{\beta}{m} - \left(\frac{\alpha}{2m}\right)^2}}\right] \sin\sqrt{\frac{\beta}{m} - \left(\frac{\alpha}{2m}\right)^2 t}\right\} \quad \text{(C-24)}$$

$$\dot{X}_j(t = t_1 + \Delta t) = e^{-\frac{C}{m}\Delta t}\left\{V_j \cos\left(\sqrt{\frac{2K}{m} - \left(\frac{C}{m}\right)^2}\, \Delta t\right) - \left[\frac{CV_j + 2K(P_j - \frac{h_j}{2K})}{m\sqrt{\frac{2K}{m} - \left(\frac{C}{m}\right)^2}}\right] \sin\left(\sqrt{\frac{2K}{m} - \left(\frac{C}{m}\right)^2}\, \Delta t\right)\right\} \quad \text{(C-25)}$$

P_j and V_j are position and velocity calculated at the end of the previous time interval.

CASE II

$\alpha^2 - 4m\beta > 0$

or

$\frac{2K}{m} - \left(\frac{C}{m}\right)^2 < 0$ This case corresponds to overdamping.

$$r = -\frac{\alpha}{2m} \pm \sqrt{\left(\frac{\alpha}{2m}\right)^2 - \frac{\beta}{m}}$$

$$X_h = e^{-\frac{\alpha}{2m}t}\left[Ae^{\sqrt{\left(\frac{\alpha}{2m}\right)^2 - \frac{\beta}{m}}\, t} + Be^{-\sqrt{\left(\frac{\alpha}{2m}\right)^2 - \frac{\beta}{m}}\, t}\right]$$

$$X_{P_j} = \frac{h_j}{\beta}$$

$$X_j = e^{-\frac{\alpha}{2m}t}\left[C_{1j}\, e^{\sqrt{\left(\frac{\alpha}{2m}\right)^2 - \frac{\beta}{m}}\, t} + C_{2j}\, e^{-\sqrt{\left(\frac{\alpha}{2m}\right)^2 \frac{\beta}{m}}\, t}\right] + \frac{h_j}{\beta} \quad \text{(C-26)}$$

at

$t = 0, \; X_j = P_j$ (C-27)

and

$\dot{X}_j = V_j$ (C-28)

Let

$$\left(\frac{\alpha}{2m}\right)^2 - \frac{\beta}{m} \equiv D$$

Then

$$\dot{X}_j = e^{-\frac{\alpha}{2m}t}\left[C_{1j}\sqrt{D}\,e^{\sqrt{D}\,t} - C_{2j}\sqrt{D}\,e^{-\sqrt{D}\,t}\right]$$

$$-\frac{\alpha}{2m}\left[C_{1j}e^{\sqrt{D}\,t} + C_{2j}e^{-\sqrt{D}\,t}\right]$$

$$\dot{X}_j = e^{-\frac{\alpha}{2m}t}\left[e^{\sqrt{D}\,t}\left(C_{1j}\sqrt{D} - C_{1j}\frac{\alpha}{2m}\right) + e^{-\sqrt{D}\,t}\left(-C_{2j}\sqrt{D} - \frac{\alpha}{2m}C_{2j}\right)\right]$$

$$\dot{X}_j = e^{-\frac{\alpha}{2m}t}\left\{e^{\sqrt{D}\,t}\,C_{1j}\left[\sqrt{D} - \frac{\alpha}{2m}\right] + e^{-\sqrt{D}\,t}(-C_{2j})\left[\sqrt{D} + \frac{\alpha}{2m}\right]\right\}$$

Application of (C-27) and (C-28) yields

$$\begin{cases} V_j = C_{1j}\left(\sqrt{D} - \frac{\alpha}{2m}\right) - C_{2j}\left(\sqrt{D} + \frac{\alpha}{2m}\right) \\ P_j = C_{1j} + C_{2j} + \frac{h_j(t=0)}{\beta} \end{cases}$$

$$\begin{cases} C_{1j}\left[\sqrt{D} - \frac{\alpha}{2m}\right] + C_{2j}\left[-\sqrt{D} - \frac{\alpha}{2m}\right] = V_j \\ C_{1j}[1] + C_{2j}[1] = P_j - \frac{h_j}{\beta} \end{cases}$$

Now apply Cramer's Rule.

$$C_{1j} = \frac{\begin{vmatrix} V_j & -\sqrt{D} - \frac{\alpha}{2m} \\ P_j - \frac{h_j}{\beta} & 1 \end{vmatrix}}{\begin{vmatrix} \sqrt{D} - \frac{\alpha}{2m} & -\sqrt{D} - \frac{\alpha}{2m} \\ 1 & 1 \end{vmatrix}}$$

$$C_{1j} = \frac{V_j + (P_j - \frac{h_j}{\beta})(\sqrt{D} + \frac{\alpha}{2m})}{\sqrt{D} - \frac{\alpha}{2m} + \sqrt{D} + \frac{\alpha}{2m}}$$

$$C_{1j} = \frac{V_j + (P_j - \frac{h_j}{\beta})(\sqrt{D} + \frac{\alpha}{2m})}{2\sqrt{D}} \qquad \text{(C-29)}$$

$$C_{2j} = \frac{\begin{vmatrix} \sqrt{D} - \frac{\alpha}{2m} & V_j \\ 1 & P_j - \frac{h_j}{\beta} \end{vmatrix}}{2\sqrt{D}} = \frac{(\sqrt{D} - \frac{\alpha}{2m})(P_j - \frac{h_j}{\beta}) - V_j}{2\sqrt{D}} \qquad \text{(C-30)}$$

Substitute (C-29) and (C-30) into (C-26)

$$X_j = e^{-\frac{\alpha}{2m}t} \left[\frac{V_j + \left(P_j - \frac{h_j}{\beta}\right)\left(\sqrt{D} + \frac{\alpha}{2m}\right)}{2\sqrt{D}} e^{\sqrt{D}\,t} \right. \qquad \text{(C-31)}$$

$$\left. + \frac{\left(\sqrt{D} - \frac{\alpha}{2m}\right)\left(P_j - \frac{h_j}{\beta}\right) - V_j}{2\sqrt{D}} e^{-\sqrt{D}\,t} \right] + \frac{h_j}{\beta}$$

$$X_j(t=t_1+\Delta t) = e^{-\frac{c}{m}\Delta t}\left[\frac{V_j + \left(P_j - \frac{h_j(t=t_1)}{2K}\right)\left(\sqrt{(\frac{c}{m})^2 - \frac{2K}{m}} + \frac{c}{m}\right)}{2\sqrt{(\frac{c}{m})^2 - \frac{2K}{m}}} e^{\sqrt{(\frac{c}{m})^2 - \frac{2K}{m}}\,\Delta t}\right.$$

(C-32)

$$\left. + \frac{\sqrt{(\frac{c}{m})^2 - \frac{2K}{m}}\left(P_j - \frac{h_j}{2K}\right) - V_j}{2\sqrt{(\frac{c}{m})^2 - \frac{2K}{m}}} e^{-\sqrt{(\frac{c}{m})^2 - \frac{2K}{m}}\,\Delta t}\right] + \frac{h_j(t=t_1)}{2K}$$

P_j and V_j are position and velocity calculated at the end of the previous time interval.

Now, calculate $\dot{X}_j$.

$$\dot{X}_j = e^{-\frac{\alpha t}{2m}}\left[C_{1j}\sqrt{D}\, e^{\sqrt{D}\,t} - C_{2j}\sqrt{D}\, e^{-\sqrt{D}\,t}\right]$$

$$- \frac{\alpha}{2m} e^{-\frac{\alpha t}{2m}}\left[C_{1j}\, e^{\sqrt{D}\,t} + C_{2j}\, e^{-\sqrt{D}\,t}\right]$$

$$\dot{X}_j = e^{-\frac{\alpha t}{2m}}\left[e^{\sqrt{D}\,t}\left(C_{1j}\sqrt{D} - \frac{\alpha}{2m}C_{1j}\right) + e^{-\sqrt{D}\,t}\left(-C_{2j}\sqrt{D} - \frac{\alpha}{2m}C_{2j}\right)\right]$$

$$\dot{X}_j = e^{-\frac{\alpha t}{2m}}\left[C_{1j}\left(\sqrt{D} - \frac{\alpha}{2m}\right)e^{\sqrt{D}\,t} + C_{2j}\left(-\sqrt{D} - \frac{\alpha}{2m}\right)e^{-\sqrt{D}\,t}\right]$$

$$\dot{X}_j(t=t_1+\Delta t) = e^{-\frac{c}{m}t} \left\{ \left[\frac{V_j + \left(P_j - \frac{h_j(t=t_1)}{2K}\right)\left(\sqrt{\left(\frac{c}{m}\right)^2 - \frac{2K}{m}} + \frac{c}{m}\right)}{2\sqrt{\left(\frac{c}{m}\right)^2 - \frac{2K}{m}}} \right] \right. \tag{C-33}$$

$$\times \left[\sqrt{\left(\frac{c}{m}\right)^2 - \frac{2K}{m}} - \frac{c}{m} \right] e^{\sqrt{\left(\frac{c}{m}\right)^2 - \frac{2K}{m}}\,\Delta t}$$

$$+ \left[\frac{\left(\sqrt{\left(\frac{c}{m}\right)^2 - \frac{2K}{m}} - \frac{c}{m}\right)\left(P_j - \frac{h_j(t=t_1)}{2K}\right) - V_j}{2\sqrt{\left(\frac{c}{m}\right)^2 - \frac{2K}{m}}} \right] \left[-\sqrt{\left(\frac{c}{m}\right)^2 - \frac{2K}{m}} - \frac{c}{m} \right]$$

$$\left. \times\ e^{-\sqrt{\left(\frac{c}{m}\right)^2 - \frac{2K}{m}}\,\Delta t} \right\}$$

CASE III

$\alpha^2 = 4m\beta$

or

$\frac{2K}{m} = \left(\frac{c}{m}\right)^2$ This case corresponds to critical damping.

$r = -\frac{\alpha}{2m}$ Repeated roots.

$$X_h = A e^{-\frac{\alpha}{2m}t} + B t e^{-\frac{\alpha}{2m}t}$$

$$X_p = \frac{h_j}{\beta}$$

$$X_j = A_j e^{-\frac{\alpha}{2m}t} + B_j t e^{-\frac{\alpha}{2m}t} + \frac{h_j}{\beta}$$

$$\dot{X}_j = -A_j \frac{\alpha}{2m} e^{-\frac{\alpha}{2m}t} + B_j \left[e^{-\frac{\alpha}{2m}t} - \frac{\alpha}{2m} t e^{-\frac{\alpha}{2m}t} \right]$$

$$\dot{X}_j = e^{-\frac{\alpha}{2m}t} \left[-A_j \frac{\alpha}{2m} + B_j - B_j \frac{\alpha}{2m} t \right]$$

At $t = 0,\ X_j = P_j,\ \dot{X}_j = V_j$

$$\therefore \quad P_j = A_j + \frac{h_j}{\beta}$$

$$V_j = -A_j \frac{\alpha}{2m} + B_j$$

$$A_j = P_j - \frac{h_j}{\beta}$$

$$B_j = V_j + A_j \frac{\alpha}{2m} = V_j + \frac{\alpha}{2m} \left(P_j - \frac{h_j}{\beta}\right)$$

$$X_j (t=t_1 + \Delta t) = e^{-\frac{c}{m}\Delta t} \left[P_j - \frac{h_j(t=t_1)}{2K} + \Delta t \left(V_j + \frac{c}{m} \left(P_j - \frac{h_j(t=t_1)}{2K} \right) \right) \right] + \frac{h_j(t=t_1)}{2K} \quad \text{(C-34)}$$

$$\dot{X}_j (t=t_1 + \Delta t) = e^{-\frac{c}{m}\Delta t} \left\{ - \left(P_j - \frac{h_j(t=t_1)}{2K} \right) \frac{c}{m} + \left[V_j + \frac{c}{m} \left(P_j - \frac{h_j(t=t_1)}{2K} \right) \right] \left[1 - \frac{c}{m}\Delta t \right] \right\} \quad \text{(C-35)}$$

P_j and V_j are positions and velocities calculated at the end of the previous time interval.

The choice of which pair of equations ((C-21) (C-25) or (C-32) (C-33) or (C-34) (C-35)) should be used for calculating the motions of the masses is determined by the value of $\frac{2K}{m} - (\frac{c}{m})^2$.

Using the latest available calculated parameter values, one evaluates h_j at each time interval. All equations for X_j (j = 1,2,3...) are evaluated sequentially for one time interval before the next time interval is examined.

NOTE: The above solutions can be generalized to a system with all different masses, spring constants, and dampers if the following substitutions are made:

$$\beta = K_i + K_{i+1}, \ \alpha = c_i + c_{i+1}, \ m = m_i$$

Spring surging and coil clashing can also be analyzed from a continuum rather than a finite element. A derivation of the appropriate equations appears in Reference[13]. This work was done under contract to the Army Weapons Command, and a computer program is available. This approach appears to be more economical than the finite-element approach unless a transfer function can be found. The search for such a function is continuing.

A simpler treatment of inertial effects is to assume that an ideal spring is acting on a mass equal to $\frac{1}{3}$ the mass of the spring. Because the underlying assumptions are not immediately apparent, a derivation is shown below:

Assume that the velocity of any point on the spring varies linearly with spring mass between that point and the fixed end; that is,

$$V = \frac{m}{M_{SPRING}} V_{end} \,.$$

Thus, the velocity is zero at the fixed end (m=0) and is equal to V_{end} at the forced end ($m = M_{SPRING}$). Now, calculate the total kinetic energy (KE) of all mass points along the spring.

$$KE = \frac{1}{2} \int_o^{M_{SPRING}} V^2 dm = \frac{1}{2} \int_o^{M_{SPRING}} \left(\frac{m}{M_{SPRING}} \right)^2 V_{end}^2 \, dm$$

$$= \frac{1}{2} \left(\frac{V_{end}}{M_{SPRING}} \right)^2 \frac{1}{3} m^3 \Big|_o^{M_{SPRING}} = \frac{1}{2} \left[\frac{1}{3} M_{SPRING} \right] V_{end}^2$$

Thus, a mass equal to $\frac{1}{3} M_{SPRING}$ that is forced against a massless spring with velocity V_{end} will have the same kinetic energy as the spring with the distributed mass that is forced with the same velocity. The key assumption is linearity of velocity along the spring. As the spring is forced with greater velocity, this assumption becomes less accurate.

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[13]Phillips, J.W. and Costello, G.A., Large Deflections of Impacted Helical Springs, Journal of the Acoustical Society of America, VOL 51, No. 3 (Part 2), pg 967 (1972)

APPENDIX D

EXTENSION OF DETERMINISTIC MODELS TO PROBABILISTIC REGIME

The M16A1 Rifle model described in this report is deterministic. That is, one is given certain single-valued input data, and the model provides single-valued output information. Such a model describes only one particular weapon under one particular set of firing conditions, and with one particular round of ammunition. However, input data in reality have a range of values. Not all weapon parts will have the same weights and dimensions because of certain manufacturing tolerances. Not all rounds of ammunition will produce the same pressure-time curve. Not all mounts will have the same stiffness. Not all crosswinds will have the same velocity. Not all shooters will hold the weapon the same way. Not all weapons will have the same amount of lubricant and contaminant. Not all weapons are fired at the same ambient temperature. Such a list is virtually endless; however, the problem is not as hopeless as it may seem. Most of these quantities have reasonably well-defined bounds, that is, wind velocity does not vary from plus infinity to minus infinity. A reasonable estimate of mean value and standard deviation is possible. One can then construct a reasonable probability distribution function. The more experimental data that are available, the more accurate this curve is likely to be. Similarly for the other input data, one can approximate probability distribution functions; of course, some will be more difficult than others. The next problem is the determination of how to process this information. The computer should accept this stochastic input information, operate with it, and provide stochastic output.

Two possible methods are discussed by which a model could be designed to carry out this process. The first is the Monte Carlo technique and the second is a generalization of the method of partial derivatives. An alternative to statistics is also presented. This is a perturbation technique.

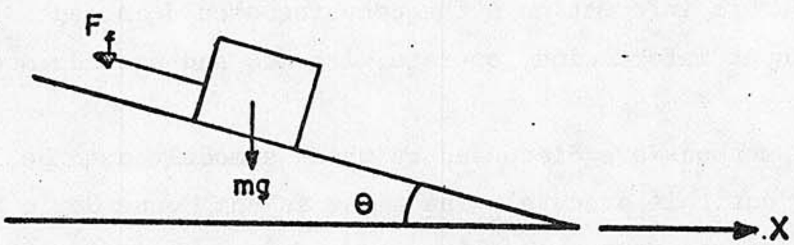
The Monte Carlo approach requires that one run the deterministic model for many input values. These values are chosen to reflect the probability distribution of the appropriate quantity. The method of partial derivatives attempts to approximate the output means and standard deviation given the input function. The perturbation technique is simply a way to examine the derivative of various quantities, with respect to the others, to determine how sensitive the first variable is to changes in the second. One can then use this knowledge of the range of values for the second variable to determine the significance of the derivative. The Monte Carlo method has a serious disadvantage in that it requires a large number of computer runs. For a complex model, this shortcoming causes the computer costs to become excessive.

The method of partial derivatives requires only one computer run and would save computer costs, but this method is more difficult to set up. The technique does not provide the probability density function; it provides a measure of the variability in output that could be expected. The perturbation technique provides even less information directly.

The three techniques will be discussed in some technical detail in the following paragraphs.

D.1 Introductory Example

First, an introductory problem will be presented to illustrate some main ideas of this discussion about probabilistic models. The problem is atypical in its lack of complexity. Let "m" be a mass sliding on an inclined plane, as shown below:



F_f is a friction force equal to μmg cos θ, where μ is the coefficient of sliding friction. The equation of motion for the mass is

$$m\ddot{x} = mg \sin \theta - \mu mg \cos \theta, \ \theta \neq 0$$

$$\text{I.C. } x(0) = \dot{x}(0) = 0$$

The solution is

$$x(t) = [g \sin \theta - \mu g \cos \theta]\frac{t^2}{2}, \ \dot{x}(t) = [g \sin \theta - \mu g \cos \theta]t$$

or

$$x(t) = A + B\mu, \ \dot{x}(t) = A_1 + B_1 \mu$$

where

$$A = [g \sin \theta]\frac{t^2}{2}, \quad B = -[g \cos \theta]\frac{t^2}{2}$$

$$A_1 = [g \sin \theta]t, \quad B_1 = -[g \cos \theta]t$$

Suppose that one selects the inclined plane and the sliding mass from a stockpile of these objects where the coefficient of friction has a normal distribution. Certainly, the surfaces will have some differences in finish and lubrication, and not all the coefficients can be expected to be the same. Suppose that the distribution has a mean of .3 and a standard deviation of .05. Then, from probability theory, $x(t)$ and $\dot{x}(t)$ have a normal distribution with means of $\overline{x} = A + B\,\overline{\mu} = A + .3B$,

$\overline{\dot{x}} = A_1 + B_1\,\overline{\mu} = A_1 + .3B_1$

and with standard deviations of

$\sigma_x = [B^2\ (.05)^2\ ]^{1/2}$

and

$\sigma_{\dot{x}} = [B_1^2\ (.05)^2\ ]^{1/2}$, respectively.

At any given time, t_s, one can determine the probability that $x(t_s)$ or $\dot{x}(t_s)$ will lie within certain limits.

For example, let us find the values of x(.5) that lie within two standard deviations of the mean of x(.5).

Let

$$\theta = 45°, \quad g = 32.2 \text{ ft/sec}^2, \quad t_s = .5 \text{ sec}$$

Then

$$A = 2.8461 \text{ ft}, \quad B = -2.8461 \text{ ft}$$

and

$$\overline{x}\,(.5) = 2.8461 - (.3)(2.8461) = 1.9923$$

$$\sigma_x = [(2.8461)^2\ (.05)^2]^{\frac{1}{2}} = .1423$$

$$P(1.9923 - 2\,\sigma_x \leq x(.5) \leq 1.9923 + 2\,\sigma_x) = .95$$

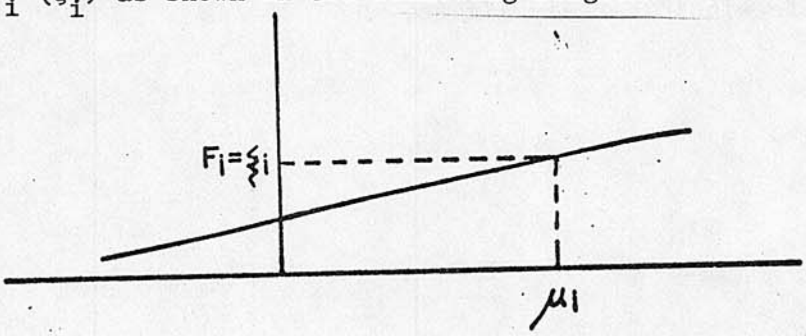
$$P(1.7077 \leq x(.5) \leq 2.2769) = .95$$

The previous results are dependent upon the fact that the differential equation can be solved analytically, and that the distribution is normal and completely determined. If μ had a log-normal distribution, it would be difficult to find the probability distribution for x(t). With a complex model, analytical solutions become virtually impossible.

D.2 Monte Carlo

To attack problems associated with complex models, other techniques are required. The first to be discussed will be the Monte Carlo technique. It will be applied to the simple problem of a mass sliding on an inclined plane. First, a preliminary discussion of the technique will be made.

Let $\mu_1, \mu_2, \ldots \mu_n$ be a sequence of random variables that are constant in time. Let $F_1(\mu_1), F_2(\mu_2) \ldots F_n(\mu_n)$ be the corresponding cumulative probability distributions. These may be known in terms of elementary functions or from test data. For each random variable μ_i, random numbers ξ_i where $0 \leq \xi_i \leq 1$ are generated from a uniform distribution. The numbers ξ_i are equated to $F(\mu_i)$ for some μ_i. Then many values for μ_i are computed from $\mu_i = F_i^{-1}(\xi_i)$ as shown in the following diagram:



The differential equations are then solved many times with the use of the μ_i values. The output values are then distributed in some fashion not necessarily similar to the input values.

Recall that the inclined plane problem is described by:

$$\ddot{x} = g \sin \theta - \mu g \cos \theta,\ x(0) = \dot{x}(0) = 0,\ \theta = 45°, \text{ and } g = 32.2 \text{ ft/sec}^2$$

where μ is normally distributed with a mean of .3 and a standard deviation of .05.

Let $Z \equiv \frac{\mu - .3}{.05}$. Then "Z" has a standard normal distribution. Let F(x) be the cumulative probability distribution function of the standard normal.

$$F(Z) = \int_{-\infty}^{Z} f(s)\,ds.$$ Generate random ξ_i and compute $Z = F^{-1}(\xi_i)$.

Then $\mu = .05 Z + .3$. Table 11 contains the values obtained.

By taking a sufficiently large sample, one can find approximate probabilities that x(t) at a given time will lie within certain limits. For example,

$$P(29 \le x(2) \le 31) \simeq \frac{\#\text{trials } (29 \le x(2) \le 31)}{\text{total } \# \text{ trials}} \simeq \frac{12}{15} = .80$$

or

$$P(1.7077 \le x(.5) \le 2.2769) \simeq \frac{\#\text{trials } (1.7077 \le x(.5) \le 2.2769)}{\text{total } \# \text{ trials}} \simeq \frac{14}{15} = .93$$

From the previously derived exact solution, $P(1.7077 \le x(.5) \le 2.2769) = .95$

It is possible to place confidence limits on the estimate that the probability is .93 that x(.5) lies between 1.7077 and 2.2769. Such information is tabulated. From pg. 147 in Reference[14], a 95% confidence interval about .93 is (.67, 1). This interval could be reduced if a larger sample were used.

An estimate of the sample size required for a $1 - \alpha$ confidence interval (P −E, P + E) for the probability "P" is $n = \frac{P(1-P)\left[Z_{1-\frac{\alpha}{2}}\right]^2}{E^2}$. ($Z_{1-\frac{\alpha}{2}}$ indicates that "Z" is a function of $1 - \frac{\alpha}{2}$.)

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[14] Haugen, E., Probabilistic Approaches to Design, John Wiley & Sons, Inc., New York (1968)

TABLE 11 SAMPLE MONTE CARLO CALCULATIONS

	ξ	Z	μ	x(.5)	x(2)
1.	.816	.90	.345	1.864	29.82
2.	.763	.72	.336	1.889	30.22
3.	.061	-1.54	.323	1.927	30.83
4.	.988	2.28	.4125	1.672	26.75
5.	.174	-.94	.253	2.126	30.02
6.	.709	.55	.3275	1.914	30.62
7.	.889	1.22	.361	1.819	29.10
8.	.772	.75	.3375	1.885	30.16
9.	.893	1.24	.362	1.816	29.05
10.	.232	.73	.3365	1.888	30.21
11.	.091	1.33	.3665	1.803	28.85
12.	.133	1.11	.3555	1.834	29.34
13.	.197	.85	.3425	1.871	29.94
14.	.469	.10	.305	1.978	31.65
15.	.061	-1.55	.2225	2.213	35.10

For the case $(1.7077 \leq x(.5) \leq 2.2769)$, $E = .05$, $\alpha = .05$, $P = .93$ and

$$n = \frac{.93(1-.93)(1.96)^2}{(.05)^2} = 100$$

Thus, a sample size of 100 would be needed to get a 95% confidence interval of (.88, .98).

D.3 Partial Derivatives

Now, consider the method of partial derivatives. This method provides estimates for the means and standard deviations of the output given the means and standard deviations of the input data. It does not provide a probability density function for the output. The technique is applied to algebraic equations in Haugen's book.[14] Here, the technique is extended to ordinary differential equations.

Consider the differential equation $\dot{x}(t) = F(x, a, t)$ (D-1)

where $x(0) = x_o$. The variable "a" is random and has a mean "$\bar{a}$" and a standard deviation "σ".

[14] Haugen, E., Probabilistic Approaches to Design, John Wiley & Sons, Inc., New York (1968)

The solution of the equation is $x(t) = \int_o^t F(x, a, \tau)\, d\tau + x_o$. (D-2)

Thus, the variable x(t) is also random.

Given that $x_1, x_2 \ldots x_n$ are random variables with means $\bar{x}_1, \bar{x}_2 \ldots \bar{x}_n$ and standard deviations $S_{x_1}, S_{x_2}, \ldots S_{x_n}$, define $z = \Psi(x_1, x_2, \ldots x_n)$.

Approximations to the mean and standard deviation of "z" are:

$$\bar{Z} \simeq \Psi(\bar{x}_1, \bar{x}_2, \ldots \bar{x}_n) \tag{D-3}$$

$$S_Z \simeq \left[\sum_{j=1}^{n} \left(\frac{\partial Z}{\partial x_j} \right)^2 S^2_{x_j} \right]^{\frac{1}{2}} \tag{D-4}$$

NOTE: In the approximation of the mean, higher-order terms in a Taylor series expansion of "z" about $\bar{x}_i$ are neglected. Some could be included for greater accuracy. The partial derivatives in the approximation to the standard deviation are evaluated at the mean values of the x_i's. These approximations are quite good if the variances are not too large. The remaining development of the method of partial derivatives will be based on these approximations.

Now apply (D-3) to (D-2)

$$\bar{x}(t, a) = \int_o^t F(x, \bar{a}, \tau)\, d\tau + x_o$$

This equation means that the mean of x(t, a) can be approximated by the solution of the differential equation where "$\bar{a}$" has been substituted for "a".

Now

$$S_{x(t, a)} = \left[\left(\frac{\partial x(t, a)}{\partial a} \right)^2 S^2_a \right]^{\frac{1}{2}}$$

From (D-2)

$$\frac{\partial x(t, a)}{\partial a} \bigg|_{a = \bar{a}} = \int_o^t \frac{\partial F(x, a, \tau)}{\partial a} \bigg|_{a = \bar{a}} d\tau$$

$$S_a = \sigma$$

$$\therefore \quad S_{x(t,\ a)} = \int_o^t \frac{\partial F(x,\ a,\ \tau)}{\partial a} \Big|_{a = \bar{a}} d\tau\ \sigma$$

Consider the example

$$\dot{x}(t) = a\ e^{-t}$$

$$x(0) = 0$$

The variable "a" has a mean "$\bar{a}$" and a standard deviation σ.

$$\bar{x}\ (t,\ a) \simeq \int_o^t F(x,\ \bar{a},\ \tau)\ d\tau + x_o = \int_o^t \bar{a}\ e^{-\tau}\ d\tau + 0 = \bar{a}\ (1 - e^{-t})$$

$$\frac{\partial F(x,\ a,\ t)}{\partial a} \Big|_{a = \bar{a}} = e^{-t}$$

$$\frac{\partial x(t,\ a)}{\partial a} \Big|_{a = \bar{a}} = \int_o^t \frac{\partial F(x,\ a,\ \tau)}{\partial a} \Big|_{a = \bar{a}} d\tau = \int_o^t e^{-\tau}\ d\tau = 1 - e^{-t}$$

$$S_{x(t,\ a)} \simeq \left| \frac{\partial x(t,\ a)}{\partial a}\ \sigma \right| = \sigma\ (1 - e^{-t})$$

For this example, the exact result can be obtained.

$$x\ (t,\ a) = a\ (1 - e^{-t})$$

$$\bar{x}\ (t,\ a) = \bar{a}\ (1 - e^{-t})$$

$$S_x(t,\ a) = \sigma\ (1 - e^{-t})$$

Thus, the approximate and exact results are equal.

This scheme will now be generalized to a system of first-order differential equations. Since one or more higher-order differential equations can be transformed to a system of first-order equations, this is a powerful generalization.

The system of equations is described by:

$$\dot{x}(t) = F(x,\ a,\ t)$$

$$x(0) = g(a)$$

where

$$\dot{x}(t) = \begin{bmatrix} \dot{x}_1(t) \\ \dot{x}_2(t) \\ \vdots \\ \dot{x}_n(t) \end{bmatrix} \qquad F(x, a, t) = \begin{bmatrix} F_1(x, a, t) \\ F_2(x, a, t) \\ \vdots \\ F_n(x, a, t) \end{bmatrix}$$

$$a = \begin{bmatrix} a_1 \\ a_2 \\ \vdots \\ a_m \end{bmatrix} \qquad g(a) = \begin{bmatrix} g_1(a) \\ g_2(a) \\ \vdots \\ g_n(a) \end{bmatrix} \qquad \bar{a} = \begin{bmatrix} \bar{a}_1 \\ \bar{a}_2 \\ \vdots \\ \bar{a}_m \end{bmatrix}$$

then

$$x(t, a) = \int_o^t F(x, a, \tau)\, d\,\tau + g(a)$$

$$\bar{x}(t, a) \simeq \int_o^t F(x, \bar{a}, \tau)\, d\,\tau + g(\bar{a})$$

$$\left[\begin{pmatrix} \left(\frac{\partial\, x_1(t, a)}{\partial\, a_1}\right)^2 & --- & \left(\frac{\partial\, x_1(t, a)}{\partial\, a_m}\right)^2 \\ \vdots & & \\ \left(\frac{\partial\, x_n(t, a)}{\partial\, a_1}\right)^2 & --- & \left(\frac{\partial\, x_n(t, a)}{\partial\, a_m}\right)^2 \end{pmatrix} \begin{pmatrix} \sigma_{a_1}^2 \\ \vdots \\ \sigma_{a_m}^2 \end{pmatrix} \right]^{1/2} \qquad \text{(D-5)}$$

The square root of the column vector is the column vector formed from the square root of each term. Partial derivatives are evaluated at $\bar{a}_1, \bar{a}_2, \ldots \bar{a}_n$.

$$\frac{\partial\, x(t, a)}{\partial\, a_j}\bigg|_{a=\bar{a}} = \int_o^t \frac{\partial\, F(x, a, \tau)}{\partial\, a_j}\bigg|_{a=\bar{a}} d\,\tau + \frac{\partial\, g(a)}{\partial\, a_j}\bigg|_{a=\bar{a}} . \qquad \text{(D-6)}$$

The following is a simple example for which exact results can also be obtained. Consider a free-falling mass. $\ddot{x} = -g$

$$x(0) = a_1$$
$$\dot{x}(0) = a_2$$

Assume a_1 has a mean of zero and a standard deviation of σ_{a_1}.

Assume a_2 has a mean of zero and a standard deviation of σ_{a_2}.

Make the following transformation:
$$\begin{cases} x_1 \equiv x \\ x_2 \equiv \dot{x} \end{cases}$$

$$\therefore \quad x_1(0) = a_1$$
$$x_2(0) = a_2$$
$$\begin{pmatrix} \dot{x}_1 \\ \dot{x}_2 \end{pmatrix} = \begin{pmatrix} x_2 \\ -g \end{pmatrix}$$

$$\begin{pmatrix} \dfrac{\partial x_1}{\partial a_1} \\ \dfrac{\partial x_2}{\partial a_1} \end{pmatrix} = \begin{pmatrix} \int_o^t \dfrac{\partial x_2}{\partial a_1} dt \\ -\int_o^t \dfrac{\partial g}{\partial a_1} dt \end{pmatrix} + \begin{pmatrix} 1 \\ 0 \end{pmatrix} = \begin{pmatrix} 1 \\ 0 \end{pmatrix}$$

$$\begin{pmatrix} \dfrac{\partial x_1}{\partial a_2} \\ \dfrac{\partial x_2}{\partial a_2} \end{pmatrix} = \begin{pmatrix} \int_o^t \dfrac{\partial x_2}{\partial a_2} dt \\ -\int_o^t \dfrac{\partial g}{\partial a_2} dt \end{pmatrix} + \begin{pmatrix} 0 \\ 1 \end{pmatrix} = \begin{pmatrix} t \\ 1 \end{pmatrix}$$

Insert these expressions into (D-5).

$$S_x(t, a) \equiv \left[\begin{pmatrix} 1 & t^2 \\ 0 & 1 \end{pmatrix} \begin{pmatrix} \sigma_{a_1}^2 \\ \sigma_{a_2}^2 \end{pmatrix} \right]^{\frac{1}{2}} = \left[\begin{matrix} \left(\sigma_{a_1}^2 + \sigma_{a_2}^2 \quad t^2 \right)^{\frac{1}{2}} \\ \sigma_{a_2} \end{matrix} \right]$$

Now, find the exact results for $S_{x(t, a)}$ and compare with the approximate expression above.

$$\ddot{x} = -g$$

$$x(0) = a_1 \qquad \dot{x}(0) = a_2$$

$$x(t) = -\frac{1}{2} g t^2 + a_2 t + a_1$$

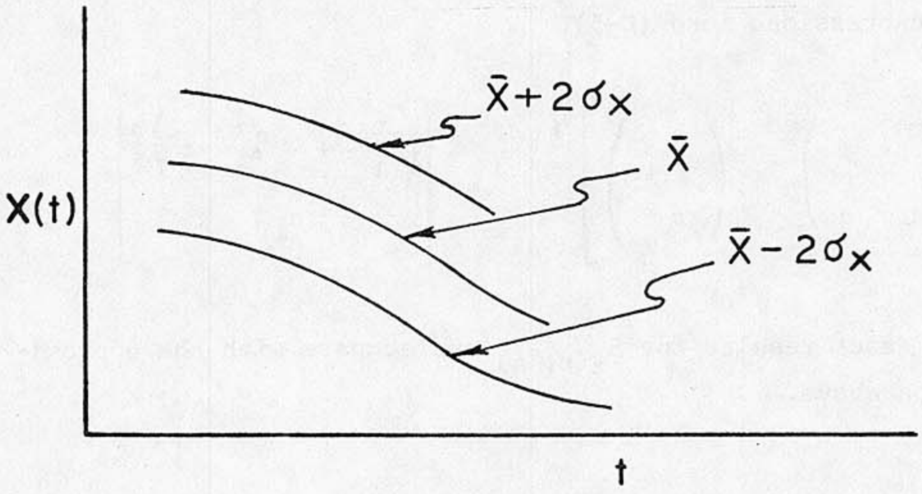
$$S_x = \left[\sigma_{a_2}^2 \; t^2 + \sigma_{a_1}^2 \right]^{\frac{1}{2}}$$

$$\dot{x}(t) = -g t + a_2$$

$$S_{\dot{x}} = \sigma_{a_2}$$

Thus, the approximate and exact results for the standard deviations are equal. It can also be shown that the approximate and exact mean values are equal.

Using this approximate method, one could get a good idea of the nature of the output without resorting to the time-consuming Monte Carlo technique. By calculating approximate output means and standard deviations, one can "bracket" the solution by graphing the results as follows:



Using the method of partial derivatives, one can avoid transformation to a system of first-order equations and can find partial derivatives directly. For example, consider a projectile that leaves a barrel with a random muzzle velocity having a mean v_o and a standard deviation σ_{v_o}. Assume that the angle of elevation θ is a random variable with mean $\overline{\theta}$ and standard deviation σ_θ. Assume that the only force on the projectile is that of gravity.

Then

$$m\ddot{y} = -g \qquad y(0) = 0, \quad \dot{y}(0) = v_o \sin \theta$$

$$m\ddot{x} = 0 \qquad x(0) = 0, \quad \dot{x}(0) = v_o \cos \theta$$

Do not transform the system to first-order, but directly take partial derivatives of the equations with respect to the random variables.

Note that

$$y_\alpha \equiv \frac{\partial y}{\partial \alpha}, \; x_\alpha \equiv \frac{\partial x}{\partial \alpha}$$

$$m \ddot{y}_{v_o} = 0$$

$$y_{v_o}(0) = 0$$

$$\dot{y}_{v_o}(0) = \sin\theta$$

$$\therefore \quad \dot{y}_{v_o} = \alpha$$

$$y_{v_o} = \alpha t + \beta$$

$$\begin{cases} y_{v_o} = (\sin\theta)\, t \\ \dot{y}_{v_o} = \sin\theta \end{cases}$$

$$m \ddot{x}_{v_o} = 0$$

$$x_{v_o}(0) = 0$$

$$\dot{x}_{v_o}(0) = \cos\theta$$

$$\therefore \quad \dot{x}_{v_o} = \alpha$$

$$x_{v_o} = \alpha t + \beta$$

$$\begin{cases} x_{v_o} = (\cos\theta)\, t \\ \dot{x}_{v_o} = \cos\theta \end{cases}$$

$$m\ddot{y}_\theta = 0$$

$$y_\theta(0) = 0$$

$$\dot{y}_\theta(0) = v_o \cos\theta$$

$$\therefore \quad \dot{y}_\theta = \alpha$$

$$y_\theta = \alpha t + \beta$$

$$\begin{cases} y_o = v_o\, (\cos\theta)\, t \\ \dot{y}_\theta = v_o \cos\theta \end{cases}$$

$$m\ddot{x}_\theta = 0$$

$$x_\theta(0) = 0$$

$$\dot{x}_\theta(0) = -v_o \sin\theta$$

$$\therefore \quad \dot{x}_\theta = \alpha$$

$$x_\theta = \alpha t + \beta$$

$$\begin{cases} x_\theta = -(v_o \sin\theta)\, t \\ \dot{x}_\theta = -v_o \sin\theta \end{cases}$$

Equation (D-4) is

$$S_Z \simeq \left[\sum_{j=1}^{n} \left(\frac{\partial Z}{\partial x_j} \right)^2 S_{x_j}^{\ 2} \right]^{\frac{1}{2}}$$

$$\therefore \quad S_{x(t)} \equiv [\sigma_{v_o}^{\ 2} \cos^2 \bar{\theta} + \sigma_\theta^2 (\bar{v}_o \sin \bar{\theta})^2]^{\frac{1}{2}} \ t$$

$$S_{\dot{x}(t)} \simeq [\sigma_{v_o}^{\ 2} \cos^2 \bar{\theta} + \sigma_\theta^2 (\bar{v}_o \sin \bar{\theta})^2]^{\frac{1}{2}}$$

$$S_{y(t)} \simeq [\sigma_{v_o}^{\ 2} \sin^2 \bar{\theta} + \sigma_\theta^2 (\bar{v}_o \cos \bar{\theta})^2]^{\frac{1}{2}} \ t$$

$$S_{\dot{y}(t)} \simeq [\sigma_{v_o}^{\ 2} \sin^2 \bar{\theta} + \sigma_\theta^2 (\bar{v}_o \cos \bar{\theta})^2]^{\frac{1}{2}}$$

The following is an illustration of the types of conclusions that can be drawn from the results of this method.

Suppose

$$\bar{\theta} = 0$$

Then

$$S_{x(t)} \equiv \sigma_{v_o} t$$

$$S_{\dot{x}(t)} \equiv \sigma_{v_o}$$

$$S_{y(t)} \equiv \sigma_\theta \bar{v}_o t$$

$$S_{\dot{y}(t)} \equiv \sigma_\theta \bar{v}_o$$

Thus, when the average elevation is zero, σ_θ has virtually no effect on $S_{x(t)}$ or $S_{\dot{x}(t)}$ if σ_θ is small.

One can, by maximizing $S_{x(t)}$, find the average elevation at which x(t) has a maximum variation. Thus, one must find $\bar{\theta}$ that maximizes

$$S_{x(t)} = [\sigma_{v_o}^{\ 2} \cos^2 \bar{\theta} + \sigma_\theta^2 v_o^{\ 2} \sin^2 \theta]^{\frac{1}{2}} \ t$$

Substitute $\sin^2 \bar{\theta} = 1 - \cos^2 \bar{\theta}$

$$S_{x(t)} = [(\sigma_{v_o}^{\ 2} - \sigma_\theta^2 v_o^{\ 2}) \cos^2 \bar{\theta} + \sigma_\theta^2 v_o^{\ 2}]^{\frac{1}{2}} t$$

If

$\theta = 0,$

then

$S_{x(t)}$ is a maximum.

D.4 Perturbation

The following perturbation method is an alternative to the statistical approach. This method is not as powerful, but it can yield much useful information.

Consider the equation $\dot{x} = f(x, t, a)$, where "a" is a random variable, and $x(0) = x_o$.

The solution of this equation is

$$x(t) = \int_o^t f(x, t, a)\, dt + x_o$$

The fundamental objective of this method is to evaluate the effect on x(t) caused by a small change in "a".

The change in x(t) can be written $\Delta x(t) = \frac{\partial x(t)}{\partial a} \Delta a$, if only the first two terms in a Taylor series expansion of "x" about "a" are used.

From (D-1)

$$\frac{\partial x(t)}{\partial a} = \int_o^t \frac{\partial f(x, t, a)}{\partial a}\, dt$$

As a simple illustration, consider the following:

$$\dot{x}(t) = e^{-at}$$

$$x(0) = 0$$

$$\frac{\partial f(x, t, a)}{\partial a} = -t\, e^{-at}$$

$$\frac{\partial x(t)}{\partial a} = \int_o^t -t\, e^{-at}\, dt = \frac{t\, e^{-at}}{a} + \frac{1}{a^2}(e^{-at} - 1)$$

$$\Delta x(t) = \left[\frac{t\, e^{-at}}{a} + \frac{1}{a^2}(e^{-at} - 1) \right] \Delta a$$

NOTE: If the equation cannot be solved analytically, $\frac{\partial x}{\partial a}$ can still be found numerically by integrating $\frac{\partial f(x, t, a)}{\partial t}$ over time with zero initial conditions. The basic approach can be extended to systems of differential equations.

Now, consider the case of a free-falling mass and find the effects of slight variations in initial velocity and displacement on velocity and displacement at some time "t".

$$m\ddot{x} = -g$$

$$x(0) = x_o$$

$$\dot{x}(0) = \dot{x}_o$$

Take partial derivatives of each equation with respect to x_o and $\dot{x}_o$ and solve the resulting equations.

$$m\ddot{x}_{x_o} = 0$$

$$x_{x_o}(0) = 1$$

$$\dot{x}_{x_o}(0) = 0$$

$$x_{x_o} = \alpha t + \beta$$

$$\begin{cases} x_{x_o}(t) = 1 \\ \dot{x}_{x_o}(t) = 0 \end{cases}$$

$$\Delta x(t) = x_{x_o}(t)\, \Delta x_o + x_{\dot{x}_o}(t)\, \Delta \dot{x}_o$$

$$\therefore \quad \Delta x(t) = \Delta x_o + t\, \Delta \dot{x}_o$$

$$m\ddot{x}_{\dot{x}_o} = 0$$

$$x_{\dot{x}_o}(0) = 0$$

$$\dot{x}_{\dot{x}_o}(0) = 1$$

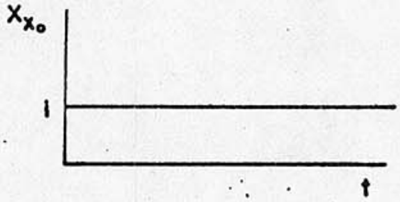
$$x_{\dot{x}_o} = \alpha t + \beta$$

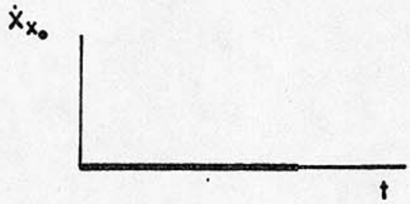
$$\begin{cases} x_{\dot{x}_o} = t \\ \dot{x}_{\dot{x}_o} = 1 \end{cases}$$

$$\Delta \dot{x}(t) = \dot{x}_{x_o}(t)\, \Delta x_o + \dot{x}_{\dot{x}_o}(t)\, \Delta \dot{x}_o$$

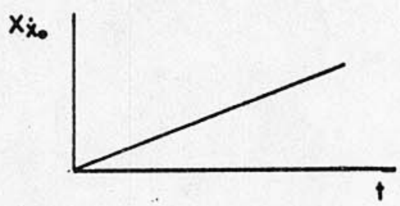
$$\Delta \dot{x}(t) = \Delta \dot{x}_o$$

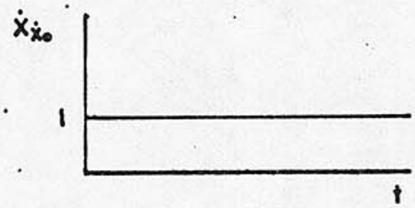
A graph can often be helpful in determining which variables should be altered to achieve a desired change in displacement or velocity.





Thus, one can see that a small change in initial displacement changes the displacement at each point in time by an equal amount. Velocity can be seen to be unaffected by a small change in displacement.





Thus, a change in initial velocity affects the displacement by an amount that increases with time. A change in initial velocity is simply added to the velocity at any other time.

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APPENDIX E

"BROAD SPECTRUM OF AMMUNITION" STUDY

The "Broad Spectrum of Ammunition" Study initiated under the Weapons Laboratory (WECOM) is designed to investigate an important, but relatively unexplored area of weapon-ammunition interaction. Emphasis is on the determination of how various ammunition parameters affect weapon operation and how these parameters are distributed in normal ammunition production. The term "broad spectrum" refers to the wide range in parameter values that occurs in production. Potentially, many useful results exist from such an investigation. For example, by understanding how gas behavior is affected by nonuniformity of propellant grain shape and, in turn, how gas behavior affects mechanism performance and reliability, one could then either stiffen or relax manufacturing tolerances on uniformity of grain shape. Also, having a more complete understanding of the weapon-ammunition interface, one could better design weapons so that they are relatively insensitive to ammunition tolerances difficult to maintain. Reference [15] provides additional background.

The general approach of this study is to answer the following three basic questions: (1) What measurable weapon characteristics should be used as indicators of weapon performance? (2) How do ammunition tolerances affect these performance indicators? (3) In normal production, what are the distributions of ammunition tolerance that are important to weapon performance? Mathematical models of weapons can be highly useful in the study of the first two questions. Statistical analyses of acceptance test data on breech and port pressures have been performed in support of the third question. See Reference [16].

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[15] "Ammunition Selection for Verification Testing of the 5.56mm, XM207, Belt-Fed Machine Gun", Technical Report 70-103, Rock Island, Illinois (Aug 1969)

[16] "Investigation of the Interaction of Weapon-Ammunition Subsystems", Technical Report SWERR-TR-72-30, AD 742723, Rock Island, Illinois (May 1972)

This task is very difficult, but it is also important. The problem it addresses cannot be solved in a straight-forward manner. Although a long-term effort is required, interim results should prove highly useful. This work interfaces with the probabilistic modeling described in Appendix D.

APPENDIX F

METHODS OF TREATING IMPACT

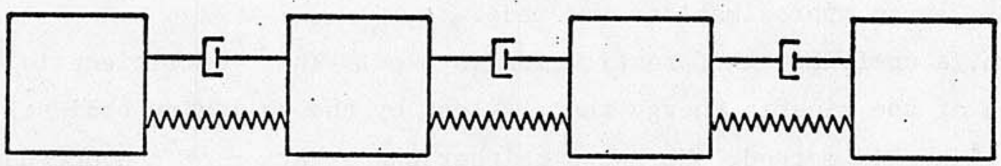
The impact between moving bodies in a weapon mechanism is very difficult to model accurately. Knowledge in this field is important for stress, wear, and fatigue analysis. In reality, time-dependent elastoplastic effects are involved. The nature of the impact depends on the motions of the masses just prior to impact, the mechanical properties of the material, the area of contact, the angle of contact, the boundary conditions on the colliding bodies, the physical dimensions of the masses, etc. However, in the interest of reasonable computation time for an already complex weapon model and in view of the lack of current theory to handle accurately impact situations, large approximations are made.

Often, a coefficient of restitution is used. This coefficient is an indication of the kinetic energy that is lost by the colliding bodies. However, with this method, one knows neither the duration of contact nor the forces involved. A better approximation would be to assume that, at the time of impact, a stiff spring and dashpot hypothetically appear between the two colliding masses. Coulomb, rather than viscous damping, could be assumed, but the question of which should be used is somewhat academic since the collision process is far too complex to be accurately modeled by either one.

Two major difficulties exist in the spring approach. The first difficulty is that it is difficult to properly choose the most appropriate spring and damping values. To some extent, the spring constant can be based on Young's modulus if one assumes that the constant is approximately AE/L. However, then a question arises as to the choice of length L. Possibly, one could let L vary and be equal to the instantaneous distance that the stress wave has traveled in the body. Another way to arrive at spring and damping constants is to correlate them with a coefficient of restitution. These coefficients are easy to measure and are often tabulated. Mr. Robert Coberly, Research Directorate, Weapons Laboratory, WECOM, has derived a relationship that will permit one to choose spring and dashpot values if the coefficient of restitution is known. The spring will then account for the force history of impact; this feat cannot be accomplished with the use of a coefficient of restitution without the spring.

The second difficulty with the spring concept is that, when a digital computer is used to solve the equations, an extremely small time increment is needed when a stiff spring is present. Otherwise, the momenta of the colliding bodies will, in the space of a single time-increment, carry these bodies so deeply into each other that the displacements represent extremely high force levels when multiplied by a large spring constant.

Another method of treating impact is to consider that the colliding bodies are hypothetically broken into a series of point masses, springs, and dashpots as follows:



This mechanical system is studied in Appendix C. However, the analysis is still too time-consuming on a computer to be practical in a large weapon model. What is needed is a transfer function that will give a direct relation between input displacement and output force. Such a model could account for another facet of impact not considered by the previously described methods. That facet is the propagation and reflection of stress waves. Parts of a colliding body, not close to the impact point, do not receive information that contact has been made until a finite length of time has elapsed. How the stress wave is reflected depends on the boundary conditions. This approach by which the body is divided into a number of segments is called a lumped-mass or finite-element approach. Simplification of this approach may be possible by replacement of the many masses and springs with a single mass-spring system where the spring constant is a function of time. This constant would be $K = M\ddot{X}/X$, where the position X of the single mass would be equal to the position history of the first mass in the large finite-element model. This ratio has been found to remain constant even if the initial conditions are changed. Thus, for a particular problem, one might establish K(t) and expect it to hold regardless of the impact velocities.

A continuum approach might also be considered. This can also be used to account for the propagation and reflection of stress waves. An example of how it might be used follows:

Navier's equation is:

$$G \nabla^2 U_i + (\lambda + G) \frac{\partial \Delta}{\partial x_i} = \rho \ddot{U}_i$$

Assume

$$\omega = v = 0$$

$$U = U(x, t)$$

Substitute into Navier's equation to obtain

$$\frac{\partial^2 U}{\partial x^2} = \frac{\rho}{\lambda + 2G} \frac{\partial^2 U}{\partial t^2}$$

$$U_{tt} = \frac{\lambda + 2G}{\rho} U_{xx}$$

$$U_{tt} = c^2 U_{xx}$$

$$c = \sqrt{\frac{\lambda + 2G}{\rho}}$$

Δ = dilitation

λ = Lamé's constant

G = Shear modulus

$$U_{tt} = c^2 U_{xx}$$

$$U(0, t) = f(t)$$

$$U(L, t) = 0$$

$$U(x, 0) = 0$$

$$U_t(x, 0) = h(x)$$

Let

$$U = v + g(x) f(t)$$

$$v(0,t) + g(0) f(t) = f(t)$$

$$v(L, t) + g(L) f(t) = 0$$

Require

$$v(0, t) = v(L, t) = 0$$

$$g(0) = 1$$

$$g(L) = 0$$

$$v_{tt} + g(x)\, f''(t) = c^2 v_{xx} + g''(x)\, f(t)$$

$$v_{tt} - c^2 v_{xx} = g''(x)\, f(t) - g(x)\, f''(t)$$

Let

$$g(x) = 1 - \frac{x}{L}$$

$$v_{tt} - c^2 v_{xx} = (\frac{x}{L} - 1)\, f''(t)$$

$$v(0, t) = 0$$

$$v(L, t) = 0$$

$$v(x, 0) = -(1 - \frac{x}{L})\, f(0)$$

$$= 0,$$

Since $f(0) = 0$

$$v_t(x, 0) = h(x) - g(x)\, f'(0)$$

Let

$$v = \Sigma\, \omega_n(t) \sin \frac{n\pi x}{L}$$

$$\text{I.C.} \Rightarrow \Sigma\, \omega_n(0) \sin \frac{n\pi x}{L} = 0$$

$$\therefore \omega_n(0) = 0$$

Write equation as

$$v_{tt} - c^2 v_{xx} = \Sigma\, Q_n(t) \sin \frac{n\pi x}{L} ,$$

where

$$Q_n(t) = \frac{2}{L} \int_0^L (\frac{x}{L} - 1)\, f''(t) \sin \frac{n\pi x}{L}\, dx.$$

By substitution,

$$\Sigma\, \omega_n'' \sin \frac{n\pi x}{L} + \Sigma\, c^2 \frac{n^2\pi^2}{L^2}\, \omega_n \sin \frac{n\pi x}{L} = \Sigma\, Q_n \sin \frac{n\pi x}{L}$$

$$\omega_n''(t) + c^2 \frac{n^2\pi^2}{L^2}\, \omega_n(t) = Q_n(t)$$

$$U_t(x, 0) = h(x)$$

$$v_t(x, 0) + g(x)\, f'(0) = h(x)$$

$$v_t(x, 0) = h(x) - f'(0)(1 - \frac{x}{L})$$

$$v_t(x, 0) = \Sigma\, \beta_n \sin \frac{n\pi x}{L}$$

where

$$\beta_n = \frac{2}{L} \int_o^L [h(x) - f'(0)(1 - \frac{x}{L}) \sin \frac{n\pi x}{L}]\, dx$$

$$v_t(x, 0) = \Sigma\, \omega_n' (0) \sin \frac{n\pi x}{L}$$

$$\therefore \omega_n' (0) = \beta_n$$

$$\omega_n''(t) + \frac{c^2 n^2 \pi^2}{L^2} \omega_n(t) = G_n(t)$$

$$\omega_n(0) = 0$$

$$\omega_n'(0) = \beta_n$$

One can solve for ω_n.

Then,

$$v = \Sigma\, \omega_n(t) \sin \frac{n\pi x}{L}$$

$$U = v + (1 - \frac{x}{L})\, f(t)$$

$$U = \Sigma\, \omega_n(t) \sin \frac{n\pi x}{L} + (1 - \frac{x}{L})\, f(t)$$

Thus,

for a given input displacement $f(t)$ at $x=0$, one knows $U(x, t)$

Thus,

one can find $\varepsilon = \frac{\partial U}{\partial x}$.

The generalized Hook's Law reduces to

$$\sigma = 2\,G\,\varepsilon + \lambda\,\varepsilon = (2\,G + \lambda)\,\varepsilon$$

$$\sigma = (2\,G + \lambda)\,\frac{\partial U}{\partial x}$$

What is needed is

$-\sigma A = K\,U + c\,\dot{U} \doteq K\,f\,(t)$, neglecting damping

$$K = \frac{-\sigma A}{f(t)}$$

$$K = \frac{-(2\,G + \lambda)\,\frac{\partial U}{\partial x}\,A}{f(t)}$$

$$K = -\,\frac{2\,G + \lambda}{f(t)}\left[\frac{\pi}{L}\sum_{n=1}^{\infty} n\,\omega_n(t) - \frac{1}{L}\,f(t)\right] A \qquad (X=L)$$

where

$$\omega_n''(t) + \frac{c^2 n^2 \pi^2}{L^2}\,\omega_n(t) = Q_n(t)$$

$$\omega_n(0) = 0$$

$$\omega_n'(0) = \beta_n$$

$$Q_n(t) = \frac{2}{L}\int_o^L \left(\frac{x}{L} - 1\right) f''(t)\,\sin\frac{n\pi x}{L}\,dx$$

$$\beta_n = \frac{2}{L}\int_o^L \left(h(x) - f'(0)\left(1 - \frac{x}{L}\right)\right) \sin\frac{n\pi x}{L}\,dx$$

λ = Lamé's constant

G = Shear modulus

$f(t)$ = displacement history at $x=0$

$h(x) = U_t(x, 0)$ = rate of change of U along body at $t=0$.

Probably $U_t(0, 0) = f'(0)$

$U_t(x > 0, 0) = 0$

Let

$$f(t) = a\ t$$

$$Q_n(t) = \frac{2}{L}\int_o^L \left(\frac{x}{L} - 1\right)(0)\ \sin\left(\frac{n\pi x}{L}\right) dx = 0$$

$$h(x) = \begin{cases} f'(0) \text{ at } x=0 \\ 0 \text{ at } x > 0 \end{cases}$$

$$\beta_n = \frac{2}{L}\int_o^L \left(-f'(0)\ \left(1 - \frac{x}{L}\right)\ \sin\frac{n\pi x}{L}\right)\ dx$$

$$\beta_n = -\frac{2\ a}{L}\int_o^L \left(1 - \frac{x}{L}\right)\ \sin\frac{n\pi x}{L}\ dx$$

$$= -\frac{2\ a}{L}\left[\int_o^L \sin\frac{n\pi x}{L}\ dx - \int_o^L \frac{x}{L}\sin\frac{n\pi x}{L}\ dx\right]$$

$$= -\frac{2\ a}{L}\left[-\frac{L}{n\pi}\cos\frac{n\pi x}{L}\ \Big|_o^L - \frac{1}{L}\left(\frac{L^2}{n^2\pi^2}\ \sin\frac{n\pi x}{L} - \frac{L}{n\pi}\ x \cos\frac{n\pi x}{L}\right)_o^L\right]$$

$$= -\frac{2\ a}{L}\left[-\frac{L}{n\pi}(-1)^n + \frac{L}{n\pi} - \frac{1}{L}\left(-\frac{L^2}{n\pi}\ (-1)^n\right)\right]$$

$$= -\frac{2\ a}{L}\left[\frac{L}{n\pi}\right] = \frac{-2\ a}{n\pi}$$

$$\beta_n = \frac{-2\ a}{n\pi}$$

$$\omega_n'' + \gamma^2\ \omega_n = 0$$

$$\omega_n(0) = 0$$

$$\omega_n'(0) = -\frac{2\ a}{n\pi}$$

$$\omega_n = A_n\ \cos\gamma_n t + B_n\ \sin\gamma_n t$$

$$\omega_n(0) = 0 \Rightarrow A_n = 0$$

$$\omega_n' = B_n\ \gamma\ \cos\ \gamma_n\ t$$

$$\omega_n'(0) = B_n\ \gamma_n = -\frac{2\ a}{n\pi}$$

$$B_n = -\frac{2\ a}{\gamma_n n\pi}$$

$$B_n = - \frac{2\ a}{n\pi}\ \frac{L}{cn\pi} = - \frac{2\ a\ L}{cn^2\pi^2}$$

$$\omega_n = - \frac{2\ a\ L}{cn^2\pi^2}\ \sin \frac{cn\pi}{L}\ t$$

$$\therefore\ K = -A\ \frac{2G + \lambda}{f(t)} \left[\sum_{n=1}^{\infty} \left(- \frac{2\ a}{cn\pi}\ \sin \frac{cn\pi}{L}\ t \right) - \frac{f(t)}{L} \right]$$

$$K = -A\ \frac{2G + \lambda}{f(t)} \left[\sum_{n=1}^{\infty} \left(- \frac{2\ a}{cn}\ \sin \frac{cn\pi}{L}\ t \right) - \frac{f(t)}{L} \right]$$

$$f(t) = a\ t$$

$$K = A(2G + \lambda) \left[+ \frac{1}{L} + \frac{1}{t} \sum_{n=1}^{\infty} \frac{2}{cn}\ \sin \frac{cn\pi}{L}\ t \right]$$

$$K = +A(2G + \lambda) \left[\frac{1}{L} + \frac{1}{t} \sum_{n=1}^{\infty} \frac{2}{cn}\ \sin \frac{cn\pi}{L}\ t \right]$$

$$K = +AE \left[\frac{1}{L} + \frac{1}{t} \sum_{n=1}^{\infty} \frac{2}{cn}\ \sin \frac{cn\pi}{L}\ t \right]$$ Spring Constant

This K can be shown to be $\qquad c = \sqrt{\frac{E}{\rho}}$

$$K = AE \left[\frac{1}{L} + \frac{\pi}{ct}\ \left(1 - \frac{c}{L}\ t\right) \right]\ ,\ 0 < t < \frac{2L}{c}$$, periodically repeated.

APPENDIX G

COUPLING OF COMPLEX MODELS

Many occasions arise when it would be desirable to couple complex mathematical models. Often a very large effort is needed to successfully combine the computer programs. Sometimes it is better "to start from scratch" than to attempt to make the programs compatible that have been written by two different people. This problem arises in weapon dynamic studies where an important consideration is the interaction between a mount-vehicle system and a weapon system. For example, if someone has a model of a certain weapon mechanism, much information could be gained by coupling it with someone else's model of a certain helicopter. The basic problem is an extremely important one and has applications far beyond weapons. However, the problem is also very difficult. The coupled system behaves as a completely new system and often bears little relation to the independent behavior of either system. A review of the literature reveals very little information concerning this problem.

One approach is to simplify one or both of the complex models. In effect, one models the model. It is possible to simplify the model to the point where it is a single analytic expression relating the force exerted by the mount to the position, velocity, and acceleration of the weapon. (See Reference[3]) However, considerable deterioration in accuracy can easily occur. Another approach is outlined below. It is much more successful in its ability to preserve the true natures of the interacting systems. However, it is more difficult to apply; but for many problems, the application of the method is simpler than simultaneous solution of all equations in both models.

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[3]Ehle, P.E., "Mathematical Model of the Stoner 5.56mm Medium Machine Gun, XM207," WECOM Technical Report 70-114, AD 862081L, Research and Engineering Directorate, Rock Island, Ill. (Oct 1969)

Let $\vec{x}_V$ locate the position of the point on the vehicle that is connected to the gun. Let $\vec{x}_G$ locate the position of the point on the gun that is connected to the vehicle. Assume that some unknown interaction force exists at this common point that causes the vehicle and gun to move together there. Assume that this force can be represented by a Fourier sine or cosine series in $(0, t_o)$.

That is,

$$\vec{F}(t) = \sum_{n=1}^{K} \vec{A}_n \sin \frac{n\pi t}{t_o}$$

where

$$\vec{A}_n = \frac{2}{t_o} \int_o^{t_o} \vec{F}(t) \sin \frac{n\pi t}{t_o} \, d\, t$$

and t_o is the maximum time for which the solution is desired. The assumption that the masses move together at the coupling point is equivalent to the constraint equation $\vec{x}_V - \vec{x}_G = \vec{\alpha}$, where $\vec{\alpha}$ accounts for any difference in the origins of the two coordinate systems. The procedure is as follows:

1. Make an initial guess for the $\vec{A}_n$ values. Denote these by $\vec{A}_{n_{(0)}}$.
2. Run the vehicle and gun programs independently with a forcing function equal to the Fourier series established with $\vec{A}_{n_{(0)}}$ values. The result will be $\vec{x}_{V_{(0)}}(t)$ and $\vec{x}_{G_{(0)}}(t)$. However, these functions will almost certainly not satisfy the constraint equation.
3. Expand $\vec{x}_V$ and $\vec{x}_G$ in a Taylor series about $\vec{A}_{n_{(0)}}$.

$$\vec{x}_V = \vec{x}_{V_{(0)}} + \sum_{n=1}^{K} \left[\frac{\partial \vec{x}_{V_{(0)}}}{\partial \vec{A}_{n_{(0)}}} \right] \Delta \vec{A}_n + \sum_{n=1}^{K} \left[\frac{\partial^2 \vec{x}_{V_{(0)}}}{\partial \vec{A}^2_{n_{(0)}}} \right] \left(\Delta \vec{A}_n \right)^2 + \cdots$$

$$\vec{x}_G = \vec{x}_{G_{(0)}} + \sum_{n=1}^{K} \left[\frac{\partial \vec{x}_{G_{(0)}}}{\partial \vec{A}_{n_{(0)}}} \right] \Delta \vec{A}_n + \sum_{n=1}^{K} \left[\frac{\partial^2 \vec{x}_{G_{(0)}}}{\partial \vec{A}^2_{n_{(0)}}} \right] \left(\Delta \vec{A}_n \right)^2 + \cdots$$

4. Substitute the results of (3.) into the constraint equation. Neglect second and higher order terms.

$$\vec{x}_{v_{(0)}}(t) - \vec{x}_{G_{(0)}}(t) - \vec{\alpha} = \sum_{n=1}^{K} \left[\frac{\partial \vec{x}_{G_{(0)}}}{\partial \vec{A}_{n_{(0)}}} - \frac{\partial \vec{x}_{v_{(0)}}}{\partial \vec{A}_{n_{(0)}}} \right] \Delta \vec{A}_n$$

5. From the gun model determine $\frac{\partial \vec{x}_{G_{(0)}}}{\partial \vec{A}_{n_{(0)}}}$; and from the vehicle model determine $\frac{\partial \vec{x}_{v_{(0)}}}{\partial \vec{A}_{n_{(0)}}}$. If the governing equations are linear, the partial derivatives can be found directly. Otherwise, they can be estimated by the running of each model and the noting of changes in $\vec{x}_{G_{(0)}}$ and $\vec{x}_{v_{(0)}}$ as the $\vec{A}_n$ are varied.

6. Write the equation in (4.) for each of k points in time scattered throughout $(0, t_o)$. One knows the values of $\vec{x}_{v_{(0)}}$, $\vec{x}_{G_{(0)}}$, $\vec{\alpha}$, $\frac{\partial \vec{x}_{G_{(0)}}}{\partial \vec{A}_{n_{(0)}}}$ and $\frac{\partial \vec{x}_{v_{(0)}}}{\partial \vec{A}_{n_{(0)}}}$. Thus, one has k algebraic equations and k unknowns $\Delta \vec{A}_n$.

7. Solve for $\Delta \vec{A}_n$ and write $\vec{A}_{n_{(1)}} = \vec{A}_{n_{(0)}} + \Delta \vec{A}_n$.

8. Repeat the above process, and use $\vec{A}_{n_{(1)}}$ as the initial guess in the Fourier series.

9. Repeat the entire process until $\vec{x}_{v_{(i)}} - \vec{x}_{G_{(i)}}$ is as close as possible or as close as desired to $\vec{\alpha}$.

There are two basic problems that may be encountered when one applies this method. First, for a very irregular interaction force over a long time interval, a large k value may be needed. Also, for some problems, a large number of iterations may be necessary.

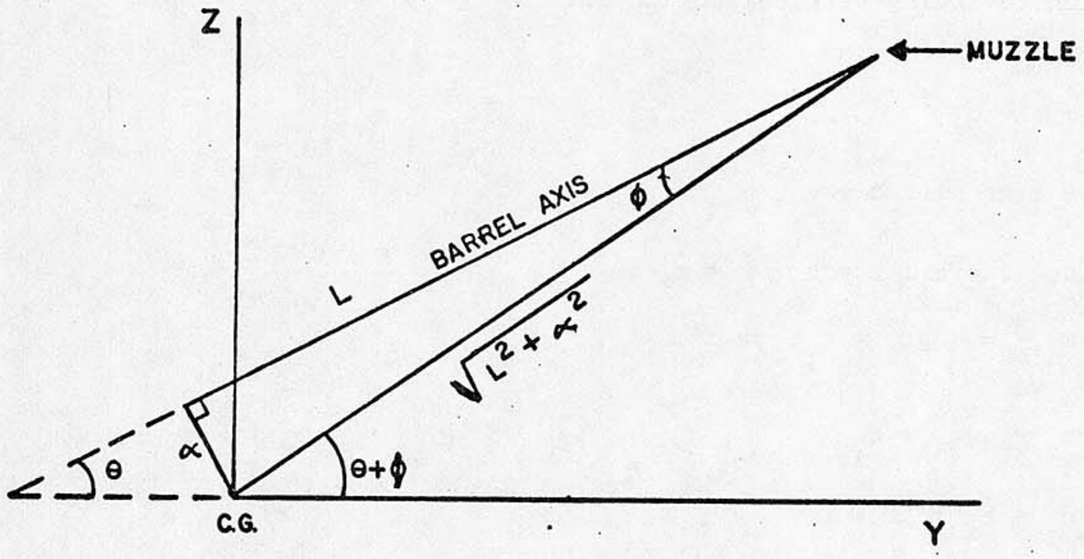
The method was applied to simple spring mass systems with nonlinear spring constants. It was also applied to a complex weapon model (XM207) in conjunction with a simple mount model. In all cases, convergence to the known interaction force was very rapid. Four iterations gave very good results. The method will not work equally well for all problems.

The approach described represents a "first cut" at the problem. Much work remains to satisfactorily solve it.

APPENDIX H

SIMPLIFIED EXTERIOR BALLISTICS ANALYSIS

A simplified exterior ballistics analysis was made for the determination of accuracy trends as various weapon parameters were varied. A sophisticated analysis is considered unnecessary for this purpose. The projectile is given only two degrees of freedom, and the drag force is assumed to be zero. Gravity is the only force that acts on the projectile. The axis of the barrel does not pass through the pivot point, which is assumed to be the center of gravity.



NOTE: α = Minimum distance from pivot point to bore axis

Figure 45 Geometry for Exterior Ballistics Analysis

Coordinates of Muzzle:

$$Z = \sqrt{L^2 + \alpha^2}\ \sin(\theta + \phi)$$

$$Y = \sqrt{L^2 + \alpha^2}\ \cos(\theta + \phi)$$

Components of Muzzle Velocity:

$$V_y = V \cos \Theta \qquad V = \text{muzzle velocity}$$

$$V_z = V \sin \Theta$$

Total velocity components of projectile at muzzle:

$$\dot{y} = \dot{Y} + V \cos \Theta = - \dot{\Theta} \sqrt{L^2 + \alpha^2} \sin (\Theta + \phi) + V \cos \Theta$$

$$\dot{z} = \dot{Z} + V \sin \Theta = \dot{\Theta} \sqrt{L^2 + \alpha^2} \cos (\Theta + \phi) + V \sin \Theta$$

The equation governing vertical motion is:

$$\ddot{z} = -g$$

$$\dot{z} = -gt + c_1$$

$$z = - \tfrac{1}{2} gt^2 + c_1 t + c_2$$

$$\text{at } t = t_i\text{: } z = z_i \quad \dot{z} = \dot{z}_i$$

$$\therefore \quad z_i = - \tfrac{1}{2} gt_i^2 + c_1 t_i + c_2$$

$$\dot{z}_i = -gt_i + c_1$$

$$c_1 = \dot{z}_i + gt_i$$

$$c_2 = z_i + \tfrac{1}{2} gt_i - t_i (\dot{z}_i + gt_i)$$

$$\therefore \quad z = - \tfrac{1}{2} gt^2 + [\dot{z}_i + gt_i] t + [z_i + \tfrac{1}{2} gt_i - t_i (\dot{z}_i + gt_i)] \qquad \text{(H-1)}$$

The equation governing horizontal motion is:

$$\ddot{y} = 0$$

$$y = k_1 t + k_2$$

$$\text{at } t = t_i\text{: } y = y_i \quad \dot{y} = \dot{y}_i$$

$$\therefore \quad y_i = k_1 t_i + k_2$$

$$\dot{y}_i = k_1$$

$$k_2 = y_i - \dot{y}_i t_i$$

$$y = \dot{y}_i t + [y_i - \dot{y}_i t_i] \qquad \text{(H-2)}$$

Now determine t when y = R = range to target

$$R = \dot{y}_i t_R + [y_i - \dot{y}_i \; t_i]$$

$$t_R = \frac{1}{\dot{y}_i} [R - y_i + \dot{y}_i t_i] \qquad \text{(H-3)}$$

Next determine z when $t = t_R$ by substitution of (H-3) into (H-1)

$$z_R = -\tfrac{1}{2} g \frac{1}{\dot{y}_i} [R - y_i + \dot{y}_i t_i]^2 + [\dot{z}_i + yt_i] \frac{1}{\dot{y}_i} [R - y_i + \dot{y}_i \; t_i]$$
$$+ [z_i + \tfrac{1}{2} gt_i - t_i(\dot{z}_i + gt_i)] \qquad \text{(H-4)}$$

Assume initial time $t_i = 0$.

Then

$$z_R = -\tfrac{1}{2} g \frac{1}{\dot{y}_i^2} [R - y_i]^2 + \dot{z}_i \frac{1}{\dot{y}_i} [R - \dot{y}_i] + z_i \qquad \text{(H-5)}$$

where

$$z_i = \sqrt{L^2 + \alpha^2} \; \sin(\Theta + \phi)$$

$$\dot{z}_i = \dot{\Theta} \sqrt{L^2 + \alpha^2} \; \cos(\Theta + \phi) + V \sin \Theta$$

$$y_i = \sqrt{L^2 + \alpha^2} \; \cos(\Theta + \phi)$$

$$\dot{y}_i = -\dot{\Theta} \sqrt{L^2 + \alpha^2} \; \sin(\Theta + \phi) + V \cos \Theta$$

$$\phi = \sin^{-1} \frac{\alpha}{L}$$

z_R is the vertical coordinate of the impact point at range R.

Nominal Values are:

$\alpha = .065$ ft

$L = 1.645$ ft

$R = 450$ ft

$V = 3180$ ft/sec

$\Theta = 0$

$\dot{\Theta}$ is obtained from the analysis of rifle rotation.

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APPENDIX I
GAS DYNAMICS

Accurate representations of gas forces are of great importance to mathematical models of automatic gas-operated weapons. At the present time, experimental pressure-time curves provide probably the most accurate simulation of these forces. However, to retain this accuracy, one must make new measurements each time changes are made in weapon parameters. Also, because of round-to-round variations, the use of any single curve is not realistic. Theoretical descriptions would allow one to account for the influence on gas force caused by changes in weapon parameters, but much work remains before really accurate predictions can be made.

In the M16A1 model, experimental pressure curves are used. However, there are many uncertainties associated with these measurements. Pressure gauges made by different manufacturers tend to disagree with one another. Also, it is very difficult to get measurements at exact points where they are needed. In addition, the presence of the gauge tends to perturb the normal fluid flow. Nevertheless, experimental measurements are probably more reliable than theoretical predictions.

There exist many computer programs that treat interior ballistics. Very few consider propellants with deterrent coatings. An unpublished one that does was constructed by T. Trafton at BRL. All of these analyses introduce gross approximations, but for many purposes, the results are satisfactory. One of the most successful analyses of flow in the M16A1 gas tube is described in Reference[9]. This analysis is fairly detailed and complex, and it provides an excellent tool for individual study of the gas tube. However, in the modeling of the dynamics of an entire weapon, a delicate balance must be struck between complexity and the limitations of computer storage and running time. This problem is compounded if the Monte Carlo technique, which requires

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[9] Spurk, J.H., "The Gas Flow in Gas-Operated Weapons," Ballistic Research Laboratories Report No. 1475, Aberdeen Proving Ground, Md. (Feb 1970)

many computer runs, is used. What is needed in this instance is a relatively simple model that can accept wide modifications in flow geometry and thermal properties and provide approximate answers. With such a gas flow analysis included in the weapon model, one could, for example, look at trends in unlocking force as changes are made in the location of the gas port, the thermal properties of the tube, or changes in the tube geometry. Such an analysis has been developed in theory in Reference[7]. However, the present computer program exhibits an instability for high rates of change of pressure typical of a weapon, and this problem is currently under investigation.

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[7] Ehle, P.E. and Rahe, A.E., "Development of a Finite Element Approach for Approximate Analysis of Unsteady Compressible Fluid Flow," WECOM Technical Report SWERR-TR-72-36, AD 746234, Rock Island, Ill (Jun 72)

APPENDIX J

CONVERSION OF PHYSICAL UNITS

TABLE 12 CONVERSION OF PHYSICAL UNITS

Area: $1\ m^2 = 10.764\ ft^2 = 1{,}550\ in^2$

Force: $1\ newton = 1\ kg\text{-}m/sec^2 = .22482\ lb_{force}$

Length: $1\ m = 3.281\ ft = 39.37\ in$

Mass: $1\ kg = 2.205\ lb_{mass}$

Pressure: $1\ newton/m^2 = 1\ kg/(m\text{-}sec^2) = .14511 \times 10^{-3}\ psi$

Velocity: $1\ m/sec = 3.281\ ft/sec = 39.37\ in/sec$

Cyclic rate:

Time for One Shot (milliseconds)	Shots Per Minute
60	1,000
61	984
62	968
63	952
64	938
65	923
66	909
67	896
68	882
69	870
70	857
71	845
72	833
73	822
74	811
75	800
76	789
77	779
78	769
79	759
80	750
81	741
82	732
83	723
84	714
85	706

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APPENDIX K

COMPUTER PROGRAM FOR M16A1 RIFLE AND SAMPLE OUTPUT

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```
0001           IMPLICIT REAL*8(A-H,O-Z)
0002           EXTERNAL FCT,OUTP
0003           REAL*4 ITMIN,ITMAX,ITX,ITY
0004           COMMON/MAS/NMASS
0005           COMMON/LAIN/ITMIN,ITMAX,ITX,ITY
0006           COMMON/RUNKA/PRMT(4),X(21),XD(21),XDD(21)
0007           COMMON/MODES/IMODE,IFG(30),IPT,IHAM,IUNLO,ISEP,IBBC,INIT,IRND
              1,NPOUN,ISR,IFFEQ,IRX,IPICK,I4DG
0008           COMMON/ASTHT/PBRCX     ,PBRCY(50),TFIRE,CCL,XLAMCC,XMUCC,ACC,BOREA,
              1 XKHYP,XCHYP,CF4,XMU4,XMB,XLD,PBRL,PCAL,CARTF(50),CARTX,PCAR
0009           COMMON/ASIT/XPBC,XKBBC,XCBBC,DERIV,XMBUL,XMARC ,PUC,AREBOL,
              1 TDEL,XIB,G,TPORT,XCBCMG,XMUBCG,EJCAR,ELEV            ,XKLBC,XCLBC
0010           COMMON/NUM/NBRCH,IFLAG,NCAV,IFLG,IFIRE
0011           COMMON/ASTHEE/PCAVT     ,PCAVY(50),FBORY(50),PBORE,FBORX
0012           COMMON/ER/XKBUFF,XCBUFF,XMBC,XMBV(3),XIM,RH,ALPHA,TSPRIN,
              1 RHH0,ALH0,RHH1,ALH1,HK,HC,
              1   DCOCK ,XKMCUN,XCMOUN,XUHBC,XDHA,EXTC,EXTF,FDIS,FSTIC
              1,R1B,R2B,XMUB,FCONX
0013           COMMON/S/XK9,XC9,XK5,XC5,BETA,ALP1,THETO,XKHG,XCHG,XMHAM,XMG,
              1    XMBUFF,CON1,XPUC,XPUC1,RO,CON2,XMUFF,XCUFF
0014           COMMON/BUFF/XBFORW,XCFORW,XBREAR,XCREAR,SLACK,XUBUF,XMWT,WTI
0015           COMMON/GRAP/TGR1,TGR2
0016           FCONX=-1.D-10
0017           DO 1 I=1,21
0018           X(I)=0.0D0
0019           XD(I)=0.0D0
0020         1 XDD(I)=0.0D0
          C     I4DG       USE ONE IF THE BUFFER MASSES ARE TREATED SEPERATELY AND 0
          C     IF USING A LUMPED MASS MODEL
0021           IPT=-1
0022           DO 2000 I=1,30
0023      2000 IFG(I)=0
          C     IRND       IRND DENOTES WHICH ROUND IS BEING FIRED
          C     IMODE       IF IMODE IS ONE THEN PRINT FORCES
          C                 IF IMODE IS ZERO THEN DON'T PRINT FORCES
          C     ISEP       IS ZERO WHEN WEAPON FIRES
          C     ISEP       IS ONE WHEN CAVITY FORCE GOES ON
          C     IUNLO       IF 1 THEN BARREL AND THE BOLT CAN SEPERATE
          C                 IF ZERO THEN THEY REMAIN LOCKED TOGETHOR
          C     IHAM       ONCE LOCKING OF THE WEAPON HAS OCCURRED, THE
          C     HAMMER BEGINS TO ROTATE FORWARD.  IT STRIKES THE FIRING PIN,AND
          C     IT IS ASSUMED ALL ITS ENERGY IS ABSORBED IN FIRING THE WEAPON,
          C     AND WHAT EVER GETS TRANSFERRED TO THE MAIN GUN DUE TO THE SPRING FORCE.
          C     WHEN IT JUST BEGINS TO REVERSE DIRECTION, THEN ITS ROTATIONAL VELOCITY
          C     AND THE DERIVATIVE OF THE ROTATIONAL VELOCITY ARE SET TO ZERO.
          C     (IHAM TAKES ON THE VALUE ZERO AT THIS POINT.)
          C     NOTE: THERE IS NO ROTATIONAL MOTION UNTIL THE BOLT CARRIER BEGINS TO
          C     REVERSE . (IHAM IS RESET TO ONE WHEN THE HAMMER IS COCKED AGAIN.)
          C     IFLAG       TAKES THE VALUE ONE WHEN XMG - BLTC IS LESS THAN FDIS
          C            AND TAKES THE VALUE ZERO WHEN BLT - BLTC IS GREATER THAN XLD
          C     IFLG        1  BOLT HAS NO CARTRIDGE
          C                 2  BOLT HAS JUST THE CASE
          C                 3  BOLT HAS CASE AND PROJECTILE
```

```
0024          TFIRE=-.000001D0
        C       IRBC       TAKES ON THE VALUE ONE WHEN THE SPRING FORCE BETWEEN THE BOLT
        C       CARRIER AND THE BOLT IS ON, AND WHEN WEAPON IS UNLOCKED
        C       INIT       WHEN WEAPON JUST BEGINS TO COCK IT TAKES ON THE VALUE ONE,
        C       AND IS SET BACK TO ZERO WHEN WEAPON FIRES.
        C       IFIRE      WHEN THE HAMMER ANGLE (THETA) BECOMES GREATER THAN ZERO, THEN
        C        THE WEAPON FIRES.(IFIRE IS SET TO ONE AT THIS POINT)
        C       IFIRE IS SET BACK TO ZERO WHEN BOLT BREAKS AWAY FROM THE GUN
        C       NROUN      NUMBER OF ROUNDS DESIRED
        C       IFREQ      FREQUENCY THAT THE FORCES ARE PRINTED OUT.
        C       IF     IREAD IS ONE THEN READ IN X AND XD
        C       IPICK      TAKES ON THE VALUE ONE WHEN THE BOLT CARRIER GETS
        C       BACK FAR ENOUGH TO PICK UP ANOTHER ROUND , AND GOES BACK TO ZERO WHEN THE
        C       GUN FIRES
        C        NSMPR      SAMPLE NUMBER FOR DETERMINING SAMPLE RATE IN GRAPHING
0025          NAMELIST/MODER/IRND,IMODE,ISEP,IUNLO,IHAM,IFLAG,IFLG,IBBC,INIT,
             1IFIRE,IFREQ,NROUN,IREAD,IPICK,NSMPR,I4DG,NMASS
0026          READ (5,MODER)
0027          PRINT 1776
0028     1776 FORMAT(30X,'CONTROL VARIABLES',/)
0029          WRITE(6,MODER)
0030          READ 100, PBRCX
0031          READ 2,NBRCH,(PBRCY(I),I=1,NBRCH)
0032          PBRCY(NBRCH + 1) =PBRCY(NBRCH)
0033          READ 100, PCAVT
0034          READ 2,NCAV,(PCAVY(I),I=1,NCAV)
0035          PCAVY(NCAV  + 1)=PCAVY(NCAV)
0036        2 FORMAT(I10,/,(8F10.5))
0037          PRINT 102, PBRCX ,( PBRCY(I),I=1,NBRCH)
0038      102 FORMAT(30X,' BREECH PRESSURE (LB/FT**2)',/,
             1 30X,' TIME STEP=',F16.8,/,(6F15.2))
0039          PRINT 103, PCAVT  ,(PCAVY(I),I=1,NCAV)
0040      103 FORMAT(20X,' CAVITY PRESSURE IN BOLT CARRIER (LB/FT**2)',/
             1,30X,' TIME STEP=',F16.8,/,(6F15.2))
0041          READ 100,CARTX
0042          READ 2,NCAR,(CARTF(I),I=1,NCAR)
0043          PRINT 165 , CARTX,(CARTF(I),I=1,NCAR)
0044          CARTF(NCAR  + 1)=CARTF(NCAR)
0045      165 FORMAT(30X,' CARTRIDGE CASE FORCE (LBS) ',/,30X,
             1' TIME STEP=',F16.8,/,(6F15.2))
0046          XI=NBRCH - 1
0047          PBRL=XI*PBRCX
0048          XI=NCAV - 1
0049          PCAL=XI*PCAVT
0050          XI=NCAR - 1
0051          PCAR=XI*CARTX
0052          READ 100,FBORX
0053          READ 2,NBOR,(FBORY(I),I=1,NBOR)
0054          XI=NBOR - 1
0055          PBORE=XI*FBORX
0056          PRINT 7001,FBORX,(FBORY(I),I=1,NBOR)
0057     7001 FORMAT(30X,' BORE FRICTION (LBS)',/,30X,
             1' TIME STEP=',F16.8,/,(6F15.2))
```

```
0058          NAMELIST/INPT1/                              BOREA,XKHYP,XCHYP,XLD,CF4,XMU4
             1 ,XMB, G
0059          NAMELIST/INPT2/XBBC,XKBBC,XCBBC,DERIV,XKLBC,XMBUL,XCLBC,
             1 AREBOL        ,TDEL,XIB ,XMARC
0060          READ(5,INPT1)
0061          READ(5,INPT2)
          C     CONVERTS FROM POUNDS TO SLUGS
0062          XMBUL=XMBUL/G
0063          XMARC=XMARC/G
0064          XMB=XMB/G
0065          NAMELIST/INPT3/TPORT,XKBUFF,XCBUFF,XCBCMG,XIM,RH,ALPHA,
             1 XKMOUN,XCMOUN,TSPRIN,XMUBCG,XMBC,R1B,R2B,CCL,XMUB
0066           NAMELIST/INPT4/XK9,XC9,XK5,XC5,BETA,ALP1,THETO,XKHG,XCHG,XMHAM,
             1   XMG,XMBUFF  ,EJCAR,ELEV,XPUC,XPUC1,RO
0067          NAMELIST/INPT5/XBFORW,XCFORW,XBREAR,XCREAR,SLACK,XUBUF,XMWT
             1,TGR1,TGR2,XUHBC,XDHA,FXTC,EXTF,FDIS,XMUFF,XCUFF,FSTIC
             2,RHH0,RHH1,ALH0,ALH1,HK,HC
          C      COMMENTS ABOUT INPUTS
          C      TGR1         ESTIMATED TIME FOR THE FIRST SHOT
          C      TGR2        ESTIMATED TIME FOR SUBSEQUENT SHOTS
0068          READ(5,INPT3)
0069          READ(5,INPT4)
0070          READ(5,INPT5)
0071          CALL READIN
          C     CONVERTS FROM POUNDS TO SLUGS
0072          XMHAM=XMHAM/G
0073          XMG=XMG/G
0074          XMBUFF=XMBUFF/G
0075          XMBC=XMBC/G
0076          XMWT=XMWT/G
0077          PRINT 9
0078        9 FORMAT(' NAME ',29X,'DESCRIPTION',39X,'VALUE',2X,'UNITS',/)
0079          PRINT 10                          ,BOREA,XKHYP
0080       10 FORMAT(
             5' BOREA',4X,'BORE AREA',51X,F20.8,2X,'FT**2',//,
             6 ' XKHYP',4X,'SPRING THAT PREVENTS MOTION BETWEEN THE BOLT AND GUN
             7',8X,F20.8,2X,'LBS/FT',/)
0081          PRINT 11,XCHYP,XLD,CF4,XMU4,XMB,G
0082       11 FORMAT(' XCHYP',4X,'DAMPING FOR THE ABOVE SPRING',32X,F20.8,
             2 2X,'LBS-SEC',//,' XLD',6X ,
             2'DISTANCE BOLT CARRIER TRAVELS BEFORE GUN IS UNLOCKED',8X,
             * F20.8,2X,'FT',// ,
             3 ' CF4',6X,'DAMPING COEFFICIENT BETWEEN BOLT AND BOLT CARRIER',11X
             4 ,F20.8,2X,'LBS-SEC/FT',//,' XMU4',5X,
             5'COEFFICIENT OF FRICTION BETWEEN BOLT AND BOLT CARRIER',7X,F20.8,
             6 2X,'NONE',//,' XMB',6X,'MASS OF THE BOLT',44X,F20.8,2X,'SLUGS',//
             7,' G',8X,'GRAVITATIONAL CONSTANT',38X,F20.8,2X,'FT/SEC**2',/)
0083          PRINT 12 ,XBBC,XKBBC,XCBBC,DERIV,XKLBC,XMBUL
0084       12 FORMAT(' XBBC',5X,'DISTANCE BOLT TRAVELS IN THE BOLT CARRIER',19X,
             1 F20.8,2X,'FT'        ,//,' XKBBC',4X,
             2'SPRING BETWEEN BOLT AND BOLT CARRIER',24X,F20.8,2X,'LBS/FT',//,
             3' XCBBC',4X,'DAMPING COEFFICIENT FOR ABOVE SPRING',24X,F20.8,2X,
             4'LBS-SEC/FT',//,' DERIV',4X,'DERIVATIVE OF THETA WITH RESPECT TO X
```

```
             4B-XBC',18X,F20.8,2X,'RAD/FT',//,
             5' XKLBC',4X,'SPRING BETWEEN BOLT AND BOLT CARRIER DURING LOCKING',
             69X,F20.8,2X,'LBS/FT',//,' XMBUL',4X,'MASS OF THE BULLET AND THE PR
             7OPELLANT',23X,F20.8,2X,'SLUGS',/)
0085          PRINT 13,XCLBC    ,AREBOL      ,TDEL,XIB,XMARC
0086      13 FORMAT(' XCLBC',4X,'DAMPING CORRESPONDING TO THE SPRING XKLBC ',
             118X,F20.8,2X,'LBS-SEC/FT',//,
             3' AREBOL',3X,'AREA OF CAVITY THE GAS FORCE ACTS ON',24X,F20.8,2X,
             4'FT**2',//,
             4' TDEL',5X,'TIME DELAY BETWEEN PORT AND CAVITY',26X,F20.8,2X,
             5   'SEC',//,
             5' XIB',6X,'MOMENT OF INERTIA OF THE BOLT',31X,
             5F20.8,2X,'SLUGS-FT**2'
             6 ,//,' XMARC',4X,'MASS OF THE CARTRIDGE CASE ',33X,F20.8,2X,'SLUGS
             6',/)
0087          PRINT 14,TPORT,XKBUFF,XCBUFF,XCBCMG,XIM,RH
0088      14 FORMAT(' TPORT',4X,'TIME IT TAKES PROJECTILE TO REACH PORT',22X,
             1 F20.8,2X,'SEC',//,' XKBUFF',3X,
             2 'INTERACTION SPRING BETWEEN BOLT CARRIER AND BUFFER',
             310X,F20.8,2X,'LBS/FT'
             3 ,//,' XCBUFF',3X,'DAMPING COEFFICIENT FOR ABOVE SPRING',24X,
             4 F20.8,2X,'LBS-SEC/FT',//,' XCBCMG',3X,
             4 'DAMPING BETWEEN BOLT CARRIER AND MAIN GUN',19X,F20.8,2X,
             4'LBS-SEC/FT'
             5 ,//,' XIM',5X,'MOMENT OF INERTIA OF THE HAMMER',29X,F20.8,2X,'SL
             6UGS-FT**2 ',//,' RH',7X,'RADIAL DISTANCE OF THE HAMMER TO POINT OF
             7 CONTACT',11X,F20.8,2X,'FT',/)
0089          PRINT 15,ALPHA             ,XKMOUN,XCMOUN,TSPRIN
0090      15 FORMAT(' ALPHA',4X,'REFERENCE ANGLE ON THE HAMMER',31X,F20.8,2X,
             2'RAD',//,
             3' XKMOUN',3X,'MOUNT SPRING CONSTANT',39X,F20.8,2X,'LBS/FT',//,
             4' XCMOUN',3X,'DAMPING FOR ABOVE SPRING',36X,F20.8,2X,'LBS-SEC/FT',
             6//,' TSPRIN',3X,'CONSTANT TORQUE DUE TO THE HAMMER SPRING',20X,
             6F20.8,2X,'FT-LBS',/)
0091          PRINT 16,XMUBCG,XMBC,XK9,XC9,XK5,XC5,BETA
0092      16 FORMAT(' XMUBCG',3X,'COEFFICIENT OF FRICTION BETWEEN THE BOLT CARR
             1RIER AND GUN',3X,F20.8,2X,'NONE',//,
             2' XMBC',5X,'MASS OF THE BOLT CARRIER',36X,F20.8,2X,'SLUGS',//,
             3' XK9',6X,'BACK PLATE SPRING CONSTANT',34X,F20.8,2X,'LBS/FT',//,
             3' XC9',6X,'DAMPING FOR THE ABOVE SPRING',32X,F20.8,2X,'LBS-SEC/FT'
             4,//,' XK5',6X,'DRIVE SPRING CONSTANT',39X,F20.8,2X,'LBS/FT',//,
             5' XC5', 6X,'DAMPING FOR ABOVE SPRING',36X,F20.8,2X,'LBS-SEC/FT',//
             6 ,' BETA',5X,'PRELOAD DISTANCE FOR THE DRIVE SPRING',23X,F20.8,2X,
             7'FT',/)
0093          PRINT 17,ALP1,THETO,XKHG,XCHG,XMHAM,XMG
0094      17 FORMAT(' ALP1',5X,'DISTANCE BUFFER TRAVELS BEFORE BACK PLATE IS HI
             1T',12X      ,F20.8,2X,'FT',//,
             2' THETO',4X,'INITIAL ANGLE OF THE HAMMER',33X,F20.8,2X,'RAD',//,
             3' XKHG',5X,'SPRING BETWEEN HAMMER AND GUN',31X,F20.8,2X,'LBS/FT',/
             4/,' XCHG' ,5X,'DAMPING FOR THE ABOVE SPRING',
             532X,F20.8,2X,'LBS-SEC/FT'
             5,//,' XMHAM',4X,'MASS OF THE HAMMER',42X,F20.8,2X,'SLUGS',//,
             6' XMG',6X,'MASS OF THE MAIN GUN',40X,F20.8,2X,'SLUGS',/)
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0095          PRINT 18,XMBUFF,EJCAR,FLEV,XPUC,XPUC1,RO
0096       18 FORMAT(' XMBUFF',3X,'MASS OF THE BUFFER',42X,F20.8,2X,'SLUGS',
             1//,' EJCAR',4X,        'DISTANCE BOLT TRAVELS BEFORE CARTRIDGE EJE
             2CTION ',12X,F20.8,2X,'FT',//,' ELEV',5X,
             3'ANGLE OF ELEVATION OF THE GUN',31X,F20.8,2X,'RAD',//,
             3' XPUC',5X,'DISTANCE OF BOLT WHEN ROUND IS PICKED UP',20X
             4  ,F20.8,2X,'FT',//,' XPUC1',4X,        'DISTANCE OF BOLT WHEN PIC
             5K UP FORCE IS OFF',18X,F20.8,2X,'FT',//,' RO',7X,
             6'DISTANCE FROM THE PIVOT POINT TO THE C.G. OF THE HAMMER', 5X
             6,F20.8,2X,'FT',/)
0097          PRINT 19,XBFORW,XCFORW,XBREAR,XCREAR
0098       19 FORMAT(' XBFORW',3X,'EFFECTIVE INTERNAL BUFFER SPRING CONSTANT (FO
             1RWARD)',9X,F20.8,2X,'LBS/FT',//,
             2' XCFORW',3X,'DAMPING COEF. FOR THE ABOVE SPRING',26X,F20.8,2X,
             3'LBS-SEC/FT',//,' XBREAR',3X,'EFFECTIVE INTERNAL BUFFER SPRING CON
             4STANT (REARWARD)',8X,F20.8,2X,'LBS/FT',//,
             5' XCREAR',3X,'DAMPING COEF. FOR THE ABOVE SPRING',26X,F20.8,2X,
             5'LBS-SEC/FT',/)
0099          PRINT 20,SLACK,XUBUF,XMWT,XUHBC,XDHA
0100       20 FORMAT(' SLACK',4X,'DISTANCE WTS. ARE ALLOWED TO MOVE',27X,F20.8,
             1 2X,'FT',//,
             2' XUBUF',4X,'COEF. OF FRICTION BETWEEN WTS. AND BUFFER',19X,
             3 F20.8,2X,'NONE',//,
             4' XMWT',5X,'MASS OF THE WTS IN THE BUFFER',31X,F20.8,2X,'SLUGS',//
             5,' XUHBC',4X,'COEF. OF FRICTION BETWEEN HAMMER AND B.C.',19X,
             6F20.8,2X,'NONE',//,' XDHA',5X,
             7'DISTANCE B.C. MOVES BEFORE FRICT. BETWEEN THE HAM. AND B.C.',
             81X,F20.8,2X,'FT',/)
0101          PRINT 31,EXTC,EXTF,FDIS,XMUFF,XCUFF,FSTIC
0102       31 FORMAT(' EXTC',5X,'EXTRACTOR DISTANCE ', 41X,F20.8,2X,'FT',// ,
             1' EXTF',5X,'EXTRACTOR FORCE',45X,F20.8,2X,'LBS',//,
             1' FDIS',5X,'DISTANCE BOLT CARRIER IS FROM BATTERY, HAMMER ROTATES'
             2 ,7X,F20.8,2X,'FT',//,
             3' XMUFF',4X,'COEF. OF FRIC. BETWEEN GUN AND BUFFER',23X,
             4F20.8,2X,'NONE',//,
             4' XCUFF',4X,'DAMPING BETWEEN BUFFER AND GUN',30X,F20.8,2X,'NONE',/
             5/,' FSTIC',4X,'STICTION FORCE',46X,F20.8,2X,'LBS',/)
0103          PRINT 35,RHH0,RHH1,ALH0,ALH1,HK,HC
0104       35 FORMAT(' RHH0',5X,'DISTANCE FROM HAMMER PIVOT TO B.C.',26X,
             1F20.8,2X,'FT',//,' RHH1',5X,
             2'DISTANCE FROM PIVOT TO TOP OF HAMMER ',23X,F20.8,2X,'FT',//,
             3' ALH0',5X, 'ANGLE CORRESPONDING TO RHH0',33X,F20.8,
             3 2X,'RAD',//,' ALH1',5X,'ANGLE CORRESPONDING TO RHH1 ',32X,F20.8,
             12X,'RAD',//,' HK',7X,'HAMMER IMPACT SPRING',40X,F20.8,2X,
             1'LBS/RAD',//,' HC',7X,'ABOVE DAMPING CONSTANT',38X,F20.8,
             12X,'LBS-SEC/RAD',/)
0105          PRINT 39,R1B,R2B,CCL,XMUB
0106       39 FORMAT(' R1B',6X,'INNER RADIUS CARTRIDGE CASE ',
             1 32X,F20.8,2X,'FT',//,' R2B',6X,'OUTER RADIUS CARTRIDGE CASE ',
             232X,F20.8,2X,'FT',//,' CCL',6X,
             3'CARTRIDGE CASE LENGTH ',38X,F20.8,2X,'FT',//,' XMUB',5X,
             4'COEFFICIENT OF FRICTION AT THE BASE',25X,F20.8,2X,'NONE',/)
0107          XMBV(1)=XMB
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0108              XMRV(2)=XMB + XMARC
0109              XMRV(3)=XMR + XMBUL  + XMARC
0110              X(5)=THETO
0111              CON1= DSIN(ELEV)
0112              CON2=DCOS(ELEV)
0113              IF(IREAD.EQ.1) GO TO 1700
          C        COMPUTE EQUILIBRIUM POINTS
0114              X(2)=(-CON1*(XMWT+ XMBC + XMBUFF)*G+BETA*XK5)/XKLBC
0115              X(4)=X(2) +(-CON1*(XMWT + XMBUFF)*G+BETA*XK5)/XKBUFF
0116              IF(ELEV.GT.0.0D0)X(6)=X(4) - SLACK
0117              IF(ELEV.LE.0.0D0)X(6)=X(4)
0118              DO 1915  I=1,4
0119         1915 X(6 + I)=X(6)
0120         1700 READ 100,PRMT
0121              IF(IREAD.NE.1) GO TO 170
          C        NOTE: X(6) CAN TAKE ON VALUES BETWEEN ZERO AND SLACK
0122              READ 100, X
0123               READ 100,XD
0124          100 FORMAT(8F10.5)
          C ****FOLLOWING DETERMINES SAMPLING RATE FOR PLOTTING PURPOSES
0125          170 XR=NROUN
0126              WTI=0.0D0
0127         1929 NP=    .075/PRMT(3)
0128              ISR=NP/NSMPR
0129              IF(ISR.EQ.0) ISR=1
0130              ITMAX=   TGR1   + PRMT(1)
0131              ITMIN=PRMT(1)
0132              IRX=IRND
0133              CALL READIT
0134              IF(I4DG.NE.1) GO TO 2900
0135              CALL READUM
0136              CALL INITAL
          C      INTEGRATION ROUTINE BEGINS HERE
0137         2900 KNUM=7 + NMASS
0138              IF(I4DG.EQ.1)KNUM=11  + NMASS
0139              PRINT 1938,NROUN
0140         1938 FORMAT('1',15X,'COMPUTED RESULTS FOR A ',I2,' SHOT BURST',//)
0141              N11=7
0142              IF(I4DG.EQ.1) N11=11
0143              L11=KNUM - 1
0144              DO 1942 I=N11,L11
0145         1942 X(I)=X(4)
0146              CALL RUNGE(KNUM,FCT,OUTP)
0147              CALL EXIT
0148              END
```

```
0001         SUBROUTINE FCT(T,X,XD,XDD,ITEST)
0002         IMPLICIT REAL*8(A-H,O-Z)
0003         DIMENSION X(21),XD(21),XDD(21)
0004         COMMON/MODES/IMODE,IFG(30),IPT,IHAM,IUNLO,ISEP,IBBC,INIT,IRND
            1,NROUN,ISR,IFREQ,IRX,IPICK,I4DG
0005         COMMON/ASTHT/PBRCX     ,PBRCY(50),TFIRE,CCL,XLAMCC,XMUCC,ACC,BOREA,
            1 XKHYP,XCHYP,CF4,XMU4,XMB,XLD,PBRL,PCAL,CARTF(50),CARTX,PCAR
0006         COMMON/NUM/NBRCH,IFLAG,NCAV,IFLG,IFIRE
0007         COMMON/ASTHEE/PCAVT     ,PCAVY(50),FBORY(50),PBORE,FBORX
0008         COMMON/ASIT/XBBC,XKBBC,XCBBC,DERIV,XMBUL,XMARC ,PUC,AREBOL,
            1 TDEL,XIB,G,TPORT,XCBCMG,XMUBCG,EJCAR,ELEV           ,XKLBC,XCLBC
0009         COMMON/ER/XKBUFF,XCBUFF,XMBC,XMBV(3),XIM,RH,ALPHA,TSPRIN,
            1 RHH0,ALH0,RHH1,ALH1,HK,HC,
            1    DCOCK ,XKMOUN,XCMOUN,XUBBC,XDHA,EXTC,EXTF,FDIS,FSTIC
            1,R1B,R2B,XMUB,FCONX
0010         COMMON/S/XK9,XC9,XK5,XC5,BETA,ALP1,THETO,XKHG,XCHG,XMHAM,XMG,
            1    XMBUFF,CON1,XPUC,XPUC1,RO,CON2,XMUFF,XCUFF
0011         COMMON/BUFF/XBFORW,XCFORW,XBREAR,XCREAR,SLACK,XUBUF,XMWT,WTI
0012         COMMON/CNTRL/DELT,SUM
0013         COMMON/PRT/FB(12),FBC(12),FMG(15),FBUF(6)
0014         COMMON/DIF/DIFF1,DIFF2,DIFF3,DIFF4,DIFF5,DIFF6
0015         COMMON/MSSS/XMS(5),XKS(6),XCS(6)
0016         DATA TOFF/-10.D0/,TCOMP/0.0D0/,IKPTRK/0/ ,IBOR/0/,IHD/0/,IDID/0/
0017         COMMON/MAS/NMASS
       C      COMMENTS
       C      X(1),XD(1)        CORRESPOND TO THE BOLT
       C      X(2),XD(2)        CORRESPOND TO THE BOLT CARRIER
       C      X(3),XD(3)        CORRESPOND TO THE MAIN GUN
       C      X(4),XD(4)        CORRESPOND TO THE BUFFER
       C      X(5),XD(5)        CORRESPOND TO THE HAMMER
       C      X(6),XD(6)        CORRESPOND TO THE WTS. IN THE BUFFER
       C      OR X(6),X(7),X(8),X(9),X(10) CORRESPOND TO BUFFER WEIGHTS
       C      X(7) ...... CORRESPOND TO DRIVE SPRING MASSES
       C      OR X(11)......... CORRESPOND TO DRIVE SPRING MASSES
       C      LAST DEFINED PARAMETER IS THE GUN ROTATION
0018         DIFF1=X(1) - X(3)
0019         DIFD1=XD(1) - XD(3)
0020         DIFF2=X(1) - X(2)
0021         DIFD2=XD(1) - XD(2)
0022         DIFF3=X(3) - X(2)
0023         DIFD3=XD(3) - XD(2)
0024         DIFF4=X(4) - X(2)
0025         DIFD4=XD(4) - XD(2)
0026         DIFF5=X(3) - X(4)
0027         DIFD5=XD(3) - XD(4)
0028         DIFF6=X(6) - X(4)
0029         DIFD6=XD(6) - XD(4)
0030         IF(IPICK.EQ.0.AND.DIFF3.GT.XPUC)  IPICK=1
0031         IF(DIFF2.GE.XBBC.AND.IBBC.EQ.0) IBBC=1
0032         IF(IBBC.EQ.1.AND.DIFF1.GE.0.0D0.AND.IFIRE.EQ.0.AND.DIFF2.LT.XBBC)
            1  IBBC=0
0033         IF(IUNLO.EQ.1.AND.DIFF1.GT.0.0D0.AND.DIFD1.LT.0.0D0.AND.IFLG.EQ.3
            1.AND.ITEST.EQ.1) GO TO 79
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           IF(IFLAG.EQ.0.AND.DIFF3.LT.FDIS.AND.IBRC.EQ.0) IFLAG=1
0034       GO TO 788
0035    79 IUNLO=0
0036       XD(1)=XD(3)
0037   788 IF(-DIFF1.GT.EJCAR.AND.IFLG.EQ.2) IFLG=1
0038       IF(IFLG.EQ.1.AND. IFG(21).NE.1) GO TO 7500
0039       GO TO 7501
0040  7500 PRINT 7502,T
0041  7502 FORMAT(' CARTRIDGE CASF IS EJECTED AT T= ',F15.8)
0042       IFG(21)=1
0043  7501 IF(X(5).GE.0.0D0.AND.IFIRE.EQ.0.AND.IFLG.EQ.3) GO TO 75
0044  6655 IF(DIFF3.GE.XLD.AND.IFLAG.EQ.1) IFLAG=0
0045       IF(IBBC.EQ.1.AND.IFIRE.EQ.1.AND.FBC(8).LT.1.D-20)    IFIRE=0
0046       GO TO 700
0047    75 IF(IDID.EQ.0) TNOW=T
0048       IF(INIT.NE.0)     INIT=0
0049       IF(IDID.NE.1)   IDID=1
0050       IF(T.LT.TNOW + TBFO) GO TO 6655
0051       IDID=0
0052       IFIRE=1
0053       TFIRE=T
0054       IFG(21)=0
0055       IFLG=2
0056       INIT=0
0057       ISEP=0
0058       IRND=IRND + 1
0059       IPICK=0
0060        IF(IRND.EQ.1) THETK=THETO
0061       IF(IRND.EQ.1)THETO=THETO - .122
0062       PRINT 150,IRND
0063   150 FORMAT(' ***********',' ROUND NUMBER  ',I1,'  REGINS  ',
0064      1'***********')
0065       PRINT 100,TFIRE
0066   100 FORMAT(' WEAPON FIRES AT T= ',F15.8)
     C      COMPUTE FB(1)
0067   700 TF1=T - TFIRE
0068       IF(IHAM.EQ.1.AND.XD(5).LT.0.0D0)IHAM=0
0069       IF(IBBC.EQ.1.AND.IHAM.FQ.0.AND.IUNLO.EQ.1) IHAM=1
0070       IF(TF1.GT.PBRL.OR.TF1.LT.0.0D0.OR.IFLG.EQ.3)  GO TO 10
0071        FB(1)=-XINTP(TF1,PBRCX,PBRCY)*BOREA
0072       IF(IFG(1).EQ.1) GO TO 11
0073       IFG(1)=1
0074       PRINT 550,T
0075   550 FORMAT(' BREECH FORCE IS ON AT T=',F15.8)
0076       GO TO 11
0077    10 FB(1)=0.0D0
0078       IF(IFG(1).EQ.0) GO TO 11
0079       IFG(1)=0
0080        PRINT 551,T
0081   551 FORMAT(' BREECH FORCE IS OFF AT T=',F15.8)
     C      COMPUTE FB(2)
0082    11 IF(-DIFF1.LT.XPUC.AND.DIFF3.GT.XPROJ.AND.IFLG.NE.3.AND.
          1XD(2).LT.0.0D0) GO TO 8915
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0083            GO TO 8916
0084       8915 TEMP=IKPTRK
0085            FB(2)=(XME*G*CON2+ XKMAG*(DELSP*TEMP - XFL + YIHT))* 2. *
               1DSIGN(1.D0, DIFD1)*XUMAG1
0086            IF(IFG(30).EQ.1) GO TO 13
0087            IFG(30)=1
0088            PRINT 8917,T,FB(2)
0089       8917 FORMAT(' AMMO AND BOLT FRICTION IS ON AT T=',F15.8,'FRIC=',F15.8)
0090            GO TO 13
0091       8916 FB(2)=0.0D0
0092            IF(IFG(30).EQ.0) GO TO 13
0093            IFG(30)=0
0094            PRINT 8918,T
0095       8918 FORMAT(' BOLT AND AMMO FRICTION IS OFF AT T=',F15.8)
          C        COMPUTE FB(3)
0096         13 IF(IFIRE.EQ.1.OR.IUNLO.EQ.0 .OR.DIFF1.LT.-EXTC.OR.IFLG.EQ.2)
               1 GO TO 14
0097            FB(3)=-EXTF
0098            IF(DIFF1.GT.0.0D0) GO TO 9916
0099            GO TO 9917
0100       9916 FB(3)=-XKHYP*DIFF1 - XCHYP*DIFD1 +FB(3)
0101       9917 IF(IFG(3).EQ.1) GO TO 15
0102            IFG(3)=1
0103            PRINT 554,T,FB(3)
0104        554 FORMAT(' SPRING EXTRACTOR FORCE IS ON AT T=',F15.8,' CONSTANT FORC
               1E',  F15.8)
0105            GO TO 15
0106         14 FB(3)=0.0D0
0107            IF(IFG(3).EQ.0) GO TO 15
0108            IFG(3)=0
0109            PRINT 556,T
0110        556 FORMAT(' SPRING BETWEEN BOLT AND BARREL IS OFF AT T=',F15.8)
          C        COMPUTE FB(4)
0111         15 FB(4)= - CF4*DIFD2 + XMU4*XMBV(IFLG)*G*DSIGN(1.0D0,-DIFD2)*CON2
          C        COMPUTE FB(5)
0112            IF(IBBC.EQ.0.OR.(DIFF2.LT.XBBC.AND.DIFF2.GT.XBBC - .52083D-2)
               1.OR.IFG(13).EQ.1) GO TO 17
0113            IF(DIFF2.LE.XBBC-.52083D-2) GO TO 9161
0114            FB(5)=-XKBBC*(DIFF2 - XBBC) - XCBBC*DIFD2
0115            IF(FB(5).GT.0.0D0) FB(5)=0.0D0
0116            GO TO 9162
0117       9161 FB(5)=-XKBBC*(DIFF2 - XBBC + .52083D-2) - XCBBC*DIFD2
0118            IF (FB(5).LT.0.0D0) FB(5)=0.0D0
0119       9162 IF(IFG(4).EQ.1) GO TO 80
0120            IFG(4)=1
0121            PRINT 557,T
0122        557 FORMAT(' SPRING FORCE BETWEEN THE BOLT AND BOLT CARRIER IS ON AT T
               1=',F15.8)
0123            GO TO 80
0124         17 FB(5)=0.0D0
0125            IF(IFG(4).EQ.0) GO TO 80
0126            IFG(4)=0
0127            PRINT 558,T
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0128        558 FORMAT(' SPRING FORCE RETWEEN BOLT AND BOLT CARRIER IS OFF AT T=',
               1 F15.8)
          C       COMPUTE FB(6) AND FB(7)        (ZERO UNLESS SPECIFIED OTHERWISE)
0129         80 FB(6)=0.0D0
0130            FB(7)=0.0D0
          C       COMPUTE FB(8)
0131         87 IF(DIFF2.GE.0.0D0) GO TO 20
0132            FB(8)=- XKLBC*(DIFF2) - XCLBC*DIFD2
0133            IF(FB(8).LT.0.0D0)FB(8)=0.0D0
0134            IF(IFG(5).EQ.1) GO TO 201
0135            IFG(5)=1
0136            PRINT 559,T
0137        559 FORMAT(' (FORWARD) BOLT PIN STRIKES END OF CAM PATH AT T=',F15.8)
0138            GO TO 201
0139         20 FB(8)=0.0D0
0140            IF(IFG(5).EQ.0) GO TO 201
0141            PRINT 560,T
0142        560 FORMAT(' (FORWARD) FORCE AT END OF CAM PATH IS OFF AT T=',F15.8)
0143            IFG(5)=0
          C       COMPUTE FB(9)
0144        201 IF(IPICK.EQ.0) GO TO 21
0145            IF(-DIFF1. LT. XPUC .AND.-DIFF1 .GT. XPUC1 . AND.
               1 XMBC*XD(2) + XMBV(IFLG)*XD(1).GT.0.0D0.AND.(ITEST.EQ.1.OR.
               2IFG(6).EQ.1).AND.T - TOFF.GT.TCOMP)GO TO 2111
0146            GO TO 21
0147       2111 TEMP=IKPTRK
0148            FB(9)=DIAC*(XME*G*CON2 + XKMAG*(DELSP*TEMP - XFL + YIHT))*
               1(XUMAG2 + XUMAG3)*DSIGN(1.D0,DIFD1)/DELSP
0149            IF(IFG(6).EQ.1) GO TO 22
0150            PRINT 561,T
0151        561 FORMAT(' FORCE TO PICK UP NEW ROUND IS ON AT T=',F15.8)
0152            IFG(6)=1
0153            IFLG=3
0154            PRINT 7553
0155       7553 FORMAT(/,' INELASTIC COLLISION OF THE ROLT AND ROUND')
0156            PRINT 7550,XMG,XD(1),XD(3)
0157       7550 FORMAT(/,' MASS OF THE GUN AND VELOCITIES OF THE BOLT AND ROUND ',
               1 /,' PRIOR TO ROUND BEING PICKED UP',/,' GUN MASS=',F15.8,
               2' BOLT VELOCITY=',F15.8,' ROUND VELOCITY (VELOCITY OF THE GUN)=',
               3F15.8)
0158            XMG=XMG-(XMARC+XMBUL)
0159            XD(1)=(XD(3)*(XMARC+ XMBUL) + XD(1)*XMBV(IFLG))/
               1(XMARC + XMBUL + XMBV(IFLG))
0160            PRINT 7589,XMG,XD(1),XD(1)
0161       7589 FORMAT(/,' MASS OF THE GUN AND VELOCITIES OF THE BOLT AND ROUND ',
               1 /,' AFTER ROUND IS PICKED UP'       ,/,' GUN MASS=',F15.8,
               2' BOLT VELOCITY=',F15.8,' ROUND VELOCITY =',F15.8)
0162            PRINT 7599,FB(9)
0163       7599 FORMAT(' FRICTIONAL FORCE TO PICK UP NEW ROUND IS',F15.8)
0164            GO TO 22
0165         21 FB(9)=0.0D0
0166            IF(IFG(6).EQ.0) GO TO 22
0167            PRINT 562,T
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0168      562 FORMAT(' FORCE TO PICK UP NEW ROUND IS OFF AT T=',F15.8)
0169          IFG(6)=0
0170          TOFF=T
0171          IKPTRK=IKPTRK + 1
0172          TEMP=IKPTRK
0173          FMI=-XKMAG*(TEMP*DELSP + YIHT - XFL)
0174          FMA=-XKMAG*((TEMP - 1.)*DELSP + YIHT  - XFL)
0175          TCOMP=DSORT(AVE/(EPSOL*XKMAG))*DARCOS(FMI/FMA)
0176           PRINT 7600,TCOMP,FMI,FMA
0177     7600 FORMAT(/,' RESPONSE TIME OF THE MAGAZINE IS', F15.8,' FMI=',
             1F15.8,' FMA=',F15.8)
        C      COMPUTE FB(10)
0178       22 TGAS= T - TFIRE - TPORT - TDEL
0179          IF(TGAS.LT.0.0D0.OR.TGAS.GT.PCAL .OR.IFLG.EQ.3)  GO TO 23
0180          FB(10)=+XINTP(TGAS,PCAVT,PCAVY)*AREBOL
0181          IF(IFG(8).EQ.1) GO TO 24
0182          PRINT 563,T
0183      563 FORMAT(' CAVITY FORCE IS ON AT T=',F15.8)
0184          IFG(8)=1
0185          ISEP=1
0186          GO TO 24
0187       23 FB(10)=0.0D0
0188          IF(IFG(8).EQ.0) GO TO 24
0189          PRINT 564,T
0190      564 FORMAT(' CAVITY FORCE IS OFF AT T=',F15.8)
0191          IFG(8)=0
0192       24 IF(IUNLO.EQ.0.OR.IBBC.EQ.0) GO TO 5510
   .    C     TBBC1=T - TBBC
        C     IF(TBBC1.GT.PCAR) GO TO 5510
        C     FB(11)= XINTP(TBBC1,CARTX,CARTF)
0193          IF(-DIFF1.GT.CCL.OR.-XMBC*DIFD3.GT.0.0D0) GO TO 5510
0194          FB(11)=-CARTF(1)*(DIFF1 + CCL)/CCL
0195          IF(IFG(20).EQ.1) GO TO 5520
0196          IFG(20)=1
0197          PRINT 5540,T
0198     5540 FORMAT( ' EXPERIMENTAL CARTRIDGE CASE EJECTION FORCE IS ON AT T= '
             1 , F15.3)
0199          GO TO 5520
0200     5510 FB(11)=0.0D0
0201          IF(IFG(20).EQ.0) GO TO 5520
0202          IFG(20)=0
0203          PRINT 5530,T
0204     5530 FORMAT( ' EXPERIMENTAL CARTRIDGE CASE EJECTION FORCE IS OFF AT T=
             1',F15.8)
        C      COMPUTE FORCES ON THE BOLT CARRIER
0205     5520 FB(12)=-CON1*G*XMBV(IFLG)
0206          FBC(1)= - FB(4)
0207          FBC(2)= - FB(5)
0208          FBC(3)=-FB(6)
0209          FBC(4)=-FB(8)
0210          FBC(5)=-FB(7)
        C      COMPUTE FBC(6)
0211          FBC(6)=XKBUFF*DIFF4 + XCBUFF*DIFD4
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0212          IF(FBC(6).LT.0.0D0)FBC(6)=0.0D0
0213          GO TO 29
0214       25 FBC(6)=0.0D0
         C      COMPUTE FBC(7)
0215       29 FBC(7)=-XCBCMG*(-DIFD3) + XMUBCG*(XMBV(IFLG) + XMBC)*G*DSIGN(1.D0,
             1DIFD3)*CON2
         C      COMPUTE FBC(8)  (ENTERS INTO THE CONSTRAINT EQUATIONS)
0216       27 FBC(8)=0.0D0
         C      COMPUTE FBC(9)
0217       28 FBC(9)=-FB(10)
         C      FRICTIONAL FORCE ACTING ON THE B.C. DUE TO THE AMMO IS COMPUTED HERE
0218          IF(T - TOFF.GT.TCOMP.AND.DIFF3.LT.XPROJ.AND.IFG(6 ).EQ.0)
             1GO TO 9600
0219          GO TO 9601
0220     9600 TEMP=IKPTRK
0221          FBC(10)=(XME*G*CON2+XKMAG*(DELSP*TEMP - XFL + YIHT))*2.*
             1DSIGN(1.D0,-DIFD3)*XUMAG1
0222           IF(IFG(28).EQ.1) GO TO 9650
0223          PRINT 9607,T,FBC(10)
0224          IFG(28)=1
0225     9607 FORMAT(' FRICTIONAL FORCE BETWEEN CARTRIDGES AND B.C. IS ON AT T=
             1',F15.8,' FBC(10)=',F15.8)
0226          GO TO 9650
0227     9601 FBC(10)=0.0D0
0228          IF(IFG(28).EQ.0) GO TO 9650
0229           IFG(28)=0
0230          PRINT 9609,T
0231     9609 FORMAT(' FRICTIONAL FORCE BETWEEN CARTRIDGES AND B.C. IS OFF AT T=
             1 ',F15.8)
0232     9650 IF(DIFF3.LT.XDHA.OR.IFG(12).NE.2) GO TO 9705
0233          FBC(11)=-DSIGN(1.D0,DIFD3)*TSPRIN*XUHBC*2./(RHH1*CONF1*DSIN(X(5)))
0234          IF(IFG(29).EQ.1) GO TO 9706
0235           IFG(29)=1
0236          PRINT 9707,T,FBC(11)
0237     9707 FORMAT(' FRICTION FORCF COMES ON BETWFEN HAMMER AND B.C. AT T=',
             1F15.8,' FBC(11)=',F15.8)
0238          GO TO 9706
0239     9705 FBC(11)=0.0D0
0240           IF(IFG(29).EQ.0) GO TO 9706
0241          PRINT 9709,T
0242     9709 FORMAT(' FRICTION FORCE BETWEEN HAMMER AND B.C. IS OFF AT T=',
             1F15.8)
0243          IFG(29)=0
0244     9706 FBC(12)=-CON1*XMBC*G
0245          FMG(1)=-XKMOUN*X(3) - XCMOUN*XD(3)
0246          FMG(2)=- FB(2)
0247          FMG(3)= - FB(3).
0248          FMG(4)= - FBC(7)
         C      COMPUTE FMG(5)
0249          FMG(5)=XK5*(X(L11) - X(3) )          + XC5*(XD(L11) - XD(3))
             1 - PREL
0250          IF(T.GE.TFIRE + PBORE.OR.IRND.EQ.0) GO TO 7050
0251          TNO=T - TFIRE
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      FMG(6)=XINTP(TNO,FBORX,FBORY)
      IF(IBOR.EQ.1) GO TO 7051
      IBOR=1
      PRINT 7053,T
 7053 FORMAT(' BORE FRICTION IS ON AT T=',F15.8)
      GO TO 7051
 7050 FMG(6)=0.0D0
      IF(IBOR.EQ.0) GO TO 7051
      IBOR=0
      PRINT 7052,T
 7052 FORMAT(' BORE FRICTION IS OFF AT T=',F15.8)
C       COMPUTE FMG(7)
 7051 IF(X(5).LT.0.0D0.OR.IHAM.EQ.0) GO TO 30
      FMG(7)=+XKHG*RH*DSIN(X(5)) + XCHG*RH*XD(5)*DCOS(X(5))
      IF(IFG(10).EQ.1) GO TO 31
      IFG(10)=1
      PRINT 567,T
  567 FORMAT(' HAMMER STRIKE OF THE MAIN GUN IS ON AT T=',F15.8)
      GO TO 31
   30 FMG(7)=0.0D0
      IF(IFG(10).EQ.0) GO TO 31
      IFG(10)=0
      PRINT 568,T
  568 FORMAT(' HAMMER STRIKE OF THE MAIN GUN IS OFF AT T=',F15.8)
C       COMPUTE FMG(8)      (ENTERS INTO CONSTRAINT EQN)
   31 FMG(8)=0.0D0
C       COMPUTE FMG(9)
        IF(DIFF5.LT.ALP1) GO TO 32
      FMG(9)=XK9*(-DIFF5+ ALP1) - XC9*DIFD5
      IF(FMG(9).GT.0.0D0) FMG(9)=0.0D0
      IF(IFG(11).EQ.1) GO TO 33
      IFG(11)=1
      PRINT 569,T
  569 FORMAT(' BUFFER STRIKES BACK PLATE AT T=',F15.8)
      PRINT 6666,XD(1),XD(2),XD(3)
 6666 FORMAT(/,' VELOCITIES PRIOR TO IMPACT',/,
     1' BLTD=',F15.8,' BLTCD=',F15.8,' XMGD=',F15.8,/)
      GO TO 33
   32 FMG( 9)=0.0D0
      IF(IFG(11).EQ.0) GO TO 33
      PRINT 570,T
  570 FORMAT(' BUFFER COMES OFF OF BACK PLATE AT T=',F15.8)
      PRINT 6667,XD(1),XD(2),XD(3)
 6667 FORMAT(/,' VELOCITIES AFTER IMPACT',/,
     1' BLTD=',F15.8,' BLTCD=',F15.8,' XMGD=',F15.8,/)
      IFG(11)=0
C ** SUM THE FORCES ON THE BOLT, BOLT CARRIER, AND GUN.
   33 FMG(10)=-FB(11)
      FMG(11)=-CON1*XMG*G
      FMG(12)=-FBC(10)
      FMG(13)=-FBC(11)
      FMG(14)=-(XMBUFF + XMWT)*G*CON2*DSIGN(1.D0,DIFD5)*XMUFF - XCUFF
     1*DIFD5
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0298          FMG(15)=-FR(9)
0299           FRUF(1)=-FBC(6)
0300          FBUF(2)=-FMG(9)
0301          FBUF(3)=-XKS5*(X(4) - X(N11)) - XC5*(XD(4) - XD(N11)) + PREL
0302          FBUF(4)=-CON1*(XMBUFF - .0014)*G
0303          FBUF(6)=-FMG(14)
0304          IF(I4DG.EQ.1) GO TO 7042
0305          FBUFF=-XMWT*XUBUF*DSIGN(1.D0,DIFD6)*G*CON2
0306          IF(DIFF6.GT.WTI) GO TO 40
0307          IF(DIFF6.LT.-SLACK+WTI) GO TO 41
0308          IF(IFG(16).EQ.0) GO TO 42
0309          PRINT 2222,T
0310     2222 FORMAT(' FORWARD OR REARWARD INTERNAL SPRING BUFFER FORCE IS OFF A
         1T T=',F15.8)
0311          IFG(16)=0
0312          GO TO 42
0313       40 FBUFF=FBUFF - XBFORW*(DIFF6 - WTI) - XCFORW*DIFD6
0314          IF(IFG(16).EQ.1) GO TO 42
0315          IFG(16)=1
0316          PRINT 3333,T
0317     3333 FORMAT(' FORWARD INTERNAL SPRING FORCE IS ON AT T=',F15.8)
0318          GO TO 42
0319       41 FBUFF=FBUFF - XBREAR*(DIFF6 + SLACK -WTI) - XCREAR*DIFD6
0320          IF(IFG(16).EQ.1) GO TO 42
0321          IFG(16)=1
0322          PRINT 4444, T
0323     4444 FORMAT(' REAR INTERNAL BUFFER SPRING IS ON AT T=',F15.8)
0324       42 XDD(6)=(-G*XMWT*CON1+FBUFF)/XMWT
0325          GO TO 4227
0326     7042 FBUFF=0.0D0
0327          DO 8 K1=1,5
0328          XDD(5 + K1)= - XUBUF*DSIGN(1.D0,XD(5  + K1) - XD(4))*G*CON2
0329          FBUFF=XMS(K1)*XDD(5 + K1) + FBUFF
0330        8 XDD(5 + K1)=XDD(5 + K1) - CON1*G
0331          DO 8056 K1=1,4
0332          IF(X(6 + K1) - X(5 + K1).GT.0.0D0) GO TO 8057
0333          GO TO 8059
0334     8057 XDD(6 + K1)=XDD(6 + K1) - (XKS(K1+1)*(X(6 + K1) - X(5 + K1)) +
         1XCS(K1 + 1)*(XD(6 + K1) -XD(5 + K1)))/XMS(K1+1)
0335          XDD(5 + K1)=XDD(5 + K1) + (XKS(K1+1)*(X(6 + K1) - X(5 + K1)) +
         1XCS(K1 + 1)*(XD(6 + K1) -XD(5 + K1)))/XMS(K1 )
0336          IF(IFG(22 + K1).EQ.1) GO TO 8056
0337          IFG(22 + K1)=1
0338           PRINT 8060,T,(IFG(I),I=22,27)
0339     8060 FORMAT(' NEW STATUS OF COLLISIONS OF BUFFER WTS. AT T=',F15.8,
         16I3)
0340          GO TO 8056
0341     8059 IF(IFG(22 + K1).EQ.0) GO TO 8056
0342          IFG(22 + K1)=0
0343           PRINT 8060,T,(IFG(I),I=22,27)
0344     8056 CONTINUE
0345          IF(DIFF6.GT.WTI) GO TO 8070
0346          IF(IFG(22).EQ.0) GO TO 8090
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0347            IFG(22)=0
0348             PRINT 8060,T,(IFG(I),I=22,27)
0349            GO TO 8090
0350       8070 FBUFF=FBUFF - XKS(1)*(DIFF6 - WTI) - XCS(1)*DIFD6
0351            XDD(6)=XDD(6) -(XKS(1)*(DIFF6 - WTI) + XCS(1)*DIFD6)/XMS(1)
0352            IF(IFG(22).EQ.1) GO TO 8090
0353            IFG(22)=1
0354             PRINT 8060,T,(IFG(I),I=22,27)
0355       8090 IF(X(10) - X(4).LT.WTI - SLACK) GO TO 8091
0356            IF(IFG(27).EQ.0) GO TO 4227
0357            IFG(27)=0
0358             PRINT 8060,T,(IFG(I),I=22,27)
0359            GO TO 4227
0360       8091 FBUFF=FBUFF -(X(10) - X(4) - WTI + SLACK)*XKS(6) -
               1 (XD(10) - XD(4))*XCS(6)
0361            XDD(10)=XDD(10) -((X(10) - X(4) - WTI + SLACK)*XKS(6) +
               1 (XD(10) - XD(4))*XCS(6))/XMS(5)
0362            IF(IFG(27).EQ.1) GO TO 4227
0363            IFG(27)=1
0364             PRINT 8060,T,(IFG(I),I=22,27)
0365       4227 SUM1=0.0D0
0366            SUM2=0.0D0
0367            SUM3=0.0D0
0368            SUM4=0.0D0
0369            FBUF(5)=-FBUFF
0370            XDD(L11)=( - FMG(5) - XK5*(X(L11) - X(L11 - 1))
               1- XC5*(XD(L11) - XD(L11 -1))-PREL)/XMDSP
0371            XDD(N11)=(- FBUF(3) - XK5*(X(N11) - X(N11 + 1))
               1-XC5*(XD(N11) - XD(N11 + 1))+PREL)/XMDSP
0372            DO 1952 I=N11M,L11M
0373       1952 XDD(I)=(XK5*(X(I + 1) - 2.*X(I) + X(I - 1))
               1+XC5*(XD(I + 1) - 2.*XD(I) + XD(I - 1)))/XMDSP
0374            DO 70 I=1,12
0375            SUM1=SUM1 + FB(I)
0376            SUM2=SUM2 + FBC(I)
0377         70 SUM3=SUM3 + FMG(I)
0378            DO 71 I=1,6
0379         71 SUM4=SUM4 + FBUF(I)
0380            SUM3=SUM3 + FMG(13) +FMG(14) + FMG(15)
0381            XDD(4)=SUM4/XMBUFF
0382            IF(IHAM.EQ.1.AND.IFLAG.EQ.1) GO TO 800
0383            GO TO 801
           C *** FOLLOWING COMPUTES THE ACCELERATION OF THE HAMMER WHEN
           C             THE GUN IS ABOUT TO FIRE
0384        800 XDD(5)=(TSPRIN - RH*FMG(7)*DCOS(X(5) + ALPHA))/XIM
0385            IF(IFG(12).EQ.1) GO TO 804
0386            PRINT 571,T
0387        571 FORMAT(' HAMMER IS CONTROLLED BY HAMMER SPRING AND MAIN GUN STOP A
               1T T=',F15.8)
0388            IFG(12)=1
0389            GO TO 804
0390        801 IF(ISEP.EQ.0  .OR.IFIRE.EQ.0.OR.ITEST.EQ.0.OR.DIFD3.LT.0.0D0.
               1OR.DIFF3.LT. 0.0D0) GO TO 803
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0391              IF(INIT.EQ.1) GO TO 804
0392              INIT=1
            C  ***** AFTER THE WEAPON HAS FIRED, THE HAMMER IS GIVEN AN INITIAL VELOCITY
            C       DETERMINED BY THE CONSTRAINT THE BOLT CARRIER HAS PUT ON THE HAMMER
            C  (I.E. ROTATIONAL VELOCITY)
0393              SEM=(RHHO*DSIN(ALHO) - DIFF3)/(RHHO*DCO)
0394              XD(5)=-(1./(1. + SEM*SFM))*DIFD3/(RHHO*DCO)
0395              X(5)=-ALHO + DATAN(SEM)
0396              IFG(12)=5
0397              PRINT 572,T
0398          572 FORMAT(' HAMMER BEGINS TO COCK AT T=',F15.8)
0399              GO TO 804
            C  ***** THE ROTATIONAL VELOCITY AND ACCELERATION OF THE HAMMER ARE ZERO EXCEPT
            C       WHEN THE WEAPON IS ABOUT TO BE FIRED, AND WHEN IT IS COCKED
0400          803 IF(INIT.EQ.1.AND.IFIRE.EQ.1) GO TO 830
0401              SEM=(RHHO*DSIN(ALHO) - DIFF3)/(RHHO*DCO)
0402              IF((ITEST.EQ.1.AND.(X(5).LT.THETO.OR.(XD(5).GT.0.0D0.AND.
                 1     -ALHO + DATAN(SEM ).LT.THETK.AND.X(5).LT.
                 1 THETK))).OR.IFG(12).EQ.2) GO TO 8509
0403              IF(INIT.EQ.0) GO TO 8509
0404              IF(X(5).LT.-ALHO + DATAN(SEM)) GO TO 5577
0405              FBC(8)=DCOS(X(5))*(X(5)+ ALHO - DATAN(SEM))*HK + DCOS(X(5))*HC
                 1*(  DIFD3/((1. + SEM*SFM)*RHHO*DCO) + XD(5))
0406              RHHU=DSQRT((RHHO*DSO - DIFF3)*(RHHO*DSO - DIFF3) + RHHO*RHHO*DCO
                 1*DCO)
0407              ALTEM=DARSIN(RHHO*DSO/RHHU)
0408              IF(IHD.EQ.1) GO TO 5555
0409              IHD=1
0410              PRINT 5578,T,FBC(8)
0411         5578 FORMAT(' HAMMER FORCE IS ON AT T=',F15.8,' FBC(8)=',F15.8)
0412              GO TO 5555
0413         5577 IHD=0
0414         5555 XDD(5)=(TSPRIN- RHHU*FBC(8)*DCOS(X(5) +ALTEM))/XIM
0415              IF(IFG(12).EQ.1) GO TO 804
0416              PRINT 691,T
0417          691 FORMAT(' HAMMER CONSTRAINT FORCE IS OFF AT T=',F15.8 )
0418              IFG(12)=1
0419              GO TO 804
0420         8509  XDD(5)=0.0D0
0421              XD(5)=0.0D0
0422              IF(IUNLO.EQ.1.AND.X(5).GT.THETO)X(5)=THETO
0423              IF(IFG(12).EQ.2) GO TO 804
0424              PRINT 573,T
0425          573 FORMAT(' HAMMER ROTATIONAL VELOCITY AND ACCELERATION ARE ZERO STAR
                 1TING AT T=',F15.8)
0426              IFG(12)=2
0427          804 IF(INIT.EQ.1.AND.IFIRE.EQ.1) GO TO 830
0428              SOMV=DCOS(X(5))*RO*XMHAM
0429              IF(DABS(XDD(5) + XD(5)).LT.1.D-10) SOMV=0.0D0
0430              XDD(3)=(-(RO*(XDD(5)*DCOS(X(5)) - XD(5)*XD(5)*DSIN(X(5)))*
                 1XMHAM + FBC(8)+FMG(7)) + SUM3)/(XMHAM + XMG - SOMV*SOMV/XIM)
0431              IF((DIFF2.GE..52083D-2.AND.DIFF2.LE.XLD.AND.IBRC.EQ.0).AND.
                 1(IFG(13).EQ.1.OR.ITEST.EQ.1)) GO TO 879
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0432        IF(IFG(13).EQ.1.AND.ITFST.EQ.0) GO TO 879
      C ****** IF THE GUN ISN'T BEING COCKED OR LOCKED UP THEN THE ACCELERATIONS OF
      C         THE BOLT AND BOLT CARRIER ARE COMPUTED HERE
0433        IF(IUNLO.EQ.0)XDD(3)=(XDD(3)*(XMHAM + XMG -SOMV*SOMV/XIM) + SUM1)/
           1(XMHAM + XMG + XMBV(IFLG) - SOMV*SOMV/XIM)
0434        XDD(1)=SUM1/XMBV(IFLG)
0435        XDD(2)=SUM2/XMBC
0436        IF(IUNLO.EQ.0)XDD(1)=XDD(3)
0437        IF(IFG(13).EQ.0) GO TO 875
0438        PRINT 575,T
0439    575 FORMAT(' WEAPON LOCKING FORCE IS OFF AT T=',F15.8)
0440        IFG(13)=0
0441        XMOM1=(XMG + XMBV(IFLG)+XMHAM)*XD(1) + XMBC*XD(2)
0442        XKEN=(XMG+XMBV(IFLG)+XMHAM)*XD(1)*XD(1)/2.+XMBC*XD(2)*XD(2)/2.+
           1 XIB*DERIV*DERIV*(XD(2)-XD(1))*(XD(2)-XD(1))/2.
0443        SA=XMG+XMBV(IFLG) +XMHAM
0444        SB=XMBC
0445        SC=(XMG+XMBV(IFLG)+XMHAM)/2.
0446        SD=XMBC/2.
0447        SE=0.0D0
0448        PRINT 2200,XD(1),XD(2)
0449        XD(2)=POSRT(SA,SB,SC,SD,SE,XMOM1,XKEN,1)
0450        XD(1)=(XMOM1 - SB*XD(2))/SA
0451        XD(3)=XD(1)
0452        PRINT 2300,XD(1),XD(2)
0453        GO TO 875
      C **** IF BEING LOCKED UP BUT NOT BEING COCKED THEN THE FOLLOWING EQUATIONS
      C       COMPUTE THE ACCELERATIONS OF THE BOLT AND BOLT CARRIER
0454    879 C1= - XIB*DERIV*DERIV
0455        IF(IUNLO.EQ.0) GO TO 1701
0456        TEMP=(XMBV(IFLG) - C1)*(XMBC - C1) - C1*C1
0457        XDD(1)=(SUM1*(XMBC - C1) - SUM2*C1) /TEMP
0458        XDD(2)=(-SUM1*C1 + (XMBV(IFLG) - C1)*SUM2)/TEMP
0459        GO TO 1700
0460   1701 TEMP=(XMBV(IFLG) + XMG + XMHAM - C1)*(XMBC - C1) - C1*C1
0461        TEMP=TEMP - SOMV*SOMV*(XMBC - C1)/XIM
0462        SUM1=SUM1 + XDD(3)*(XMHAM + XMG - SOMV*SOMV/XIM)
0463        XDD(1)=(SUM1*(XMBC - C1) - SUM2*C1) /TEMP
0464        XDD(2)=(-SUM1*C1 + (XMBV(IFLG) + XMG + XMHAM - C1 -SOMV*SOMV/XIM)
           1*SUM2)/TEMP
0465        XDD(3)=XDD(1)
      C****    CONSTRAINT FORCE ACTING ON THE BOLT DURING LOCKING
0466   1700 FB(7)= C1*(XDD(1) - XDD(2))
0467        FBC(5)=-FB(7)
0468        IF(IFG(13).EQ.1) GO TO 875
0469        PRINT 574,T
0470    574 FORMAT(' WEAPON LOCKING FORCE IS ON AT T=',F15.8)
0471        IFG(13)=1
0472        XMOM1=(XMG + XMBV(IFLG)+XMHAM)*XD(1) + XMBC*XD(2)
0473        IF(IUNLO.EQ.1)XMOM1=XMBV(IFLG)*XD(1) + XMBC*XD(2)
0474        XKEN=(XMG+XMBV(IFLG)+XMHAM)*XD(1)*XD(1)/2.+XMBC*XD(2)*XD(2)/2.
0475        IF(IUNLO.EQ.1)XKEN=XMBV(IFLG)*XD(1)*XD(1)/2. + XMBC*XD(2)*XD(2)/2.
0476        SA=XMG+XMBV(IFLG) +XMHAM
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0477        IF(IUNLO.EQ.1)SA=XMBV(IFLG)
0478        SB=XMBC
0479        SC=(XMG+XMRV(IFLG)+XMHAM)/2.
0480        IF(IUNLO.EQ.1)SC=XMBV(IFLG)/2.
0481        SD=XMBC/2.
0482        SE=XIR*DERIV*DERIV/2.
0483        PRINT 2200,XD(1),XD(2)
0484   2200 FORMAT(/,' VELOCITIES OF THE BOLT AND BOLT CARRIER PRIOR TO THE DI
           1SCONTINUITY OF THE CAM',/,' BLTD=',F15.6,' BLTCD=',F15.6)
0485        XD(2)=POSRT(SA,SB,SC,SD,SE,XMOM1,XKEN,1)
0486        XD(1)=(XMOM1 - SB*XD(2))/SA
0487        IF(IUNLO.EQ.0) XD(3)=XD(1)
0488        PRINT 2300,XD(1),XD(2)
0489   2300 FORMAT(/,' VELOCITIES OF THE BOLT AND BOLT CARRIER AFTER THE DISCO
           1NTINUITY OF THE CAM',/,' BLTD=',F15.6,' BLTCD=',F15.6)
0490        GO TO 875
      C  ***  FROM THIS POINT TO $$$$ , THE EQUATIONS ARE USED TO COMPUTE THE
      C       THE ACCELERATIONS OF THE BOLT AND THE BOLT CARRIER IF ONLY THE WEAPON IS
      C       BEING UNLOCKED
0491    830 RHHU=DSQRT((RHHO*DS0 - DIFF3)*(RHHO*DS0 - DIFF3) + RHHO*RHHO
           1*DC0*DC0)
0492        ALTEM=DARSIN(RHHO*DS0/RHHU)
0493        TEMP1=RHHU*DCOS(X(5) +ALTEM)
0494        SEM=(RHHO*DS0 - DIFF3)/(RHHO*DC0)
0495        THES=-1./((1. + SEM*SEM)*(RHHO*DC0))
0496        SEM1=(1. + SEM*SEM)*RHHO*DC0
0497        FDDP=-2.*SEM/(SEM1*SEM1)
0498        TEMP2=XIM*THES/TEMP1
0499        SOMV=DCOS(X(5))*RO*XMHAM
0500        IF(DABS(XDD(5) + XD(5)).LT.1.D-10) SOMV=0.0D0
0501        TT1=XMBC - TEMP2
0502        TT2=TEMP2 +SOMV/TEMP1
0503         TT3=SUM2 + TSPRIN/TEMP1 - FDDP*DIFD3*DIFD3*XIM/TEMP1
0504        TEMP3=RO*DCOS(X(5))
0505        V1=-XMHAM*TEMP3*THES + TEMP2
0506        V2=XMG + XMHAM*TEMP3*THES + XMHAM - TEMP2- SOMV*SOMV/XIM
           1 - SOMV/TEMP1
0507        V3=SUM3 + XMHAM*XD(5)*XD(5)*DSIN(X(5))*RO - TSPRIN/TEMP1 - FMG(7)
           1 + XIM*DIFD3*DIFD3*FDDP/TEMP1 - XMHAM*RO*DCOS(X(5))*FDDP*DIFD3*
           2DIFD3
0508        IF((DIFF2.GE..52083D-2.AND.DIFF2.LE.XLD.AND.IBRC.EQ.0).AND.
           1(IFG(14).EQ.1.OR.ITEST.EQ.1)) GO TO 831
0509        IF(IFG(14).EQ.1.AND.ITEST.EQ.0) GO TO 831
0510        IF(IUNLO.EQ.0) GO TO 1702
0511        GO TO 1703
0512   1702 DIVI=TT1*V2 - V1*TT2
0513        XGE   =(TT1*V3 - V1*TT3)/DIVI
0514        V2=V2 + XMRV(IFLG)
0515        V3=V3 + SUM1
0516   1703 XDD(1)=SUM1/XMBV(IFLG)
0517        XBE=XDD(1)
0518        DIVI=TT1*V2 - V1*TT2
0519        XDD(2)=(TT3 * V2 - TT2*V3)/DIVI
```

```
      XDD(3)=(TT1*V3 - V1*TT3)/DIVI
      IF(IUNLO.EQ.0)XDD(1)=XDD(3)
      IF(IFG(14).EQ.0) GO TO 877
      IFG(14)=0
      PRINT 596,T
  596 FORMAT(' WEAPON IS UNLOCKED AT T=',F15.8)
      XMOM1=(XMG + XMBV(IFLG)+XMHAM)*XD(1) + XMBC*XD(2)
      XKEN=(XMG+XMBV(IFLG)+XMHAM)*XD(1)*XD(1)/2.+XMBC*XD(2)*XD(2)/2.+
     1 XIB*DERIV*DERIV*(XD(2)-XD(1))*(XD(2)-XD(1))/2.
      SA=XMG+XMBV(IFLG) +XMHAM
      SB=XMBC
      SC=(XMG+XMBV(IFLG)+XMHAM)/2.
      SD=XMBC/2.
      SE=0.0D0
      PRINT 2200,XD(1),XD(2)
      XD(2)=POSRT(SA,SB,SC,SD,SE,XMOM1,XKEN,0)
      XD(1)=(XMOM1 - SB*XD(2))/SA
      XD(3)=XD(1)
      PRINT 2300,XD(1),XD(2)
C     $$$$
      GO TO 877
C     THESE EQUATIONS ARE USED TO COMPUTE THE ACCELERATIONS OF THE BOLT
C  AND BOLT CARRIER  IF THE WEAPON IS UNLOCKING (TO &&&&)
  831 C1=-XIB*DERIV*DERIV
 1705 CONX=1. - DSIGN(1.D0,FCONX)*CONB
      TT1=XMBC - C1 - TEMP2 -V1*(CONX - 1.)
      TT2=C1 + TT2  -(CONX -1.)*(V2 + XMARC)
      TT3=TT3 - V3*(CONX - 1.)
      V1=V1*CONX + C1
      V2=(V2 + XMARC)*CONX - XMARC + XMBV(IFLG) - C1
      V3=V3*CONX + SUM1
      DIVI=TT1*V2 - V1*TT2
      XDD(2)=(TT3 * V2 - TT2*V3)/DIVI
      XDD(3)=(TT1*V3 - V1*TT3)/DIVI
      XDD(1)=XDD(3)
C      &&&&
C      CONSTRAINT FORCE ACTING ON THE BOLT DURING UNLOCKING
 1704 FCONX=(-C1*(XDD(1) - XDD(2)) + (XMBV(IFLG) - XMARC)*XDD(1)
     1 - SUM1)/CONX
      FB(6)=FCONX*(CONX - 1.) + C1*(XDD(1)- XDD(2))
      FBC(3)=-FB(6)
      IF(IFG(14).EQ.1) GO TO 877
      IFG(14)=1
      PRINT 595,T
  595 FORMAT(' WEAPON BEGINS TO UNLOCK AT T=',F15.8)
      XMOM1=(XMG + XMBV(IFLG)+XMHAM)*XD(1) + XMBC*XD(2)
      XKEN=(XMG+XMBV(IFLG)+XMHAM)*XD(1)*XD(1)/2.+XMBC*XD(2)*XD(2)/2.
      SA=XMG+XMBV(IFLG) +XMHAM
      SB=XMBC
      SC=(XMG+XMBV(IFLG)+XMHAM)/2.
      SD=XMBC/2.
      SE=XIB*DERIV*DERIV/2.
      PRINT 2200,XD(1),XD(2)
```

```
            XD(2)=POSRT(SA,SB,SC,SD,SE,XMOM1,XKEN,0)
            XD(1)=(XMOM1 - SB*XD(2))/SA
            XD(3)=XD(1)
            PRINT 2300,XD(1),XD(2)
C  ****  CONSTRAINT FORCE ACTING BETWEEN THE THE BOLT CARRIER AND GUN
C         DURING COCKING OF THE HAMMER
  877 FBC(8)=(-XIM*THES*(XDD(3) - XDD(2)) + TSPRIN + XIM*2.*DIFD3*DIFD3
     1*SEM/(SEM1*SEM1) -SOMV*XDD(3))/(RHHU*DCOS(X(5) + ALTEM))
C  ***** COMPUTED ACCELERATION OF THE HAMMER . THIS PROVIDES A CHECK ON THE
C         CORRECT SOLVING OF THE SYSTEM OF ALGEBRAIC EQUATIONS NECESSARY TO GET THE
C         ACCELERATIONS
            XDD(5)=(TSPRIN - RHHU*FBC(8)*DCOS(X(5) +ALTEM))/XIM
C         CONSTRAINT FORCE ACTING AT THE HAMMER PIVOT POINT
  875 XDD(5)=XDD(5) - SOMV*XDD(3)/XIM
            FMG(8)=-(MHAM*RO*(XDD(5)*DCOS(X(5)) - XD(5)*XD(5)*DSIN(X(5))
     1 + XDD(3)/RO) + FBC(8) + FMG(7))
                          XDD(L1)=(P20*FMG(1) - R10*(XDD(3)* XMG
     1 - FMG(1)) - XKG* X(L1) - XCG*XD(L1))/XIG
 1450 IF(IUNLO.NE.0.OR.IFLAG.NE.0.OR.IFLG.EQ.3) GO TO 1775
            IF(IUNLO.EQ.0.AND.IFLAG.EQ.0.AND.(XGE-XBE)/(1./XMBV(IFLG)+1./XMG)
     1.GT.FSTIC)IUNLO=1
 1775 IF(IUNLO.EQ.1) GO TO 951
            GO TO 950
  951 IF(IFG(15).EQ.0) RETURN
            IFG(15)=0
            PRINT 598,T
  598 FORMAT(' BOLT AND MAIN GUN ARE TWO MASSES AT T=',F15.8)
            TBRC=T
            RETURN
  950 IF(IFG(15).EQ.1) RETURN
            IFG(15)=1
            PRINT 597,T
  597 FORMAT(' BOLT AND MAIN GUN ARE CONSIDERED AS ONE MASS AT T=',
     1 F15.8)
            RETURN
            ENTRY READIT
            NAMELIST/MAG/NC,NI
            NAMELIST/MAG1/      YE,YF,XKMAG,XFL,XUMAG1,XUMAG2,XUMAG3
     1 ,XPROJ,SPR,EPSOL,DIAC
C           XPROJ MUST BE LESS THAN XPUC1
            NAMELIST/MANP/TBFO,XMDSP
            READ (5,MANP)
            XMDSP=XMDSP/G
            PRINT 9560,TBFO,XMDSP
 9560 FORMAT(' TBFO',5X,'DELAY BETWEEN HAMMER STRIKE AND IGNITION',
     120X,F20.8,2X,'SEC',// ,' XMDSP',4X,'MASS OF THE DRIVE SPRING',
     136X,F20.8,2X,'SLUGS',/)
            READ (5,MAG)
            READ (5,MAG1)
            PREL=XK5*BETA
            TEMP=NMASS + 1
            XK5=XK5*TEMP
            XMDSP=XMDSP/(TEMP - 1.)
```

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0604          PRINT 9500,NC,YE,YF,NI,XKMAG
0605     9500 FORMAT(//,10X,' INPUT PARAMETERS FOR FEED MECHANISM',//,
             1' NC=',I2,' (NUMBER OF ROUNDS WHEN MAGAZINE IS FULL)',/,
             2' YE=',F10.5,'FT',' (HT. OF MAG. SPRING WHEN EMPTY)',/,
             3' YF=',F10.5,'FT',' (HT. OF MAG. SPRING WHEN FULL)',/,
             4' NI=',I2,' (INITIAL NUMBER OF ROUNDS IN THE MAGAZINE)',/,
             5' XKMAG=',F10.5,'LBS/FT',' (MAGAZINE SPRING CONSTANT)')
0606          PRINT 9501,XFL,XUMAG1,XUMAG2,XUMAG3,XPROJ,SPR,EPSOL,DIAC
0607     9501 FORMAT(' XFL=',F10.5,'FT',' (FREE LENGTH OF MAGAZINE SPRING)',/,
             1' XUMAG1=',F10.5,' (COFF. OF FRICTION BETWEEN B.C. AND ROUNDS)',/,
             2' XUMAG2=',F10.5,' (COFF. OF FRICTION BETWEEN MAG. AND ROUNDS)',/,
             3' XUMAG3=',F10.5,' (COFF. OF FRICTION BETWEEN ROUNDS)',/,' XPROJ='
             4        ,F10.5,'FT',' (DISTANCE BOLT CARRIER MOVES WHEN FRICTION B
             5ETWEEN B.C. AND ROUNDS IS OFF)',/,
             5' SPR=',F10.5,'LBS',' (A THIRD THE SPRING MASS AND THE FOLLOWER MA
             5SS)',/,
             6' EPSOL=',F10.5,' (EFFICIENCY OF MAGAZINE SPRING SYSTEM)',/,
             7' DIAC=',F10.5,'FT',' (DIAM. OF CASE)')
0608          L1=7 + NMASS
0609          IF(I4DG.EQ.1)L1=11 + NMASS
0610          L11=L1 - 1
0611          N11=7
0612          IF(I4DG.EQ.1)N11=11
0613          L11M=L11 - 1
0614          N11M=N11 + 1
0615          TEMP=NC
0616           DELSP=(YE - YF)/TEMP
0617          TEMP1=NI
0618          XME=TEMP1*(XMBUL + XMARC) + SPR/G
0619          XMG=TEMP1*(XMBUL + XMARC) + XMG
0620          YIHT=YE - DELSP*TEMP1
0621          SINM1=DELSP/DIAC
0622          COSM1=DSQRT(1.D0 - SINM1*SINM1)
0623          PRINT 9056,DELSP,YIHT,XME
0624     9056 FORMAT(/,10X,' COMPUTED PARAMETERS ASSOCIATED WITH THE MAG.',//,
             1' DELSP=',F10.5,'FT',' (SPACE PER ROUND)',/,
             2' YIHT=',F10.5,'FT',' (INITIAL HT. OF THE MAG. SPRING)',/,
             1' XME=',F10.5,'SLUGS',' (EFFECTIVE MASS ASSOC. WITH THE MAGAZINE)'
             1)
0625          CONF1=DCOS(ALH1)
0626          DS0=DSIN(ALH0)
0627          DC0=DCOS(ALH0)
0628          CONT=DCOS(ALPHA)
0629          CONB=2.*XMUB*(R2B*R2B + R1B*R2B + R1B*R1B)*DERIV/
             1((R1B + R2B)*3.)
0630          RETURN
0631          ENTRY READUM
0632          READ 1718,XMS,XKS,XCS
0633     1718 FORMAT(5F10.0,/,6F10.0,/,6F10.0)
0634          PRINT 1719,XMS,XKS,XCS
0635     1719 FORMAT(/,'       MASSES, SPRING CONSTANTS, AND DAMPING COEFS.',
             1/,' UNITS ARE SLUGS, LBS/FT, AND LBS-SEC/FT, RESPECTIVELY',
             1/,' THE FIRST MASS CORRESPONDS TO THE MASS NEAREST THE BOLT CARRIE
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                2R ' ,/,' XMS=',5F15.8,/,' XKS=',6F10.2,/,' XCS=',6F10.2)
0636             NAMELIST/ACCUR/R10,R20,XIG,XKG,XCG
0637             READ(5,ACCUR)
0638             PRINT 1720,R10,R20,XIG,XKG,XCG
0639        1720 FORMAT(//,15X,'PARAMETERS FOR ACCURACY',//,
                1' R10=',F15.8,'FT (BARREL OFFSET FROM THE C.G.)',/,
                2' R20=',F15.8,'FT (MOUNT FORCE OFFSET FROM THE C.G.)',/,
                2' XIG=',F15.8,'SLUG - FT**2 (MOMENT OF INERTIA OF THE GUN)',/,
                3' XKG=',F15.8,'FT-LBS/RAD (TORSIONAL SPRING CONSTANT)',/,
                3' XCG=',F15.8,'FT-LBS-SEC/RAD (DAMPING FOR TORSIONAL SPRING)')
0640             RETURN
0641             END
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0001          SUBROUTINE OUTP(T,N)
0002          IMPLICIT REAL*8(A-H,O-Z)
0003          REAL*8 FBMA(12)/12*0.0D0/, FBCMA(12)/12*0.0D0/,FMGMA(15)/15*0.0D0/
             1,FBUFMA(6)/6*0.0D0/
0004          REAL*4 ITMIN,ITMAX,ITX,ITY
0005          DATA IQUIT,K/0,1/,IDUMB/0/,IAIM/0/,IDPR/0/,FMCI/0.0D0/,
             1FMCA/0.0D0/
0006          COMMON/MAS/NMASS
0007          COMMON/LAIN/ITMIN,ITMAX,ITX,ITY
0008          COMMON/DIF/DIFF1,DIFF2,DIFF3,DIFF4,DIFF5,DIFF6
0009          COMMON/RUNKA/PRMT(4),X(21),XD(21),XDD(21)
0010          COMMON/MODES/IMODE,IFG(30),IPT,IHAM,IUNLO,ISEP,IBBC,INIT,IRND
             1,NROUN,ISR,IFREQ,IRX,IPICK,I4DG
0011          COMMON/ASTHT/PBRCX     ,PBRCY(50),TFIRE,CCL,XLAMCC,XMUCC,ACC,BOREA,
             1 XKHYP,XCHYP,CF4,XMU4,XMB,XLD,PBRL,PCAL,CARTF(50),CARTX,PCAR
0012          COMMON/ASIT/XBBC,XKBBC,XCBBC,DERIV,XMBUL,XMARC ,PUC,AREBOL,
             1 TDEL,XIB,G,TPORT,XCHCMG,XMURCG,EJCAR,FLEV              ,XKLBC,XCLBC
0013          COMMON/NUM/NBRCH,IFLAG,NCAV,IFLG,IFIRE
0014          COMMON/ASTHEE/PCAVT     ,PCAVY(50),FBORY(50),PBORE,FBORX
0015          COMMON/ER/XKBUFF,XCBUFF,XMBC,XMBV(3),XIM,RH,ALPHA,TSPRIN,
             1 RHH0,ALHO,RHH1,ALH1,HK,HC,
             1    DCOCK  ,XKMOUN,XCMOUN,XUHBC,XDHA,EXTC,EXTF,FDIS,FSTIC
             1,R1B,R2B,XMUB,FCONX
0016          COMMON/S/XK9,XC9,XK5,XC5,BETA,ALP1,THETO,XKHG,XCHG,XMHAM,XMG,
             1     XMBUFF,CON1,XPUC,XPUC1,RO,CON2,XMUFF,XCUFF
0017          COMMON/BUFF/XBFORW,XCFORW,XBREAR,XCREAR,SLACK,XUBUF,XMWT,WTI
0018          COMMON/PRT/FB(12),FBC(12),FMG(15),FBUF(6)
0019          COMMON/GRAP/TGR1,TGR2
0020          COMMON/MSSS/XMS(5),XKS(6),XCS(6)
0021          REAL*4 IMT(600),IBLT(600),IBLTD(600),IBLTC(600),IBLTCD(600),
             1IBUF(600),IBUFD(600),IBFW(600),IBFWD(600),IGUN(600),IGUND(600),
             2IBFWX(600),IROT(600),IROTD(600),IDRB(600),IDRG(600)
0022          REAL*4 IBLTDD(600),ICDD(600),IGDD(600),IBDD(600),IHDD(600),
             1IWDD(600),TAXI(600),FB6(600),FB7(600),FBC8(600)
0023          COMMON/PLOP/MTX
0024          INTEGER*2 MTX(51,111)
0025          INTEGER*2 CHR,CHR1,CHS(5)/'1','2','3','4','5'/
0026          INTEGER XCORD(4)/'TIME',' (SE','C)  ','   '/,YCORD(4),NAME(4)
0027          REAL*4          BUFMI,BUFMA,GUNMI,GUNMA,GUNDMI,GUNDMA,BFWMI,BFWMA,
             1ROTMI,ROTMA,ROTDMI,ROTDMA,FMTMI,FMTMA,BLTMI,BLTMA,
             2BLTDMI,BLTDMA,BLCDMI,BLCDMA              ,BUFDMI,BUFDMA,BBWMI,BBWMA,
             2BFWDMI,BFWDMA,BLDDMI,BLDDMA,CADDMI,CADDMA,GUDDMI,GUDDMA,BUDDMI,
             3BUDDMA,HDDMI,HDDMA,WDDMI,WDDMA,FENMI,FENMA
0028          IF(IMMAX.EQ.0) GO TO 5000
0029          DO 5001 I=1,12
0030          FBMA(I)=DMAX1(FBMA(I),DABS(FB(I)))
0031     5001 FBCMA(I)=DMAX1(FBCMA(I),DABS(FBC(I)))
0032          DO 5002 I=1,15
0033     5002 FMGMA(I)=DMAX1(FMGMA(I),DABS(FMG(I)))
0034          DO 5003 I=1,6
0035     5003 FBUFMA(I)=DMAX1(FBUFMA(I),DABS(FBUF(I)))
0036          FMCI=DMIN1(FCONX,FMCI)
0037          FMCA=DMAX1(FCONX,FMCA)
0038     5000 IF(IRND.EQ.1.AND.T.GE.TFIRE + TMUZ.AND.IAIM.EQ.0)
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```
      1 GO TO 4995
 4996 IF(IRND.GT.1.AND.IRND.GT.IDPR) GO TO 4899
      GO TO 4897
 4899 CALL ACCUM
      IDPR=IRND
      PRINT 1000,T,X,XD,XDD
       PRINT 1001,FB,FBC,FMG,FBUF,XMBV(IFLG),XMG
 4897 IF(IPT.NE.-1) GO TO 9270
      PRINT 1000,T,X,XD,XDD
       PRINT 1001,FB,FBC,FMG,FBUF,XMBV(IFLG),XMG
      REAL*4 IFB(12),EFB(12),IFBC(12),EFBC(12),IFMG(15),
     1EFMG(15),IFBUF(6),EFBUF(6)
      COMMON/ACKY/IFB,EFB,IFBC,EFBC,IFMG,EFMG,IFBUF,EFBUF
      DO 7880 I=1,12
      IFB(I)=FB(I)/2.
      EFB(I)=FB(I)*XD(1)/2.
      IFBC(I)=FBC(I)/2.
 7880 EFBC(I)=FBC(I)*XD(2)/2.
      DO 7881 I=1,15
      IFMG(I)=FMG(I)/2.
 7881 EFMG(I)=FMG(I)*XD(3)/2.
      DO 7882 I=1,6
      IFBUF(I)=FBUF(I)/2.
 7882 EFBUF(I)=FBUF(I)*XD(4)/2.
 9270 DO 7883 I=1,12
      IFB(I)=IFB(I) + FB(I)
      EFB(I)=EFB(I) + FB(I)*XD(1)
      IFBC(I)=IFBC(I) + FBC(I)
 7883 EFBC(I) = EFBC(I) + FBC(I)*XD(2)
      DO 7884 I=1,15
      IFMG(I)=IFMG(I) + FMG(I)
 7884 EFMG(I)=EFMG(I) + FMG(I)*XD(3)
      DO 7885 I=1,6
      IFBUF(I)=IFBUF(I) + FBUF(I)
 7885 EFBUF(I)=EFBUF(I) + FBUF(I)*XD(4)
      IF(DIFF3.GT.ALP1.AND.IDUMB.EQ.0) GO TO 7886
      GO TO 9200
 7886 IDUMB=1
      CALL ACCUM
 9200 IPT=IPT + 1
      IF(IMODE.EQ.1) GO TO 1600
      IF(MOD(IPT,ISR).NE.0)GO TO 1600
      IF(K.GT.600) GO TO 1600
      IDRB(K)=FBUF(3)
      IDRG(K)=FMG(5)
      IBUF(K)=X(4) - X(3)
      IGUN(K)=X(3)
      IGUND(K)=XD(3)
      IF(I4DG.EQ.1) GO TO 2000
      IBFWX(K)=X(6) - X(3)
      IBFWD(K)=XD(6)
      GO TO 2001
 2000 IBFWX(K)=(X(6)*XMS(1) + X(7)*XMS(2) + X(8)*XMS(3) +
     1X(9)*XMS(4) + X(10)*XMS(5))/XMWT - X(3)
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0090          IBFWD(K)=(XD(6)*XMS(1) + XD(7)*XMS(2) + XD(8)*XMS(3) +
             1 XD(9)*XMS(4) + XD(10)*XMS(5))/XMWT
0091     2001 IROT(K)=X(5)
0092          IF(IWSV.NE.1) GO TO 2042
0093          FB6(K)=FB(6)
0094          FB7(K)=FB(7)
0095          FBC8(K)=FBC(8)
0096     2042 IROTD(K)=XD(5)
0097          IMT(K)=FMG(1)
0098          IBLT(K)=DIFF1
0099          IBLTD(K)=XD(1)
0100          IBLTCD(K)=XD(2)
0101          IBLTC(K)=- DIFF3
0102          IBUFD(K)=XD(4)
0103          IBFW(K)=DIFF6
0104          IF(I4DG.NE.1) GO TO 1880
0105          ITX=T
0106          ITY=DIFF6
0107          CALL DETER(ITX,ITY,ITMIN,ITMAX,BBWMI,BBWMA,I,J)
0108          MIX(J,I)=CHS(1)
0109          ITY=X(7) - X(4) - .057
0110          CALL DETER(ITX,ITY,ITMIN,ITMAX,BBWMI,BBWMA,I,J)
0111          MIX(J,I)=CHS(2)
0112          ITY=X(8) - X(4) -.114
0113          CALL DETER(ITX,ITY,ITMIN,ITMAX,BBWMI,BBWMA,I,J)
0114          MTX(J,I)=CHS(3)
0115          ITY=X(9) - X(4) -.171
0116          CALL DETER(ITX,ITY,ITMIN,ITMAX,BBWMI,BBWMA,I,J)
0117          MTX(J,I)=CHS(4)
0118          ITY=X(10) - X(4) - .253666
0119          CALL DETER(ITX,ITY,ITMIN,ITMAX,BBWMI,BBWMA,I,J)
0120          MTX(J,I)=CHS(5)
0121     1880 IF(IOPT.EQ.1) GO TO 1922
0122          TAXI(K)=T
0123          K=K + 1
0124          GO TO 1600
0125     1922 IBLTDD(K)=XDD(1)
0126          ICDD(K)=XDD(2)
0127          IGDD(K)=XDD(3)
0128          IBDD(K)=XDD(4)
0129          IHDD(K)=XDD(5)
0130          IWDD(K)=XDD(6)
0131          TAXI(K)=T
0132          K=K + 1
0133     1600 IF(IRND.GT.1.AND.IRND.GT.IRX.AND.T.GE.TFIRE + TMUZ) GO TO 50
0134          IF(IMODE.EQ.0) GO TO 99
         C     /////////////     PRINT FORCES
0135          IF(MOD(IPT,IFREQ) .NE.0) GO TO 99
0136          PRINT 1000,T,X,XD,XDD
0137           PRINT 1001,FB,FBC,FMG,FBUF,XMBV(IFLG),XMG
0138     1000 FORMAT(' T=',E12.5,'X=',11E10.3,/,1X,10E12.5,/,
             1' XD=',11E11.4,/,1X,10E11.4,/,'XDD=',11E11.4,/,1X,10E11.4)
0139     1001 FORMAT(' FB=',6D12.5,/,6D13.5,/,
             1' FBC=',6D12.5,/,6D13.5,/,
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     2' FMG=',7D12.5,/,8D13.5,/,
     3' FBUF=',6D12.5,/,' XMR=',E12.5,' XMG=',E12.5,/)
C     /////////////     PRINT FORCES
   99 IF(T - TFIRE.GT..110D0) GO TO 100
      IF(IPICK.EQ.0.AND.T - TFIRE.GT..06D0) GO TO 201
      RETURN
  100 PRINT 101,T
  101 FORMAT(' TIME IS EQUAL TO ',F15.8,/,' /////////WEAPON HAS FAILED T
     1O FIRE AFTER 110 MS //////////')
      GO TO 200
  201 PRINT 203
  203 FORMAT(' ////////// WEAPON HAS FAILED TO RECOIL FAR ENOUGH TO PICK
     1UP ANOTHER ROUND //////////')
  200 IQUIT=1
      PRINT 1000,T,X,XD,XDD
       PRINT 1001,FB,FBC,FMG,FBUF,XMBV(IFLG),XMG
      GO TO 1500
   50 PRINT 1000,T,X,XD,XDD
       PRINT 1001,FB,FBC,FMG,FBUF,XMBV(IFLG),XMG
   51 FORMAT(' PROGRAM TERMINATED SINCE ROUND REQUEST IS MET')
 1500 PRINT 150
  150 FORMAT(//,' TERM',20X,'DEFINITION',15X,'UNITS',//,
     1 ' XMG',6X,'GUN DISPLACEMENT' ,24X,'FT',//
     2' XMGD',5X,'VELOCITY OF THE GUN',21X,'FT/SEC',//,
     3' BLT',6X,'BOLT DISPLACEMENT',23X,'FT',//,
     4' BLTD',5X,'BOLT VELOCITY',27X,'FT/SEC',//,
     5' BLTC',5X,'BOLT CARRIER DISPLACEMENT',15X,'FT',//,
     6' BLTCD',4X,'BOLT CARRIER VELOCITY',19X,'FT/SEC',/)
      PRINT 151
  151 FORMAT(' BUFF',5X,'BUFFER DISPLACEMENT',21X,'FT',//,
     1' BUFFD' ,4X,'BUFFER VELOCITY',25X,'FT/SEC',//,
     2 ' BUFW',5X,'INTERNAL BUFFER WT. DISPLACEMENT',8X,'FT',//
     3 ' BUFWD',4X,'INTERNAL BUFFER WT. VELOCITY',12X,'FT/SEC',//,
     4 ' HAMR',5X,'ROTATION OF THE HAMMER',18X,'RAD',//,
     5' HAMRD',4X,'ROTATIONAL VELOCITY OF THE HAMMER',7X,'RAD/SEC',//)
      PRINT 152
  152 FORMAT(' NOTE:BOLT, BOLT CARRIER, AND BUFFER DISPLACEMENTS ARE WIT
     1H RESPECT TO THE GUN AND NOT THE INERTIAL REFERENCE FRAME')
      IF(IMMAX.EQ.0) GO TO 5010
      PRINT 5011,FBMA,FBCMA,FMGMA,FBUFMA
 5011 FORMAT(//,' ABSOLUTE MAXIMUMS OF INDIVIDUAL FORCES',
     1/,' MAX FB=',6E12.5,/,6E12.5,/,' MAX FBC=',6E12.5,/,6E12.5,/,
     1' MAX FMG=',7E12.5,/,8E12.5,/,' MAX FBUF=',6E12.5)
       PRINT 9076,FMCI,FMCA
 9076 FORMAT(' FMCI=',E12.5,' FMCA=',E12.5)
 5010 K=K - 1
      IDUMB=0
 4995 IAIM=1
      TEMP=DSIN(X(L1) + PHIE)
      TEMP1=DCOS(X(L1) + PHIE)
      ZI=SQR1*TEMP
      ZDI=XD(L1)*SQR1*TEMP1 + DSIN(X(L1))*VPR
      YI=SQR1*TEMP1
      YDI=-XD(L1)*SQR1*TEMP + DCOS(X(L1))*VPR
```

```
            TEMP=RANGE - YI
            ZCAP=-.5*G*TEMP*TEMP/
           1(YDI*YDI) + ZDI*TEMP/YDI + ZI
            PRINT 2988,ZCAP,X(L1),XD(L1)
      2988  FORMAT(' ZCAP=',F15.8,'FT (DEFLECTION OF PROJECTILE)',/,
           1' X(L1)=',F15.8,'RAD (GUN ROTATION)',/,
           2' XD(L1)=',F15.8,'RAD/SEC (ROTATIONAL VELOCITY OF THE GUN)')
            IF(IRND.EQ.1.AND.IQUIT.NE.1) GO TO 4996
      2985  IF(IMODE.EQ.1) CALL EXIT
            IF(IWSV.NE.1) GO TO 2043
            PRINT 2045,(TAXI(I),FB6(I),FB7(I),FBC8(I),I=1,K)
      2045  FORMAT(' CONSTRAINT FORCES FB(6) FB(7) FBC(8)',/,(4E10.3,2X,4E10.3
           1,/))
      2043  IF(IPRI.NE.1) GO TO 1920
            PRINT 1917,(TAXI(I),IBLTC(I),I=1,K)
      1917  FORMAT(//,40X,'BOLT CARRIER DISPLACEMENT',/,(10F12.5,/))
            PRINT 1918,(TAXI(I),IBLTCD(I),I=1,K)
      1918  FORMAT(//,40X,'BOLT CARRIER VELOCITY',/,(10F12.5,/))
      1920  IF(I4DG.NE.1) GO TO 2073
            CALL PLOT2(ITMIN,ITMAX,BB*MI,BBWMA,XCORD,16HDISP. (FT)        ,
           1   16HBUFW-BUFF              ,0.0,0.0,16H                ,1,
           1CHR,CHR1)
      2073  CALL PLOTO(TAXI    ,ITMIN,ITMAX,0.0,0.0,XCORD,YCORD,NAME,CHR,
           1IMT,0.0,0.0,16H                 ,0,CHR,K)
            CALL PLOT1(IMT,1H*,FMTMI,FMTMA)
            CALL PLOT2(ITMIN,ITMAX,FMTMI,FMTMA,XCORD,16HFORCE (LBS)       ,
           1 16HMOUNT FORCE          ,0.0,0.0,1,16H                ,CHR,
           1CHR1)
            CALL PLOTO(TAXI    ,ITMIN,ITMAX,0.0,0.0,XCORD,YCORD,NAME,CHR,
           1IMT,0.0,0.0,16H                 ,0,CHR,K)
C           CALL PLOT1(IBLT,1H*,BLTMI,BLTMA)
C           CALL PLOT1(IBLTC,1H+,BLTMI,BLTMA)
C           CALL PLOT2(ITMIN,ITMAX,BLTMI,BLTMA,XCORD,16HDISP. (FT)        ,
C          1 16HBLT-* BLTC-+         ,0.0,0.0,16H                ,1,CHR,
C          1CHR1)
            CALL PLOT1(IDRB,1H*,FENMI,FENMA)
            CALL PLOT1(IDRG,1H+,FENMI,FENMA)
            CALL PLOT2(ITMIN,ITMAX,FENMI,FENMA,XCORD,16HFORCE (LBS)       ,
           1   16HFBUF-* FMG-+        ,0.0,0.0,16H
           2,1,CHR,CHR1)
            CALL PLOTO(TAXI    ,ITMIN,ITMAX,0.0,0.0,XCORD,YCORD,NAME,CHR,
           1IMT,0.0,0.0,16H                 ,0,CHR,K)
            CALL PLOT1(IBLTD,1H*,BLTDMI,BLTDMA)
            CALL PLOT1(IBLT,1H+,BLTMI,BLTMA)
            CALL PLOT2(ITMIN,ITMAX,BLTDMI,BLTDMA,XCORD,16HVELOC. (FT/SEC)   ,
           1   16HBLTD-* BLT-+        ,BLTMI,BLTMA,16HDISP. (FT) (+)   ,
           1 2,'*','+')
            CALL PLOTO(TAXI    ,ITMIN,ITMAX,0.0,0.0,XCORD,YCORD,NAME,CHR,
           1IMT,0.0,0.0,16H                 ,0,CHR,K)
            CALL PLOT1(IBLTCD,1H*,BLCDMI,BLCDMA)
            CALL PLOT1(IBLTC,1H+,BLTMI,BLTMA)
            CALL PLOT2(ITMIN,ITMAX,BLCDMI,BLCDMA,XCORD,16HVELOC. (FT/SEC)   ,
           1  16HBLTCD-* BLTC-+              ,BLTMI,BLTMA,16HDISP. (FT) (+)   ,
           12,'*','+')
```

```
0206          CALL PLOTO(TAXI    ,ITMIN,ITMAX,0.0,0.0,XCORD,YCORD,NAME,CHR,
             1IMT,0.0,0.0,16H                        ,0,CHR,K)
0207          CALL PLOT1(IBUFD,1H*,BUFDMI,BUFDMA)
0208           CALL PLOT1(IBUF,1H+,BUFMI,BUFMA)
0209          CALL PLOT2(ITMIN,ITMAX,BUFDMI,BUFDMA,XCORD,16HVELOC. (FT/SEC)    ,
             1  16HBUFFD-* BUFF-+      ,BUFMI,BUFMA,16HDISP. (FT) (+)        ,2,
             2'*','+')
0210          CALL PLOTO(TAXI    ,ITMIN,ITMAX,0.0,0.0,XCORD,YCORD,NAME,CHR,
             1IMT,0.0,0.0,16H                        ,0,CHR,K)
0211          CALL PLOT1(IBFWD,1H*,BFWDMI,BFWDMA)
0212          CALL PLOT1(IBFWX,1H+,BFWMI,BFWMA)
0213          CALL PLOT2(ITMIN,ITMAX,BFWDMI,BFWDMA,XCORD,16HVELOC. (FT/SEC)    ,
             1  16HBUFWD-* BUFW-+      ,BFWMI,BFWMA,16HDISP. (FT) (+)        ,2,
             1'*','+')
0214          CALL PLOTO(TAXI    ,ITMIN,ITMAX,0.0,0.0,XCORD,YCORD,NAME,CHR,
             1IMT,0.0,0.0,16H                        ,0,CHR,K)
0215          CALL PLOT1(IGUN,'+',GUNMI,GUNMA)
0216          CALL PLOT1(IGUND,'*',GUNDMI,GUNDMA)
0217           CALL PLOT2(ITMIN,ITMAX,GUNDMI,GUNDMA,XCORD,16HVELOC. (FT/SEC)    ,
             116HXMGD-* XMG-+         ,GUNMI,GUNMA,16HDISP. (FT) (+)        ,
             2  2,'*','+')
0218          CALL PLOTO(TAXI    ,ITMIN,ITMAX,0.0,0.0,XCORD,YCORD,NAME,CHR,
             1IMT,0.0,0.0,16H                        ,0,CHR,K)
0219          CALL PLOT1(IROT,'+',ROTMI,ROTMA)
0220           CALL PLOT1(IROTD,'*',ROTDMI,ROTDMA)
0221          CALL PLOT2(ITMIN,ITMAX,ROTDMI,ROTDMA,XCORD,16HHAMRD (RAD/SEC)    ,
             1  16HHAMRD-* HAMR-+        ,ROTMI,ROTMA,16HHAMR (RAD) (+)        ,
             2 2,'*','+')
0222          IF(I4DG.EQ.1) GO TO 2700
0223          CALL PLOTO(TAXI    ,ITMIN,ITMAX,0.0,0.0,XCORD,YCORD,NAME,CHR,
             1IMT,0.0,0.0,16H                        ,0,CHR,K)
0224          CALL PLOT1(IBFW,1H*,BBWMI,BBWMA)
0225          CALL PLOT2(ITMIN,ITMAX,BBWMI,BBWMA,XCORD,16HDISP. (FT)            ,
             1   16HBUFW-BUFF               ,0.0,0.0,16H                       ,1,
             1CHR,CHR1)
0226     2700 IF(IOPT.NE.1) GO TO 1865
0227          CALL PLOTO(TAXI    ,ITMIN,ITMAX,0.0,0.0,XCORD,YCORD,NAME,CHR,
             1IMT,0.0,0.0,16H                        ,0,CHR,K)
0228          CALL MINMAX(IBLTDD,BLDDMI,BLDDMA,K)
0229          CALL PLOT1(IBLTDD,'*',BLDDMI,BLDDMA)
0230          CALL PLOT2(ITMIN,ITMAX,BLDDMI,BLDDMA,XCORD,16HACC. (FT/SEC**2)    ,
             116HBLTDD-*            ,0.0,0.0,16H                 ,1,CHR,CHR1)
0231          CALL PLOTO(TAXI    ,ITMIN,ITMAX,0.0,0.0,XCORD,YCORD,NAME,CHR,
             1IMT,0.0,0.0,16H                        ,0,CHR,K)
0232          CALL MINMAX(ICDD   ,CADDMI,CADDMA,K)
0233          CALL PLOT1(ICDD   ,'*',CADDMI,CADDMA)
0234          CALL PLOT2(ITMIN,ITMAX,CADDMI,CADDMA,XCORD,16HACC. (FT/SEC**2)    ,
             116HBLTCDD-*           ,0.0,0.0,16H                 ,1,CHR,CHR1)
0235          CALL PLOTO(TAXI    ,ITMIN,ITMAX,0.0,0.0,XCORD,YCORD,NAME,CHR,
             1IMT,0.0,0.0,16H                        ,0,CHR,K)
0236          CALL MINMAX(IGDD   ,GUDDMI,GUDDMA,K)
0237          CALL PLOT1(IGDD,'*',GUDDMI,GUDDMA)
0238          CALL PLOT2(ITMIN,ITMAX,GUDDMI,GUDDMA,XCORD,16HACC. (FT/SEC**2)    ,
             116HXMGDD-*            ,0.0,0.0,16H                 ,1,CHR,CHR1)
```

```
0239          CALL PLOTO(TAXI    ,ITMIN,ITMAX,0.0,0.0,XCORD,YCORD,NAME,CHR,
             1IMT,0.0,0.0,16H                         ,0,CHR,K)
0240          CALL MINMAX(IBDD   ,BUDDMI,BUDDMA,K)
0241          CALL PLOT1(IBDD,'*',BUDDMI,BUDDMA)
0242          CALL PLOT2(ITMIN,ITMAX,BUDDMI,BUDDMA,XCORD,16HACC. (FT/SEC**2)    ,
             116HBUFFDD-*          ,0.0,0.0,16H                ,1,CHR,CHR1)
0243          CALL PLOTO(TAXI    ,ITMIN,ITMAX,0.0,0.0,XCORD,YCORD,NAME,CHR,
             1IMT,0.0,0.0,16H                         ,0,CHR,K)
0244          CALL MINMAX(IHDD   ,HDDMI ,HDDMA ,K)
0245          CALL PLOT1(IHDD,'*',HDDMI,HDDMA)
0246          CALL PLOT2(ITMIN,ITMAX,HDDMI ,HDDMA ,XCORD,16HACC. (FT/SEC**2)    ,
             116HHAMPDD-*          ,0.0,0.0,16H                ,1,CHR,CHR1)
0247          CALL PLOTO(TAXI    ,ITMIN,ITMAX,0.0,0.0,XCORD,YCORD,NAME,CHR,
             1IMT,0.0,0.0,16H                         ,0,CHR,K)
0248          CALL MINMAX(IWDD   ,WDDMI ,WDDMA ,K)
0249          CALL PLOT1(IWDD,'*',WDDMI,WDDMA)
0250          CALL PLOT2(ITMIN,ITMAX,WDDMI ,WDDMA ,XCORD,16HACC. (FT/SEC**2)    ,
             116HBUFWDD-*          ,0.0,0.0,16H                ,1,CHR,CHR1)
0251     1865 PRINT 18
0252       18 FORMAT('1')
0253          IF(IRND.LE.NROUN) GO TO 700
0254          PRINT 51
0255          CALL EXIT
0256      700 IRX=IRND
0257          K=1
0258          ITMIN=T
0259          ITMAX=ITMIN + TGR2
0260          IF(IQUIT.EQ.1) CALL EXIT
0261          IF(I4DG.NE.1) GO TO 2074
0262          CALL PLOTO(TAXI    ,ITMIN,ITMAX,0.0,0.0,XCORD,YCORD,NAME,CHR,
             1IMT,0.0,0.0,16H                         ,0,CHR,K)
0263     2074 RETURN
0264            ENTRY READIN
        C       BUFMI,BUFMA       EST. MAX. AND MIN. VALUES FOR BUFFER DISPLACEMENT
        C       GUNMI,GUNMA       EST. MAX. AND MIN. VALUES FOR GUN DISPLACEMENT
        C       GUNDMI,GUNDMA       EST. MAX. AND MIN. VALUES FOR GUN VELOCITIES
        C       BFWMI,BFWMA        EST. MAX AND MIN. VALUES FOR BUFFER WEIGHT DISPL.
        C       (WITH RESPECT TO THE GUN)
        C       ROTMI,ROTMA       MAX. AND MIN. VALUES OF ROTATION
        C       ROTDMI,ROTDMA,       MAX. AND MIN. VALUES OF ROTATIONAL VELOCITY
        C       FMTMI,FMTMA       MAX. AND MIN. VALUES OF THE MOUNT FORCE
        C       BLTMI,BLTMA       MAX. AND MIN. VALUES OF THE BOLT DISPL.
        C       BLCDMI,BLCDMA       MAX. AND MIN. VALUES OF THE BOLT CARRIER VELOCITY
        C       BUFDMI,BUFDMA       MAX. AND MIN. VALUES OF THE BUFFER VELOCITY
        C       BBWMI,BBWMA       MAX. AND MIN. VALUES OF THE BUFFER WT. WITH RESPECT TO
        C       THE BUFFER
        C       BFWDMI,BFWDMA       MAX. AND MIN. VALUES OF THE BUFFER WT. VELOCITY
        C       FENMI,FENMA       EST. MAX AND MIN VALUES FOR DRIVE SPRING CONSTANT
0265          NAMELIST/INPT6/BUFMI,BUFMA,GUNMI,GUNMA,GUNDMI,GUNDMA,BFWMI,BFWMA,
             1ROTMI,ROTMA,ROTDMI,ROTDMA,FMTMI,FMTMA,BLTMI,BLTMA,
             2BLTDMI,BLTDMA,BLCDMI,BLCDMA,           BUFDMI,BUFDMA,BBWMI,BBWMA,
             2BFWDMI,BFWDMA,FENMI,FENMA
0266          READ(5,INPT6)
0267          L1=7 +NMASS
```

```
0268              IF(I4DG.EQ.1)   L1=11 +NMASS
           C       FOR PLOTTING PURPOSES MAX AND MIN ACCELERATIONS ARE COMPUTED
           C       BLDDMI,BLDDMA       BOLT MAXIMUM AND MINIMUM ACCELERATIONS
           C       CADDMI,CADDMA        BOLT CARRIER MAX AND MIN ACCELERATIONS
           C       GUDDMI,GUDDMA        GUN MAXIMUM AND MINIMUM ACCELERATIONS
           C       BUDDMI,BUDDMA        BUFFER MAXIMUM AND MINIMUM ACCELERATIONS
           C       HDDMI,HDDMA,       HAMMER MAX AND MIN ACCELERATIONS
           C       WDDMI,WDDMA       BUFFER *T. MAX AND MIN ACCELERATIONS
           C       IF IPRI IS EQUAL TO ONE THEN THE BOLT CARRIER VELOCITY AND DISPLACEMENT
           C        WIL BE PRINTED
0269              NAMELIST/INPT7/IOPT,IPRI,IWSV,IMMAX
           C       IF IWSV IS ONE THEN THE CONSTRAINT FORCES WILL BE PRINTED
           C       IF IOPT EQUAL ONE THEN GRAPH THE ACCELERATIONS
0270              READ(5,INPT7)
0271              IF(I4DG.EQ.1)BBWMI=BBWMI - .2536666
0272              RETURN
0273              ENTRY INITAL
0274              CALL PLOT0(TAXI    ,ITMIN,ITMAX,0.0,0.0,XCORD,YCORD,NAME,CHR,
                 1IMT,0.0,0.0,16H                       ,0,CHR,K)
0275              NAMELIST/ACCUR1/XLB,XALPH,RANGE,VPR,TMUZ
0276              READ(5,ACCUR1)
0277              PRINT 1781,XLB,XALPH,RANGE,VPR,TMUZ
0278         1781 FORMAT(' XLB=',F15.8,'FT (PIVOT POINT TO BARREL END)',/,
                 1' XALPH=',F15.8,'FT (BARREL OFFSET)',/,
                 2' RANGE=',F15.8,'FT (TARGET RANGE)',
                 4/,' VPR=',F15.8,'FT/SEC (MUZZLE VELOCITY)',/,
                 1' TMUZ=',F15.8,'SEC (TIME TO REACH MUZZLE)')
0279              SQR1=DSQRT(XLB*XLB + XALPH*XALPH)
0280              PHIE=DARSIN(XALPH/SQR1)
0281              RETURN
0282              END
```

```
0001            SURROUTINE RUNGE(N,FCT,OUTP)
0002            IMPLICIT REAL*8(A-H,O-Z)
          C      SOLVES A SYSTEM OF SECOND ORDER DIFF EQS.
          C      PRMT(1)        INITIAL TIME
          C      PRMT(2)        FINAL TIME
          C      PRMT(3)        TIME INCREMENT
          C      PRMT(4)        STOPS INTEGRATING IF THIS TERM IS NEGATIVE
          C      ITEST        ITEST IS ONE THEN A NEW TIME INCREMENT IS STARTING
          C      AND IF ITEST IS ZERO THEN IN THE MIDDLE OF A TIME INCREMENT
          C      X,XD       CONTAINS INITIAL VALUES BEFORE COMING INTO THE ROUTINE
          C      XDD       SECOND DERIVATIVE TERM
          C      FCT       SUBROUTINE TO EVALUATE THE SECOND DERIVATIVES
          C      OUTP        SUBROUTINE TO PRINT
0003            COMMON/RUNKA/PRMT(4),X(21),XD(21),XDD(21)
0004            DIMENSION AK1(21),AK2(21),AK3(21),AK4(21)
0005            DIMENSION TX(21),TXD(21)
          C      TIME INCREMENT CAN BE CHANGED BY JUST CHANGING DELT IN ROUTINE
          C      FCT AND COMPUTING THE NEW VALUE FOR SUM
0006            COMMON/CNTRL/DELT,SUM
0007            FINAL=PRMT(2)
0008            DELT=PRMT(3)
0009            T=PRMT(1)
0010            PRMT(4)=1.0D0
0011            SUM=DELT*.5D0
0012       1000 CALL FCT(T,X,XD,XDD,1)
0013            CALL OUTP(T,N)
0014            IF(T.GE.FINAL.OR.PRMT(4).LT.0.0D0) RETURN
0015            DO 1 I=1,N
0016            AK1(I)=DELT*XDD(I)
0017            TX(I)=X(I)+.5D0*DELT*XD(I) + DELT*AK1(I)*.125D0
0018          1 TXD(I)=XD(I) + .5D0*AK1(I)
0019            T=T + SUM
0020            CALL FCT(T,TX,TXD,XDD,0)
0021            DO 2 I=1,N
0022            AK2(I)=DELT*XDD(I)
0023          2 TXD(I)=XD(I) + .5D0*AK2(I)
0024            CALL FCT(T,TX,TXD,XDD,0)
0025            DO 3 I=1,N
0026            AK3(I)=DELT*XDD(I)
0027            TX(I)=X(I) + DELT*XD(I) + DELT*AK3(I)*.5D0
0028          3 TXD(I)=XD(I) + AK3(I)
0029            T=T + SUM
0030            CALL FCT(T,TX,TXD,XDD,0)
0031            DO 4 I=1,N
0032            AK4(I)=DELT*XDD(I)
0033            X(I)=X(I) + DELT*(XD(I) + .1666666666666667D0*(AK1(I)
               1 + AK2(I) + AK3(I)))
0034          4 XD(I)=XD(I) + (AK1(I) + 2.D0*(AK2(I) + AK3(I)) + AK4(I))
               1* .1666666666666667D0
0035            GO TO 1000
0036            END
```

```
      SUBROUTINE DETER(X,Y,XMIN,XMAX,YMIN,YMAX,I,J)
      I=(X     - XMIN)*110./(XMAX - XMIN) + 1.5
      IF(I.LT.1)I=1
      IF(I.GT.111)I=111
      J=(Y          - YMIN)*50./(YMAX - YMIN) + 1.5
      IF(J.LT.1)J=1
      IF(J.GT.51)J=51
      RETURN
      END
```

```
FORTRAN IV G LEVEL  20                XINTP              DATE = 72245           11/55/11              PAGE 0001

 0001                FUNCTION XINTP(A,X,Y)
 0002                IMPLICIT REAL*8(A-H,O-Z)
 0003                DIMENSION Y(50)
            C         ASSUMES EQUALLY SPACED POINTS
            C         X-COORDINATE STARTS AT ZERO WITH STEP SIZE OF X
 0004                I=A/X
 0005                XI=I
 0006                I=I + 1
 0007                XL = XI*X
 0008                XINTP=Y(I) + (Y(I + 1) - Y(I))*(A - XL  )/X
 0009                RETURN
 0010                END
```

```
0001        FUNCTION POSRT(SA,SB,SC,SD,SE,XMOM1,XKEN,ITE)
0002        IMPLICIT REAL*8(A-H,O-Z)
0003        CA=SC*SB*SB/(SA*SA)+SE*(SB/SA + 1.)*(SB/SA+1.) +SD
0004        CB=-2.*XMOM1*(SC*SB/(SA*SA) +  SE*(SB/SA+1.)/SA)
0005        CC=-XKEN + XMOM1*XMOM1*(SC+SE)/(SA*SA)
0006        IF(ITE.EQ.0)
           1POSRT=(-CB-DSQRT(CB*CB - 4.*CA*CC))/(2.*CA)
0007        IF(ITE.EQ.1)
           1POSRT=(-CB+DSQRT(CB*CB - 4.*CA*CC))/(2.*CA)
0008        RETURN
0009        END
```

```
      SUBROUTINE DETER(X,Y,XMIN,XMAX,YMIN,YMAX,I,J)
      I=(X     - XMIN)*110./(XMAX - XMIN) + 1.5
      IF(I.LT.1)I=1
      IF(I.GT.111)I=111
      J=(Y          - YMIN)*50./(YMAX - YMIN) + 1.5
      IF(J.LT.1)J=1
      IF(J.GT.51)J=51
      RETURN
      END
```

```
      SUBROUTINE ACCUM
      IMPLICIT REAL*8(A-H,O-Z)
      REAL*4 IFB(12),EFB(12),IFBC(12),EFBC(12),IFMG(15),
     1EFMG(15),IFBUF(6),EFBUF(6)
      COMMON/ACKY/IFB,EFB,IFBC,EFBC,IFMG,EFMG,IFBUF,EFBUF
      COMMON/RUNKA/PRMT(4),X(11),XD(11),XDD(11)
      COMMON/PRT/FB(12),FBC(12),FMG(15),FBUF(6)
      DIMENSION SUM(15)
      DO 1 I=1,12
    1 SUM(I)=(IFB(I) - FB(I)/2.)*PRMT(3)
      PRINT 2,(SUM(I),I=1,12)
    2 FORMAT(' BOLT IMPULSES',6F15.8,/,6F15.8)
       DO 3 I=1,12
    3 SUM(I)=(EFB(I) - FB(I)*XD(1)/2.)*PRMT(3)
      PRINT 4,(SUM(I),I=1,12)
    4 FORMAT(' BOLT ENERGY',6F15.8,/,6F15.8)
      DO 5 I=1,12
    5 SUM(I)=(IFBC(I) - FBC(I )/2.)*PRMT(3)
      PRINT 6,(SUM(I),I=1,12)
    6 FORMAT(' BOLT CARRIER IMPULSES',6F15.8,/,6F15.8)
      DO 7 I=1,12
    7 SUM(I)=(EFBC(I) - XD(2)*FBC(I)/2.)*PRMT(3)
      PRINT 8,(SUM(I),I=1,12)
    8  FORMAT(' BOLT CARRIER ENERGY',6F15.8,/,6F15.8)
      DO 9 I=1,15
    9 SUM(I)=(IFMG(I) - FMG(I)/2.)*PRMT(3)
      PRINT 10,(SUM(I),I=1,15)
   10 FORMAT(' GUN IMPULSE',7F14.8,/,8F15.8)
      DO 11 I=1,15
   11 SUM(I)=(EFMG(I) - FMG(I)*XD(3)/2.)*PRMT(3)
      PRINT 12,(SUM(I),I=1,15)
   12 FORMAT(' GUN ENERGY',7F14.8,/,8F15.8)
      DO 13 I=1,6
   13 SUM(I)=(IFBUF(I) - FBUF(I)/2.)*PRMT(3)
      PRINT 14,(SUM(I),I=1,6)
   14 FORMAT(' BUFFER IMPULSE',6F15.8)
      DO 15 I=1,6
   15 SUM(I)=(EFBUF(I) - XD(4)*FBUF(I)/2.)*PRMT(3)
      PRINT 16,(SUM(I),I=1,6)
   16 FORMAT(' BUFFER ENERGY',6F15.8)
      RETURN
      END
```

```
      SUBROUTINE PLOTO(X   ,XMIN,XMAX,YMIN,YMAX,XCORD,YCORD,
     1 NAME,CHR,ISTORE,ZMIN,ZMAX,ZCORD,ITEST,CHR1,NPTS)
      COMMON/PLOP/MTX
      INTEGER*2 MTX(51,111),CHR,B/' '/,CHR1
      INTEGER XCORD(4),YCORD(4),NAME(4),ZCORD(4)
      REAL*4 ISTORE(600),X(600)
      DO 1 I=1,51
      DO 1 J=1,111
    1 MTX(I,J)=B
      RETURN
C     ///////////////
      ENTRY PLOT1(ISTORE,CHR,YMIN,YMAX)
C     ///////////////
      DO 1772 K=1,NPTS
      I=(X(K) - XMIN)*110./(XMAX - XMIN) + 1.5
      IF(I.LT.1)I=1
      IF(I.GT.111)I=111
      J=(ISTORE(K) - YMIN)*50./(YMAX - YMIN) + 1.5
      IF(J.LT.1)J=1
      IF(J.GT.51)J=51
 1772 MTX(J,I)=CHR
      RETURN
C     ////////////////////////////////////
      ENTRY PLOT2(XMIN,XMAX,YMIN,YMAX,XCORD,YCORD,NAME,ZMIN,ZMAX,ZCORD,
     1 ITEST,CHR,CHR1)
C     ////////////////////////////////////
      DIMENSION XVAR(12)
      TEMP=ALOG10(YMAX-YMIN)
      IF(TEMP.LT.0.0)TEMP=TEMP-1.
      IFY=TEMP
      TEMP=ALOG10(XMAX-XMIN)
      IF(TEMP.LT.0.0)TEMP=TEMP-1.
      IFX=TEMP
      Y1=YMAX/10.**IFY
      DELY=(YMAX-YMIN)/10.**(IFY+1)
      IF(ITEST.NE.2) GO TO 35
      TEMP=ALOG10(ZMAX-ZMIN)
      IF(TEMP.LT.0.0)TEMP=TEMP-1.
      IFZ=TEMP
      DELZ=(ZMAX-ZMIN)/10.**(IFZ+1)
      Z1=ZMAX/10.**IFZ
   35 IF(ITEST.NE.2) GO TO 36
      PRINT 5,CHR,CHR1,(NAME(I),I=1,4)
    5 FORMAT('1'/' ','CHR(',A1,')','   CHR(',A1,')',40X,4A4)
      GO TO 38
   36 PRINT 47,(NAME(I),I=1,4)
   47 FORMAT('1'/' ',55X,4A4)
   38 DO 13 L=1,11
      N0=56-5*L
      N1=N0-26
      IF(ITEST.NE.2) GO TO 27
      PRINT 28,Y1,Z1
   28 FORMAT(' ',F6.2,' **',F6.2)
      Z1=Z1-DELZ
```

```
      GO TO 26
   27 PRINT 6,Y1
    6 FORMAT(' ',9X,F6.2)
   26 Y1=Y1-DELY
      PRINT 7
    7 FORMAT('+',16X,11('|----------'),'|')
      PRINT 8,(MTX(NO,J),J=1,111)
    8 FORMAT('+',16X,111A1)
      IF(L.EQ.11) GO TO 13
      DO 12 K=1,4
      PRINT 9
    9 FORMAT(' ',16X,11('|          '),'|')
      IF(ITEST.EQ.2) GO TO 30
      IF(NO-K.EQ.24) PRINT 10,(YCORD(I),I=1,4)
   10 FORMAT('+',4A4)
      IF(NO-K.EQ.23) PRINT 11,IFY
   11 FORMAT('+SCALE 10**',I3)
      GO TO 12
   30 IF(NO-K.EQ.29)PRINT 10,YCORD
      IF(NO-K.EQ.28)PRINT 11,IFY
      IF(NO-K.EQ.24)PRINT 10,ZCORD
      IF(NO-K.EQ.23)PRINT 11,IFZ
   12 PRINT 8,(MTX(NO-K,J),J=1,111)
   13 CONTINUE
      PRINT 14
   14 FORMAT(' ',16X,11('+..........'),'+')
      XVAR(1)=XMIN/10.**IFX
      DELY=(XMAX - XMIN)/(11.*10.**IFX)
      DO 19 I=2,12
   19 XVAR(I)=XVAR(I-1)+DELY
      PRINT 15,XVAR
   15 FORMAT(' ',13X,F6.2,11(4X,F6.2))
      PRINT 16,(XCORD(I),I=1,4)
   16 FORMAT('0',55X,4A4)
      PRINT 17,IFX
   17 FORMAT(' ',55X,' SCALED BY 10**',I3)
      RETURN
      ENTRY MINMAX(ISTORE,ZMIN,ZMAX,NPTS)
       ZMIN=ISTORE(1)
      ZMAX=ISTORE(1)
      DO 50 I=2,NPTS
      ZMIN=AMIN1(ZMIN,ISTORE(I))
   50 ZMAX=AMAX1(ZMAX,ISTORE(I))
      RETURN
      END
```

CONTROL VARIABLES

```
&MODER
IRND=        0,IMODE=        0,ISEP=        0,IUNLO=        0,IHAM=        1,IFLAG=        1,IFLG=        3,IBBC=
     0,INIT=        0,IFIRE=        0,IFREQ=        6,NROUN=        1,IREAD=        0,IPICK=        0,NSMPR=
   400,I4DG=        1,NMASS=        5
&END
                              BREECH PRESSURE (LB/FT**2)
                              TIME STEP=      0.00010000
        0.0        144000.00       432000.00       720000.00      1584000.00      5184000.00
   7200000.00     8352000.00      7200000.00      5040000.00      3600000.00      2736000.00
   2160000.00     1728000.00      1440000.00
                        CAVITY PRESSURE IN BOLT CARRIER (LB/FT**2)
                              TIME STEP=      0.00026400
        0.0        180000.00       360000.00       381600.00       345600.00       288000.00
    216000.00      158400.00        86400.00        57600.00        43200.00        36000.00
     28800.00       21600.00        14400.00        14400.00         7200.00         7200.00
                              CARTRIDGE CASE FORCE (LBS)
                              TIME STEP=      0.00012500
      -0.94            0.0
                              BORE FRICTION (LBS)
                              TIME STEP=      0.00010000
       210.00         325.00          295.00          265.00          240.00          210.00
       180.00         155.00          125.00          100.00           70.00           40.00
        20.00            0.0             0.0
```

NAME	DESCRIPTION	VALUE	UNITS
BOREA	BORE AREA	0.00026159	FT**2
XKHYP	SPRING THAT PREVENTS MOTION BETWEEN THE BOLT AND GUN	100000.00000000	LBS/FT
XCHYP	DAMPING FOR THE ABOVE SPRING	18.00000000	LBS-SEC
XLD	DISTANCE BOLT CARRIER TRAVELS BEFORE GUN IS UNLOCKED	0.02083330	FT
CF4	DAMPING COEFFICIENT BETWEEN BOLT AND BOLT CARRIER	0.01000000	LBS-SEC/FT
XMU4	COEFFICIENT OF FRICTION BETWEEN BOLT AND BOLT CARRIER	0.20000000	NONE
XMB	MASS OF THE BOLT	0.00404037	SLUGS
G	GRAVITATIONAL CONSTANT	32.20000000	FT/SEC**2
XBBC	DISTANCE BOLT TRAVELS IN THE BOLT CARRIER	0.02604160	FT
XKBBC	SPRING BETWEEN BOLT AND BOLT CARRIER	100000.00000000	LBS/FT
XCBBC	DAMPING COEFFICIENT FOR ABOVE SPRING	18.00000000	LBS-SEC/FT
DERIV	DERIVATIVE OF THETA WITH RESPECT TO XB-XBC	25.13300000	RAD/FT
XKLBC	SPRING BETWEEN BOLT AND BOLT CARRIER DURING LOCKING	100000.00000000	LBS/FT
XMBUL	MASS OF THE BULLET AND THE PROPELLANT	0.00037658	SLUGS
XCLBC	DAMPING CORRESPONDING TO THE SPRING XKLBC	37.00000000	LBS-SEC/FT
AREBOL	AREA OF CAVITY THE GAS FORCE ACTS ON	0.00136600	FT**2
TDEL	TIME DELAY BETWEEN PORT AND CAVITY	0.00020000	SEC

XIB	MOMENT OF INERTIA OF THE BOLT	0.00000105	SLUGS-FT**2
XMARC	MASS OF THE CARTRIDGE CASE	0.00041078	SLUGS
TPORT	TIME IT TAKES PROJECTILE TO REACH PORT	0.00110000	SEC
XKBUFF	INTERACTION SPRING BETWEEN BOLT CARRIER AND BUFFER	100000.00000000	LBS/FT
XCBUFF	DAMPING COEFFICIENT FOR ABOVE SPRING	14.06000000	LBS-SEC/FT
XCBCMG	DAMPING BETWEEN BOLT CARRIER AND MAIN GUN	0.01000000	LBS-SEC/FT
XIM	MOMENT OF INERTIA OF THE HAMMER	0.00002000	SLUGS-FT**2
RH	RADIAL DISTANCE OF THE HAMMER TO POINT OF CONTACT	0.11083000	FT
ALPHA	REFFRENCE ANGLE ON THE HAMMER	0.30530000	RAD
XKMOUN	MOUNT SPRING CONSTANT	300.00000000	LBS/FT
XCMOUN	DAMPING FOR ABOVE SPRING	9.53100000	LBS-SEC/FT
TSPRIN	CONSTANT TORQUE DUE TO THE HAMMER SPRING	0.50000000	FT-LBS
XMUBCG	COEFFICIENT OF FRICTION BETWEEN THE BOLT CARRRIER AND GUN	0.20000000	NONE
XMBC	MASS OF THE BOLT CARRIER	0.01820807	SLUGS
XK9	BACK PLATE SPRING CONSTANT	60000.00000000	LBS/FT
XC9	DAMPING FOR THE ABOVE SPRING	10.78000000	LBS-SEC/FT
XK5	DRIVE SPRING CONSTANT	19.20000000	LBS/FT
XC5	DAMPING FOR ABOVE SPRING	0.00010000	LBS-SEC/FT
BETA	PRELOAD DISTANCE FOR THE DRIVE SPRING	0.33700000	FT
ALP1	DISTANCE BUFFER TRAVELS BEFORE BACK PLATE IS HIT	0.31700000	FT
THETO	INITIAL ANGLE OF THE HAMMER	-1.22173000	RAD
XKHG	SPRING BETWEEN HAMMER AND GUN	50000.00000000	LBS/FT
XCHG	DAMPING FOR THE ABOVE SPRING	0.27800000	LBS-SEC/FT
XMHAM	MASS OF THE HAMMER	0.00212112	SLUGS
XMG	MASS OF THE MAIN GUN	0.17670807	SLUGS
XMBUFF	MASS OF THE BUFFER	0.00306460	SLUGS
EJCAR	DISTANCE BOLT TRAVELS BEFORE CARTRIDGE EJECTION	0.17400000	FT
ELEV	ANGLE OF ELEVATION OF THE GUN	-0.00110000	RAD
XPUC	DISTANCE OF BOLT WHEN ROUND IS PICKED UP	0.23441670	FT
XPUC1	DISTANCE OF BOLT WHEN PICK UP FORCE IS OFF	0.15316670	FT

RO	DISTANCE FROM THE PIVOT POINT TO THE C.G. OF THE HAMMER	0.06250000	FT
XBFORW	EFFFCTIVE INTERNAL BUFFER SPRING CONSTANT (FORWARD)	22567.00000000	LBS/FT
XCFORW	DAMPING COEF. FOR THE ABOVE SPRING	6.99000000	LBS-SEC/FT
XBREAR	EFFFCTIVE INTERNAL BUFFER SPRING CONSTANT (REARWARD)	26405.00000000	LBS/FT
XCREAR	DAMPING COEF. FOR THE ABOVE SPRING	7.56000000	LBS-SEC/FT
SLACK	DISTANCE WTS. ARE ALLOWED TO MOVE	0.01083000	FT
XUBUF	COEF. OF FRICTION BETWEEN WTS. AND BUFFER	0.20000000	NONE
XMWT	MASS OF THE WTS IN THE BUFFER	0.00695497	SLUGS
XUHBC	COEF. OF FRICTION BETWEEN HAMMER AND B.C.	0.15000000	NONE
XDHA	DISTANCE B.C. MOVES BEFORE FRICT. BETWEEN THE HAM. AND B.C.	0.11500000	FT
EXTC	EXTRACTOR DISTANCE	0.00780000	FT
EXTF	EXTRACTOR FORCE	7.50000000	LBS
FDIS	DISTANCE BOLT CARRIER IS FROM BATTFRY, HAMMER ROTATES	0.01966700	FT
XMUFF	COEF. OF FRIC. BETWEEN GUN AND BUFFER	0.20000000	NONE
XCUFF	DAMPING BETWEEN BUFFER AND GUN	0.01000000	NONE
FSTIC	STICTION FORCE	0.0	LBS
RHH0	DISTANCE FROM HAMMER PIVOT TO B.C.	0.0[illegible]83000	FT
RHH1	DISTANCE FROM PIVOT TO TOP OF HAMMER	0.13200000	FT
ALH0	ANGLE CORRESPONDING TO RHH0	0.38400000	RAD
ALH1	ANGLE CORRESPONDING TO RHH1	0.26200000	RAD
HK	HAMMER IMPACT SPRING	4500.00000000	LBS/RAD
HC	ABOVE DAMPING CONSTANT	0.08600000	LBS-SEC/RAD
R1B	INNER RADIUS CARTRIDGE CASE	0.00781250	FT
R2B	OUTER RADIUS CARTRIDGE CASE	0.01562500	FT
CCL	CARTRIDGE CASE LENGTH	0.14580000	FT
XMUB	COEFFICIENT OF FRICTION AT THE BASE	0.20000000	NONE
TBFO	DELAY BETWEEN HAMMER STRIKE AND IGNITION	0.0	SEC
XMDSP	MASS OF THE DRIVE SPRING	0.00414907	SLUGS

INPUT PARAMETERS FOR FEED MECHANISM

NC=19 (NUMBER OF ROUNDS WHEN MAGAZINE IS FULL)

```
YE=    0.37500FT (HT. OF MAG. SPRING WHEN EMPTY)
YF=    0.08850FT (HT. OF MAG. SPRING WHEN FULL)
NI=19 (INITIAL NUMBER OF ROUNDS IN THE MAGAZINE)
XKMAG=  10.80000LBS/FT (MAGAZINE SPRING CONSTANT)
XFL=   0.64700FT (FREE LENGTH OF MAGAZINE SPRING)
XUMAG1=    0.24200 (COEF. OF FRICTION BETWEEN B.C. AND ROUNDS)
XUMAG2=    0.30200 (COEF. OF FRICTION BETWEEN MAG. AND ROUNDS)
XUMAG3=    0.30200 (COEF. OF FRICTION BETWEEN ROUNDS)
XPROJ=   0.19490FT (DISTANCE BOLT CARRIER MOVES WHEN FRICTION BETWEEN B.C. AND ROUNDS IS OFF)
SPR=   0.03000LBS (A THIRD THE SPRING MASS AND THE FOLLOWER MASS)
EPSOL=   1.00000 (EFFICIENCY OF MAGAZINE SPRING SYSTEM)
DIAC=   0.03125FT (DIAM. OF CASE)

          COMPUTED PARAMETERS ASSOCIATED WITH THE MAG.

DELSP=   0.01508FT (SPACE PER ROUND)
YIHT=   0.08850FT (INITIAL HT. OF THE MAG. SPRING)
XME=   0.01589SLUGS (EFFECTIVE MASS ASSOC. WITH THE MAGAZINE)

     MASSES, SPRING CONSTANTS, AND DAMPING COEFS.
UNITS ARE SLUGS, LBS/FT, AND LBS-SEC/FT, RESPECTIVELY
THE FIRST MASS CORRESPONDS TO THE MASS NEAREST THE BOLT CARRIER
XMS=     0.00126136     0.00126136     0.00126136     0.00126136      0.00191190
XKS=  60000.00  60000.00  60000.00  60000.00  60000.00  60000.00
XCS=     12.00     12.00     12.00     12.00     12.00     12.00

              PARAMETERS FOR ACCURACY

R1O=     0.06500000FT (BARREL OFFSET FROM THE C.G.)
R2O=    -0.02830000FT (MOUNT FORCE OFFSET FROM THE C.G.)
XIG=     0.13520000SLUG - FT**2 (MOMENT OF INERTIA OF THE GUN)
XKG=    50.00000000FT-LBS/RAD (TORSIONAL SPRING CONSTANT)
XCG=     2.82800000FT-LBS-SEC/RAD (DAMPING FOR TORSIONAL SPRING)
XLB=     1.64500000FT (PIVOT POINT TO BARREL END)
XALPH=     0.06500000FT (BARREL OFFSET)
RANGE=  450.00000000FT (TARGET RANGE)
VPR=  3180.00000000FT/SEC (MUZZLE VELOCITY)
TMUZ=     0.00130000SEC (TIME TO REACH MUZZLE)
```

COMPUTED RESULTS FOR A 1 SHOT BURST

```
(FORWARD) BOLT PIN STRIKES END OF CAM PATH AT T=      0.0
FRICTIONAL FORCE BETWEEN CARTRIDGES AND B.C. IS ON AT T=      0.0        FBC(10)=    -2.67172608
HAMMER IS CONTROLLED BY HAMMER SPRING AND MAIN GUN STOP AT T=      0.0
BOLT AND MAIN GUN ARE CONSIDERED AS ONE MASS AT T=      0.0
T= 0.0         X= 0.0          0.647D-04 0.0          0.129D-03-0.122D 01 0.129D-03 0.129D-03 0.129D-03 0.129D-03 0.129D-03 0.129D-03
 0.12942D-03 0.12942D-03 0.12942D-03 0.12942D-03 0.0          0.0         0.0         0.0         0.0         0.0
XD= 0.0        0.0         0.0         0.0         0.0         0.0         0.0         0.0         0.0         0.0         0.0
 0.0        0.0         0.0         0.0         0.0         0.0         0.0         0.0         0.0         0.0
XDD= 0.6948D 01-0.1403D 03 0.6948D 01 0.3558D 02 0.2498D 05-0.6405D 01-0.6405D 01-0.6405D 01-0.6405D 01-0.6405D 01 0.0
 0.4704D-14 0.4704D-14 0.4704D-14-0.1797D 02-0.6402D 00 0.0          0.0         0.0         0.0         0.0
FB= 0.0         0.0          0.0          0.31091D-01 0.0          0.0
 0.0        0.64714D 01  0.0          0.0          0.0          0.17100D-03
FBC=-0.31091D-01 0.0          0.0          -0.64714D 01 0.0         0.64708D 01
 0.14835D 00  0.0          0.0          -0.26717D 01  0.0          0.64493D-03
FMG= 0.0         0.0          0.0          -0.14835D 00-0.64555D 01 0.0          0.0
-0.11476D 01  0.0          0.0          0.67889D-02  0.26717D 01  0.0          -0.64526D-01  0.0
FBUF=-0.64708D 01 0.0          0.64704D 01 0.58960D-04 0.44805D-01 0.64526D-01
XMB= 0.48277D-02 XMG= 0.19167D 00

NEW STATUS OF COLLISIONS OF BUFFER WTS. AT T=     0.00015000  1  0  0  0  0  0
NEW STATUS OF COLLISIONS OF BUFFER WTS. AT T=     0.00017500  1  1  0  0  0  0
NEW STATUS OF COLLISIONS OF BUFFER WTS. AT T=     0.00020000  0  1  0  0  0  0
NEW STATUS OF COLLISIONS OF BUFFER WTS. AT T=     0.00020000  0  1  1  0  0  0
NEW STATUS OF COLLISIONS OF BUFFER WTS. AT T=     0.00020000  1  1  1  0  0  0
NEW STATUS OF COLLISIONS OF BUFFER WTS. AT T=     0.00022500  1  1  1  1  0  0
NEW STATUS OF COLLISIONS OF BUFFER WTS. AT T=     0.00025000  1  1  1  0  0  0
NEW STATUS OF COLLISIONS OF BUFFER WTS. AT T=     0.00025000  1  1  1  0  1  0
NEW STATUS OF COLLISIONS OF BUFFER WTS. AT T=     0.00025000  0  1  1  0  1  0
NEW STATUS OF COLLISIONS OF BUFFER WTS. AT T=     0.00025000  0  1  1  1  1  0
NEW STATUS OF COLLISIONS OF BUFFER WTS. AT T=     0.00025000  1  1  1  1  1  0
NEW STATUS OF COLLISIONS OF BUFFER WTS. AT T=     0.00035000  0  1  1  1  1  0
NEW STATUS OF COLLISIONS OF BUFFER WTS. AT T=     0.00035000  0  1  1  1  0  0
NEW STATUS OF COLLISIONS OF BUFFER WTS. AT T=     0.00035000  1  1  1  1  0  0
NEW STATUS OF COLLISIONS OF BUFFER WTS. AT T=     0.00052500  1  1  1  1  1  0
**********  ROUND NUMBER  1  BEGINS  **********
WEAPON FIRES AT T=      0.00990000
BREECH FORCE IS ON AT T=      0.00990000
BORE FRICTION IS ON AT T=      0.00990000
HAMMER STRIKE OF THE MAIN GUN IS ON AT T=      0.00990000
NEW STATUS OF COLLISIONS OF BUFFER WTS. AT T=      0.01012500  0  1  1  1  1  0
HAMMER STRIKE OF THE MAIN GUN IS OFF AT T=      0.01017500
HAMMER ROTATIONAL VELOCITY AND ACCELERATION ARE ZERO STARTING AT T=      0.01017500
(FORWARD) FORCE AT END OF CAM PATH IS OFF AT T=      0.01025000
NEW STATUS OF COLLISIONS OF BUFFER WTS. AT, T=     0.01040000  0  0  1  1  1  0
NEW STATUS OF COLLISIONS OF BUFFER WTS. AT T=     0.01042500  0  0  0  1  1  0
NEW STATUS OF COLLISIONS OF BUFFER WTS. AT T=     0.01045000  0  0  0  0  1  0
NEW STATUS OF COLLISIONS OF BUFFER WTS. AT T=     0.01045000  0  0  0  0  0  0
(FORWARD) BOLT PIN STRIKES END OF CAM PATH AT T=      0.01050000
NEW STATUS OF COLLISIONS OF BUFFER WTS. AT T=     0.01090000  1  0  0  0  0  0
NEW STATUS OF COLLISIONS OF BUFFER WTS. AT T=     0.01092500  1  1  0  0  0  0
NEW STATUS OF COLLISIONS OF BUFFER WTS. AT T=     0.01095000  1  1  1  0  0  0
NEW STATUS OF COLLISIONS OF BUFFER WTS. AT T=     0.01100000  1  1  1  1  0  0
NEW STATUS OF COLLISIONS OF BUFFER WTS. AT T=     0.01105000  1  1  1  1  1  0
CAVITY FORCE IS ON AT T=      0.01122500
ZCAP=    -0.04125794FT (DEFLECTION OF PROJECTILE)
X(L1)=     0.00026430RAD (GUN ROTATION)
XD(L1)=     0.40899012RAD/SEC (ROTATIONAL VELOCITY OF THE GUN)
BREECH FORCE IS OFF AT T=      0.01132500
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BORE FRICTION IS OFF AT T=      0.01132500
(FORWARD) FORCE AT END OF CAM PATH IS OFF AT T=      0.01175000
HAMMER BEGINS TO COCK AT T=      0.01175000
WEAPON BEGINS TO UNLOCK AT T=      0.01225000

VELOCITIES OF THE BOLT AND BOLT CARRIER PRIOR TO THE DISCONTINUITY OF THE CAM
BLTD=      -2.367407 BLTCD=      -18.026211

VELOCITIES OF THE BOLT AND BOLT CARRIER AFTER THE DISCONTINUITY OF THE CAM
BLTD=      -2.392839 BLTCD=      -17.749314
WEAPON IS UNLOCKED AT T=      0.01305000

VELOCITIES OF THE BOLT AND BOLT CARRIER PRIOR TO THE DISCONTINUITY OF THE CAM
BLTD=      -1.126611 BLTCD=      -22.884965

VELOCITIES OF THE BOLT AND BOLT CARRIER AFTER THE DISCONTINUITY OF THE CAM
BLTD=      -1.090576 BLTCD=      -23.277296
SPRING FORCE BETWEEN THE BOLT AND BOLT CARRIER IS ON AT T=      0.01327500
BOLT AND MAIN GUN ARE TWO MASSES AT T=      0.01327500
EXPERIMENTAL CARTRIDGE CASE EJECTION FORCE IS ON AT T=      0.01327500
HAMMER CONSTRAINT FORCE IS OFF AT T=      0.01327500
NEW STATUS OF COLLISIONS OF BUFFER WTS. AT T=      0.01380000  0  1  1  1  1  0
NEW STATUS OF COLLISIONS OF BUFFER WTS. AT T=      0.01382500  0  0  1  1  1  0
NEW STATUS OF COLLISIONS OF BUFFER WTS. AT T=      0.01382500  0  0  0  1  1  0
NEW STATUS OF COLLISIONS OF BUFFER WTS. AT T=      0.01385000  0  0  0  0  1  0
NEW STATUS OF COLLISIONS OF BUFFER WTS. AT T=      0.01385000  0  0  0  0  0  0
SPRING FORCE BETWEEN BOLT AND BOLT CARRIER IS OFF AT T=      0.01422500
SPRING FORCE BETWEEN THE BOLT AND BOLT CARRIER IS ON AT T=      0.01447500
NEW STATUS OF COLLISIONS OF BUFFER WTS. AT T=      0.01467500  0  0  0  0  0  1
NEW STATUS OF COLLISIONS OF BUFFER WTS. AT T=      0.01485000  0  0  0  0  1  1
NEW STATUS OF COLLISIONS OF BUFFER WTS. AT T=      0.01515000  0  0  0  1  1  1
CAVITY FORCE IS OFF AT T=      0.01570000
NEW STATUS OF COLLISIONS OF BUFFER WTS. AT T=      0.01592500  0  0  0  0  1  1
SPRING FORCE BETWEEN BOLT AND BOLT CARRIER IS OFF AT T=      0.01605000
NEW STATUS OF COLLISIONS OF BUFFER WTS. AT T=      0.01635000  0  0  0  1  1  1
NEW STATUS OF COLLISIONS OF BUFFER WTS. AT T=      0.01637500  0  0  1  1  1  1
NEW STATUS OF COLLISIONS OF BUFFER WTS. AT T=      0.01847500  0  1  1  1  1  1
HAMMER ROTATIONAL VELOCITY AND ACCELERATION ARE ZERO STARTING AT T=      0.01855000
FRICTION FORCE COMES ON BETWEEN HAMMER AND B.C. AT T=      0.01857500 FRC(11)=      1.20600619
EXPERIMENTAL CARTRIDGE CASE EJECTION FORCE IS OFF AT T=      0.02175000
AMMO AND BOLT FRICTION IS ON AT T=      0.02340000FRIC=      2.67172608
FRICTIONAL FORCE BETWEEN CARTRIDGES AND B.C. IS OFF AT T=      0.02340000
CARTRIDGE CASE IS EJECTED AT T=      0.02342500
SPRING FORCE BETWEEN THE BOLT AND BOLT CARRIER IS ON AT T=      0.02382500
SPRING FORCE BETWEEN BOLT AND BOLT CARRIER IS OFF AT T=      0.02435000
BOLT AND AMMO FRICTION IS OFF AT T=      0.02750000
SPRING FORCE BETWEEN THE BOLT AND BOLT CARRIER IS ON AT T=      0.02797500
SPRING FORCE BETWEEN BOLT AND BOLT CARRIER IS OFF AT T=      0.02860000
BUFFER STRIKES BACK PLATE AT T=      0.03042500

VELOCITIES PRIOR TO IMPACT
BLTD=   -16.52286533 BLTCD=   -15.73988025 XMGD=    -0.90620382

BOLT IMPULSES     -1.23365625     0.01095406     0.0            0.00026084    -0.18698827    -0.02008823
    0.0            0.18188831     0.0            0.80843809     0.00395857     0.00000497
BOLT ENERGY       2.58875664    -0.17248485     0.0           -0.00507367     2.63359922     0.03631125
    0.0           -0.42042500     0.0           -3.61488438    -0.07243737    -0.00004847
BOLT CARRIER IMPULSES    -0.00026084     0.18698827     0.02008823    -0.18188831     0.0     0.39182319
    0.00455814     0.05452869    -0.80843809     0.00447669     0.01540618     0.00002025
BOLT CARRIER ENERGY    -0.00191320    -3.66714375    -0.40927129     0.28863145     0.0     -5.30655971
   -0.10436242    -0.96319688    13.15499375    -0.55793066    -0.25632532    -0.00022124
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  0.0          -0.42455156     0.0           -3.60525625    -0.07255833    -0.00004904
BOLT CARRIER IMPULSES    -0.00029817     0.18920697     0.02006953    -0.19589825    0.0           0.43797752
  0.00460198     0.05433560    -0.80843809     0.00461028     0.01570649     0.00002044
BOLT CARRIER ENERGY    -0.00145280    -3.69377188    -0.40796426     0.29269648     0.0          -5.73168743
  -0.10396989    -0.95755605    13.12821250    -0.55841211    -0.25689453    -0.00022189
GUN IMPULSE     0.35106385    -0.01108765     0.0           -0.00460198    -0.28658475     0.21824980     0.04980952
  -0.10524895    -0.00344598    -0.00398173     0.00021519    -0.00461028    -0.01570649    -0.00398648    0.0
GUN ENERGY    -0.51334131     0.01080588     0.0            0.00627309     0.24284976    -0.13222244     0.00801545
  0.09183917     0.00620876     0.00403501    -0.00017917     0.03158816     0.01563468     0.00461456    0.0
BUFFER IMPULSE    -0.43797752     0.00344598     0.34055798     0.00000187     0.05149081     0.00398648
BUFFER ENERGY     5.54423899    -0.08664709    -4.46477598    -0.00002028    -0.68780433    -0.08263077
SPRING FORCE BETWEEN THE BOLT AND BOLT CARRIER IS ON AT T=      0.03172500
NEW STATUS OF COLLISIONS OF BUFFER WTS. AT T=      0.03362500  0  0  0  0  0  1
NEW STATUS OF COLLISIONS OF BUFFER WTS. AT T=      0.03377500  0  0  0  0  1  1
NEW STATUS OF COLLISIONS OF BUFFER WTS. AT T=      0.03392500  0  0  0  1  1  1
SPRING FORCE BETWEEN BOLT AND BOLT CARRIER IS OFF AT T=      0.03395000
NEW STATUS OF COLLISIONS OF BUFFER WTS. AT T=      0.03405000  0  0  1  1  1  1
NEW STATUS OF COLLISIONS OF BUFFER WTS. AT T=      0.03415000  0  1  1  1  1  1
NEW STATUS OF COLLISIONS OF BUFFER WTS. AT T=      0.03507500  0  0  1  1  1  1
NEW STATUS OF COLLISIONS OF BUFFER WTS. AT T=      0.03507500  0  0  0  1  1  1
BUFFER COMES OFF OF BACK PLATE AT T=      0.03512500

VELOCITIES AFTER IMPACT
BLTD=     6.71591603 BLTCD=     5.81941633 XMGD=    -3.35274859

NEW STATUS OF COLLISIONS OF BUFFER WTS. AT T=      0.03512500  0  0  0  0  1  1
NEW STATUS OF COLLISIONS OF BUFFER WTS. AT T=      0.03515000  0  0  0  0  0  1
NEW STATUS OF COLLISIONS OF BUFFER WTS. AT T=      0.03627500  0  0  0  0  1  1
NEW STATUS OF COLLISIONS OF BUFFER WTS. AT T=      0.03747500  0  0  0  1  1  1
SPRING FORCE BETWEEN THE BOLT AND BOLT CARRIER IS ON AT T=      0.03920000
NEW STATUS OF COLLISIONS OF BUFFER WTS. AT T=      0.03942500  0  0  1  1  1  1
SPRING FORCE BETWEEN BOLT AND BOLT CARRIER IS OFF AT T=      0.03982500
NEW STATUS OF COLLISIONS OF BUFFER WTS. AT T=      0.04032500  0  1  1  1  1  1
FORCE TO PICK UP NEW ROUND IS ON AT T=      0.04045000

INELASTIC COLLISION OF THE BOLT AND ROUND

MASS OF THE GUN AND VELOCITIES OF THE BOLT AND ROUND
PRIOR TO ROUND BEING PICKED UP
GUN MASS=     0.19166786  BOLT VELOCITY=     5.40006587 ROUND VELOCITY (VELOCITY OF THE GUN)=    -2.64627849

MASS OF THE GUN AND VELOCITIES OF THE BOLT AND ROUND
AFTER ROUND IS PICKED UP
GUN MASS=     0.19088050  BOLT VELOCITY=     4.27179363 ROUND VELOCITY =     4.27179363
FRICTIONAL FORCE TO PICK UP NEW ROUND IS     -6.90975269
SPRING FORCE BETWEEN THE BOLT AND BOLT CARRIER IS ON AT T=      0.04232500
SPRING FORCE BETWEEN BOLT AND BOLT CARRIER IS OFF AT T=      0.04310000
SPRING FORCE BETWEEN THE BOLT AND BOLT CARRIER IS ON AT T=      0.04425000
NEW STATUS OF COLLISIONS OF BUFFER WTS. AT T=      0.04967500  0  1  1  1  1  0
NEW STATUS OF COLLISIONS OF BUFFER WTS. AT T=      0.04992500  0  1  1  1  0  0
NEW STATUS OF COLLISIONS OF BUFFER WTS. AT T=      0.04995000  0  1  1  0  0  0
NEW STATUS OF COLLISIONS OF BUFFER WTS. AT T=      0.04997500  0  1  0  0  0  0
NEW STATUS OF COLLISIONS OF BUFFER WTS. AT T=      0.05000000  0  0  0  0  0  0
SPRING FORCE BETWEEN BOLT AND BOLT CARRIER IS OFF AT T=      0.05065000
NEW STATUS OF COLLISIONS OF BUFFER WTS. AT T=      0.05070000  1  0  0  0  0  0
NEW STATUS OF COLLISIONS OF BUFFER WTS. AT T=      0.05075000  1  1  0  0  0  0
SPRING FORCE BETWEEN THE BOLT AND BOLT CARRIER IS ON AT T=      0.05085000
NEW STATUS OF COLLISIONS OF BUFFER WTS. AT T=      0.05085000  1  1  1  0  0  0
NEW STATUS OF COLLISIONS OF BUFFER WTS. AT T=      0.05100000  1  1  1  1  0  0
NEW STATUS OF COLLISIONS OF BUFFER WTS. AT T=      0.05115000  1  1  1  1  1  0
NEW STATUS OF COLLISIONS OF BUFFER WTS. AT T=      0.05247500  1  0  1  1  1  0
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NEW STATUS OF COLLISIONS OF BUFFER WTS. AT T=      0.05247500  1  0  0  1  1  0
NEW STATUS OF COLLISIONS OF BUFFER WTS. AT T=      0.05247500  1  0  0  0  1  0
NEW STATUS OF COLLISIONS OF BUFFER WTS. AT T=      0.05247500  1  0  0  0  0  0
NEW STATUS OF COLLISIONS OF BUFFER WTS. AT T=      0.05247500  0  0  0  0  0  0
NEW STATUS OF COLLISIONS OF BUFFER WTS. AT T=      0.05407500  0  0  0  0  0  1
FORCE TO PICK UP NEW ROUND IS OFF AT T=      0.05435000

RESPONSE TIME OF THE MAGAZINE IS      0.00893390 FMI=      5.86894737 FMA=      6.03180000
NEW STATUS OF COLLISIONS OF BUFFER WTS. AT T=      0.05435000  0  0  0  0  1  1
SPRING FORCE BETWEEN BOLT AND BOLT CARRIER IS OFF AT T=      0.05470000
NEW STATUS OF COLLISIONS OF BUFFER WTS. AT T=      0.05487500  0  0  0  1  1  1
NEW STATUS OF COLLISIONS OF BUFFER WTS. AT T=      0.05585000  0  0  1  1  1  1
NEW STATUS OF COLLISIONS OF BUFFER WTS. AT T=      0.05745000  0  1  1  1  1  1
NEW STATUS OF COLLISIONS OF BUFFER WTS. AT T=      0.05880000  0  1  1  1  1  0
NEW STATUS OF COLLISIONS OF BUFFER WTS. AT T=      0.05885000  0  1  1  0  1  0
NEW STATUS OF COLLISIONS OF BUFFER WTS. AT T=      0.05885000  0  1  1  0  0  0
NEW STATUS OF COLLISIONS OF BUFFER WTS. AT T=      0.05887500  0  0  1  0  0  0
NEW STATUS OF COLLISIONS OF BUFFER WTS. AT T=      0.05887500  0  0  0  0  0  0
FRICTION FORCE BETWEEN HAMMER AND B.C. IS OFF AT T=      0.06150000
SPRING FORCE BETWEEN THE BOLT AND BOLT CARRIER IS ON AT T=      0.06217500
SPRING FORCE BETWEEN BOLT AND BOLT CARRIER IS OFF AT T=      0.06300000
FRICTIONAL FORCE BETWEEN CARTIRIDGES AND B.C.IS ON AT T=      0.06330000 FBC(10)=      -2.59290541
SPRING FORCE BETWEEN THE BOLT AND BOLT CARRIER IS ON AT T=      0.06405000
NEW STATUS OF COLLISIONS OF BUFFER WTS. AT T=      0.07007500  0  0  0  0  0  1
SPRING FORCE BETWEEN BOLT AND BOLT CARRIER IS OFF AT T=      0.07020000
SPRING EXTRACTOR FORCE IS ON AT T=      0.07062500 CONSTANT FORCE      -7.50000000
SPRING FORCE BETWEEN THE BOLT AND BOLT CARRIER IS ON AT T=      0.07082500
NEW STATUS OF COLLISIONS OF BUFFER WTS. AT T=      0.07097500  0  0  0  0  0  0
SPRING FORCE BETWEEN BOLT AND BOLT CARRIER IS OFF AT T=      0.07147500
WEAPON LOCKING FORCE IS ON AT T=      0.07150000

VELOCITIES OF THE BOLT AND BOLT CARRIER PRIOR TO THE DISCONTINUITY OF THE CAM
BLTD=      8.322588 BLTCD=      9.911152

VELOCITIES OF THE BOLT AND BOLT CARRIER AFTER THE DISCONTINUITY OF THE CAM
BLTD=      8.419253 BLTCD=      9.885522
HAMMER IS CONTROLLED BY HAMMER SPRING AND MAIN GUN STOP AT T=      0.07157500
SPRING BETWEEN BOLT AND BARREL IS OFF AT T=      0.07175000
BOLT AND MAIN GUN ARE CONSIDERED AS ONE MASS AT T=      0.07175000
WEAPON LOCKING FORCE IS OFF AT T=      0.07340000

VELOCITIES OF THE BOLT AND BOLT CARRIER PRIOR TO THE DISCONTINUITY OF THE CAM
BLTD=      0.856913 BLTCD=      9.685520

VELOCITIES OF THE BOLT AND BOLT CARRIER AFTER THE DISCONTINUITY OF THE CAM
BLTD=      0.842262 BLTCD=      9.844710
(FORWARD) BOLT PIN STRIKES END OF CAM PATH AT T=      0.07395000
NEW STATUS OF COLLISIONS OF BUFFER WTS. AT T=      0.07437500  1  0  0  0  0  0
NEW STATUS OF COLLISIONS OF BUFFER WTS. AT T=      0.07460000  1  1  0  0  0  0
NEW STATUS OF COLLISIONS OF BUFFER WTS. AT T=      0.07490000  1  1  1  0  0  0
NEW STATUS OF COLLISIONS OF BUFFER WTS. AT T=      0.07535000  1  1  1  1  0  0
NEW STATUS OF COLLISIONS OF BUFFER WTS. AT T=      0.07545000  1  1  1  1  1  0
(FORWARD) FORCE AT END OF CAM PATH IS OFF AT T=      0.07590000
NEW STATUS OF COLLISIONS OF BUFFER WTS. AT T=      0.07660000  1  1  1  1  0  0
NEW STATUS OF COLLISIONS OF BUFFER WTS. AT T=      0.07665000  1  1  1  0  0  0
NEW STATUS OF COLLISIONS OF BUFFER WTS. AT T=      0.07667500  1  1  0  0  0  0
NEWSTATUS OF COLLISIONS OF BUFFER WTS. AT T=      0.07670000  1  0  0  0  0  0
NEWSTATUS OF COLLISIONS OF BUFFER WTS. AT T=      0.07672500  0  0  0  0  0  0
(FORWARD) BOLT PIN STRIKES END OF CAM PATH AT T=      0.07822500
NEW STATUS OF COLLISIONS OF BUFFER WTS. AT T=      0.07875000  0  0  0  0  0  1
NEW STATUS OF COLLISIONS OF BUFFER WTS. AT T=      0.07917500  0  0  0  0  1  1
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NEW STATUS OF COLLISIONS OF BUFFER WTS. AT T=      0.07972500  0  0  0  1  1  1
NEW STATUS OF COLLISIONS OF BUFFER WTS. AT T=      0.08090000  0  0  1  1  1  1
**********  ROUND NUMBER  2  BEGINS  **********
WEAPON FIRES AT T=      0.08205000
BREECH FORCE IS ON AT T=      0.08205000
BORE FRICTION IS ON AT T=      0.08205000
HAMMER STRIKE OF THE MAIN GUN IS ON AT T=      0.08205000
BOLT IMPULSES     -1.23365625      0.01108765     -0.05113695      0.00030866      0.02720405     -0.02006953
    0.00526676      0.48969722     -0.09604452      0.80843809      0.00398173      0.00001337
BOLT ENERGY      2.58804180     -0.17320861     -0.29506406     -0.00900426      2.85447773      0.03640155
    0.02719227      0.03226258     -0.41878594     -3.60525625     -0.07255833     -0.00000329
BOLT CARRIER IMPULSES     -0.00030866     -0.02720405      0.02006953     -0.48969722     -0.00526676      1.30187764
   -0.00426197      0.05433560     -0.80843809     -0.01878916     -0.01766694      0.00005291
BOLT CARRIER ENERGY     -0.00170448     -3.95102500     -0.40796426     -0.84181964     -0.05151292     -5.46915919
   -0.17355852     -0.95755605     13.12821250     -0.83779028     -0.46797012     -0.00003194
GUN IMPULSE     1.52004713     -0.01108765      0.05113695      0.00426197     -0.87370159      0.21299980      0.04880393
   -0.14541239     -0.50360117     -0.00398173      0.00055583      0.01878916      0.01766694      0.00174806      0.09604452
GUN ENERGY     -2.22065129      0.01080588      0.03438353     -0.00230822      0.82701963     -0.13234693      0.00799160
    0.02269532      1.14934707      0.00403501     -0.00034499      0.03681586     -0.03627704      0.00020290     -0.14212896
BUFFER IMPULSE     -1.30187764      0.50360117      0.83480412      0.00000484     -0.02178150     -0.00174806
BUFFER ENERGY      4.69725447     -1.74261152     -1.54798262     -0.00000292     -1.22874798     -0.12940998
T= 0.82050D-01X=-0.495D-01-0.494D-01-0.508D-01-0.493D-01 0.582D-02-0.594D-01-0.604D-01-0.604D-01-0.603D-01-0.603D-01 0.538D-02
 0.48289D-01 0.59566D-01 0.23713D-01-0.27782D-01 0.87248D-02 0.0          0.0          0.0          0.0          0.0
XD= 0.1888D 01 0.2000D 01 0.1888D 01 0.3044D 01 0.2588D 03 0.2044D 00 0.4187D 01 0.4113D 01 0.3946D 01 0.3643D 01 0.1043D 02
 0.1029D 02 0.1146D 02 0.7829D 01 0.6316D 01-0.9727D-01 0.0          0.0          0.0          0.0          0.0
DD= 0.1203D 04 0.8606D 03 0.1203D 04-0.2847D 04-0.1 52D 06 0.6475D 01 0.3105D 03 0.1728D 03-0.3158D 03-0.1342D 04-0.1642D 04
-0.4391D 04-0.6543D 04-0.2171D 04 0.3957D 04-0.1123D 03 0.0          0.0          0.0          0.0          0.0
FB= 0.0          0.0          0.0          0.29782D-01 0.0          0.0
 0.0          0.66191D 01  0.0          0.0          0.0          0.15766D-03
FBC=-0.29782D-01 0.0          0.0         -0.66191D 01 0.0          0.25058D 02
-0.14704D 00  0.0          0.0         -0.25929D 01  0.0          0.64493D-03
FMG=-0.27681D 01 0.0          0.0          0.14704D 00-0.51083D 01 0.21000D 03 0.40223D 02
-0.16850D 02  0.0          0.0          0.67610D-02  0.25929D 01  0.0          0.76078D-01  0.0
FBUF=-0.25058D 02 0.0          0.14062D 02 0.58960D-04 0.23469D 01-0.76078D-01
XMB= 0.44511D-02 XMG= 0.19088D 00

NEW STATUS OF COLLISIONS OF BUFFER WTS. AT T=      0.08217500  0  0  1  1  1  0
NEW STATUS OF COLLISIONS OF BUFFER WTS. AT T=      0.08225000  0  0  1  1  0  0
NEW STATUS OF COLLISIONS OF BUFFER WTS. AT T=      0.08227500  0  0  0  1  0  0
NEW STATUS OF COLLISIONS OF BUFFER WTS. AT T=      0.08227500  0  0  0  0  0  0
HAMMER STRIKE OF THE MAIN GUN IS OFF AT T=      0.08232500
NEW STATUS OF COLLISIONS OF BUFFER WTS. AT T=      0.08232500  0  1  0  0  0  0
HAMMER ROTATIONAL VELOCITY AND ACCELERATION ARE ZERO STARTING AT T=      0.08232500
NEW STATUS OF COLLISIONS OF BUFFER WTS. AT T=      0.08235000  0  1  1  0  0  0
NEW STATUS OF COLLISIONS OF BUFFER WTS. AT T=      0.08242500  0  1  1  1  0  0
NEW STATUS OF COLLISIONS OF BUFFER WTS. AT T=      0.08260000  0  1  1  1  1  0
NEW STATUS OF COLLISIONS OF BUFFER WTS. AT T=      0.08317500  0  0  1  1  1  0
NEW STATUS OF COLLISIONS OF BUFFER WTS. AT T=      0.08320000  0  0  0  1  1  0
NEW STATUS OF COLLISIONS OF BUFFER WTS. AT T=      0.08320000  0  0  0  0  1  0
NEW STATUS OF COLLISIONS OF BUFFER WTS. AT T=      0.08322500  0  0  0  0  0  0
CAVITY FORCE IS ON AT T=      0.08337500
T= 0.83400D-01X=-0.491D-01-0.478D-01-0.504D-01-0.474D-01 0.484D-01-0.558D-01-0.558D-01-0.559D-01-0.559D-01-0.559D-01 0.175D-01
 0.58258D-01 0.68930D-01 0.32449D-01-0.16010D-01 0.87907D-02 0.0          0.0          0.0          0.0          0.0
XD=-0.2362D 01-0.2032D 01-0.2362D 01-0.2048D 01 0.0          0.3450D 01 0.3324D 01 0.3213D 01 0.3043D 01 0.2946D 01 0.7125D 01
 0.4526D 01 0.2415D 01 0.5229D 01 0.1067D 02 0.2916D 00 0.0          0.0          0.0          0.0          0.0
DD=-0.9739D 03-0.8176D 04-0.9739D 03-0.7852D 04 0.0         -0.6405D 01-0.6405D 01-0.6405D 01-0.6405D 01-0.6405D 01-0.3353D 04
-0.4178D 04-0.6545D 04-0.1663D 04 0.1953D 04 0.9024D 02 0.0          0.0          0.0          0.0          0.0
FB=-0.41436D 03 0.0          0.0          0.31968D-01 0.0          0.0
 0.0          0.13880D 03  0.0          0.46568D 02  0.0          0.15766D-03
FBC=-0.31968D-01 0.0          0.0         -0.13880D 03 0.0          0.39275D 02
-0.14923D 00  0.0         -0.46568D 02 -0.25929D 01  0.0          0.64493D-03
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FMG= 0.37631D 02 0.0          0.0          0.14923D 00-0.37957D 01 0.0          0.0
 0.20658D 01  0.0          0.0          0.67610D-02  0.25929D 01  0.0          0.67672D-01  0.0
FBUF=-0.39275D 02 0.0          0.15236D 02 0.58960D-04 0.44805D-01-0.67672D-01
XMB= 0.44511D-02 XMG= 0.19088D 00
```

TERM	DEFINITION	UNITS
XMG	GUN DISPLACEMENT	FT
XMGD	VELOCITY OF THE GUN	FT/SEC
BLT	BOLT DISPLACEMENT	FT
BLTD	BOLT VELOCITY	FT/SEC
BLTC	BOLT CARRIER DISPLACEMENT	FT
BLTCD	BOLT CARRIER VELOCITY	FT/SEC
BUFF	BUFFER DISPLACEMENT	FT
BUFFD	BUFFER VELOCITY	FT/SEC
BUFW	INTERNAL BUFFER WT. DISPLACEMENT	FT
BUFWD	INTERNAL BUFFER WT. VELOCITY	FT/SEC
HAMR	ROTATION OF THE HAMMER	RAD
HAMRD	ROTATIONAL VELOCITY OF THE HAMMER	RAD/SEC

NOTE:BOLT, BOLT CARRIER, AND BUFFER DISPLACEMENTS ARE WITH RESPECT TO THE GUN AND NOT THE INERTIAL REFERENCE FRAME

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ABSOLUTE MAXIMUMS OF INDIVIDUAL FORCES
MAX FB= 0.21848D 04 0.26717D 01 0.19305D 03 0.25568D 00 0.43364D 03 0.34970D 02
0.22636D 02 0.34686D 03 0.69098D 01 0.51978D 03 0.93983D 00 0.17100D-03
MAX FBC= 0.25568D 00 0.43364D 03 0.34970D 02 0.34686D 03 0.22636D 02 0.31211D 03
0.37294D 00 0.51655D 02 0.51978D 03 0.26717D 01 0.12059D 01 0.64493D-03
MAX FMG= 0.43385D 02 0.26717D 01 0.19305D 03 0.37294D 00 0.23069D 02 0.32500D 03 0.26475D 03
0.87628D 02 0.32991D 03 0.93983D 00 0.67889D-02 0.26717D 01 0.12059D 01 0.32797D 00 0.69098D 01
MAX FBUF= 0.31211D 03 0.32991D 03 0.19207D 02 0.58960D-04 0.16385D 03 0.32797D 00
FMCI=-0.42921D 03 FMCA= 0.0
ZCAP=       3.76849016FT (DEFLECTION OF PROJECTILE)
X(L1)=       0.00879073RAD (GUN ROTATION)
XD(L1)=       0.29159483RAD/SEC (ROTATIONAL VELOCITY OF THE GUN)
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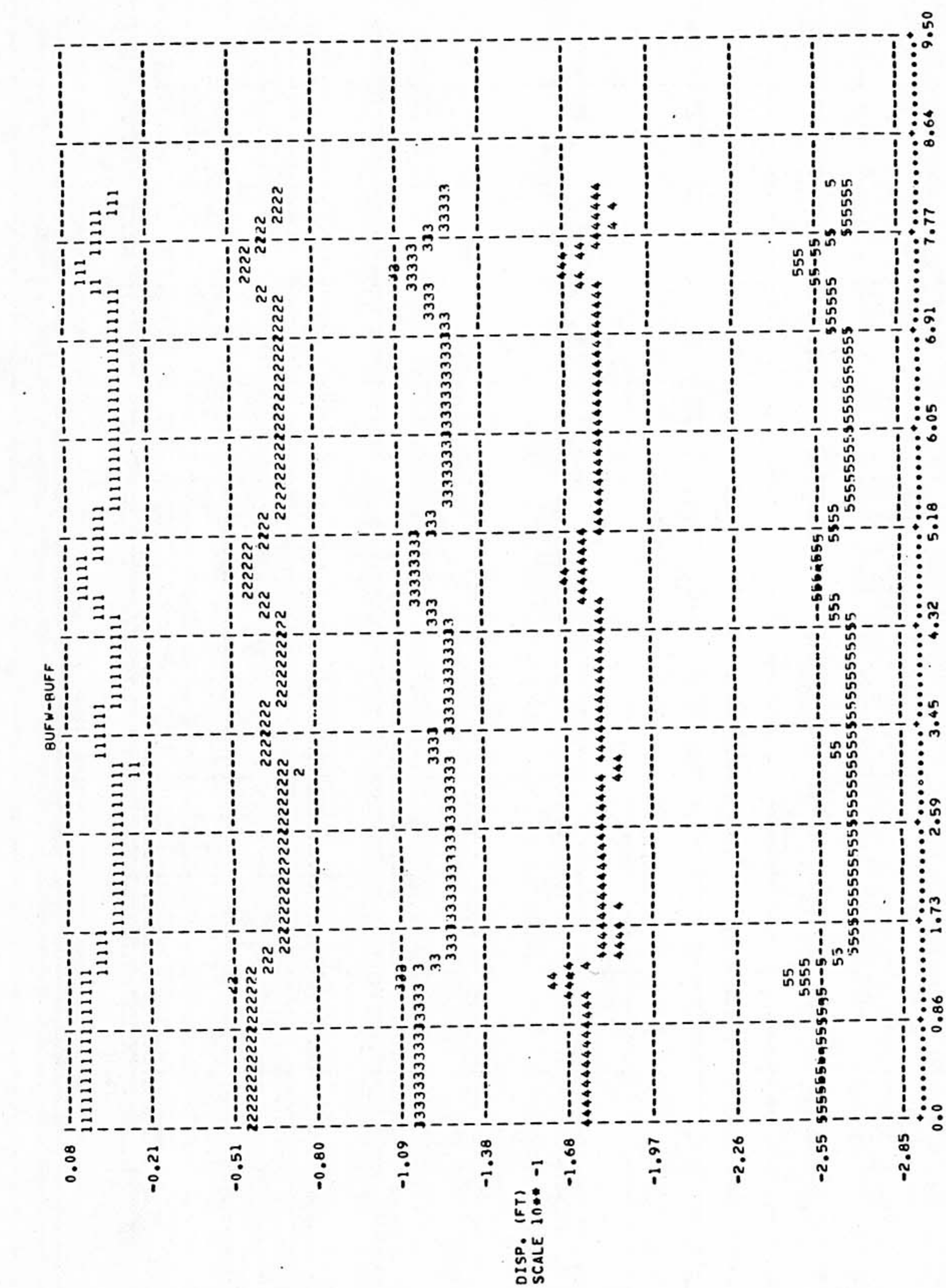
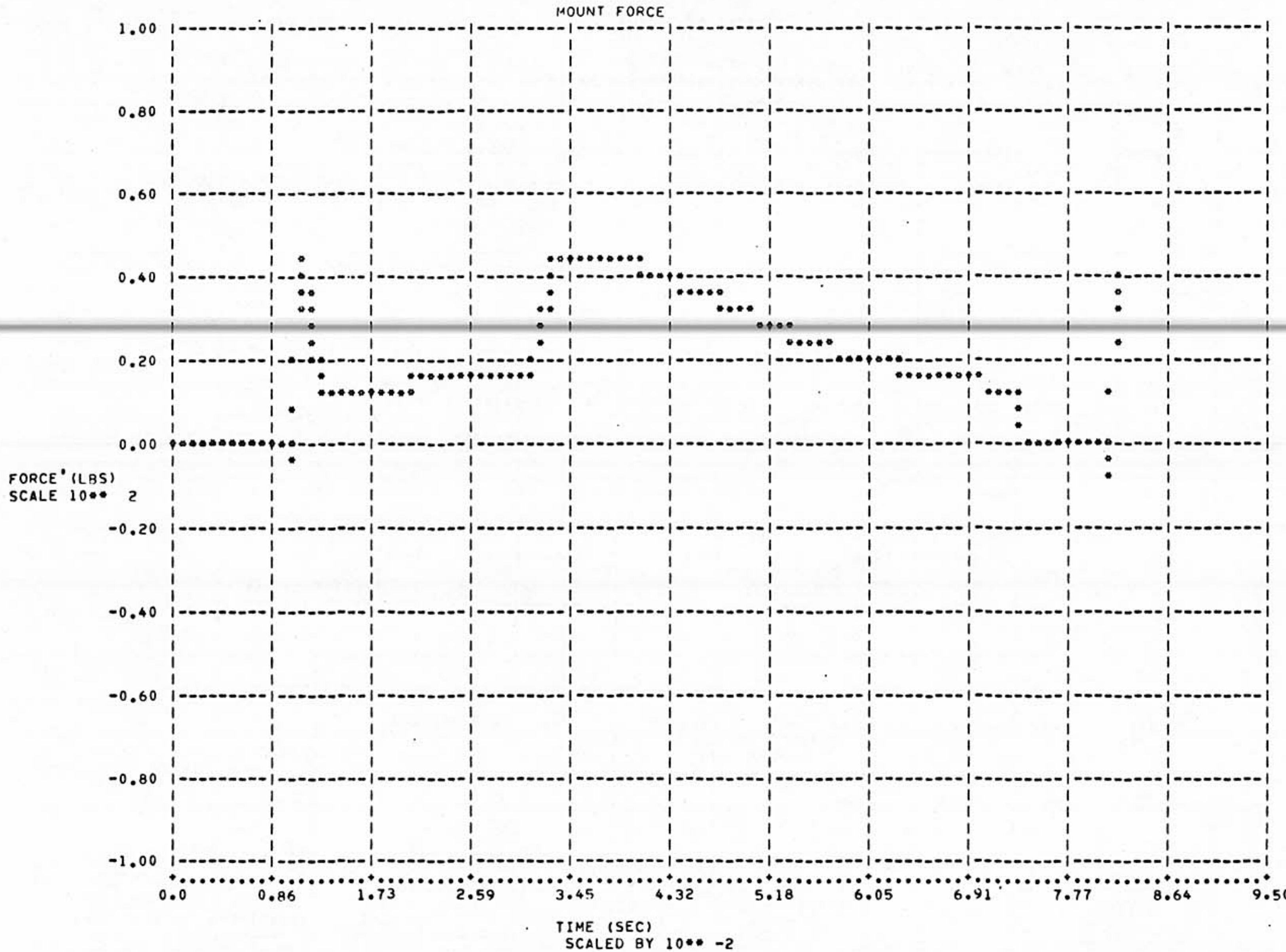
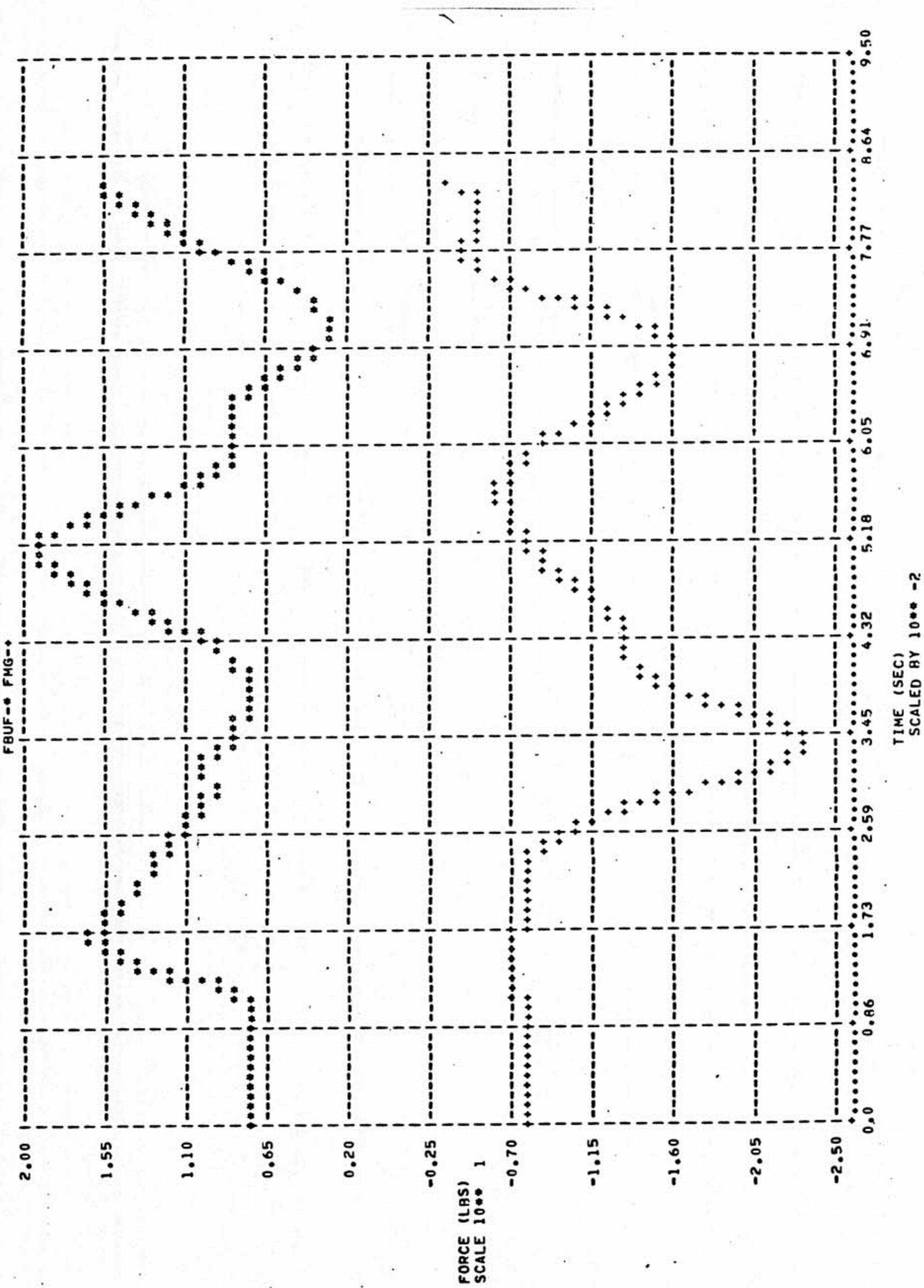
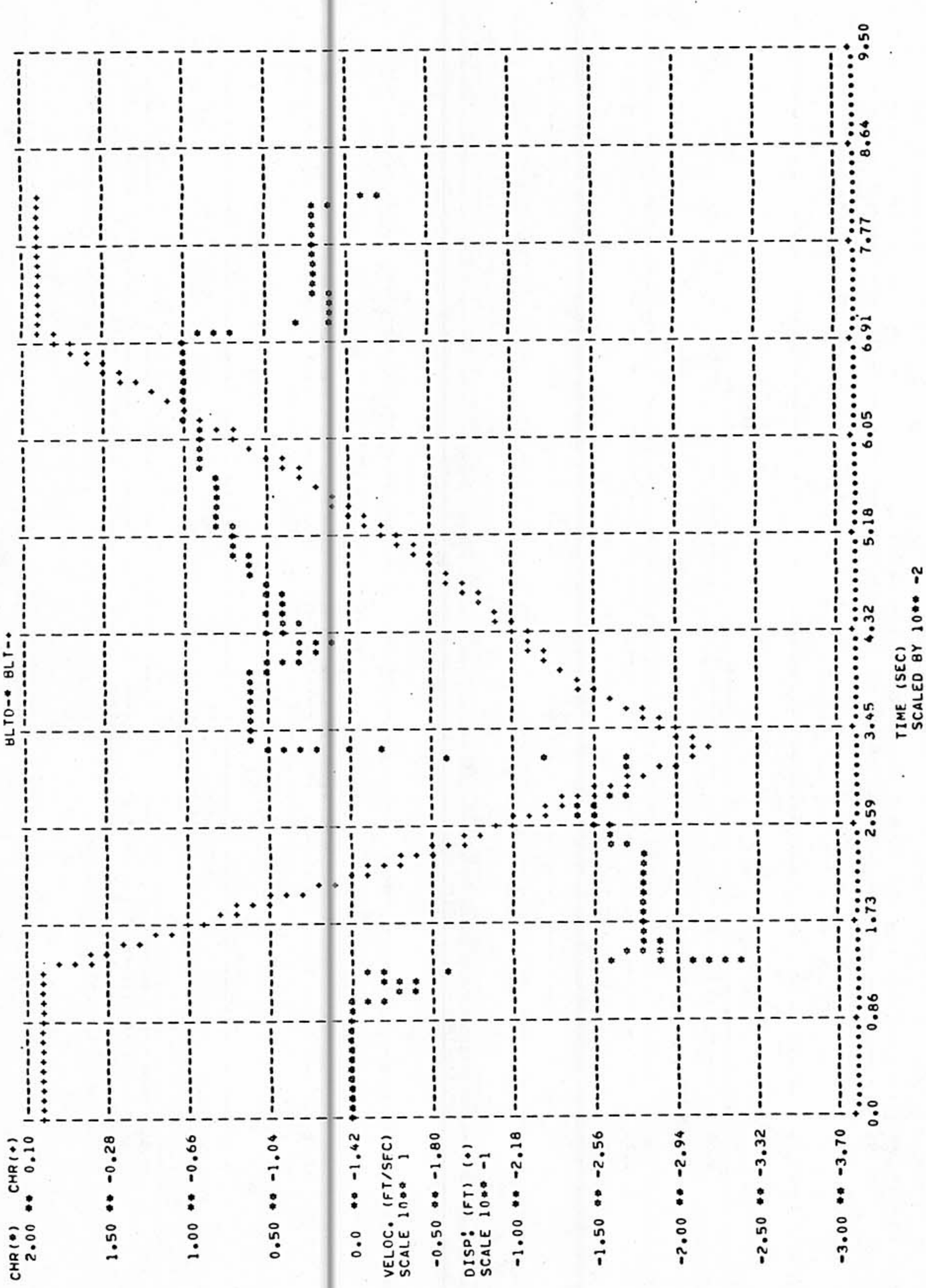
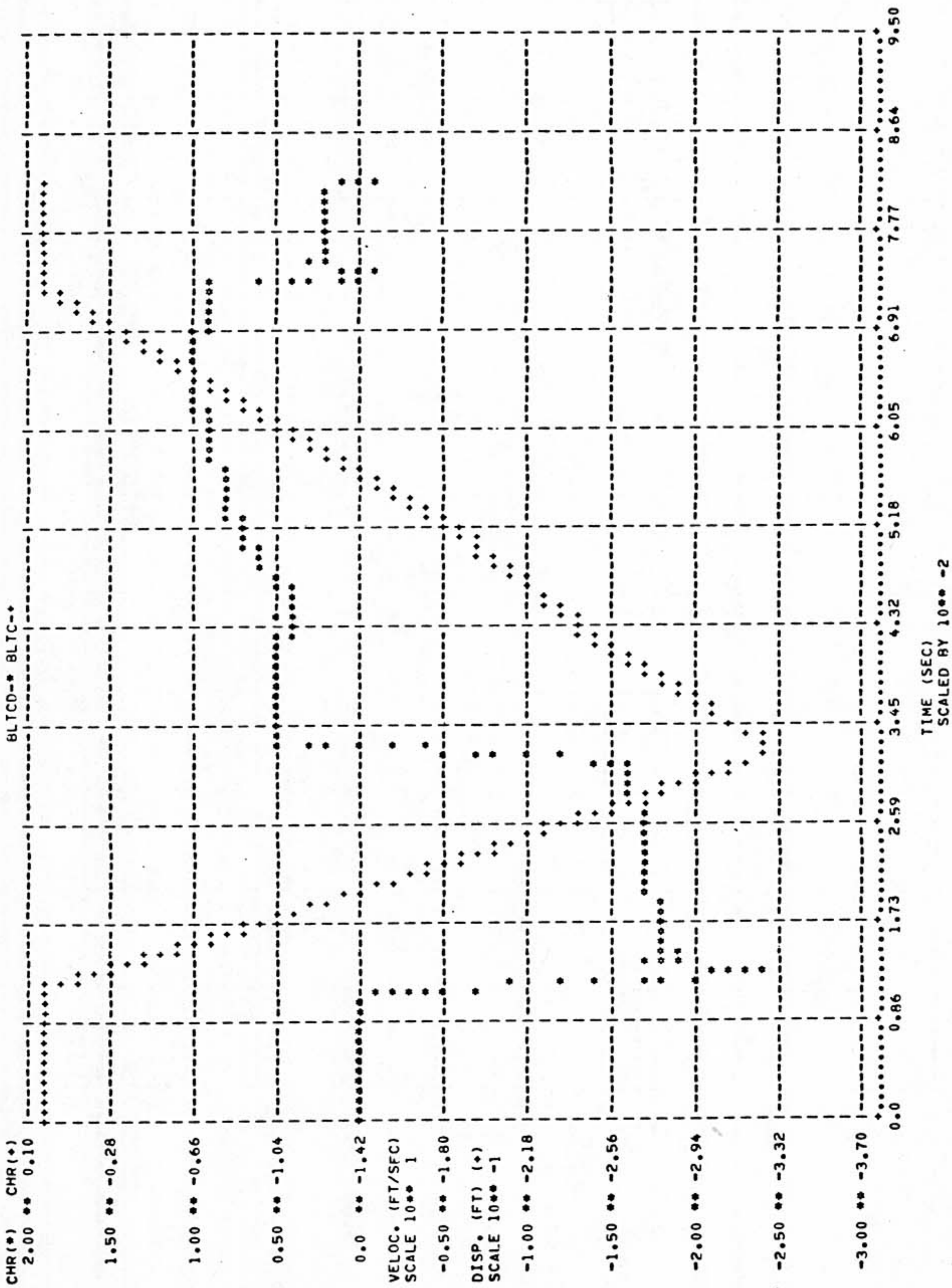

BUFW-BUFF
DISP. (FT)
SCALE 10** -1
0.08
-0.21
-0.51
-0.80
-1.09
-1.38
-1.68
-1.97
-2.26
-2.55
-2.85
0.0
0.86
1.73
2.59
3.45
4.32
5.18
6.05
6.91
7.77
8.64
9.50
TIME (SEC)
SCALED BY 10** -2

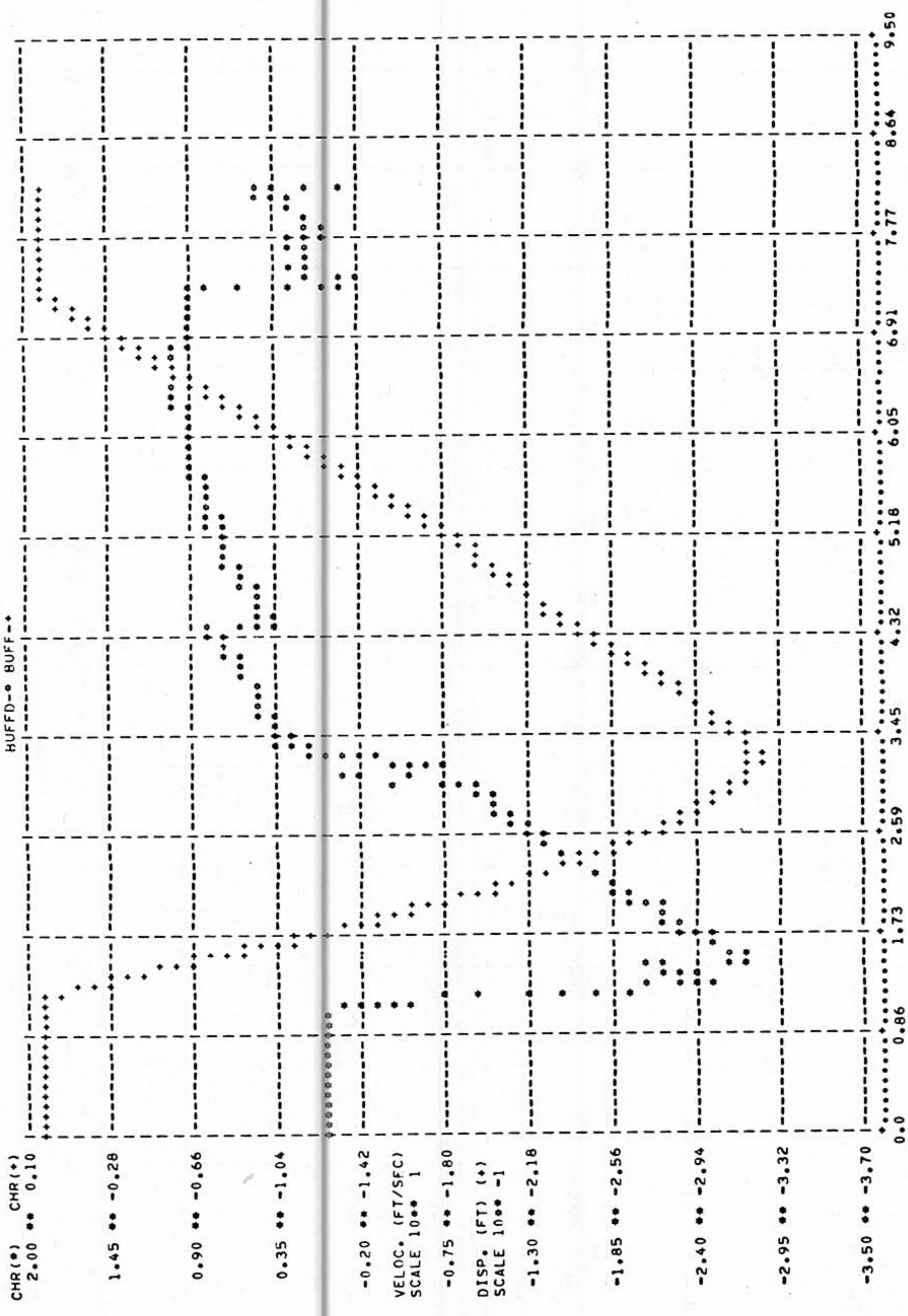

MOUNT FORCE
1.00
0.80
0.60
0.40
0.20
0.00
-0.20
-0.40
-0.60
-0.80
-1.00
FORCE' (LBS)
SCALE 10** 2
0.0
0.86
1.73
2.59
3.45
4.32
5.18
6.05
6.91
7.77
8.64
9.50
TIME (SEC)
SCALED BY 10** -2

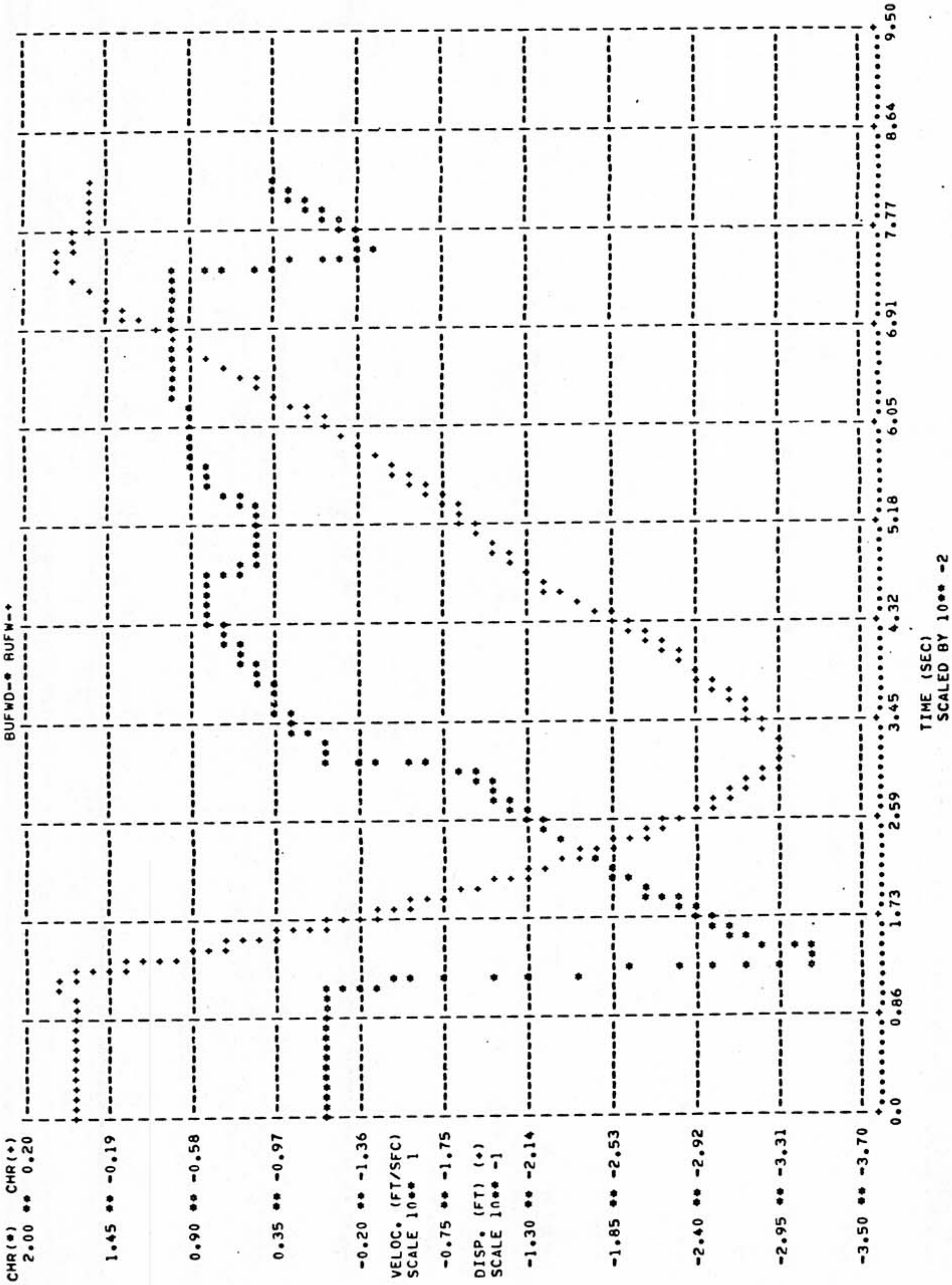


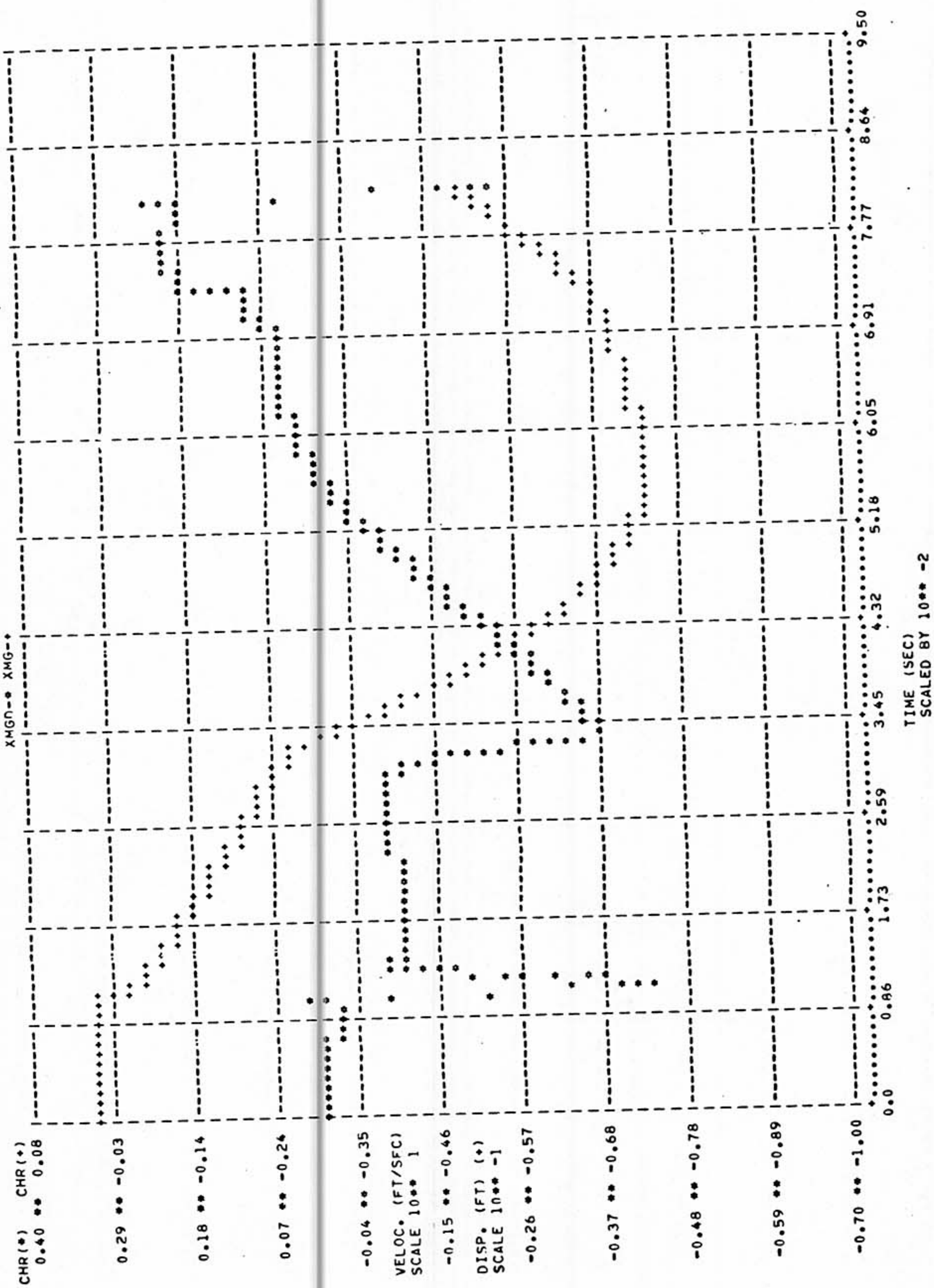
FBUF-* FMG-+
2.00
1.55
1.10
0.65
0.20
-0.25
-0.70
-1.15
-1.60
-2.05
-2.50
FORCE (LBS)
SCALE 10** 1
0.0
0.86
1.73
2.59
3.45
4.32
5.18
6.05
6.91
7.77
8.64
9.50
TIME (SEC)
SCALED BY 10** -2

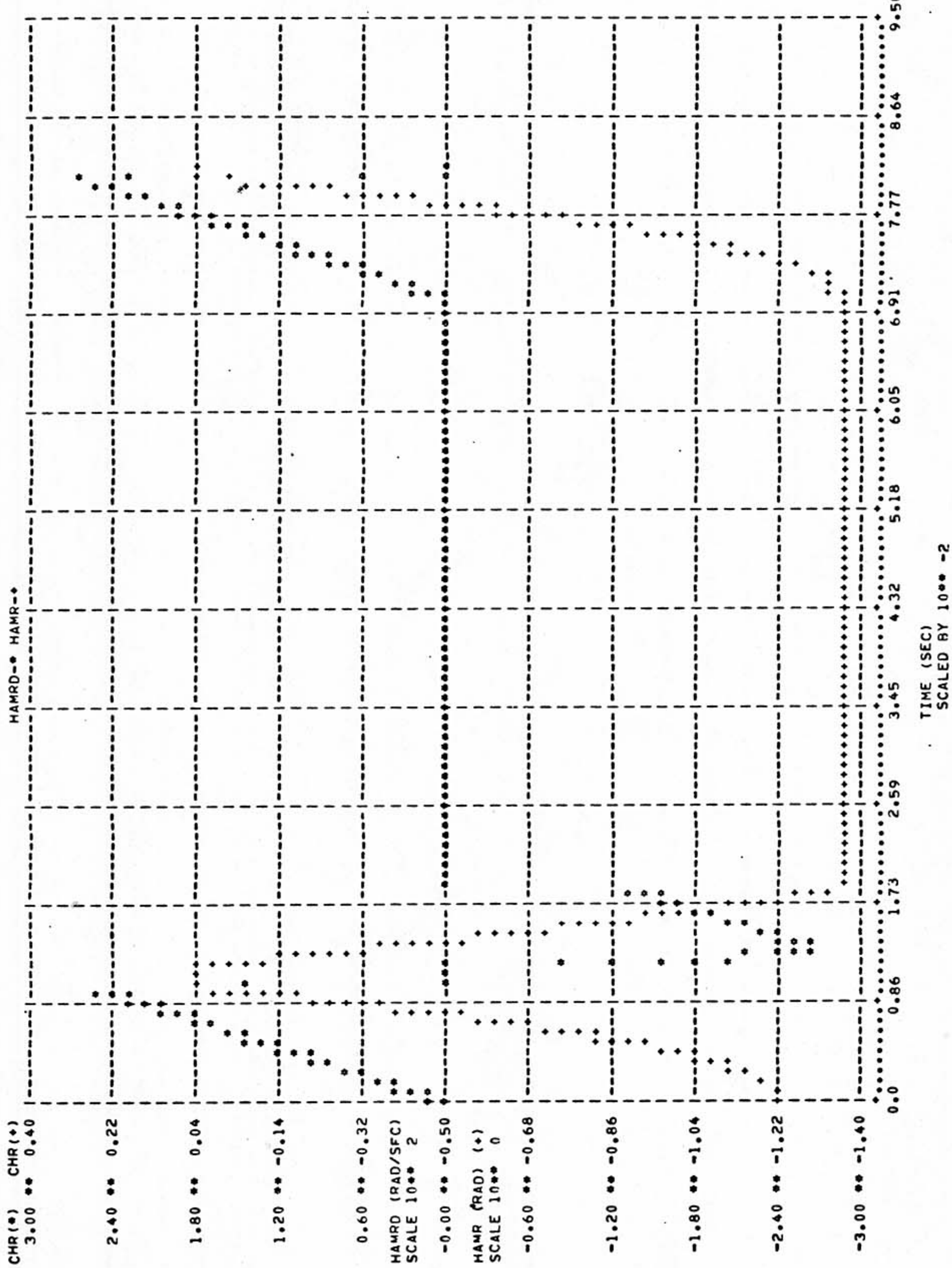

CHR(*) CHR(+)
2.00 ** 0.10
1.50 ** -0.28
1.00 ** -0.66
0.50 ** -1.04
0.0 ** -1.42
VELOC. (FT/SEC)
SCALE 10** 1
-0.50 ** -1.80
DISP. (FT) (+)
SCALE 10** -1
-1.00 ** -2.18
-1.50 ** -2.56
-2.00 ** -2.94
-2.50 ** -3.32
-3.00 ** -3.70
BLTD-* BLT-+
0.0
0.86
1.73
2.59
3.45
4.32
5.18
6.05
6.91
7.77
8.64
9.50
TIME (SEC)
SCALED BY 10** -2


BLTCD-* BLTC-+
CHR(*) CHR(+)
2.00 ** 0.10
1.50 ** -0.28
1.00 ** -0.66
0.50 ** -1.04
0.0 ** -1.42
VELOC. (FT/SEC) SCALE 10** 1
-0.50 ** -1.80
DISP. (FT) (+) SCALE 10** -1
-1.00 ** -2.18
-1.50 ** -2.56
-2.00 ** -2.94
-2.50 ** -3.32
-3.00 ** -3.70
0.0
0.86
1.73
2.59
3.45
4.32
5.18
6.05
6.91
7.77
8.64
9.50
TIME (SEC)
SCALED BY 10** -2


BUFFD-* BUFF-+
CHR(*) CHR(+)
2.00 ** 0.10
1.45 ** -0.28
0.90 ** -0.66
0.35 ** -1.04
-0.20 ** -1.42
VELOC. (FT/SEC) SCALE 10** 1
-0.75 ** -1.80
DISP. (FT) (+) SCALE 10** -1
-1.30 ** -2.18
-1.85 ** -2.56
-2.40 ** -2.94
-2.95 ** -3.32
-3.50 ** -3.70
0.0
0.86
1.73
2.59
3.45
4.32
5.18
6.05
6.91
7.77
8.64
9.50
TIME (SEC) SCALED BY 10** -2


BUFWD-* RUFW-+
CHR(*) CHR(+)
2.00 ** 0.20
1.45 ** -0.19
0.90 ** -0.58
0.35 ** -0.97
-0.20 ** -1.36
VELOC. (FT/SEC) SCALE 10** 1
-0.75 ** -1.75
DISP. (FT) (+) SCALE 10** -1
-1.30 ** -2.14
-1.85 ** -2.53
-2.40 ** -2.92
-2.95 ** -3.31
-3.50 ** -3.70
0.0
0.86
1.73
2.59
3.45
4.32
5.18
6.05
6.91
7.77
8.64
9.50
TIME (SEC)
SCALED BY 10** -2


XMGD-* XMG-+
CHR(*) CHR(+)
0.40 ** 0.08
0.29 ** -0.03
0.18 ** -0.14
0.07 ** -0.24
-0.04 ** -0.35
VELOC. (FT/SEC) SCALE 10** 1
-0.15 ** -0.46
DISP. (FT) (+) SCALE 10** -1
-0.26 ** -0.57
-0.37 ** -0.68
-0.48 ** -0.78
-0.59 ** -0.89
-0.70 ** -1.00
0.0
0.86
1.73
2.59
3.45
4.32
5.18
6.05
6.91
7.77
8.64
9.50
TIME (SEC)
SCALED BY 10** -2



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APPENDIX L

COMPUTER PROGRAM FOR SPRING SURGE AND SAMPLE OUTPUT

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//RAHE    JOB (---------,4),'M-16  '                              JOB 134
C       PROGRAM WRITTEN BY ALBERT PATSCHE
      DIMENSION XBUF(7), XDBUF(7), XDDBUF(7), BUFK(9), BUFKON(4),
     1 BUFC(9), BUFCON(4), BUFDEL(9), BUFM(3)
      NRCDS=0
      REWIND 4
      READ 1, NCORD
      DIMENSION XCORD(20), YCORD(20)
      READ 2, (XCORD(I), YCORD(I), I=1,NCORD )
      DO 90 I=1,NCORD
      XCORD(I)=XCORD(I)*0.08/173.1
   90 YCORD(I)=32.0 - YCORD(I)*3.645/ 97.9
      READ 2, XMG, XMGD, XOP, XOPD, TEND,H
    1 FORMAT(I10)
    2 FORMAT(8F10.0)
      DO 10 I=1,7
      XBUF(I)=0.0
   10 XDBUF(I)=0.0
      READ 2,(BUFKON(I), BUFCON(I), I=1,4)
      DO 11 I=1,9
      BUFK(I)=0.0
   11 BUFC(I)=0.0
      READ 2,(BUFM(I),I=1,3)
      READ 2,(BUFDEL(I),I=1,9)
      T=0.0
          XOPTU=0.0
          IXOP=0
          TLAG=0.2
      DIMENSION XDS(44), XDOTDS(44)
      READ 1, NCOILS
      READ 2, DSK,DSC,DSFL,DSIL,DSM
      PRINT 70, XMG, XMGD, XOP, XOPD, TEND, H, (BUFKON(I),I=1,4),
     1   (BUFCON(I),I=1,4), (BUFM(I),I=1,3), (BUFDEL(I),I=1,9)
   70 FORMAT('1',50X,'I N P U T    D A T A'////54X,'B U F F E R '///
     1 3X,'XMG',11X,'XMGDOT',8X,'XOP',11X,'XOPDOT',8X,'TEND',10X,'DELTA
     2T'/6E14.6//3X,'K1',12X,'K2...K6',7X,'K8&K9'9X,'K7'12X,'C1',12X,
     3 'C2...C6',7X,'C8&C9',9X,'C7'/8E14.6//3X,'M1',12X,'M2...M6',7X,'M7
     4 '/3E14.6//50X,'DELTA 1 THRU DELTA 9'/9E14.6)
      PRINT 71, NCOILS, DSK, DSC, DSFL, DSIL, DSM
   71 FORMAT(////54X,'S P R I N G'//3X,'COILS'/I5//3X,'K',13X,'C',13X,
     1 'FREE LENGTH',3X,'INITL LENGTH',3X,'M'/5E14.6//)
      READ 1, NTHTRN
      NTIME=NTHTRN
      READ 1, NTHPLT
      NOWPLT=NTHPLT
      PRINT 73, NTHTRN, NTHPLT
   73 FORMAT(20X,I5,'=NTHTRN',20X,I5,'=NTHPLT'//)
      Z=NTHTRN
      Z=Z*H
      CALL SPRNGU(NCOILS,DSFL,DSIL,XBUF(1),XMG-DSK,DSC,DSM,Z,XDS,XDOTDS,
     1 FNOT,XDBUF(1))
```

```
      FRUF=FNOT
      CALL BUFF(BUFKON,BUFCON,BUFM)
      PRINT 72, DSK, DSC, DSM
   72 FORMAT(44X,'A F T E R   A D J U S T M E N T'//3X,'K',13X,'C',13X,
     1 'M'/3F14.6)
      INTEGER*2 IPLOT(101,51)
      CALL PLOTO(IPLOT)
      REAL AA1(15), AA2(15), AA3(15), AA4(15), AA5(15), AA6(15), AA7(15)
      REAL AA8(15)
      READ 2,(AA1(I),I=1,6)
      DO 12 I=1,6
      AA2(I)=AA1(I)
      AA3(I)=AA1(I)
      AA4(I)=AA1(I)
      AA5(I)=AA1(I)
      AA6(I)=AA1(I)
      AA7(I)=AA1(I)
   12 AA8(I)=AA1(I)
      CALL PLOT1(AA1)
      CALL PLOT1(AA2)
      CALL PLOT1(AA3)
      CALL PLOT1(AA4)
      CALL PLOT1(AA5)
      CALL PLOT1(AA6)
      CALL PLOT1(AA7)
      CALL PLOT1(AA8)
      REAL TITLE(5), VLAB(4), HLAB(4)
      READ 9,TITLE
      READ 9,VLAB
      READ 9,HLAB
    9 FORMAT(5A4)
      INTEGER*2 CH1/'*'/,CH2/'2'/,CH3/'3'/,CH4/'4'/,CH5/'5'/,CH6/'6'/,
     * CH7/'7'/,CH8/'*'/
      INTEGER*2 JPLOT(101,51)
      CALL PLOTO(JPLOT)
      REAL BBB(44,15),A(15)
      READ 2, (BBB(1,I),I=1,6)
      DIMENSION IDSPLT(44)
      READ 3,(IDSPLT(I),I=1,44)
    3 FORMAT(44I1)
      INTEGER*2 DSCHAR(44)/'A','B','C','D','E','F','G','H','I','J','K',
     * 'L','M','N','O','P','Q','R','S','T','U','V','W','X','Y','Z','1',
     * '2','3','4','5','6','7','8','9','0','*','+','$','@','=','%','#',
     * '&'/
      REAL TITL2(5), VLAB2(4), HLAB2(4)
      READ 9,TITL2
      READ 9,VLAB2
      READ 9,HLAB2
      DO 7 I=7,15
    7 BBB(1,I) = 0.0
      DO 5 I=1,44
      IF ( IDSPLT(I) .EQ. 0 ) GO TO 5
      DO 6 J=1,15
    6 BBB(I,J) = BBB(1,J)
    5 CONTINUE
      DO 15 I=1,44
      IF ( IDSPLT(I) .EQ. 0 ) GO TO 15
      DO 16 J=1,6
   16 A(J) = BBB(I,J)
      CALL PLOT1(A)
      BBB(I,7) = A(7)
```

```
      BBB(I,8) = A(8)
      BBB(I,15) = A(15)
   15 CONTINUE
      INTEGER*2 KPLOT(101,51)
      CALL PLOTO(KPLOT)
      REAL AB2(15), AB3(15), AB4(15), AB5(15), AB6(15), AB7(15)
      READ 2,(AB2(I), I=1,6)
      DO 61 I=1,6
      AB3(I)=AB2(I)
      AB4(I)=AB2(I)
      AB5(I)=AB2(I)
      AB6(I)=AB2(I)
      AB7(I)=AB2(I)
   61 CONTINUE
      CALL PLOT1(AB2)
      CALL PLOT1(AB3)
      CALL PLOT1(AB4)
      CALL PLOT1(AB5)
      CALL PLOT1(AB6)
      CALL PLOT1(AB7)
      REAL TITL3(5), VLAB3(4), HLAB3(4)
      READ 9, TITL3
      READ 9, VLAB3
      READ 9, HLAB3
      COILS=NCOILS
  100 CONTINUE
      NTIME=NTIME+1
      IF ( NTIME .LT. NTHTRN ) GO TO 150
      NTIME=0
         CALL XNOW(T,XOP,XOPD,XCORD,YCORD)
      CALL SPRING(XDS,XDOTDS,XMG,XBUF(1),XMGD,XDBUF(1),FBUF)
  150 CONTINUE
      CALL BUFFER(H,XBUF,XDBUF,BUFDEL,FBUF,XMG,XOP,XMGD,XOPD,FNOT)
      T=T+H
      NOWPLT=NOWPLT+1
      IF ( NOWPLT .LT. NTHPLT ) GO TO 60
      NOWPLT=0
      PX1=XBUF(1)+8.0
      PX2=XBUF(2)+8.0-0.3775
      PX3=XBUF(3)+8.0-0.3775-(0.684)*1.0
      PX4=XBUF(4)+8.0-0.3775-(0.684)*2.0
      PX5=XBUF(5)+8.0-0.3775-(0.684)*3.0
      PX6=XBUF(6)+8.0-0.3775-(0.684)*4.0
      PX7=XBUF(7)+8.0-0.3775-(0.684)*4.0-0.9565
      PX8=PX1-4.85
      CALL PLOT2(IPLOT,CH1,AA1,T,PX1,0)
      CALL PLOT2(IPLOT,CH2,AA2,T,PX2,0)
      CALL PLOT2(IPLOT,CH3,AA3,T,PX3,0)
      CALL PLOT2(IPLOT,CH4,AA4,T,PX4,0)
      CALL PLOT2(IPLOT,CH5,AA5,T,PX5,0)
      CALL PLOT2(IPLOT,CH6,AA6,T,PX6,0)
      CALL PLOT2(IPLOT,CH7,AA7,T,PX7,0)
      CALL PLOT2(IPLOT,CH8,AA8,T,PX8,0)
      DO 25 I=1,44
      IF ( IGSPLT(I) .EQ. 0 ) GO TO 25
      DO 26 J=9,15
   26 A(J) = BBB(I,J)
      FLOATI=I
      XCOIL = XDS(I) + (COILS + 1.0 - FLOATI)*DSIL/COILS
      CALL PLOT2(JPLOT,DSCHAR(I),A,I,XCOIL,0)
      DO 27 J=9,15
```

```
      BAR(I,J) = A(J)
   27 CONTINUE
   25 CONTINUE
      PY2=PX1-PX2
      PY3=PX1-PX3
      PY4=PX1-PX4
      PY5=PX1-PX5
      PY6=PX1-PX6
      PY7=PX1-PX7
      CALL PLOT2(KPLOT,CH2,AB2,T,PY2,0)
      CALL PLOT2(KPLOT,CH3,AB3,T,PY3,0)
      CALL PLOT2(KPLOT,CH4,AB4,T,PY4,0)
      CALL PLOT2(KPLOT,CH5,AB5,T,PY5,0)
      CALL PLOT2(KPLOT,CH6,AB6,T,PY6,0)
      CALL PLOT2(KPLOT,CH7,AB7,T,PY7,0)
      WRITE (4) T,PY2,PY3,PY4,PY5,PY6,PY7
      NRCDS=NRCDS+1
   60 CONTINUE
      IF ( T .LT. TEND ) GO TO 100
      CALL PLOT3(IPLOT,AA1,TITLE,VLAB,HLAB,1)
      CALL PLOT3(JPLOT,A,TITL2,VLAB2,HLAB2,1)
      CALL PLOT3(KPLOT,AB2,TITL3,VLAB3,HLAB3,1)
      CALL EXIT
      END
      SUBROUTINE SPRNGO(N,FL,IL,XOP,XMG,K,C,M,INCR,X,XDOT,F1,XOPDOT)
      REAL K,M,INCR,IL
      DIMENSION X(44),XDOT(44)
      DO 10 I=1,N
      X(I)=0.0
   10 XDOT(I)=0.0
      REALN=N
      CAPDEL=FL/(REALN+1.0)
      DEL=IL/(REALN+1.0)
      DEL1=XOP+(CAPDEL-DEL)
      DEL2=XMG-(CAPDEL-DEL)
      K=K*(REALN+1.0)
      C=C*(REALN+1.)
      M=M/REALN
      ALPHA=2.*C
      BETA=2.*K
      POWER=-ALPHA/(2.0*M)
      ETERM=EXP(POWER*INCR)
      IF((BETA/M)-(ALPHA/(2.*M))**2)61,62,63
   63 IFLAG=1
      ROOT=SQRT((BETA/M)-(ALPHA/(2.0*M))**2)
      COSTM=COS(ROOT*INCR)
      SINTM=SIN(ROOT*INCR)
      PRINT 903
  903 FORMAT(20X,'SPRING IS UNDER DAMPED')
      GO TO 60
   62 IFLAG=0
      PRINT 902
  902 FORMAT(20X,'SPRING IS CRITICALLY DAMPED')
      GO TO 60
   61 IFLAG=-1
      ROOT=SQRT((ALPHA/(2.*M))**2-(BETA/M))
      ETERMP=EXP(ROOT*INCR)
      ETERMN=EXP(-ROOT*INCR)
      PRINT 901
  901 FORMAT(20X,'SPRING IS OVER DAMPED')
   60 CONTINUE
```

```
      F1=-K*(XOP-X(1)-DEL1)-C*(XOPDOT-XDOT(1))
      N1=N-1
      RETURN
      ENTRY SPRING(X,XDOT,XMG,XOP,XMGDOT,XOPDOT,F1)
      IF(IFLAG)601,602,603
  603 CONTINUE
      H=K*(X(2)+XOP+CAPDEL-DEL-DEL1)+C*(XDOT(2)+XOPDOT)
      COEF=X(1)-H/BETA
      X(1)=ETERM*(COEF*COSTM+(XDOT(1)+ALPHA*COEF/(2.*M))*SINTM/ROOT)
     1 +H/BETA
      XDOT(1)=ETERM*(XDOT(1)*COSTM-SINTM*(ALPHA*XDOT(1)+2.*BETA*COEF)/
     1 (2.*M*ROOT))
      IF (N .EQ. 2) GO TO 200
      DO 100 I=2,N1
      H=K*(X(I-1)+X(I+1))+C*(XDOT(I-1)+XDOT(I+1))
      COEF=X(I)-H/BETA
      X(I)=ETERM*(COEF*COSTM+(XDOT(I)+ALPHA*COEF/(2.*M))*SINTM/ROOT)
     1 +H/BETA
  100 XDOT(I)=ETERM*(XDOT(I)*COSTM-SINTM*(ALPHA*XDOT(I)+2.*BETA*COEF)/
     1 (2.*M*ROOT))
  200 CONTINUE
      H=K*(X(N-1)+XMG-CAPDEL+DEL-DEL2)+C*(XDOT(N-1)+XMGDOT)
      COEF=X(N)-H/BETA
      X(N)=ETERM*(COEF*COSTM+(XDOT(N)+ALPHA*COEF/(2.*M))*SINTM/ROOT)
     1 +H/BETA
      XDOT(N)=ETERM*(XDOT(N)*COSTM-SINTM*(ALPHA*XDOT(N)+2.*BETA*COEF)/
     1 (2.*M*ROOT))
      GO TO 9999
  602 CONTINUE
      H=K*(X(2)+XOP+CAPDEL-DEL-DEL1)+C*(XDOT(2)+XOPDOT)
      COEF=X(1)-H/BETA
      X(1)=ETERM*(COEF-(POWER*COEF-XDOT(1))*INCR)+H/BETA
      XDOT(1)=ETERM*((XDOT(1)-POWER*COEF)*(1.+POWER*INCR)+POWER*COEF)
      IF (N .EQ. 2) GO TO 202
      DO 102 I=2,N1
      H=K*(X(I-1)+X(I+1))+C*(XDOT(I-1)+XDOT(I+1))
      COEF=X(I)-H/BETA
      X(I)=ETERM*(COEF-(POWER*COEF-XDOT(I))*INCR)+H/BETA
  102 XDOT(I)=ETERM*((XDOT(I)-POWER*COEF)*(1.+POWER*INCR)+POWER*COEF)
  202 CONTINUE
      H=K*(X(N-1)+XMG-CAPDEL+DEL-DEL2)+C*(XDOT(N-1)+XMGDOT)
      COEF=X(N)-H/BETA
      X(N)=ETERM*(COEF-(POWER*COEF-XDOT(N))*INCR)+H/BETA
      XDOT(N)=ETERM*((XDOT(N)-POWER*COEF)*(1.+POWER*INCR)+POWER*COEF)
      GO TO 9999
  601 CONTINUE
      H=K*(X(2)+XOP+CAPDEL-DEL-DEL1)+C*(XDOT(2)+XOPDOT)
      COEF1=(XDOT(1)+(ROOT-POWER)*(X(1)-H/BETA))/(2.*ROOT)
      COEF2=(X(1)-H/BETA)-COEF1
      X(1)=ETERM*(COEF1*ETERMP+COEF2*ETERMN)+H/BETA
      XDOT(1)=ETERM*(COEF1*ETERMP*(ROOT+POWER)-COEF2*ETERMN*(ROOT-POWER)
     1 )
      IF (N .EQ. 2) GO TO 201
      DO 101 I=2,N1
      H=K*(X(I-1)+X(I+1))+C*(XDOT(I-1)+XDOT(I+1))
      COEF1=(XDOT(1)+(ROOT-POWER)*(X(1)-H/BETA))/(2.*ROOT)
      COEF2=(X(1)-H/BETA)-COEF1
      X(I)=ETERM*(COEF1*ETERMP+COEF2*ETERMN)+H/BETA
  101 XDOT(I)=ETERM*(COEF1*ETERMP*(ROOT+POWER)-COEF2*ETERMN*(ROOT-POWER)
     1 )
  201 CONTINUE
```

```
      H=K*(X(N-1)+XMG-CAPDEL+DEL-DEL2)+C*(XDOT(N-1)+XMGDOT)
      COEF1=(XDOT(N)+(ROOT-POWER)*(X(N)-H/BETA))/(2.*ROOT)
      COEF2=(X(N)-H/BETA)-COEF1
      X(N)=FTERM*(COEF1*ETERMP+COEF2*ETERMN)+H/BETA
      XDOT(N)=ETERM*(COEF1*ETERMP*(ROOT+POWER)-COEF2*ETERMN*(ROOT-POWER)
     1 )
 9999 F1=-K*(XOP-X(1)-DEL1)-C*(XOPDOT-XDOT(1))
      F2=-K*(XMG-X(N)-DEL2)-C*(XMGDOT-XDOT(N))
      RETURN
      END
      SUBROUTINE XNOW(T,XOP,XOPD,X,Y)
      DIMENSION X(20), Y(20)
      I=1
      CALL LINEAR(T,X,Y,XOP,I)
      XOPD=(Y(I+1)-Y(I))/(X(I+1)-X(I))
      RETURN
      END
      SUBROUTINE LINEAR (A,X,Y,VV,I)
      DIMENSION X(20),Y(20)
    2 IF(A-X(I)) 3,1,1
    1 I=I+ 1
      GO TO 2
    3 I=I-1
      VV=Y(I)*(A-X(I+1))/(X(I)-X(I+1))+Y(I+1)*(A-X(I))/(X(I+1)-X(I))
      RETURN
      END
      SUBROUTINE BUFF(BK,BC,BM)
      DIMENSION BK(4), BC(4), BM(3)
      REAL K(9), KON(9), C(9), CON(9), M(7)
      M(1)=BM(1)
      M(7)=BM(3)
      KON(1)=BK(1)
      CON(1)=BC(1)
      KON(7)=BK(4)
      CON(7)=BC(4)
      KON(8)=BK(3)
      KON(9)=BK(3)
      CON(9)=BC(3)
      CON(8)=BC(3)
      DO 1 I=2,6
      M(I)=BM(2)
      KON(I)=BK(2)
    1 CON(I)=BC(2)
      RETURN
      ENTRY BUFFER(INCR,X,XDOT,DEL,FBUF,XMG,XOP,XMGD,XOPD,FNOT)
      REAL INCR
      DIMENSION X(7), XDOT(7), DEL(9)
      FOFT=FBUF-FNOT
      CALL ZERO(K,C)
      IF(  XOP-X(1)  .LE. DEL(1)  ) K(1)=KON(1)
      IF(  XOP-X(1)  .LE. DEL(1)  ) C(1)=CON(1)
      IF( X(1)-X(2)  .LE. DEL(2)  ) K(2)=KON(2)
      IF( X(1)-X(2)  .LE. DEL(2)  ) C(2)=CON(2)
      IF( X(7)+DEL(8)  .LE. X(1)  ) K(8)=KON(8)
      IF( X(7)+DEL(8)  .LE. X(1)  ) C(8)=CON(8)
      IF(  XMG-X(1)  .GE. DEL(9)  ) K(9)=KON(9)
      IF(  XMG-X(1)  .GE. DEL(9)  ) C(9)=CON(9)
      ALPHA=C(1) + C(2) + C(8) + C(9)
      BETA =K(1) + K(2) + K(8) + K(9)
      POWER=-ALPHA/(2.*M(1))
      ETERM=EXP(POWER*INCR)
```

```
      IF ( BETA/M(1) - (ALPHA/(2.*M(1)))**2) 11,12,13
   11 ROOT=SQRT((ALPHA/(2.*M(1)))**2 - BETA/M(1))
      ETERMP=EXP(ROOT*INCR)
      ETERMN=EXP(-ROOT*INCR)
      H=FOFT-K(1)*(DEL(1)-XOP )+C(1)* XOPD   +K(2)*(DEL(2)+X(2))+C(2)*
     1 XDOT(2)+K(9)*( XMG-DEL(9))+C(9)* XMGD   +K(8)*(X(7)+DEL(8))+C(8)*
     2 XDOT(7)
      COEF1=(XDOT(1)+(ROOT-POWER)*(X(1)-H/BETA))/(2.*ROOT)
      COEF2=X(1)-H/BETA-COEF1
      X(1)=ETERM*(COEF1*ETERMP+COEF2*ETERMN)+H/BETA
      XDOT(1)=ETERM*(COEF1*ETERMP*(ROOT+POWER)-COEF2*ETERMN*(ROOT-POWER)
     1 )
      GO TO 20
   12 BETA=BETA+10.**(-5)
   13 ROOT=SQRT(BETA/M(1) - (ALPHA/(2.*M(1)))**2)
      COSTM=COS(ROOT*INCR)
      SINTM=SIN(ROOT*INCR)
      H=FOFT-K(1)*(DEL(1)-XOP )+C(1)* XOPD   +K(2)*(DEL(2)+X(2))+C(2)*
     1 XDOT(2)+K(9)*( XMG-DEL(9))+C(9)* XMGD   +K(8)*(X(7)+DEL(8))+C(8)*
     2 XDOT(7)
      COEF=X(1)-H/BETA
      X(1)=ETERM*(COEF*COSTM+(XDOT(1)+ALPHA*COEF/(2.*M(1)))*SINTM/ROOT)
     1 +H/BETA
      XDOT(1)=ETERM*(XDOT(1)*COSTM-SINTM*(ALPHA*XDOT(1)+2.*BETA*COEF)
     1 /(2.*M(1)*ROOT))
   20 CONTINUE
      DO 30 I=2,6
      CALL ZFRO(K,C)
      IF( X(I-1)-X(I)  .LE. DEL(I) ) K(I)=KON(I)
      IF( X(I-1)-X(I)  .LE. DEL(I) ) C(I)=CON(I)
      IF( X(I)-X(I+1)  .LE. DEL(I+1) ) K(I+1)=KON(I+1)
      IF( X(I)-X(I+1)  .LE. DEL(I+1) ) C(I+1)=CON(I+1)
      ALPHA=C(I)+C(I+1)
      BETA=K(I)+K(I+1)
      POWER=-ALPHA/(2.*M(I))
      ETERM=EXP(POWER*INCR)
      IF ( BETA/M(I) - (ALPHA/(2.*M(I)))**2) 21,22,23
   21 ROOT=SQRT((ALPHA/(2.*M(I)))**2 - BETA/M(I))
      ETERMP=EXP(ROOT*INCR)
      ETERMN=EXP(-ROOT*INCR)
      H=K(I)*(X(I-1)-DEL(I))+C(I)*XDOT(I-1)+K(I+1)*(X(I+1)+DEL(I+1))
     1 +C(I+1)*XDOT(I+1)
      COEF1=(XDOT(I)+(ROOT-POWER)*(X(I)-H/BETA))/(2.*ROOT)
      COEF2=X(I)-H/BETA-COEF1
      X(I)=ETERM*(COEF1*ETERMP+COEF2*ETERMN)+H/BETA
      XDOT(I)=ETERM*(COEF1*ETERMP*(ROOT+POWER)-COEF2*ETERMN*(ROOT-POWER)
     1 )
      GO TO 30
   22 BETA=BETA+10.**(-5)
   23 ROOT=SQRT(BETA/M(I) - (ALPHA/(2.*M(I)))**2)
      COSTM=COS(ROOT*INCR)
      SINTM=SIN(ROOT*INCR)
      H=K(I)*(X(I-1)-DEL(I))+C(I)*XDOT(I-1)+K(I+1)*(X(I+1)+DEL(I+1))
     1 +C(I+1)*XDOT(I+1)
      COEF=X(I)-H/BETA
      X(I)=ETERM*(COEF*COSTM+(XDOT(I)+ALPHA*COEF/(2.*M(I)))*SINTM/ROOT)
     1 +H/BETA
      XDOT(I)=ETERM*(XDOT(I)*COSTM-SINTM*(ALPHA*XDOT(I)+2.*BETA*COEF)
     1 /(2.*M(I)*ROOT))
   30 CONTINUE
      CALL ZFRO(K,C)
```

```
      IF( X(6)-X(7) .LE. DEL(7) ) K(7)=KON(7)
      IF( X(6)-X(7) .LE. DEL(7) ) C(7)=CON(7)
      IF( X(7)+DEL(8) .LE. X(1) ) K(8)=KON(8)
      IF( X(7)+DEL(8) .LE. X(1) ) C(8)=CON(8)
      ALPHA=C(7)+C(8)
      BETA=K(7)+K(8)
      POWER=-ALPHA/(2.*M(7))
      ETERM=EXP(POWER*INCR)
      IF ( BETA/M(7) - (ALPHA/(2.*M(7)))**2) 31,32,33
   31 ROOT=SQRT((ALPHA/(2.*M(7)))**2 - BETA/M(7))
      ETERMP=EXP(ROOT*INCR)
      ETERMN=EXP(-ROOT*INCR)
      H=K(7)*(X(6)-DEL(7))+C(7)*XDOT(6)-K(8)*(DEL(8)-X(1))+C(8)*XDOT(1)
      COEF1=(XDOT(7)+(ROOT-POWER)*(X(7)-H/BETA))/(2.*ROOT)
      COEF2=X(7)-H/BETA-COEF1
      X(7)=ETERM*(COEF1*ETERMP+COEF2*ETERMN)+H/BETA
      XDOT(7)=ETERM*(COEF1*ETERMP*(ROOT+POWER)-COEF2*ETERMN*(ROOT-POWER)
     1 )
      GO TO 40
   32 BETA=BETA+10.**(-5)
   33 ROOT=SQRT(BETA/M(7) - (ALPHA/(2.*M(7)))**2)
      COSTM=COS(ROOT*INCR)
      SINTM=SIN(ROOT*INCR)
      H=K(7)*(X(6)-DEL(7))+C(7)*XDOT(6)-K(8)*(DEL(8)-X(1))+C(8)*XDOT(1)
      COEF=X(7)-H/BETA
      X(7)=ETERM*(COEF*COSTM+(XDOT(7)+ALPHA*COEF/(2.*M(7)))*SINTM/ROOT)
     1 +H/BETA
      XDOT(7)=ETERM*(XDOT(7)*COSTM-SINTM*(ALPHA*XDOT(7)+2.*BETA*COEF)
     1 /(2.*M(7)*ROOT))
   40 CONTINUE
      RETURN
      END
      SUBROUTINE ZERO(X,Y)
      DIMENSION X(9), Y(9)
      DO 1 I=1,9
      X(I)=0.
    1 Y(I)=0.
      RETURN
      END
/*
//GO.SYSIN DD *
        20
0.0       0.0       9.7       18.6      11.6      21.2      13.1      23.0
16.2      26.7      28.1      45.0      38.1      60.0      45.6      72.0
52.1      80.5      69.1      97.9      71.1      97.3      73.1      96.9
74.1      96.6      87.1      87.0      103.1     73.5      117.6     60.0
129.1     49.0      138.1     39.0      173.1     0.0       99990000. 0.0
10.       0.0       32.0      -123.14   0.20      .00001
50.       0.        50.       0.        50.       0.        50.       0.
.0002570  .0001057  .00005449
32.0      0.0       0.0       0.0       0.0       0.0       0.0       0.13
13.8125
        44
1.4       0.0       12.2      8.16      0.0003364
         10
          1
0.0       0.2       -2.       8.0       0.0       0.0
BUFFER MOTION
DISPLACEMENT
TIME
0.0       0.2       -0.5      9.50      0.0       0.0
```

```
1         1         1         1         1         1         1
SPRING MOTION
DISPLACFMENT
     TIME
0.0       0.2       0.0       5.0       0.0       0.0
RELATIVF MOTION
DISPLACFMENT
TIMF
/*
//FT04F001 DD DSN=&TAPE4,UNIT=2314,SPACE=(324,(1000,100)),
//         DCB=(RECFM=VBS,LRECL=32,BLKSIZE=324),DISP=(NEW,DELETE)
/*
```

I N P U T   D A T A

B U F F E R

XMG	XMGDOT	XOP	XOPDOT	TEND	DELTA T		
0.100000E 02	0.0	0.320000E 02	-0.123140E 03	0.200000E 00	0.100000E-04		
K1	K2...K6	K8&K9	K7	C1	C2...C6	C8&C9	C7
0.500000E 02	0.500000E 02	0.500000E 02	0.500000E 02	0.0	0.0	0.0	0.0
M1	M2...M6	M7					
0.257000E-03	0.105700E-03	0.544900E-04					

DELTA 1 THRU DELTA 9

0.320000E 02	0.0	0.0	0.0	0.0	0.0	0.0	0.130000E 00	0.138125E 02

S P R I N G

COILS
44

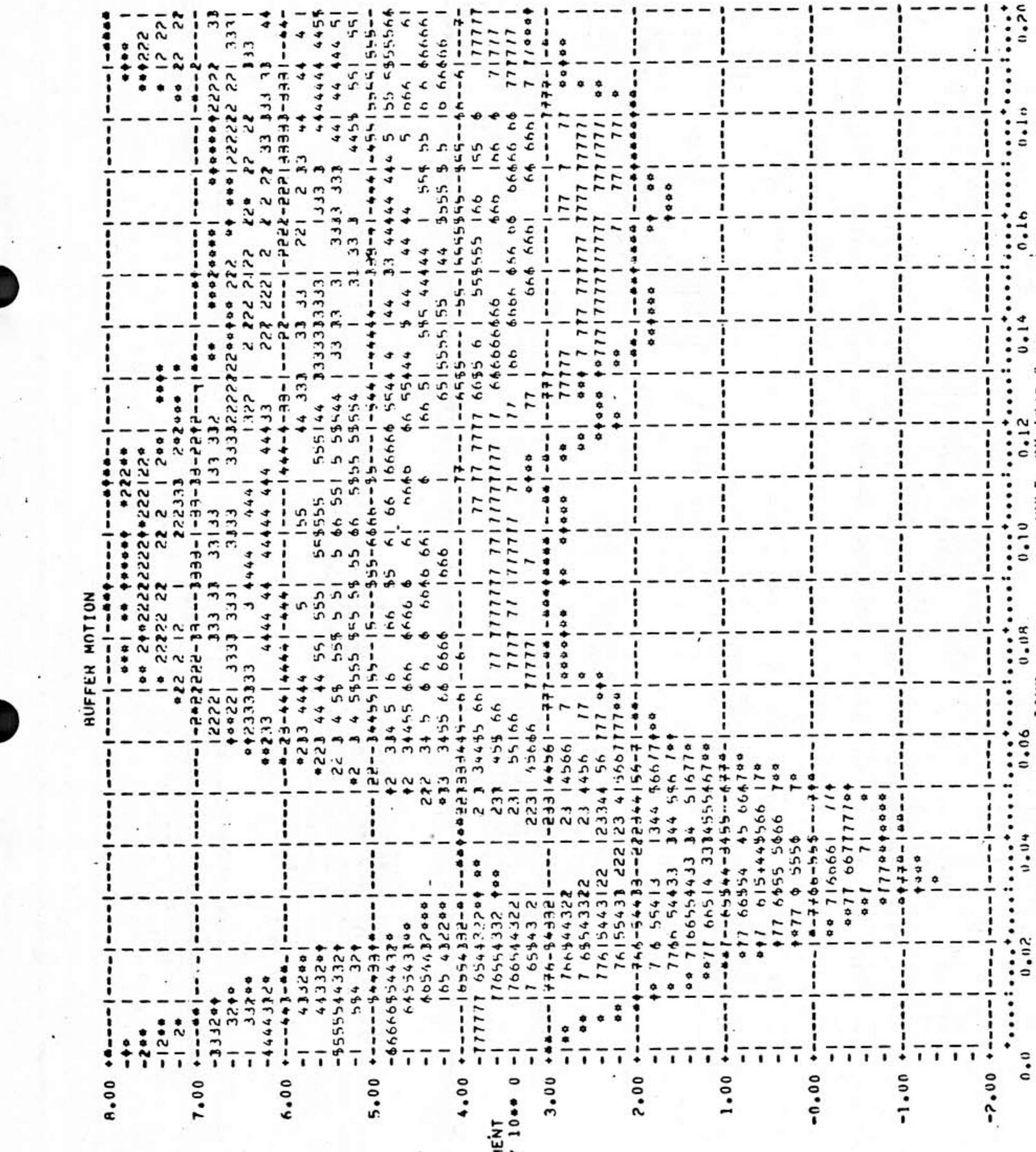
K	C	FREE LENGTH	INITL LENGTH	M
0.140000E 01	0.0	0.122000E 02	0.816000E 01	0.336400E-03

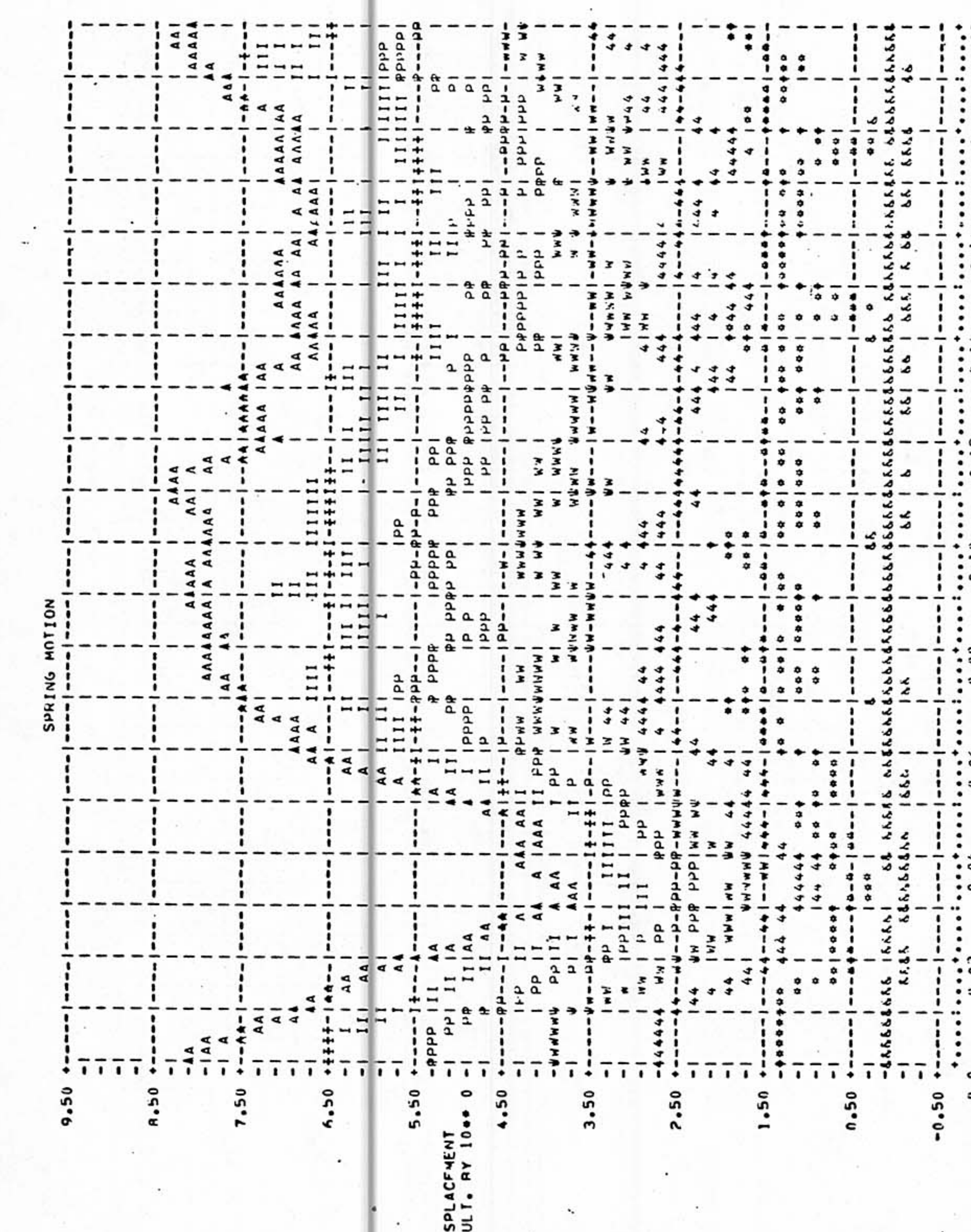
10=NTHTRN   1=NTHPLT

SPRING IS UNDER DAMPED

A F T E R   A D J U S T M E N T

K	C	M
0.630000E 02	0.0	0.764545E-05


BUFFER MOTION
DISPLACEMENT
MULT. BY 10** 0
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
-0.00
-1.00
-2.00
0.0
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
0.18
0.20
TIME
MULT. BY 10** 0


SPRING MOTION
DISPLACEMENT
MULT. BY 10** 0
9.50
8.50
7.50
6.50
5.50
4.50
3.50
2.50
1.50
0.50
-0.50
0.0
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
0.18
0.20
TIME
MULT. BY 10** 0

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Technical Report # R-TR-75-010

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Theory and Application of Mathematical Modeling of Shoulder-Fired Weapons
Part I of II, Final Report

Prepared By: Paul E. Ehle and Albert E. Rahe
Security Class. (of this report): Unclassified
Technical Report R-TR-75-010

243 Pages, Incl Figures

A mathematical model of the M16A1 Rifle was constructed by personnel of the Research Directorate to serve as (1) a vehicle to extend the state-of-the-art in weapon modeling, (2) a basis with which to compare performance characteristics of other weapons such as the XM19 Rifle, (3) an aid to troubleshoot the weapon (4) a means to increase present knowledge of the M16A1, and (5) a way to explore and demonstrate the capabilities and limitations of mathematical models of weapons.

UNCLASSIFIED

1. M16 Rifle
2. Dynamics
3. Simulation
4. Man Weapon
5. Kinematics
6. Mathematical Model

I. Paul E. Ehle and Albert E. Rahe
II. Rock Island Arsenal
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Theory and Application of Mathematical Modeling of Shoulder-Fired Weapons
Part I of II, Final Report

Prepared By: Paul E. Ehle and Albert E. Rahe
Security Class. (of this report): Unclassified
Technical Report R-TR-75-010

243 Pages, Incl Figures

A mathematical model of the M16A1 Rifle was constructed by personnel of the Research Directorate to serve as (1) a vehicle to extend the state-of-the-art in weapon modeling, (2) a basis with which to compare performance characteristics of other weapons such as the XM19 Rifle, (3) an aid to troubleshoot the weapon (4) a means to increase present knowledge of the M16A1, and (5) a way to explore and demonstrate the capabilities and limitations of mathematical models of weapons.

UNCLASSIFIED

1. M16 Rifle
2. Dynamics
3. Simulation
4. Man Weapon
5. Kinematics
6. Mathematical Model

I. Paul E. Ehle and Albert E. Rahe
II. Rock Island Arsenal
III. Research Directorate
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